SENSORS CHARACTERISTICS

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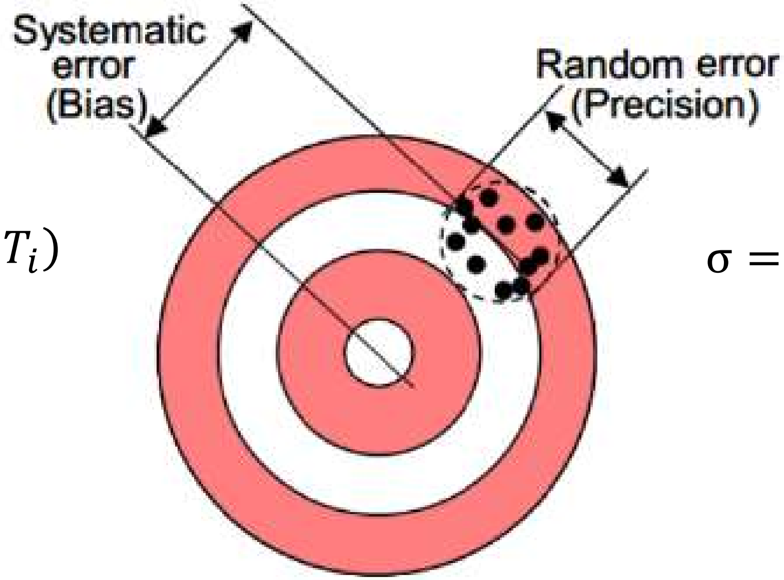
ISO 5725 – Accuracy (trueness and precision) of measurement methods and results

$$\frac{1}{N}\sum_{i=1}^{N}(x_i - T_i)$$

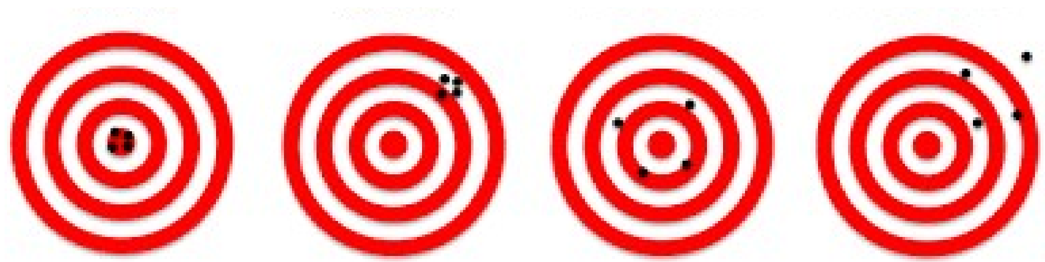
$$\bar{x} - \mathrm{T}$$



$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(\mathrm{d}_i - \bar{\mathrm{d}})^2}$$

$$d_i = (x_i - T_i)$$

Compare trueness and precision in these 4 illustrations:



Accuracy (exactitude) combines both trueness and precision

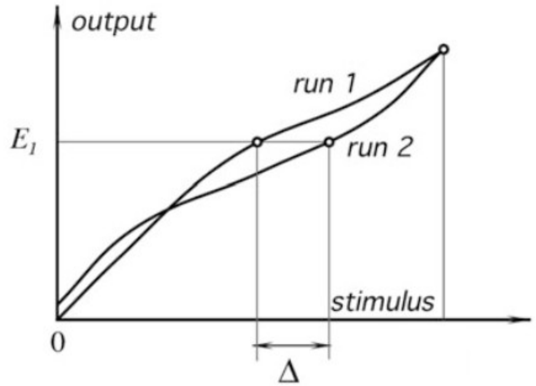
$$A = \sqrt{bias^2 + \sigma^2}$$

Two terms closely related to precision: Repeatability and Reproducibility

Repeatability

- precision of a set of measurements taken on the same measurand, under same condtions, over a short time interval

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

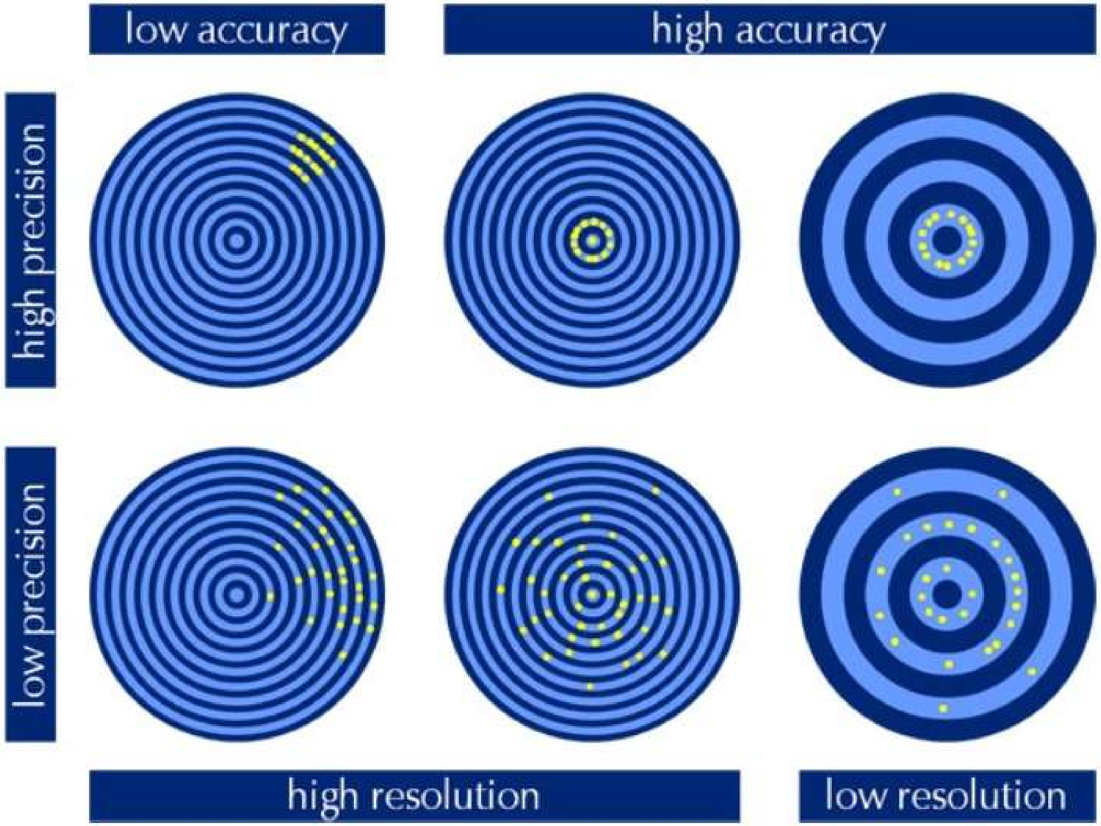


Reproducibility

- precision of a set of measurements BUT:
- taken over a long time interval or performed by different operators or in different laboratories

Resolution (Discrimination)

minimal change of the input necessary to produce a detectable change at the output



Exercice

You want to compare three sensors to measure a physical quantity whose true value is known (T=100). You collect for each instrument 5 measurements of the same quantity under identical conditions (same sensor, environment, and setup) and measure:

1) 102, 102, 102, 102, 102
2) 99, 101, 100, 100, 100
3) 97, 99, 100, 103, 110

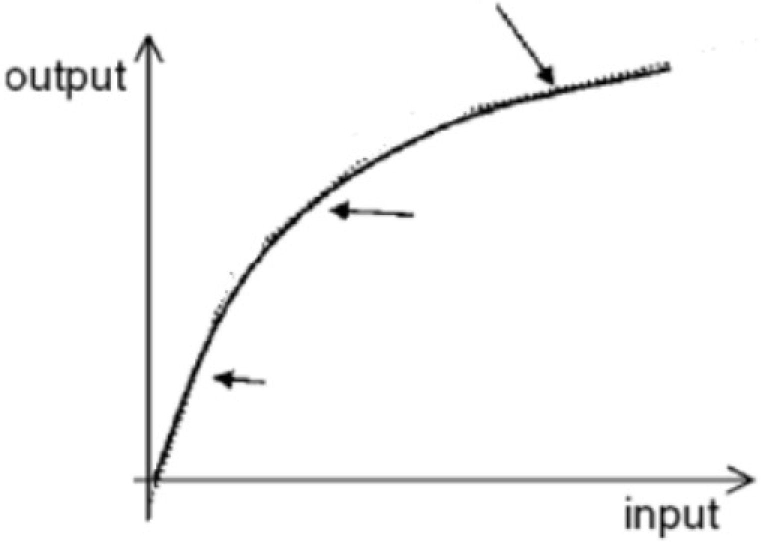
	1)	2)	3)
Mean	102	100	101.8
Bias	2	0	1,8
Repetability	0	0.82	5.07
Reproductibility			
Precision	2	0.82	5.38

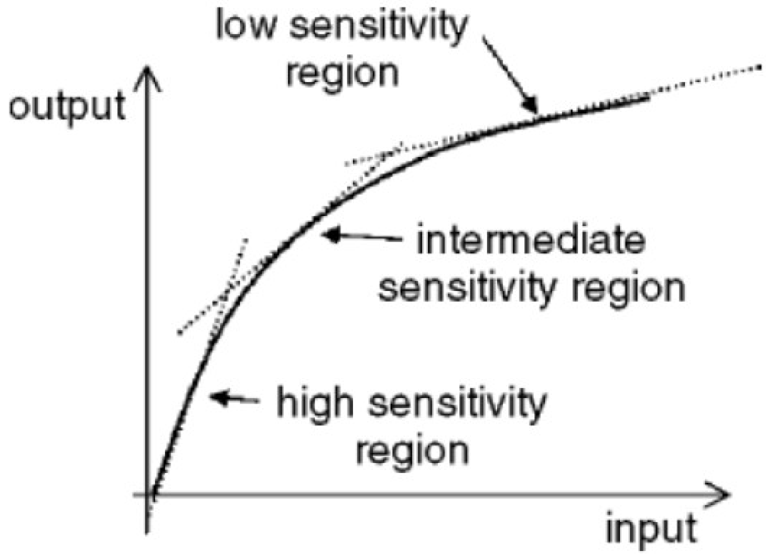
Sensitivity: The slope of the transfer function

- An ideal sensor will have a large and constant sensitivity
- A nonlinear transfer function exhibits different sensitivities at different points

