Introduction to Electro-Mechanical Sensors and Actuators
ENSC 387 (4)

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Some text was taken from notes by Yaser M. Roshan

ENSC 387

- Instructor – Bob Gill P.Eng., FEC
  - Email: balbirg@sfu.ca
  - Office hours: in ASB 10855 Mon. & Wed. 10:30-12:30

- Course Schedule:
  - Lecture:
    - Mon. 8:30-10:20 WMC 3210
    - Wed. 8:30-9:20 WMC 3210
  - Tutorial: Wed. 9:30-10:20 WMC 3210
  - Final exam: TBD

Course plan

Week	Topic
1	Introduction, Control, and Instrumentation
2	Impedance Matching, Performance Analysis
3	Analog Sensors (potentiometer, variable inductance, tachometer)
4	Analog Sensors (variable capacitance, piezo sensor, strain gauge, accelerometer)
5	Analog Sensors (torque sensor, tactile sensor, optical and ultrasonic sensors, thermofluid sensors)
6	Digital Sensors (shaft encoder, incremental encoder, absolute encoder)
7	Digital Sensors (digital tachometer, hall effect sensor)
8	Magnetic Circuits
9	Stepper motor (permanent magnet, variable reluctance)
10	AC Induction Motors
11	DC Motors
12	Synchronous Motors
13	Motor Speed Control

Laboratory

- Problems with lab equipment:
  - Gary Houghton gary_houghton@sfu.ca
  - Gary Shum gcshum@sfu.ca
- TAs:
  - Gil Herrnstad shahramp@sfu.ca
- Lab. office hours:
  - Mon. 10:00-12:00 Lab01
  - Wed. 15:00-17:00 Lab01

Lab No.	Subject	Start Date	End Date
1	Position and Velocity Sensors	Jan	Jan
2	Accelerometers	Feb	Feb
3	Strain Gauge for Poisson's Ratio and Young's Modulus	Feb	Feb
4	Stepper Motor	Mar	Mar
5	DC Motor	Mar	Mar

Laboratory Sign-Up Sheet

Coming Soon !!

Marks Distribution / Textbook

Component	Percentage of Overall Mark
Assignments (4 of 5)	10 %
Laboratories (5 labs)	20 %
Midterm (1)	20 %
Final Exam	50 %

- Textbooks:
  - Sensors and Actuators: Control System Instrumentation, Clarence W. de Silva, 2nd Edition, CRC Press
  - Principles of Electric Machines and Power Electronics, P. C. Sen, 2nd Edition, John Wiley & Sons, 1996.

Assignments/Midterm

Assignment No.	Available date	Due date
1	TBA	TBA
2	TBA	TBA
3	TBA	TBA
4	TBA	TBA
5	TBA	TBA

Midterm	Tentative date (subject to change)
MT-Exam	TBA

Control and Instrumentation

- Control System: Dynamic system that contains a controller.
- Controller: Generate control signals to drive the process to be controlled (the plant) in the desired manner.
- Actuator: Perform control action.
- Sensor/Transducer: Process responses of the system / monitoring / diagnosis
- Signal conditioning/conversion: Based on different types and levels of signals in control systems.

What is a Sensor ? Various Interpretations

A *sensor* is an object whose purpose is to detect events or changes in its environment, and then provide a corresponding output.

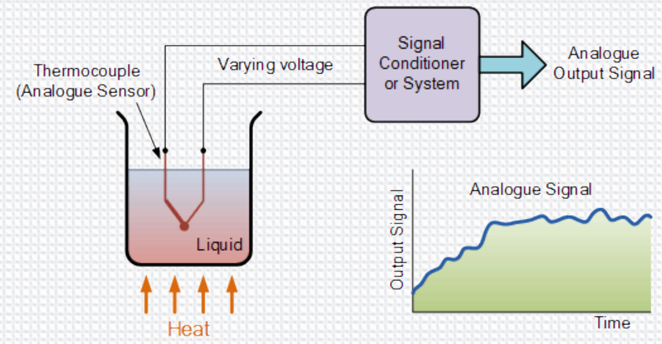
A *sensor* is a type of transducer; *sensors* may provide various types of output, but typically use electrical or optical signals.

Sensor - As the term suggests, it is a body which **reacts** to a physical, chemical or biological condition. It **senses**. It can be considered as a detector.

Check this site:
http://what-is-a-sensor.com/

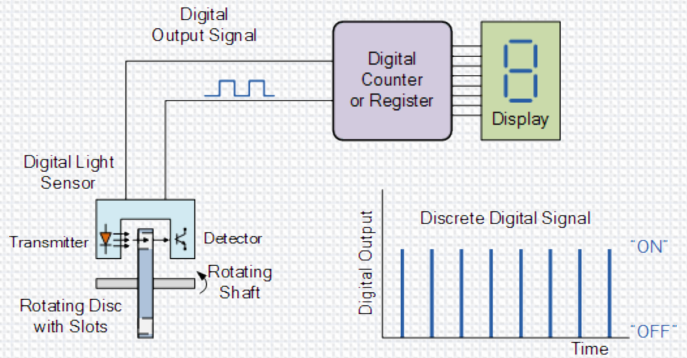
Analog and Digital Sensors

Analogue Sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured. Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc are all analogue quantities as they tend to be continuous in nature. For example, the temperature of a liquid can be measured using a thermometer or thermocouple which continuously responds to temperature changes as the liquid is heated up or cooled down.



Thermocouple used to produce an Analogue Signal

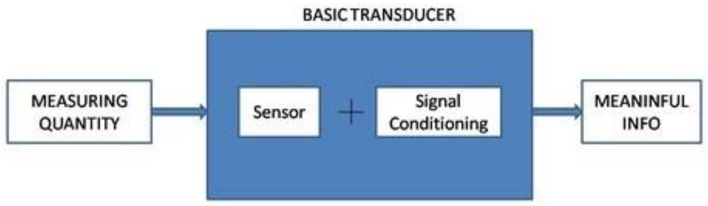
Digital Sensors produce a discrete digital output signals or voltages that are a digital representation of the quantity being measured. Digital sensors produce a Binary output signal in the form of a logic "1" or a logic "0", ("ON" or "OFF"). This means then that a digital signal only produces discrete (non-continuous) values which may be outputted as a single "bit", (serial transmission) or by combining the bits to produce a single "byte" output (parallel transmission).



Light Sensor used to produce an Digital Signal

What is a Transducer ?

A Transducer is more than a sensor. It consists of a sensor/actuator along with signal conditioning circuits.

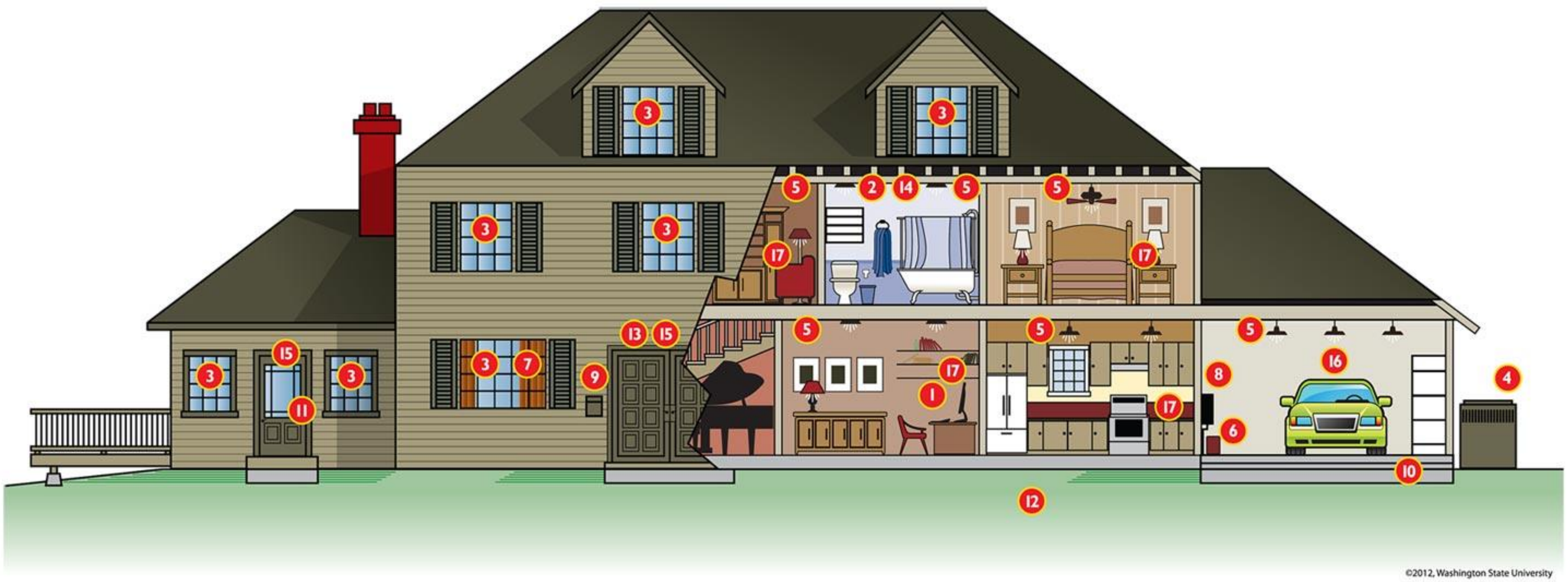


A signal conditioning circuit, by the name is a circuit which conditions the signal so that it is strong enough for further processing. A system might contain many stages before the signal finally reaches its destination to derive meaningful information.

