POLYTECHNIC UNIVERSITY OF THE PHILIPPINES
PARAÑAQUE CITY CAMPUS

INSTRUCTIONAL MATERIAL
FOR

CMPE 30153

FUNDAMENTALS OF MIXED SIGNALS AND SENSORS

COMPILED BY
ENGR. MARVIN DE PEDRO

Course Description and Learning Outcomes

This course focuses on the application electronic devices in developing signal conversion circuits that allow measurement, processing, and control of physical parameters by digital processing systems such as a finite state machine or a digital computer.

After completing the course, the student must be able to:

- Recognize important concepts and terminologies in signal processing, including the properties of mixed signals and how they work;
- Illustrate how sensors and actuators work and apply engineering techniques in creating electronic systems that include them;
- Summarize the significance of signal analysis in different engineering applications, especially in evaluating the electrical and electronic quantities of a mixed signal; and
- Develop an electronic circuit that makes use of mixed signals and sensors.

Course Overview and Outline

Chapter 2 (Mixed Signals in Communications Systems)

Chapter 3 (Mixed-Signal Systems and the Industry 4.0)

Class Rules

Due to the restrictions brought by COVID-19 threats, there will still be no face-to-face class sessions for the 1st Semester of A.Y. 2021-2022, except probably for some hands-on activities. With that, we will use a "virtual classroom" method of distance learning instead. It's a combination of online technology and home schooling type of class sessions wherein:

1. Class lectures will be done asynchronously through recorded videos. Students can get a copy of all lecture videos and other class materials (downloadable from a given Google Drive folder), and from time to time, check the updates on the class' official FB group.
2. Oral assessments and class huddles will be done synchronously through a video conference (Zoom or Google Meet). There will be 2 synchronous class sessions for each chapter (4 modules) where students can also ask questions regarding the lessons, class requirements, and activities.
3. Students can have self-paced learning through the provided class materials. They can feel free to share it with other people at home and may take the lessons as a productive hobby during this season.
4. Those who can't attend the scheduled synchronous class session as well as those who can't participate or comply with certain class requirements must submit a formal letter explaining his/her valid reason. This letter should be submitted as early as possible so that necessary adjustments or arrangements can be done ahead.
5. Some class requirements will be done as team tasks wherein each member is expected to cooperate and contribute to the team's output. **Please report anyone who does not*.

Knowing that some students may not have access to a reliable internet connection, your cooperation and resourcefulness are highly encouraged. Some of you may ask someone to download the materials on your behalf. Some may even ask to have the downloaded files saved in an SD card and send it to them via *Lalamove* or any courier services available. Same methods can be used for submitting the outputs to the leader who will upload the team's final output. These can be done without compromising safety.

Also, each one as an engineering student is encouraged and expected to:

- Practice self-discipline and time management in the individual and team tasks.

- Be responsible enough to cooperate with groupmates without the instructor's supervision and/or coercion.
- Take time to research and read beyond the given lecture materials.
- Be more serious in developing his/her own engineering skills and virtues.

Grading System

Class Standing		50%
• Quizzes / Laboratory Tasks	30%	
• Class Activities	20%	
Exam		30%
Performance Task		20%

		100%

Transmutation Table	
1.00	97 to 100
1.25	94 to 96.99
1.50	91 to 93.99
1.75	88 to 90.99
2.00	85 to 87.99
2.25	82 to 84.99
2.50	79 to 81.99
2.75	76 to 78.99
3.00	75 to 75.99
5.00	Below 75

Grades will be uploaded on the SIS right after the end of the first semester. A period of 3-5 days will be given for any necessary changes before the grades will be finalized.

Course Requirements

Class Activities (20%) + **Exam** (30%) – Team Task

- Study the given *Lego Mindstorms EV3 User Guide* PDF
- Research about possible robotics project that can be developed out of the available parts of the kit, and create a PDF documentation of it with the following content:
  - ✓ Brief description of the project with system block diagram
  - ✓ Working principles and instructions on how to operate it.
  - ✓ Breakdown of project cost (price list) and materials specifications
- Documentation should be in a normal formatting style (letter-size paper) and in PDF file format. Include an enticing cover page, as well as header and footer on each page. At the last page, the leader should indicate the contribution of each member.
- All outputs to this requirement must be submitted within the last week of the semester, but it's best to start working on them early to avoid bottlenecking of the tasks at the said

deadline period. Feel free to comment your queries on the dedicated FB group post or ask them during one of the synchronous class sessions.

Quizzes (30%) – Team Task

- All three teams will work together to perform a system study for a proposed *disaster risk reduction and management system* for Brgy. Sto Niño. Compile the information gathered in this study into a single 5-10 minute AVP and PDF documentation.
- Preferably, each team will assign representatives for each of the following tasks:
  - ✓ Discuss about the general information of the site, including its geography, demography, culture, economy, commercial activities, and governance.
  - ✓ Discuss the common disasters encountered within the site and the existing mitigation for such disasters. Gather information from residents and officials, and relate these with the discussed general information about the site.
  - ✓ Discuss the existing communications services and infrastructures installed within the site, and the possible technologies that could be part of risk mitigation for the said disasters. Apply concepts discussed in this course.
- All outputs to this requirement must be submitted within the last week of November. Feel free to comment your queries on the dedicated FB group post or ask them during one of the synchronous class sessions.

Performance Task (20%) – Team Task

- This grade component will come from the system proposal with feasibility study for the assigned project. It basically requires proper documentation and video presentation.
- See the given content outline document for the specific instructions.
- All “behind-the-scene” activities related to compliance to this requirement must also be documented by taking photos of group members performing the tasks, and by taking screenshots of the accomplished work in any necessary software tools as well as of the conversations, charts, and other project management details of the group.
- All outputs to this requirement must be submitted within the last week of the semester, but it’s best to start working on them early to avoid bottlenecking of the tasks at the said deadline period. Feel free to comment your queries on the dedicated FB group post or ask them during one of the synchronous class sessions.

Rubrics:

Criteria	Description	Weight Score
Substance	Output includes the expected key points and correct components.	50
Form	Output is presented accurately and systematically with minimum grammatical and formatting errors.	25
Compliance	Output meets the prescribed length, coverage, and other specified instructions.	25
	TOTAL	**100**

Introduction to Mixed-Signal Systems

(CMPE 30153 – Fundamentals of Mixed Signals & Sensors)

1 Chapter

I. OVERVIEW

Mixed-signal processing involves the integration of digital and analog circuitry within computer systems to enable systems to take signals from the analog world and process them within a digital system. In fact, recent advances in VLSI technology performance now allow for the integration of digital and analog circuits on a single chip, a process that requires the use of analog pre- and post-processing systems such as converters, filters, sensors, drivers, buffers, and actuators.

II. MODULE OBJECTIVES

After successful completion of modules 1-4 of Chapter 1, you should be able to:

1) Remember important concepts and principles of mixed-signal systems;
2) Understand the purpose of mixed-signal processing and the electronic circuits involved, including sensors and actuators;
3) Evaluate the different types of signals and common processes in signal analysis; and
4) Apply the concepts of mixed-signal systems in developing computer technologies intended to solve real-world problems.

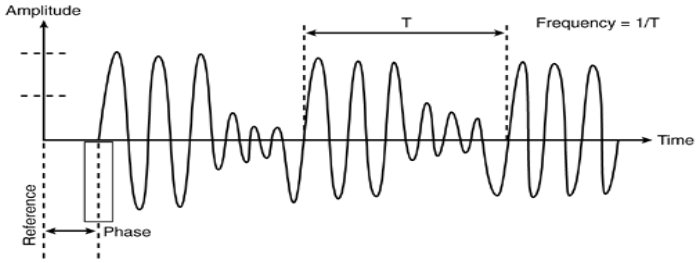
III. COURSE MATERIALS

Suggested Online Resources for Further Learning

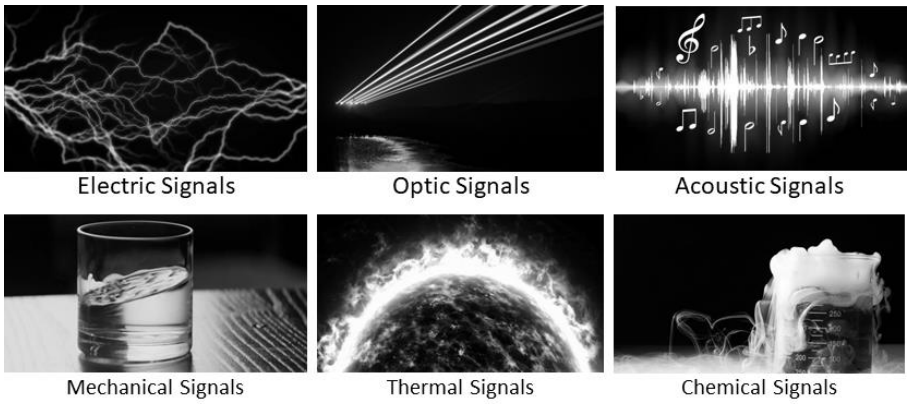
- Downloadable Course AVPs: https://bit.ly/3Fs7iFM
- Downloadable Course PDFs: https://bit.ly/2YFv8gu

Module 1: **Basics of Signals and Transducers**

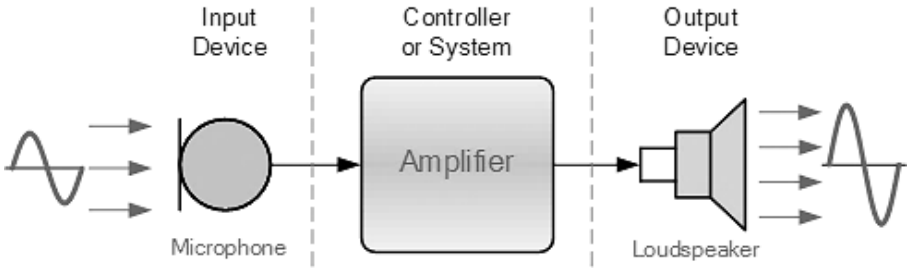
Electronic Signal is a time varying voltage, current or EM wave that potentially provides information on the status of a physical system, or conveys a message between observers, among other possibilities. It can be either analog or digital; their combination is ***called mixed signal***



Real-world signals include:



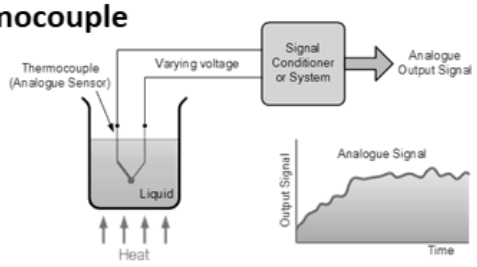
Electronic Transducer is a device which changes one form of energy into other i.e. it changes one type of physical variation to another type of variation, and vice versa. It converts physical variation such as pressure, light, temperature, etc. to variation of Electrical Voltage, and vice versa.



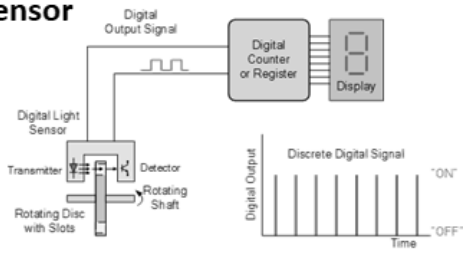
In electronic systems, signals are provided by a ***sensor***, and often the original form of a signal is converted to another form of energy using an ***actuator***. According to IEEE, electronic signals can be in the form of audio, video, speech, image, communication, geophysical, sonar, radar, medical and musical signals.

Common Types of Sensor

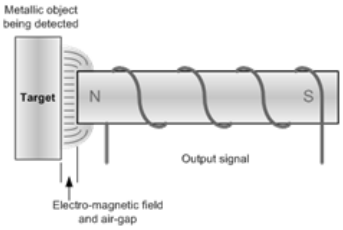
Thermocouple



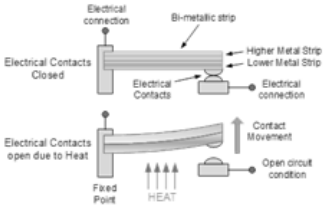
Light Sensor



Position Sensor

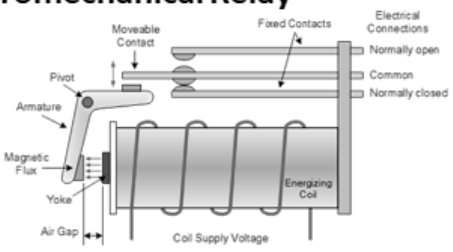


Temperature Sensor

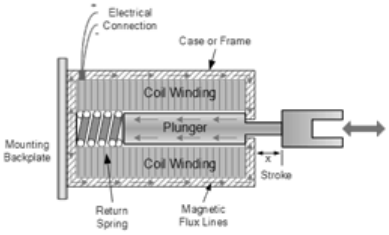


Common Types of Actuator

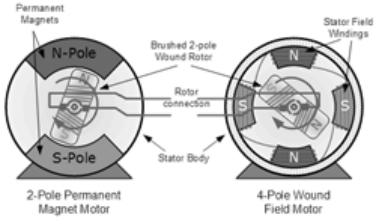
Electromechanical Relay



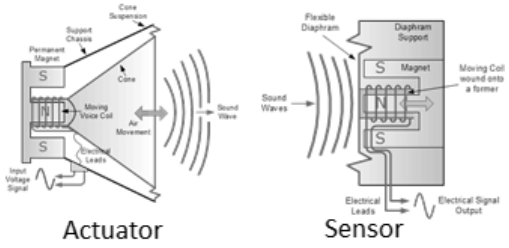
Pull-type Linear Solenoid



DC Motors

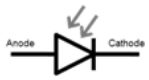


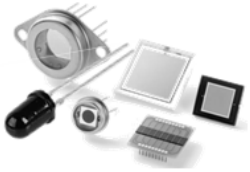
Sound Transducers



Common Optical/Optoelectronic Transducers

Photodiode



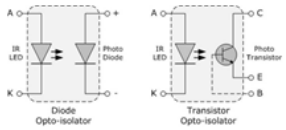


A photodiode or photovoltaic cell is a semiconductor device that converts light into an electrical current.

PMT

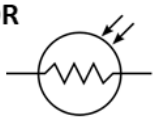
Photomultiplier tubes (PMTs) are extremely sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum.

Optocoupler



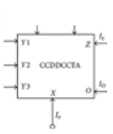
An opto-isolator or optocoupler is an electronic component that transfers electrical signals between two isolated circuits by using light.

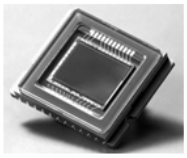
LDR



Photoresistor or light-dependent resistor (LDR) is a light-controlled variable resistor.

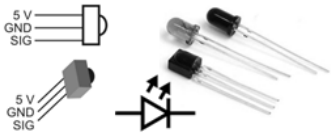
CCD





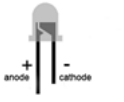
A charge-coupled device (CCD) is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value.

Infrared Sensors & LEDs



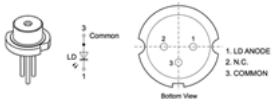
Infrared light-emitting diodes are often used as transmitters while infrared sensors are receivers of infrared communication links such as those in remote controls.

LED



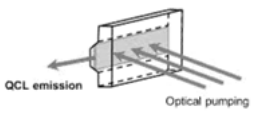
A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated.

LD / ILD



A laser diode, (LD), injection laser diode (ILD), or diode laser is a semiconductor device similar to a light-emitting diode in which the laser beam is created at the diode's junction.

QCL



Quantum cascade lasers (QCLs) are semiconductor lasers that emit in the mid- to far-infrared portion of the electromagnetic spectrum.

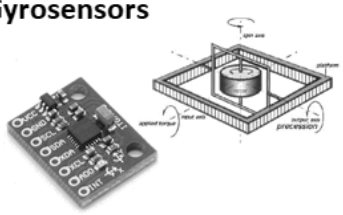
Common Piezoelectric Transducers

Piezoelectric Sensors

A piezoelectric sensor is a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge. Examples include:

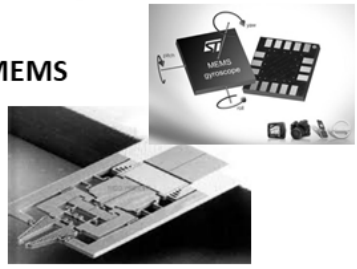
- Engine Knock Sensor
- Pressure Sensor
- SONAR and Ultrasonic Sensor
- Piezoelectric Microphone
- Piezoelectric Heat Sensor
- Piezovibration Sensor

Gyrosensors



A gyroscope sensor or gyrosensor is a sensor used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself.

MEMS



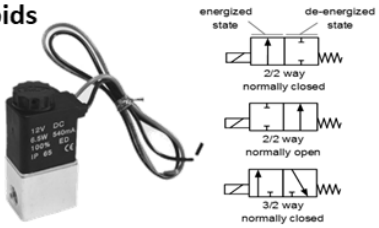
Microelectromechanical systems (MEMS) is the technology of microscopic devices, particularly those with moving parts. It merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micromachines in Japan, or micro systems technology (MST) in Europe.

Piezoelectric Actuators

As very high electric fields correspond to only tiny changes in the width of the crystal, this width can be changed with better-than-µm precision, making piezo crystals the most important tool for positioning objects with extreme accuracy — thus their use in actuators like:

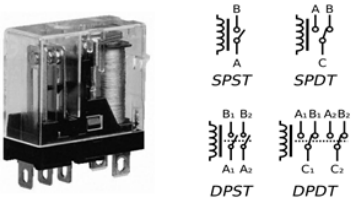
- Piezoelectric Loudspeakers
- Diesel Fuel Injectors
- X-Ray Shutters
- Optical Adjustment Actuator
- Piezoelectric Motor
- Piezoelectric Igniter

Solenoids



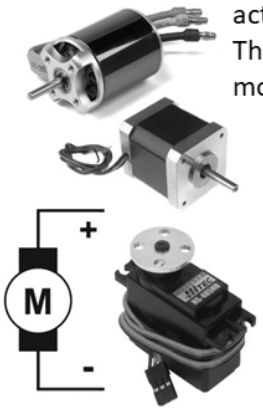
Solenoids are the simplest electromechanical devices, and consist of only a single coil. The coil is used to actuate an armature, which is in turn connects to a mechanism. Solenoids react quickly, but can only move over a very limited range.

Relays



Relays are a specialized type of solenoid actuator. Here, the armature of the solenoid is used to actuate an electrical contact. In shot, a relay is an electrically controlled switch.

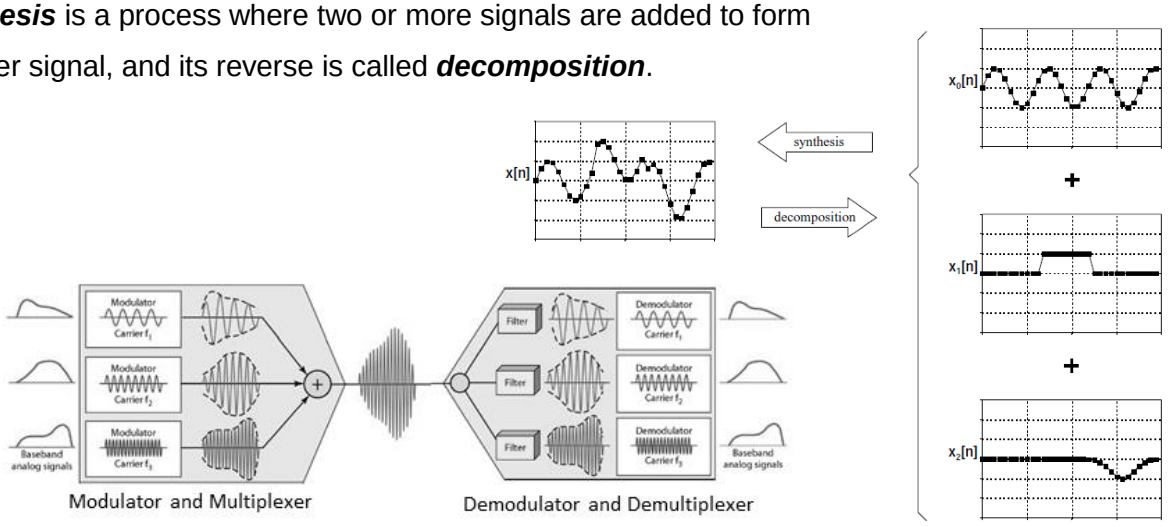
Motors



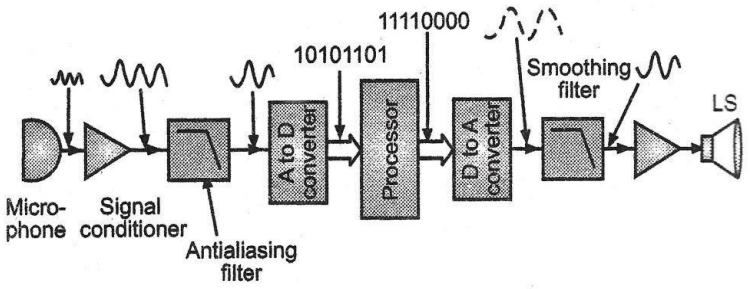
Electrical motors are a more complex group of electromechanical actuators. They use electrical energy to produce a rotational force. This motion is created through the interaction between the motor's magnetic field and the current through its windings.

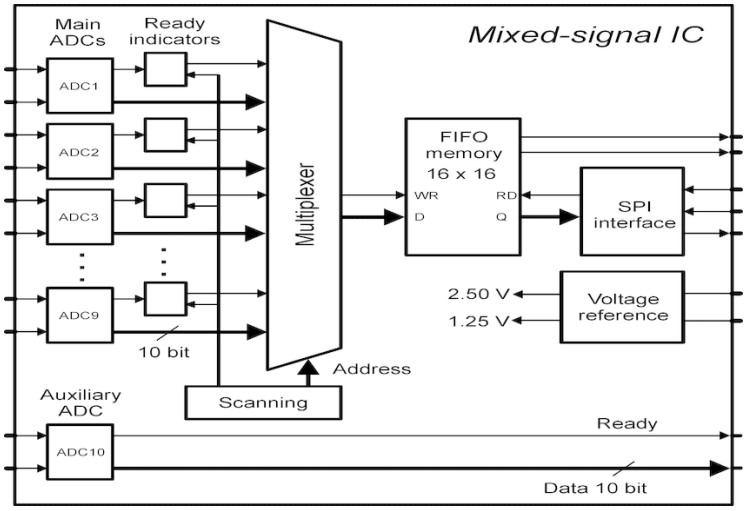
- **Brushless DC motors** are used in high efficiency and high power density applications.
- **Stepper motors** are optimized for slow, precise motion. As the name implies, stepper motors move in small, discrete steps.
- **Servo motors** are a closed-loop system that consists of three parts: an actuator, a sensor, and a controller. With a feedback mechanism, its actuator can detect and recover from failures.

Signal Converter is a device that converts signals from sensors to current signals, converts input signals to output signals, normalizes signals, or isolates signals. In signal processing, ***synthesis*** is a process where two or more signals are added to form another signal, and its reverse is called ***decomposition***.

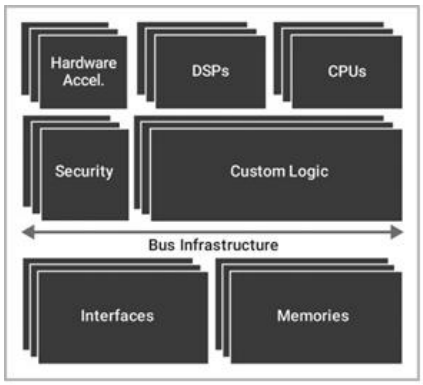


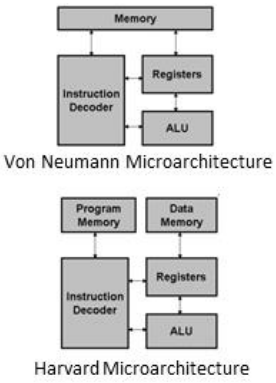
Mixed-signal circuits or *hybrid circuits*, are those that contain elements and properties of both analog circuit and digital circuit. Examples: Comparators, Timers, PLLs, ADCs, and DACs.





System on a Chip (*SoC*) is an integrated circuit or chip that integrates all components of a computer or other electronic system. It can include CPU, GPU, network modems, Bluetooth module, and all types of sensors, processors, and modules on a single chip.





ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. How can electronic systems process real-world signals? What essential device is needed for this function?
2. Discuss how optical or optoelectronic transducers work and give examples how they can be used in an electronic system.
3. In what ways can we find gyrosensors and MEMS useful nowadays? Mention some modern device features that rely on them.
4. What is the purpose of microcontrollers with regards to the use of sensors and actuators? Is it possible to use a generic microprocessor for that purpose?

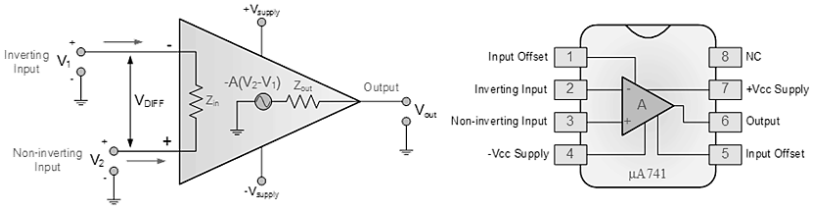
Research Activity

Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

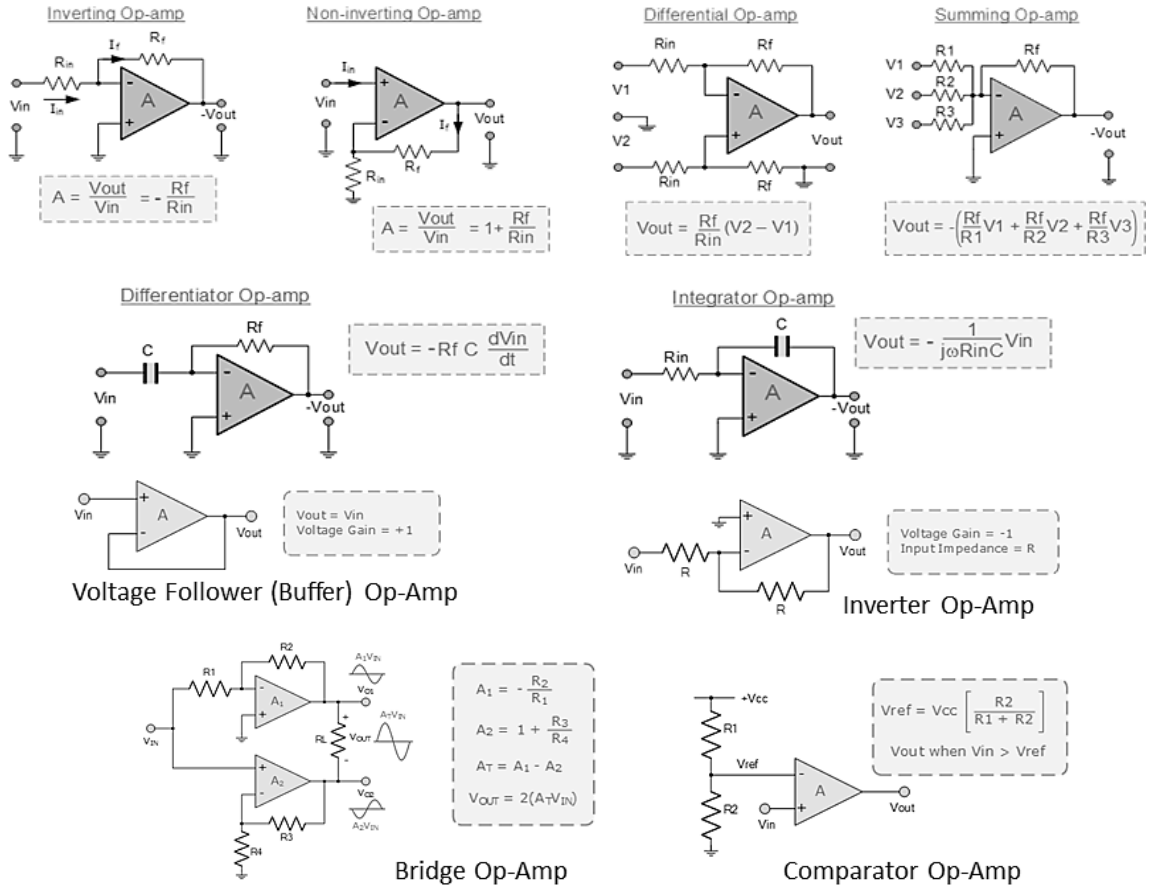
- ✓ How to Download and Install Audacity
- ✓ How to Use Audacity 2020

Module 2: **Review of Basic Electronic Circuits**

Amplifier Circuit is the generic term used to describe a circuit which produces and increased version of its input signal. An ***operational amplifier*** (op-amp) is a multi-stage , direct coupled, high gain negative feedback amplifier that has one or more differential amplifiers and its concluded with a level translator and an output stage.



Op-amps are available as integrated circuits and they are used to amplify AC/DC input signals and for basic mathematical operations. Common op-amp configurations are:



Op-Amp Characteristics

Characteristics	Ideal Value	Practical Value
Voltage Gain	∞	2×10^5
Input Impedance	∞	2 MΩ
Output Impedance	0	75 Ω
Bandwidth	∞	1 MHz
Input Offset Voltage	0	2 mV
Input Bias Current	0	50 nA
Input Offset Current	0	6 nA
CMRR	∞	90 dB
Slew Rate	∞	0.5 V/μs
PSRR	0	150 μV/V

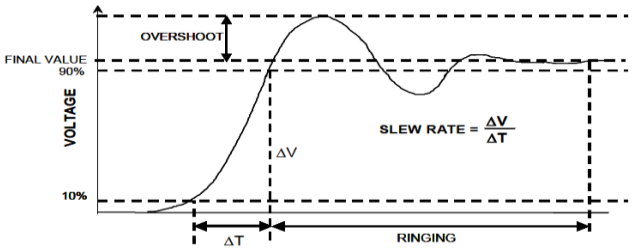
1. Gain Bandwidth Product (GBP or *open-loop gain*), can be very high and is a measure of how good an amplifier is
2. Frequency Response Curve – shows the product of the gain with respect to frequency
3. Common-Mode Rejection Ratio (CMRR) – the ratio of the common-mode gain to differential-mode gain; when expressed in dB, it is generally referred to as common-mode rejection (CMR)

$$CMRR = 20log\left(\frac{A_d}{A_{CM}}\right)$$

4. Power Supply Rejection Ratio (PSRR) – similar to CMRR, if a change of X volts in the supply produces the same output change as a differential input change of Y volts, then the PSRR on that supply is X/Y

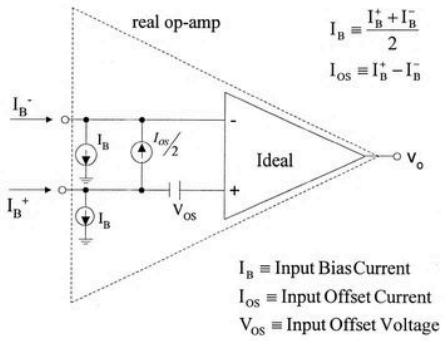
$$PSRR = \frac{\Delta V_{OS}}{\Delta V_{DC}} = 20\log\left|\frac{\Delta V_{OS}}{\Delta V_{DC}}\right|$$

5. Slew Rate (SR) – maximum rate of change of voltage of an amplifier at its output, expressed in V/s.

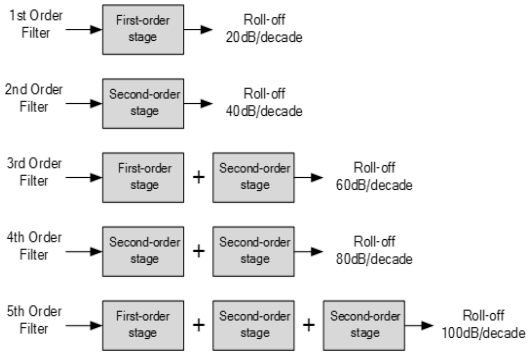


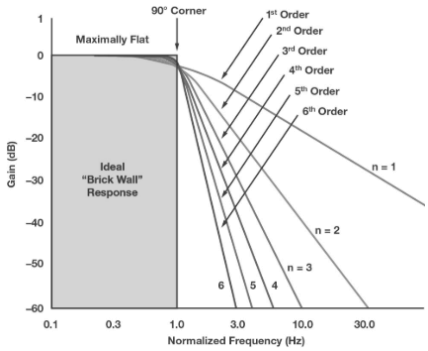
$$SR = 2\pi f V_P$$

6. Input Bias Current – ideally, inputs have infinite impedance and so no current flows into the input terminals



7. Roll-Off Rate – measured at [dB/decade] or [dB/octave] as the rate change of power at 10 times (decade) or 2 times (octave) change of frequency in the stop band



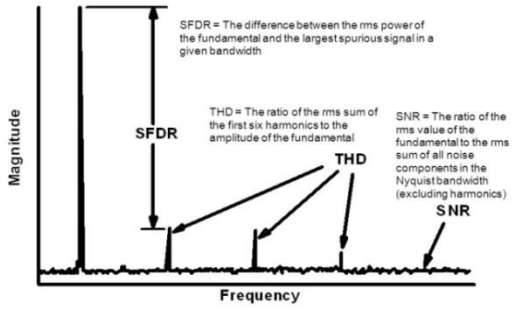


8. Signal-to-Noise Ratio (SNR or S/N) – the dynamic range of the system, usually expressed in dB. The reference level is the maximum signal level and the rms level of the noise is the floor.

$$SNR = 10\log\frac{S}{N}dB$$

9. Total Harmonic Distortion (THD) – the ratio of the harmonically related (2X, 3X, 4X, and so on the fundamental frequency) signal components caused by amplifier nonlinearity.

$$\text{THD + N} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2 + V_{noise}^2}}{V_s}$$

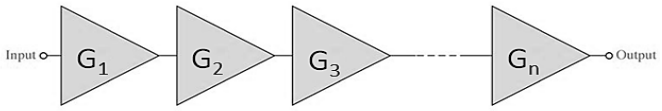


Amplifier Gain is the measure of how much an amplifier "amplifies" the input signal. It is the ratio of the output signal to the input signal, which can also be expressed in terms of ***decibels***.

$$G_{dB} = 10\ log\ \frac{P_2}{P_1}$$

$$G_{dB} = 20\ log\ \frac{V_2}{V_1}$$

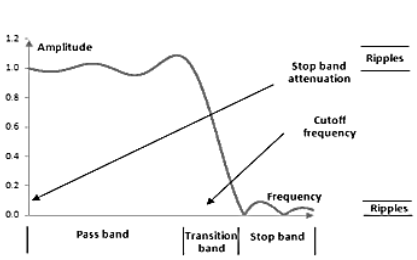
$$G_{dB} = 20\ log\ \frac{I_2}{I_1}$$

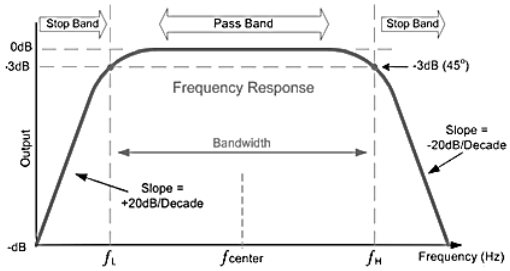


$$G_T = G_1\ G_2 G_3\ \ldots G_n$$

$$G_{T_{dB}} = G_{1_{dB}} + G_{2_{dB}} + G_{3_{dB}} + \cdots + G_{n_{dB}}$$

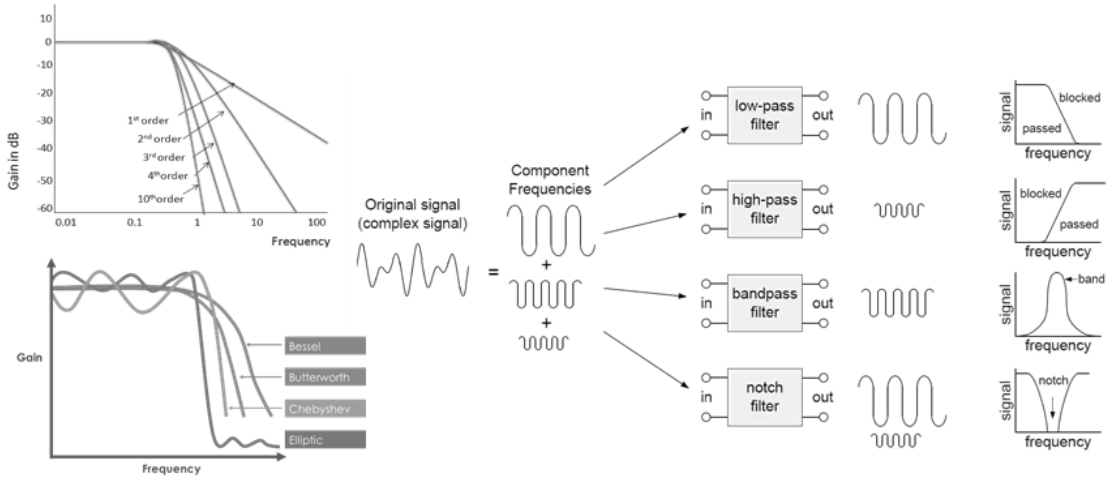
Filter Circuit is an electronic circuit capable of passing (or amplifying) certain frequencies while attenuating other frequencies, and can extract important frequencies from signals that also contain undesirable or irrelevant frequencies.