Absolute Sensitivity = ΔOutput / Δinput

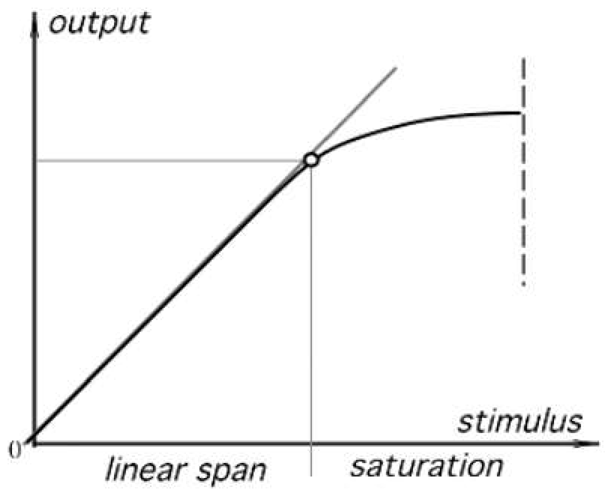
Relative Sensitivity = Srel = $\frac{I_{max}}{O_{max}}\frac{dO}{dI}$

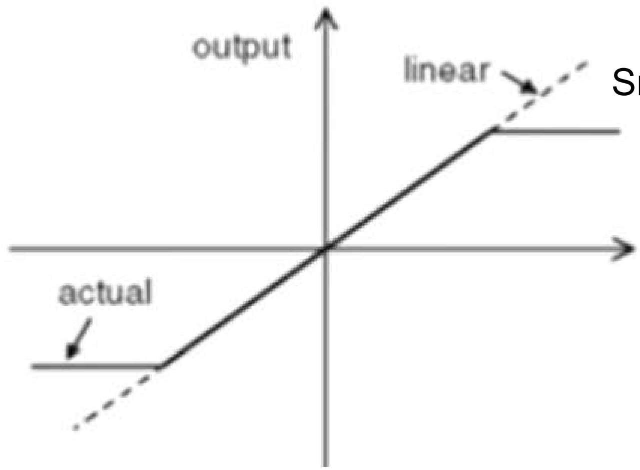




Saturation

- Every sensor has its operating limits.
- At some levels of the input stimulus, its output signal no longer will be responsive.

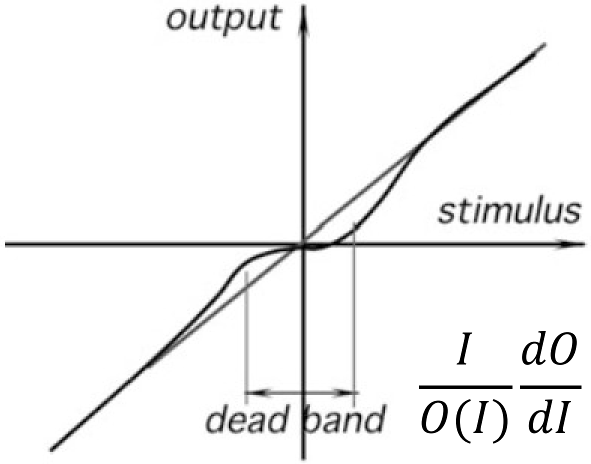




Srel < Threshold

Dead-band

- Insensitivity of a sensor in a specific range of the input signals
- In that range, the output may remain near a certain value over an entire dead-band zone



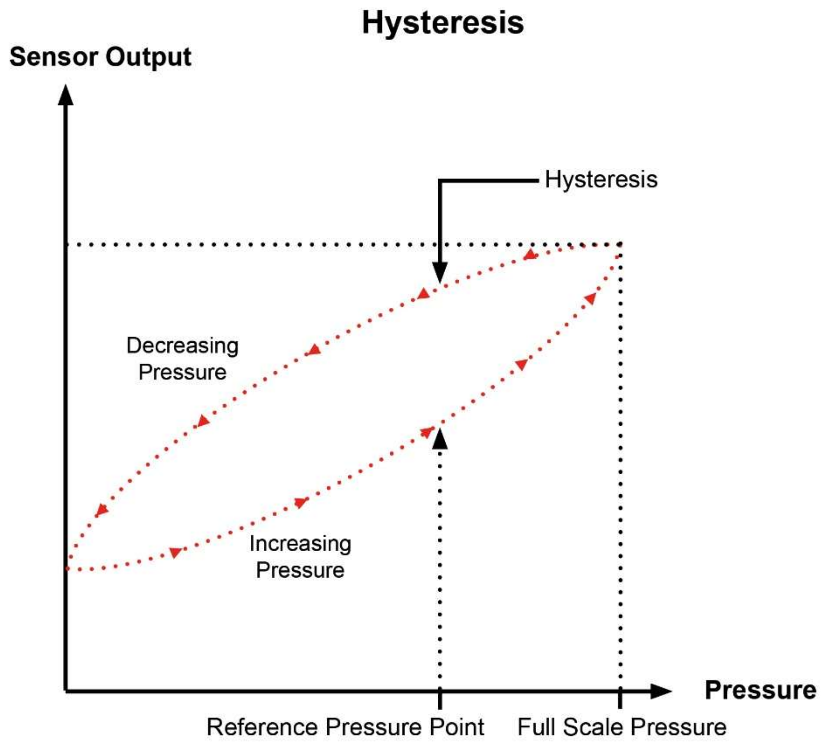
$$\frac{I}{O(I)}\frac{dO}{dI} < Threshold$$

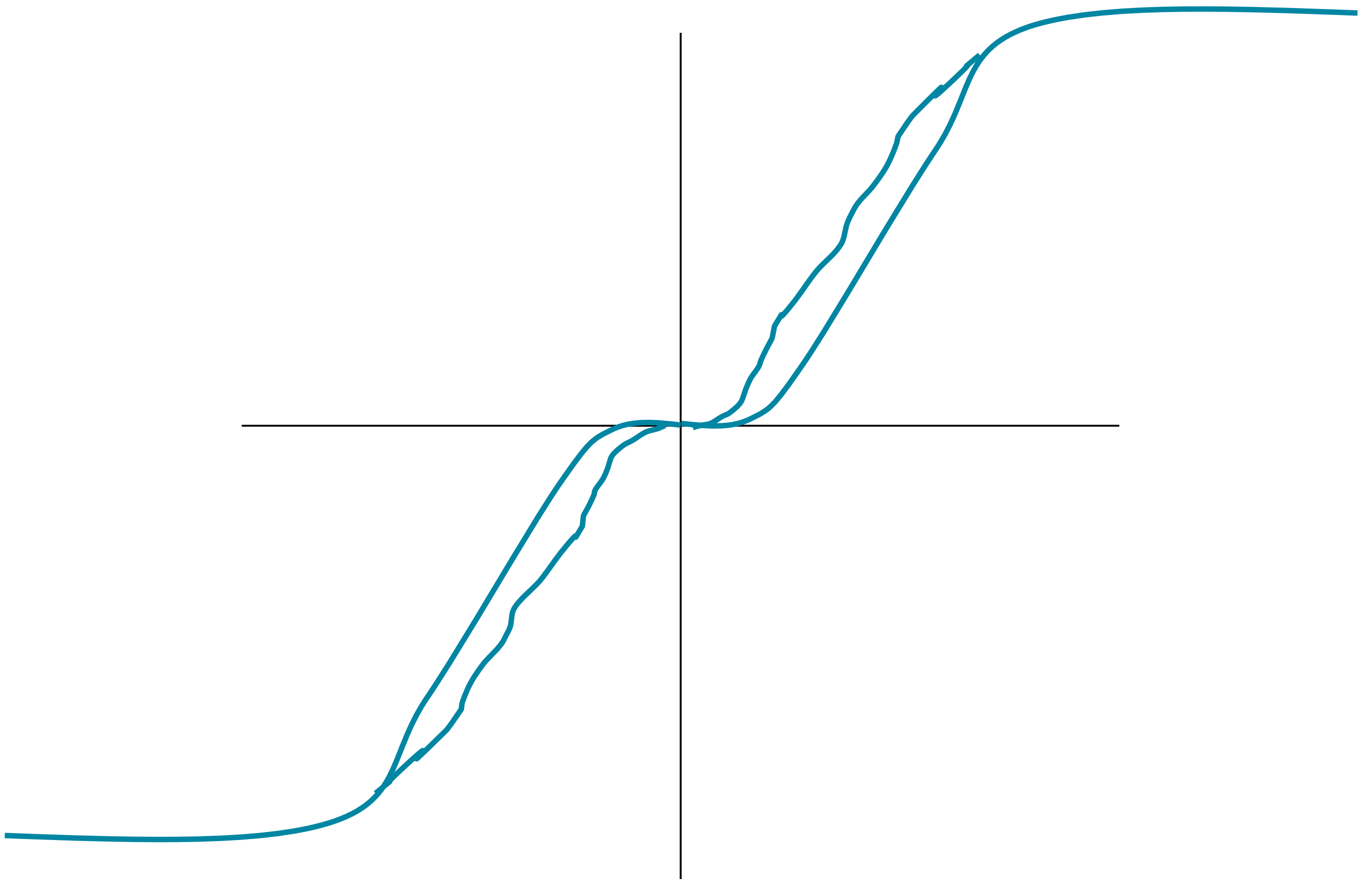
Example : A joystick doesn't respond until you move it ±2 mm then reports position changes in 1 mm increments

Hysteresis

Deviation of the sensor's output at a specified point of the input signal when it is approached from the opposite directions.

$$h = O_{up} - O_{down}$$





NOISE

Noise = random, unwanted variation in the sensor's output that is not caused by changes in the measured quantity.

$$A = \sqrt{bias^2 + \sigma^2}$$

σ : variance due to random error

So for independent noise (random):

$$\sigma^2 = \sigma_r^2 + \sigma_R^2 + \sigma_{Hyst}^2 + \sigma_{Temp}^2 + \sigma_{humidity}^2 + \sigma_{Poisson}^2 + \sigma_{longterm\ drift}^2 + \cdots$$

- Le bruit d'agitation thermique (bruit de Johnson)
- Le bruit de grenaille (bruit de Schottky) (Shot noise)

