Automotive Sensors

Basics of Sensor

Automotive Intelligence Lab.

Contents

- Definition of automotive sensor
- Measurement methods
- Sensor performance and characteristics

Definition of automotive sensor

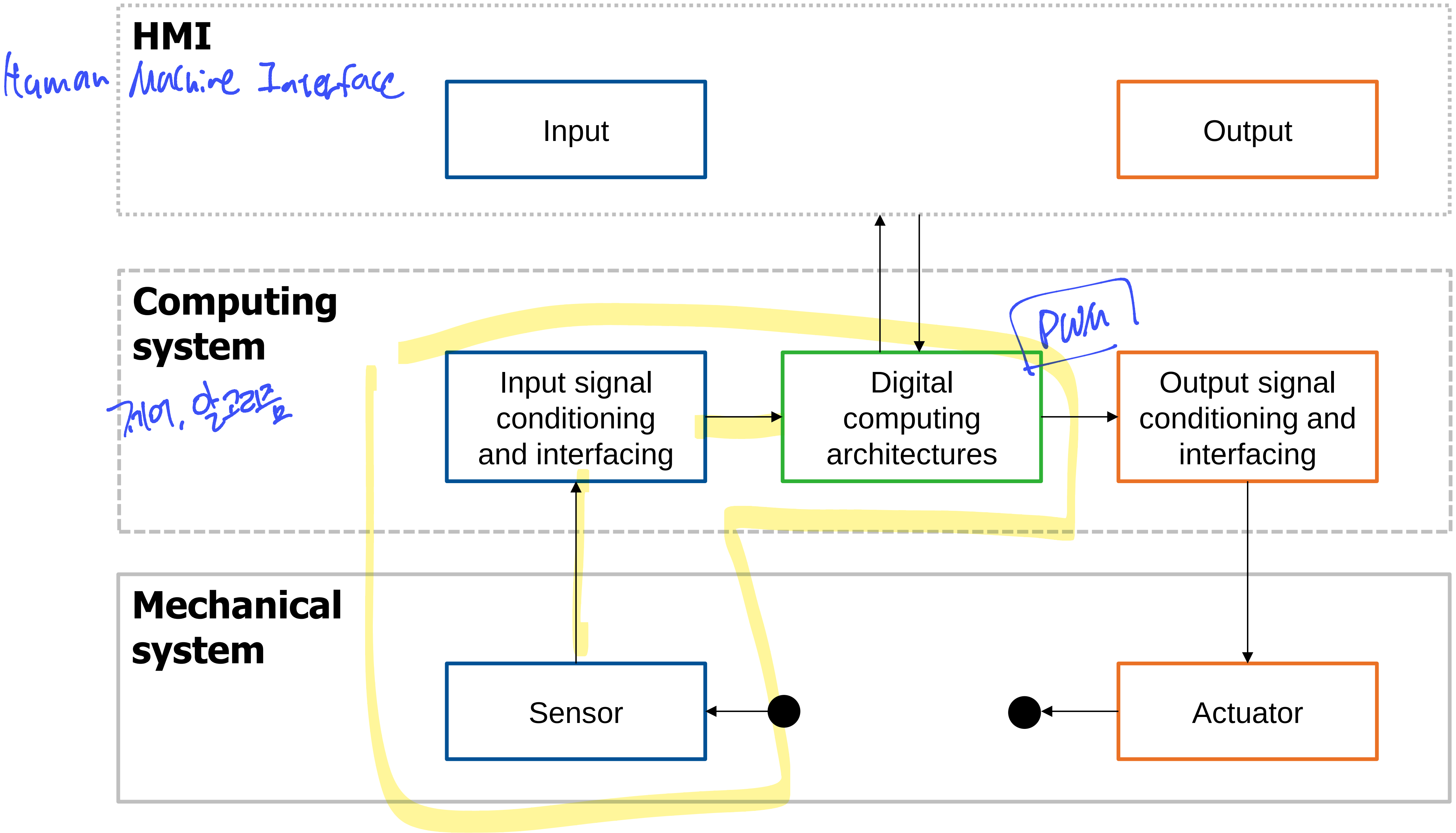
What is Sensor?

- **A device that detects $\boxed{\text{Physical quantities}}$ from a measurement objects and converts them into $\boxed{\text{electrical signal}}$**

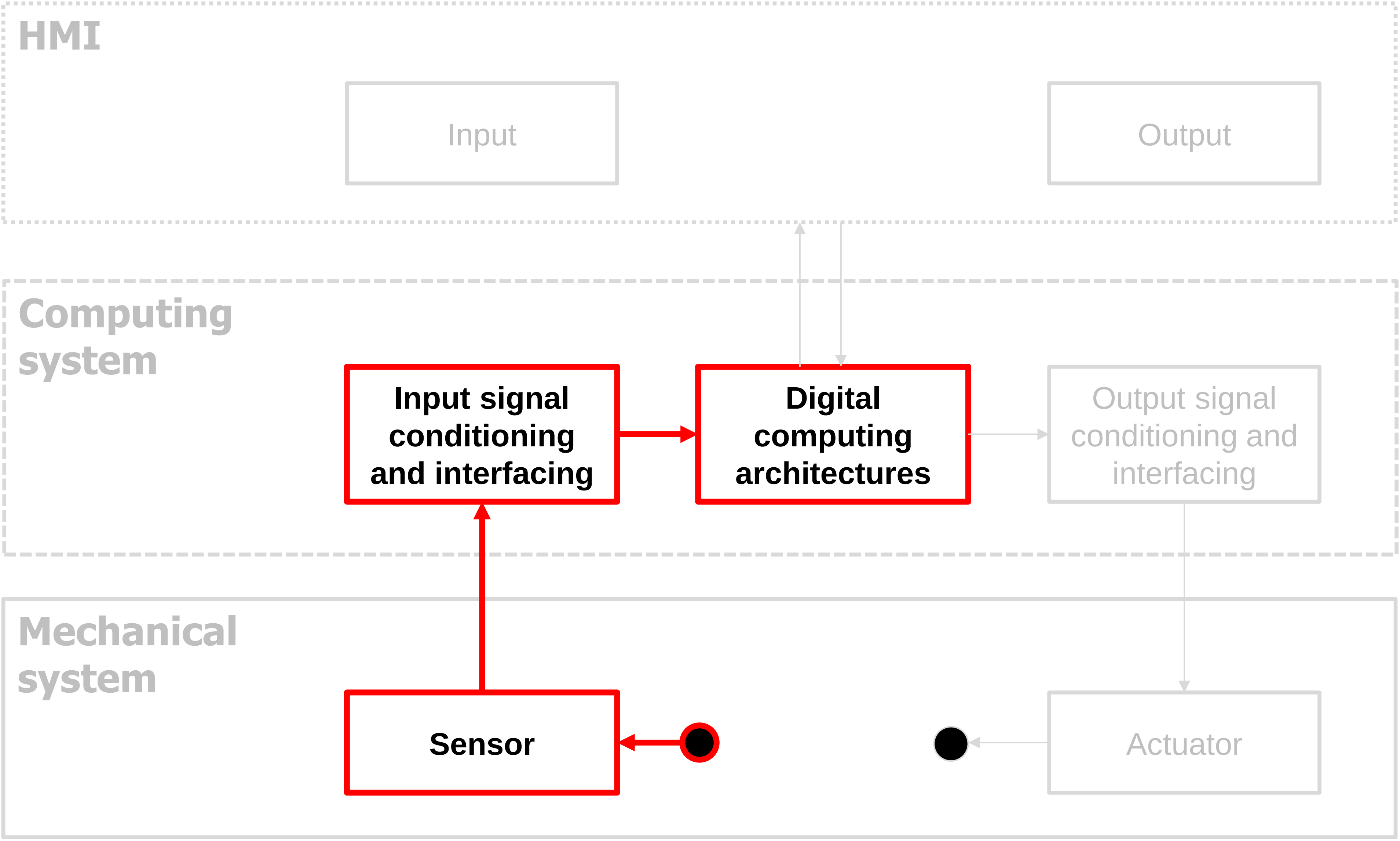
- **Purpose of sensor**
  - Replace human sensory functions with other controllable signals.
  - In addition, sensors allow us to detect more than just our sense organs.

Five senses	Sight	Hearing	Smell	Taste	Touch
As behavior	See the thing Feel the light	Listen the sound Feel the shaking Take the balance	Smell the thing	Feel the taste	By touching, feel the heat, force, or texture
Sensory organ as human	Eye	Ear	Nose	Tongue	Skin
Typical sensors as machinery	Image sensor Light intensity sensor Camera..	Acoustic sensor Ultrasonic sensor 응급차 감지 등	Gas component sensor	Liquid component sensor	Pressure sensor Temperature sensor Humidity sensor Displacement sensor

Structure of Automotive Systems



Automotive Sensors



Automotive Electronic Sensors

- **Measurement device for monitoring and control of mechatronics system.**
  - Electronics sensor: changes “real world” parameter into “electrical signal”.
  - Signal conditioning and interfacing converts electrical signal into analog or digital values.

Physical values

- Position, velocity, acceleration
- force, torque, strain pressure
- temperature, flow rate, humidity