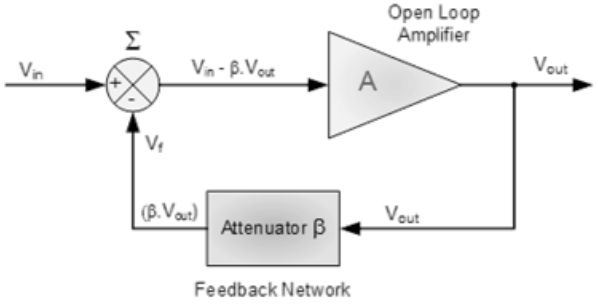


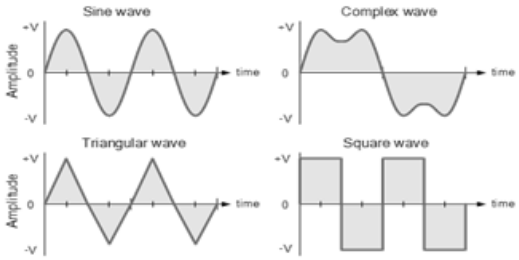
Filter Parameters

1. Passband
2. Stopband
3. Attenuation
4. Insertion loss
5. Impedance
6. Ripple
7. Shape Factor (or Bandwidth Ratio)
8. Quality Factor (Q)
9. Poles and Zeros
10. Envelope/Time Delay
11. Roll-off Rate (or Attenuation Rate)
12. Cutoff Frequency (-3dB Frequency)
13. Center Frequency (f0)
14. Bandwidth (BW)



Tuned Circuits and Oscillators are circuits that produce a periodic, oscillating electronic signal, often a sine wave or a square wave. These are widely used in many electronic devices, including radio and TV transmitters, computers and quartz clocks, and electronic beepers and video games.



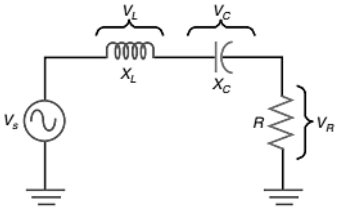


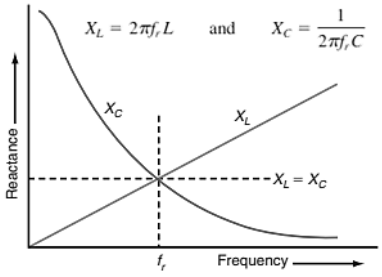
A ***tuned circuit*** (or *resonant circuit*) is made up of inductance and capacitance and resonates at a specific frequency, the resonant frequency. Because tuned circuits are frequency-selective, they respond best at their resonant frequency and at a narrow range of frequencies around the resonant frequency. A ***clock*** circuit is an oscillator that generates a sequence of repetitive pulses called the *clock signal* which is distributed to all the memory elements in the circuit.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

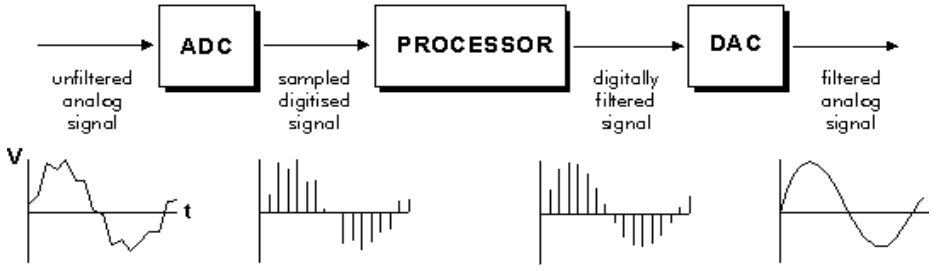
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$BW = \frac{f_r}{Q} = \frac{f_H - f_L}{Q}$$



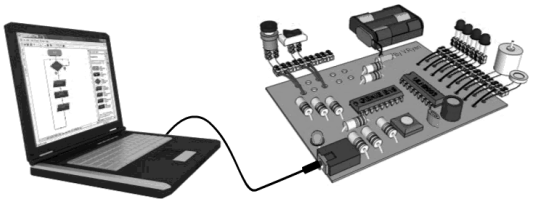


Analog-to-Digital and ***Digital-to-Analog converters*** (ADCs and DACs) are devices used to interface the microprocessor to the analog world. Many events monitored and controlled by the microprocessor are analog events. These range from monitoring all forms of events, even speech, to controlling motors and like devices.



Controllers

PIC MICROCONTROLLERS

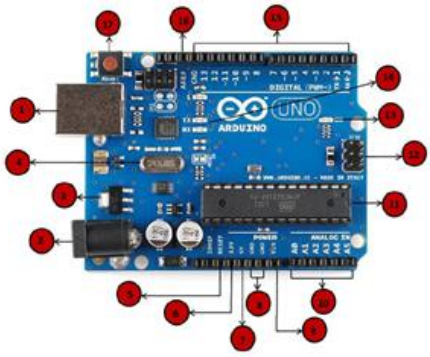


CIRCUIT WIZARD SOFTWARE - USED TO PROGRAM THE GENIE PIC MICROCONTROLLER

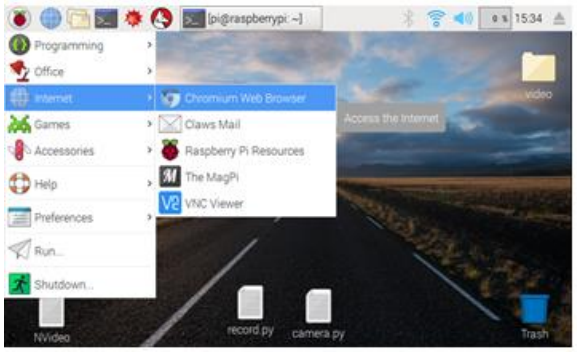
A GENIE PIC MICROCONTROLLER PROGRAMMABLE CIRCUIT

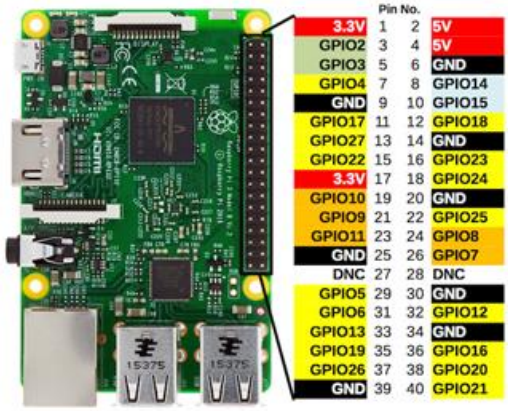
Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or *Integrated Development Environment* (IDE) that runs on a computer, used to write and upload computer code to the physical board. Technically, it is the ***ATmega328*** single-chip microcontroller that runs the Arduino board.

1. Power USB
2. Power (Barrel Jack)
3. Voltage Regulator
4. Crystal Oscillator
5 and 17. Arduino Reset
6. 3.3V Output Voltage
7. 5V Output Voltage
8. GND
9. Vin
10. Analog Pins
11. Main Controller
12. ICSP Pin
13. Power LED Indicator
14. Tx and Rx LEDs
15. Digital I/O
16. AREF



Raspberry Pi is a low cost, credit-card sized computer that plugs into a computer monitor or TV, and uses a standard keyboard and mouse. For example, *Raspberry Pi* 4 uses a Broadcom BCM2711 SoC with a 1.5 GHz 64-bit quad-core ***ARM*** Cortex-A72 processor, with 1 MiB shared L2 cache.





	Pin No.		
3.3V	1	2	5V
GPIO2	3	4	5V
GPIO3	5	6	GND
GPIO4	7	8	GPIO14
GND	9	10	GPIO15
GPIO17	11	12	GPIO18
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10	19	20	GND
GPIO9	21	22	GPIO25
GPIO11	23	24	GPIO8
GND	25	26	GPIO7
DNC	27	28	DNC
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Why is it important to understand the characteristics of op-amps and pay attention to an op-amp's specifications when selecting one?
2. If a sensor requires a minimum trigger voltage of 20mV, what should be the minimum input voltage of a 20 dB pre-amplifier placed before the sensor at the input section of an electronic system?
3. What are the differences and similarities between filter circuits and oscillator circuits?
4. Research about clock circuits and explain their significance in digital electronic systems.

Research Activity

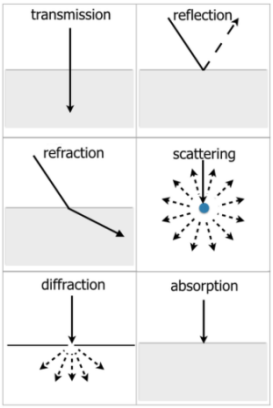
Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

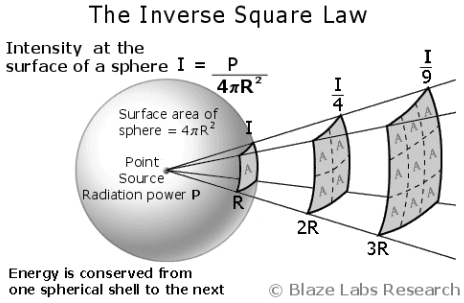
- ✓ Signal Paths | Digital Audio Fundamentals

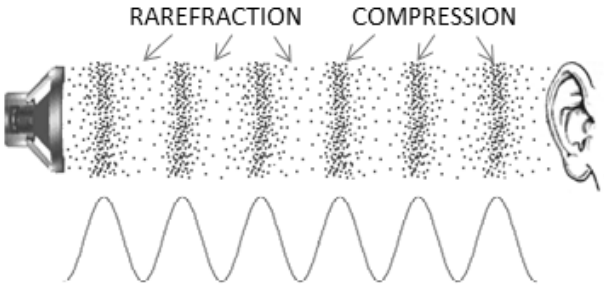
Module 3: **Acoustic and Optic Signals**

Wave is the disturbance (change from equilibrium) of one or more fields such that the field values oscillate repeatedly about a stable equilibrium value. It can only exist in fields when there is a force that tends to restore the field to equilibrium.

QUANTITY	SYMBOL	UNIT	RELATIONS
wavelength	λ	m	
period	τ	s	$\tau = \frac{1}{f}$
frequency	f	/s, s^{-1} or Hz	$f = \frac{1}{\tau}$
amplitude	A	m	
speed	v	m/s	$v = \lambda f$; $v = \frac{\lambda}{\tau}$







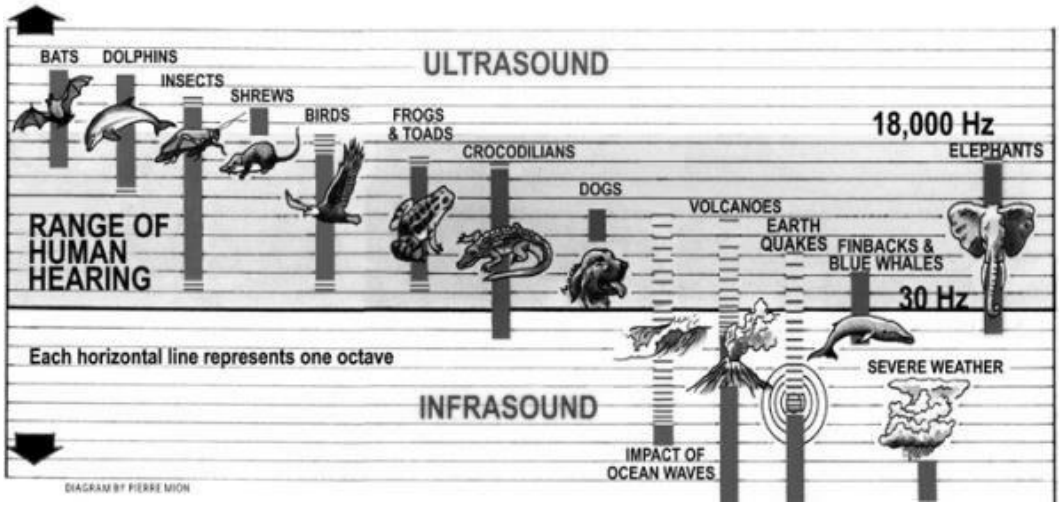
Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including topics such as vibration, sound, ultrasound and infrasound. It is concerned with the production, control, transmission, reception, and effects of sound. ***Sound Waves*** are the most significant example of longitudinal waves. They travel through a medium by causing disturbance via its vibration.

$$Mach\ Number = \frac{Speed\ of\ Object}{Speed\ of\ Sound}$$

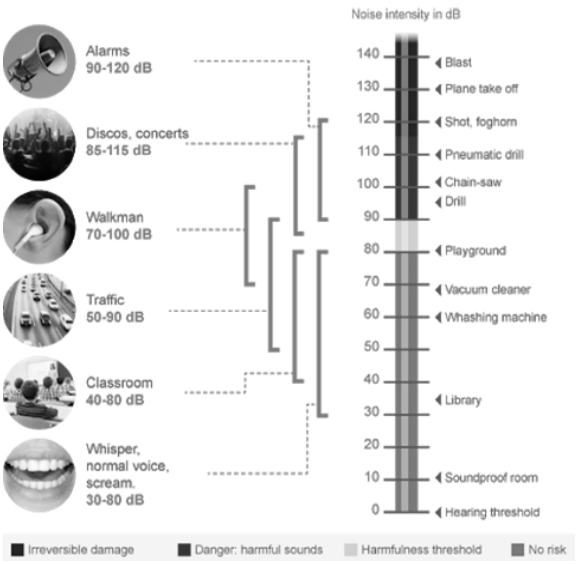
Category	Mach No.
Subsonic	< 1.0
Transonic	1.0
Supersonic	> 1.0
Hypersonic	> 5.0

Medium	*Speed (m/s)*
Gases	
Air (20°C)	343
Air (0°C)	331
Liquids at 25°C	
Sea water	1533
Water	1493
Mercury	1450
Methyl alcohol	1143
Solids	
Rubber	1600
Gold	3240
Iron	5130
Pyrex glass	5640
Diamond	12000

While ***frequency*** measures the cycle rate of the physical waveform, ***pitch*** is how high or low it sounds when you hear it. This is directly related to frequency: the higher the frequency of a waveform, the higher the pitch of the sound you hear.



The ***amplitude*** of a sound wave determines its ***loudness*** or volume. A larger amplitude means a louder sound, and a smaller amplitude means a softer sound. The ***decibel scale*** is a logarithmic measure of sound intensity. An increase of 20 dB means the sound wave is amplified 10 times greater, but the human ears only perceive it to be about twice as loud.



<u>Threshold of Hearing</u>

- faintest sounds the human ear can detect
- **0 dB** (10^{-12} W/m^2 @ 1000 Hz)

<u>Threshold of Pain</u>

- loudest sounds the human ear can tolerate
- **140 dB** (1 W/m^2 @ 1000 Hz)

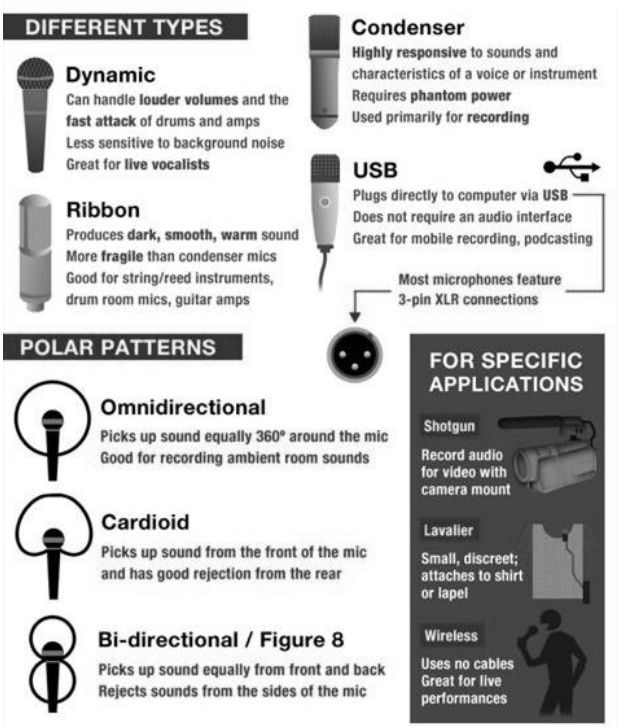
$$PWL = 10\log\frac{P}{P_0} \qquad P_0 = 10^{-12}\ W$$

$$SIL = 10\log\frac{I}{I_0} \qquad I_0 = 10^{-12}\ \frac{W}{m^2}$$

$$SPL = 20\log\frac{\rho}{\rho_0} \qquad \rho_0 = 2\ x\ 10^{-5}\ Pa$$

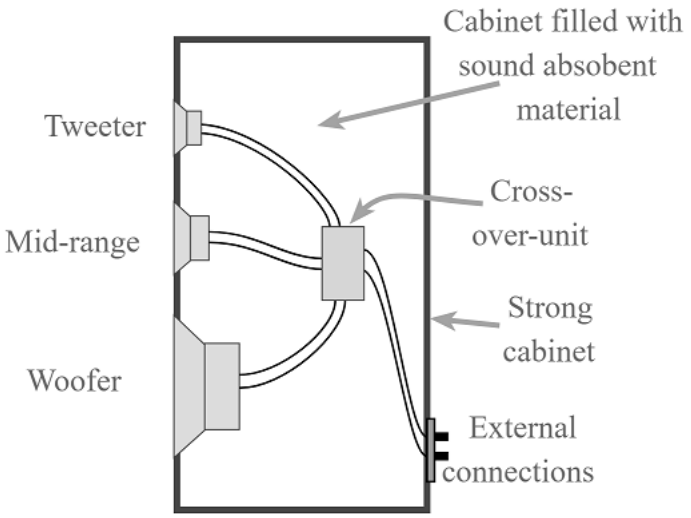
Sound Measurements

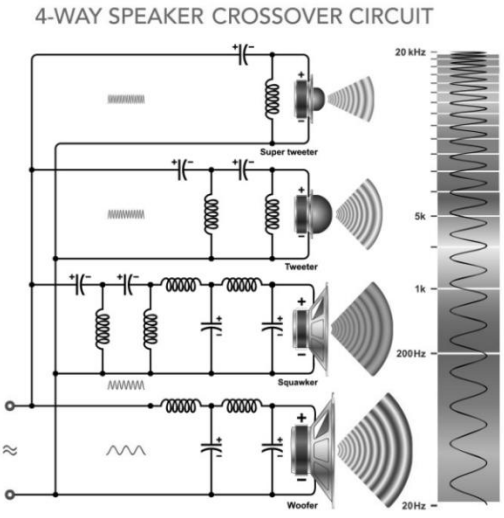
1. Sound Power (P) – rate at which sound energy is emitted, reflected, transmitted or received, per unit time, measured in Watts (W); decibel value is called *sound power level* (PWL)
2. Sound Intensity (I) – power per unit area carried by a wave, measured in Watts per square meter (W/m^2); decibel value is called *sound intensity level* (SIL)
3. Sound Pressure (ρ) – most commonly used indicator of the acoustic wave strength, measured in Pascal (Pa); decibel value is called *sound pressure level* (SPL)



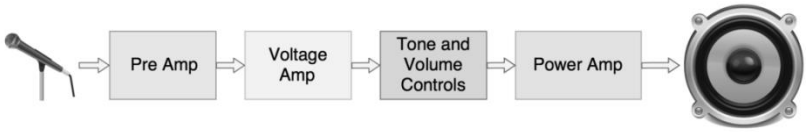
Microphones are electronic transducers that convert acoustic energy to electric energy, while ***speakers*** convert electric energy to acoustic energy.

Basic Speaker Assembly

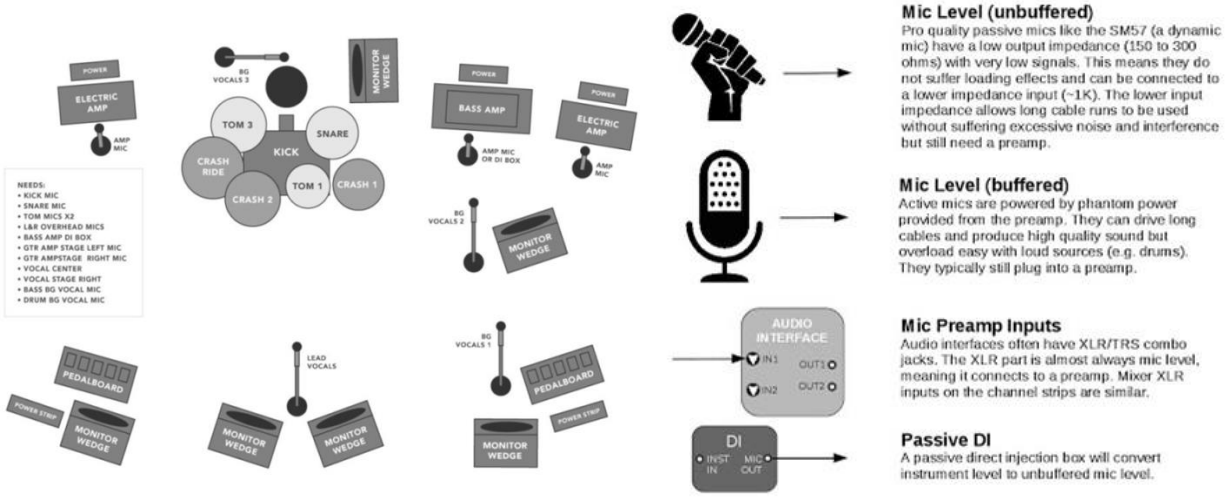




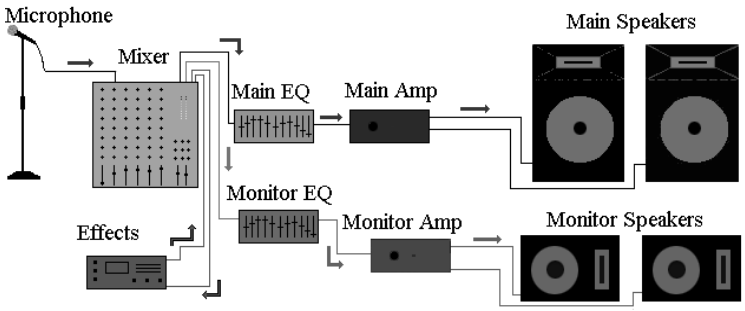
Audio amplifiers are basically designed to increase the power of an electrical signal whose vibrations are confined to the *audio frequency range* — the range that can be perceived by the human ear. ***Preamplifier*** (preamp) is intended to raise a *mic-level* or *instrument-level* signal up to a *line-level* signal. ***Voltage amplifiers*** convert a small input voltage into a much larger output voltage, while ***power amplifiers*** are used to drive a motor or feed a loudspeaker, or any other applications that require high switching currents.



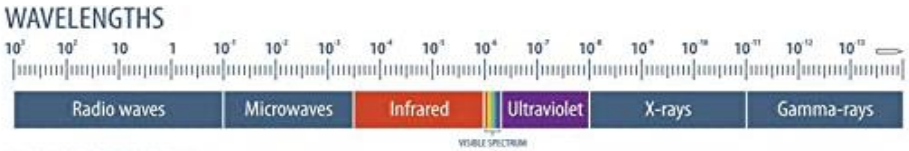
Block Diagram of an Audio Amplifier

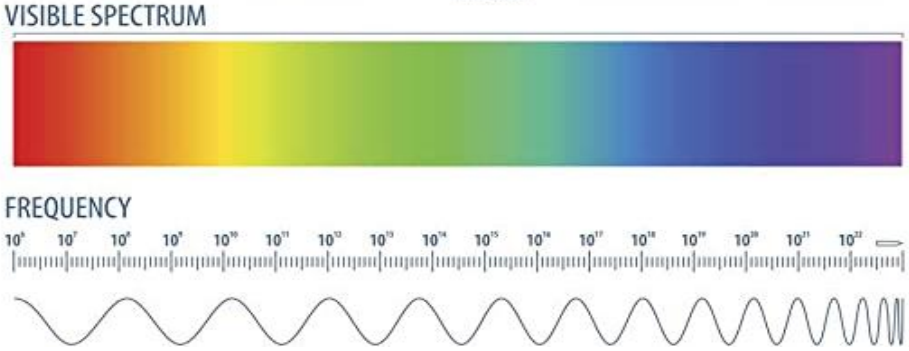


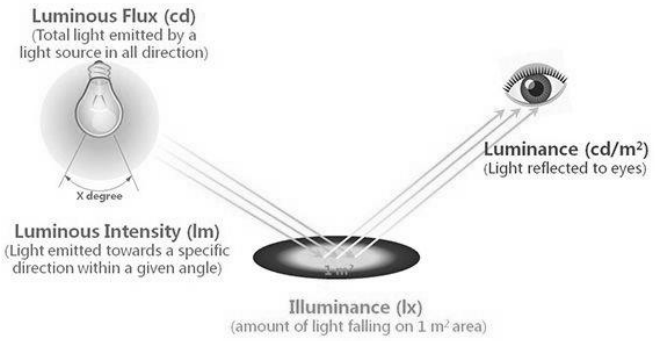
A ***mixer***, or *audio interface*, combines the individual inputs and "mixes" them into controllable outputs, while an ***equalizer*** (EQ) controls/shapes, the frequencies to achieve a better sound or eliminate unwanted noise before feeding the output to the amplifier. Mixers often include a built-in equalizer.



Optics is the field of physical science that deals with the properties and phenomena of both visible and invisible light and with vision. It has two branches: *Geometric Optics* (Rays) and *Physical Optics* (Waves).





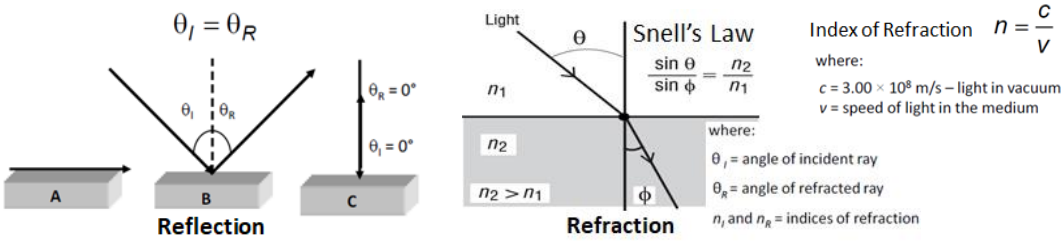


Light Waves (Visible Light)

- electromagnetic radiation within the portion (405–790 THz) of the electromagnetic spectrum that can be perceived by the human eye
- measured in terms of:
  - ✓ Illuminance – light level incident on a surface or plane from a source or sources; expressed in ***lux*** (lumens/m^2) or ***footcandle*** (lumens/ft^2)
  - ✓ Light Intensity – luminous flux per unit solid angle, measured in **candelas** (cd)
  - ✓ Luminance – measurement of the product of the incident light and the surface – anything that is reflected, and is also considered the human perception of brightness, measured in cd/m^2

Reflection and Refraction of Light

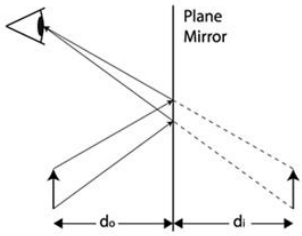
In general, ***total internal reflection*** takes place at the boundary between two transparent media when a ray of light in a medium of higher index of refraction approaches the other medium at an *angle of incidence greater than the critical angle*.



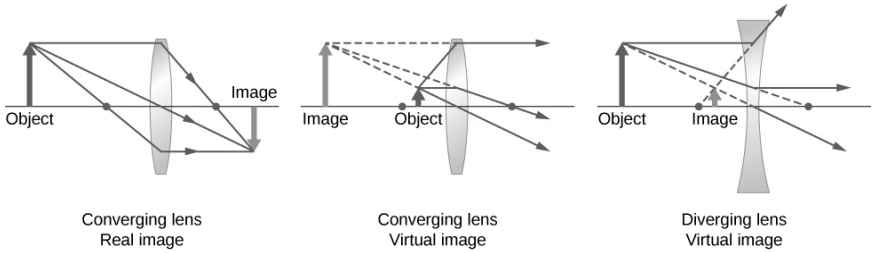
Mirrors are reflective surfaces, typically of glass coated with a metal amalgam, that reflect a clear image. They can be either plane or spherical (concave and convex). ***Mirror Equation*** is used for finding the location of the image

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

f = the distance from V to F
** Note that f will be negative if the focal length is behind the mirror.*
d_o = the distance from object to mirror
d_i = the distance from image to mirror
** Note that d_i will be negative if the image is behind the mirror (virtual image).*

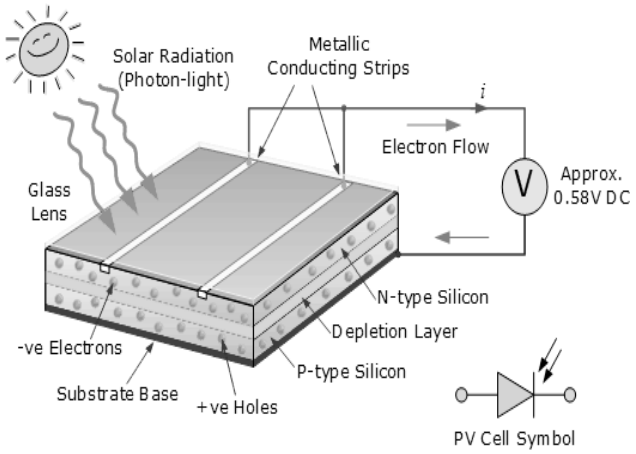


Lenses are optical systems with two refracting surfaces. These are glasses or other transparent substances with curved sides for concentrating or dispersing light rays, used singly (as in a magnifying glass) or with other lenses (as in a telescope). In simple ***magnification***, light from an object passes through a biconvex lens and is bent (refracted) towards your eye. It makes it appear to have come from a much bigger object.

