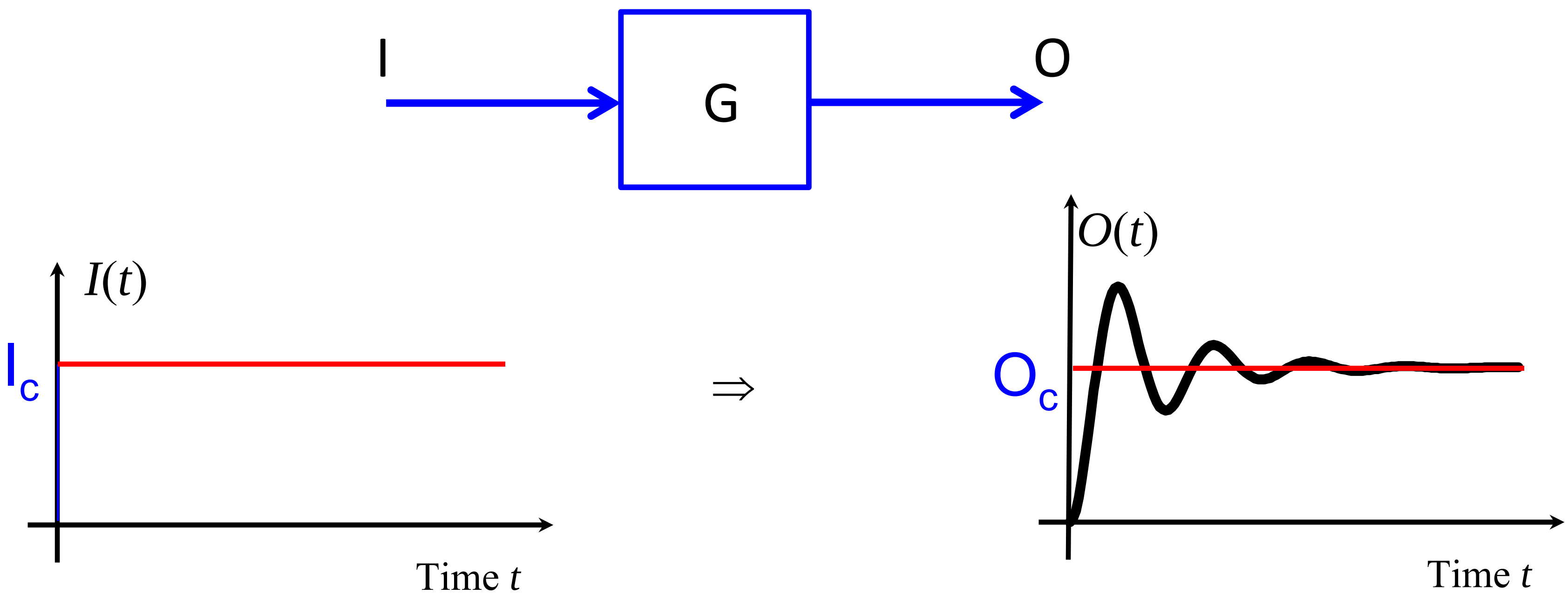
# Static Response Characterization

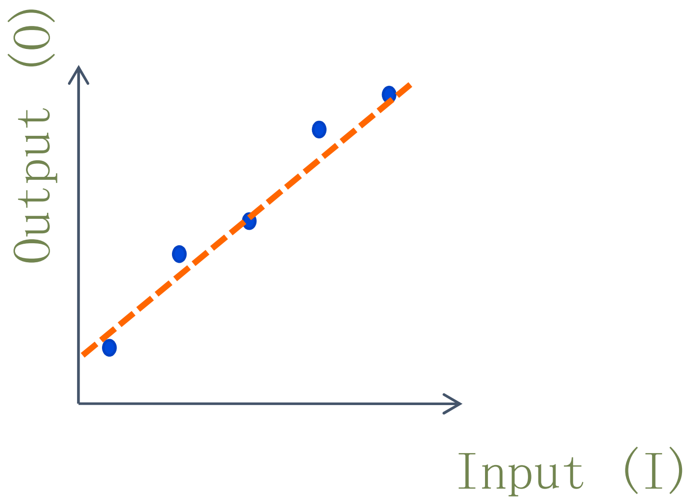
Study the final values of the responses of a system to constant input signals:




Concern $O_c$ vs $I_c$ only!

# Static response characteristics

- Static relationship between input (I) and output (O)