Common sensors and actuators in engineering applications

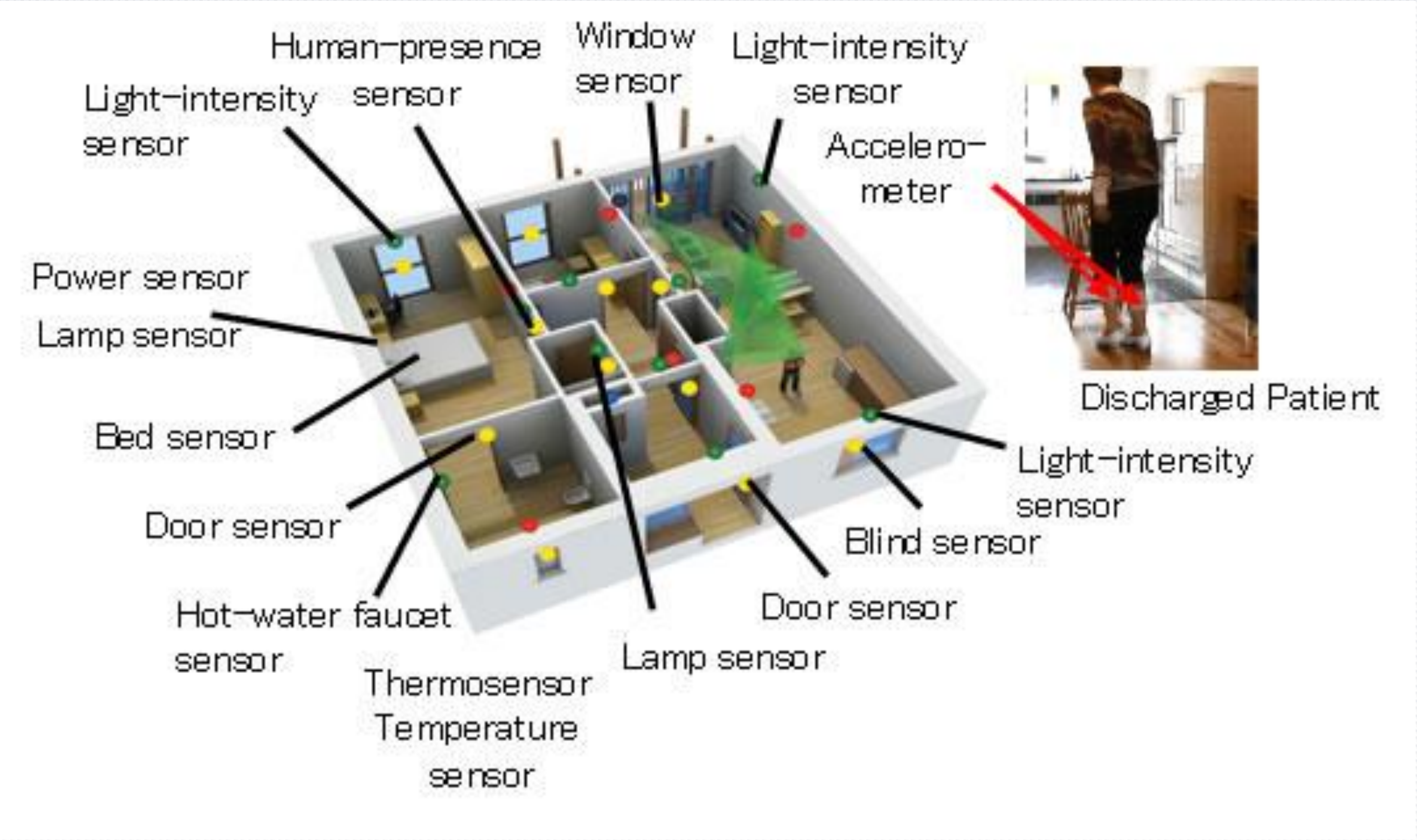
Process	Typical Sensors	Typical Actuators
Aircraft	Displacement, speed, acceleration, elevation, force, pressure, temperature, GPS	DC motors, stepper motors, relays, valve actuators, pumps, heat sources, jet engines
Automobile	Displacement, speed, force, pressure, temperature, fluid flow, fluid level, voltage, current	DC motors, stepper motors, valve actuators, pumps, heat sources
Home heating system	Temperature, pressure, fluid flow	Motors, pumps, heat sources
Milling machine	Displacement, speed, force, temperature, voltage, current	DC motors, AC motors
Robot	Optical image, displacement, speed, force, torque, voltage, current	DC motors, stepper motors, AC motors, hydraulic actuators
Wood Drying Kiln	Temperature, relative humidity, moisture content, air flow	AC motors, DC motors, pumps, heat sources

Sensors in a Home

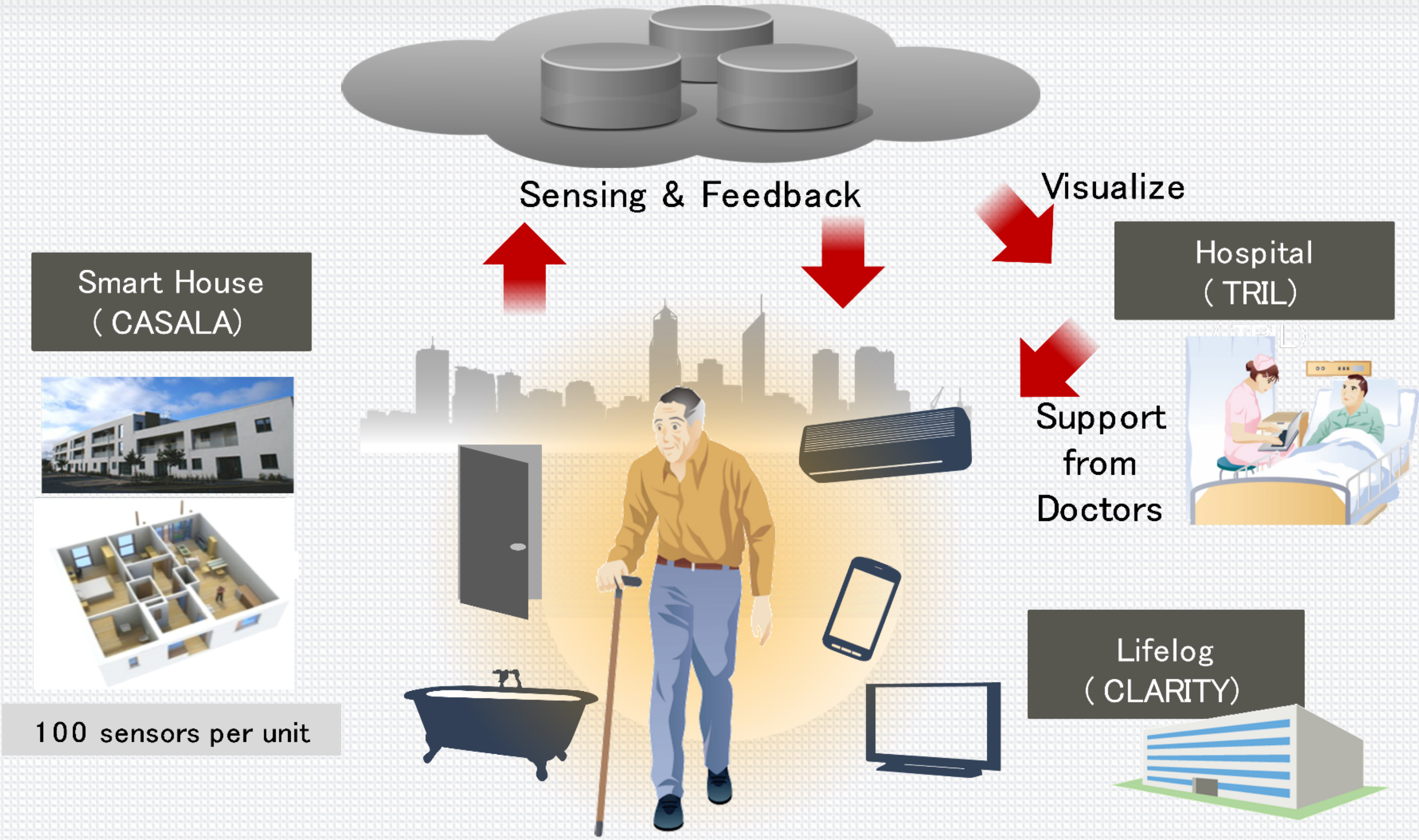


1 Ambient Intelligence Agent (AmI) Control
2 Light Sensor
3 Windows and Door Control
4 HVAC Control
5 Lighting Control
6 Automatic Pet Feeder
7 Motorized Drapes
8 Automatic Watering
9 Mailbox Sensor
10 Driveway Sensor
11 Security System
12 Lawn Moisture Sensor
13 Face Recognition Sensor
14 Motion Sensors
15 Door Sensors
16 AmI Interface with Car
17 AmI Interface with Smart Phone