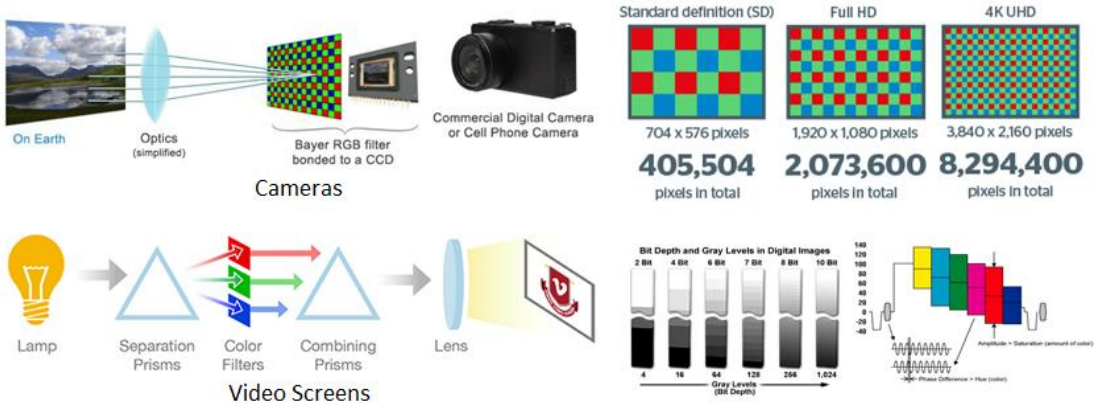


Optoelectronics

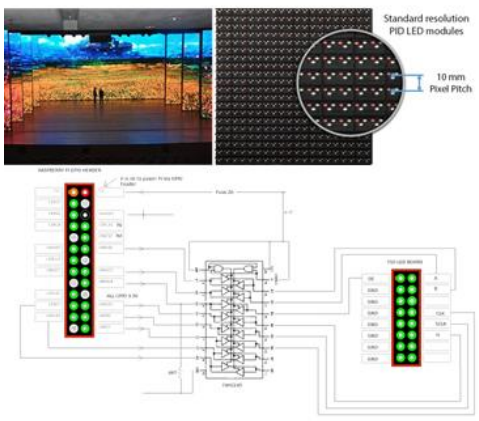
- study and application of electronic devices and systems that source, detect and control light
- usually considered a sub-field of *photonics*
- important applications include optocoupler circuits, infrared communications, LED walls, solar panels, photography & videography, and optical fiber communications.

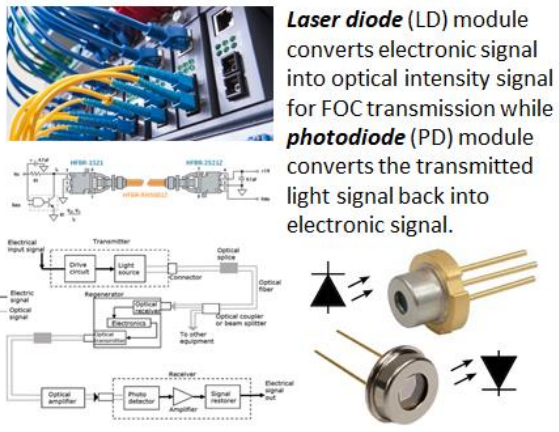


Cameras and Video Screens



LED Walls and Fiber Optics





Laser diode (LD) module converts electronic signal into optical intensity signal for FOC transmission while ***photodiode*** (PD) module converts the transmitted light signal back into electronic signal.

ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Why should engineers consider the human hearing range and threshold of hearing in designing any system that involves audio signals?
2. Discuss the possible ways that having knowledge in sound measurements and other concepts of acoustics becomes helpful in doing computer engineering projects.
3. Explain the similarities and differences between mirrors and lenses.
4. In your own idea, what is the significance of having knowledge in the properties of light, as well as the concepts of mirrors and lenses in the design of fiber optic cables?

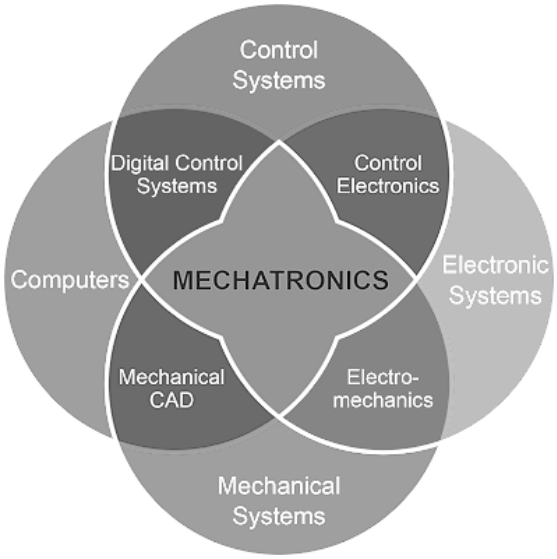
Research Activity

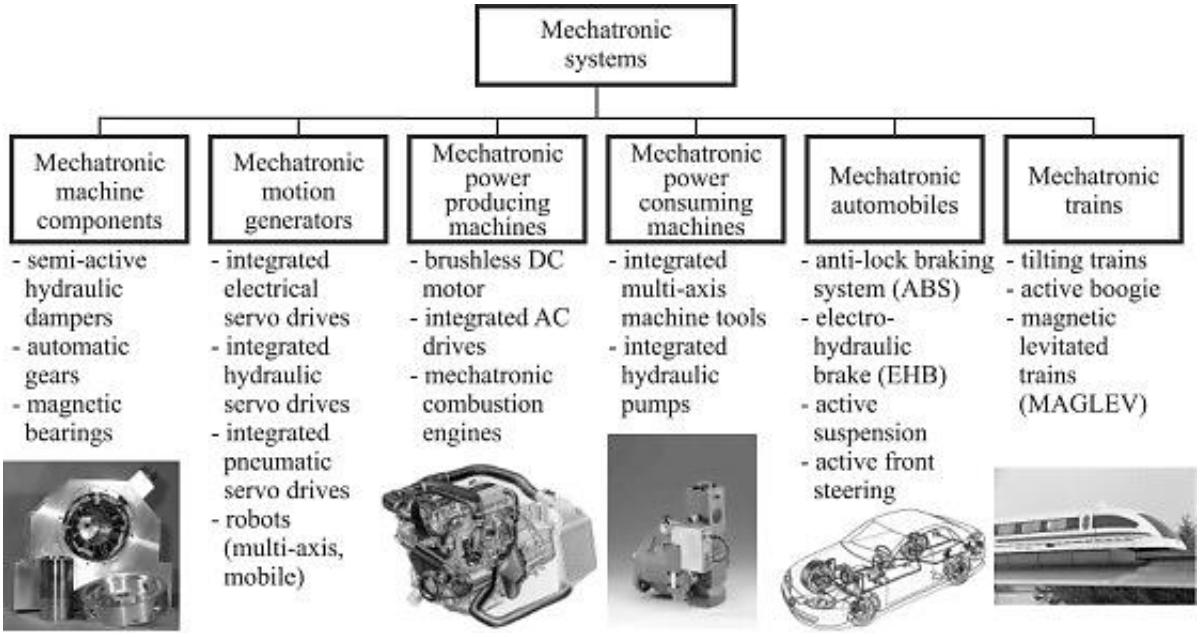
Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

- ✓ Sampling Theorem | Digital Audio Fundamentals
- ✓ Common Audio Sample Rates | Digital Audio Fundamentals
- ✓ Understanding Aliasing | Digital Audio Fundamentals

Module 4: **Basics of Mechatronics**

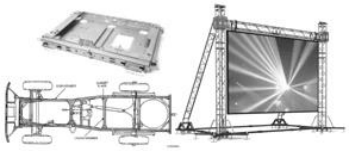
Mechatronics Engineering focuses on the engineering of both electrical and mechanical systems, and also includes a combination of robotics, electronics, computer, telecommunications, systems, control, and product engineering. It is an Interdisciplinary field that values systems thinking and an interdisciplinary approach to problem solving related to designing products and manufacturing processes.





Machine Elements

- Structural Elements – stationary parts that hold certain parts of the machine or even the whole structure of the machine


Frame Members

Axles

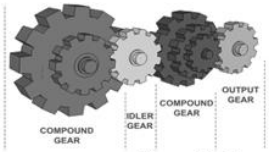

Bearings


Seals

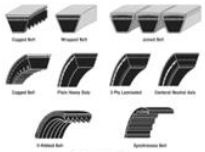

Splines


Fasteners

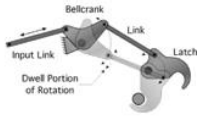
- Mechanisms – control movement in various ways such as gear trains, belt or chain drives, linkages, cam and follower systems, including brakes and clutches



Gear Trains

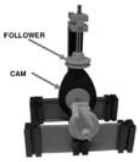

Belt Drives


Chain Drives



Linkages

Cam and Follower Systems



Clutches

Brakes

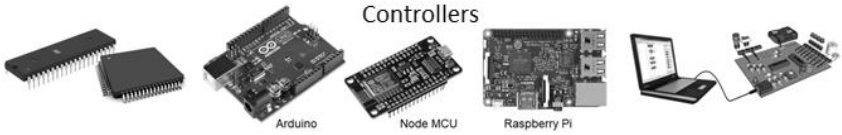
- Control Components – components that are part of the controlling, instrumentation, or any signal processing functions of the system


Switches and Adjusters

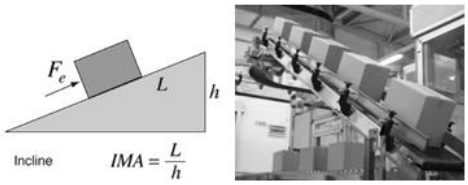

Sensors


Actuators and Indicators

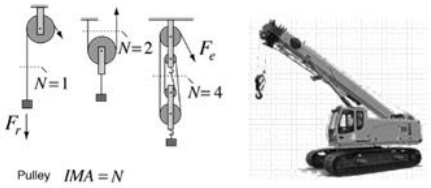
Controllers



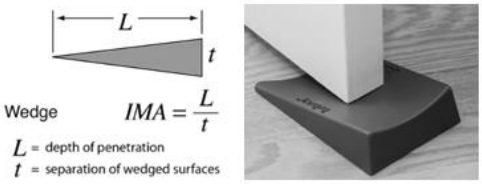
Simple Machines



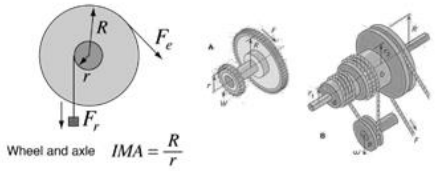
Inclined Plane



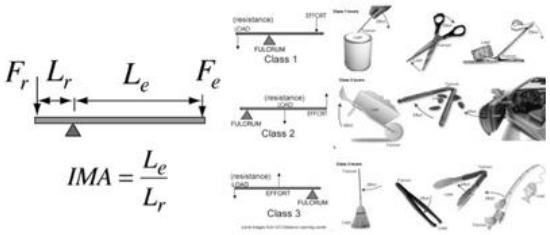
Pulley



Wedge



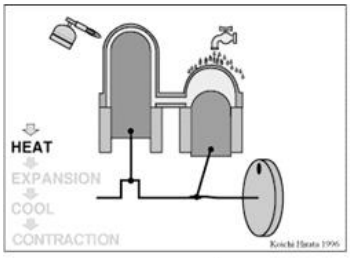
Wheel and Axle



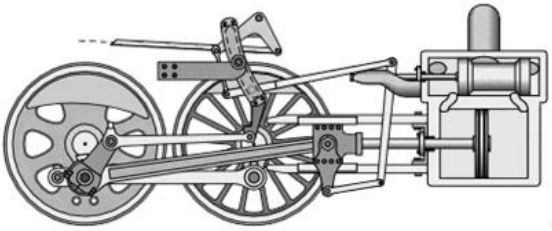
Lever

Screw

Thermodynamic Machines

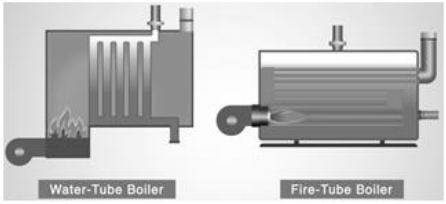


Heat Engine

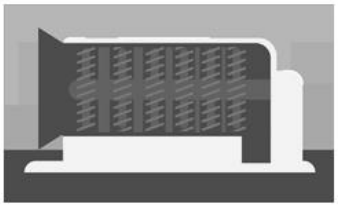


Steam Engine

Air Compressor



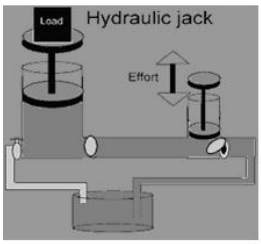
Boiler

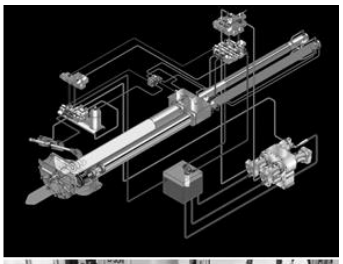


Fluid Power refers to the use of fluids under pressure to generate, control, and transmit power. It is subdivided into:

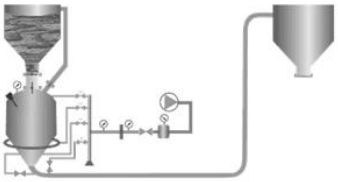
- Hydraulics – concerned with the conveyance of liquids through pipes and channels, especially as a source of mechanical force or control
- Pneumatics – deals with the mechanical properties of gases and the application of such gases to produce motion

Hydraulic system	Pneumatic system
Speed is limited	Very high speed is possible
Operates at high pressure	operates at low pressure
Pump is necessary	No pump at all
No noise is produced	A lot of noise is produced
Resistances to fluctuating load	Non-resistant to fluctuating load.
Suitable for feed movement in m/c tools	Unsuitable for teed movement.
Most expensive	Less expensive
Oil as a media to transfer energy	Air as a media to transfer energy
Cavitations is a big problem	No cavitation problem

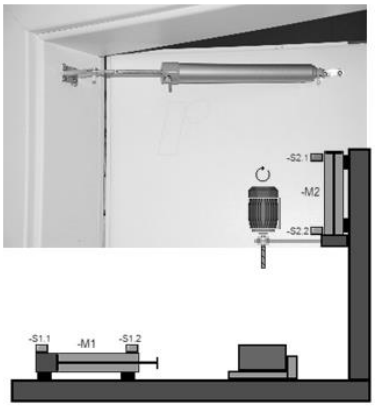




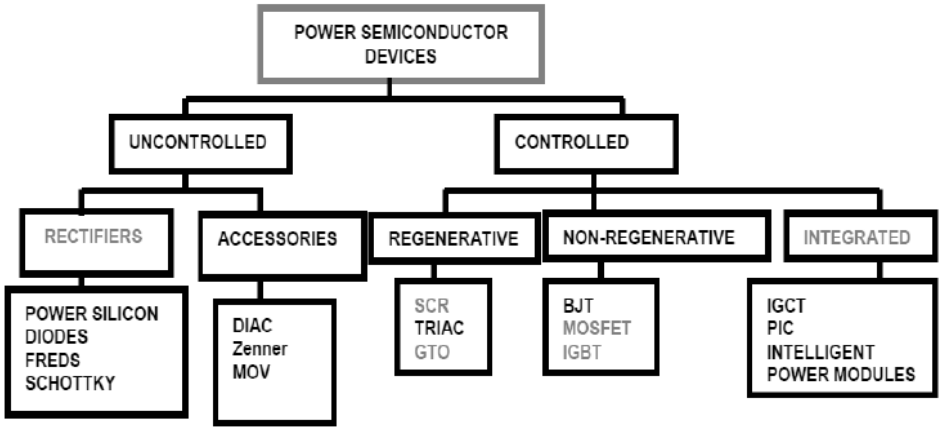
Hydraulic Applications



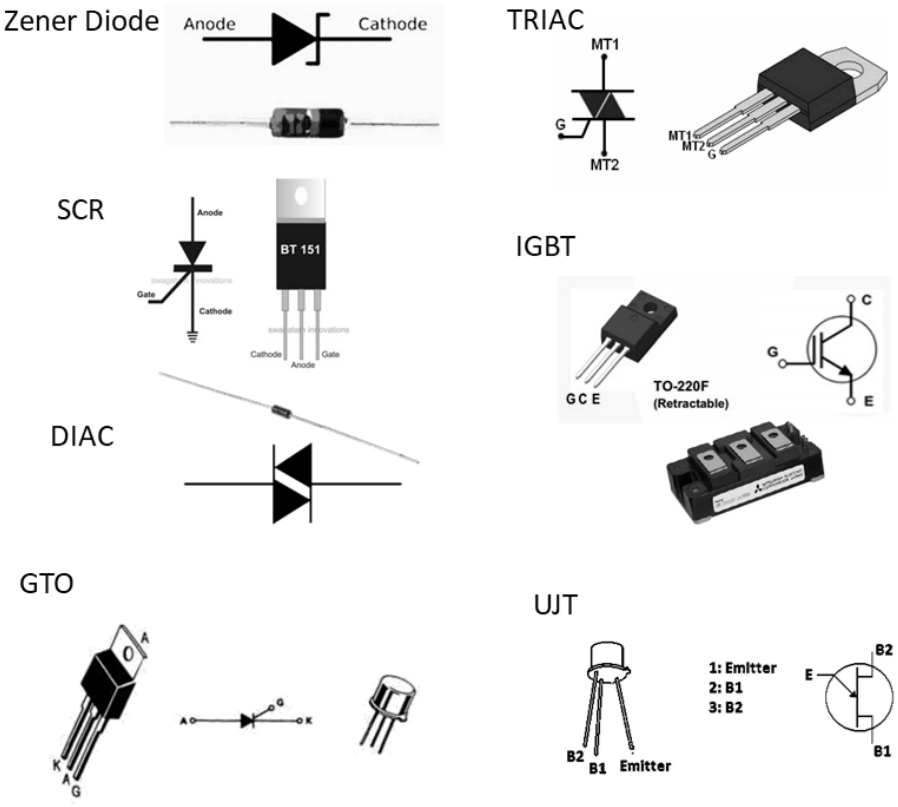
Pneumatic Applications



Power Electronics refers to the process of controlling the flow of current and voltage and converting it to a form that is suitable for user loads. The most desirable power electronic system is one whose efficiency and reliability is 100%.

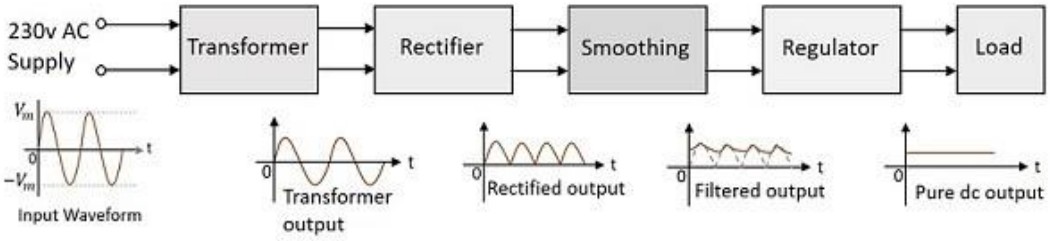


The **thyristor** is a family of three-terminal devices that include SCRs, GTOs, and MCT. For most of the devices, a gate pulse turns the device on.



A ***power supply*** is an electronic *system* that converts an AC voltage source into a DC voltage output. Thus, it is also known as *AC-DC converter*. It is basically composed of:

- Transformer − input for the stepping down of the 230v AC power supply.
- Rectifier − converts the AC components present in the signal to DC components.
- Smoothing − a filtering circuit that smoothens the variations present in the rectified output.
- Regulator − controls the voltage to a desired output level.
- Load − uses the pure dc output from the regulated output.



AC-AC Converters (AC Voltage Controllers)

- used to produce a variable AC output voltage from a fixed AC source
- output voltage is controlled by varying the conduction time of firing angle of the TRIAC

DC-DC Converters (Chopper or Switching Regulator)

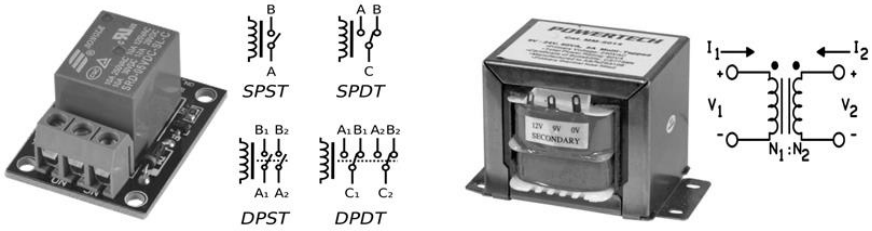
- average output voltage is obtained by controlling the conduction time t of transistor $Q1$. If T is the chopping period, then $t1 = dT$, where d is the *duty cycle*

DC-AC Converters (Inverter)

- involve switching the transistors on and off in pairs
- in the given circuit M_1 and M_2 conduct for one-half cycle, while M_3 and M_4conduct for the other half

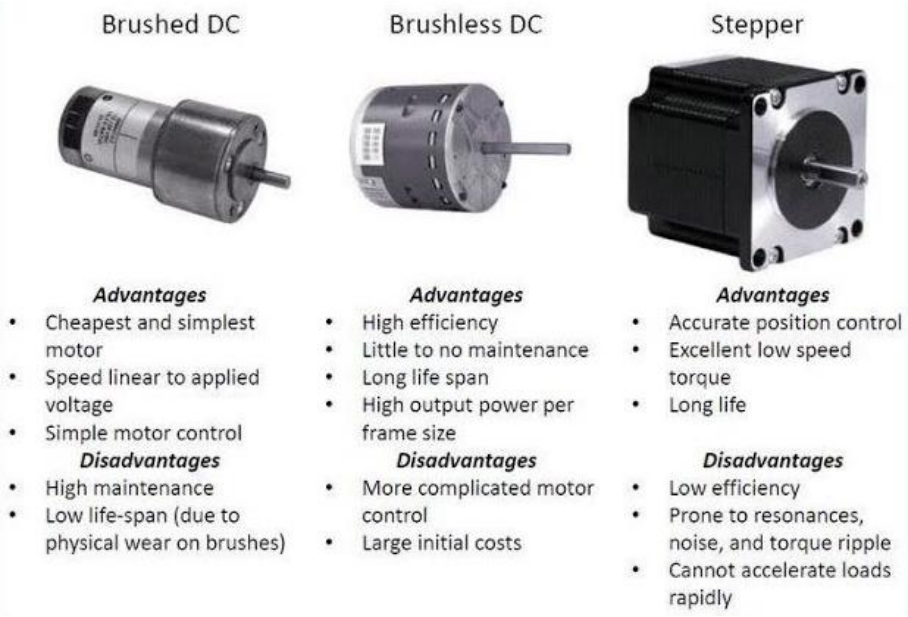
Solenoid is a wire wound into a tightly packed helix, forming a coil used as an electromagnet. It creates a magnetic field from electric current and uses it to create linear motion. It also refers to any device that converts electrical energy to mechanical energy using a solenoid.

Relay is an electrically operated switch used where it is necessary to control a circuit by a separate low-power signal, or where several circuits must be controlled by one signal, while ***Transformer*** is an electrical device that transfers electrical energy between two or more circuits through electromagnetic induction to increase or decrease AC voltage levels.



Electrical motors are a more complex group of electromechanical actuators. They use electrical energy to produce a rotational force. This motion is created through the interaction between the motor's magnetic field and the current through its windings.

- *Brushless DC motors* are used in high efficiency and high power density applications.
- *Stepper motors* are optimized for slow, precise motion. As the name implies, stepper motors move in small, discrete steps.
- *Servo motors* are a closed-loop system that consists of three parts: an actuator, a sensor, and a controller. With a feedback mechanism, its actuator can detect and recover from failures.



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Discuss the relationship between mechatronics and control systems. What makes mechatronics essential in the Industry 4.0 applications of control systems?
2. What are the important physical concepts that must be understood and considered when choosing machine elements and simple machines to be part of a mechatronic system?
3. In your own idea, why would it be a big advantage for a control systems engineer to have background in thermodynamic, hydraulic, and pneumatic machines, especially in the advent of the Industry 4.0?
4. What makes electromagnetic devices and power semiconductors relevant to the operations of PLC, HMI, and mixed reality in the context of mechatronics?

Research Activity

Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

- ✓ Quantization | Digital Audio Fundamentals
- ✓ Bit Depth | Digital Audio Fundamentals

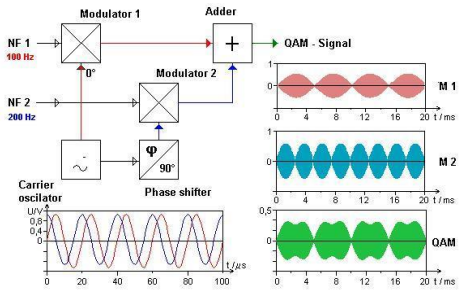
Mixed Signals in Communications Systems

(CMPE 30153 – Fundamentals of Mixed Signals & Sensors)

Chapter 2

I. OVERVIEW

A communications system is a collection of communications equipment that is integrated into a coherent system. These allow different people to stay in touch over a geographical system. Many communications technologies nowadays makes use of mixed-signal integrated circuits (ICs) such as in modern smartphones, wireless communications, data converters, analog-to-digital converters, digital-to-analog converters, digital radio, etc.



II. MODULE OBJECTIVES

After successful completion of modules 5-8 of Chapter 2, you should be able to:

1) Remember the basic working principles of communications systems;
2) Understand the role of mixed signals and sensors in communications;
3) Evaluate the signal processing methods and technologies involved mixed-signal circuits; and
4) Apply the key concepts of mixed signals and sensors in developing systems that involve data transmission.

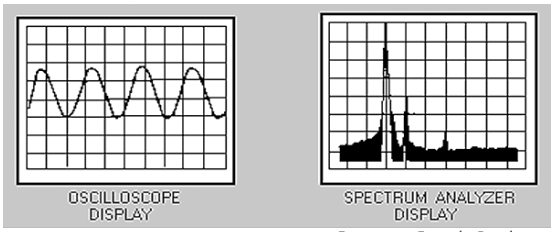
III. COURSE MATERIALS

Suggested Online Resources for Further Learning

- Downloadable Course AVPs: https://bit.ly/3Fs7iFM
- Downloadable Course PDFs: https://bit.ly/2YFv8gu

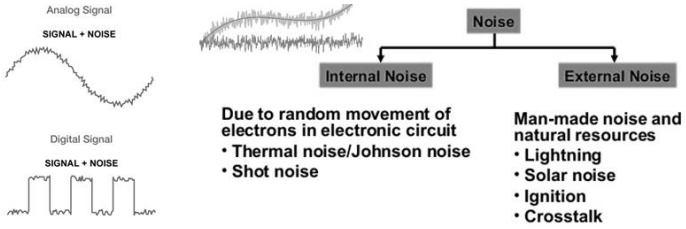
Module 5: **Signal Analysis and Processing**

Signal analysis is the study of collecting, understanding, and deducing information and intelligence from various signals, while ***signal processing*** covers the analysis, modification, and synthesis of signals.

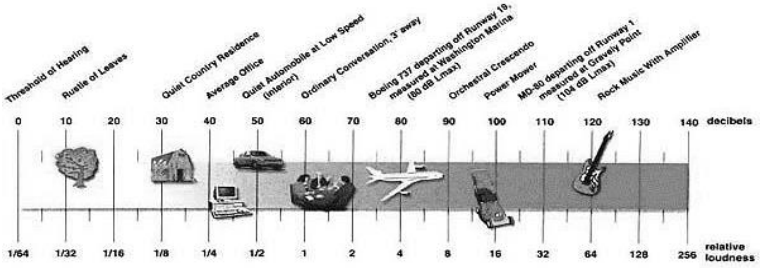


Time-Domain Graph Frequency-Domain Graph

Noise is an undesired coupling (energy transfer) from one circuit or medium to another. It also refers to any phenomenon by which a signal transmitted on one frequency creates an undesired effect on another frequency.

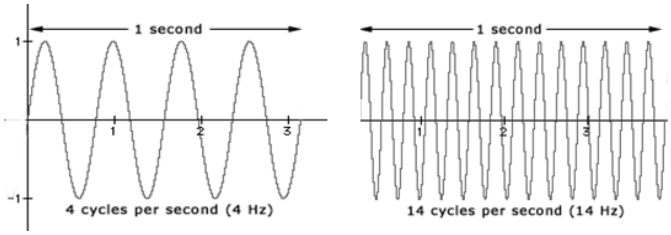


Amplitude of a signal refers to the extreme range, or magnitude, of a fluctuating value such as an acoustic or electromagnetic signal. It is measured perpendicular to the to the time axis of a time-domain graph, or to the frequency of a frequency-domain diagram. It describes the measure of the intensity, loudness, power, strength, or volume level of a signal. The amplitude is also measured in terms of ***gain***, which can be expressed as absolute value (unitless) or logarithmic (***decibel*** or dB).

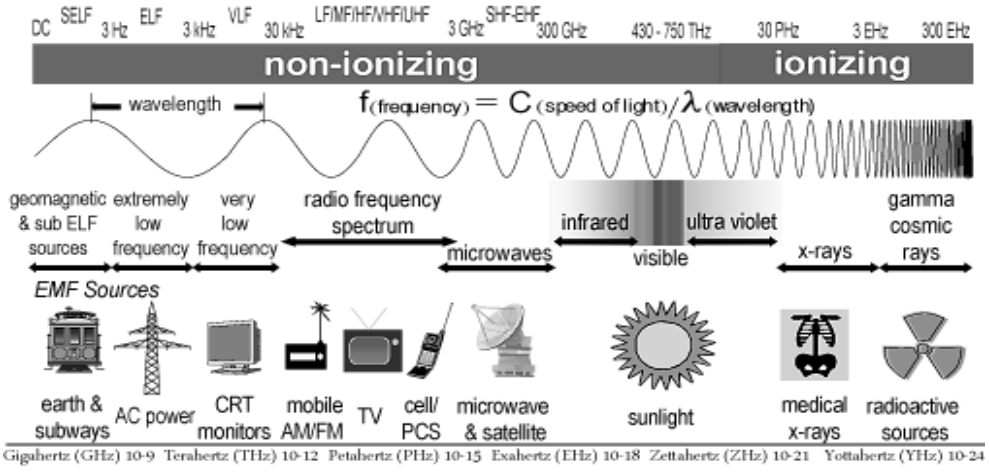


The **decibel (dB)** is a unit for describing sound pressure levels. A-weighted sound measurements (dBA) are filtered to reduce the effect of very low and very high frequencies, better representing human hearing. With A-weighting, sound monitoring equipment approximates the human ear's sensitivities to the different sounds of frequencies.

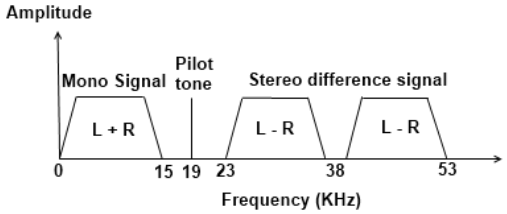
Frequency of a signal refers to the number of cycles per unit time, measured in Hertz (Hz). It describes how fast the sound or EM wave is oscillating. It can be thought of as the "specific path" of the electronic signal (RF) and it represents the pitch of the sound (AF). The ***period*** is the duration of time of one cycle in a repeating event, so the period is the reciprocal of the frequency.



The ***Electromagnetic Spectrum*** is a continuum of all electromagnetic waves arranged according to frequency and wavelength. From radio waves to gamma rays, all electromagnetic waves in the universe are invisible, except for the visible waves that range from infrared to ultraviolet.



A ***frequency band*** is an interval in the frequency domain, delimited by a lower frequency and an upper frequency. The term may refer to a radio band or an interval of some other spectrum.