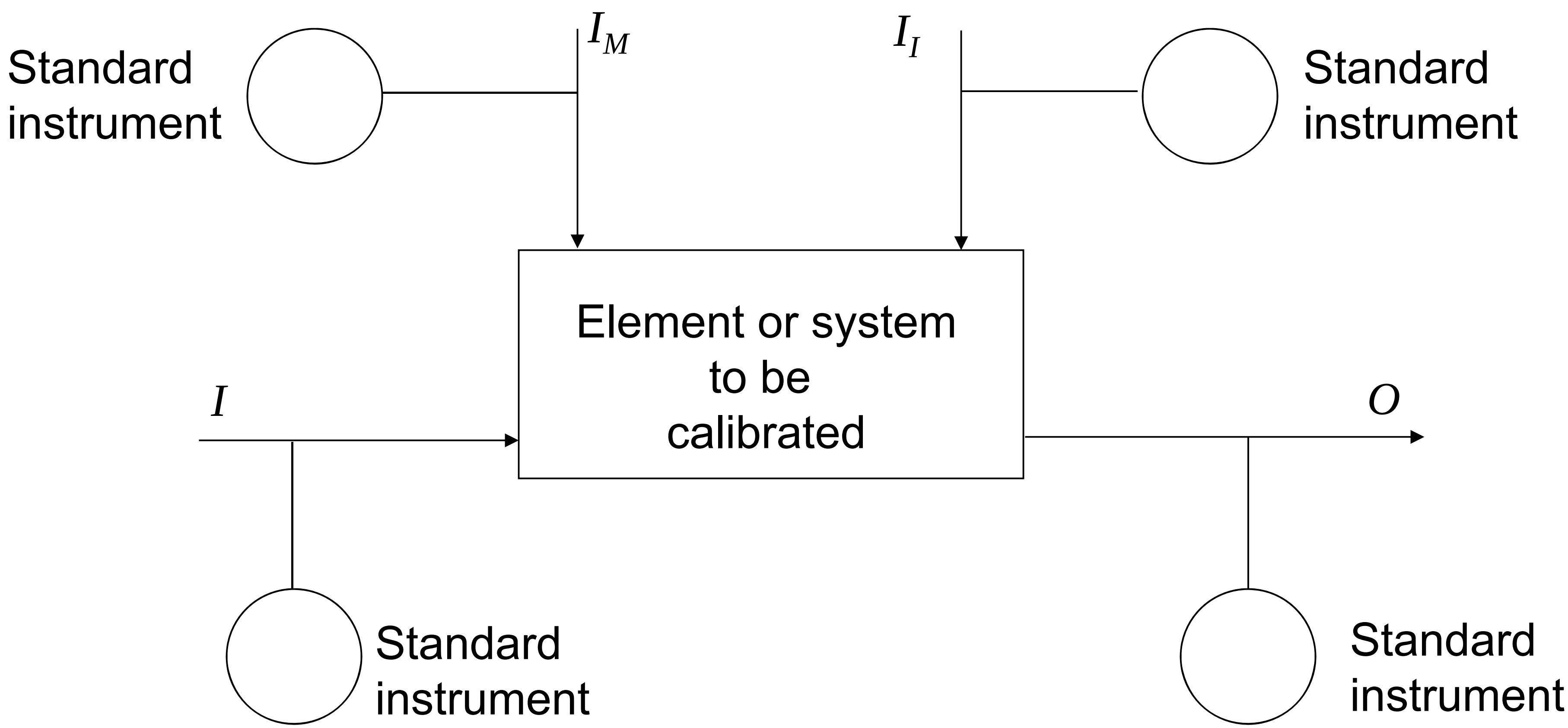



- **Range**: the values of the measurand to which the system responds properly
- **Span**: the difference between the upper and lower values of the range
- **Ideal linear** (straight-line) **relationship**: $O_{ideal} = KI + a$
- **Sensitivity K**: $dO/dI$ (e.g., $K$ could be the slope of a straight line)
- **Non-linearity**: difference of actual and ideal straight-line behavior:

$$N(I) = O(I) - (KI + a)$$

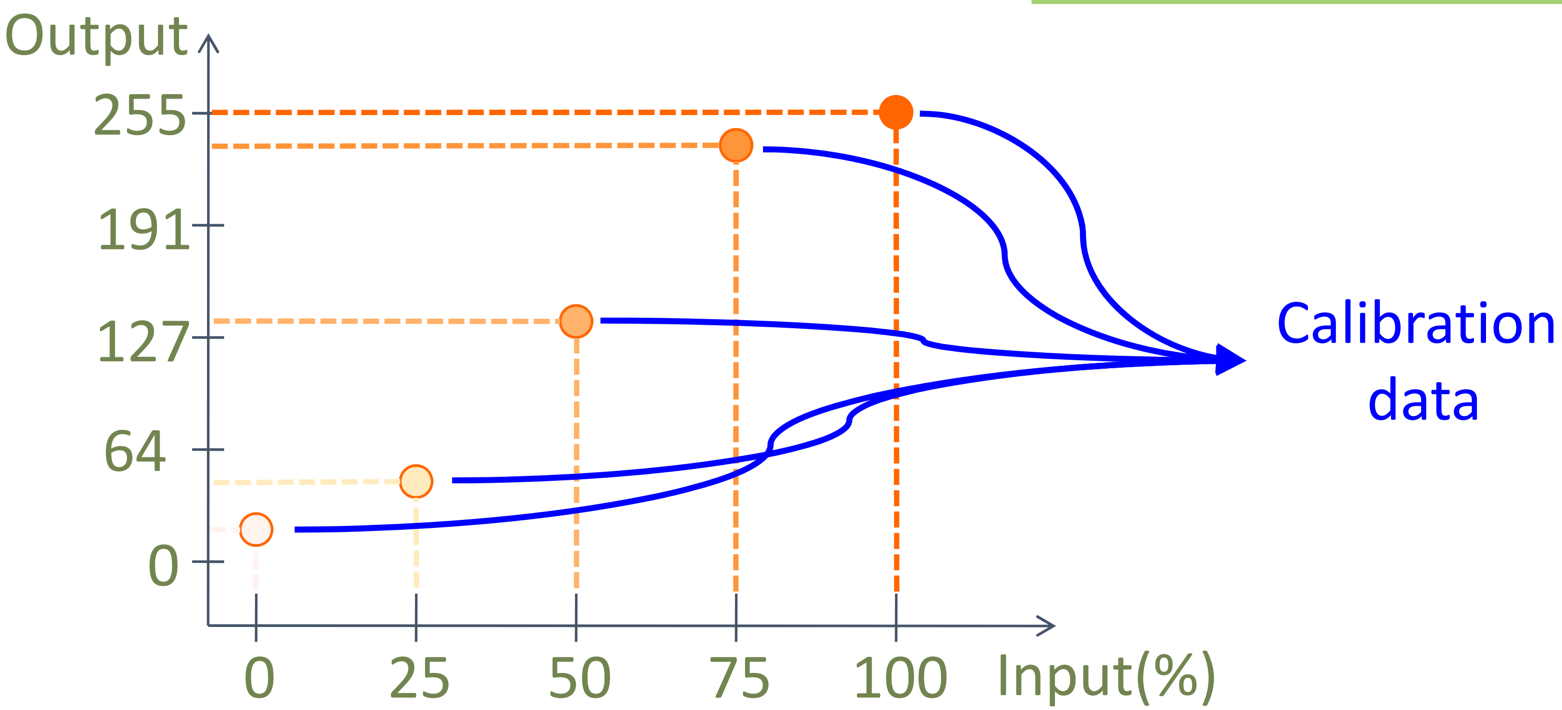
# Static Calibration

- Static characteristics of an element are found by measuring the corresponding values of the constant input I and the steady-state output O and the environmental inputs at constant values with instruments of known response



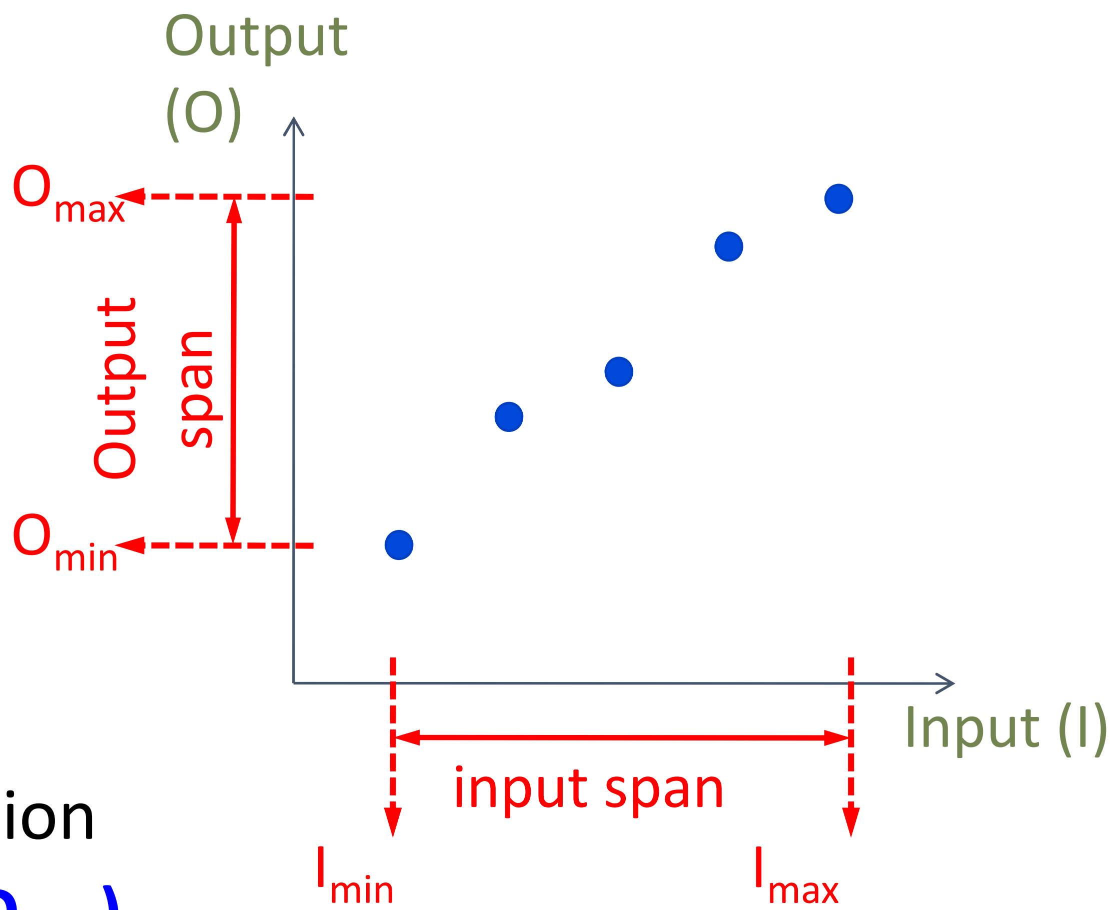
# Example: color calibration

- Spectrophotometer – Reflective color measurement
  - Use test target with “known” color/tone values as inputs to the spectrophotometer



# Range and span

- Input Range:
  $[I_{min}\ ,\ I_{max}]$
- Input Span:
  $(I_{max} - I_{min})$
- Output Range:
  $[O_{min}\ ,\ O_{max}]$
- Output Span:
  $(O_{max} - O_{min})$
- Full Scale Deflection
  $(fsd) = (O_{max} - O_{min})$



# Solid State Pressure Sensors
# D8M

## Solid State Pressure Sensors with Analog, Pulse or Frequency Outputs

- Compact housing measures 30L x 30W x 12.4H mm.
- Accept 4 mm OD tubing (D8M-A1, -R1); 3 mm OD tubing for (D8M-D1, -D2), 6 mm OD tubing for D8M-D82.
- Chemical-resistant plastic (PBT) body.
- Metal shield mounted version (D8M-D82) available.
- IP40 enclosure rating for embedded applications.
- Pre-wired and PCB mounting models available.