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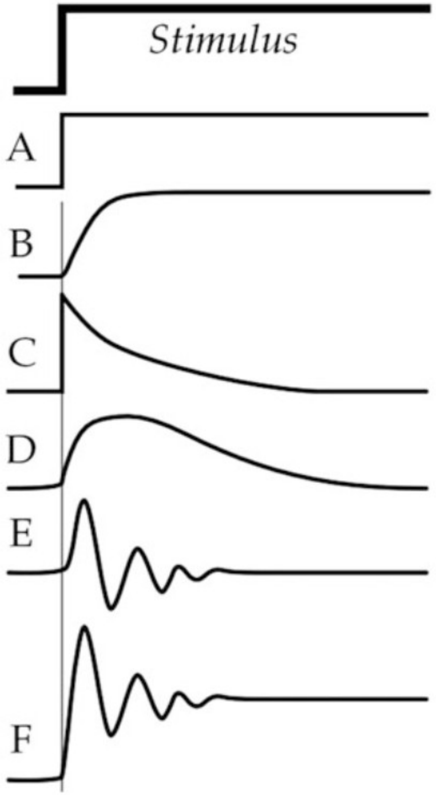
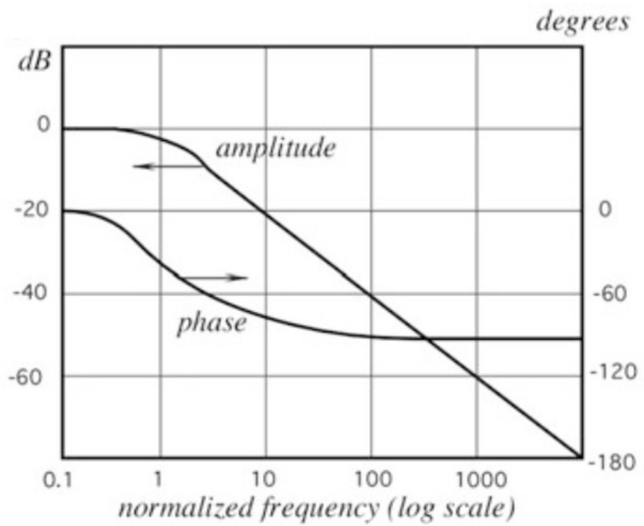
Dynamic characteristics (peak time, rise time, oscillations, frequency response,etc.)





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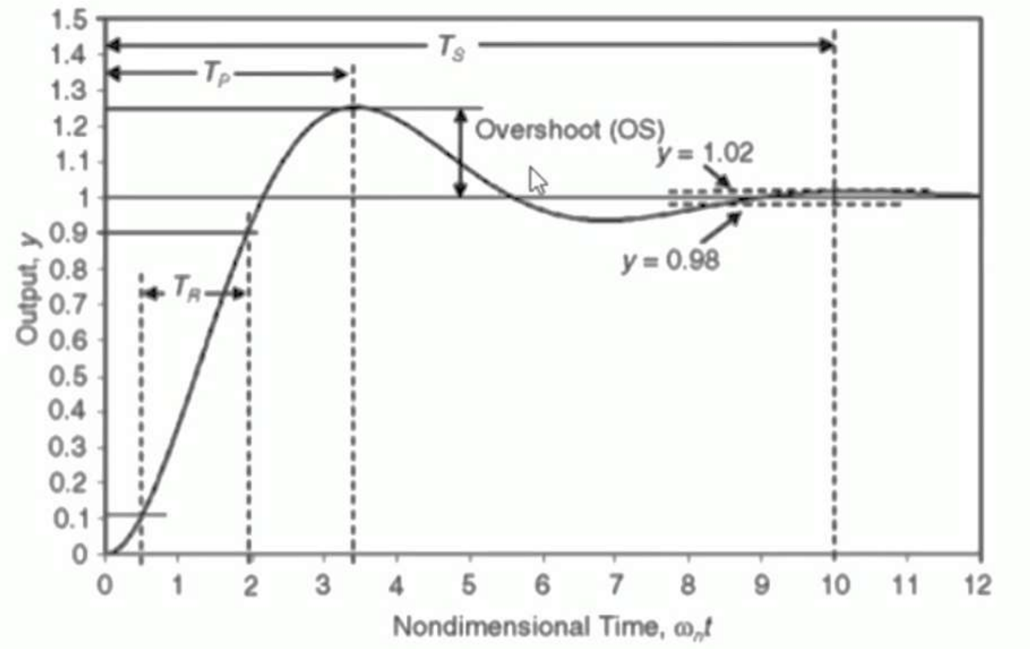
- **Settling time**. 7s the time when the system response remains within ± 2% of the steady-std value
- **Rise time**. *TR* time required for the response to go from 10% to 90% of the steady-state value

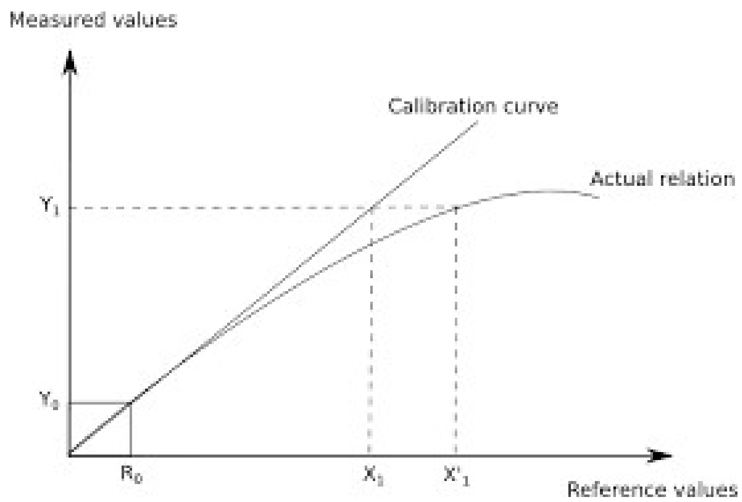
- peak time: the time required to reach the fist (or maximum) peak
- percent overshoot. %OS amount the response exceeds or overshoof w/.t the steady-state value



CALIBRATION

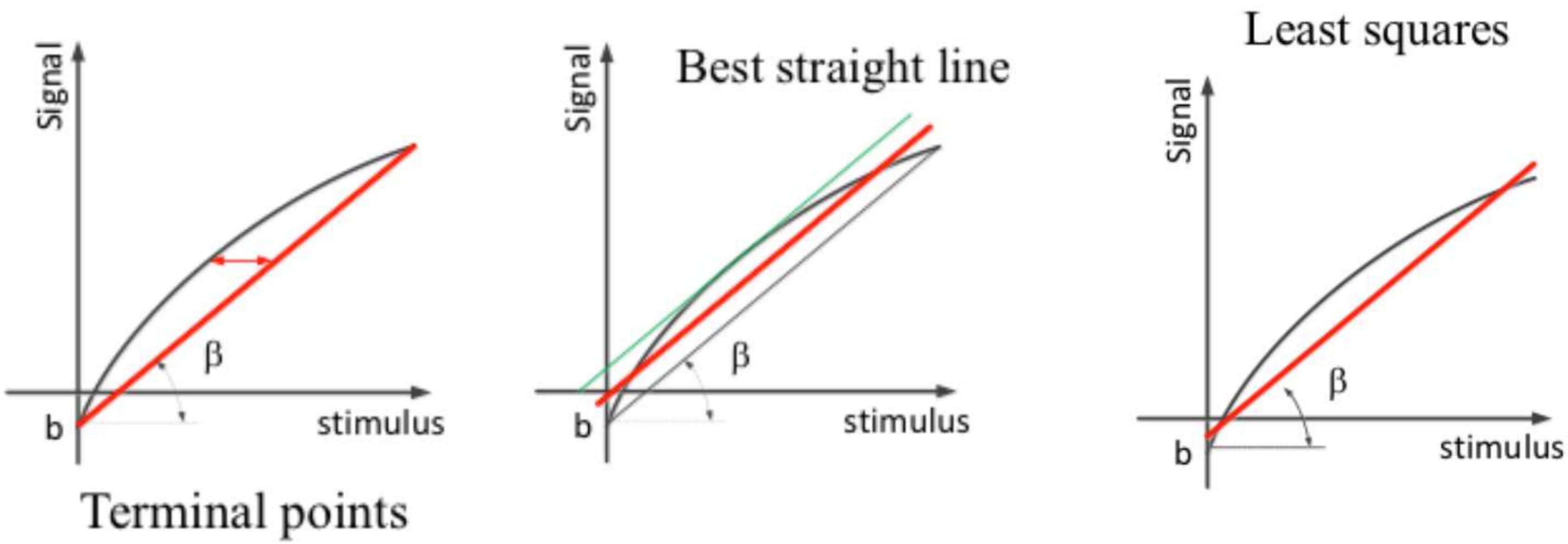
- A test during which known values of the measurand are applied to the sensor and corresponding output readings are recorded under specified conditions

- **A calibration allows**
  - **To assess the sensor transfer function**
  - **to adjust, rectify and document the accuracy of the sensor**



Nonlinearity - Approximation

- Several ways of specifying nonlinearity, depending on how the line is superimposed on the transfer function
  - Terminal points
  - Best straight line
  - Least squares



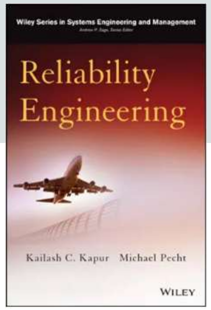
For instance for a LED, calibration curves of interest are:

- Forward voltage vs current (I–V characteristic)
- Optical power
  - vs forward current, temperature, etc.
- Spectral output
  - vs wavelength, temperature, (humidity)
- Radiating pattern, etc.

Sample to sample manufacturing variations:

- even two sensors from the same manufacturer production run may yield slightly different readings
- Sensors subject to heat, cold, shock, humidity etc. during storage, shipment and/or assembly may show a change in response
- Some sensor technologies 'age' and their response will naturally change overtime -requiring periodic re-calibration

RELIABILITY ENGINEERING



Focus Areas:

- **Failure analysis:** Identifying modes and causes of failure.
- **Life testing:** Estimating component lifetime under normal or accelerated conditions.
- **Maintainability and availability:** Designing for easy maintenance and high uptime.
- **Environmental and stress testing:** Assessing how factors like temperature, humidity, vibration, and electrical stress affect reliability.

Key Metrics:

- **Mean Time To Failure**
  - average time a non-repairable component works before failing.
- **Mean Time Between Failures**
  - average time between failures for repairable components.
- **Failure rate**
  - failures per unit time.
- **Probability of survival / reliability function**
  - probability that a component works up to time.