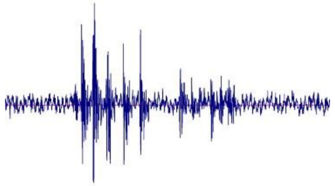
…

Sensor

Electrical signal

- Resistance
- Capacitance
- Inductance
- Magnetic
- Piezoelectric
- Optical

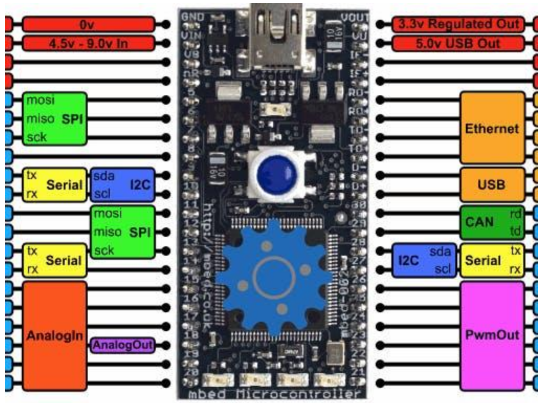
…



Input signal conditioning and interfacing

Digital computing architectures

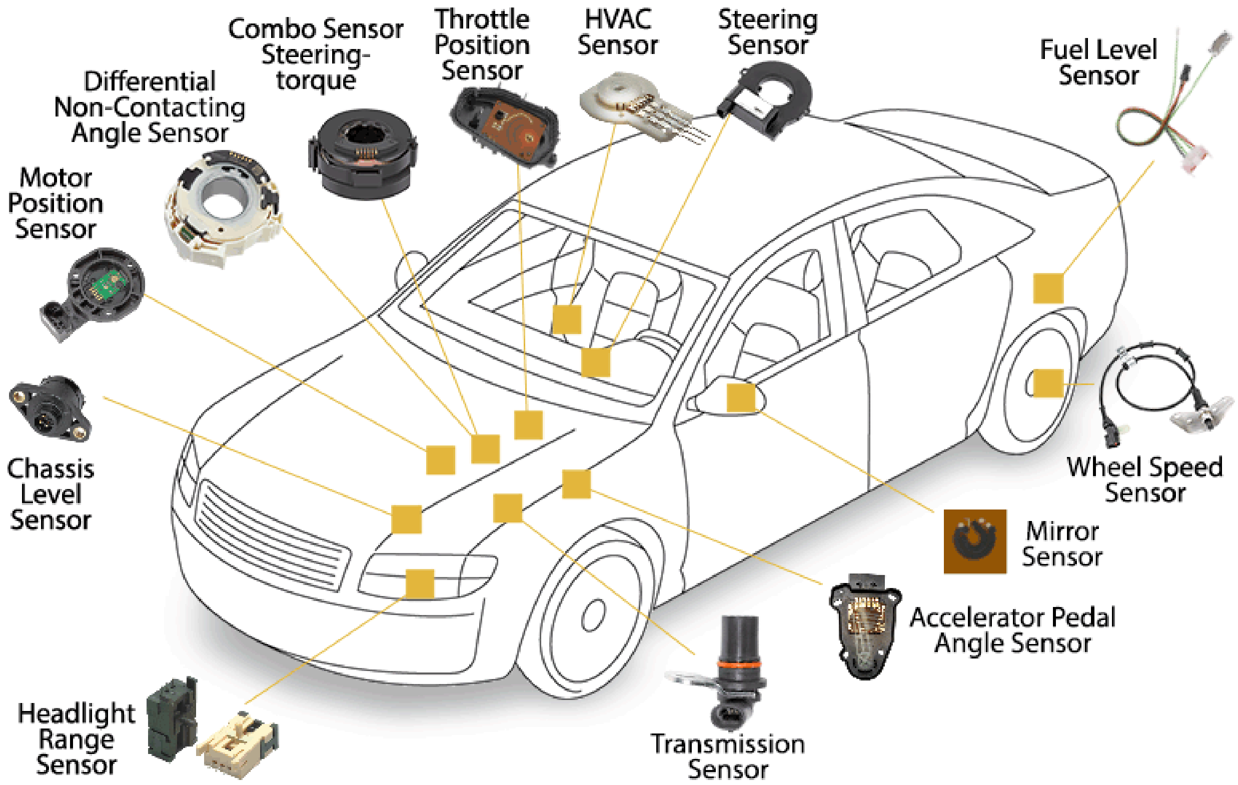
- Analog (voltage) ADC
- Digital



Automotive Sensors – Past

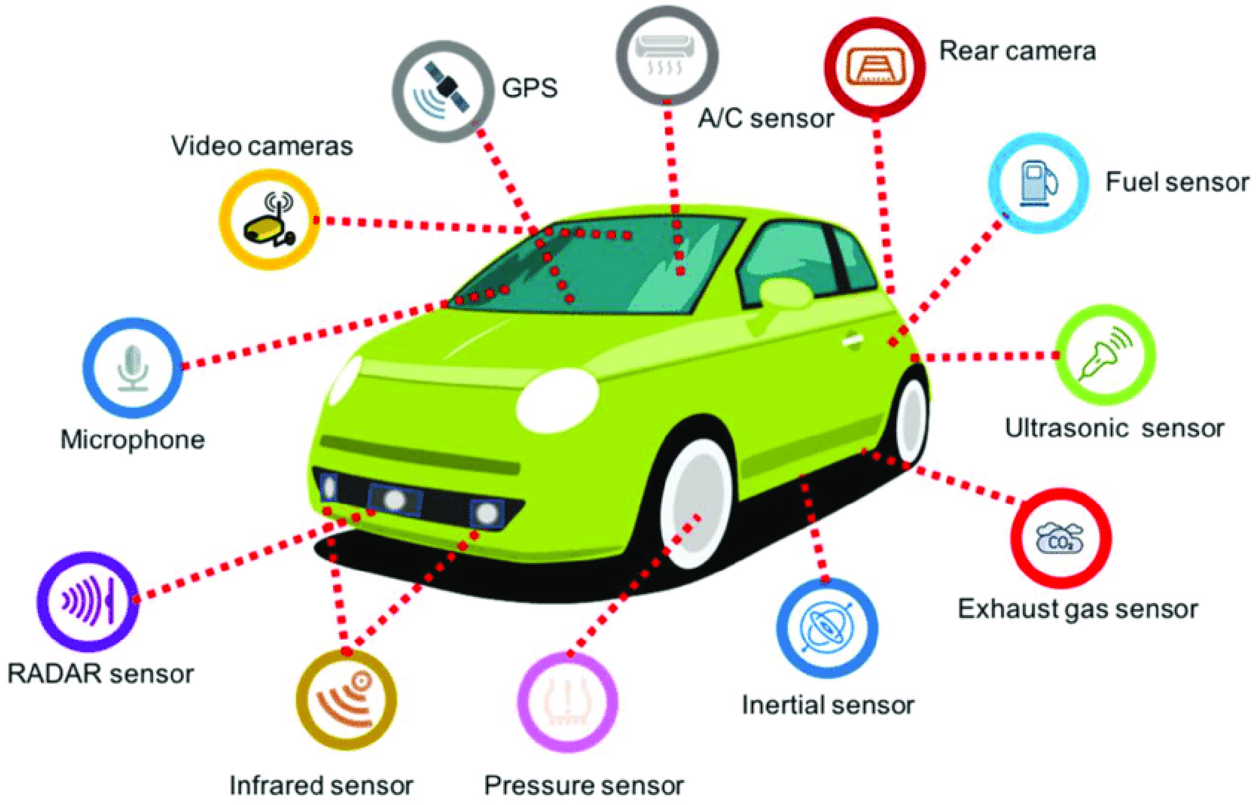
- **Use of sensors is limited.**
  - Used to detect and monitor the status of the vehicle.
  - Mainly used to measure pressure, speed, engine temperature, etc.
  - Most parts consisted only of mechanical parts and wires.

ADAS



Automotive Sensors – Present & Future

- **Sensors are used in various area.**
  - Applied for driving safety, fuel efficiency, vehicle condition monitoring, etc.
  - Increasing use of electronic controllers.
  - Has more advanced data processing and communication capabilities.



Measurement methods

어떤식으로 측정?

Passive vs. Active

- Passive Sensor

  ex) 광센서 (외부광원)
  └ 카메라

  - Outputs electrical signals directly in response to external stimuli.
  - **Pros:** Does not require any additional energy source & **only a receiver needed.**
  - **Cons: Being vulnerable to noise.** – 환경의 영향 ↑

- Active Sensor

  ex) 초음파센서, LiDAR, Radar..

  - Sends a random signal and detects it by analyzing the reflected signal.
  - **Pros: High measurement accuracy.**
  - **Cons: Requiring additional power and circuit.**

Passive Sensing

Active Sensing

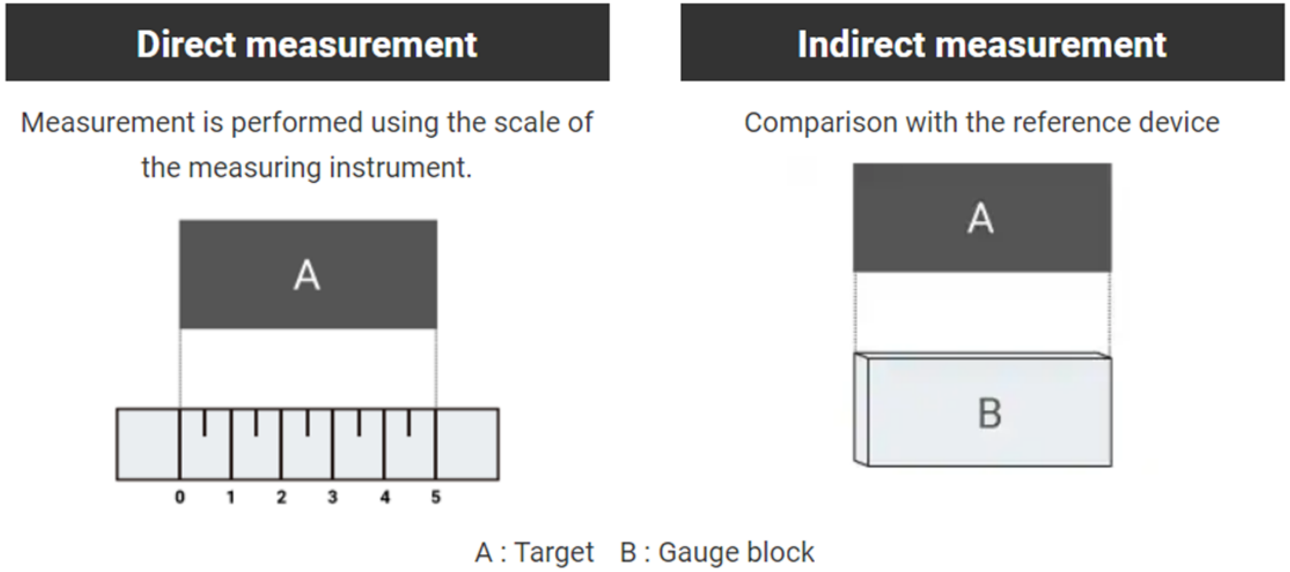
Sensor Fusion

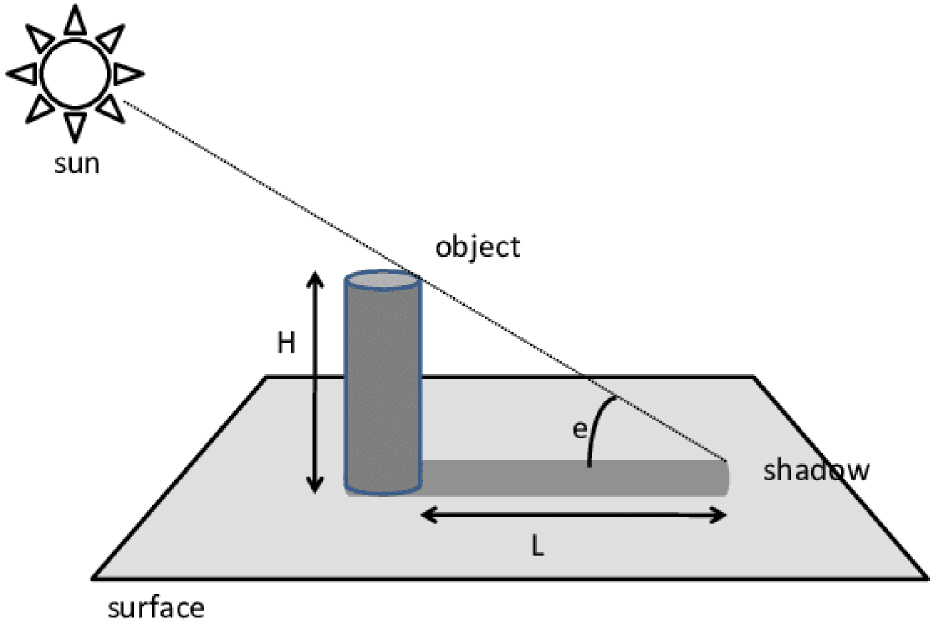
A+B

Direct vs. Indirect

- Direct measurement
  - ▶ Compare the same kind of reference quantity with the quantity you want to measure.

- Indirect measurement.
  - ▶ Determining the quantity of a target by measuring another quantity that has a certain relationship with the quantity to be measured.





Absolute vs. Relative

■ Absolute measurement

▶ To measure the measurement that is an absolute value itself.

■ Relative measurement

▶ To measure the measurement that is the relative value from reference quantity.

Absolute measurement

Relative measurement

Example of Absolute and Relative Measurement

- **Adaptive Cruise Control (ACC)**
  - Maintain the safe **relative** distance for the front vehicle.
  - Time gap control
    - Time gap = **Relative** distance / **Absolute** vehicle speed

time gap

V (absolute V)

Relative distance

Deflection vs. Null

- Deflection method
  - A method of measurement that compares with the scale.

- Null method
  - A method of measurement that get the value when it is balanced compared to the reference value by adjusting the reference size.