Sensors in a Home Cont'd



- Joint project with hospital and smart house
- Monitoring and assisting independent living for senior citizens and patients
- Application of various sensing technologies on Fujitsu Laboratories' processing platform



Sensors for Body

Table 2: **Examples of commercial fiber-optic biomedical sensors by type**

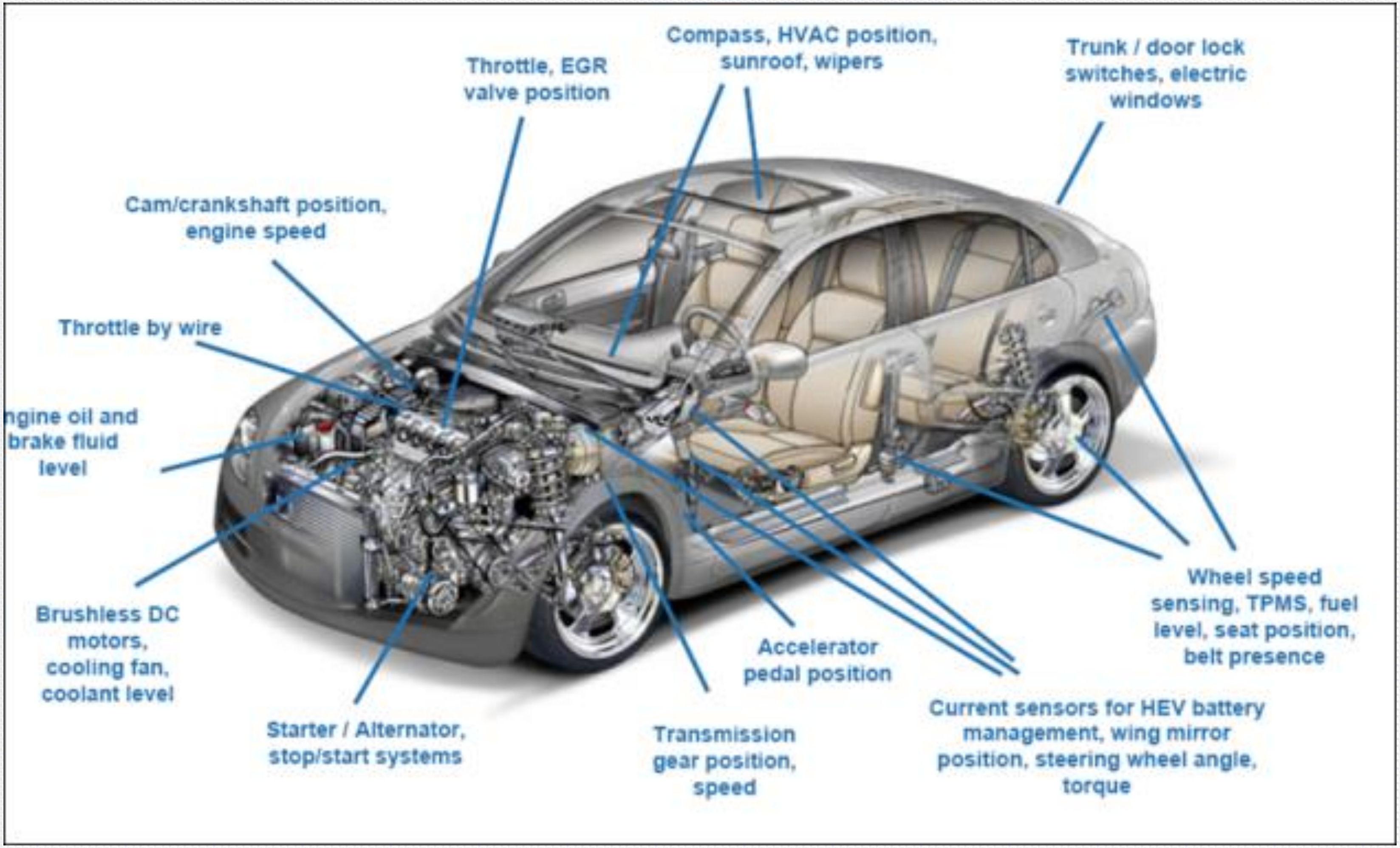
Parameter	Company
Temperature	Fiso, LumaSense, Neoptix, OpSens, RJC
Pressure	Fiso, Maquet, OpSens, Samba Sensors, RJC
Coronary imaging	InfraRedx
Oxygenation	ISS
Pulse oximeter	Nonin
Blood flowmeter	ADInstruments
Shape/position	Hansen Medical, Intuitive Surgical, Luna, Measurand, Technobis
Force	EndoSense
EKG/EEG	Srico

Optical fiber-enabled biomedical sensors by type

Physical	Chemical	Biological	Imaging
Body temperature	pH	Antigens	Endoscopy
Blood pressure	pO_2	Antibodies	Optical coherence tomography (OCT)
Blood flow	PCO_2	Electrolytes	Photodynamic therapy (PDT)
Heart rate	Oximetry (SaO_2, SvO_2)	Enzymes	
Force	Glucose	Inhibitors	
Position	Bile	Metabolites	
Respiration	Lipids	Proteins	
Shape sensing			

Source: A. Mendez, *Laser Focus World*, 47, 1, 91–94 (2011).