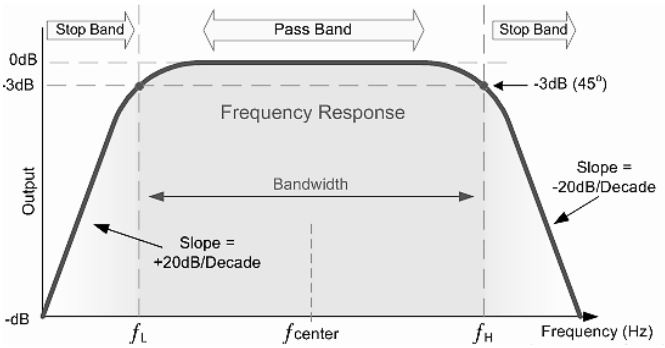


The modulating, (base-band) signal for a stero VHF F.M transmission

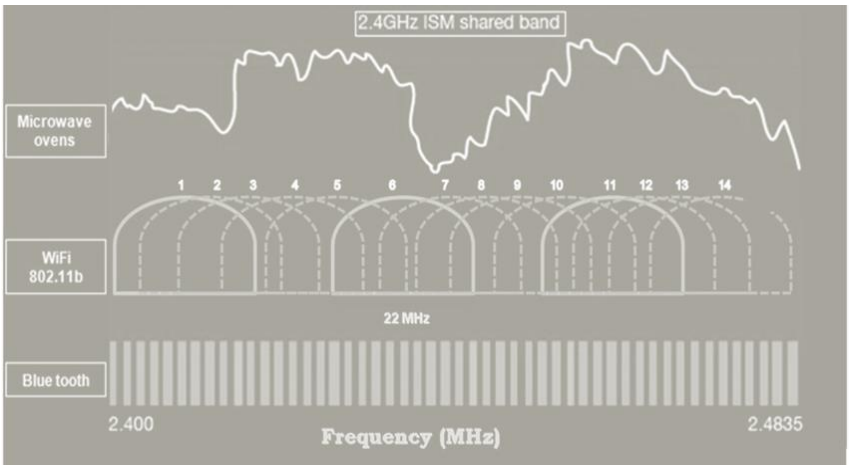
Bandwidth is the range of frequencies within a given band, in particular that is used for transmitting a signal, while a ***frequency band*** is an interval in the frequency domain, delimited by a lower frequency and an upper frequency.

Note: Human Voice Range = 300 Hz to 3400 Hz

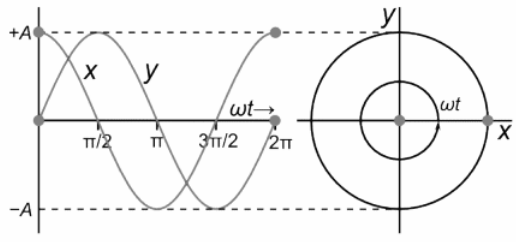
Human Hearing Range = 20 Hz to 20000 Hz



$$BW = f_H - f_L = 2f_C$$



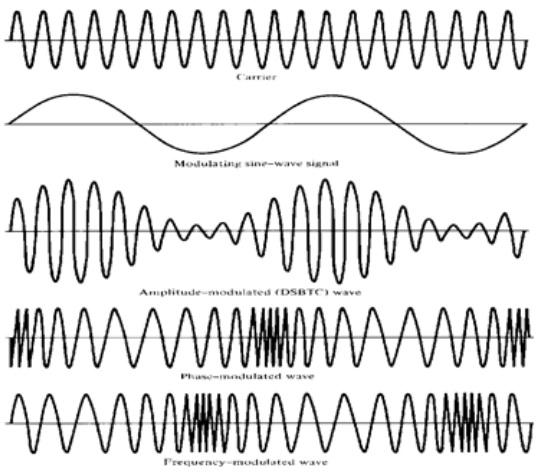
Phase of a Signal describes the position of a point in time (an instant) on a waveform cycle, which is the interval required for the waveform to return to its arbitrary initial value. It can also be an expression of relative displacement between two corresponding features (for example, peaks or zero crossings) of two waveforms having the same frequency.



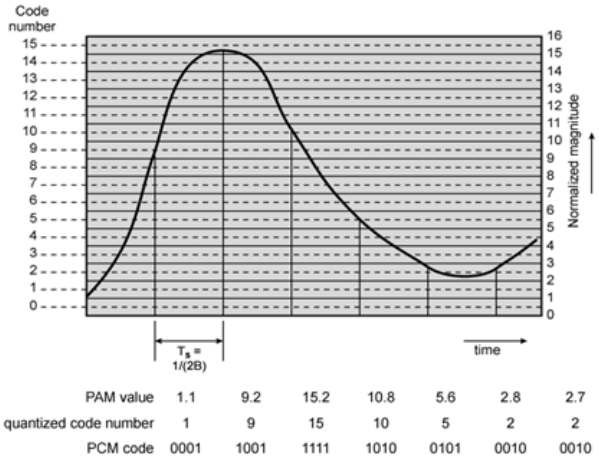
Data is information in numerical form that can be digitally transmitted or processed**,** while ***signal*** is a function that conveys information and can be used to transfer data from one device to another device. Both can have either an analog or a digital form.

Term	Definition	Unit
Data Element	a single binary 1 or 0	Bit
Data Rate / Bit Rate	rate at which data elements are transmitted	Bits per second (bps)
Signal Element	part of a signal that occupies the shortest interval of a signaling code	Digital: voltage pulse of constant amplitude Analog: voltage pulse of constant amplitude, frequency, and phase
Signaling Rate / Baud Rate (Modulation Rate)	rate at which signal elements are transmitted	Baud

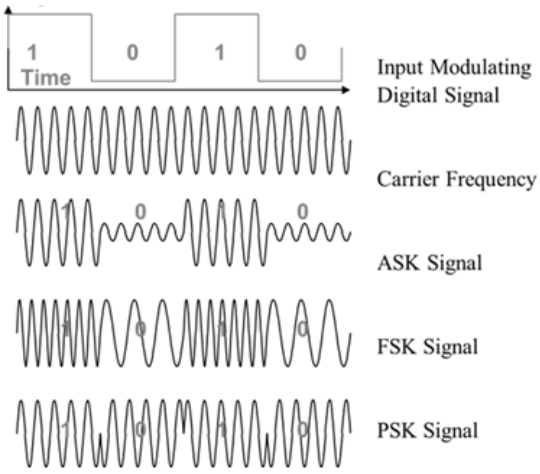
Analog Data, Analog Signal



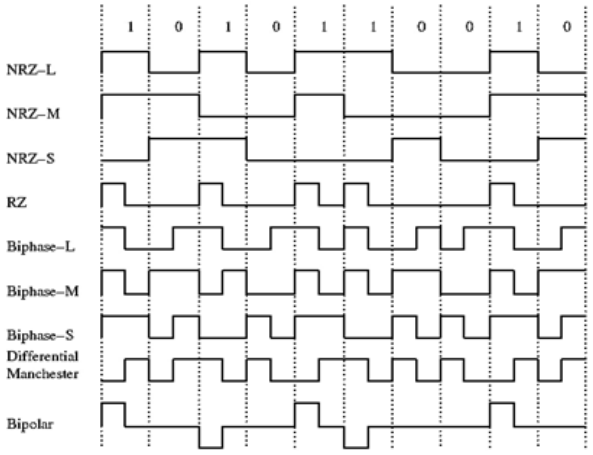
Analog Data, Digital Signal



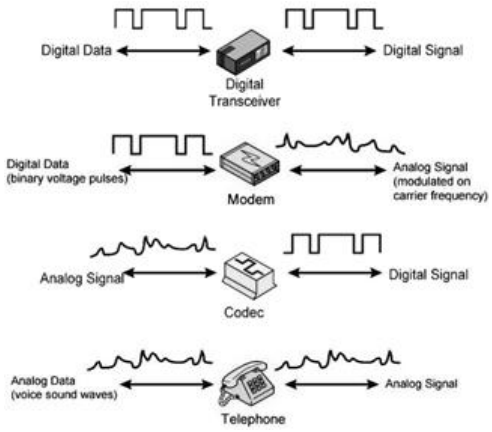
Digital Data, Analog Signal

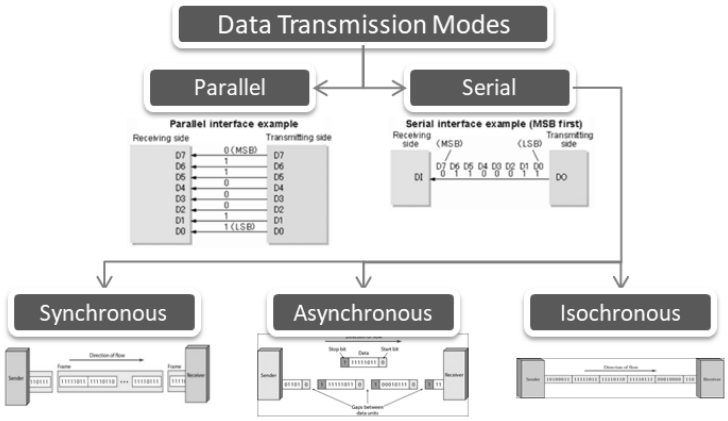


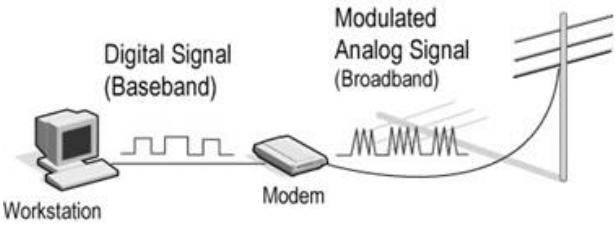
Digital Data, Digital Signal



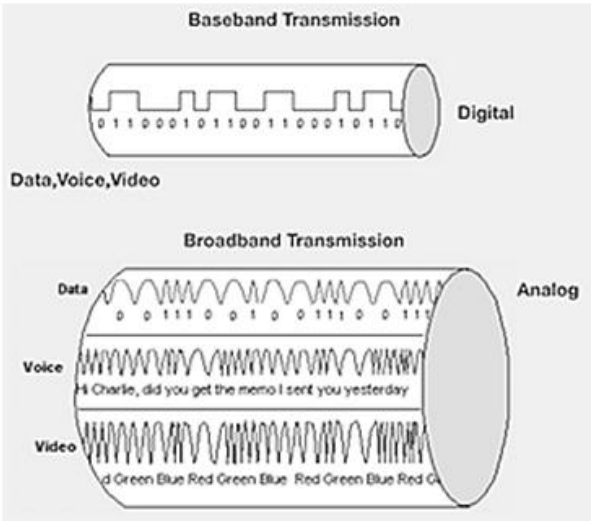
Data transmission is the process of transferring data between two or more digital devices. Data is transmitted from one device to another in analog or digital format.



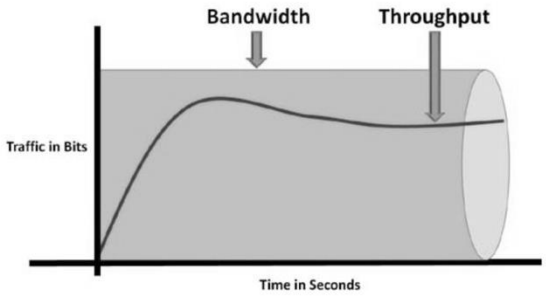




BASEBAND TRANSMISSION	BROADBAND TRANSMISSION
Baseband Transmission is a transmission technique that one signal requires the entire bandwidth of the channel to send data.	Broadband Transmission is a transmission technique that many signals with multiple frequencies transmit data through a single channel simultaneously.
Baseband Transmission uses digital signals.	Broadband Transmission uses analog signals.



Throughput is an <u>actual</u> measure of transmission speed or how much data is successfully transferred per unit time, while ***bandwidth*** is a <u>theoretical</u> measure of how much data could be transferred from source to destination.



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Research about oscilloscopes and spectrum analyzers, and discuss how they are used in analyzing signals in the time-domain and frequency-domain, respectively.
2. What is the relationship between the EM spectrum and the frequency of an EM wave? With your answer, explain why EM frequencies are considered as natural resources?
3. Differentiate amplifier circuits from filter circuits. Is it possible for an amplifier circuit to serve as a filter?
4. Which data-signal configuration (e.g. Analog Data, Analog Signal) makes use of an ADC and/or DAC? Explain your answer.

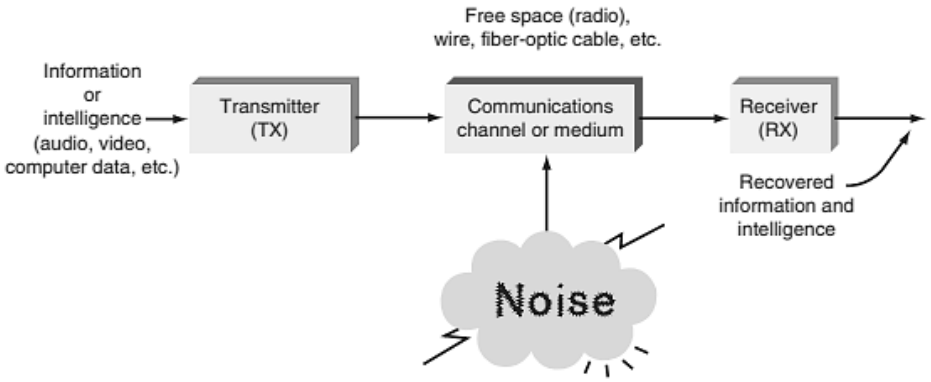
Research Activity

Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

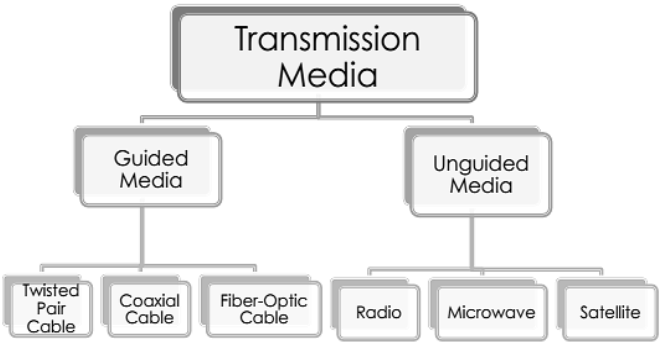
- ✓ How to Edit Your Voice in Audacity
- ✓ Multitrack Audio Editing with Audacity

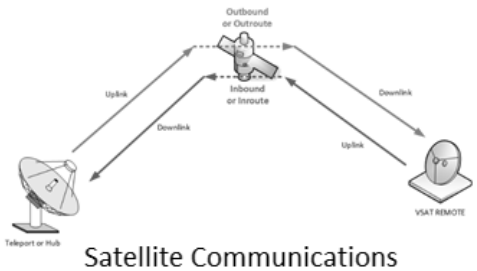
Module 6: **Principles of Communications**

Electronic Communications refers to the transmission, reception, and processing of information or message (in the form of signals) between two or more locations with the use of circuits.

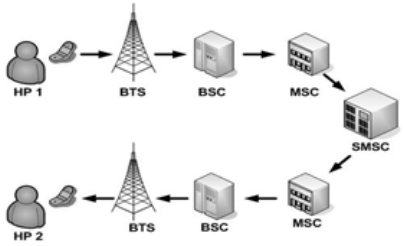


Transmission Media refers to a communication channel that carries the information from the sender to the receiver. It is the physical path between communication components that that can mediate the propagation of signals for the purposes of telecommunication





Satellite Communications



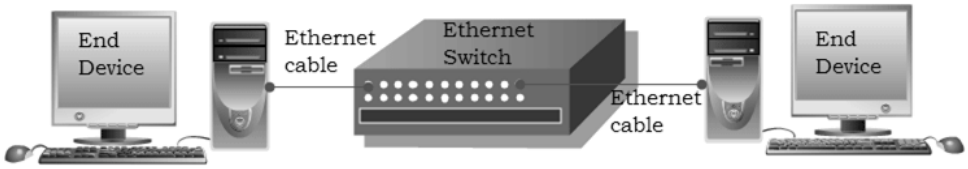
Cellular Communications

Terrestrial Microwave Communications

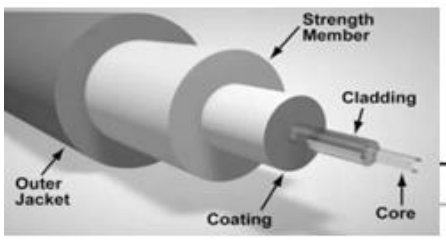
Fiber Optic Communications

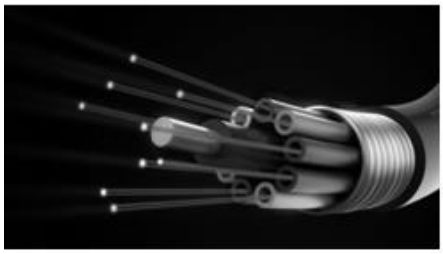
Ethernet is a widely deployed LAN technology standardized in IEEE 802.3. Its connector is the *network interface card* (NIC) equipped with 48-bit MAC address, which helps other Ethernet devices to identify and communicate with remote devices in Ethernet.

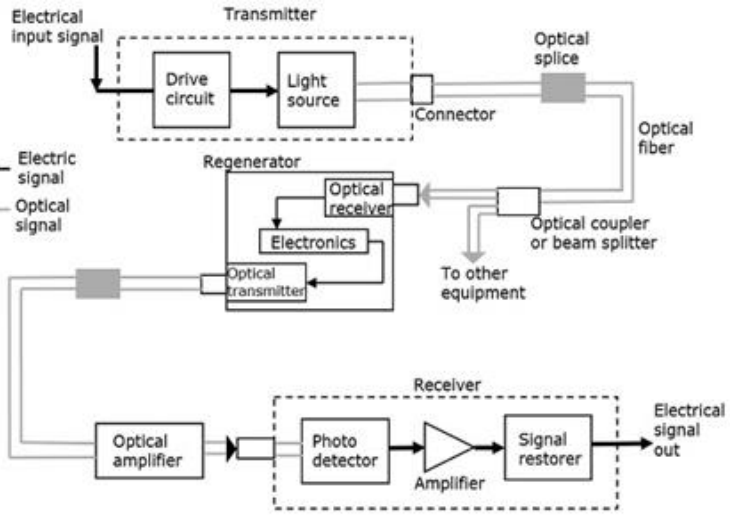
Ethernet Type	Bandwidth	Cable Type	Max. Distance
10Base-T	10Mbps	Cat 3/Cat 5 UTP	100m
100Base-TX	100Mbps	Cat 5 UTP	100m
100Base-TX	200Mbps	Cat 5 UTP	100m
100Base-FX	100Mbps	Multi-mode fiber	400m
100Base-FX	200Mbps	Multi-mode fiber	2Km
1000Base-T	1Gbps	Cat 5e UTP	100m
1000Base-TX	1Gbps	Cat 6 UTP	100m
1000Base-SX	1Gbps	Multi-mode fiber	550m
1000Base-LX	1Gbps	Single-mode fiber	2Km
10GBase-T	10Gbps	Cat 6a/Cat 7 UTP	100m
10GBase-LX	10Gbps	Multi-mode fiber	100m
10GBase-LX	10Gbp	Single-mode fiber	10Km



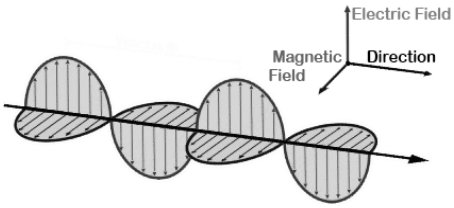
Fiber Optic Cable (FOC or OFC) is a high-speed data transmission medium consisting one or more strands of glass, each only slightly thicker than a human hair. It can support data transmissions rated at 10 Gbps, 40 Gbps, and 100 Gbps. ***Fiber to the X*** (FTTX) or *fiber-in-the-loop* is a generic term for any broadband network architecture using optical fiber to provide all or part of the local loop used for last mile telecommunications.



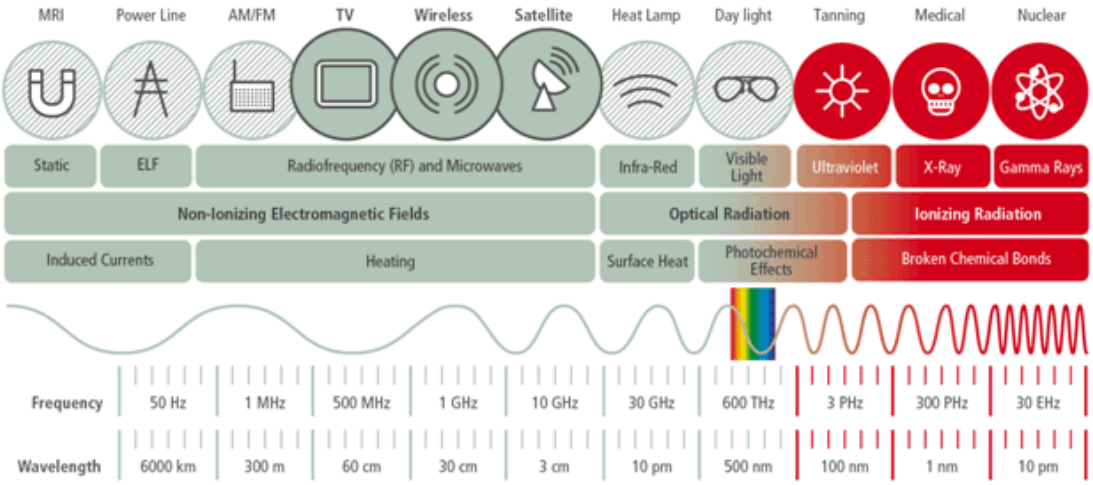




Electromagnetic Waves (EM Waves) are created as a result of vibrations between an electric field and a magnetic field, propagating through space, carrying electromagnetic radiant energy



$$\lambda = \frac{c}{f} = \frac{3\ x\ 10^8\ m/s}{f}$$



Common Applications of EM Waves in the Spectrum

Extremely Low Frequencies. *Extremely low frequencies (ELFs)* are in the 30- to 300-Hz range. These include ac power line frequencies (50 and 60 Hz are common), as well as those frequencies in the low end of the human audio range.

Voice Frequencies. *Voice frequencies (VFs)* are in the range of 300 to 3000 Hz. This is the normal range of human speech. Although human hearing extends from approximately 20 to 20,000 Hz, most intelligible sound occurs in the VF range.

Very Low Frequencies. *Very low frequencies (VLFs)* extend from 9 kHz to 30 kHz and include the higher end of the human hearing range up to about 15 or 20 kHz. Many musical instruments make sounds in this range as well as in the ELF and VF ranges. The VLF range is also used in some government and military communication. For example, VLF radio transmission is used by the navy to communicate with submarines.

Low Frequencies. *Low frequencies (LFs)* are in the 30- to 300-kHz range. The primary communication services using this range are in aeronautical and marine navigation. Frequencies in this range are also used as *subcarriers,* signals that are modulated by the baseband information. Usually, two or more subcarriers are added, and the combination is used to modulate the final high-frequency carrier.

Medium Frequencies. *Medium frequencies (MFs)* are in the 300- to 3000-kHz (0.3- to 3.0-MHz) range. The major application of frequencies in this range is AM radio broadcasting (535 to 1605 kHz). Other applications in this range are various marine and amateur radio communication.

High Frequencies. *High frequencies (HFs)* are in the 3- to 30-MHz range. These are the frequencies generally known as short waves. All kinds of simplex broadcasting and half duplex two-way radio communication take place in this range. Broadcasts from Voice of America and the British Broadcasting Company occur in this range. Government and military services use these frequencies for two-way communication. An example is diplomatic communication between embassies. Amateur radio and CB communication also occur in this part of the spectrum.

Very High Frequencies. *Very high frequencies (VHFs)* encompass the 30- to 300-MHz range. This popular frequency range is used by many services, including mobile radio, marine and aeronautical communication, FM radio broadcasting (88 to 108 MHz), and television channels 2 through 13. Radio amateurs also have numerous bands in this frequency range.

Ultrahigh Frequencies. *Ultrahigh frequencies (UHFs)* encompass the 300- to 3000-MHz range. This, too, is a widely used portion of the frequency spectrum. It includes the UHF TV channels 14 through 51, and it is used for land mobile communication and services such as cellular telephones as well as for military communication. Some radar and navigation services occupy this portion of the frequency spectrum, and radio amateurs also have bands in this range.

Microwaves and SHFs. Frequencies between the 1000-MHz (1-GHz) and 30-GHz range are called *microwaves.* Microwave ovens usually operate at 2.45 GHz. *Superhigh frequencies (SHFs)* are in the 3- to 30-GHz range. These microwave frequencies are widely used for satellite communication and radar. Wireless local-area networks (LANs) and many cellular telephone systems also occupy this region.

Extremely High Frequencies. *Extremely high frequencies (EHFs)* extend from 30 to 300 GHz. Electromagnetic signals with frequencies higher than 30 GHz are referred to as *millimeter waves*. Equipment used to generate and receive signals in this range is extremely complex and expensive, but there is growing use of this range for satellite communication telephony, computer data, short-haul cellular networks, and some specialized radar.

Frequencies Between 300 GHz and the Optical Spectrum. This portion of the spectrum is virtually uninhabited. It is a cross between RF and optical. Lack of hardware and components limits its use.

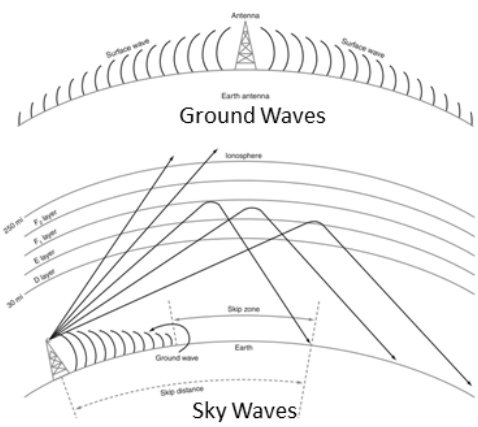
Infrared. The *infrared region* is sandwiched between the highest radio frequencies (i.e., millimeter waves) and the visible portion of the electromagnetic spectrum. Infrared occupies the range between approximately 0.1 millimeter (mm) and 700 nanometers (nm), or 100 to 0.7 micrometer (μm). One micrometer is one-millionth of a meter. Infrared wavelengths are often given in micrometers or nanometers. Infrared radiation is generally associated with heat.

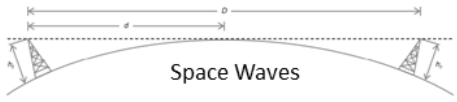
The Visible Spectrum. Just above the infrared region is the *visible spectrum* we ordinarily refer to as *light.* Light is a special type of electromagnetic radiation that has a wavelength in the 0.4- to 0.8-μm range (400 to 800 nm). Light wavelengths are usually expressed in terms of angstroms (Å). An angstrom is one ten-thousandth of a micrometer; for example, 1 Å = 10^{-10} m. The visible range is approximately 8000 Å (red) to 4000 Å (violet). Red is low-frequency or long-wavelength light, whereas violet is high-frequency or short-wavelength light.

Ultraviolet. *Ultraviolet light (UV)* covers the range from about 4 to 400 nm. Ultraviolet generated by the sun is what causes sunburn. Ultraviolet is also generated by mercury vapor lights and some other types of lights such as fluorescent lamps and sun lamps. Ultraviolet is not used for communication; its primary use is medical.

Beyond the visible region are the X-rays, gamma rays, and cosmic rays. These are all forms of electromagnetic radiation, but they do not figure into communication systems and are not covered here.

Modes of EM Wave Propagation



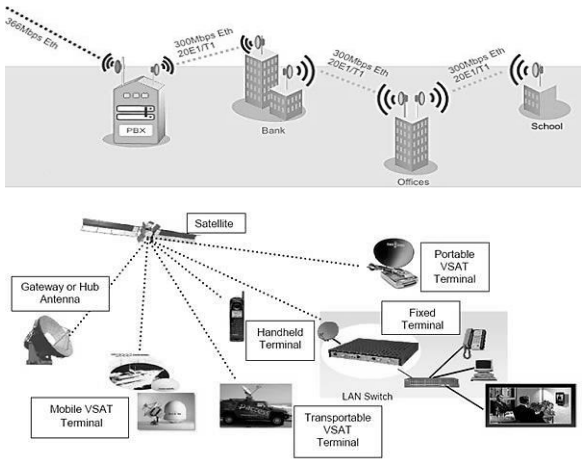


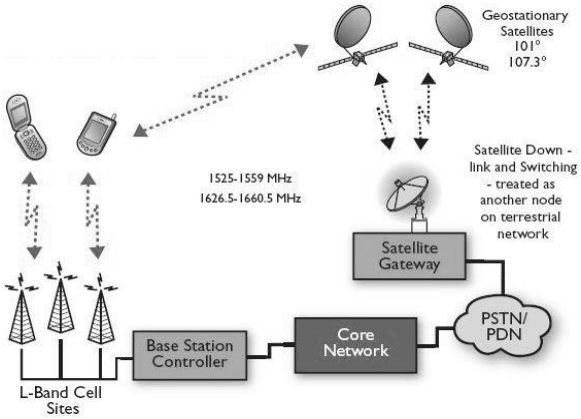
$$d = \sqrt{2h_T} + \sqrt{2h_R}$$

$$P_R = \frac{P_T G_T G_R \lambda^2}{16\pi^2 d^2}$$

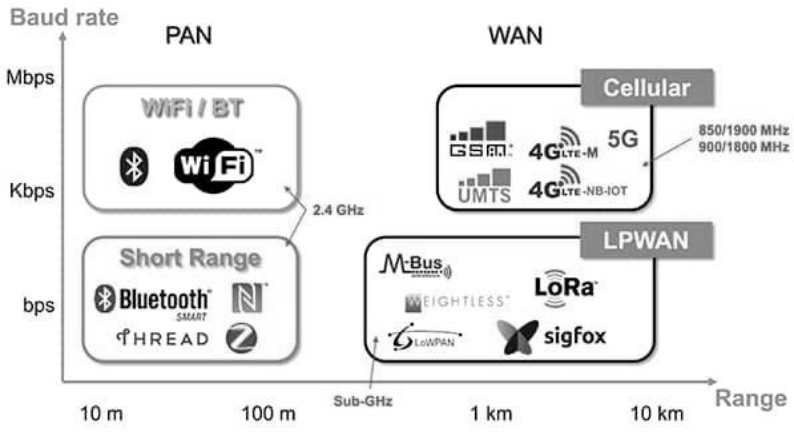
where: λ = wavelength of the EM wave
G_T = transmitting gain
G_R = receiving gain
d = distance between Tx and Rx

Microwaves are radio waves with frequencies between 300 MHz (1 m) and 300 GHz (1 mm). They travel by line-of-sight (LOS); so terrestrial microwave communication links are limited by the visual horizon to about 40 miles (64 km).





Microwave Transmission is an LOS wireless communication technology that uses high frequency beams of radio waves to provide high speed wireless connections that can send and receive voice, video, and data information. ***Satellite Communications*** is the use of artificial satellites to provide communication links between various points on Earth. Telecommunication satellites are designed to relay several, or more usually many, signals simultaneously.



Wireless Fidelity (Wi-Fi) is a wireless networking technology that uses radio waves to provide wireless high-speed internet and network connections. It is based on the IEEE 802.11 family of standards and is primarily designed to provide in-building broadband coverage.

Mobile Telephony or *cellular telephony* refers to the provision of telephone services to phones which may move around freely rather than stay fixed in one location.

ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. In your own idea, why do scientists and engineers consider electromagnetic waves as natural resources?
2. Research about principles of communications engineering and explain how electronic communications work in transmitting/receiving EM waves.
3. What is the purpose of modulation? How is it related to network modems?
4. Discuss the importance of having basic understanding in electronic communications for computer engineers.

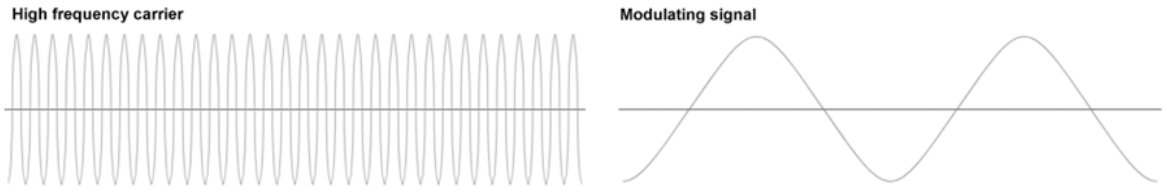
Research Activity

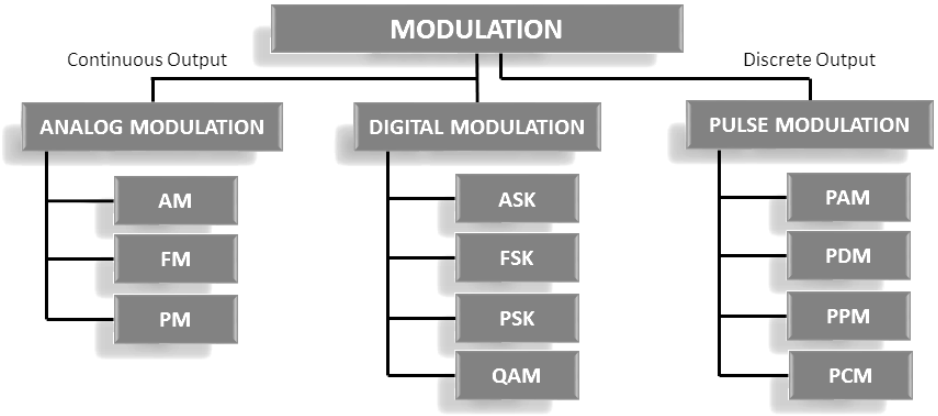
Watch the following YouTube tutorials about Audacity and perform the tasks they feature:

- ✓ Dithering | Digital Audio Fundamentals
- ✓ Dither Types | Digital Audio Fundamentals

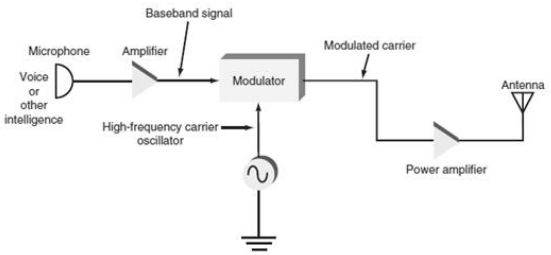
Module 7: **Modulation Techniques**

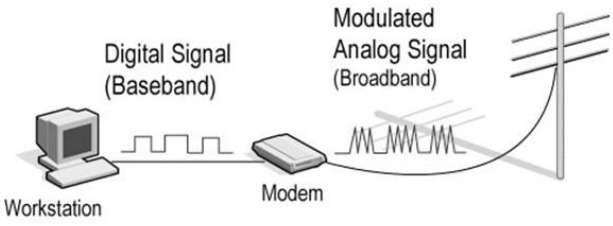
Modulation is the process of having a baseband voice, video, or digital signal modify another, higher-frequency signal, the carrier. Information or intelligence to be sent is said to be *impressed* upon the carrier, which is usually a sine wave generated by an oscillator.