## Ordering Information

| Operating pressure range | Output signal | Output frequency | Power supply voltage | Withstand pressure | Model |
|---|---|---|---|---|---|
| 0 to 4.9 kPa (0 to 0.71 psi) | Analog, 15 to 1247 mV | - | 2.2 ±0.1 VDC | 58.8 kPa (8.53 psi) for 3 minutes | D8M-A1 |
| 0 to 5.88 kPa (0 to 0.85 psi) | Pulse count, 1 pulse/9.81 Pa (1/0.0014 psi) | - | 2.2 to 3.4 VDC with regulator | 58.8 kPa (8.53 psi) for 3 minutes | D8M-D1 |
| 0 to 5.88 kPa (0 to 0.85 psi) | Pulse count, 1 pulse/9.81 Pa (1/0.0014 psi) | -- | 2.2 to 3.4 VDC with regulator | 58.8 kPa (8.53 psi) for 3 minutes | D8M-D2 |
| 0 to 4.9 kPa (0 to 0.71 psi) | Pulse coun 1 pulse/9.8 (1/0.0014 p | | | | |
| 0 to 196.13 Pa (0 to 0.028 psi) | Frequency, 1 kHz/9.81 (1 kHz/0.0C | | | | |

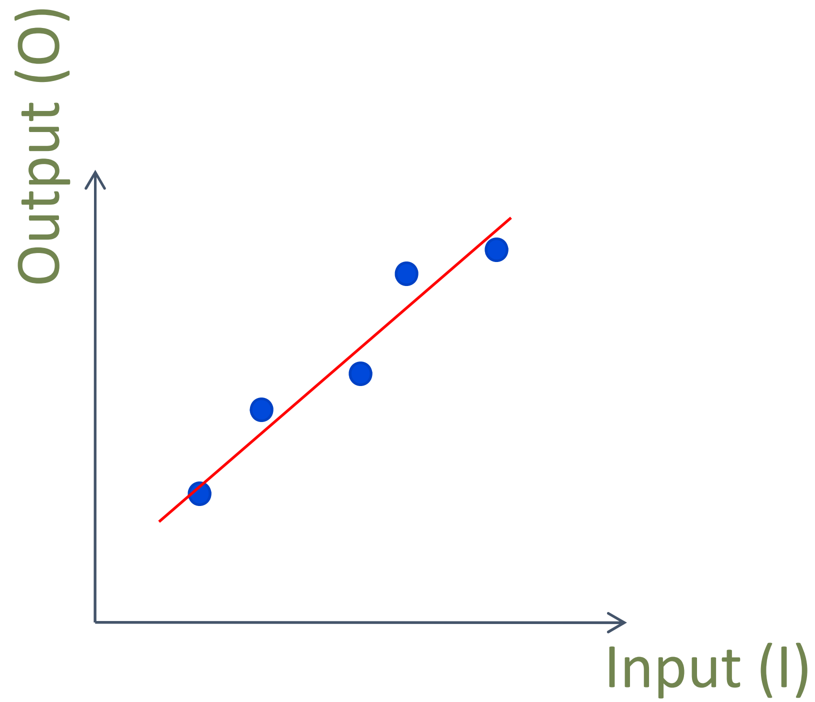
| Operating pressure range | Output signal |
|---|---|
| 0 to 4.9 kPa (0 to 0.71 psi) | Analog, 15 to 1247 mV |

# Best linear (straight line) fit

- Generate a linear relationship between the input (I) and output (O), i.e.

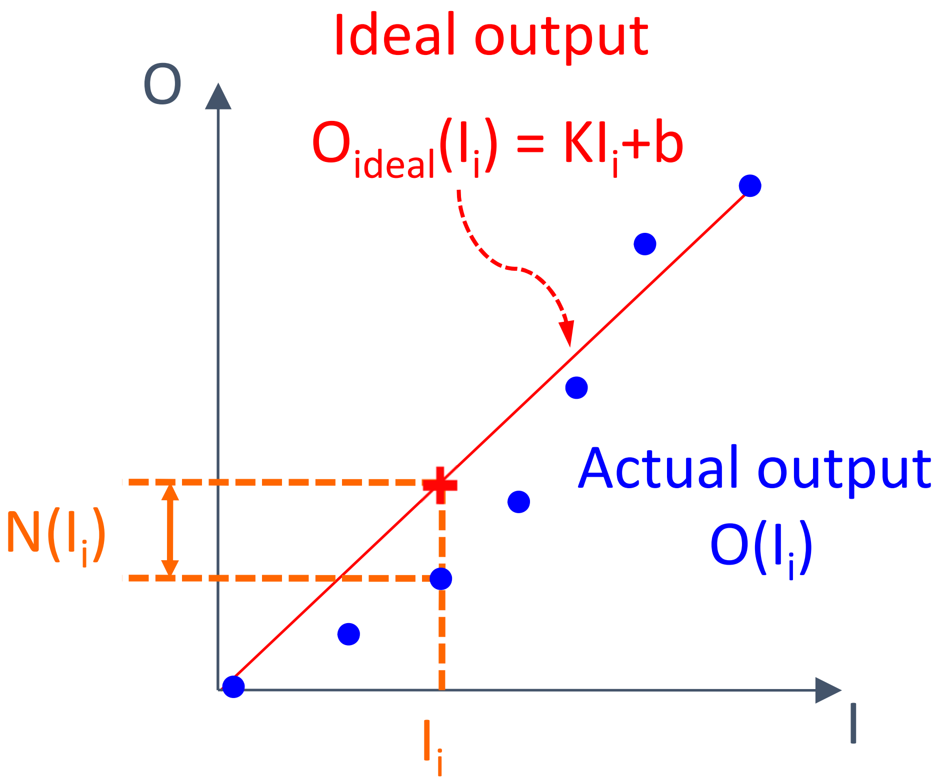
$$O_{ideal} = K \cdot I + b$$

  - One way to generate a best straight line fit is using linear regression.