Sensors on an Automobile



Sensors on an Automobile Cont'd

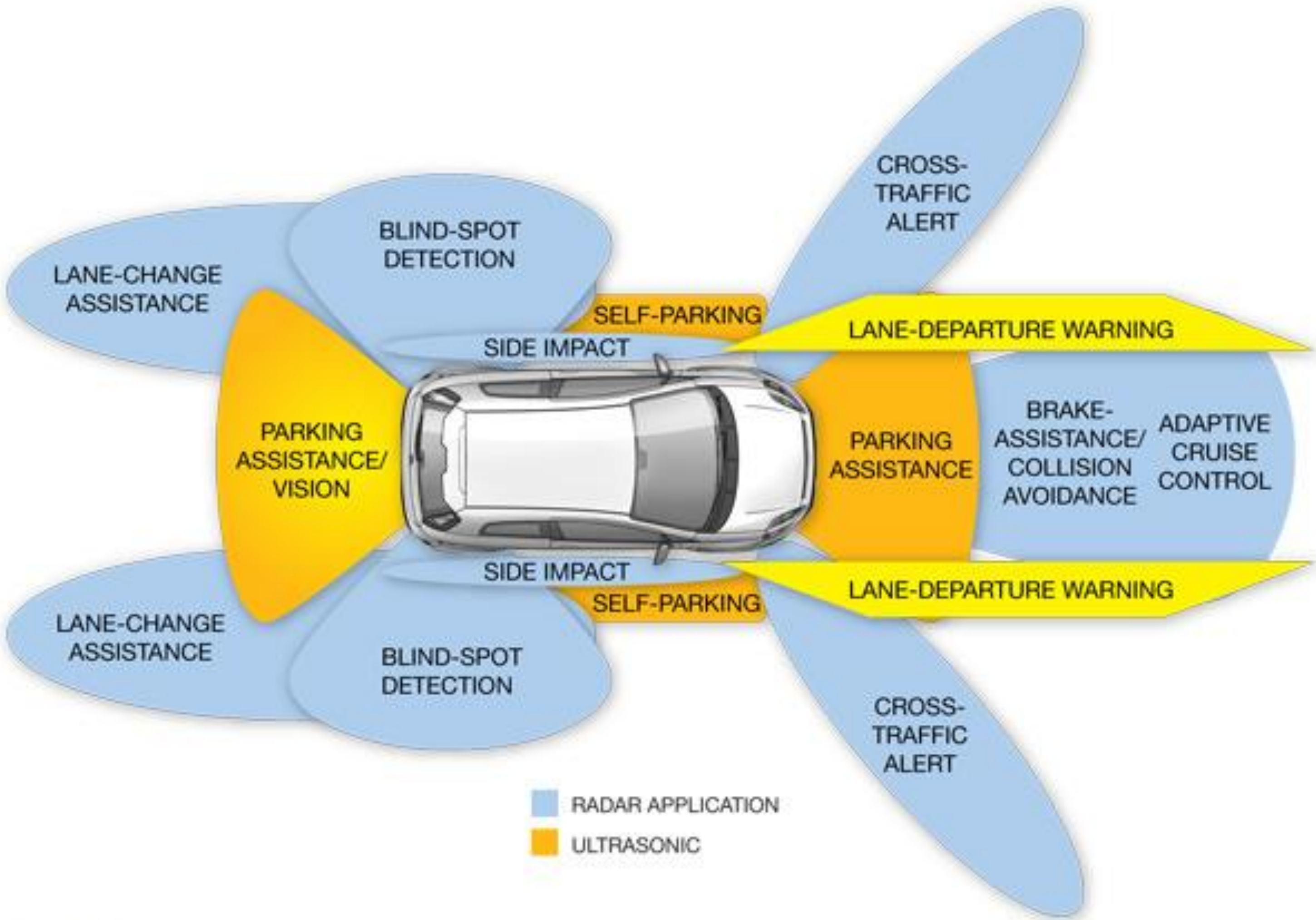
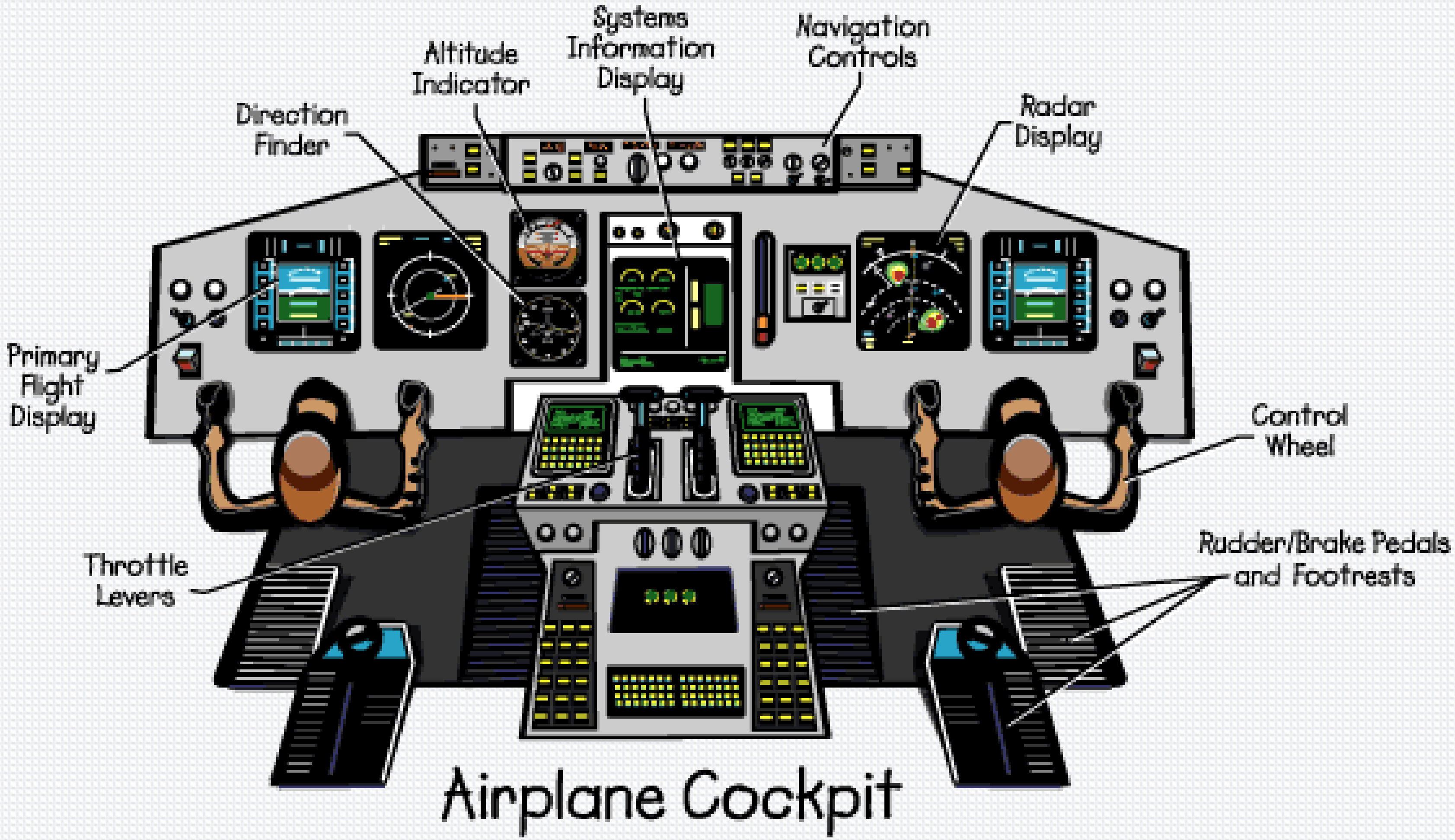


Figure 2 Several driver-assistance systems are currently using radar technology to provide blind-spot detection, parking assistance, collision avoidance, and other driver aids (courtesy Analog Devices).

Sensors in a Plane



Criteria to choose a Sensor

There are certain features which have to be considered when we choose a sensor. They are as given below:

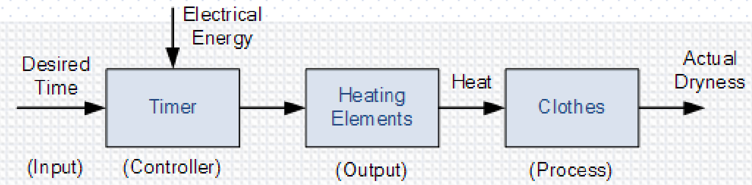
- Accuracy
- Environmental condition.
  - *usually has limits for temperature/ humidity*
- Range
  - *Measurement limit of sensor*
- Calibration
  - *Essential for most of the measuring devices as the readings changes with time*
- Resolution
  - *Smallest increment detected by the sensor*
- Cost
- Repeatability
  - *The reading that varies is repeatedly measured under the same environment*

GOOD control system

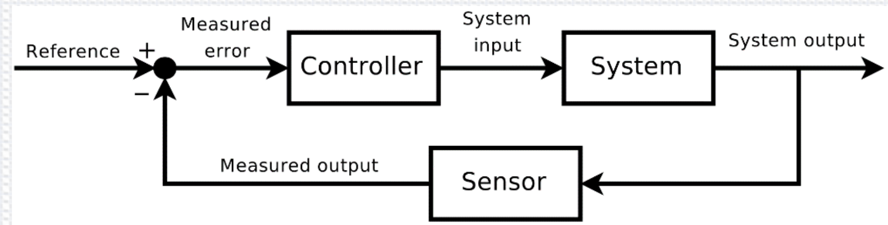
- Sufficiently stable response
- Sufficiently fast response
- Low sensitivity to noise and other variations
- High sensitivity to control inputs
- Low error
- Reduced coupling among system variables

Control system types

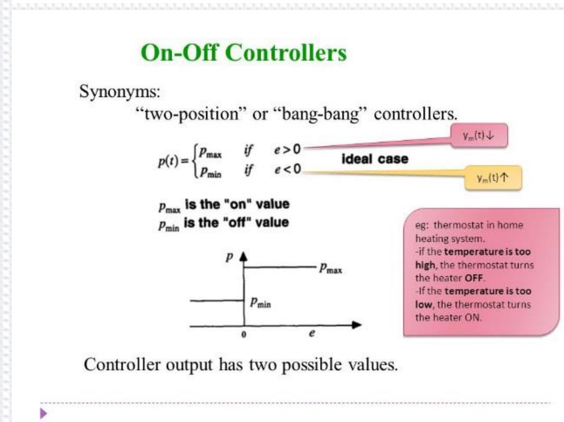
- Open loop control

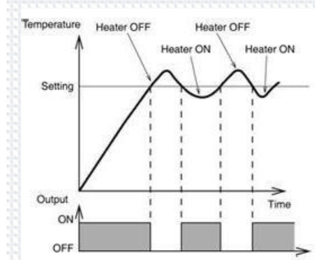


- Feedback control

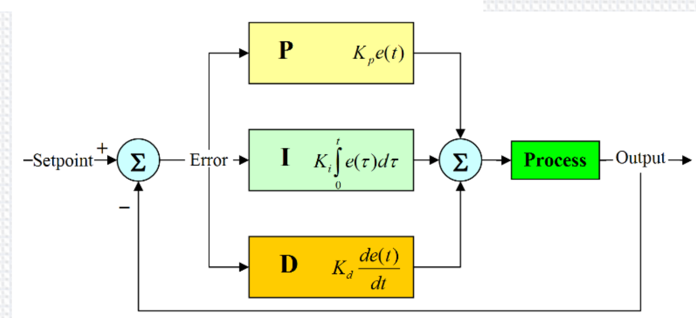


  - On/Off (bang-bang)