- ISO 60068 series – **Environmental testing**
- ISO 16750 series – Road vehicles: Environmental conditions and testing for electrical/electronic equipment

- Examples:

Test	Test description
Electrical	20°C 500 hours, Maximum current.
Thermal cycle	-40 to 90°C, 4.5H cycle 250 cycles (total test time: 1125h). Standard power operation
High Temp	+90°C 500 hours, Standard power operation

Test	Test description
High temp / high humidity	85°C/85%RH 500 hours not powered,
Thermal shocks	-40 to 90°C, soak time: 40mn at each temperature, transcient time < 30s 500 shocks (1 shock = 2 temperatures changes) Total test time: 675h (81mn / cycle), air-air, Not powered
ESD	ESD shoot on not powered part (on lead frame pads)

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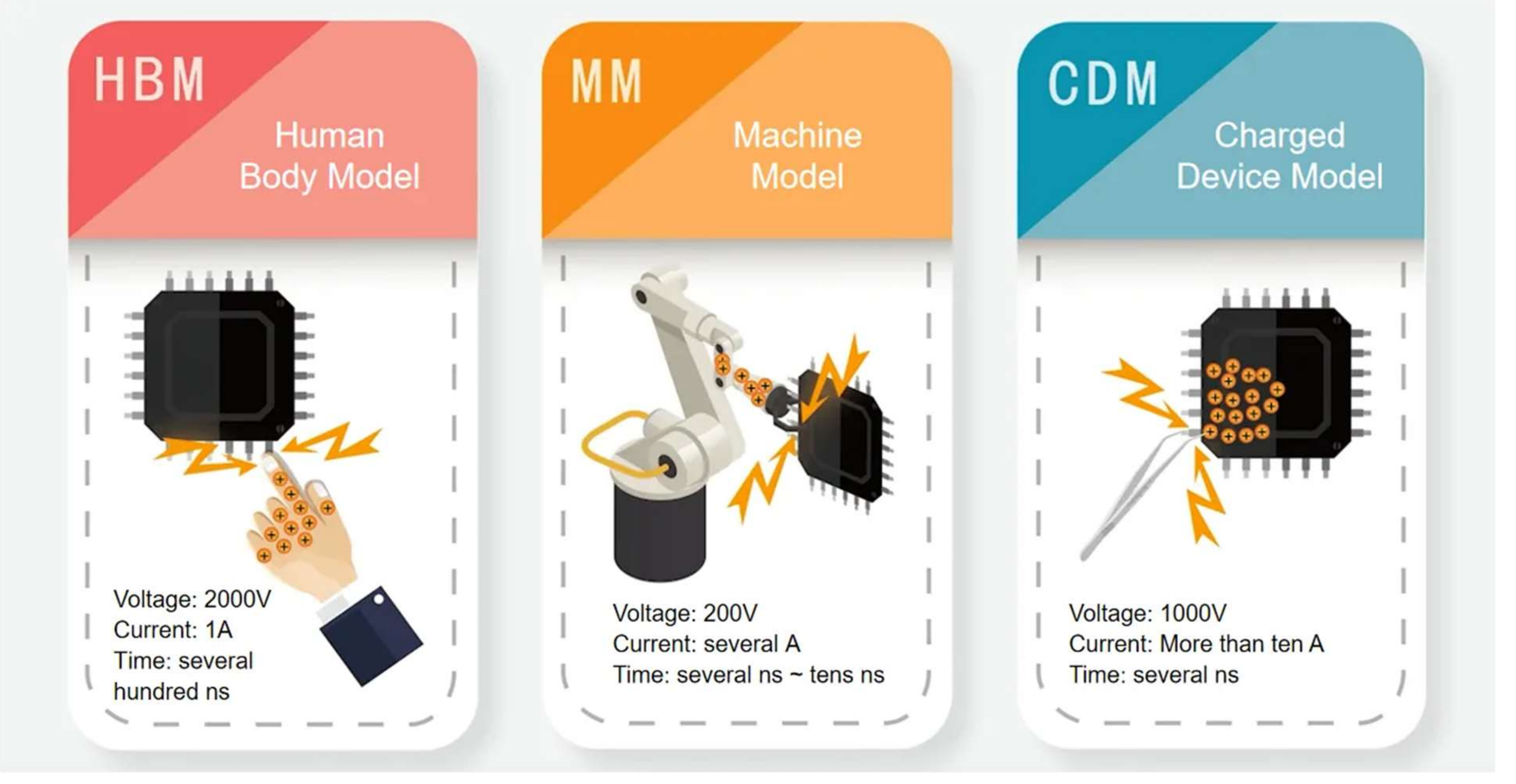

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The **error budget** quantifies all sources of measurement uncertainty (bias, noise, environmental effects) in a sensor or system.

It helps predict how these uncertainties affect **performance over time and under varying conditions**, allowing to assess **failure risk, maintainability, and system dependability**.

Exemple:

- Service Level Objective : Temperature sensor must be within ±1 °C.
- Error budget : ±0.56 °C.
- Conclusion : Sensor meets the SLO.

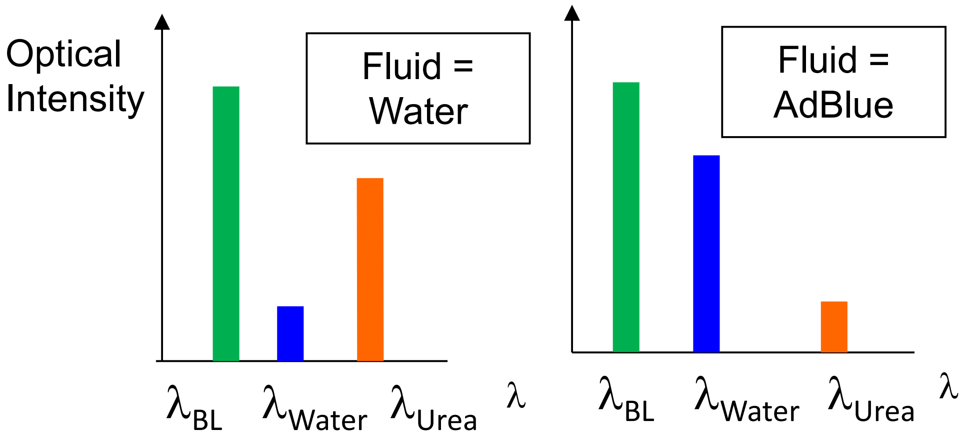
SENSOR INDUSTRY

UREA QUALITY SENSOR

- DEF contains 2 main absorption species :
  - Urea (N-H chemical bond ; 1020nm; C = 32,5%)
  - Water (O-H chemical bond ; 970nm; C = 67,5%)
- The amount of **light absorbed** by the fluid is proportional to the concentration of attenuation species.

We consider 3 wavelengths :

- λ_{Water} : 970nm. This wavelength is highly absorbed by O-H chemical bonds (water)
- λ_{Urea}: 1050nm.This wavelength is highly absorbed by N-H chemical bonds (urea)
- $\lambda_{BaseLine}$:810nm.This wavelength is not absorbed by N-H & O-H bonds. It is used as a baseline



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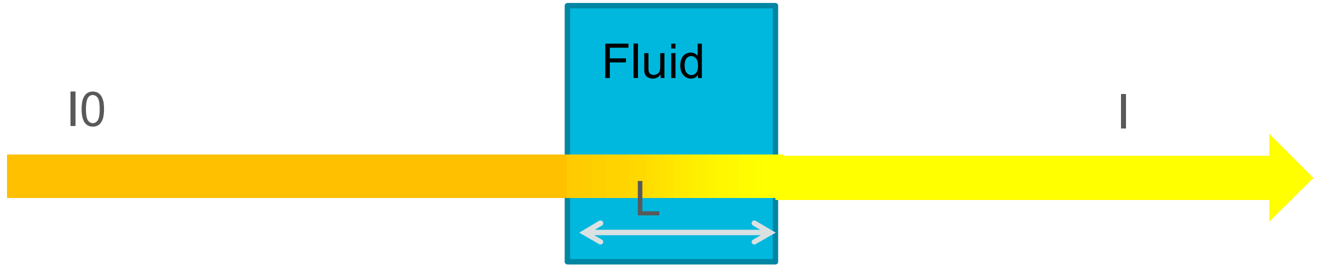
BEER-LAMBERT LAW



- The amount of **light absorbed** by the fluid **is proportional** to the **concentration** of attenuation species.
- Adblue contains 2 main attenuation species :
  - Urea (N-H chemical bond ; C = 32,5%)
  - Water (H-O chemical bond ; C = 67,5%)