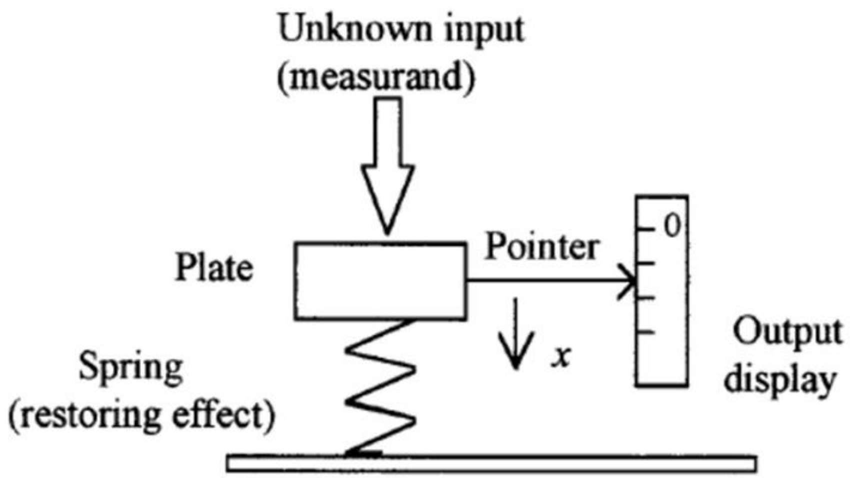


Figure: A deflection instrument (spring scale in this case) requires input from only one source

Deflection method

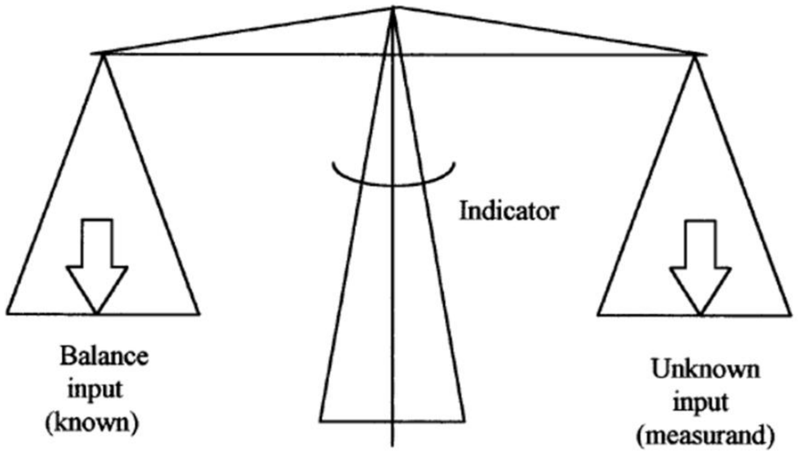


Figure: An equal arm balance scale (The measurand and the known quantities balanced one another in a null instrument)

Null method

Sensor performance and characteristics

Accuracy, Precision, Resolution

Accuracy and precision

- **Accuracy** is used to describe the closeness of a measurement to the true value.
- **Precision** is the degree to which repeated measurements under unchanged conditions show the same results.

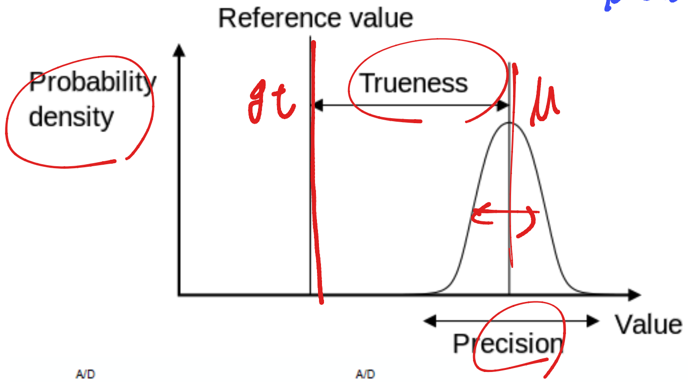
Resolution 해상도

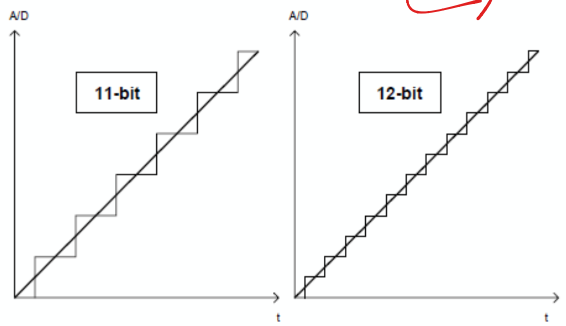
- **Resolution** refers to the smallest change in the measured variable that can be detected by the sensor.

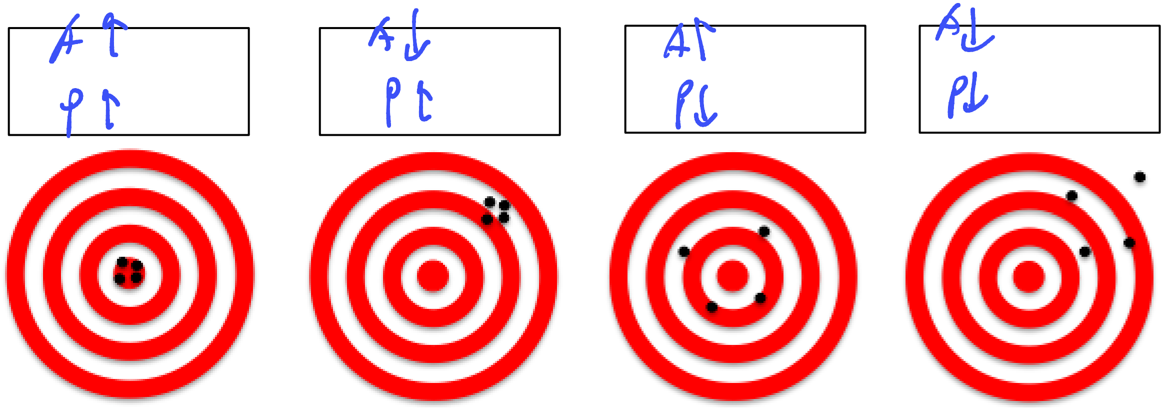
Gaussian distribution (평균, 분산 ..)

gt
ground truth

SLAM



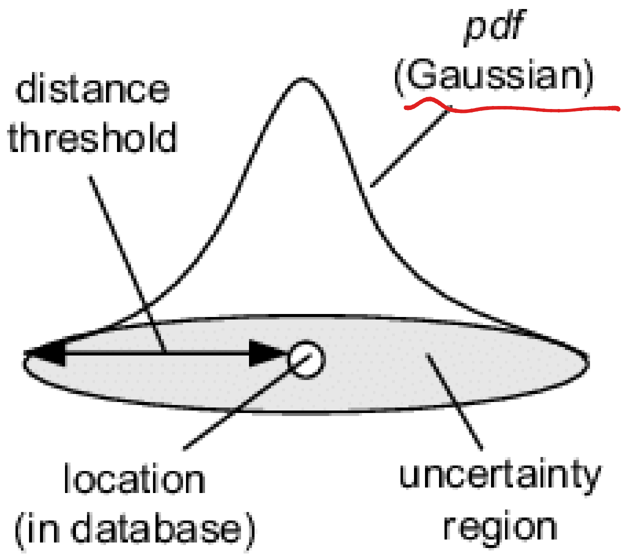




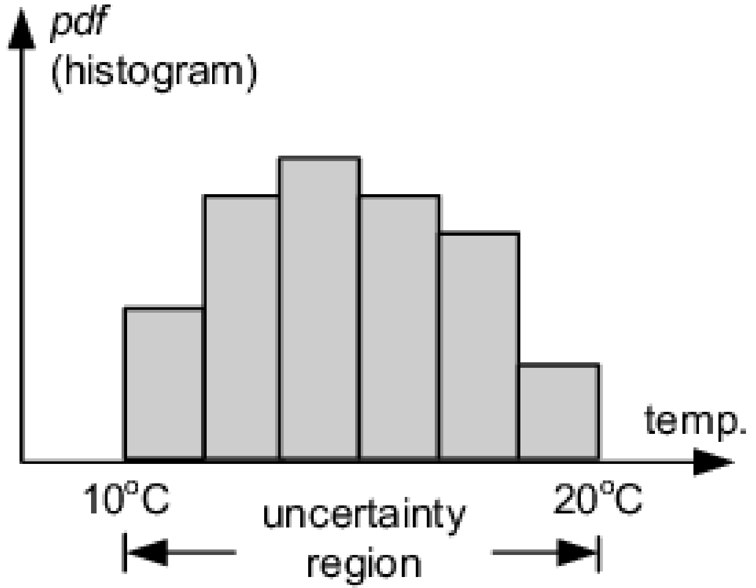
Reference: https://en.wikipedia.org/wiki/Accuracy_and_precision

Uncertainty

- The degree of difference between the sensor measurement and the actual value.
- The greater the difference between the measured value and the true value, the greater the uncertainty.



(a)

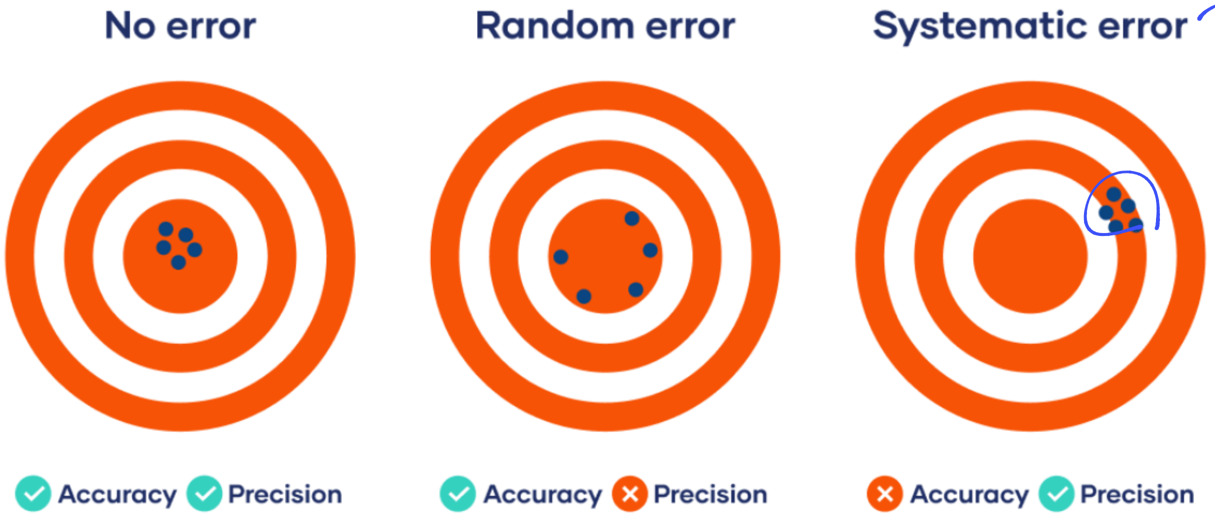


(b)

Elements of Uncertainty

- Random error — Low pass filter .. 노이즈제거에 편함
  gt 관계없음.
  - Errors due to random fluctuations.
  - Measurements vary erratically over time.
  - Statistical averaging of multiple measurements reduces the effect of random error.
- Systematic error — 해결 어려움. — gt를 정확히 모름. — Reference Sensor (비쌈)
  - Corrects errors caused by sensor manufacturing process, installation location, etc.
  - May appear consistently under certain conditions, requiring calibration or compensation.

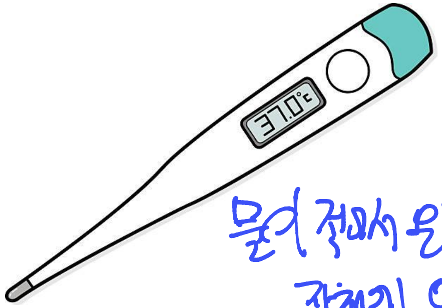
IMU 쓰기어려움.