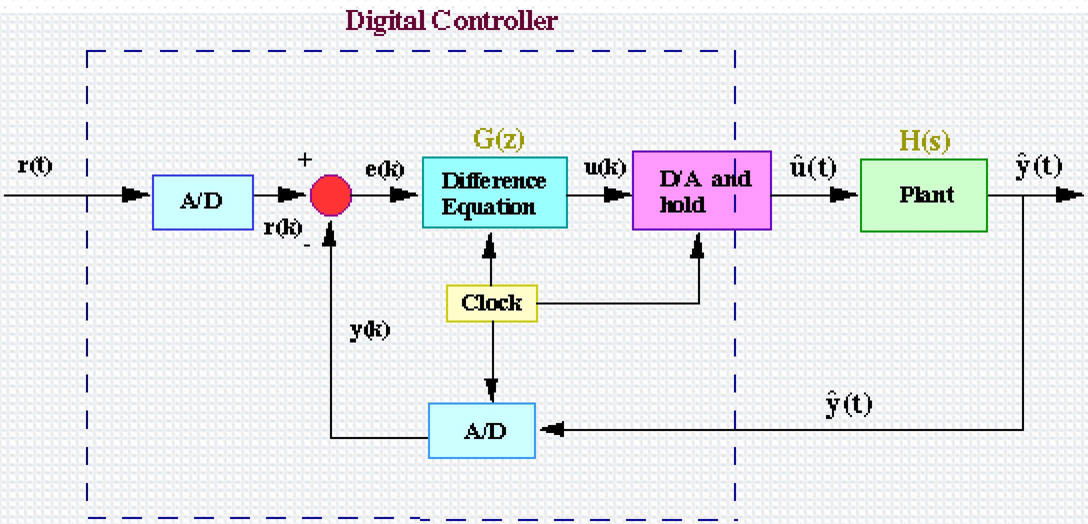


  - Proportional
  - PID : A proportional–integral–derivative **controller** (**PID controller**) is a **control** loop feedback mechanism (**controller**) commonly used in industrial **control** systems. A **PID controller** continuously calculates an error value as the difference between a measured process variable and a desired set point.