$$A_\lambda = -\log \frac{I}{I_0} = \varepsilon_\lambda \cdot \ell \cdot C.$$

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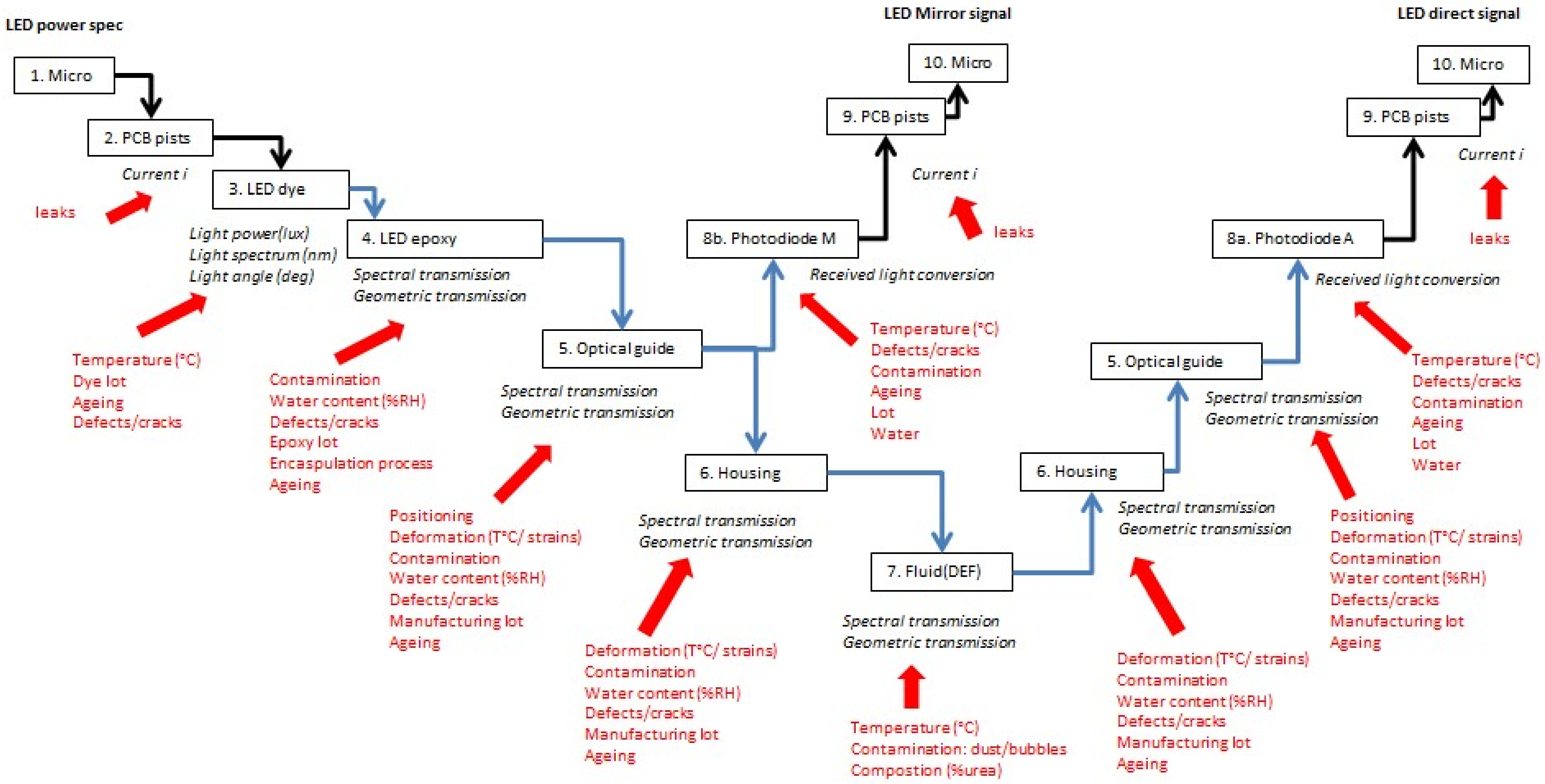
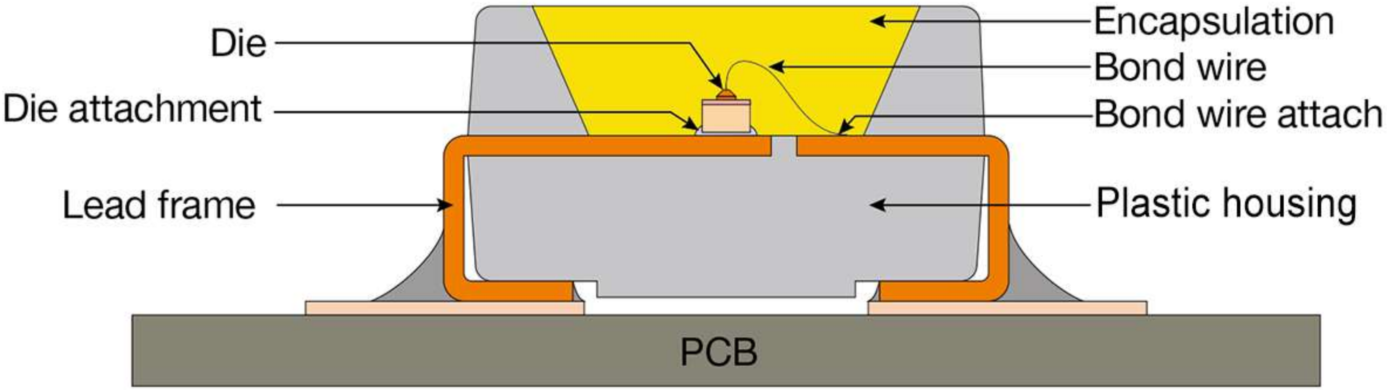
EXPLORATION OF THE LED SIGNALS MEASUREMENT CHAIN




Die
Die attachment
Lead frame
Encapsulation
Bond wire
Bond wire attach
Plastic housing
PCB

ENVIRONMENTAL SENSORS

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CAPTEUR DE FLAMME

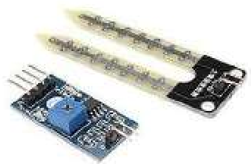
PRESSION/ALTITUDE

CAPTEUR DE SON

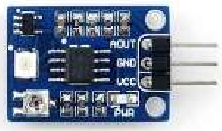
THERMOMÈTRE INFRAROUGE

CAPTEUR LUMIÈRE RGB

CELLULE PHOTOÉLECTRIQUE



CAPTEUR D'HUMIDITÉ DES SOLS



CAPTEUR UV

CAPTEURS DE GAZ

THERMISTOR

CAPTEUR DE PLUIE

COMPTEUR GEGER

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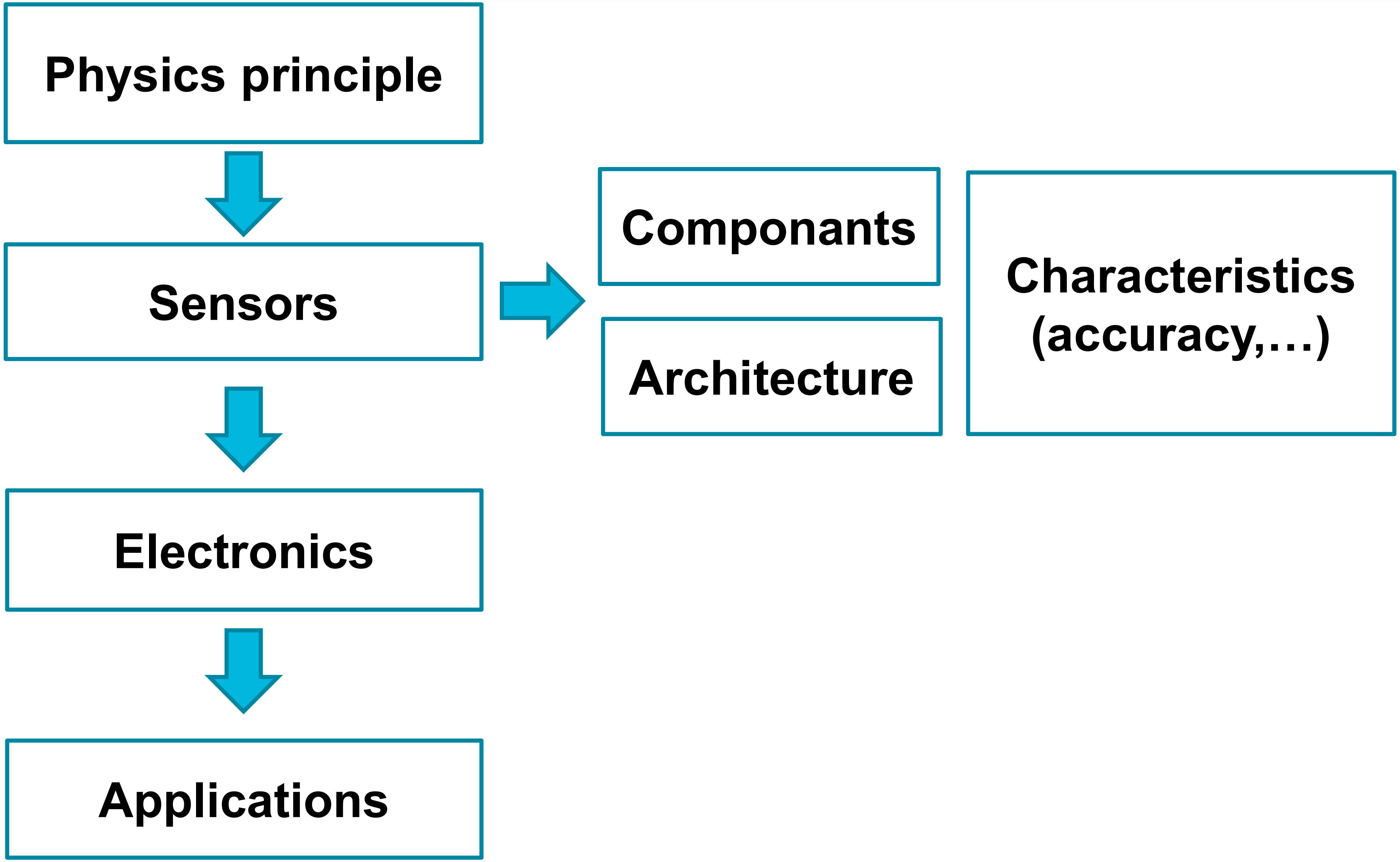

Physics principle
Sensors
Electronics
Applications
Componants
Architecture
Characteristics (accuracy,…)

Principe Physique

Principe : Photochimique; Photoconductivité, Photoélectrique, Transfert thermique

Capteurs Optiques

Composants :
Plaque photo, photorésistance, photodiodes, CCD, CMOS, PMT, bolomètres, fibres

Architecture : Single or multiple sensors; Flood imaging or scanning; Object or Fourier domain

Caractéristiques :

- Transfer Function
- Accuracy
- Calibration
- Hysteresis
- Nonlinearity
- Saturation
- Repeatability
- Resolution
- Dynamic Characteristics

Electronique

Applications

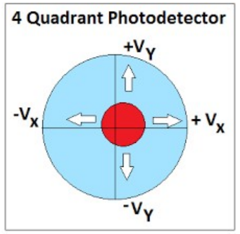
Applications :

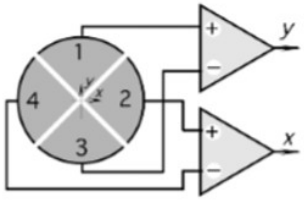
- Imagerie
- Capteurs environementaux
- Etc.