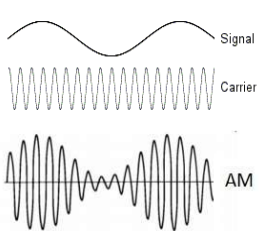
The carrier is fed to a ***modulator*** along with the baseband intelligence signal. The intelligence signal changes the carrier in a unique way and the modulated carrier, which is now the ***broadband signal***, is amplified and sent to the antenna for transmission. This process is called *broadband transmission.* On the other end, the process of recovering the message from the received broadband signal is called **demodulation**.

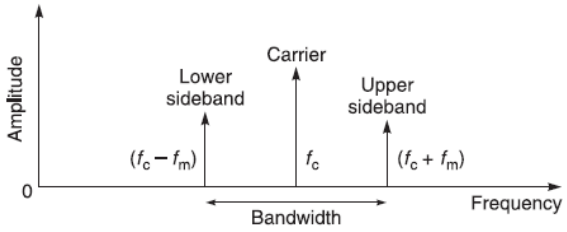




Amplitude Modulation (AM) is where the amplitude (signal strength) of the carrier wave is varied in proportion to the waveform being transmitted. It is used in portable two-way radios, VHF aircraft radio, Citizen's Band Radio, and in computer modems (in the form of QAM). Only the AM sidebands contain the information; thus, transmission is done in either of the two modes:

- Double-Sideband (DSB) – both sidebands are transmitted
- Single-Sideband (SSB) – only one sideband is transmitted

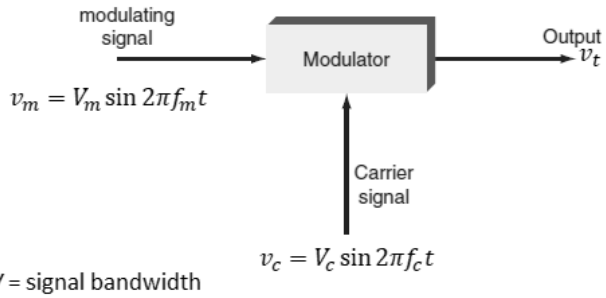




$$v(t) = V_c \cos 2\pi f_c t + \frac{1}{2} V_m \cos[2\pi(f_c + f_m)t] + \frac{1}{2} V_m \cos[2\pi(f_c - (f_m)]t$$

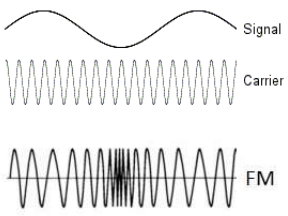
$$m = \frac{V_m}{V_c} \qquad BW = 2f_m$$

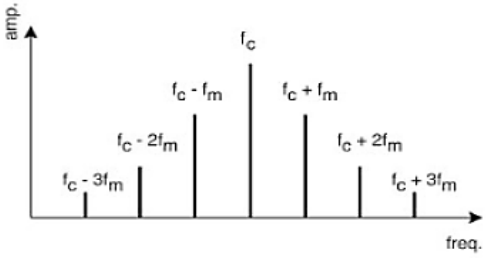
$$P_t = P_c\left(1 + \frac{m^2}{2}\right)$$



where:
- $v(t)$ = modulated voltage
- v_c = carrier voltage
- v_m = modulating voltage
- m = modulation index
- f_c = carrier frequency
- f_m = modulating frequency
- t = any given time
- BW = signal bandwidth
- P_t = transmitted power
- P_c = carrier power

Frequency Modulation (FM) is where encoding of information in a carrier wave is done by varying the instantaneous frequency of the wave. It has a larger signal-to-noise ratio and therefore rejects radio frequency interference better than an equal power amplitude modulation (AM) signal. It is widely used for FM radio broadcasting, telemetry, radar, seismic prospecting, two-way radio systems, music synthesis, magnetic tape-recording systems and some video-transmission systems.

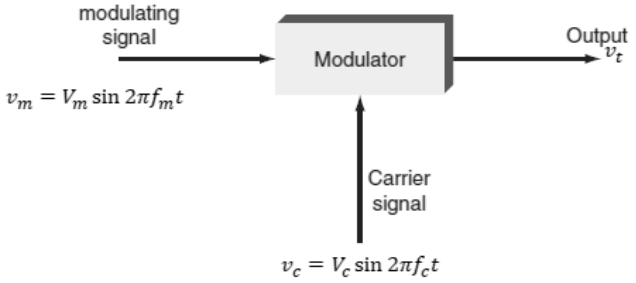




$$v(t) = V_c \cos[\,2\pi f_c t + m\cos(2\pi f_m t)]$$

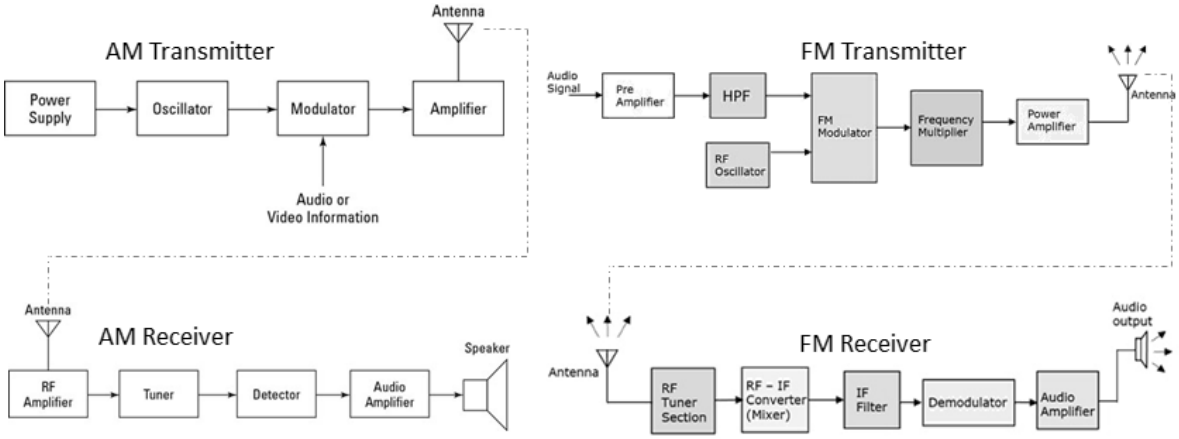
$$m = \frac{\Delta f_c}{f_m} \qquad BW = 2(m+1)f_m$$

$$\Delta f_c = kV_m$$

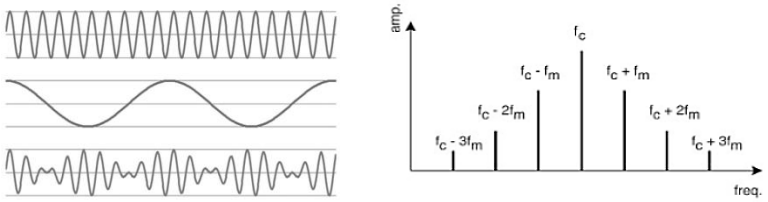


where:
- $v(t)$ = modulated voltage
- v_c = carrier voltage
- v_m = modulating voltage
- m = modulation index
- f_c = carrier frequency
- f_m = modulating frequency
- BW = signal bandwidth
- t = any given time
- k = *frequency sensitivity*

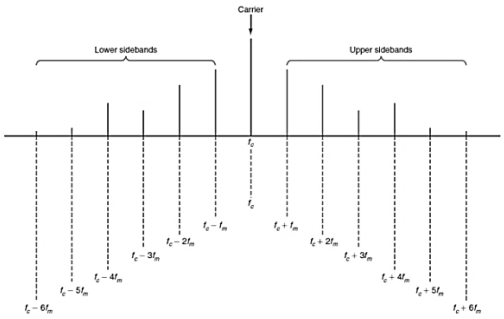
AM and FM System Block Diagrams



Pulse Modulation (PM) is where the phase of a carrier signal is modulated to follow the changing voltage level or amplitude of modulation signal. Analysis and final result (modulated signal) is similar to those of frequency modulation. This modulation is widely used for transmitting radio waves and is an integral part of many digital transmission coding schemes that underlie a wide range of technologies like Wi-Fi, GSM and satellite television.



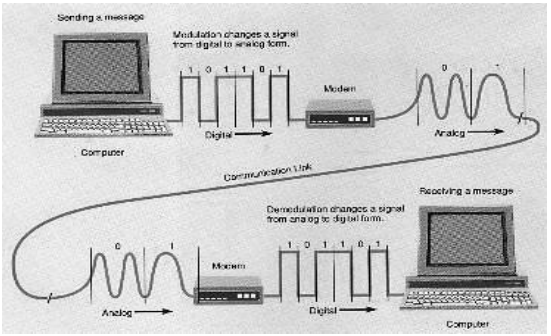
In FM and PM, as in AM, sum and difference sideband frequencies are produced and a large number of pairs of upper and lower sidebands are generated. Thus, the spectrum of an FM or PM signal is usually wider than that of an equivalent AM signal. It is also possible to generate a special narrowband FM signal whose bandwidth is only slightly wider than that of an AM signal. Carrier and sideband amplitudes for different modulation indexes of FM signals are based on the ***Bessel Functions***.



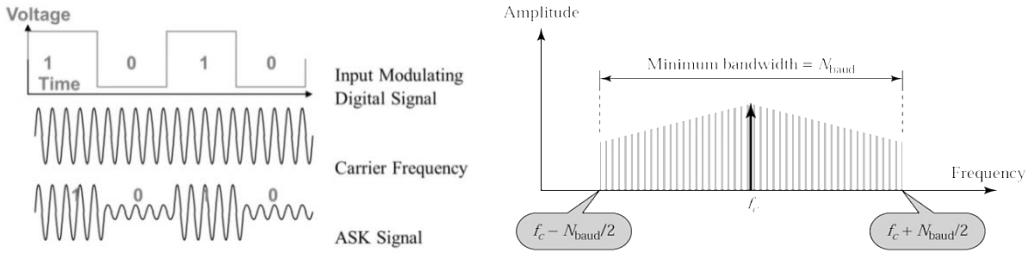
Modulation Index	Carrier	Sidebands (Pairs)															
		1st	2d	3d	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th
0.00	1.00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.25	0.98	0.12	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0.5	0.94	0.24	0.03	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1.0	0.77	0.44	0.11	0.02	—	—	—	—	—	—	—	—	—	—	—	—	—
1.5	0.51	0.56	0.23	0.06	0.01	—	—	—	—	—	—	—	—	—	—	—	—
2.0	0.22	0.58	0.35	0.13	0.03	—	—	—	—	—	—	—	—	—	—	—	—
2.5	−0.05	0.50	0.45	0.22	0.07	0.02	—	—	—	—	—	—	—	—	—	—	—
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01	—	—	—	—	—	—	—	—	—	—
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02	—	—	—	—	—	—	—	—	—
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02	—	—	—	—	—	—	—	—
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02	—	—	—	—	—	—	—
7.0	0.30	0.00	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02	—	—	—	—	—	—
8.0	0.17	0.23	−0.11	−0.29	−0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03	—	—	—	—	—
9.0	−0.09	0.24	0.14	−0.18	−0.27	−0.06	0.20	0.33	0.30	0.21	0.12	0.06	0.03	0.01	—	—	—
10.0	−0.25	0.04	0.25	0.06	−0.22	−0.23	−0.01	0.22	0.31	0.29	0.20	0.12	0.06	0.03	0.01	—	—
12.0	−0.05	−0.22	−0.08	0.20	0.18	−0.07	−0.24	−0.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01
15.0	−0.01	0.21	0.04	0.19	−0.12	0.13	0.21	0.03	−0.17	−0.22	−0.09	0.10	0.24	0.28	0.25	0.18	0.12

To transmit the digital data over an analog media, it must go through a digital-to-analog converter (DAC) first. It can be through bandpass filters (BPF) that allow only the frequencies of interest to pass, or through low-pass filters that allow to pass only frequencies that are below the cut-off. Analog carrier signals are modified to reflect digital data. Thus, ***digital modulation*** or analog transmission of digital data can be in the form of:

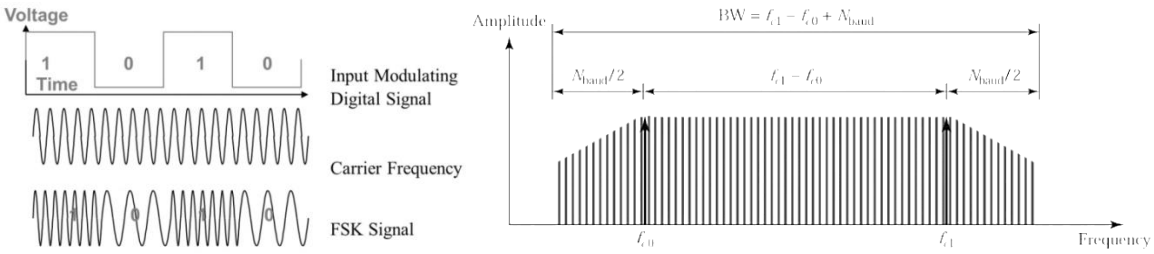
- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)
- Quadrature Amplitude Modulation (QAM)



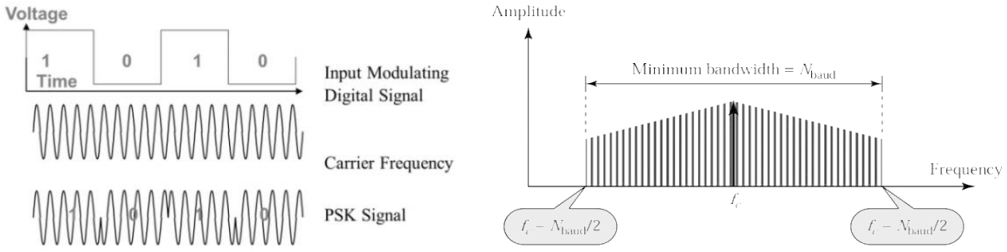
Amplitude-Shift Keying (ASK) is where digital information is transmitted through discrete frequency changes of an analog carrier signal. This type of modulation uses a pair of discrete frequencies to transmit binary (0s and 1s) information wherein the "1" is called the mark frequency and the "0" is called the space frequency. It is used for communication systems such as amateur radio, caller ID, and emergency broadcasts.



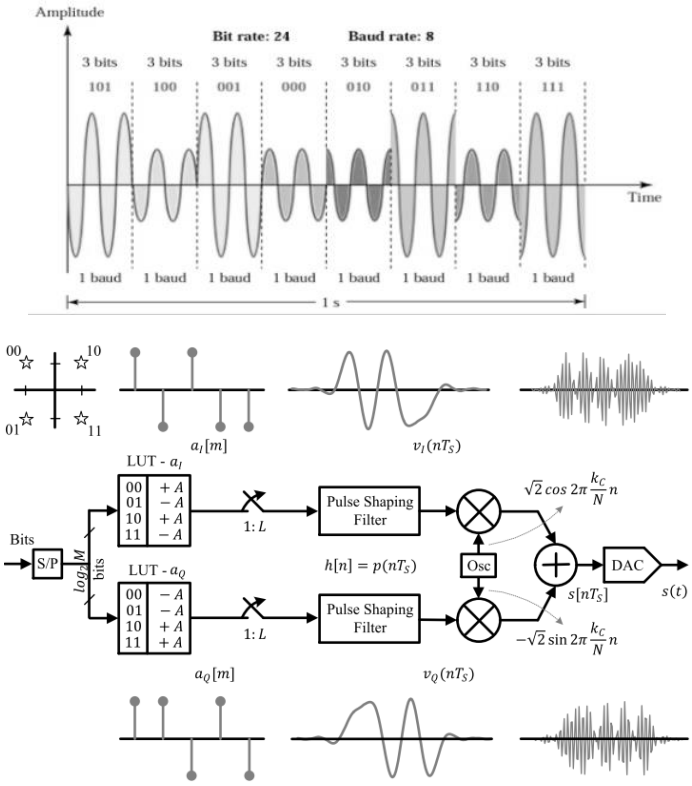
Frequency-Shift Keying (FSK) is where digital information is transmitted through discrete frequency changes of an analog carrier signal. It uses a pair of discrete frequencies to transmit binary (0s and 1s) information wherein the "1" is called the mark frequency and the "0" is called the space frequency. It is used for communication systems such as amateur radio, caller ID, and emergency broadcasts.



Phase-Shift Keying (PSK) conveys data by changing (modulating) the phase of a reference signal (the carrier wave). Modulation occurs by varying the sine and cosine inputs at a precise time. It uses a finite number of phases, each assigned a unique pattern of binary digits. It is widely used for wireless LANs, RFID and Bluetooth communication.

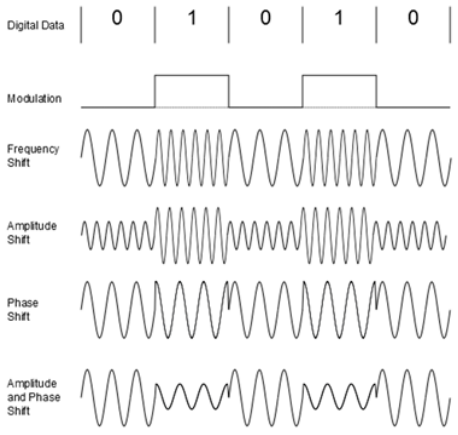


Quadrature Amplitude Modulation (QAM) uses two carriers with the same frequency are amplitude-modulated independently and their phases are 90 degrees shifted each other. There are 2^N QAM processes N bits in a single channel, so it has N times spectral efficiency compared with ***On-Off Keying*** (OOK). It is a combination of ASK and PSK and it has wide applications in transmitting digital signals like digital cable television, internet services, cellular technology, and other wireless device technologies.

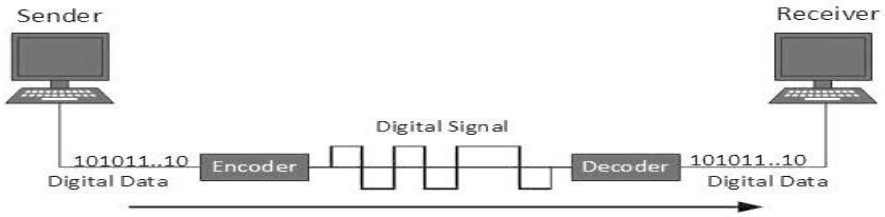


Types of Digital Modulation

Modulation	Units	Bits/Baud	Baud rate	Bit Rate
ASK, FSK, 2-PSK	Bit	1	N	N
4-PSK, 4-QAM	Dibit	2	N	2N
8-PSK, 8-QAM	Tribit	3	N	3N
16-QAM	Quadbit	4	N	4N
32-QAM	Pentabit	5	N	5N
64-QAM	Hexabit	6	N	6N
128-QAM	Septabit	7	N	7N
256-QAM	Octabit	8	N	8N

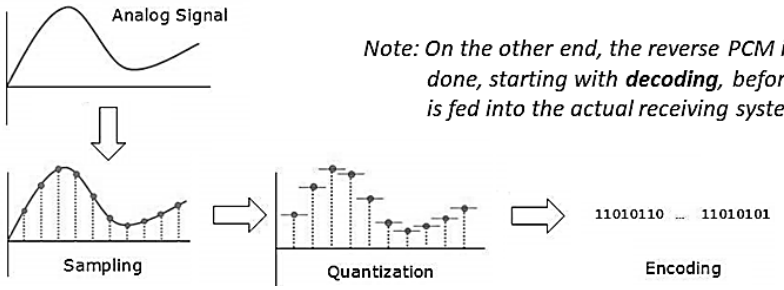


Digital transmission of digital data basically involves the ***line coding*** and ***block coding*** processes. Line coding is the process for converting digital data (binary bits) into digital signal.



Furthermore, to ensure accuracy of the received data frame, block coding is done wherein ***redundant bits*** are used. For example, in even-parity, one parity bit is added to make the count of 1s in the frame even and so the original number of bits is increased. Overall, line coding is necessary while block coding is optional,

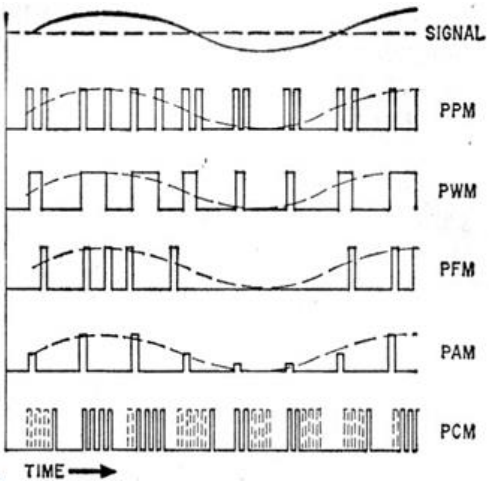
In digital transmission of analog data, digitization must be done first. ***Pulse Code Modulation*** (PCM) is the most common method used and it comes in three steps:



*Note: On the other end, the reverse PCM is done, starting with **decoding**, before data is fed into the actual receiving system.*

The same process with Line Coding happens in the encoding stage of PCM. Other pulse modulation techniques include:

S.No	Pulse Amplitude Modulation (PAM)	Pulse Duration/Width Modulation (PDM/PWM)	Pulse Position Modulation (PPM)
1	Amplitude of the pulse proportional to amplitude of modulating signal	Width of the pulse is proportional to amplitude of modulating signal	The relative position of the pulse is proportional to amplitude of modulating signal
2	Bandwidth of the transmission channel depends on the pulse width	Bandwidth of the transmission channel depends on the rise time of the pulse	Bandwidth of the transmission channel depends on the rising time of the pulse
3	Instantaneous power of the transmitter varies	Instantaneous power of the transmitter varies	Instantaneous power of the transmitter remains constant
4	Noise interference is high	Noise interference is minimum	Noise interference is minimum
5	System is complex to implement	System is simple to implement	System is simple to implement
6	Similar to amplitude modulation	Similar to frequency modulation	Similar to phase modulation



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. How does modulation work and why is it important in electronic systems?
2. Summarize the properties of AM, FM, and PM. Mention also their common denominator as analog modulation techniques.
3. Research about modems and discuss what digital modulation techniques are involved in their operations.
4. Explain the difference between digital transmission of analog data and analog transmission of digital data. What are the signal processing operations involved in each of them?

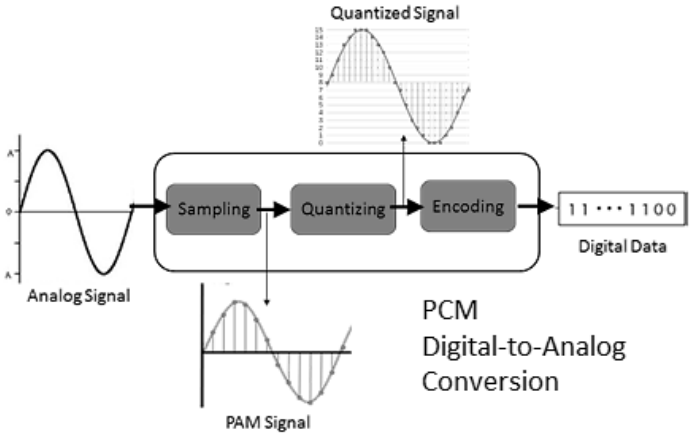
Research Activity

Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

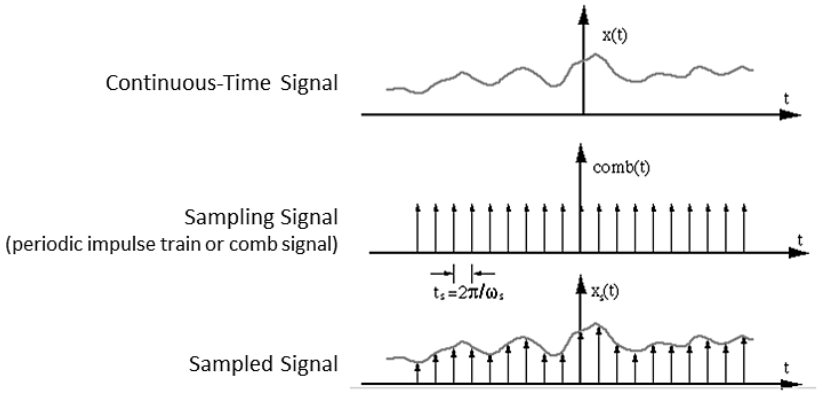
- ✓ Noise Shaping | Digital Audio Fundamentals
- ✓ Pulse Code Modulation | Digital Audio Fundamentals

Module 8: **Digitization of Signals**

Digitization refers to taking analog information and encoding it into 1s and 0s so that computers can store, process, and transmit such information. ***Sampling*** is the process of measuring the instantaneous values (*samples*) of continuous-time signal in a discrete form, while ***Quantizing*** is the process of discretizing the sample points of the sampled signal with a number of quantization levels.



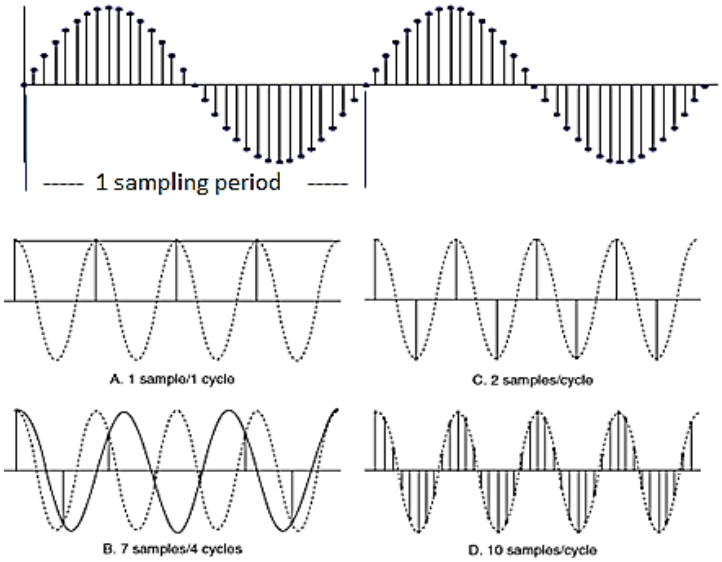
How the Sample/Hold Process Works



Sampling Period, the reciprocal of the ***Sampling Rate***, is the fixed gap between the samples of the discretized signal, while ***Nyquist Rate*** refers to the rate of sampling at which the data in the message signal should neither be lost nor it should get over-lapped as described by the ***Sampling Theorem***.

$$f_s > f_N = 2B$$

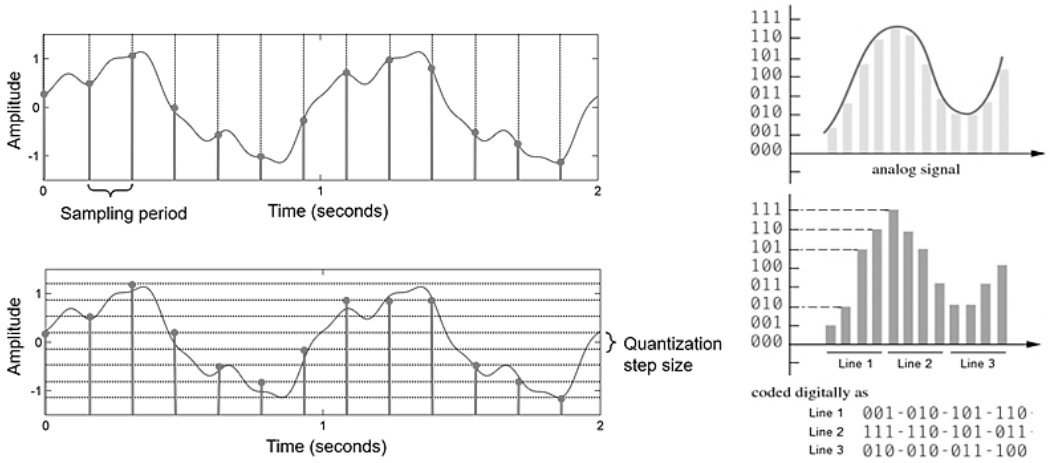
Aliasing is the phenomenon of a high-frequency component in the spectrum of a signal, taking on the identity of a low-frequency component in the spectrum of its sampled version. Corrective measures to reduce its effect include:



- ✓ the use of a low-pass ***anti-aliasing filter*** at the transmitter side to eliminate the unwanted high frequency components
- ✓ sampling the filtered signal at a rate slightly higher than the Nyquist rate

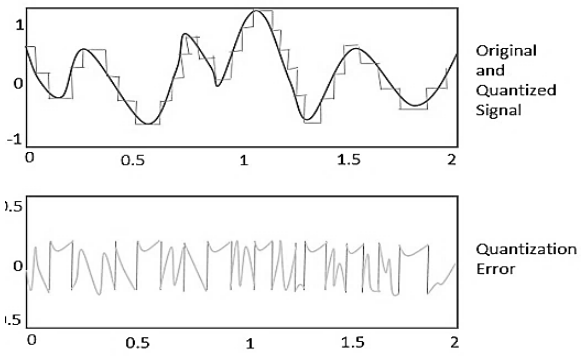
Choosing a sampling rate higher than Nyquist rate also helps in the easier design of the ***reconstruction filter*** at the receiver.

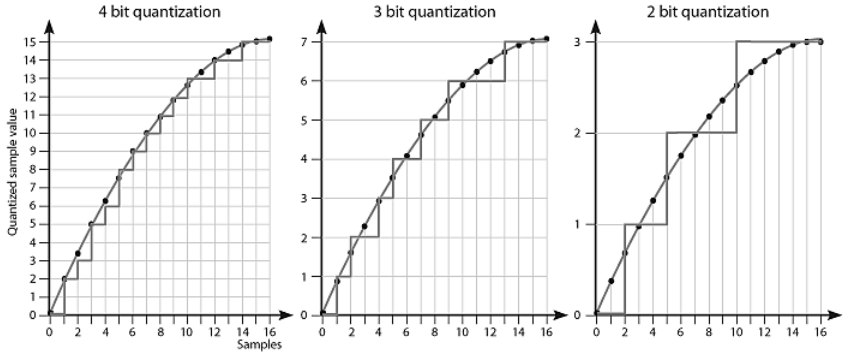
How the Quantization and Encoding Processes Work

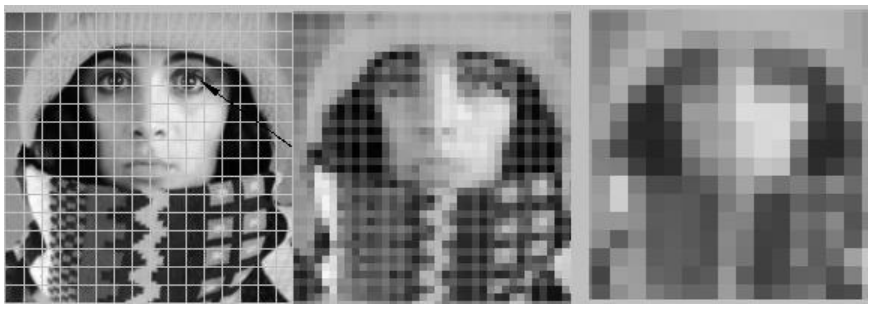


Bit Depth refers to the no. of bits of information per sample. It directly corresponds to the *resolution* of each sample. ***Representation Levels*** are discrete amplitudes of quantized output. These are also known as *reconstruction levels*. ***Resolution*** is the number of *representation levels* over the range of analog values.

Quantum is the spacing between two adjacent representation levels and it is also known as *step-size*. ***Quantization Error*** is the difference between an input value and its quantized value, while ***Dynamic Range*** refers to the ratio of the highest amplitude to the lowest amplitude of the quantized signal.