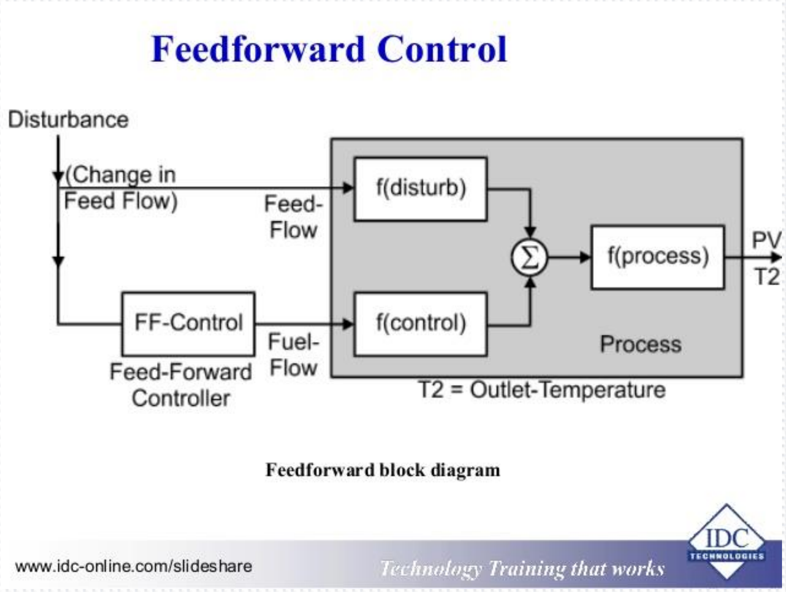


Control system types .. Cont'd

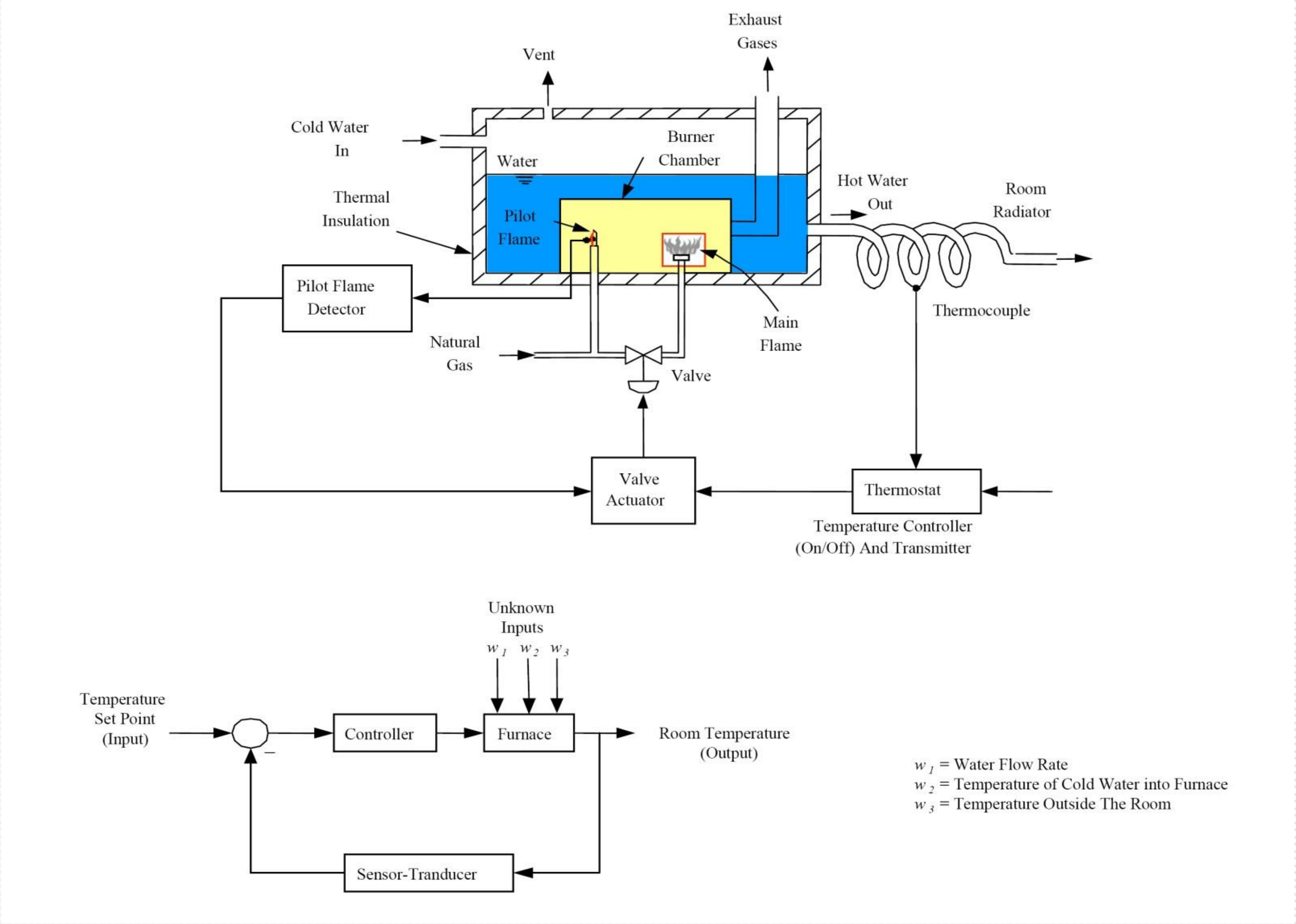
- Digital control



- Feed--forward control

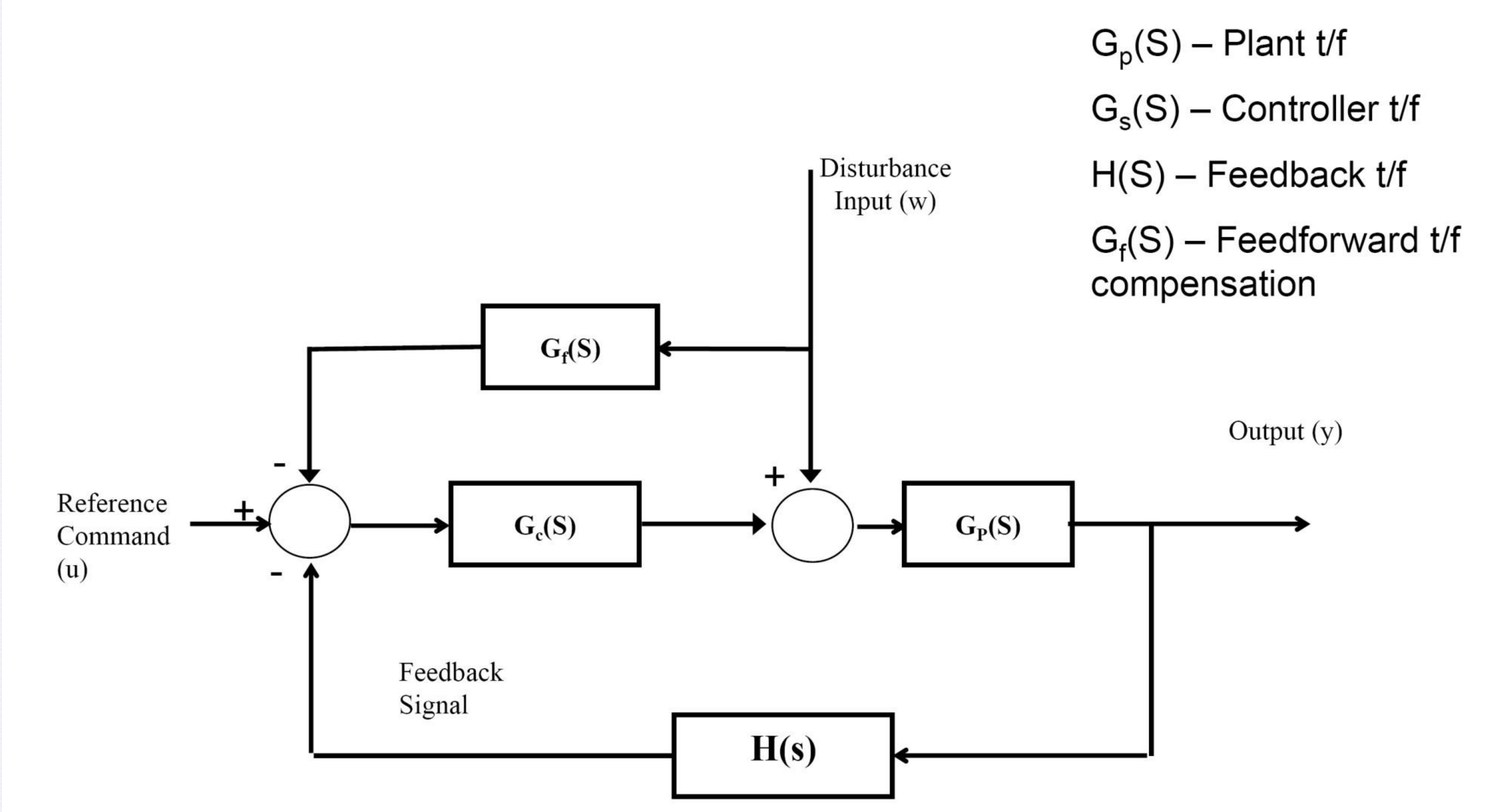


Feed--forward system example



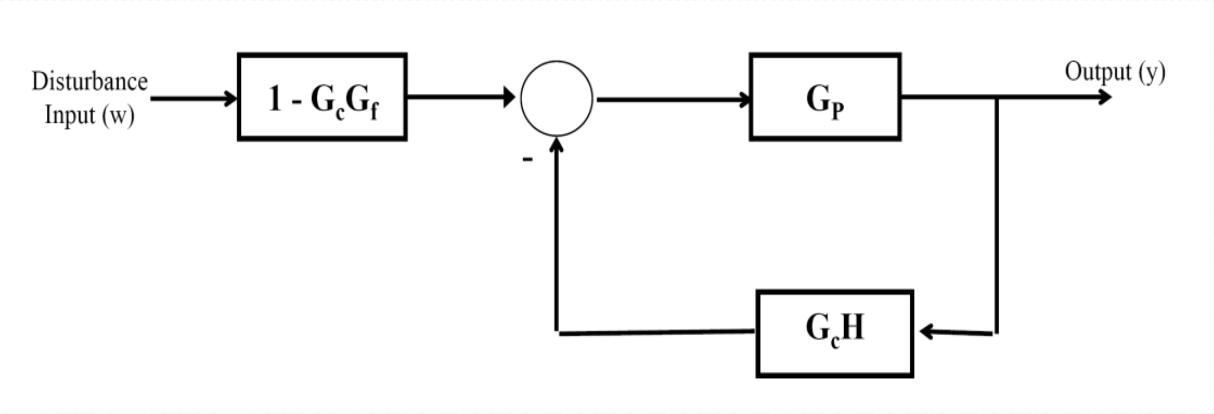
Example 1:

Consider the system shown below:



Example 1 (Cont'd):

- Obtain the transfer function relationship between the output y and the driving input u in the absence of disturbance input w.
- Show that in the absence of u, the block diagram can be drawn as below.
- Obtain the transfer function relationship between y and w in this case.



- From previous sections, write an expression for y in terms of u and w.
- Show that the effect of disturbance is fully compensated if the feed--forward compensator is given by

$$G_f(S) = \frac{1}{G_c(S)}$$

Instruments rating parameters

Sensitivity	Magnitude of output signal corresponding to unit input
Resolution	The *smallest change in a signal that can be detected* by the sensor
Dynamic range	Ratio of the largest to the smallest possible values of (in dB)
Repeatability	The sensor's ability to give the same output under repeated identical conditions
Linearity	Maximum error which the device deviates from its expected linear output as a function of input
Drift	Deviation of the device from its pre-calibrated values (zero, full scale) due to aging or operating condition change
Response time	Determines the speed of operation of the device
Bandwidth	Determines maximum speed or frequency at which the device can be operated

Example 2: Confusion made complicated

Consider an instrument with a 12 bit Analog--to-- Digital converter (ADC).

Estimate the dynamic range of the instrument.

Hint: Find the resolution and minimum value then use the following formula for the dynamic range

$$Dynamic\ Range = 20\log_{10}\frac{Maximum\ (Highest) Value\ (Range\ of\ Operation)}{Minimum\ Detectable\ Value\ (Resolution)}$$

Calculations: Need more information about the operating Range first.

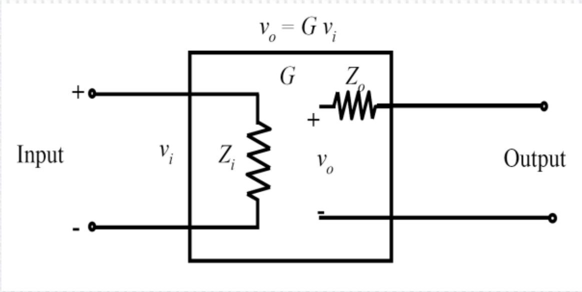
- The dynamic range is the ratio of the maximum voltage to the minimum voltage that the ADC can convert. The maximum voltage is 5 volts. Since it is a 12 bit converter, it has a resolution of 2^{12} - 1 or 4095. Thus the minimum voltage, for which the ADC would have only the *least significant bit (or Min Detectable Value), is 1.22 millivolts*. So the dynamic range of your ADC is 5/.00122 = 4095 = 72.2 dB

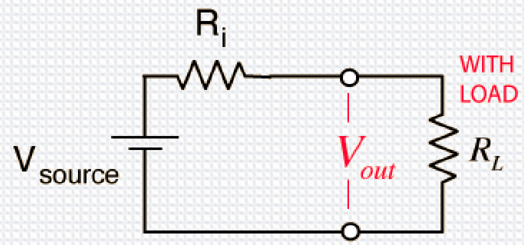
- In general, the dynamic range is only a function of the number of bits, not the maximum input voltage. We could have calculated DR as 6.02N = 6.02*12 = 72.24 dB