# Nonlinearity

- Difference between actual and ideal straight line behavior




Input: $I_i \quad i = 1, 2, \ldots, N$

Actual Output: $O(I_i)$

Best linear fit:

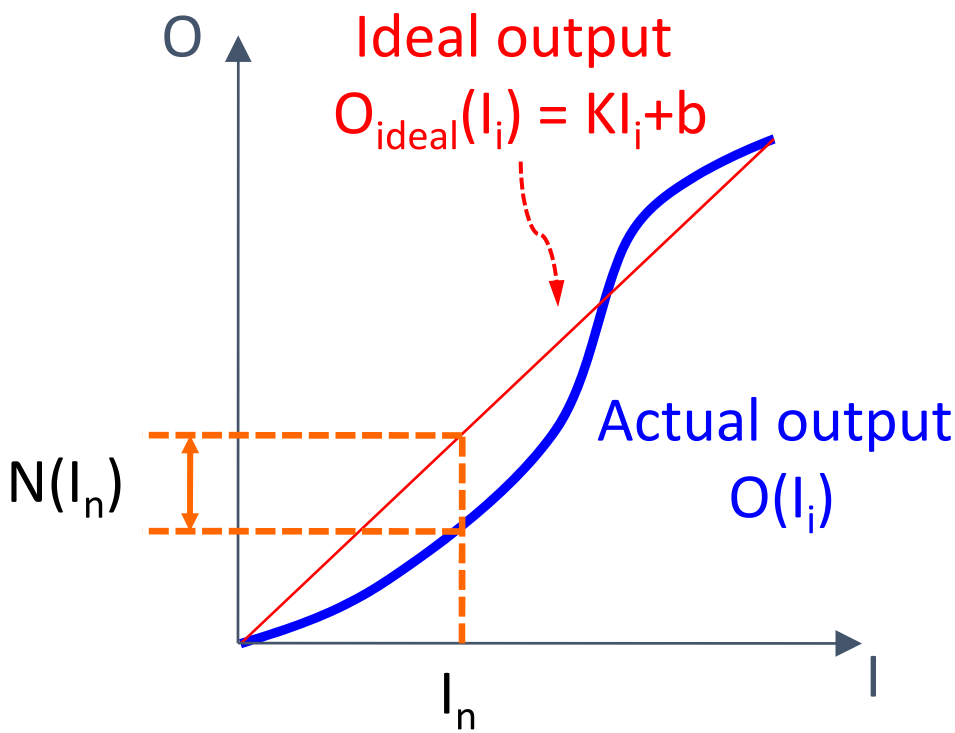
$$O_{ideal}(I_i) = KI_i + b$$

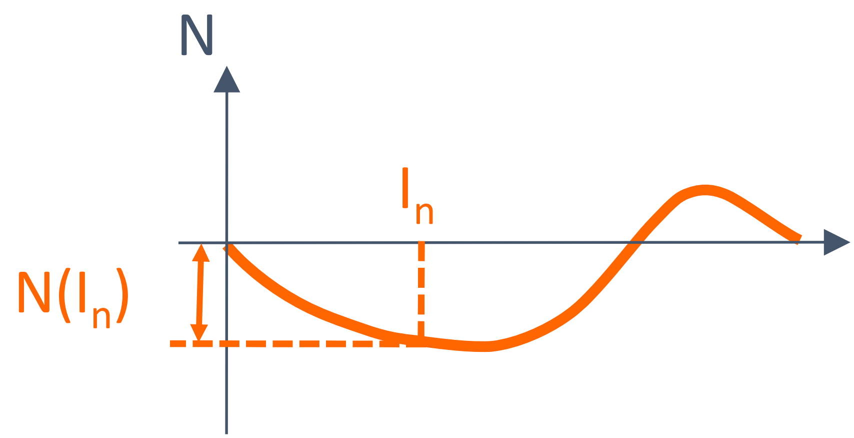
**<u>Nonlinearity</u>**:

$$N(I_i) = O(I_i) - O_{ideal}(I_i)$$

$$= O(I_i) - (KI_i+b)$$

# Nonlinearity



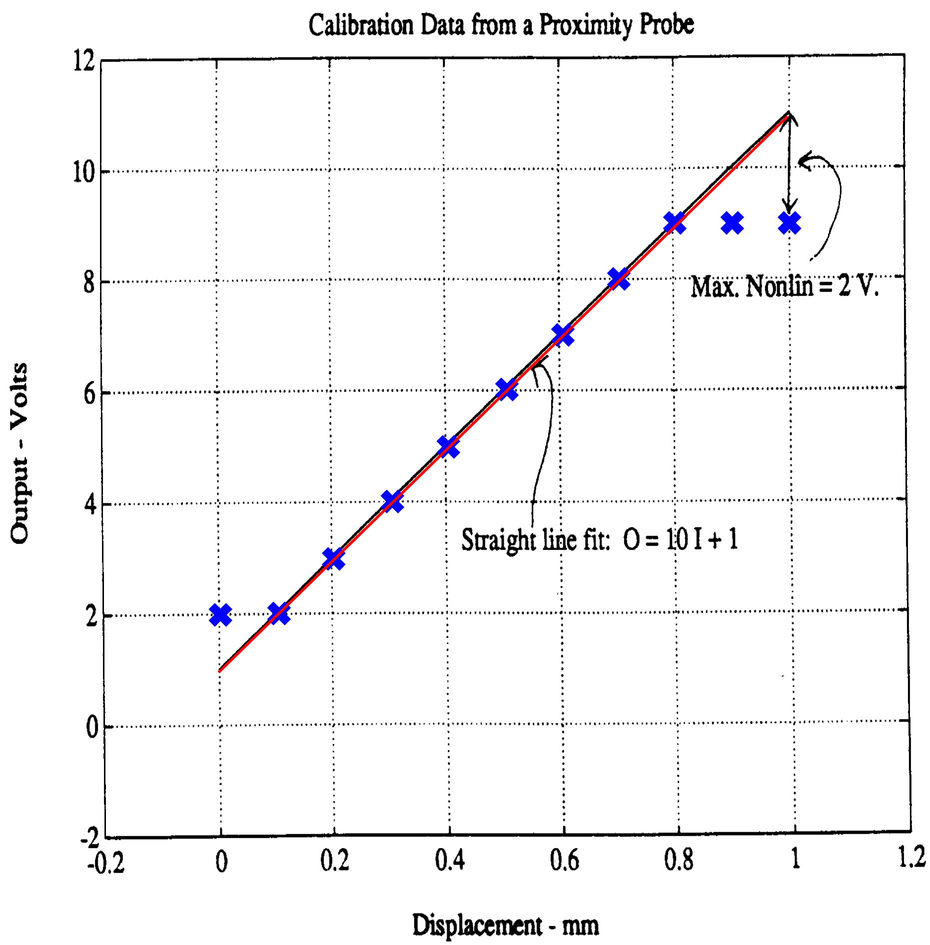

**Maximum nonlinearity:**

$$\underset{i}{\mathrm{Max}}\,\mathrm{N}(\mathrm{I_i})$$

**Maximum nonlinearity as a % of fsd:**

$$= \frac{\underset{i}{\mathrm{Max}}\,N(I_i)}{fsd} \times 100\% = \frac{\underset{i}{\mathrm{Max}}\,N(I_i)}{\left|O_{\mathrm{max}} - O_{\mathrm{min}}\right|} \times 100\%$$

# Nonlinearity: example

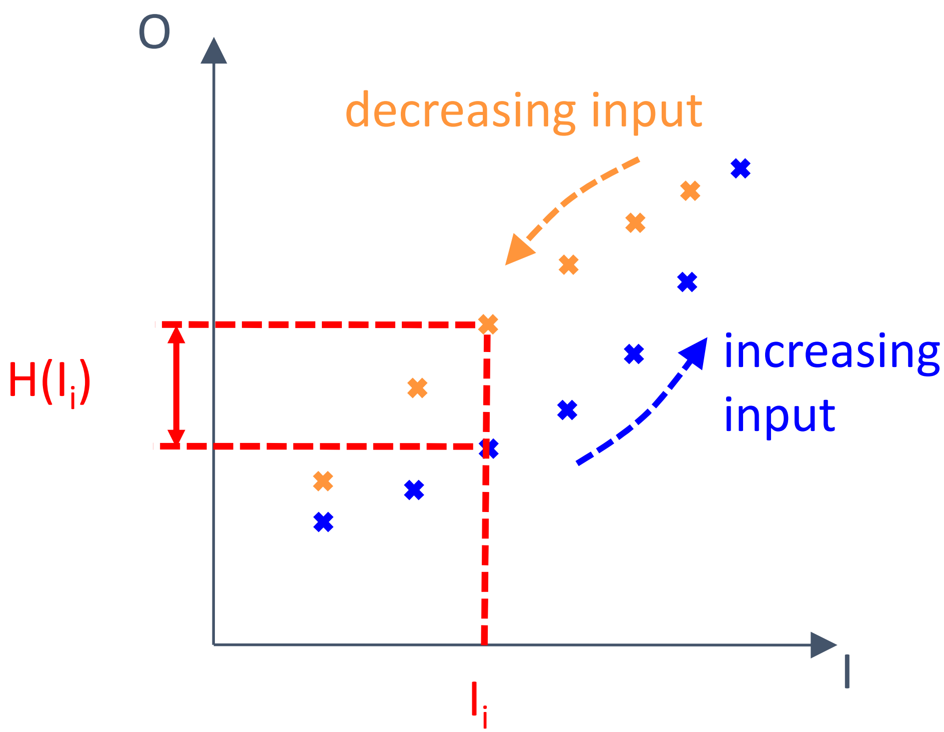



Maximum nonlinearity:

Maximum nonlinearity as % of fsd:

# Hysteresis

- The difference between the output values for increasing and decreasing inputs (I), at each value of the input.