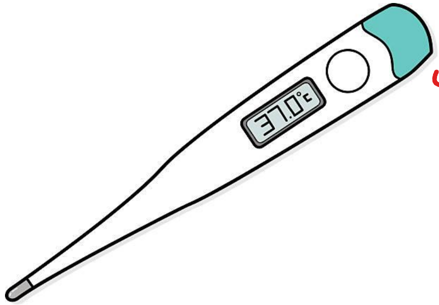
Loading Error

측정기가 측정값에 영향을 주는 정도

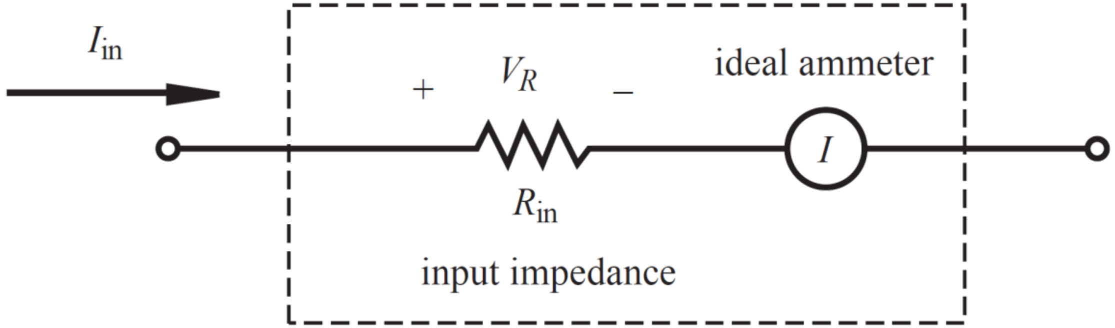
- Mechanical loading error



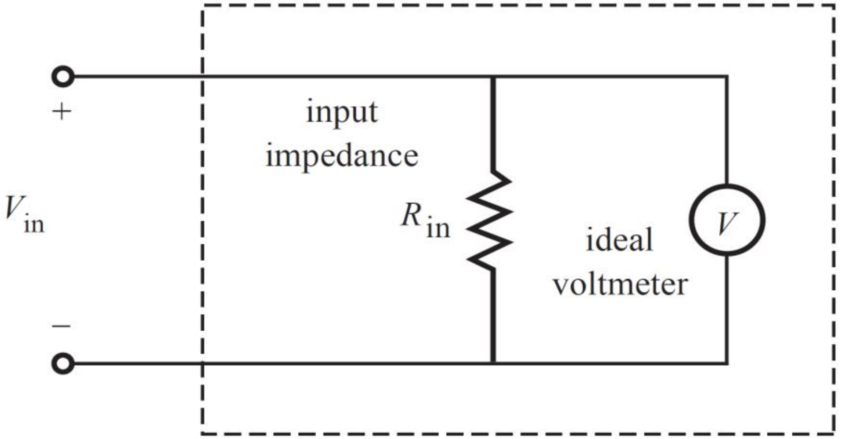
물이 적어서 온도계
자체에 영향 받을수있음



- Electrical loading error



Real ammeter with input impedance.



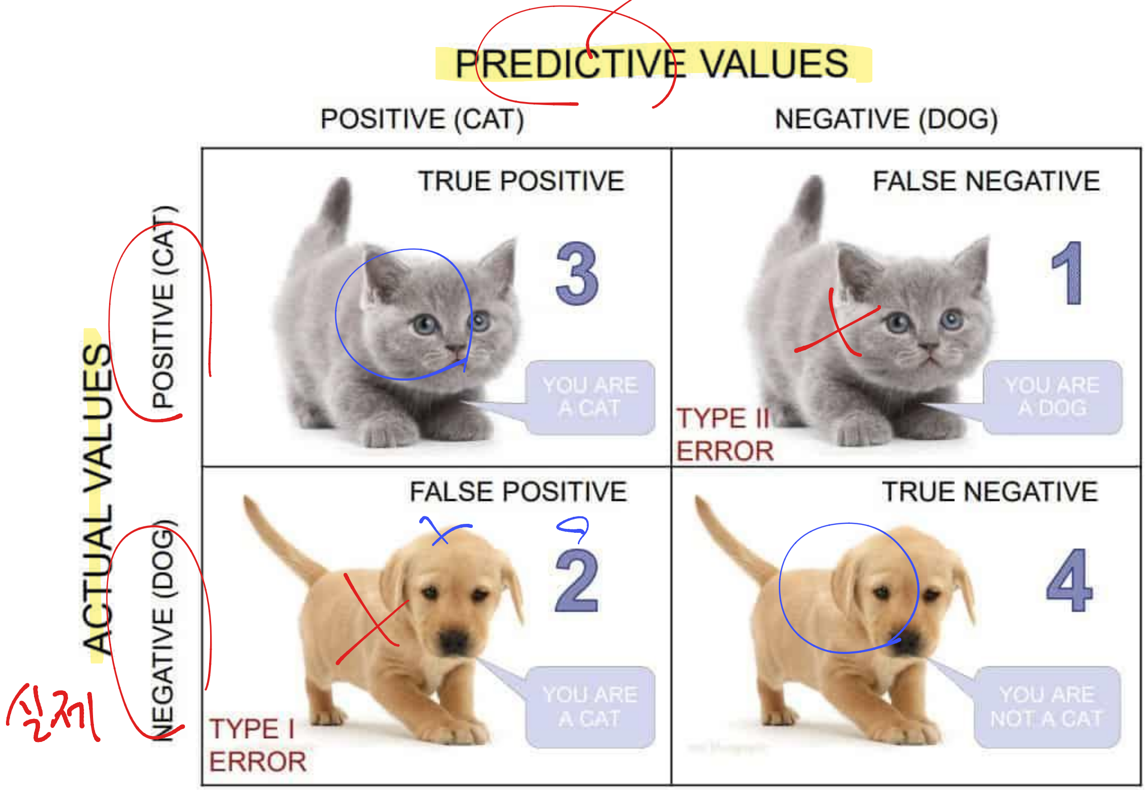
Real voltmeter with input impedance.

Classification Performance & Confusion Matrix

- Classification performance refers to the sensor's ability to accurately identify and categorize objects in the surrounding environment.

분류기

- Confusion Matrix is a table used to evaluate performance in classification problems.
  - True Positive (TP)
    - Correctly predicted the actual **True** as **True**.
  - False Positive (FP)
    - Incorrectly predicted the actual **False** as **True**.
  - False Negative (FN)
    - Incorrectly predicted the actual **True** as **False**.
  - True Negative (TN)
    - Correctly predicted the actual **False** as **False**.



Accuracy, Precision, Recall

- **Accuracy: The proportion of correct predictions among the total number of observations.**
- **Precision: The proportion of actual positives among the observations predicted as positive.**
- **Recall: The proportion of observations that were predicted as positive among the actual positive observations.**

Accuracy

$\frac{TP+TN}{TP+FP+FN+TN}$

		Actual	
		Positive	Negative
Predicted	Positive	TP	FP
	Negative	FN	TN

Precision

$\frac{TP}{TP+FP}$

		Actual	
		Positive	Negative
Predicted	Positive	TP	FP
	Negative	FN	TN

Recall

$\frac{TP}{TP+FN}$

		Actual	
		Positive	Negative
Predicted	Positive	TP	FP
	Negative	FN	TN

Reference: https://ai-com.tistory.com/

F1 Score

F1 score

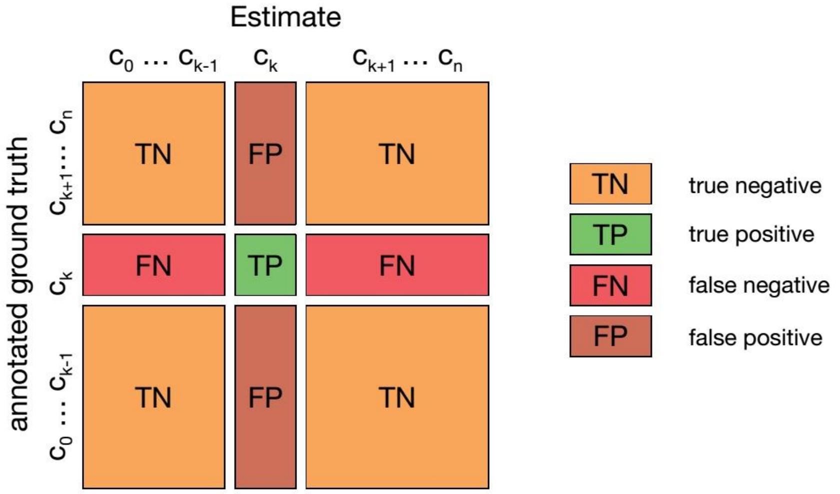
- The harmonic mean of $\boxed{\text{Precision}}$ and $\boxed{\text{Recall}}$.
- Advantageous when considering both metrics simultaneously.

$$\boxed{F1\,Score = 2 \times \frac{1}{\frac{1}{Precision} + \frac{1}{Recall}} = 2 \times \frac{Precision \times Recall}{Precision + Recall}}$$

Example

True Class / Predicted Class

	airplane	automobile	bird	cat	deer	dog	frog	horse	ship	truck
airplane	923	4	21	8	4	1	5	5	23	6
automobile	5	972	2					1	5	15
bird	26	2	892	30	13	8	17	5	4	3
cat	12	4	32	826	24	48	30	12	5	7
deer	5	1	28	24	898	13	14	14	2	1
dog	7	2	28	111	18	801	13	17		3
frog	5		16	27	3	4	943	1	1	
horse	9	1	14	13	22	17	3	915	2	4
ship	37	10	4	4		1	2	1	931	10
truck	20	39	3	3			2	1	9	923



Reference: https://ai-com.tistory.com/

Static vs. Dynamic

- Static Characteristic
  - When the input **does not change** over time.
    - When the sensor in a steady state.
  - **Essential for understanding the basic operating range and performance of the sensor.**
  - Example
    - Accuracy, precision, resolution, sensitivity, linearity.

- Dynamic Characteristic

미분방정식

  - When the input **changes** over time.
    - Indicates how a sensor responds to changing conditions.
  - **Essential for evaluating how well a sensor can track signals that change over time.**
  - Example
    - Response time, frequency characteristic.

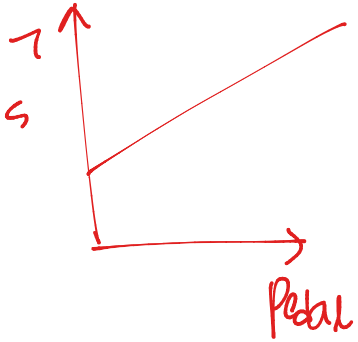
Static Characteristic – Factors Affecting Performance