- $Dynamic\ Range = 20\log_{10}\frac{2^{12}-1-0}{2^{0}-0}$ = 72.2 dB

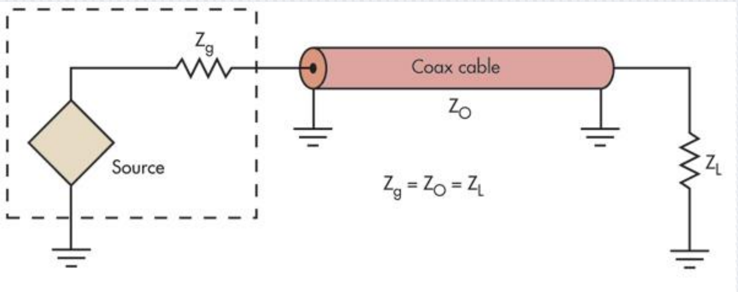
Impedance matching

- Definitions

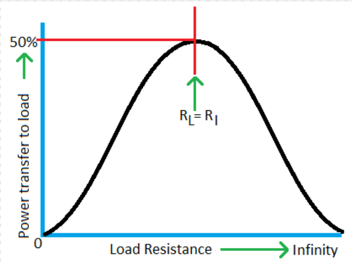




OUTPUT VOLTAGE UNDER LOAD $V_{out} = V_{source}\dfrac{R_L}{(R_i + R_L)}$



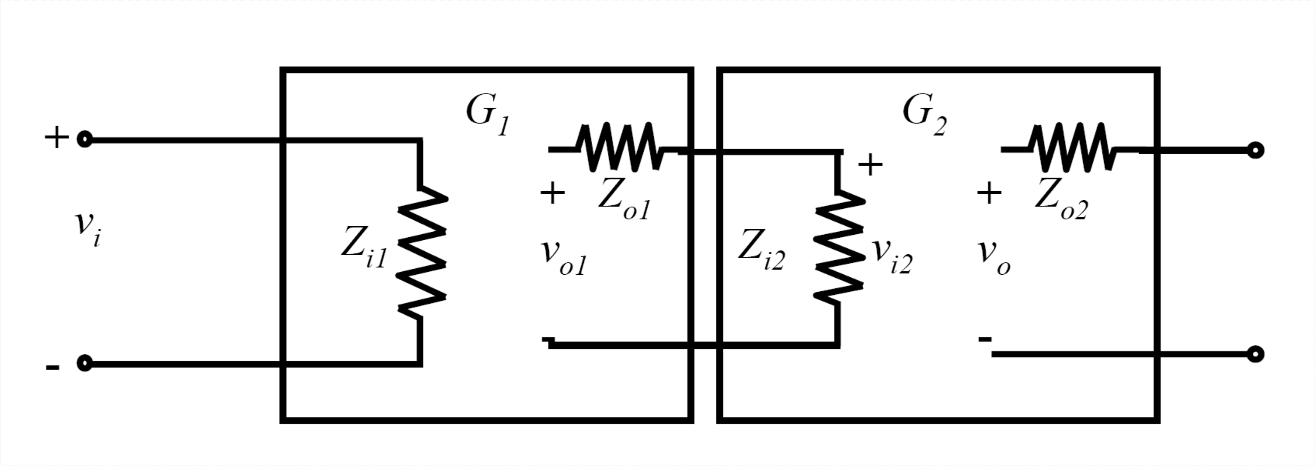
- Output impedance

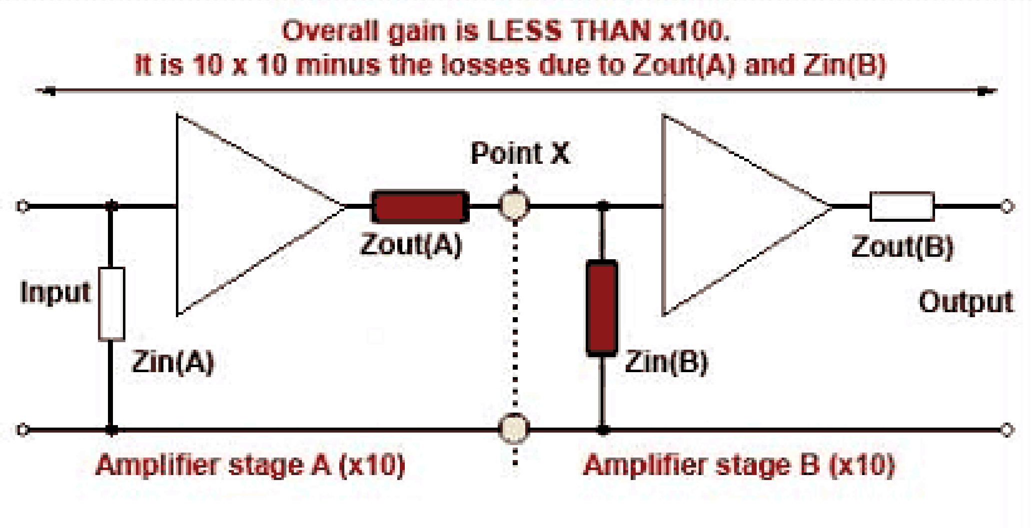


- Input impedance

Impedance matching

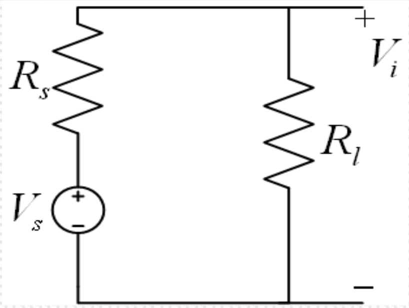
- Cascaded devices

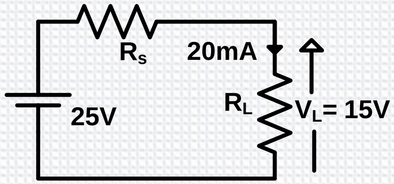




Impedance matching

- Loading effect





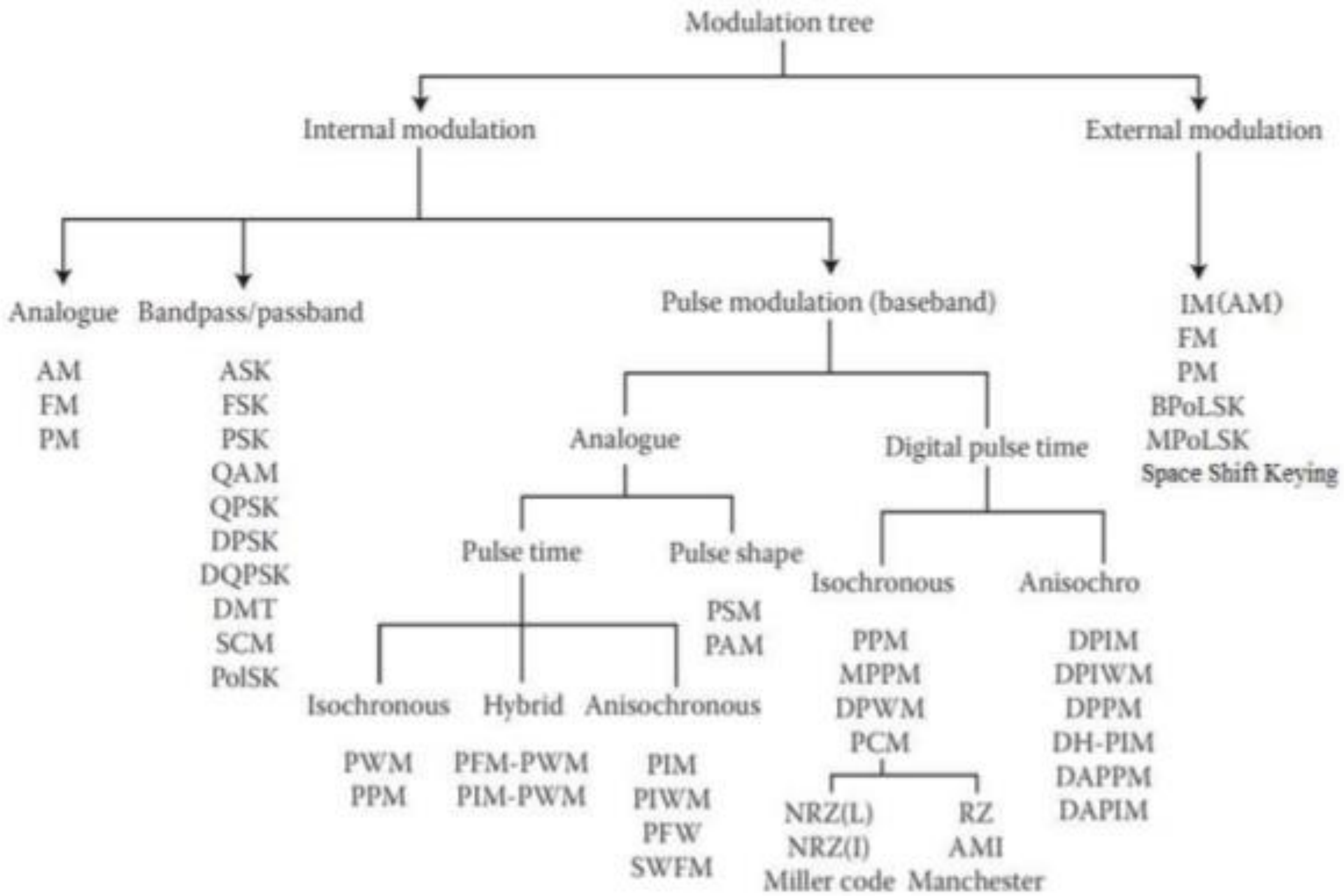
Modulation

Use *Modulating Signal* to change a property of a *Carrier Signal*.