Quantization and Encoding Parameters

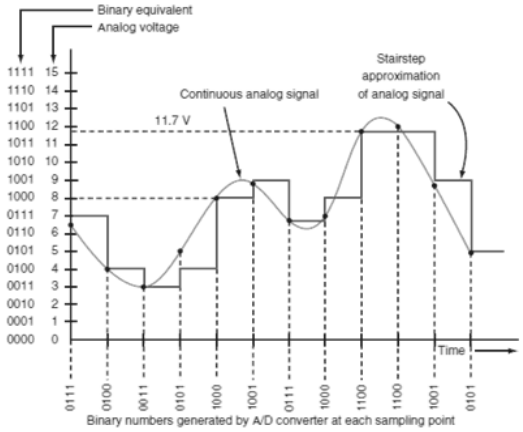
$$Resolution: \quad R = (2^n)V_{MAX}$$

$$Quantization\ Error: \quad QE = \frac{1}{2}V_{MIN}$$

$$Dynamic\ Range \quad DR = \frac{V_{MAX}}{V_{MIN}} = N - 1$$

$$Peak\ Voltage \quad V_{MAX} = (N-1)V_{MIN}$$

where N (no. of quantum levels) = 2^n
n = bit depth
V_{MIN} = step-size or quantum



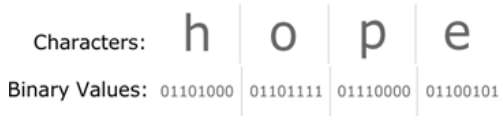
Standard Audio Digitization Parameters

PLATFORM	BANDWIDTH	SAMPLING RATE	RESOLUTION	BIT RATE compressed - uncompressed
TELEPHONY	300-3400 Hz	8 kHz	8 bit	2.4 - 64kbit/sec
PC/MULTIMEDIA WIDEBAND SPCH	100Hz-5kHz 50Hz-7kHz	11.025kHz 16 kHz	16 bit	16-256kbit/sec
PC/MULTIMEDIA MUSIC, GAMES	20Hz-10kHz	22.05 kHz	16 bit	32-352kbit/sec
HI-FI/Consumer CD Studio - DAT	20Hz-20kHz 20Hz-20kHz	44.1kHz 48-96 kHz	16 bit 16,24,32 bit	64kbit/sec – 2.4Mbit/sec

Digital Image Parameters

- Resolution – number of pixels in an image or the measure of width and height of the image in terms of pixels
- Pixels (Picture Elements) – little dots that make up the images on video frames
- Color Depth (Bit Depth) – number of bits used to indicate the color of a single pixel
- Aspect Ratio – ratio of image width to its height, denoted by a colon in between
- Frame Rate (frames per second or FPS) is the rate at which consecutive images (frames) appear on a display

Data Representation refers to the form in which data is stored, processed, and transmitted. It also describes how data types are structured such as how signs are represented in numerical values and how strings are formatted (enclosed in quotes, terminated with a null, etc.).



Data Representation as Text

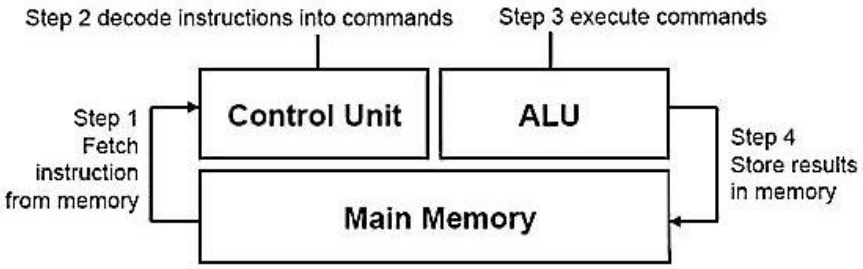
- ASCI (American Standard Code for Information Interchange)
- UTF-8 (8-bit Unicode Transformation Format)

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENG OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

ASCII Table

How Data is Processed

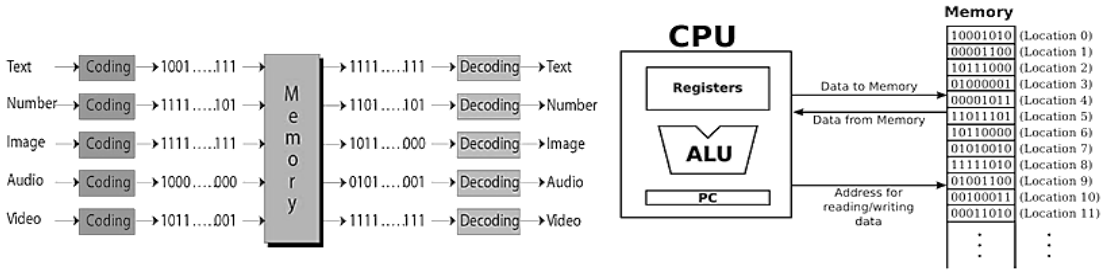
Upon reception of the input data, a program is used to process that information. Such program may calculate, manipulate, or organize the data to create information that is understandable and presentable to the user. The processed data is then displayed as output to the user and the computer can store it in the memory.



Encoding is the process of converting the data or a given sequence of characters, symbols, alphabets etc., into a specified format, for the secured transmission of data, while ***decoding*** is the reverse process of encoding that extracts the information from the converted format. A ***codec*** encodes a data stream or a signal for transmission and storage, possibly in encrypted form, and the decoder function reverses the encoding for playback or editing.

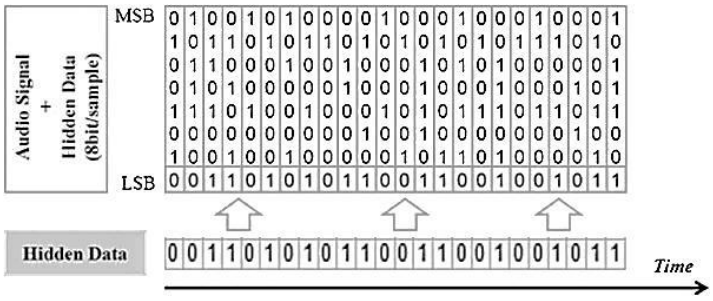
How Data is Stored

Each data is stored in computers as binary digits (bits). Data must be represented in a way that it captures the essence of the information, and in a form that is convenient for computer processing.



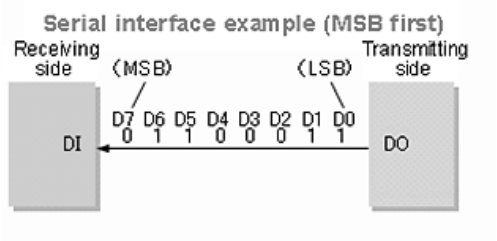
Data compression (*source coding* or *bit-rate reduction*) is the process of modifying, encoding or converting the bits structure of data in such a way that it consumes less space on disk. It enables reducing the storage size of data instances or elements.

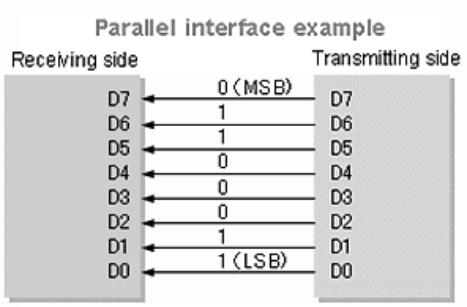
A ***computer file*** is a computer resource for recording data discretely in a computer storage device. A ***file type*** or a *filename extension* is an identifier specified as a suffix to the name of a computer file.



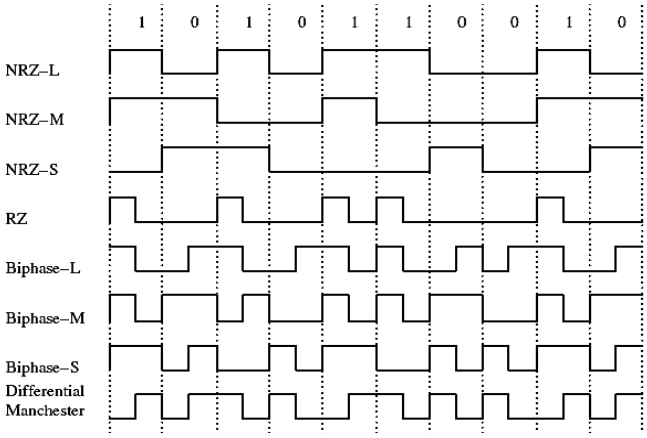
How Data is Transmitted

Data transmission is the process of transferring data between two or more digital devices. Data is transmitted from one device to another in analog or digital format. ***Serial Data Transmission*** is the process of sending data one bit at a time, sequentially, over a computer bus or a communication channel. This is in contrast to ***Parallel Data Transmission***, where several bits are sent as a whole, on a link with several parallel channels.

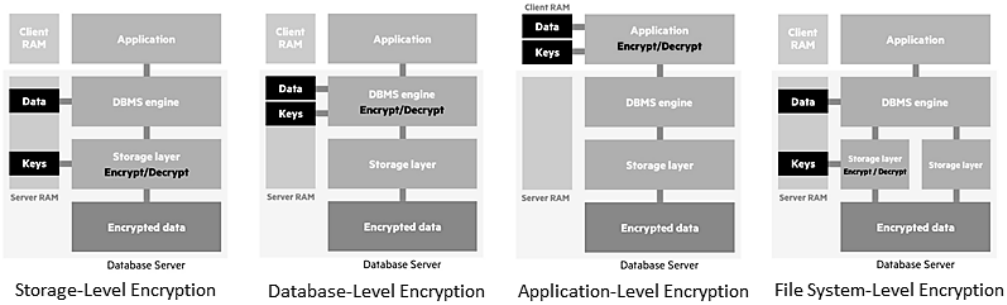




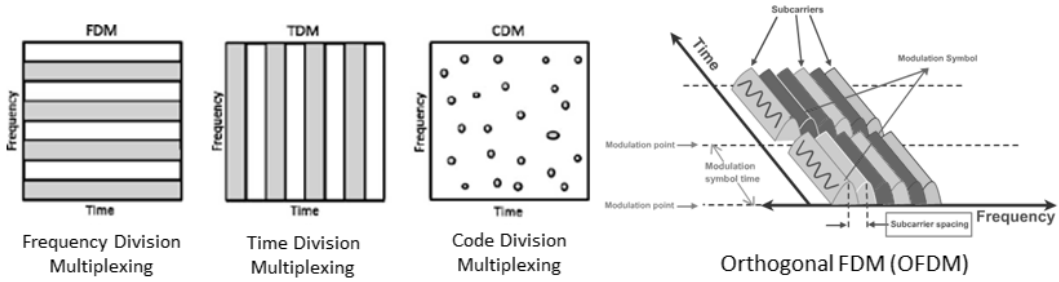
Line coding is the process of converting digital data to digital signals. At the sender side, digital data are encoded into a digital signal and at the receiver side the digital data are recreated by decoding the digital signal.



Encryption is a process that encodes a message or file so that it can be only be read by certain people. It uses an algorithm to scramble, or encrypt, data and then uses a key for the receiving party to unscramble, or decrypt, the information. ***Decryption*** is the process of converting the encoded or encrypted text back into its original form.



Multiplexing is a technique by which different streams of transmission can be simultaneously processed over a shared link. It divides the high capacity medium into low capacity logical medium which is then shared by different streams. The reverse of this process is called ***demultiplexing***.



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Discuss the purpose of sampling, as well as the reason of having the sampling rate as high as possible.
2. How does quantization work? How are the bit depth, representation level, and resolution determined in this process?
3. What is data representation and how is it related to digitization of signals?
4. Discuss the advantages and disadvantages of serial data transmission and parallel data transmission when compared to each other.

Research Activity

Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

- ✓ Multiplexing and Error Correction
- ✓ Containers and File Format

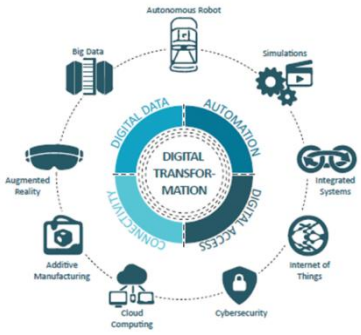
Mixed-Signal Systems and the Industry 4.0

(CMPE 30153 – Fundamentals of Mixed Signals & Sensors)

3 Chapter

I. OVERVIEW

Application and demand for Mixed-signal designs is growing fast electronics and semiconductor industry. Seeing this high growth opportunities in areas like mobile communication, medical, automobile industry, power management etc, more and more semiconductor companies are focusing on mixed-signal design business. Cyber-physical systems form the basis of *Industry 4.0*. They use modern control systems, have embedded software systems and dispose of an Internet address to connect and be addressed via IoT.



II. MODULE OBJECTIVES

After successful completion of modules 9-12 of Chapter 3, you should be able to:

1) Remember the basics of biometric and RFID technologies, and how they are used in instrumentation and control systems;
2) Understand the working principles of robotic systems and artificial intelligence;
3) Evaluate the technologies involved in the design and development of internet-of-things systems; and
4) Apply the principles of mixed signals and sensors in developing systems involving Industry 4.0 technologies.

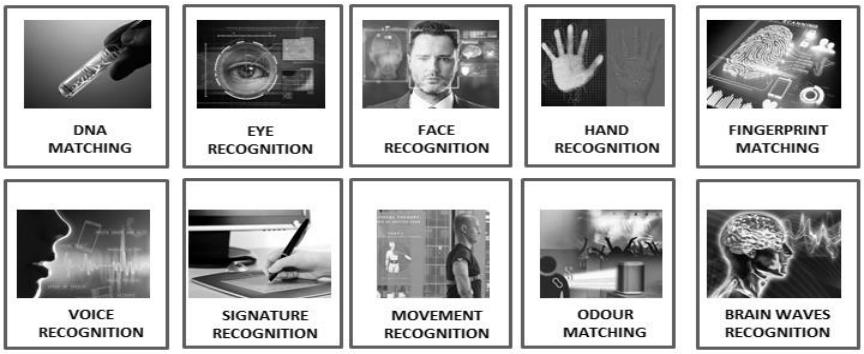
III. COURSE MATERIALS

Suggested Online Resources for Further Learning

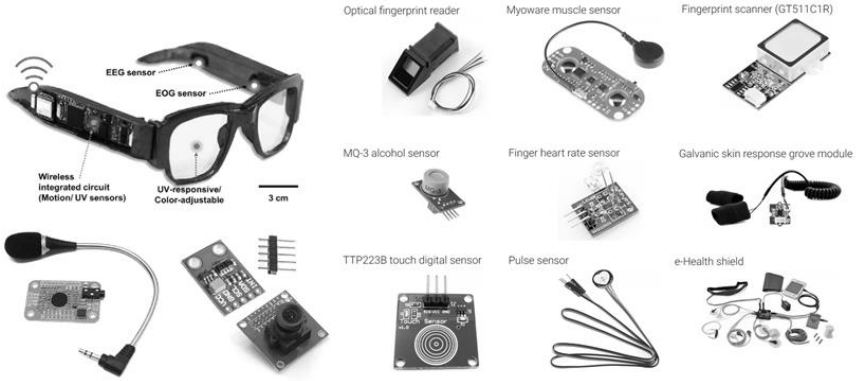
- Downloadable Course AVPs: https://bit.ly/3Fs7iFM
- Downloadable Course PDFs: https://bit.ly/2YFv8gu

Module 9: **Biometrics and RFID**

Biometrics refers to body measurements and calculations metrics related to human characteristics. Different biometric technologies are being used today in various applications.

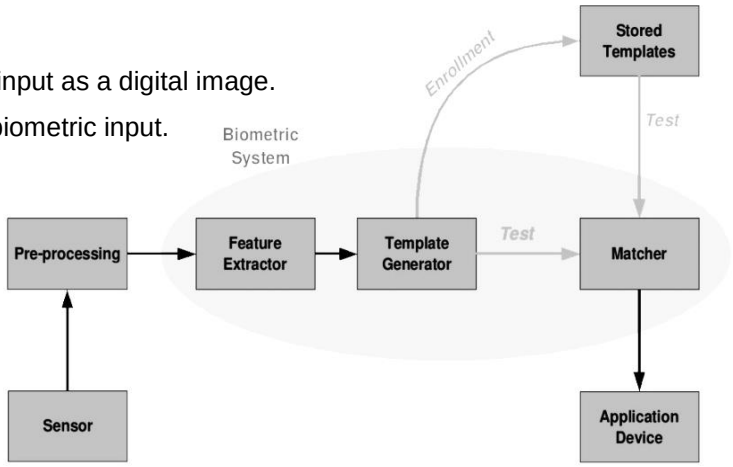


Biometric Sensors

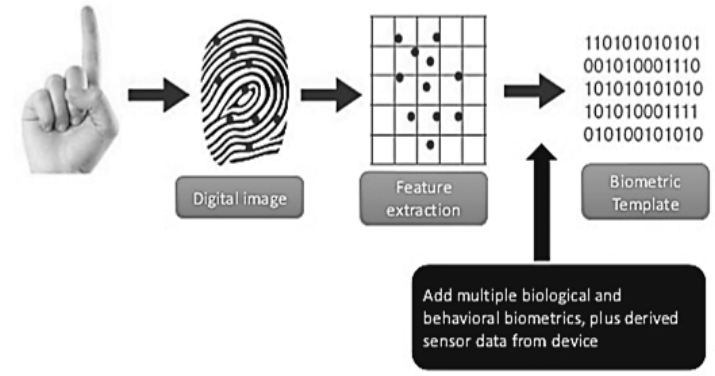


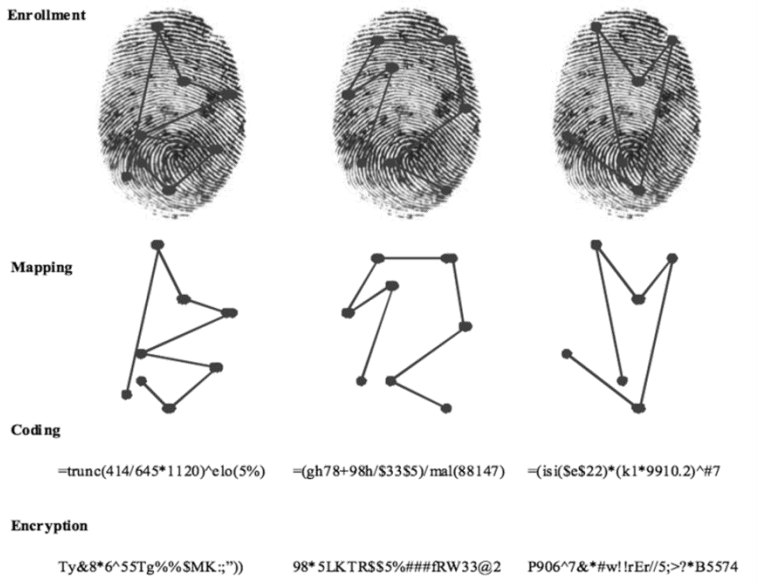
How Biometrics Work

1. Sensor reads the biometric input.
2. Biometric system pre-processes the input as a digital image.
3. Feature extraction performed in the biometric input.
4. Generate biometric template.
5. Generated template is tested for pattern matching.
6. For enrollment, generated template is stored first.
7. Application device is triggered.



Pre-Processing, Feature Extractor, and Template Generation



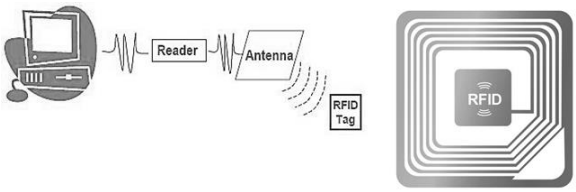


Factors Affecting Biometric Authentication

- Universality
- Uniqueness
- Permanence
- Measurability
- Performance
- Acceptability
- Circumvention

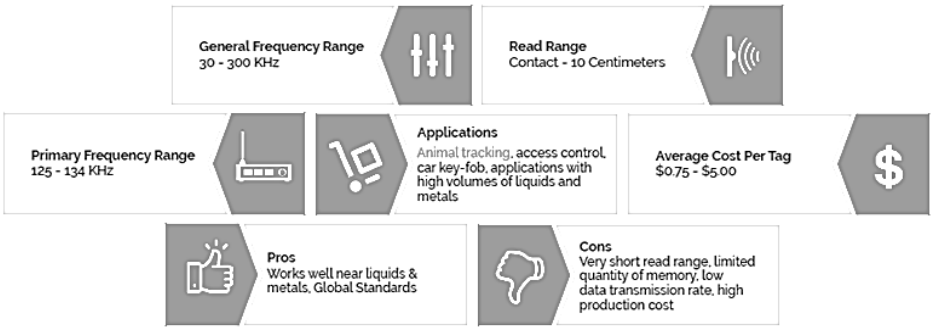
Multimodal Biometric System combines several biometric sources to increase security and accuracy. It usually requires two biometric credentials for identification, such as face and fingerprints instead of one, and it can overcome limitations commonly encountered in unimodal systems. For several years, the use of several biometric features in combination. For example, the face and fingerprints, has made it possible to reduce error rates considerably.

Radio Frequency Identification (RFID) is a technology-based identification system that helps identifying objects just through the tags attached to them. It does not require any line-of-sight distance between the tags and the tag reader. It only needs radio communication between the tag and the reader.

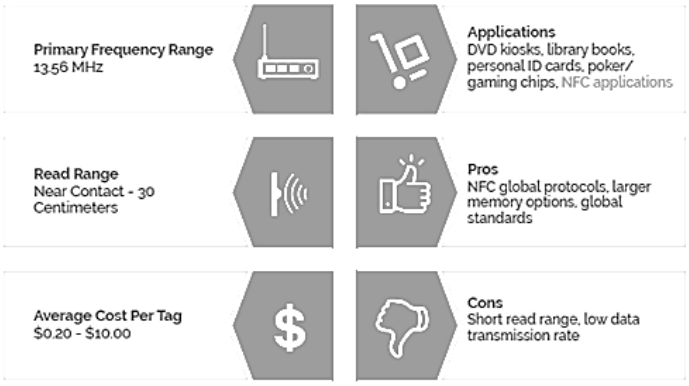


Classifications of RFID

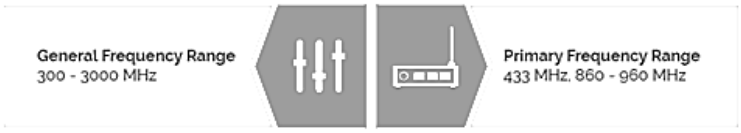
1. Low-Frequency (LF) RFID



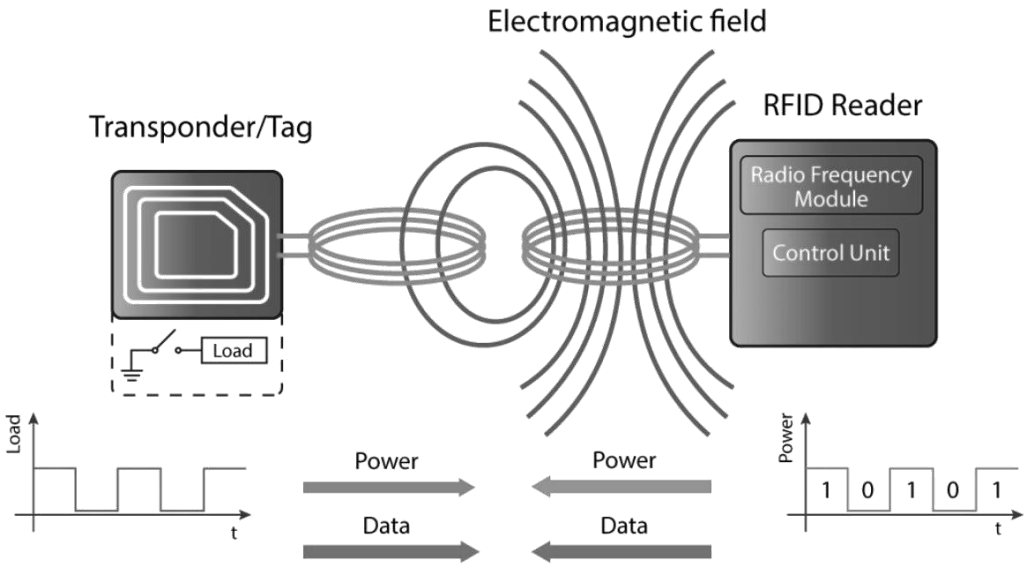
2. Low-Frequency (LF) RFID



3. Ultrahigh-Frequency (UHF) RFID



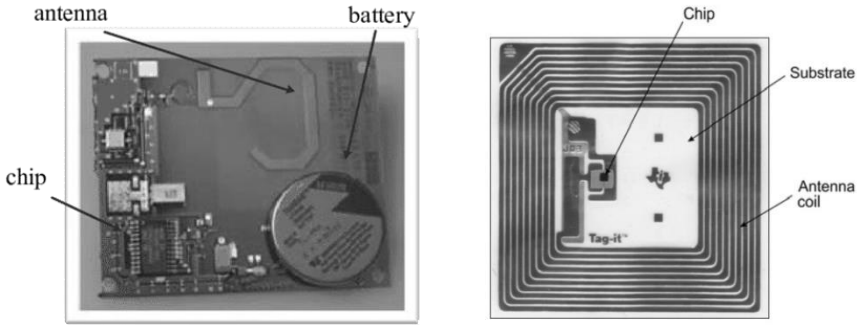
How RFID Works



1. Tag enters RF field.
2. RF signal powers tag.
3. Tag transmits ID with the data in it.
4. Reader captures data and sends it to the computer.
5. Computer determines action.

Types of RFID Tag (Transponder)

Active and Passive RFID



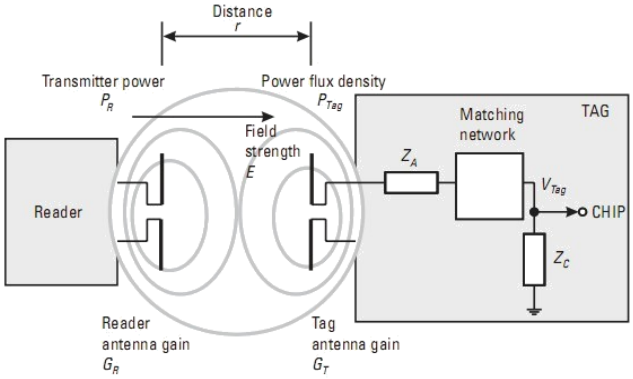
Active RFID

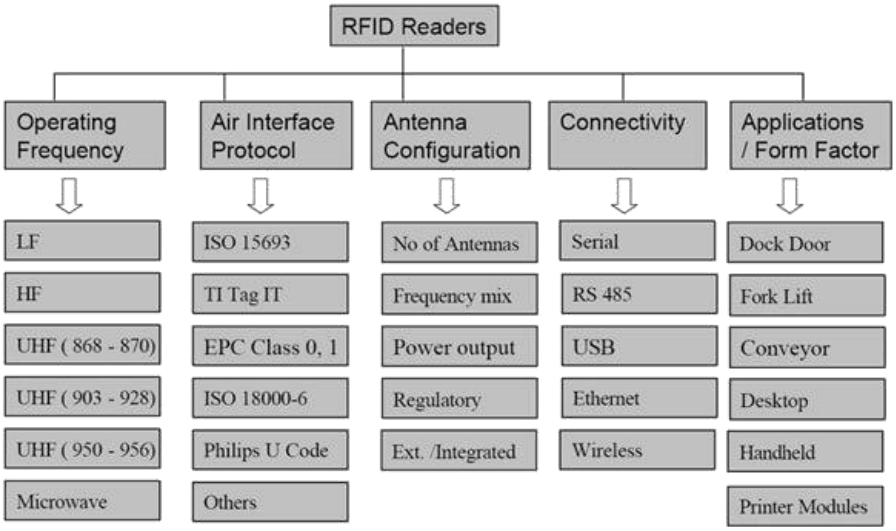
- **Primary Frequency Range:** 433 MHz, (Can use 2.45 GHz - under the Extremely High Frequency Range)
- **Read Range:** 30 - 100+ Meters
- **Average Cost Per Tag:** $25.00 - $50.00
- **Applications:** Vehicle Tracking, Auto Manufacturing, Mining, Construction, Asset Tracking
- **Pros:** Very Long Read Range, Lower Infrastructure Cost (vs. Passive RFID), Large Memory Capacity, High Data Transmission Rates
- **Cons:** High Per Tag Cost, Shipping Restrictions (due to batteries), Complex Software may be Required, High Interference from Metal and Liquids; Few Global Standards.

Passive RFID

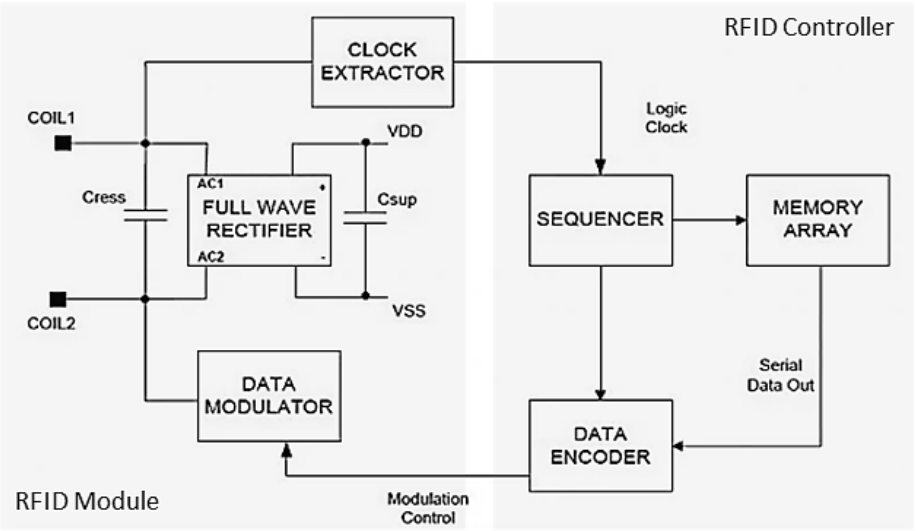
- **Primary Frequency Range:** 860 MHz - 960 MHz
- **Read Range:** Near Contact - 25 Meters
- **Average Cost Per Tag:** $0.09 - $20.00
- **Applications:** Supply Chain Tracking, Manufacturing, Pharmaceuticals, Electronic Tolling, Inventory Tracking, Race Timing, Asset Tracking
- **Pros:** Long Read Range, Low Cost Per Tag, Wide Variety of Tag Sizes and Shapes, Global Standards, High Data Transmission Rates
- **Cons:** High Equipment Costs, Moderate Memory Capacity, High Interference from Metal and Liquids

RFID Reader (Interrogator)





Inside an RFID Reader



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. What is the purpose of generating a biometric template, especially in applications that involve biometric authentication and identification?
2. Choose 3 factors affecting biometric authentication and explain their importance in biometric signal processing and image processing.
3. What are the pros and cons of active and passive RFID compared to each other?
4. In your own idea, how can we overcome the distance and obstacle issues in an RFID system?

Research Activity

Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

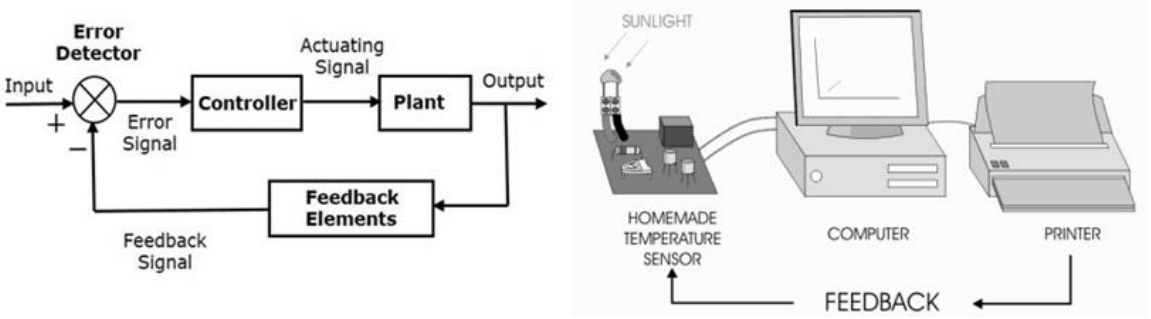
- ✓ What is MATLAB
- ✓ How to Install MATLAB
- ✓ Getting Started with MATLAB

Module 10: **Instrumentation and Control**

Instrumentation is a collective term for measuring instruments that are used for indicating, measuring and recording physical quantities such as flow, temperature, level, distance, angle, or pressure.

Data Logger is a device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. It is a ***data acquisition system*** (DAQ) that doesn't need to remain tethered to a computer to acquire data.

Control System is a system that manages, commands, directs, or regulates the behavior of other devices or systems using control loops.



Controllers

MICROPROCESSOR	MICROCONTROLLER
A component that performs the instructions and task involved in computer processing	A compact integrated circuit designed for a specific operation in an embedded system
Used for applications that require intensive processing	Used for an application that performs a particular task
Memory, IO ports, timers, etc. are connected to the CPU externally	CPU and all other elements are integrated into a single chip or a board
Microprocessor based applications perform multiple tasks. Therefore, it requires more memory	Performs a single task. Therefore, it does not require more memory and IO ports
Has a high clock speed	Has a lower clock speed
32bit or 64bit	8 bit, 16bit or 32bit
Uses USB, UART, and high-speed Ethernet as the peripheral interfaces	Uses I2C, UART and SPI for the peripheral interfaces
Consumes more power	Consumes less power
Cost more	Cost less
Larger	Smaller
Used by personal computers and laptops	Used by microwave ovens and washing machines

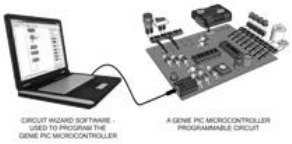
Visit www.PEDIAA.com

MICROPROCESSORS

MICROCONTROLLERS

MICROCONTROLLER MODULES

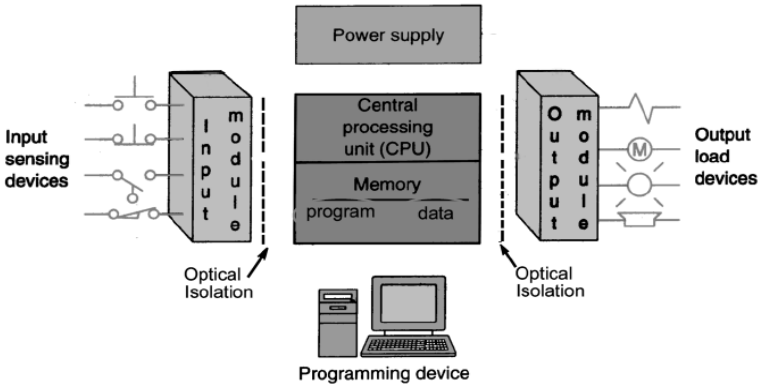
PIC MICROCONTROLLERS



Programmable Logic Controller (PLC) is a special form of microprocessor-based controller that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes.