Static input–output relationship

- Ideal
  - $Output = K_{gain} \times Input$

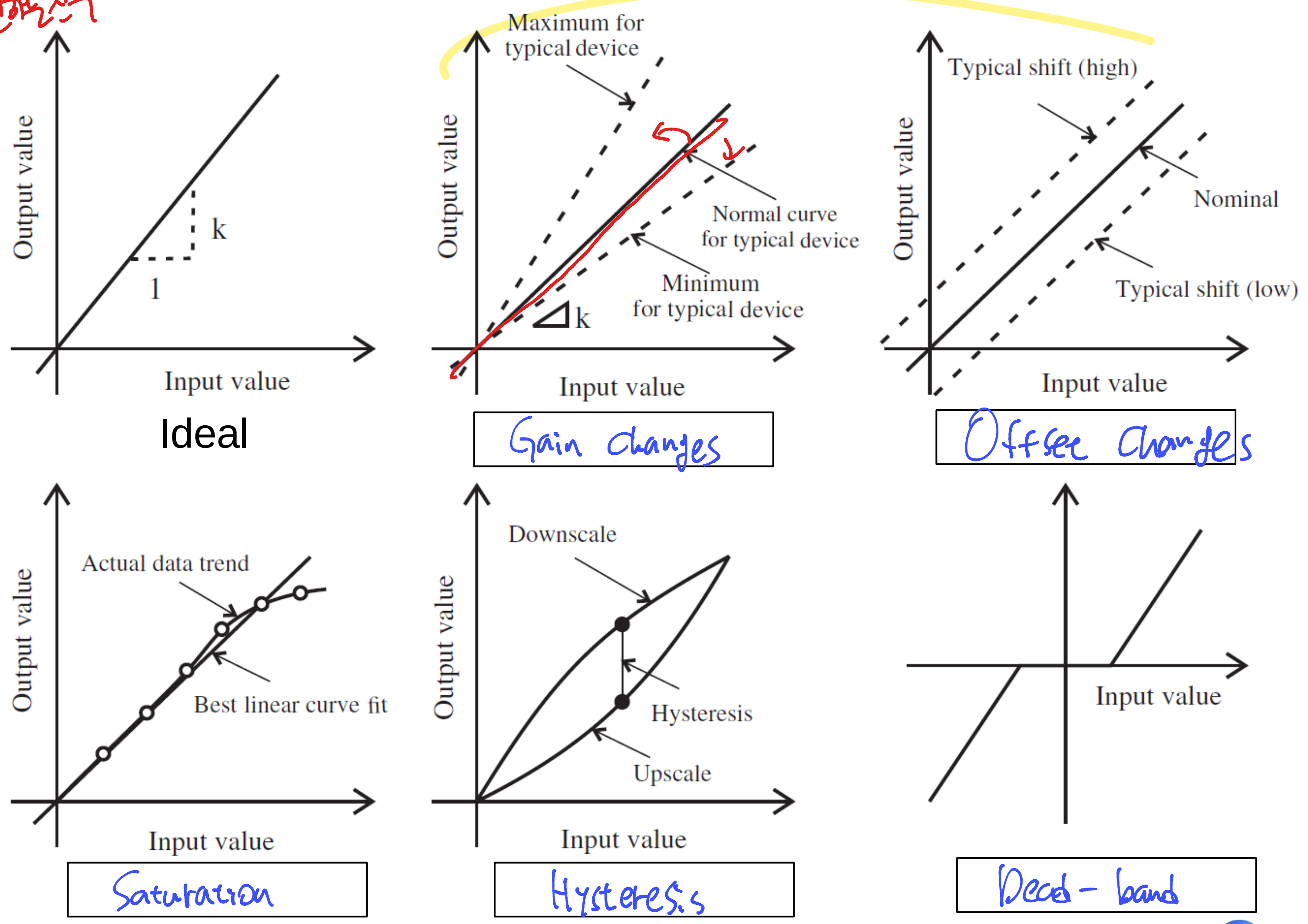
전압 등

단위변환



초음파, 온도..

가속도



Dynamic Characteristic – Response Model (I)

1st order dynamic filter transient response model

- Time Constant (τ)
  - The time that output reaches 63.2% of the steady state value.

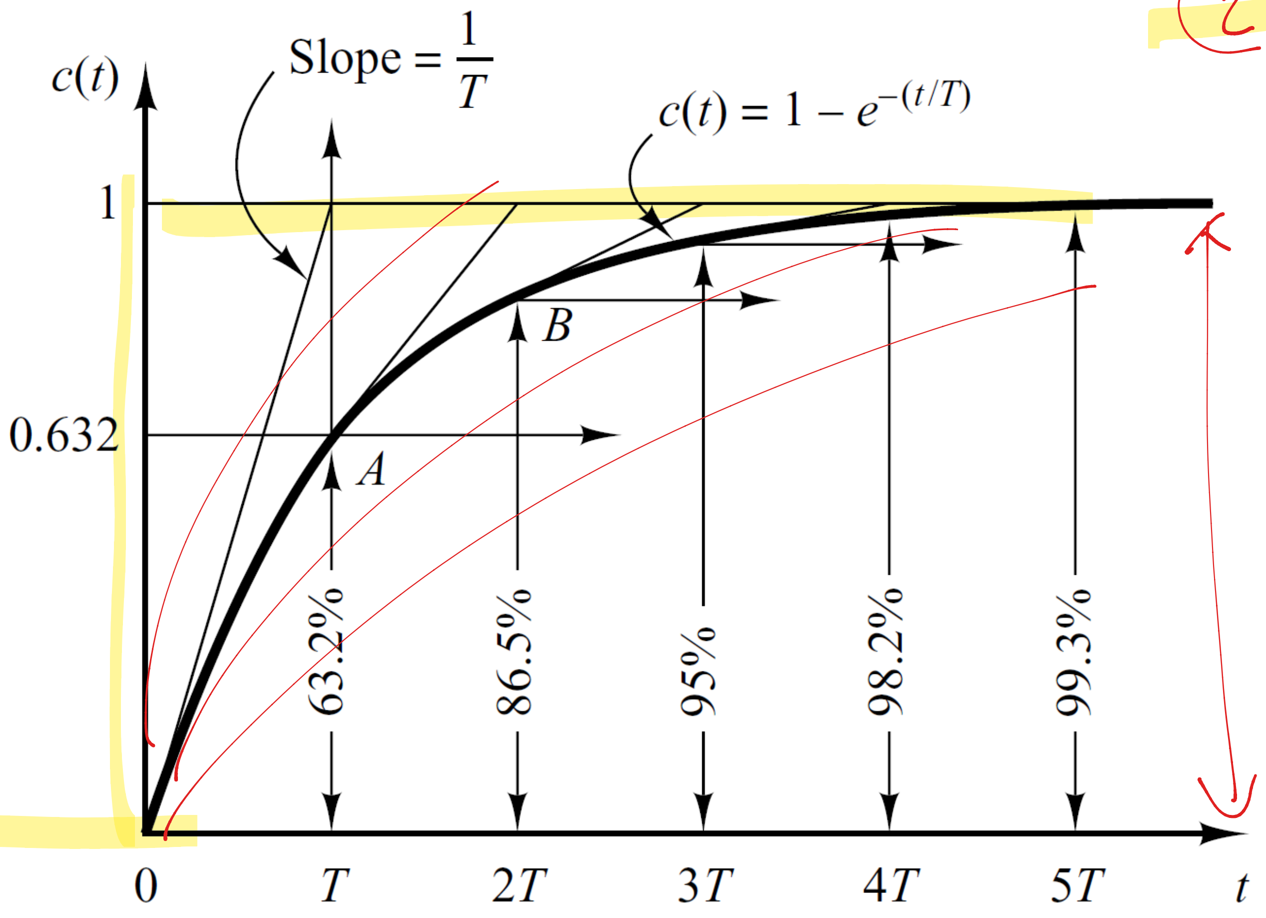
τ time constant

K : gain

센서 반응이 느린게?

→ τ가 클때? . .

센서의 반응함



K (gain)

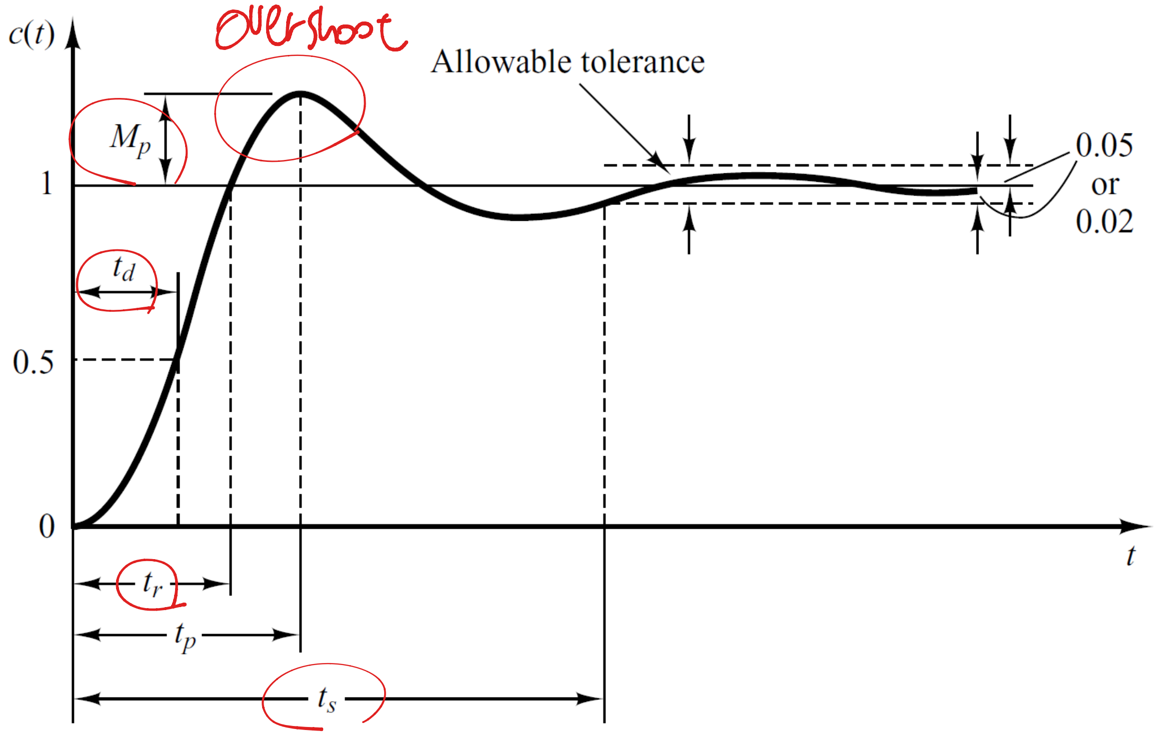
input

Reference: Modern control engineering, Katsuhiko Ogata

Dynamic Characteristic – Response Model (II)

2nd order dynamic filter transient response model

- Rise time, t_r
  - The time that takes for the response to rise from (10% to 90%), (5% to 95%) or (0% to 100%) of the final value.
  - Rise time from 0% to 100% is usually used in under damped 2nd order systems, and rise time from 10% to 90% in overdamped 2nd order systems.
- Maximum Overshoot, M_p
  - The maximum value of the response curve - 1
  - $Maximum\ overshoot = \frac{c(t_p) - c(\infty)}{c(\infty)} * 100\%$
- Settling time, t_s
  - The time it takes that response curve to stay within 2% or 5% of the final value.

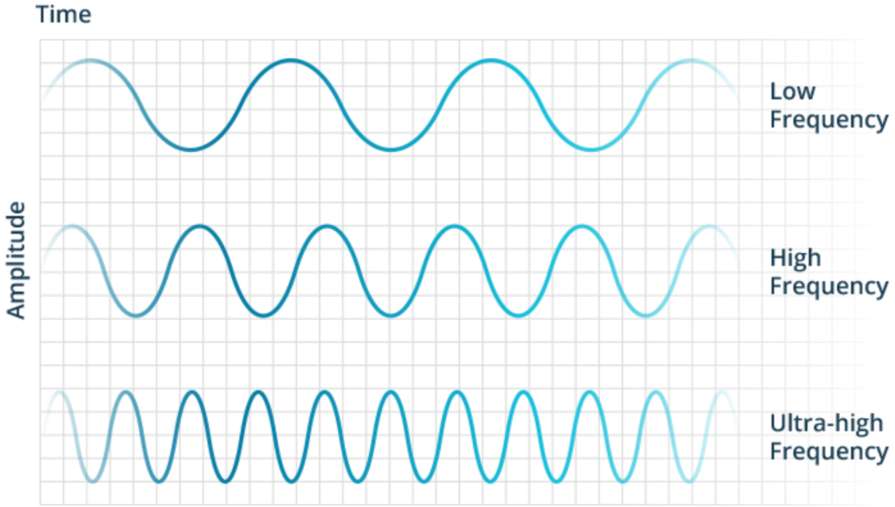


Reference: Modern control engineering, Katsuhiko Ogata

Frequency Response Analysis

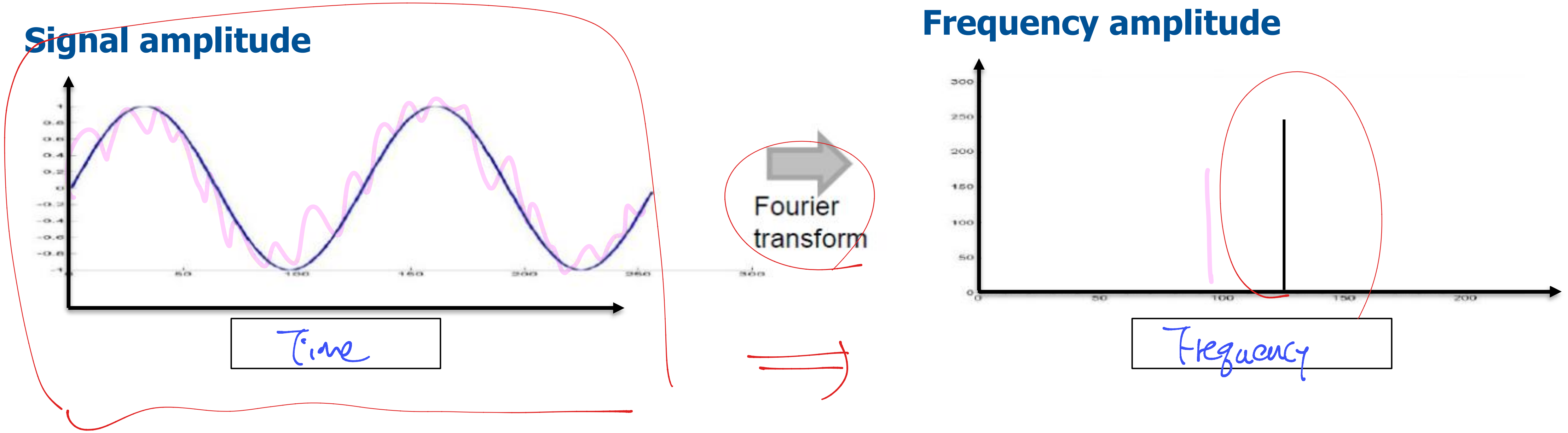
Physical values
- position, velocity, acceleration,
- force, torque, strain, pressure,
- temperature, flow rate, humidity
…

→ **Sensor** → ?