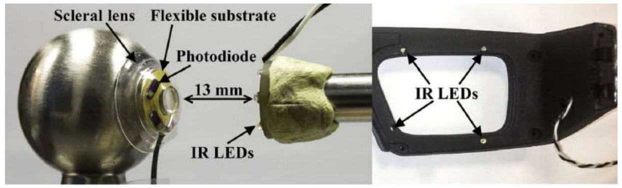
EXEMPLE OF ENVIRONMENTAL SENSORS

1. Position, niveau
2. Détecteur de mouvement, présence
3. Mouvement angulaire
4. Pression
5. Température
6. Pluie
7. Oxygénation
8. Turbidité
9. Capteur de flammes
10. Automobile

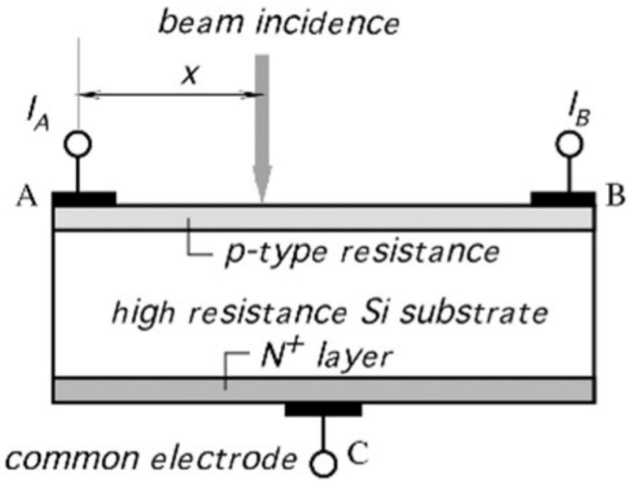
4-Quadrant sensor





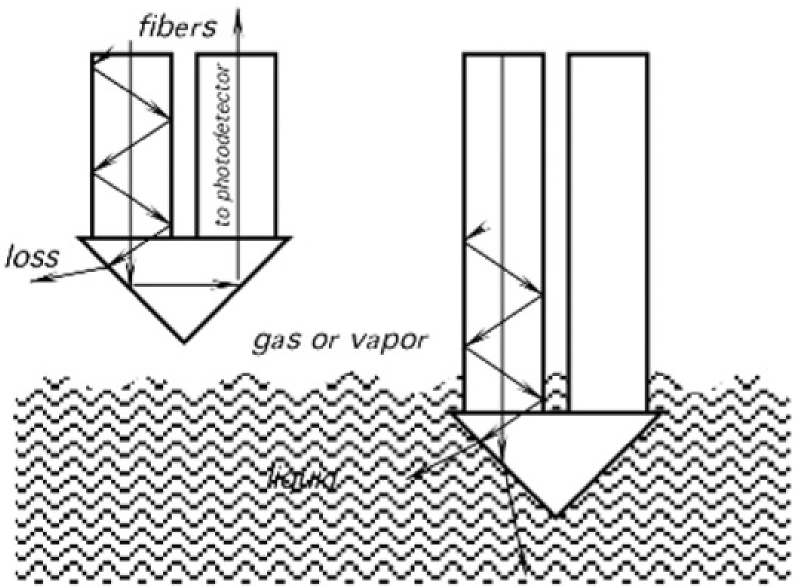


Position sensing device (PSD)

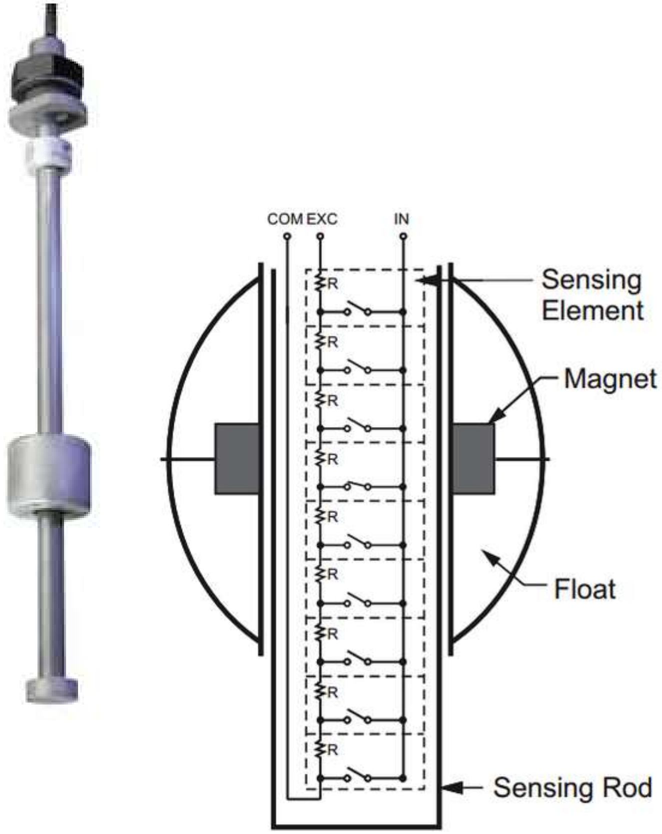


What are the pro and cons of such sensors vs a standard camera ?

Optical level sensor



Floater + REED sensor



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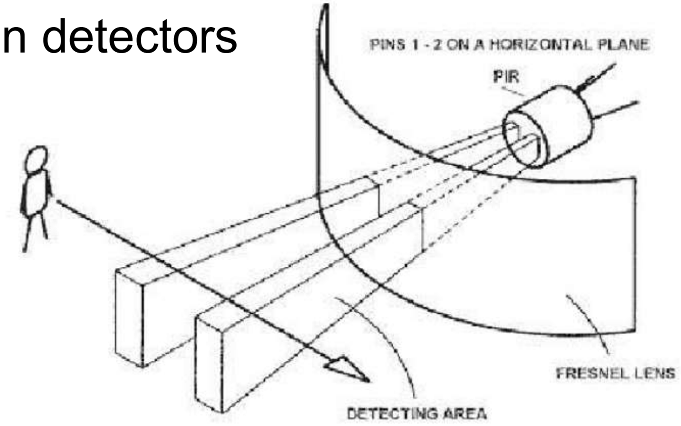
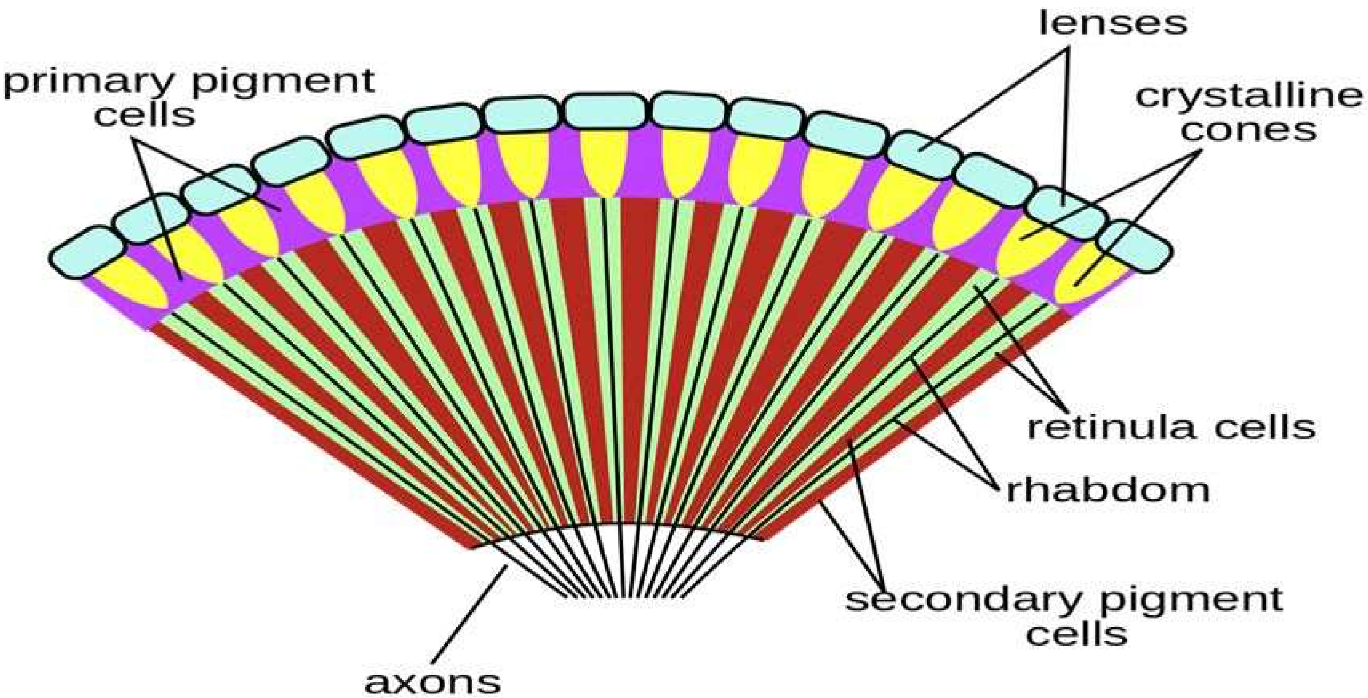
Optoelectric sensor