Advantages:

- Less Hard Wiring
- Increased Reliability
- Faster Response Time
- Communications Capability
- Lower Cost
- More Flexibility
- Easier to Troubleshoot



PLC Sizes

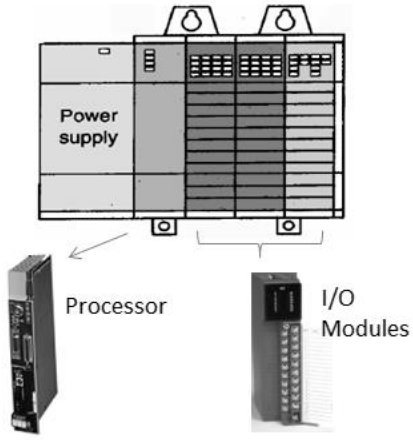
Nano PLC
(up to 16 I/O Points)

Micro PLC
(up to 32 I/O Points)

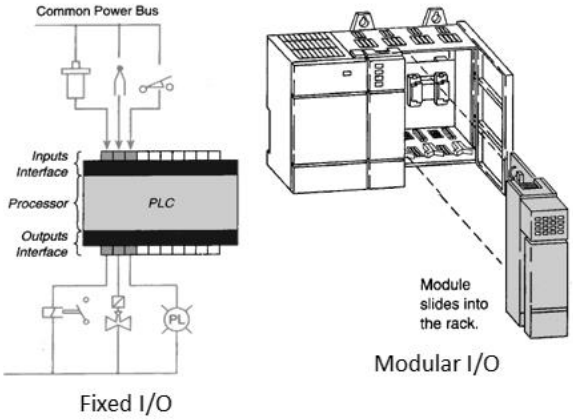
Allen-Bradley PLC-5 PLC
(up to thousands of I/O Points)

Allen-Bradley SLC-500 PLC
(up to 960 I/O Points)

Basic Parts of a PLC

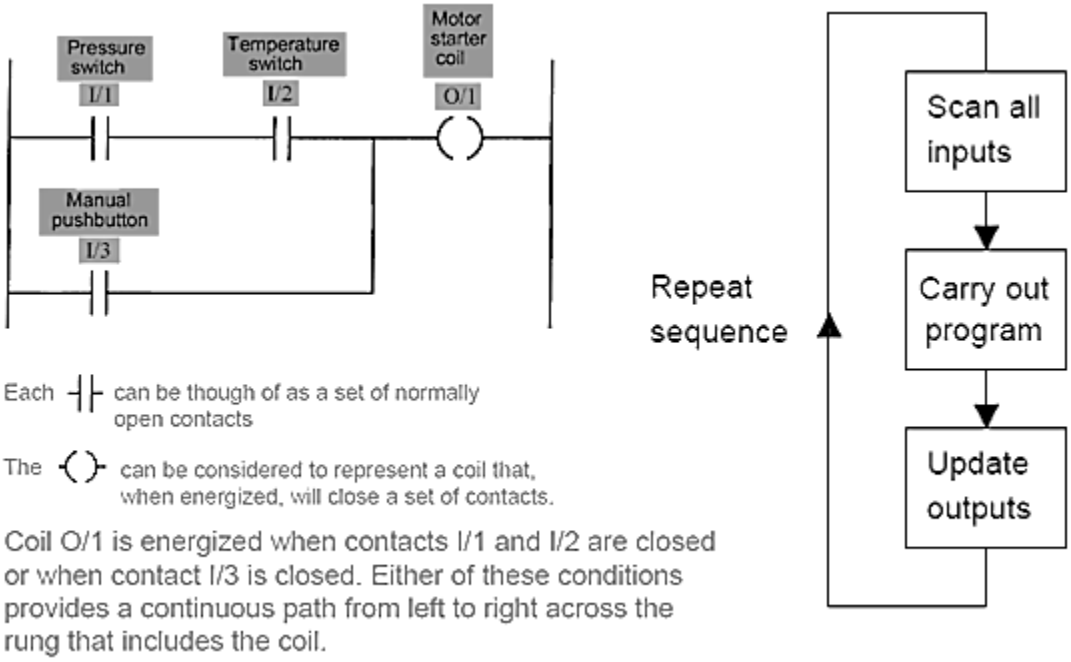


PLC I/O Configurations

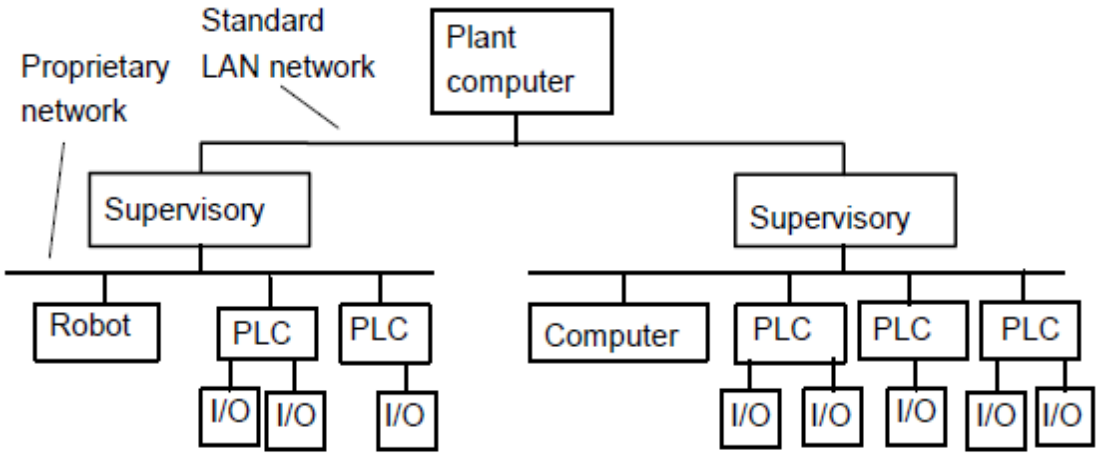


PLC Operating Cycle

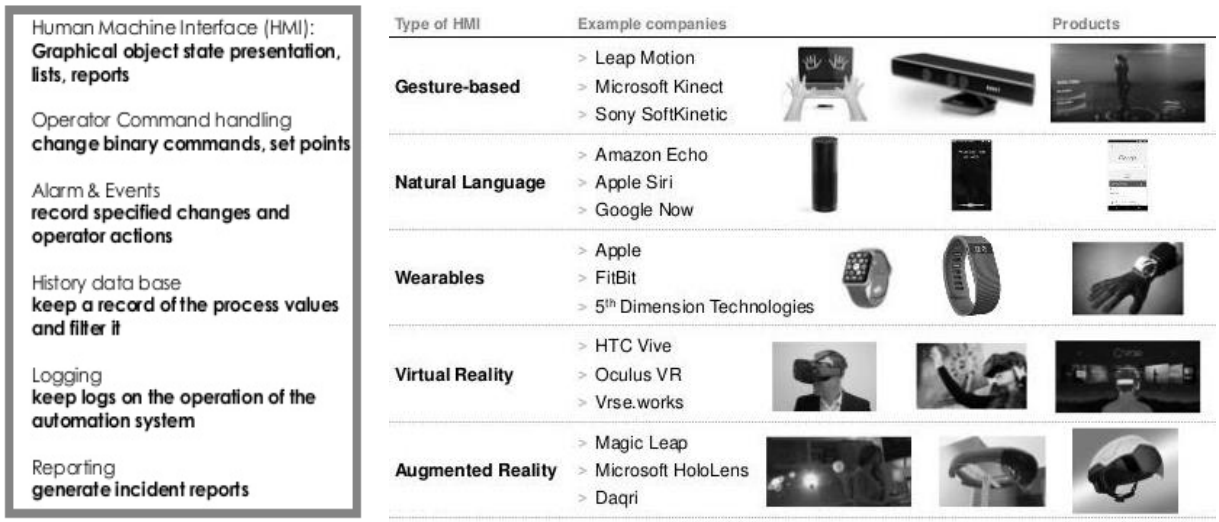
- During each operating cycle, the controller examines the status of input devices, executes the user program, and changes outputs accordingly.
- The completion of one cycle of this sequence is called a ***scan***. The *scan time*, which is the time required for one full cycle, provides a measure of the speed of response of the PLC.



Often, PLCs figure in an entire hierarchy of communications. These in turn may be part of a network involved with a large mainframe company computer controlling all.



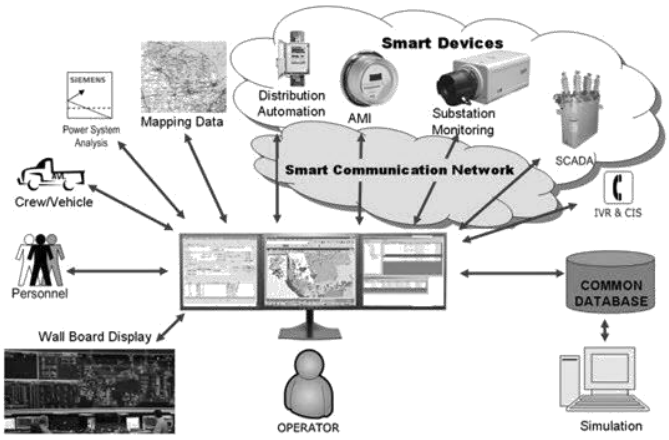
Human-Machine Interface (HMI) is a collection of screens, graphic displays, and other technologies used by the operator to monitor and interact with the control system.



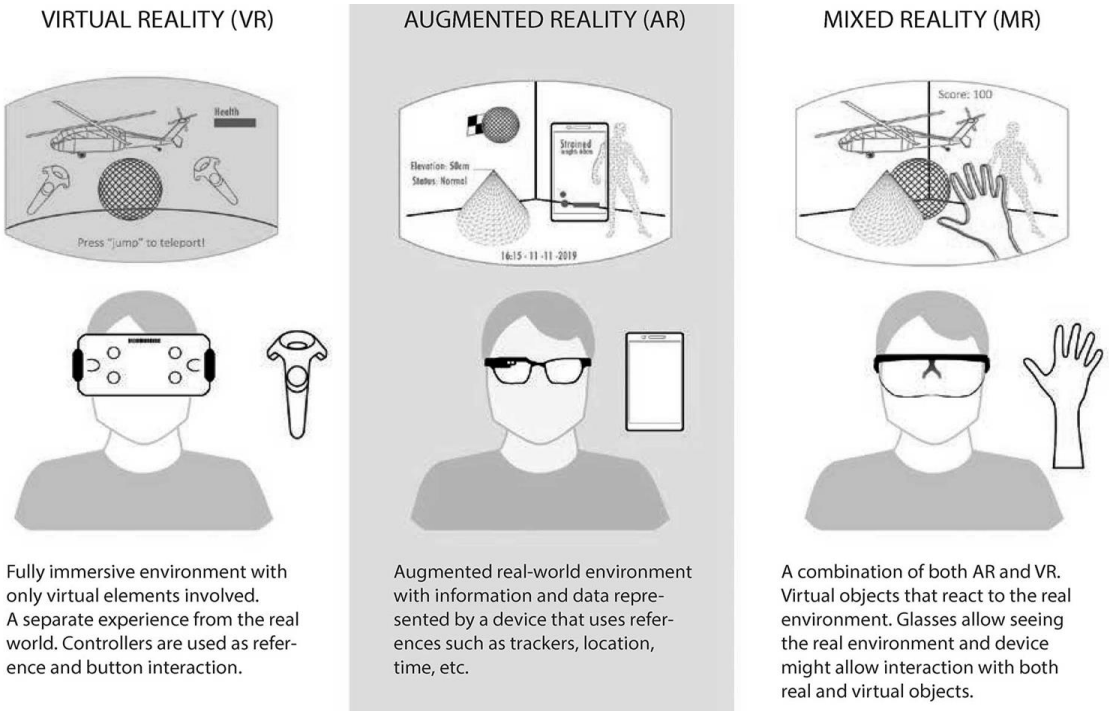
The HMI hardware includes a processor, display unit, input unit, communication interface, data storage unit, etc. On the other hand, the HMI software is generally divided into two parts, the system software running in HMI hardware and the screen configuration software running under the PC Windows operating system.

Supervisory Control and Data Acquisition Systems (SCADA) is the basis of any real-time control system. The system collects data from multiple sources and pre-processes and stores the data. The data is transferred to a data base where it's available for various users and applications. The following six items are the basis for modern SCADA systems:

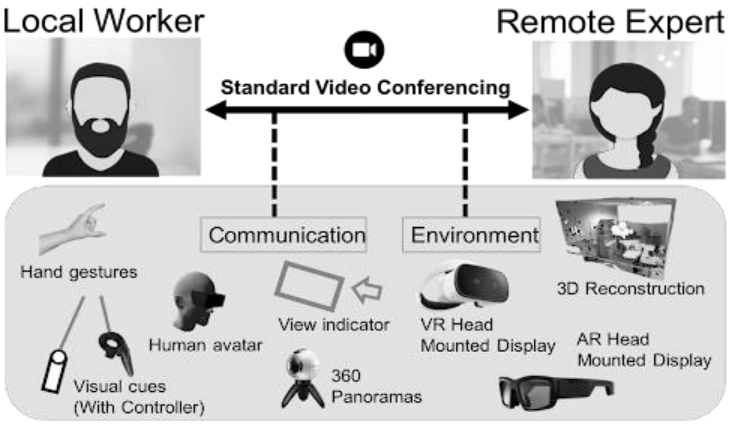
- Data acquisition
- Monitoring and event processing
- Control
- Data storage archiving and analysis
- Application-specific decision support
- Reporting



Mixed Reality is the merging of real and **virtual** worlds to produce new environments and visualizations, where physical and digital objects co-exist and interact in real time.



A mixed reality solution accesses features like ***computer vision*** to understand the world around the user and build on it with new images and objects. Additionally, sensors and trackers are necessary to ensure users can interact with the things they see. Increasingly, these controllers are becoming more advanced.



Improvements for the exchange of information via Mixed Reality

ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. What is the role of a data logger in instrumentation systems? How does it work?
2. Explain the relationship between controllers and embedded systems.
3. Give at least 3 examples of practical applications of a PLC in instrumentation and control systems.
4. How does a SCADA system work? Discuss the possible instrumentation applications of it through embedded systems, PLCs, and HMIs.

Research Activity

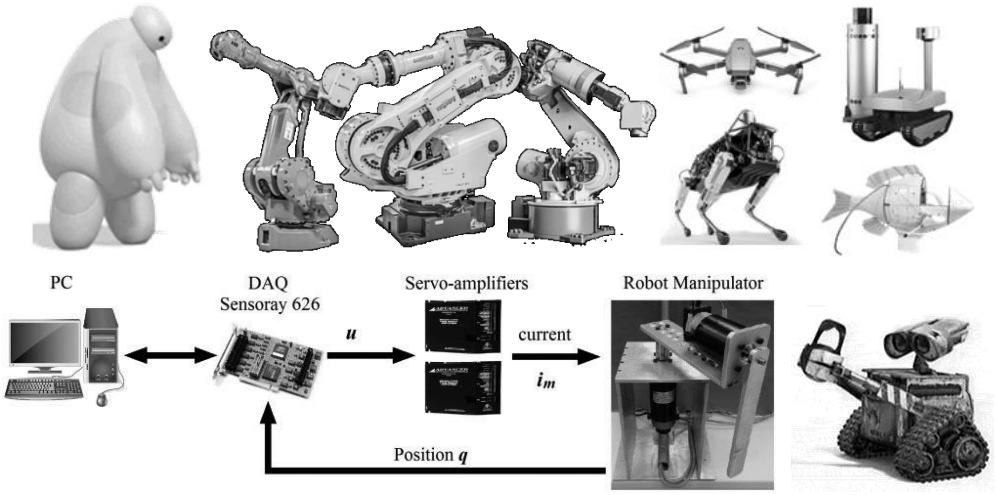
Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

- ✓ What is Simulink?
- ✓ How to Process Signals as Frames in Simulink
- ✓ Generating Signals in Simulink
- ✓ Introduction to Signal Processing Apps in MATLAB

Module 11: **Robotic Systems and AI**

Robotics is an industry related to the engineering, assembly and operation of robots that generally involves looking at how any physical constructed technology system can perform a task or play a role in any interface or new technology.

A ***robot*** is a computer-controlled device that combines the technology of digital computers with the technology of servocontrol of articulated chains. It is a reprogrammable multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks. ***Robotic systems*** provide intelligent services and information by interacting with their environment, including human beings, via the use of various sensors, actuators and human interface.



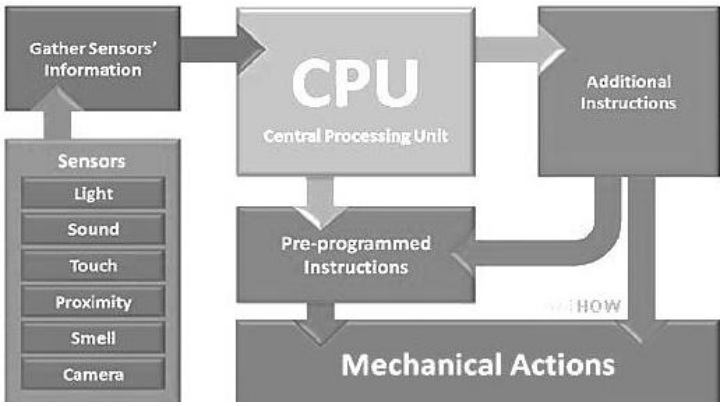
Isaac Asimov proposed “3 Laws of Robotics”. He later added the “0th law”

- Law 0: A robot may not injure humanity or allow humanity to come to harm.
- Law 1: A robot may not injure a human being or through inaction, allow a human being to come to harm, unless this would violate a higher order law.
- Law 2: A robot must obey orders given to it by human beings, except where such orders would conflict with a higher order law.
- Law 3: A robot must protect its own existence as long as such protection does not conflict with a higher order law.

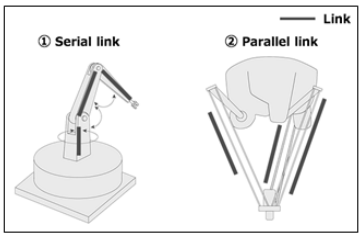
3 Main Classifications of Robotic Systems

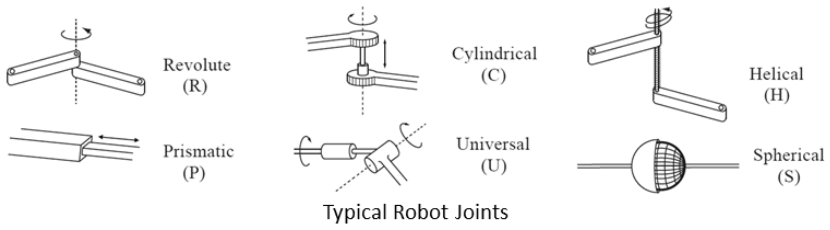
1. Manipulation Robotic System – most extensively used robotic system that is found mainly in manufacturing industries; these are made up of many of the robot arms with 4-6 axes and varying degrees of freedom, and can perform several different functions, including welding, material handling, and material removal applications
2. Mobile Robotic System – usually an automated platform that carries goods from one place to another; its motion can also be controlled autonomously and might have a pre-programmed destination from where the system might load or unload automatically.
3. Data Acquisition & Control Robotic System – used for acquiring, processing, and transmitting important data used for generating various signals; these are generally meant for activities that require less human participation, a control robotic system generates signals that can be used for controlling other robots, and are also used for CAD systems used in engineering and business processes.

How Robotic Systems Work



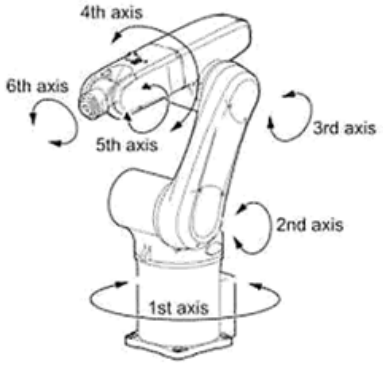
The mechanical manipulator of an industrial robot is made up of a sequence of ***link*** and ***joint*** combinations. *Links* are the rigid members connecting the *joints* (also called *axes*), which are the movable components of the robot that cause relative motion between adjacent links.



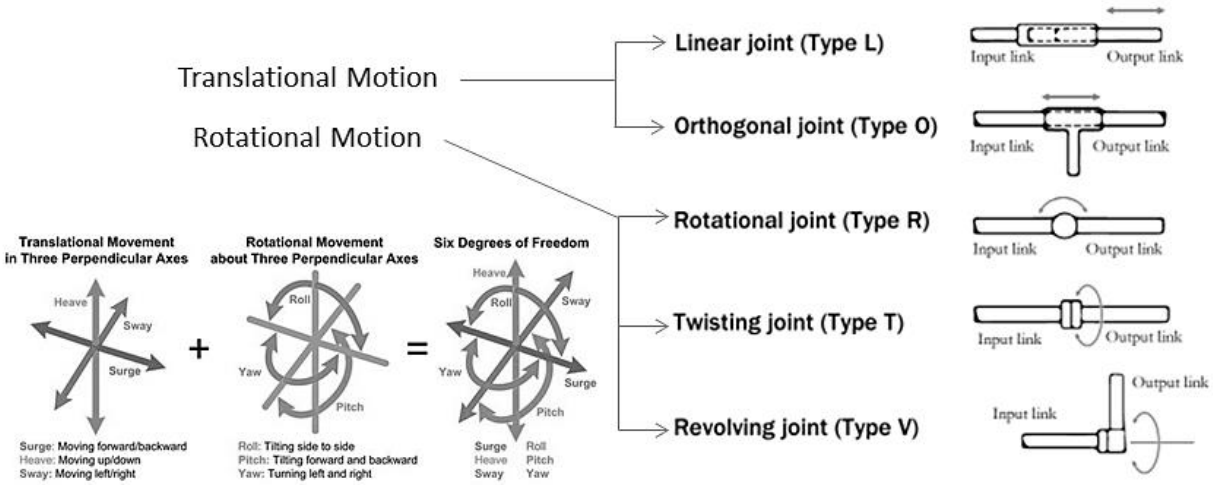


Degrees of Freedom (DoF) refers to the specific, defined modes in which a mechanical device or system can move. It is equal to the total number of independent displacements or aspects of motion and it defines the motion capabilities of robots; a machine may operate in two or three dimensions but have more than three degrees of freedom.

Joint type	dof f	Constraints c between two planar rigid bodies	Constraints c between two spatial rigid bodies
Revolute (R)	1	2	5
Prismatic (P)	1	2	5
Helical (H)	1	N/A	5
Cylindrical (C)	2	N/A	4
Universal (U)	2	N/A	4
Spherical (S)	3	N/A	3



Types of Robot Motion

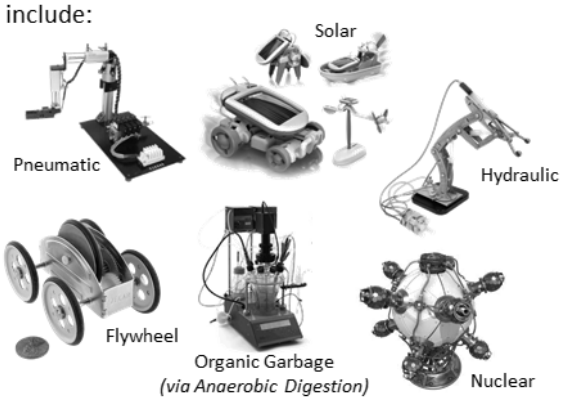


Common Aspects of Robotic Systems

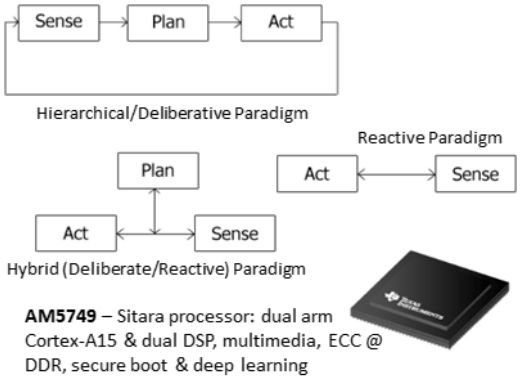
1. All robots have some kind of mechanical construction, a frame, form or shape designed to achieve a particular task.
2. Robots have electrical components which power and control the machinery.
3. All robots contain some level of computer programming code.

Primary Components of a Robotic System

Power Source – mostly (lead-acid) batteries are used, but other potential power sources include:

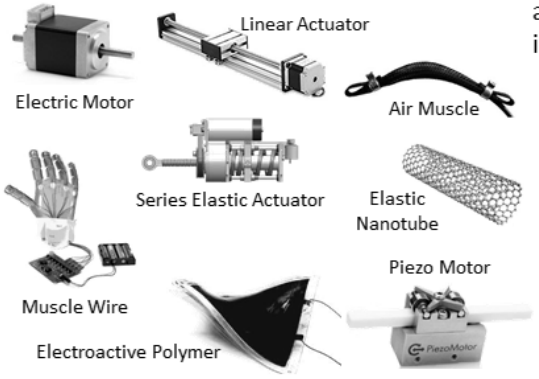


Controller – involves three distinct phases – perception, processing, and action.

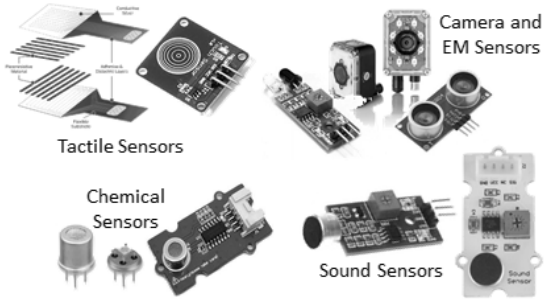


AM5749 – Sitara processor: dual arm Cortex-A15 & dual DSP, multimedia, ECC @ DDR, secure boot & deep learning

Actuators – convert stored energy into movement; most popular actuators are electric motors and linear actuators

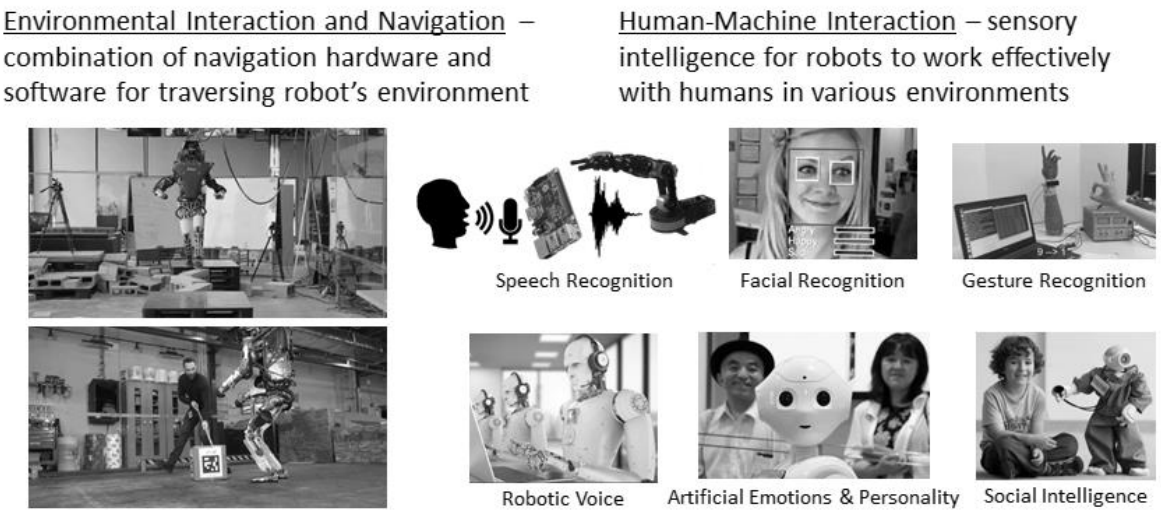


Sensors – allow robots to receive information about a certain measurement of the environment or internal components to give them warnings about safety or errors, and to provide real-time information of the task it is performing

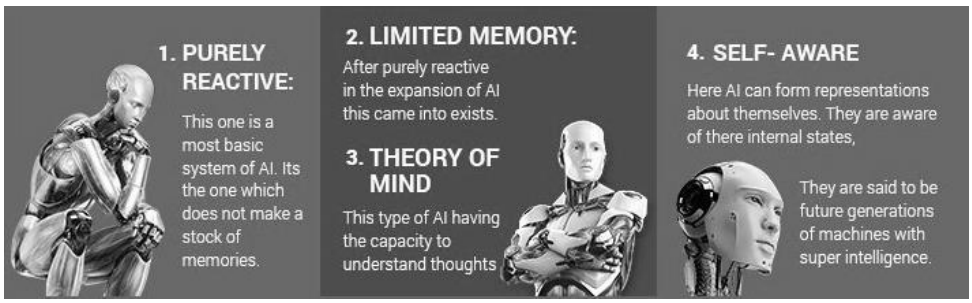


Manipulation Components – used to manipulate objects; pick up, modify, destroy, or otherwise have an effect; the "hands" of a robot are often referred to as *end effectors*, while the "arm" is referred to as a *manipulator*

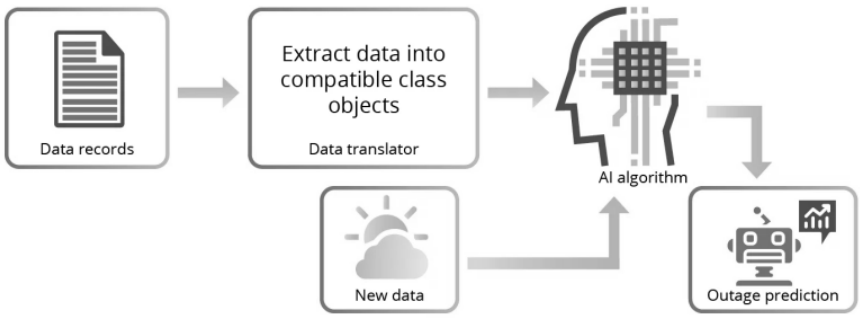
Locomotion Mechanism – allow robots to maneuver in a way that somehow mimics humans, animals, and various objects



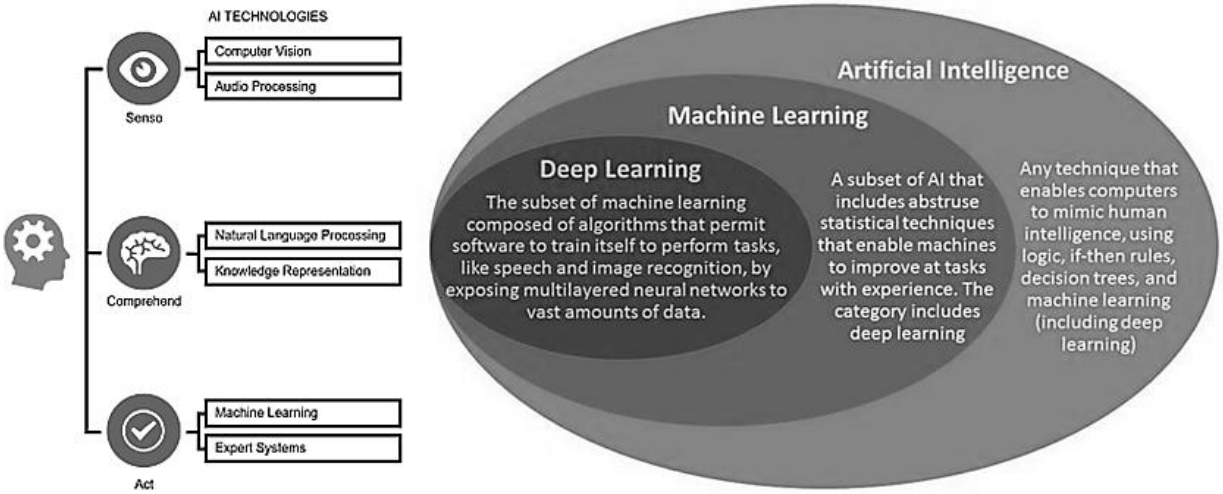
Artificial Intelligence (AI) is a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence. Popular commercial AI technologies include Amazon's *Alexa*, Google's *Assistant*, Microsoft's *Cortana*, Apple's *Siri*, and Samsung's *Bixby*.