What is Fourier Transform?

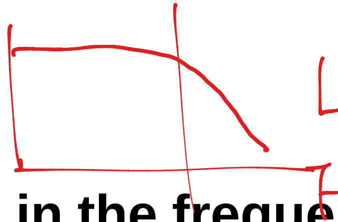
- **Convert an aperiodic function from the time domain to the frequency domain.**
  - Continuous time Fourier transform : $F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt$
  - Discrete time Fourier transform : $X[k] = \sum_{n=0}^{N-1} x[n] \cdot e^{-j\frac{2\pi}{N}kn}$



이런 신호의 주파수성분 분해했을 결과

Bandwidth

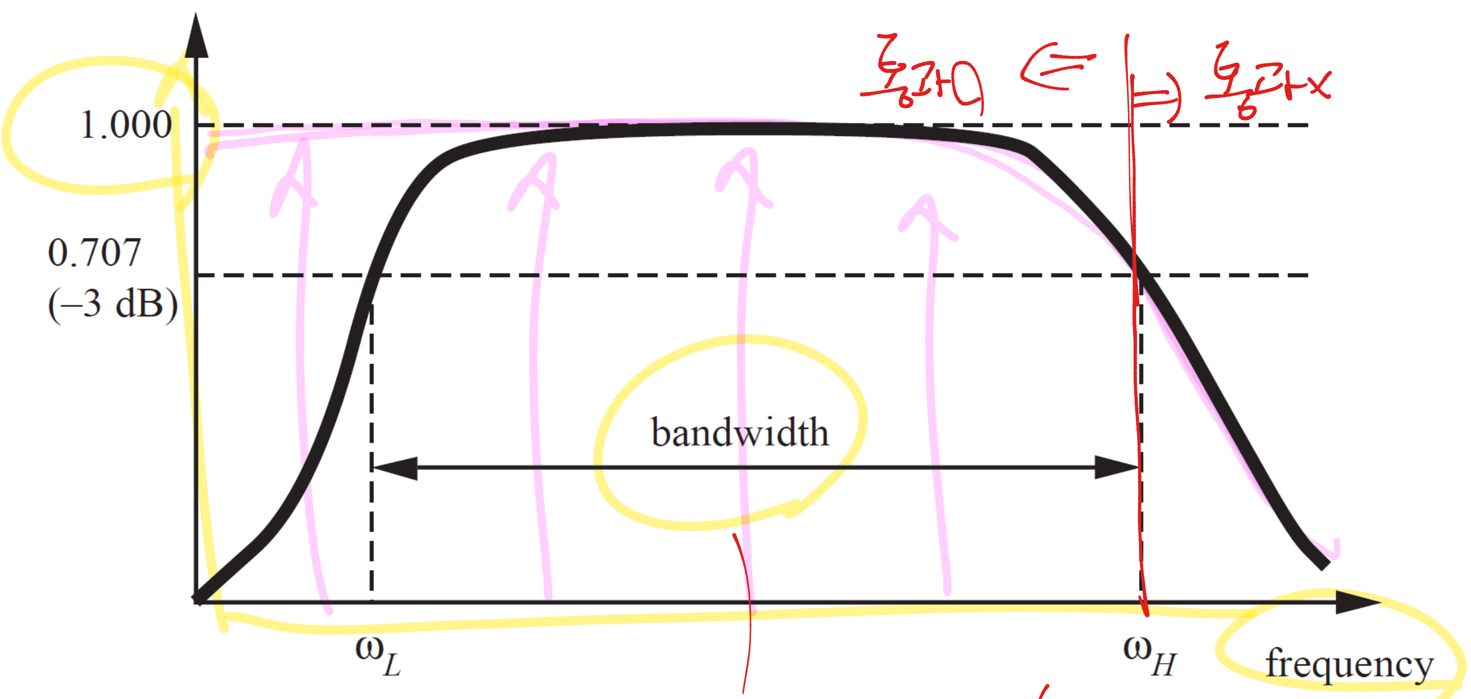
응답 빠름 - Bandwidth (큼)



Low Pass Filter

The range of frequencies that a signal occupies in the frequency spectrum.

- Defines as a frequency where the input is not attenuated to -3dB
- $\frac{P_{out}}{P_{in}} = \frac{1}{2}, \quad \frac{A_{out}}{A_{in}} = \sqrt{\frac{P_{out}}{P_{in}}} = \sqrt{\frac{1}{2}} \approx 0.707, \quad 20log\sqrt{\frac{1}{2}}\ dB \approx -3dB$



영역밖 신호↓ / 센서가 허용할수있는 범위

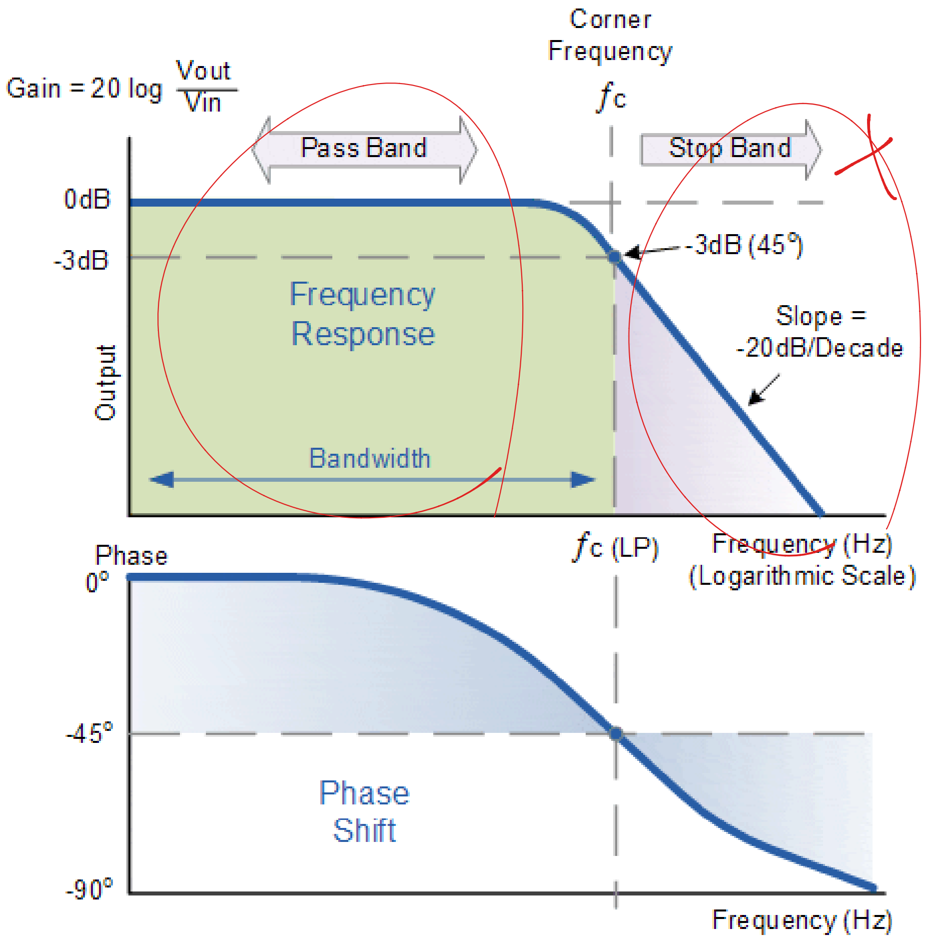
dB	Power ratio	Amplitude ratio
100	10 000 000 000	100 000
90	1 000 000 000	31 623
80	100 000 000	10 000
70	10 000 000	3 162
60	1 000 000	1 000
50	100 000	316 .2
40	10 000	100
30	1 000	31 .62
20	100	10
10	10	3 .162
6	3 .981 ≈ 4	1 .995 ≈ 2
3	1 .995 ≈ 2	1 .413 ≈ $\sqrt{2}$
1	1 .259	1 .122
0	1	1
−1	0 .794	0 .891
−3	0 .501 ≈ ½	0 .708 ≈ $\sqrt{½}$
−6	0 .251 ≈ ¼	0 .501 ≈ ½
−10	0 .1	0 .316 2
−20	0 .01	0 .1
−30	0 .001	0 .031 62
−40	0 .000 1	0 .01
−50	0 .000 01	0 .003 162
−60	0 .000 001	0 .001
−70	0 .000 000 1	0 .000 316 2
−80	0 .000 000 01	0 .000 1
−90	0 .000 000 001	0 .000 031 62
−100	0 .000 000 000 1	0 .000 01

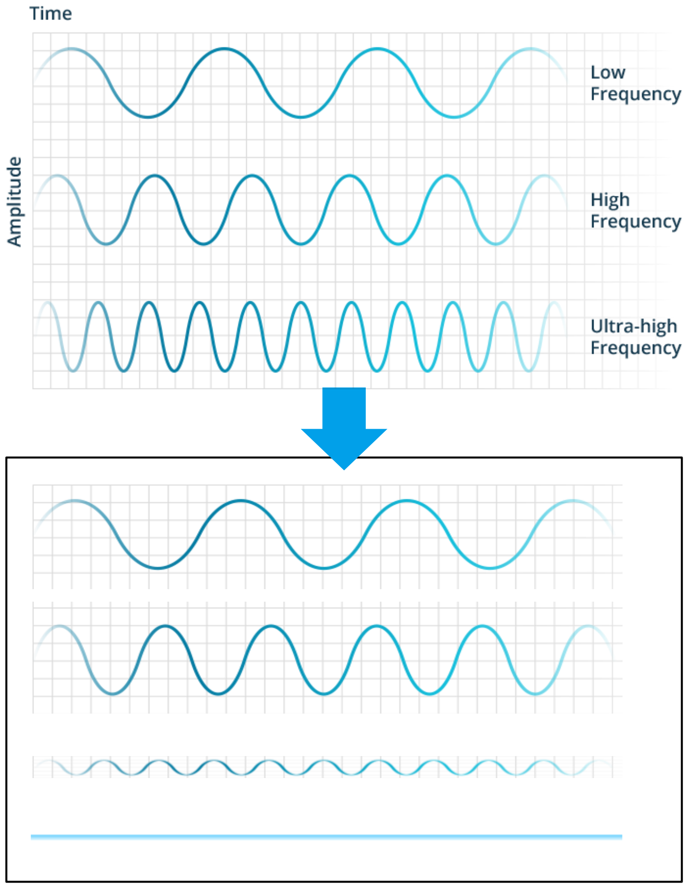
An example scale showing power ratios x, amplitude ratios $\sqrt{x}$, and dB equivalents $10 \log_{10} x$.