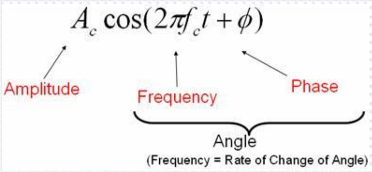
- Amplitude Modulation
- Frequency Modulation
- Pulse Width Modulation
- Etc.

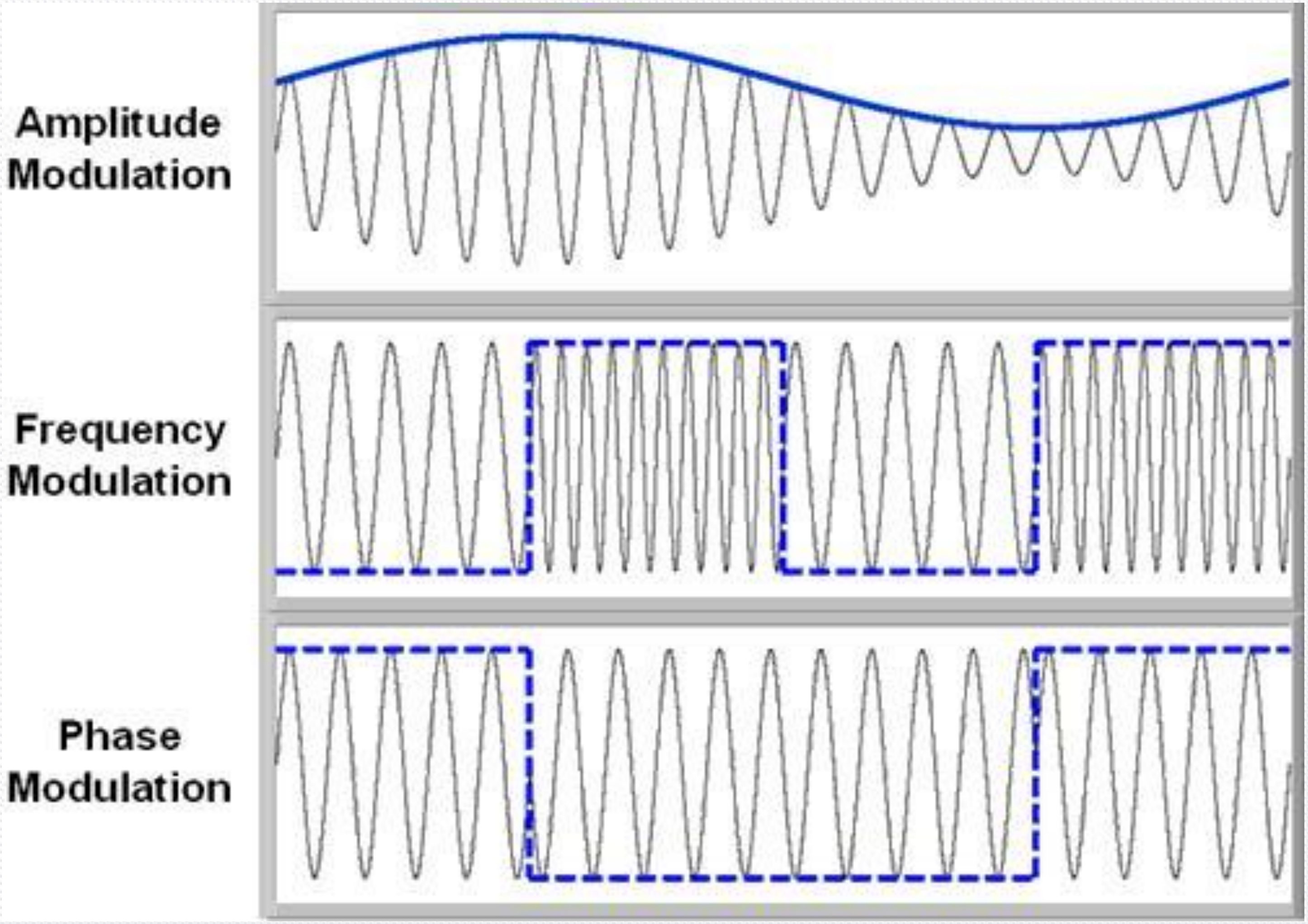
- De-Modulation

MODULATION TECHNIQUES

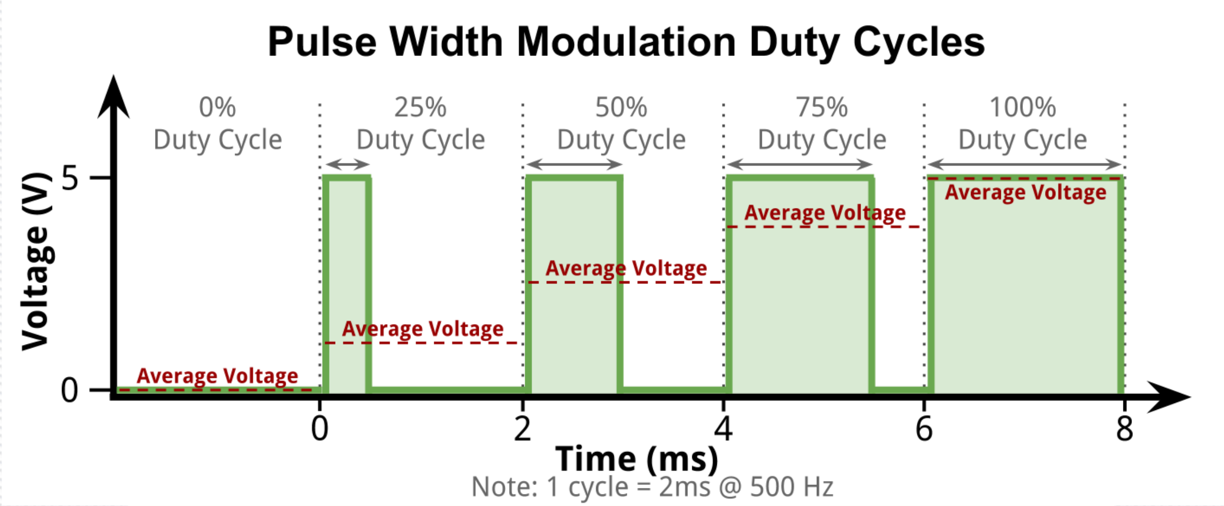


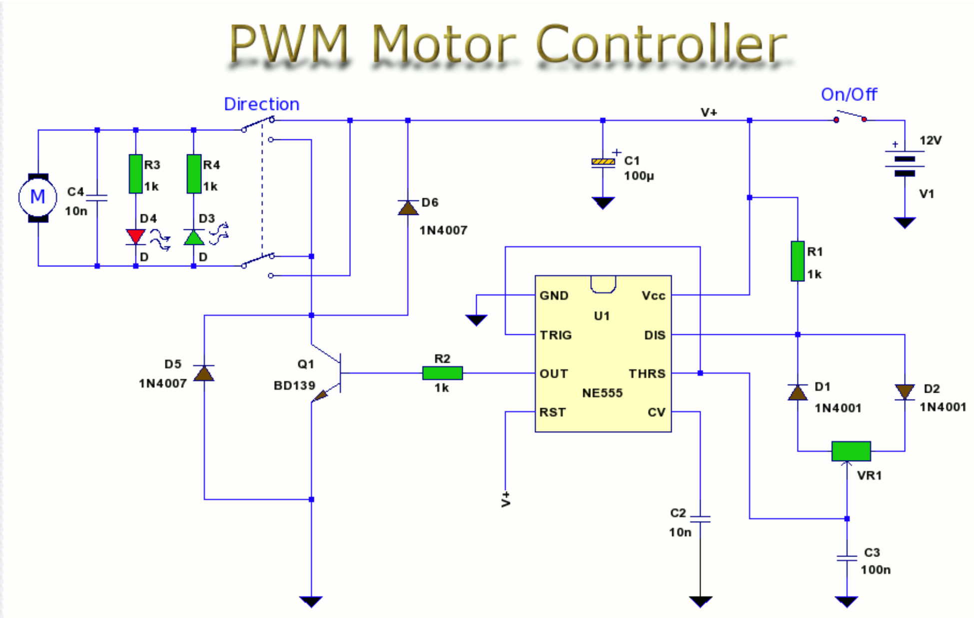
Modulation Schemes AM FM & PM





Pulse Width Modulation





De-Modulation