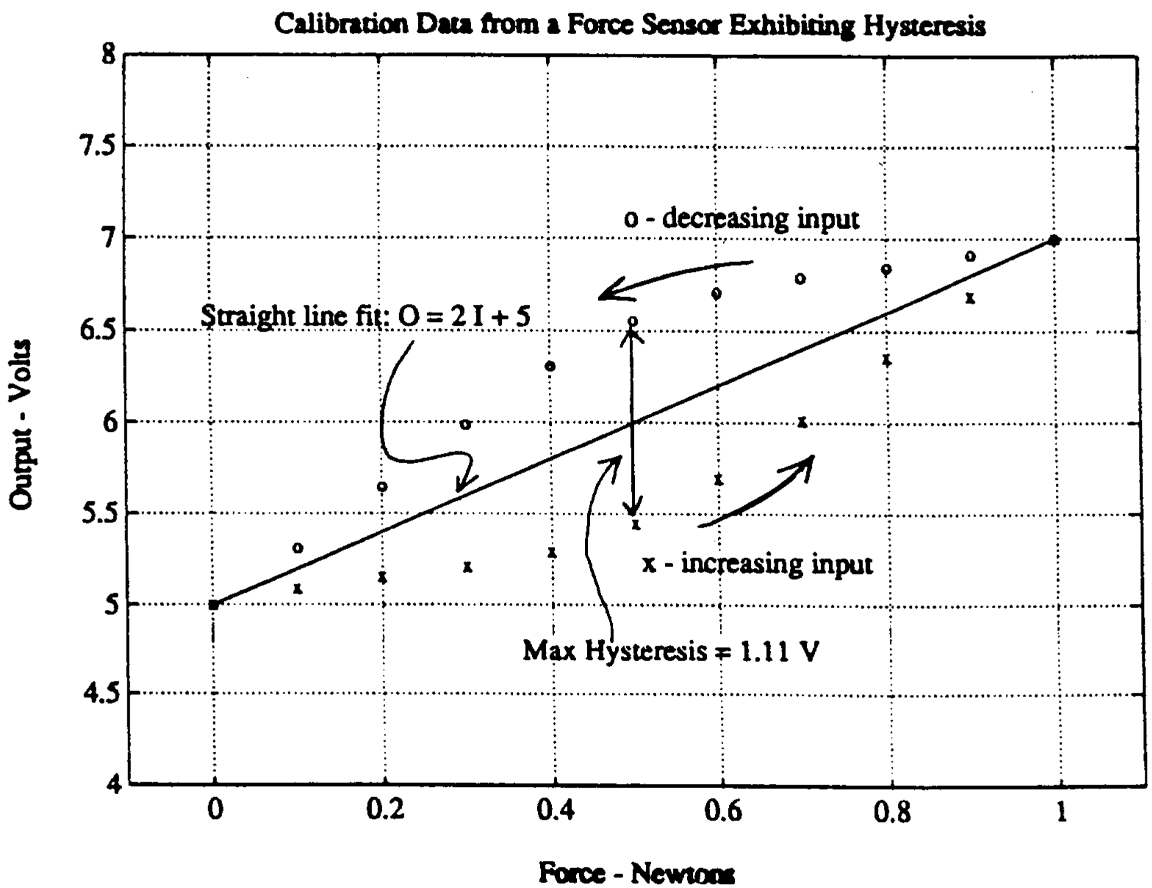



**Maximum hysteresis**

$$\underset{i}{\mathrm{Max}}\, H(I_i)$$

**Maximum hysteresis as a % of fsd:**

# Hysteresis: example



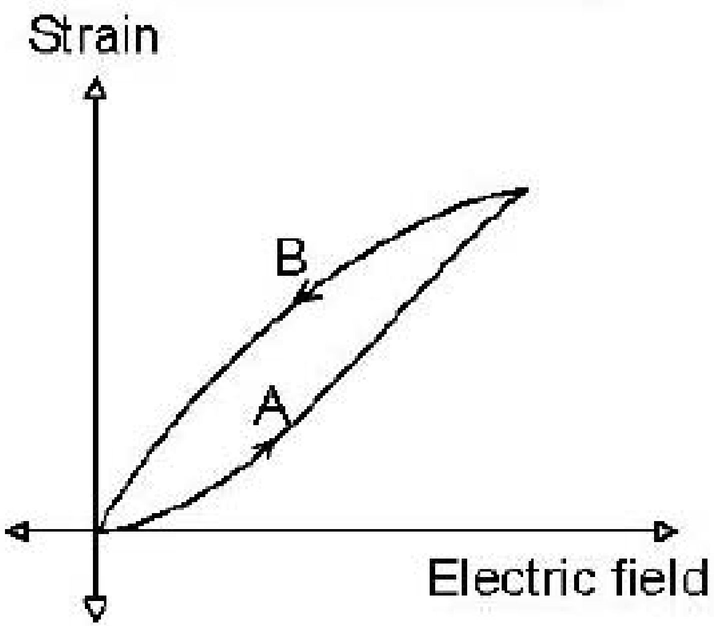

Maximum hysteresis:

Maximum hysteresis as % of fsd:

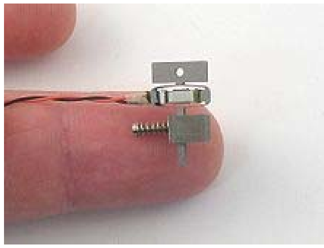
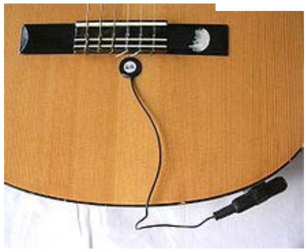
# Hysteresis in piezoelectric material