- Passive infrared (PIR) motion detectors

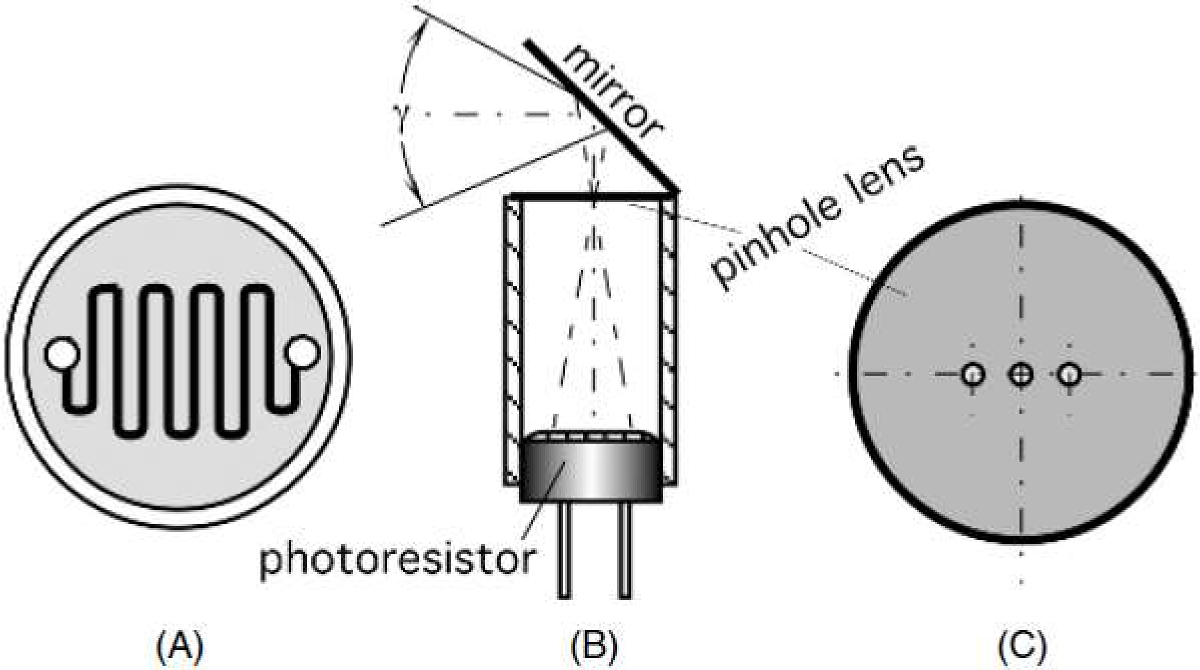


- Active

Compound Eye Anatomy



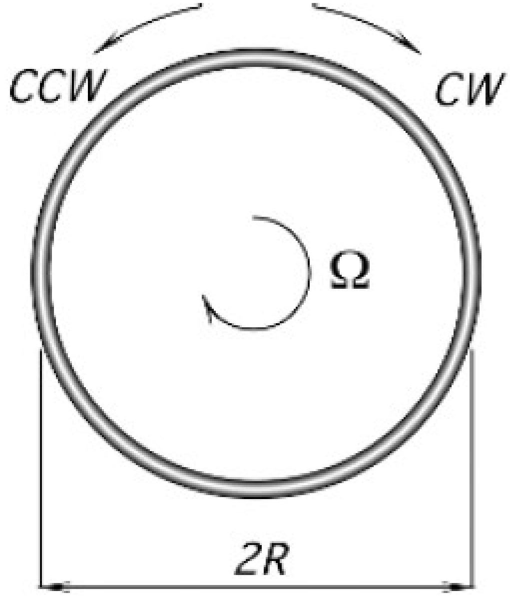
MOTION SWITCH

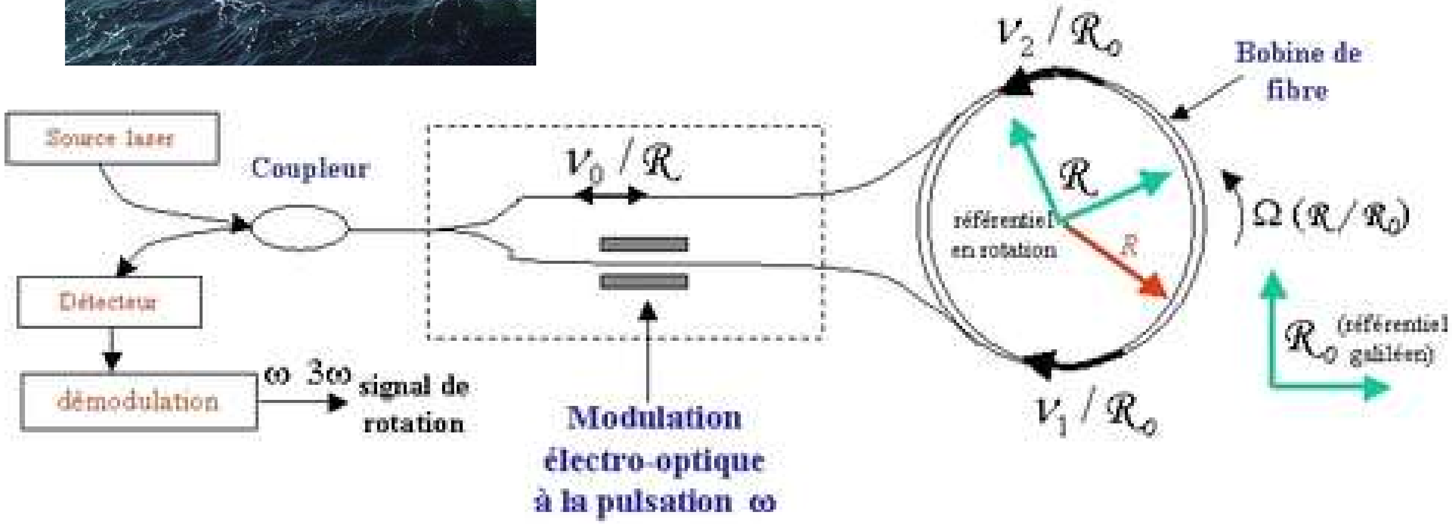


Motion Switch manufactured by Intermatic, Inc., IL)

GYROSCOPE OPTIQUE

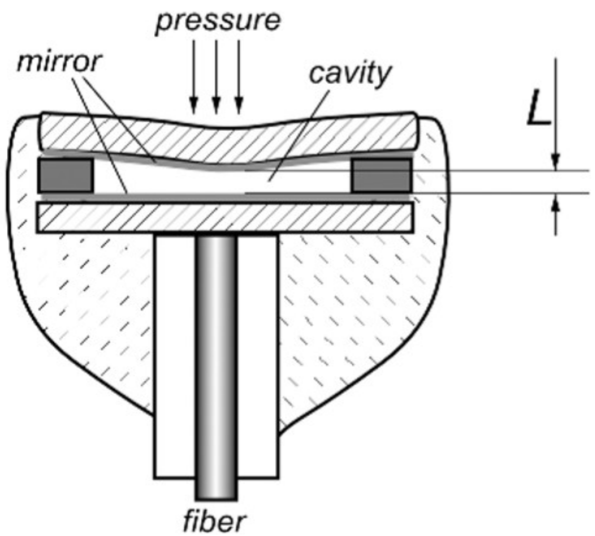
- Sagnac effect
- Therefore, to accurately measure the angular rotation
  - optical resonators,
  - Interferometers.



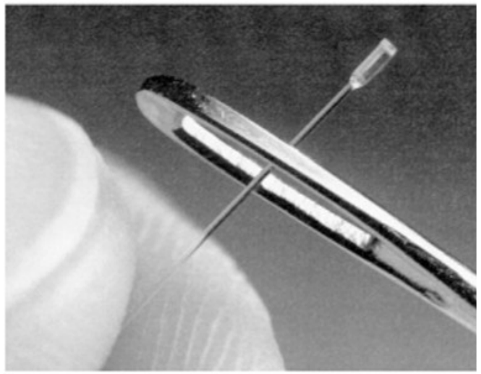


PRESSURE SENSORS

- low-level pressures
- thick membranes are required to enable a broad dynamic range,
- Reduced temperature dependence (/capa)
- simple encapsulation
- small temperature effects,
- high resolution, and high accuracy.



(A)



(B)

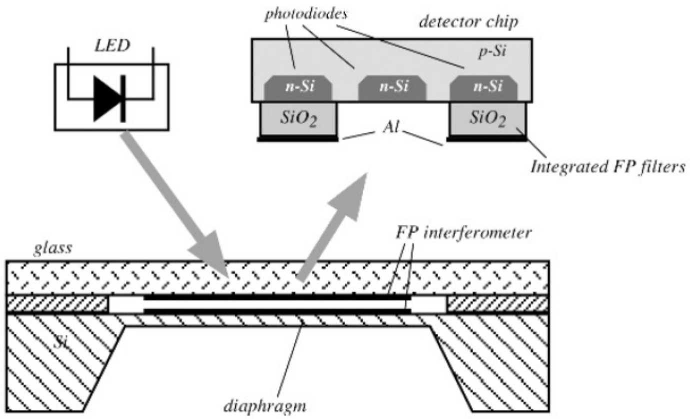
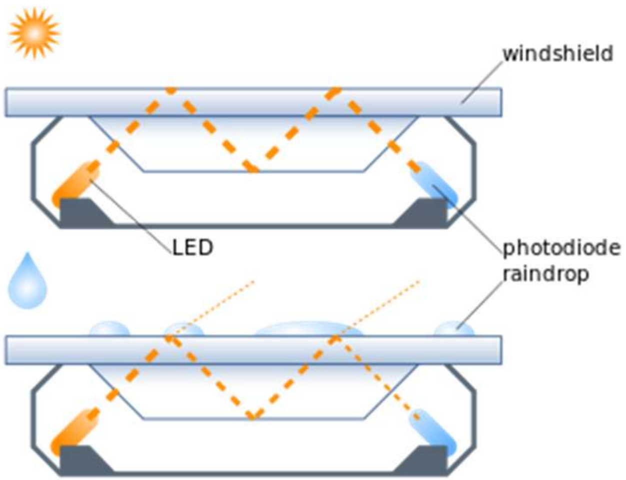


Fig. 7.31. Construction of a Fabry–Perot pressure sensor (A) and view of FISO FOP-M pressure sensor (B).

MESURE DE TEMPÉRATURE

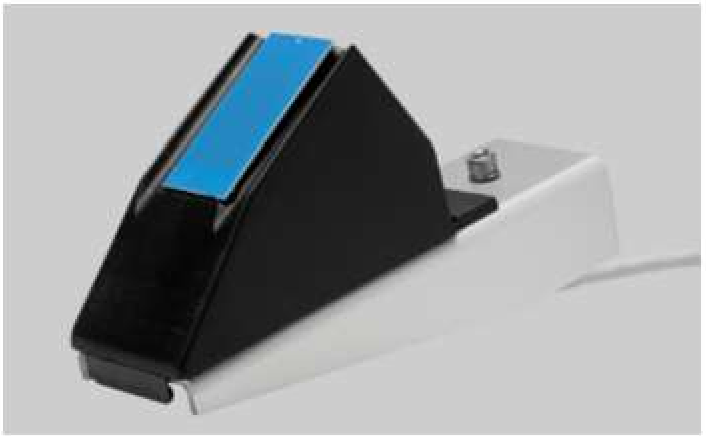
- Contact
- Non contact (rapide, milieu hostile)
- IR (pyrometer)
- Interferometric
- Fluoroptic
- Thermochromic Solution Sensor (biomed applications)