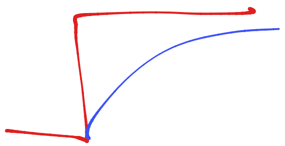
Low-Pass Filter

응답이 높을수록 Z↑

- **Filters that allow frequencies below a certain frequency and block higher frequencies.**
  - Low-pass filter is used to remove or attenuate $\boxed{\text{high frequency Components}}$ from a signal.

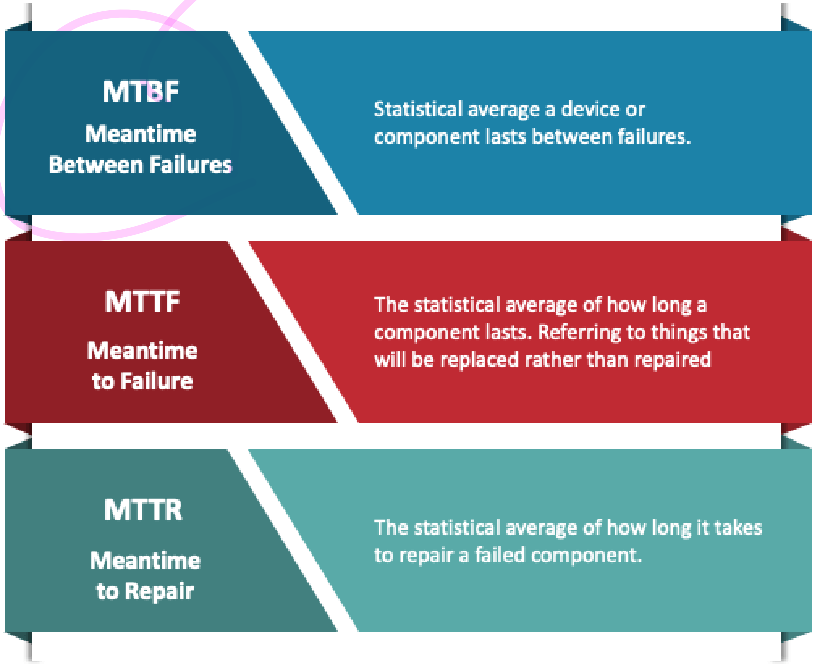


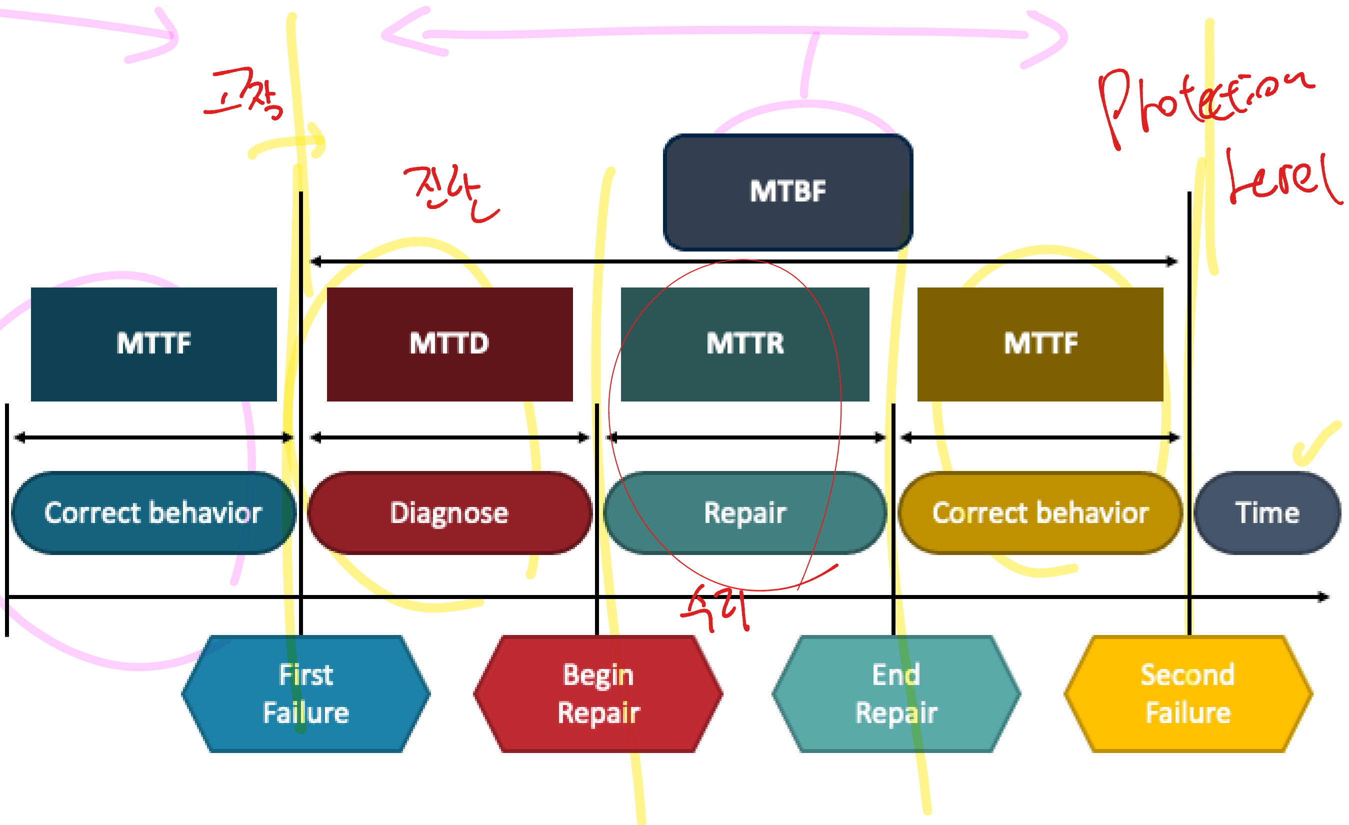




What is Reliability? (신뢰성신뢰도)

- Reliability is the ability of a system, product, or service to consistently perform as intended, with minimal or swift recovery from failures under given conditions.



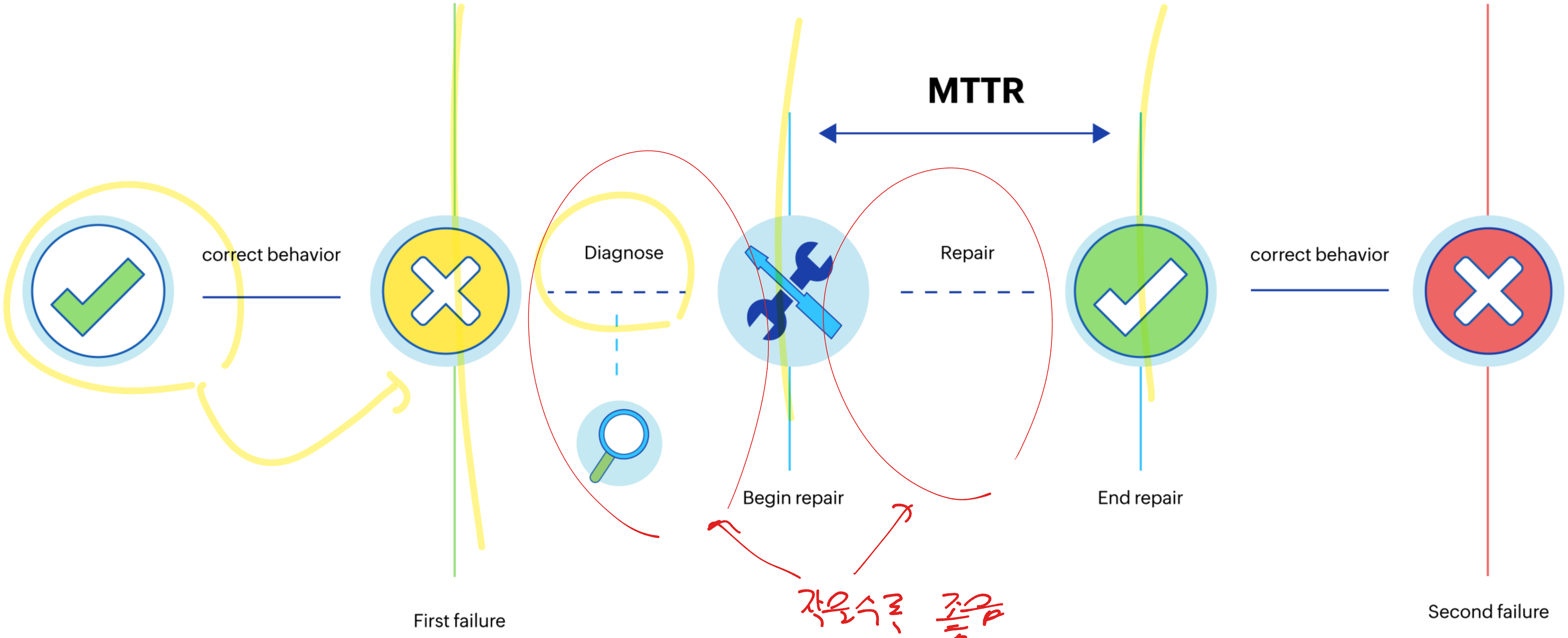


Reliability MTBF vs. MTTR vs. MTTR

Reliability - Mean Time To Repair

Mean Time To Repair (MTTR)

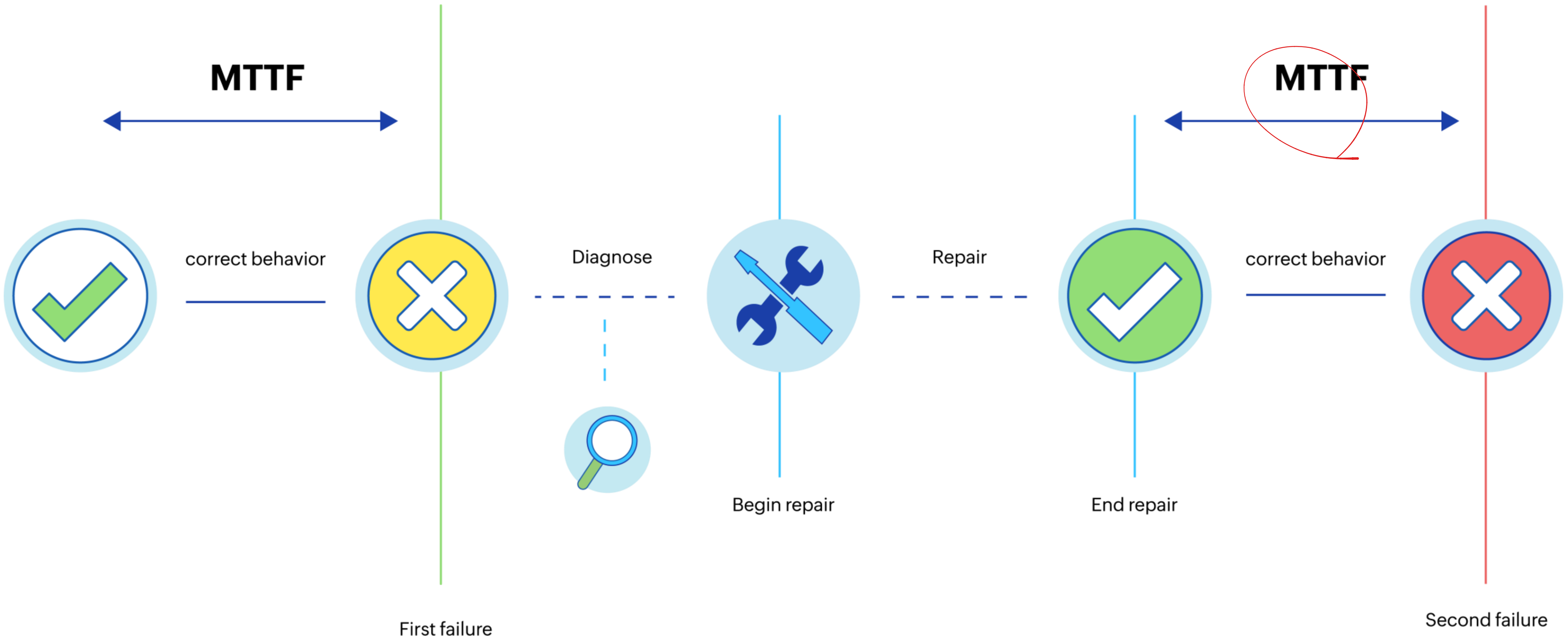
- Mean Time To Repair is the average time a system or device can be repaired after a failure.
- Low MTTR means faster repairs and more reliable system behavior.