Types of AI



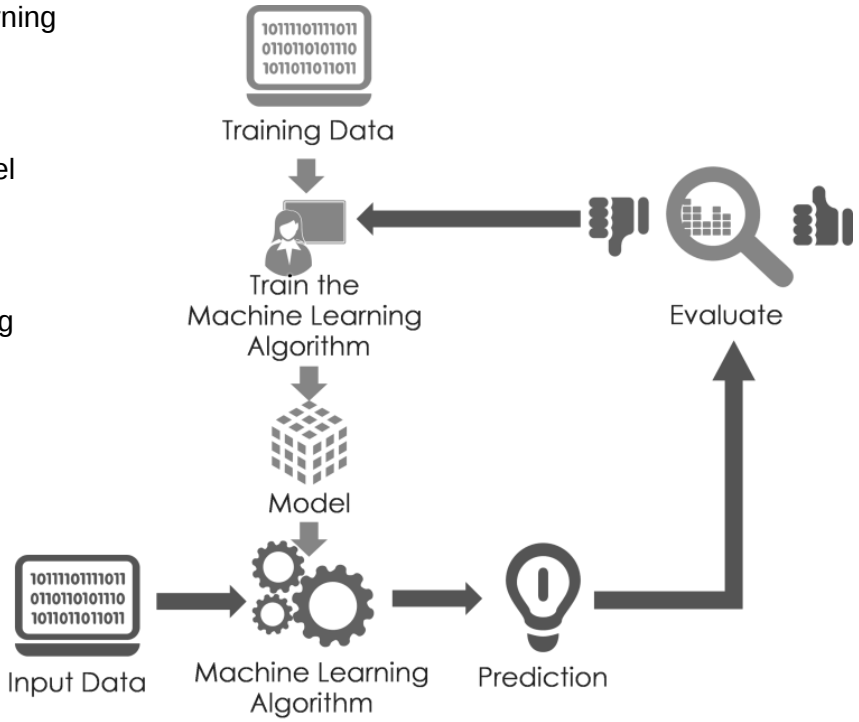
How AI Works

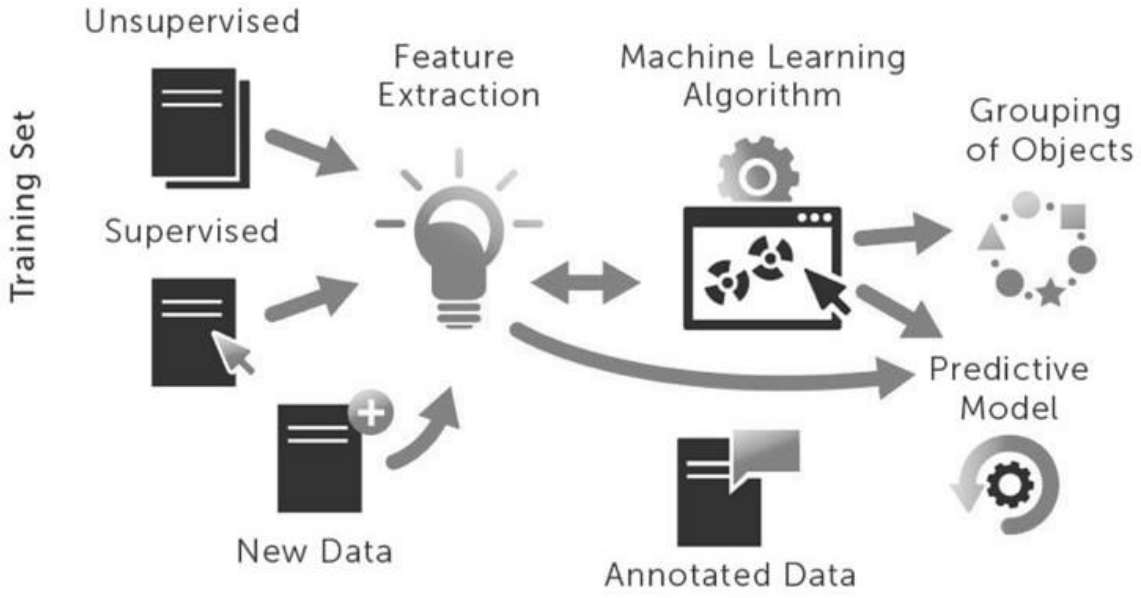


Machine Learning is an application of *artificial intelligence* (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed. It is the study of computer algorithms that improve automatically through experience, and it focuses on the development of computer programs that can access data and use it learn for themselves.

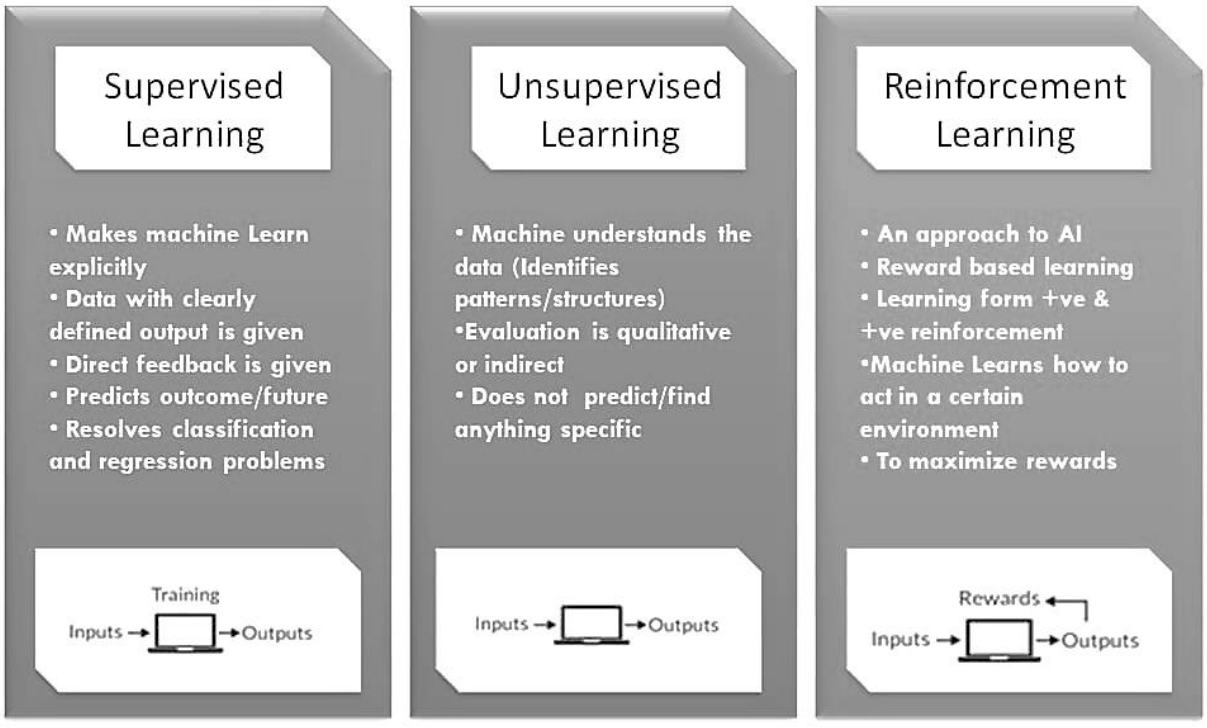
7 Steps of Machine Learning

1. Data Gathering
2. Data Preparation
3. Choosing a Model
4. Training
5. Evaluation
6. Parameter Tuning
7. Prediction





Types of Machine Learning



ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Explain, in a nutshell, how a robotic system works, as well as the differences between its 3 main classifications.
2. How do the robot's links and joints define the DoF and other aspects of robotic motion?
3. What is the purpose of a control system in robotic applications? In what applications is it necessary to use a digital signal processor in a robotic system?
4. In your own idea, what does machine learning have to do with the locomotion mechanism, environment interaction and navigation, and human-machine interaction aspects of robots?

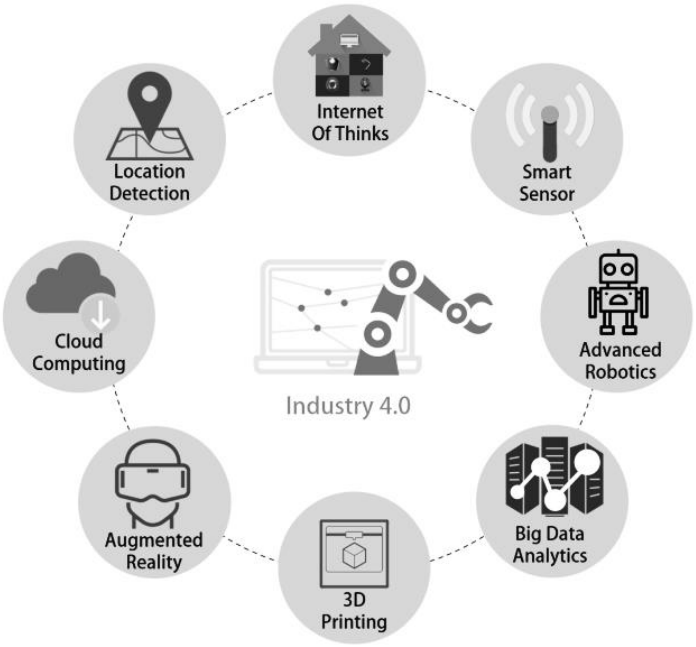
Research Activity

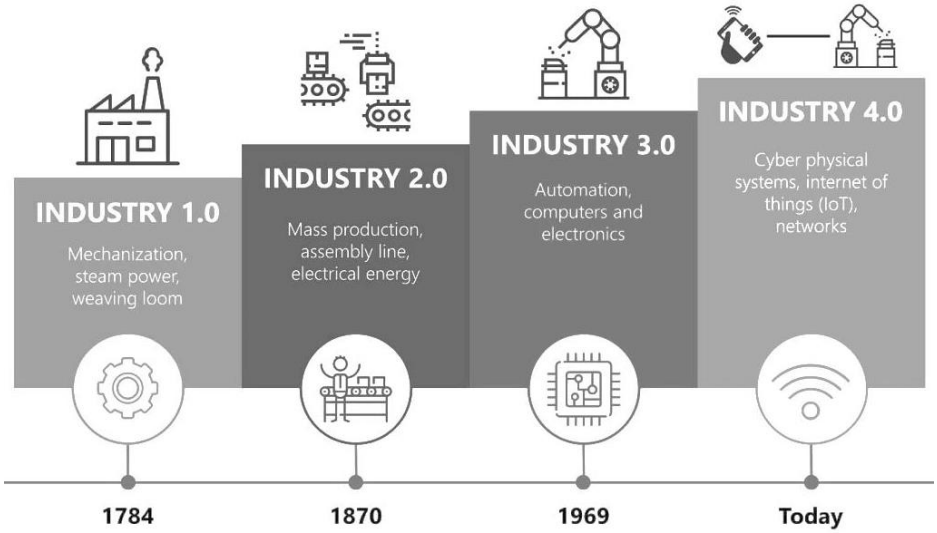
Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

- ✓ Learning Robotics with MATLAB and Simulink
- ✓ Installing Hardware Support Packages for MATLAB and Simulink
- ✓ LEGO Workshop for Mobile Robotics

Module 12: **Industrial Internet-of-Things**

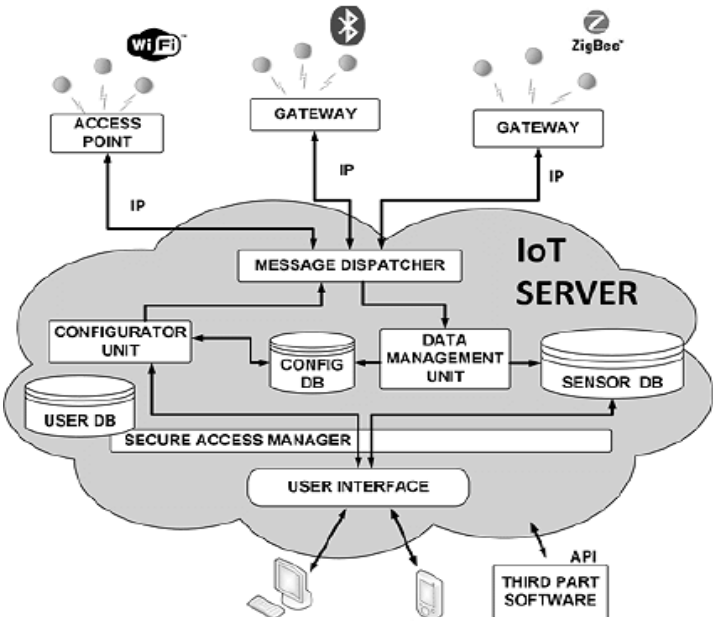
Industry 4.0, also known as the *Fourth Industrial Revolution* (4IR or FIRe), refers to the digital transformation of manufacturing/production and related industries and value creation processes. This new phase in the Industrial Revolution focuses heavily on interconnectivity, automation, machine learning, and real-time data.





Internet of Things (IoT) is a system of interrelated computing devices and machines provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. It creates opportunities for more direct, integration of the physical world into computer-based systems, resulting in efficiency improvements, economic benefits, and reduced human exertions.

Architecture and 3 Cs of an IoT System



Components

Connecting the Real World to the Internet

Connections

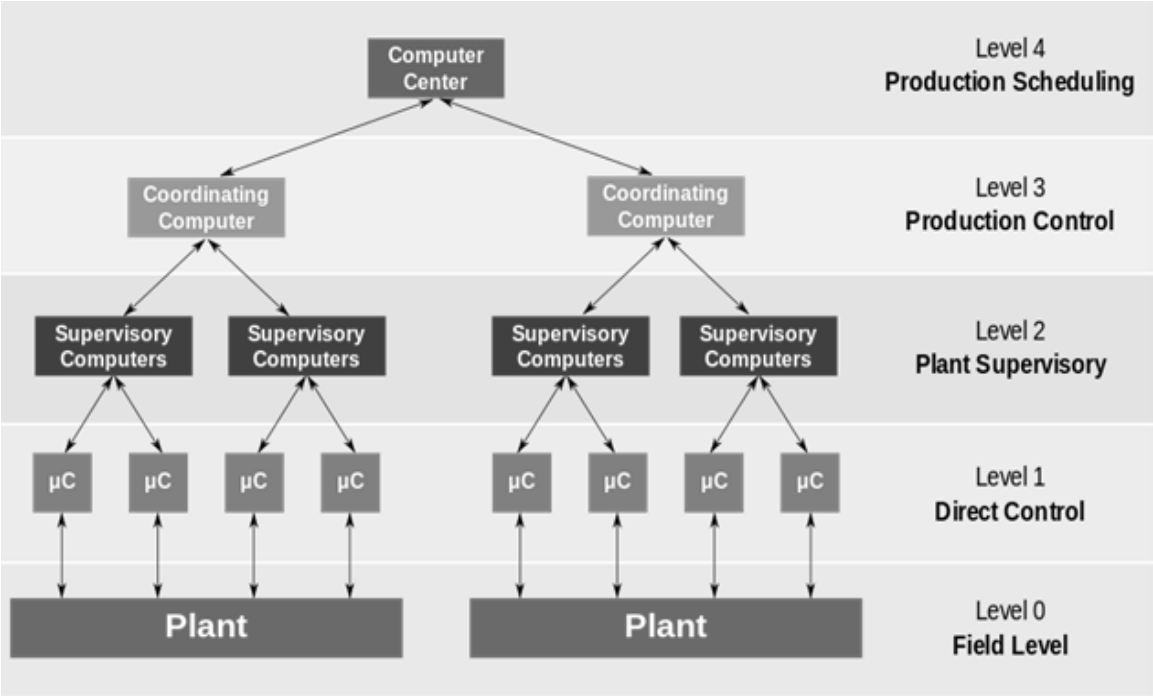
Holding the System Parts Together

Cloud

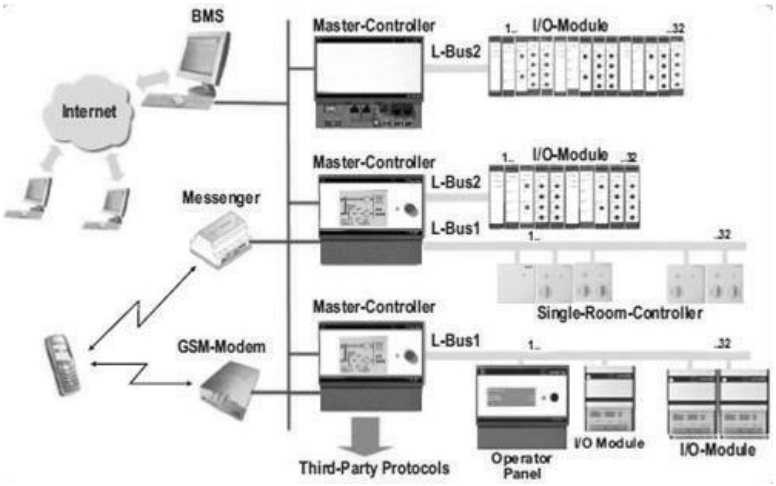
Storing and securing all the System Data

IoT Components

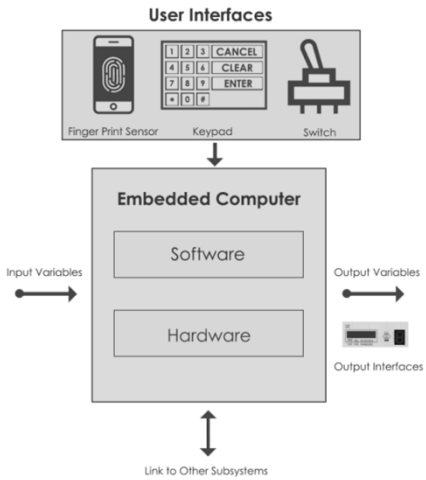
Industrial Control Systems



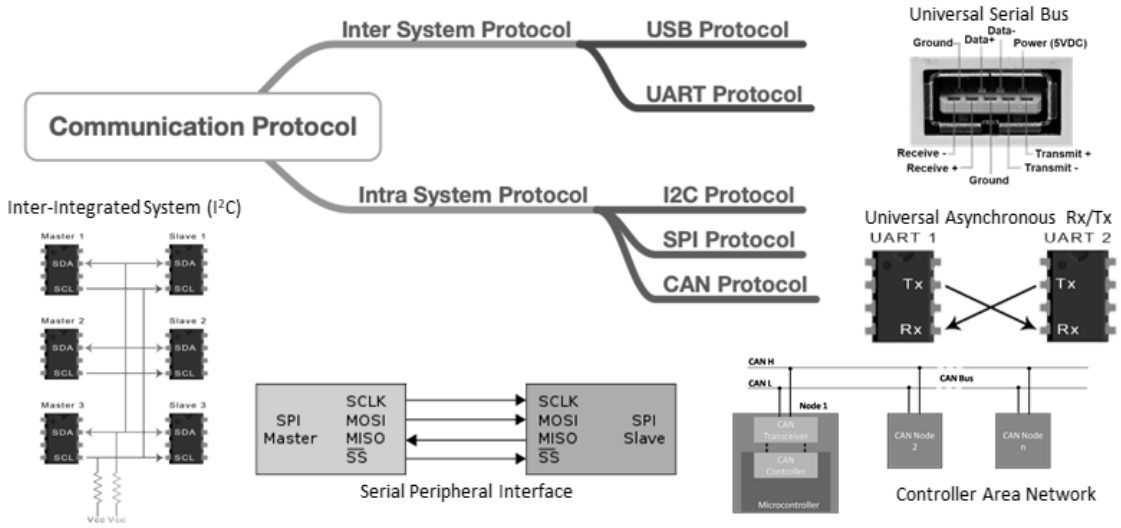
Building Management System



Embedded System



IoT Connectivity



Universal Asynchronous Receiver/Transmitter (UART)

- device for asynchronous serial communication configurable data format and transmission speeds

Serial Peripheral Interface (SPI)

- synchronous serial communication interface specification used for short-distance communication, primarily in embedded systems

Inter-Integrated Circuit (I2C or I2C)

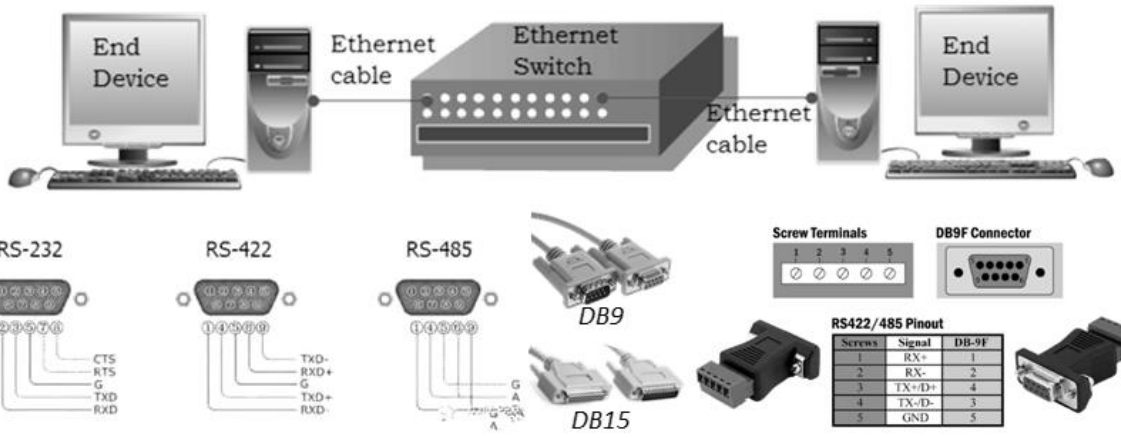
- serial protocol for 2-wire interface to connect low-speed devices like microcontrollers and other similar peripherals in embedded systems

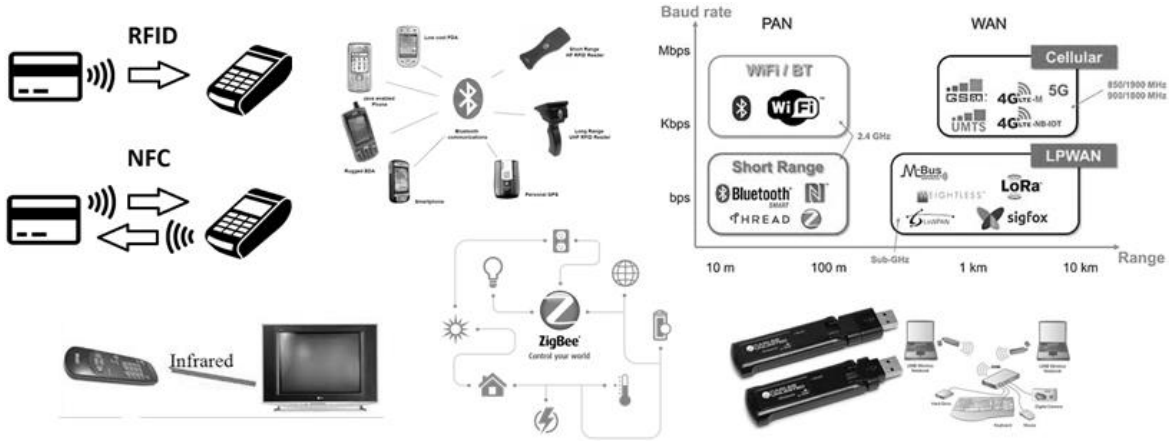
Universal Serial Bus (USB)

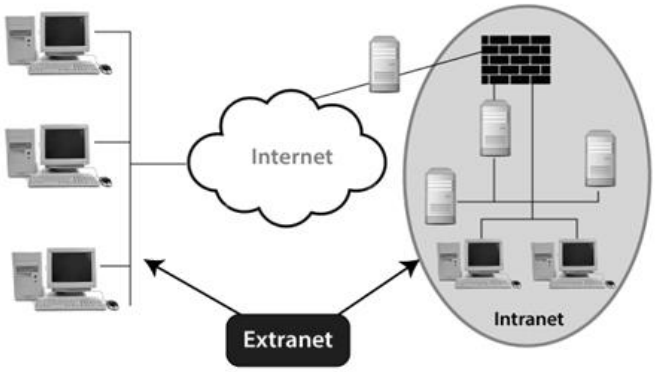
- enables communication between devices and a host controller such as a PC
- external bus standard that supports data transfer rates of 12 Mbps and can be used to connect up to 127 peripheral devices

Standard	Tx Type	# Signal Wires	Data Rate & Distance	Hardware $	Scalability	Application Example
UART	Asynchronous	2	20kbps @ 15m	Medium (transceiver)	Low (point-to-point)	Diagnostic display
LIN	Asynchronous	2	20kbps @ 40m	Medium (transceiver)	High (identifier)	Washing machine subsystem network
SPI	Synchronous	4+	25Mbps @ 0.1m	Low	Medium (chip selects)	High speed chip to chip link
I2C	Synchronous	2	1Mbps @ 0.5m	Low (resistors)	High (identifier)	System sensor network

Wired and Wireless Technologies for Data Communications and Computer Networks



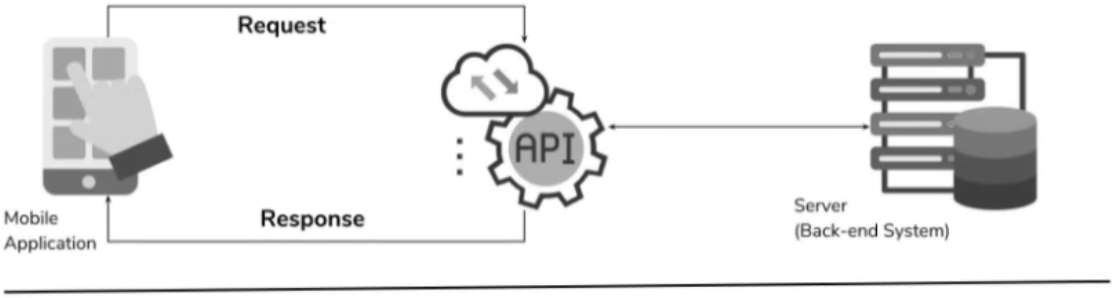


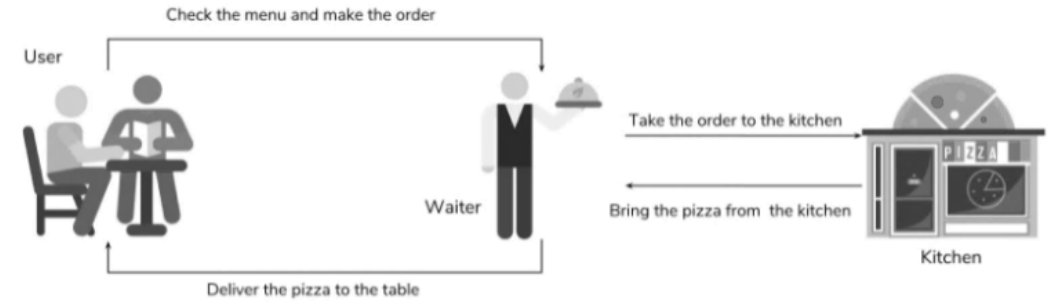


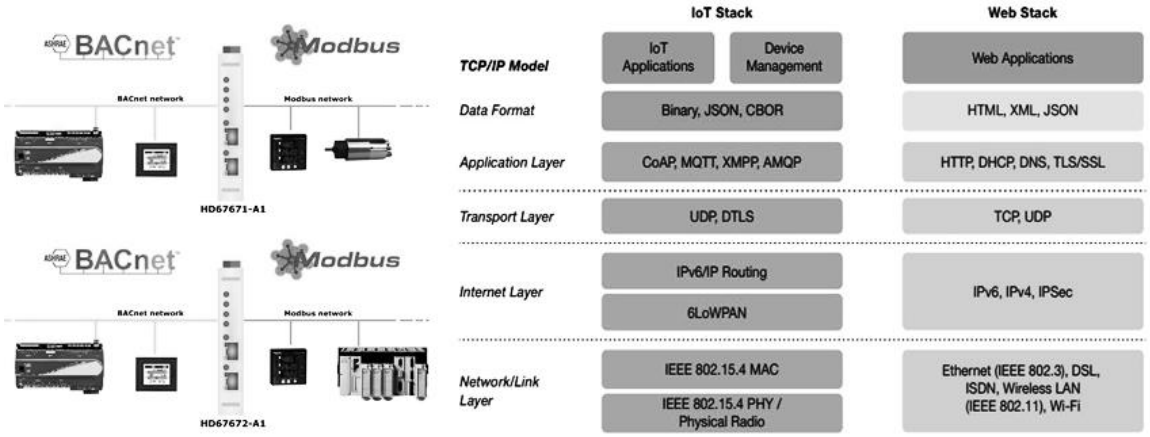
Parameter	Internet	Intranet	Extranet
Type of Network	Public	Private	Private/VPN
Size	Large number of connected devices	Limited number of connected devices	Limited number of connected devices over internet
Security	Depends on the device connected to the device	Firewall protected	Firewall separates Internet and Extranet
Policy	Internet Communication Protocols	Organizational Policies	Organizational policies, contractual policies and Internet Policies
Accessibility	Anyone	Authorized people	Authorized people
Information Sharing	Information can be shared across the world	Information can be shared securely within an Organization	Information can be shared between employees and external people
Owner	Not owned by anyone	Owned by a particular Organization	Owned by one or more Organizations
Example	World Wide Web, Email, Chat, Social Media	Internal Operations Network of an Organisation	Network of Collaboration between two Corporations

IoT Data Communications and Storage

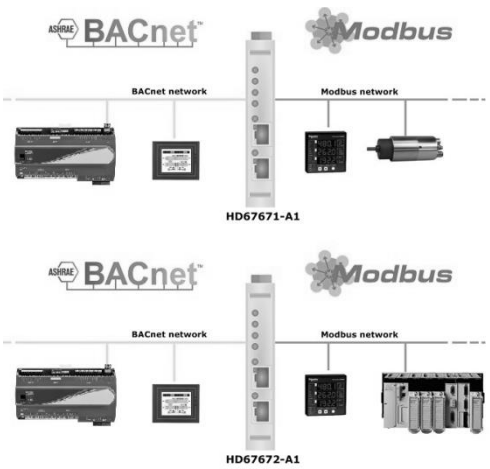
Cloud Computing is everything, from computing power to computing infrastructure, applications, business processes to personal collaboration— can be delivered as a service wherever and whenever needed. ***Application Programming Interface*** (API) is a set of routines, protocols, and tools for building software applications, as well as for communication among various components and interaction among software components

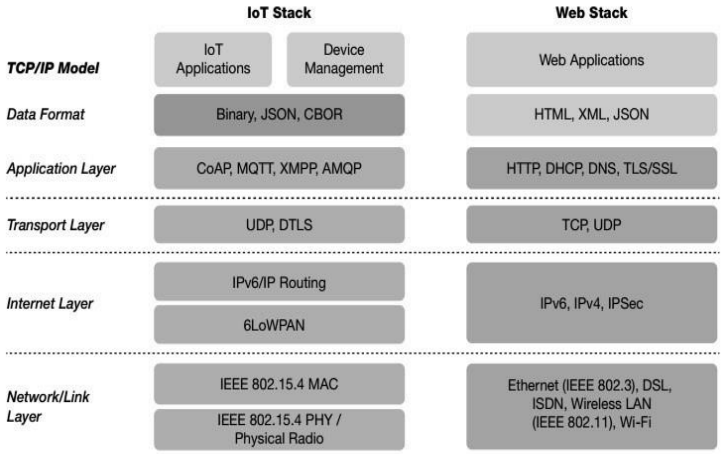






BMS and IoT Protocols





Categories of IoT

- Home Automation – also known as *domotics*, it controls lighting, climate, entertainment systems, appliances, and home security
- Web-of-Things – approaches, architectural styles, and programming patterns, that allow real-world objects to be part of the WWW
- Smart Grid – electrical grid which includes a variety of operational and energy measures, including smart meters, smart appliances, renewable energy resources, and energy efficient resources
- Cyber-Physical System – a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users
- Data Distribution System – aims to enable scalable, real-time, dependable, high-performance, and interoperable data exchange using a publish-subscribe pattern
- Cloud Manufacturing – developed from existing manufacturing models and enterprise information technologies supported by cloud computing, virtualization and service-oriented technologies, and advanced computing technologies
- Ambient Intelligence – the element of a pervasive computing environment that enables it to interact with and respond appropriately to the humans in that environment.

ASSESSMENT

Q&A

Answer what is asked in the following items. Each answer should be in a narrative form with at least 3 sentences and with normal formatting details.

1. Based on what you have learned, what are the distinct and revolutionary features of Industry 4.0 as compared to the previous industrial revolutions?
2. Discuss, in your own words, how industrial IoT works based on the 3 Cs. Which of the 3Cs do the embedded systems belong?
3. How can a SCADA system enable real-time control in industrial operations? What possible IoT connectivity technologies can be used for this function?
4. Explain the importance of cloud computing technologies and APIs in real-time IoT applications of control systems.

Research Activity

Watch the following YouTube tutorials about MATLAB and perform the tasks they feature:

- ✓ Getting Started with Arduino and the ThingSpeak Cloud
- ✓ Cloud-Based People Counter using MATLAB
- ✓ How to Analyze IoT Data in ThingSpeak

References and Suggested Readings

- Don Johnson, *Fundamentals of Electrical Engineering I*
- Louis E. Frenzel Jr., *Principles of Electronic Communication Systems*
- Tomasi, Wayne, *Digital Communication Systems*
- Stallings, William, *Data and Computer Communication*
- Manuel Gooding, P.E., *Introduction to Control and Instrumentation*
- Tracy Adams, P.E., *SCADA System Fundamentals*
- John R. Hackworth, Frederick D. Hackworth, Jr., *Programmable Logic Controllers*
- Shakhatreh, Fareed, *The Basics of Robotics*
- *The Beginner's Guide to RFID Systems*
- *Biometrics: A Guide*
- **Various Online Resources**

Downloadable Course AVPs: https://bit.ly/3Fs7iFM
Downloadable Course PDFs: https://bit.ly/2YFv8gu