CAPTEUR DE PLUIE



VAISALA

Détecteur de pluie DRD11A

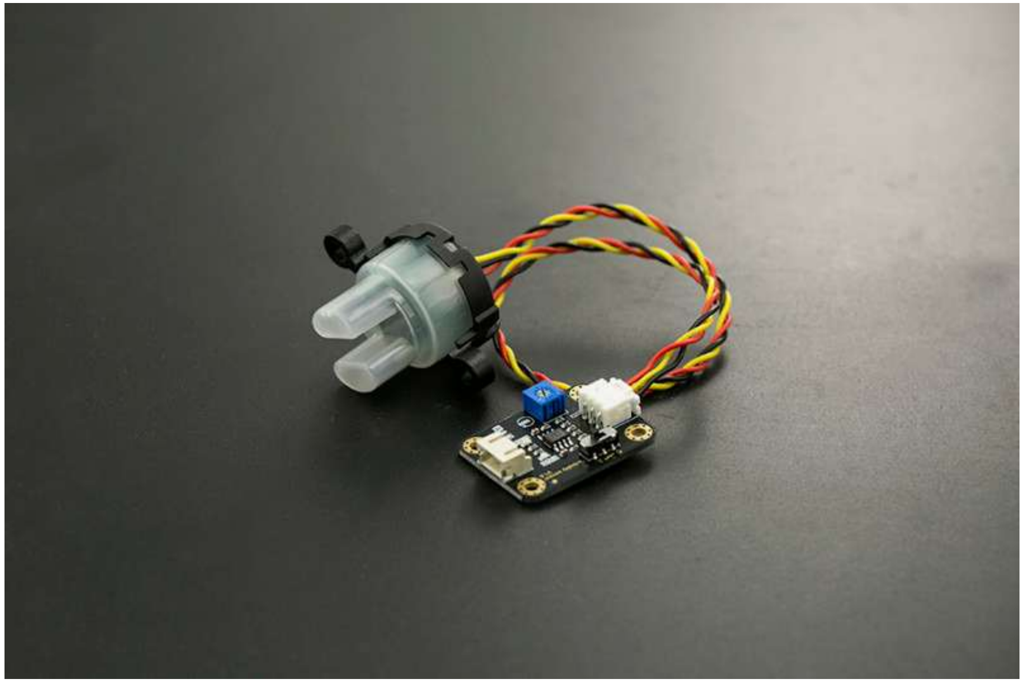


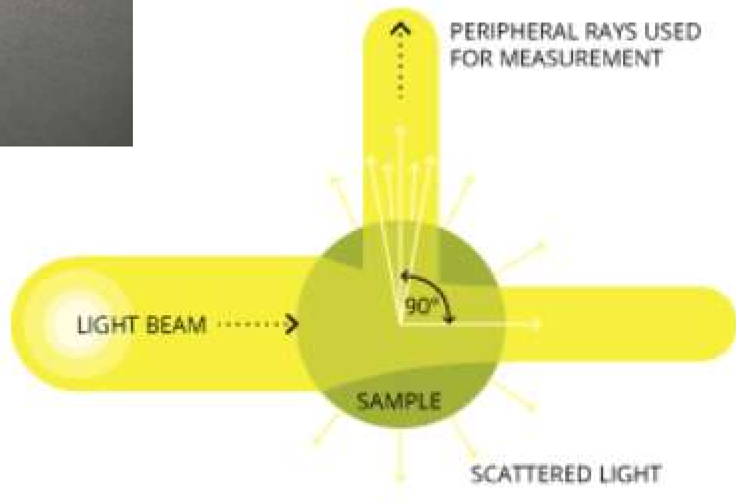
Caractéristiques

- Détection rapide et précise des précipitations (ON/OFF)
- Mesure de l'intensité de la pluie avec unité de traitement
- Élément chauffant pour empêcher la condensation et l'accumulation de neige, aussi pour assécher la surface du capteur rapidement
- Sans entretien

Pulse oximetry

MESURE DE TURBIDITÉ





Nephelometry measures the amount of light scattered at a 90 degree angle from the transmitted light.

turbidity measurement taken at the end of each wash cycle. By measuring the turbidity of the wash water, the dishwasher can conserve energy on lightly soiled loads by only washing as long as necessary. This will result in energy savings for the consumer.

Specifications

Part Number
165D6042P003

Rated Voltage
DC 5V (between No #4 & Ground)

Voltage Differential
2.9V ± 20%

Test Method
After testing voltage in water (0 NTU),
voltage test in water (4000 NTU))
(Voltage between No #2 pin & Ground)

Operating Temperature Range
-30°C ~ 80°C

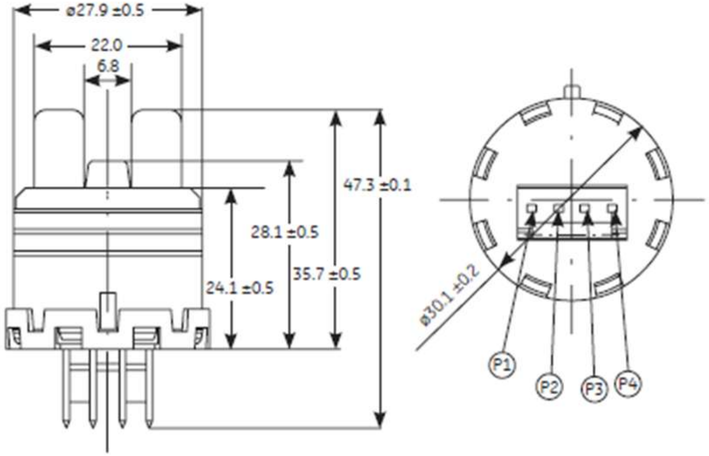
Storage Temperature Range
-10°C~ 80°C

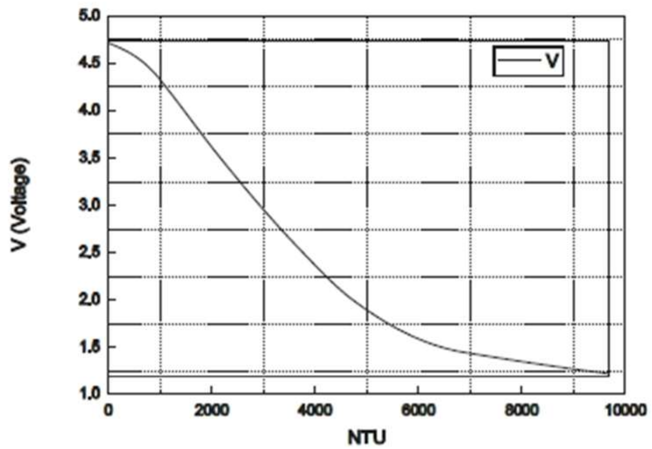
Resistance
R25°C = 10kΩ ± 5%

B Value
B(25/85) = 4100K ± 2%

Rated Current
Max. 30 mA

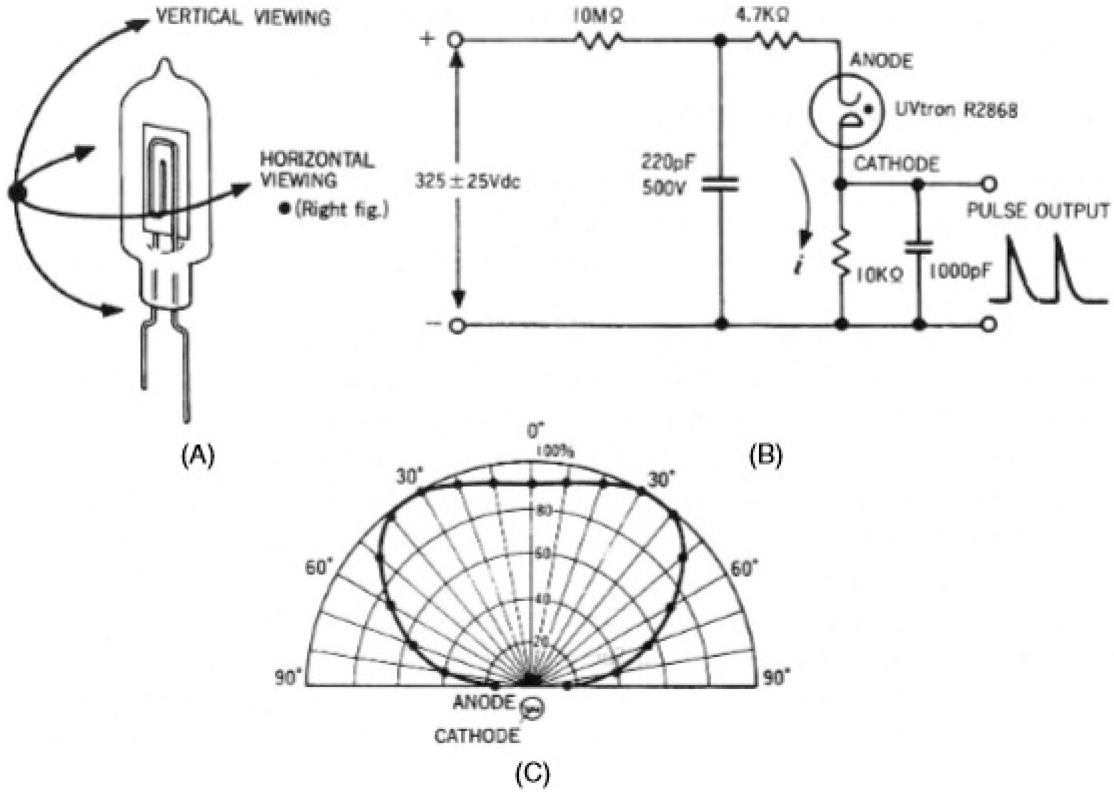
Insulation Resistance
Min 100 MΩ by 500V DC





Application Section
Detecting the turbidity degree of water

CAPTEUR DE FLAMMES



RADIOMETRIC VS PHOTOMETRIC UNIT

QUANTITY	RADIOMETRIC	PHOTOMETRIC
Power	W	Lumen (lm) = cd·sr
Power Per Unit Area	W/m^2	Lux (lx) = $cd \cdot sr/m^2$ = lm/m^2
Power Per Unit Solid Angle	W/sr	Candela (cd)
Power Per Unit Area Per Unit Solid Angle	$W/m^2 \cdot sr$	cd/m^2 = $lm/m^2 \cdot sr$ = nit

The luminous flux (or visible power) in a light source is defined by the photopic luminosity function. The following equation calculates the total luminous flux in a source of light:

$$\Phi_V = 683.002 \int_0^{\infty} V(l)\phi(\lambda)d\lambda$$

where

Φv is the luminous flux, in lumens;
Φ is the spectral radiant flux, in watts per nanometre;
$V(\lambda)$, is the luminosity function, dimensionless;
λ is the wavelength, in nanometres.

Photopic spectral luminous efficiency curve:

$V(\lambda)=1.019 \exp(-285.4(\lambda-0.559)^2)$ (λ in microns)

For example,

- 5mW red (650nm) laser pointer
  - V(650) = 0.096
  - 683 x 0.096lm/W x 0.005W = 0.33lm

- 5mW green (532nm) laser pointer
  - 683 x 0.828lm/W x 0.005W x 683lm/W = 2.83lm.

Same radiant flux but the green laser pointer will appear approximately 8.5 times brighter than the red one