Reliability - Mean Time To Failures

Mean Time To Failures (MTTF)

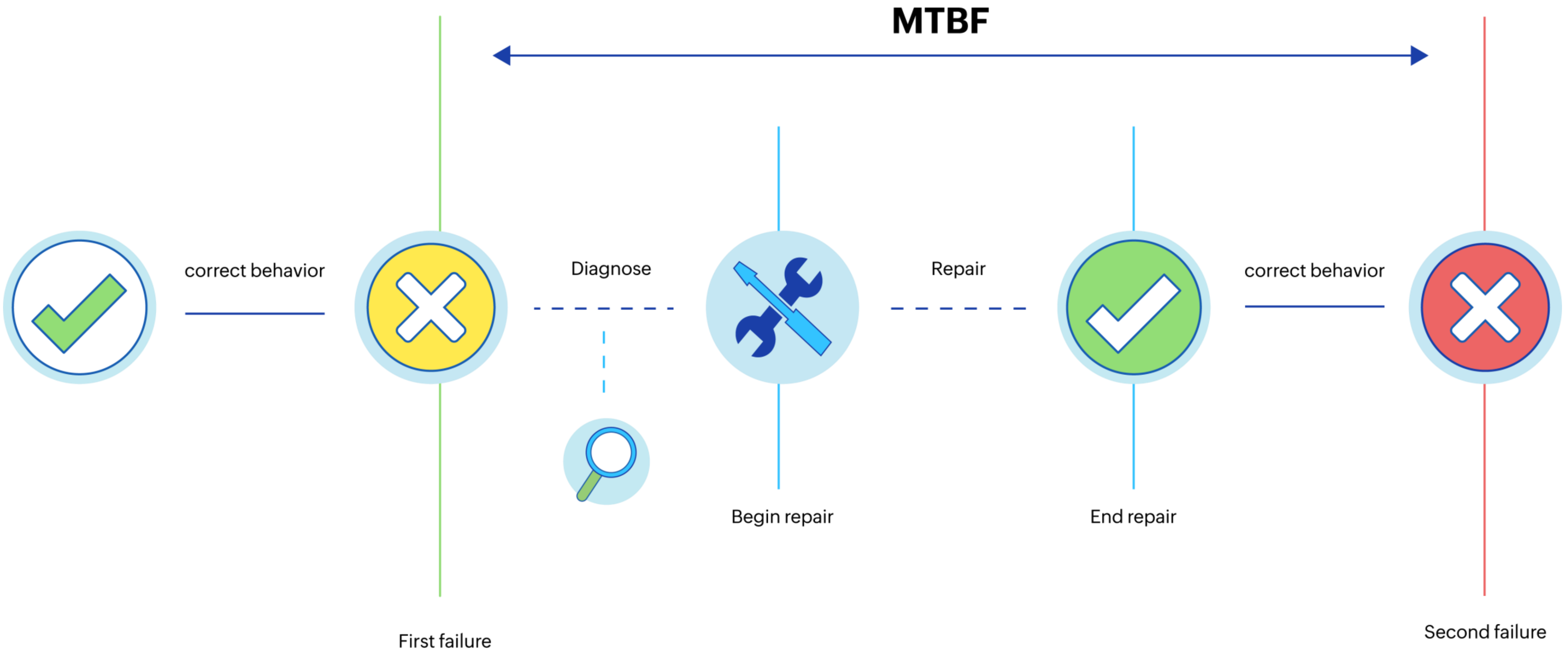
- Mean Time To Failure is the average time a system or device can operate before failing.
- $\boxed{\text{High MTTF}}$ means fewer failures and more reliable system behavior.



Reliability - Mean Time Between Failures

Mean Time Between Failures (MTBF)

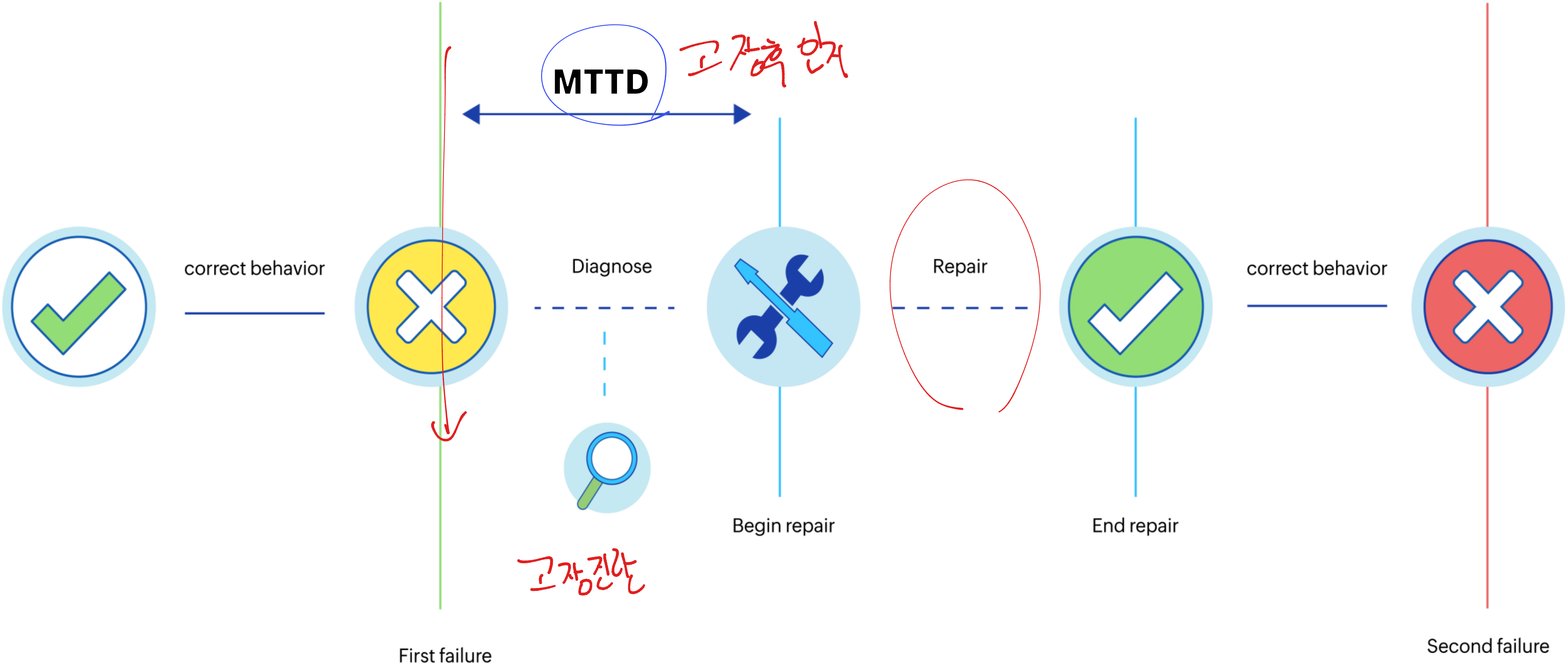
- Mean time between failures is the average time a system or device can operate before it fails.
- High MTBF means fewer failures and more reliable system operation.



Reliability - Mean Time To Detection

Mean Time To Detection (MTTD)

- Mean time to detection is the average time a system or device can detect a failure.
- Low MTTD means faster the system can detect anomalous behavior or attacks.



Reliability - Extreme Testing

- Extreme testing to ensure that your product will perform reliably under any extreme conditions.

ADAS

ABS

ESC

MDDS

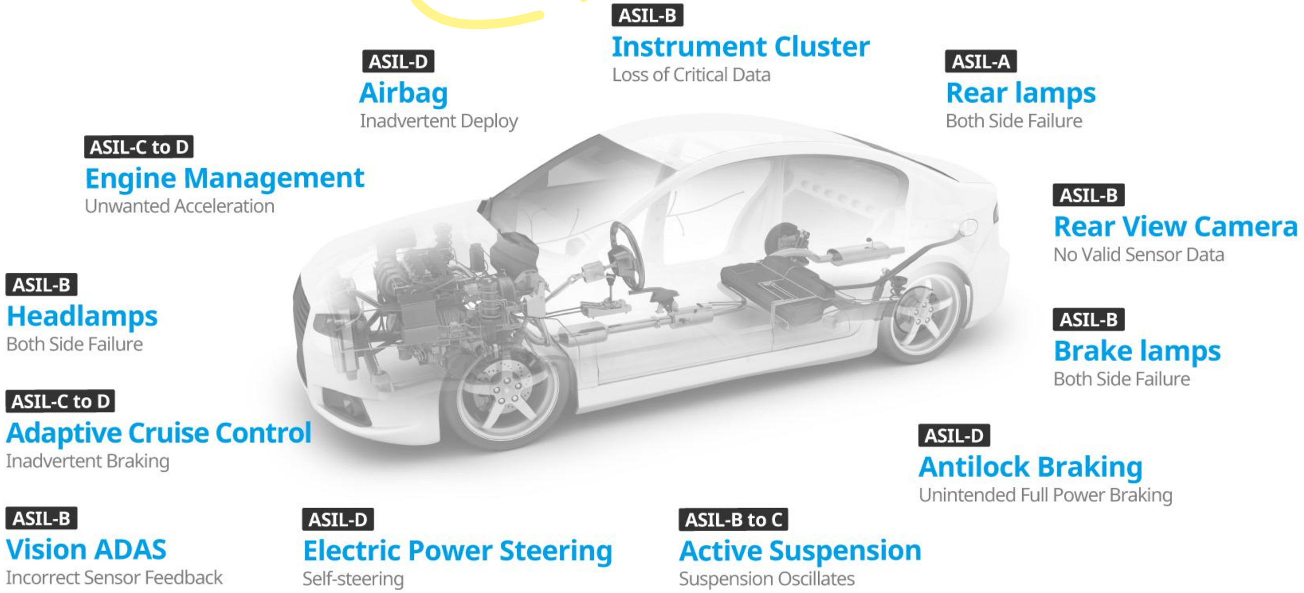
SPAS

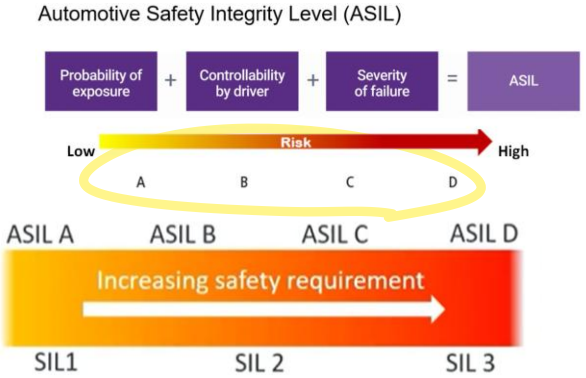
Reliability - Automotive Safety Integrity Level

Automotive Safety Integrity Level (ASIL)

- **Risk classification** scheme defined by the **ISO26262.** (International Standards for automotive functional safety)
  - ISO26262: International standards for automotive functional safety.
- **ASIL** is determined by result of hazard analysis and risk assessment.
- **ASIL D** is the highest degree of automotive hazard and highest degree of rigor applied.
- **QM** represents automotive risk-free application.

$$ASIL = \underbrace{Severity}_{\text{심각도}} * (\underbrace{Exposure}_{\text{빈도}} * Controllability)$$





D로 갈수록 위험!!

THANK YOU
FOR YOUR ATTENTION