- Piezoelectricity
  the charge which accumulate in certain solid materials in response to applied mechanical strain
  - Power conversion
  - Microphone, guitar pickup, sta gage, electric drum pad, pressure/force sensing
  - Speaker, motor, atomic force microscope,

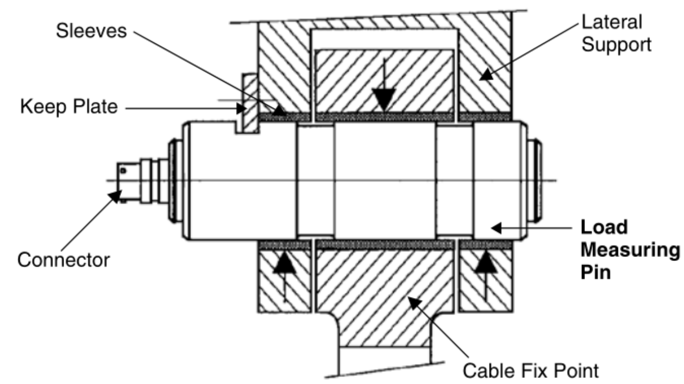
| Material | Hysteresis (%) |
|---|---|
| S1 | 19 |
| S2 | 13 |
| H1 | 20 |





*Model LB 236*
*Load Measuring Pin*




www.magtrol.com

| ELECTRICAL CHARACTERISTICS | | | |
|---|---|---|---|
| Operating Principle | | Double full-bridge strain gauge | |
| Bridge Impedance:<br>• Input<br>• Output | | 800 Ω<br>700 Ω | |
| Power Supply | | 5 to 12 V DC / AC | |
| Zero Adjustment | | ± 1% of fsd | |
| Transducer Sensitivities | 0.5 mV/V ± 3% | 1 mV/V ± 3% | 1 mV/V ± 3% |
| Non-linearity Error | | < 0.2% of fsd | |
| Non-linearity + Hysteresis Error | | < 0.4% of fsd | |
| Repeatability | | ± 0.1% of fsd | |
| OIML Class | not available | R60 D0.1 | not available |
| Operating Temperature | | -25 °C to +80 °C | |
| Storage Temperature | | -55 °C to +125 °C | |
| Temperature Influence:<br>• On Zero<br>• On Sensitivity | | ± 0.02% of fsd / K<br>± 0.02% / K | |
| Influence on Measurement Signal (Shift of Force Angle with Respect to Measurement Axis) | | According to the cosine function | |

# Measurement characteristics

- **Range**
  the values of the input and output to which the measurement system will respond properly
  - $[I_{min}, I_{max}]$
  - $[O_{min}, O_{max}]$

- **Span**
  the difference between the upper and lower values of the range
  - $(I_{max} - I_{min})$
  - $(O_{max} - O_{min})$

- **Ideal Linear (Straight-line) Relationship**: $O_{ideal} = KI + b$
  where $K$ is ideal straight-line slope and $b$ is ideal straight-line intercept

- **Sensitivity**: $dO/dI$
  (for the ideal case, this is $K$, the slope of the ideal straight-line)

- **Bias**
  intercept of the best-fit straight line with the output (O) axis, for the ideal case, this is $b$

# Measurement characteristics

- **Nonlinearity**
  difference between actual and ideal straight-line behavior
  $N(I_i) = O(I_i) - (KI_i + b)$
- **Maximum Nonlinearity**
  the maximum nonlinearity within the input range: $\underset{i}{\mathrm{Max}}\, N(I_i)$
  - As a percept of full scale deflection (fsd)

$$\frac{\underset{i}{\mathrm{Max}}\, N(I_i)}{\left|O_{\max} - O_{\min}\right|} \times 100\%$$

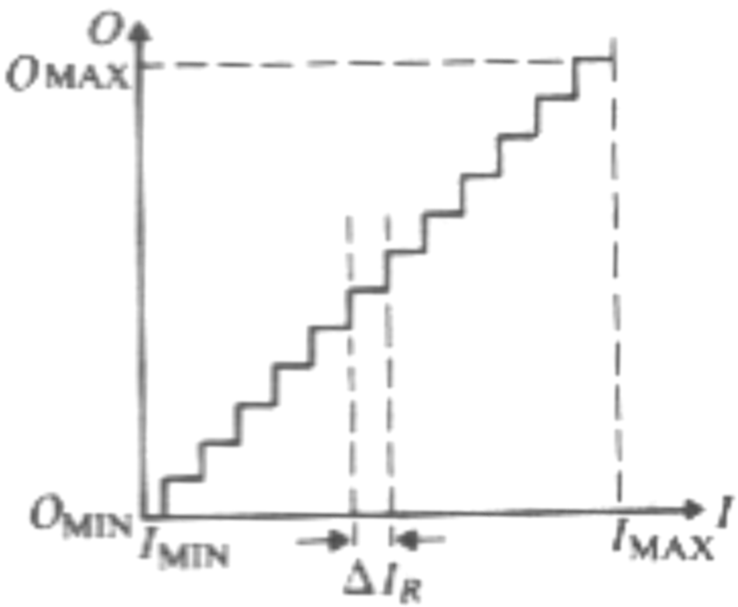
- **Hysteresis**
  difference between the output values for increasing and decreasing inputs
- **Maximum Hysteresis**
  the maximum hysteresis within the input range: $\underset{i}{\mathrm{Max}}\, H(I_i)$
  - As a percept of full scale deflection (fsd)

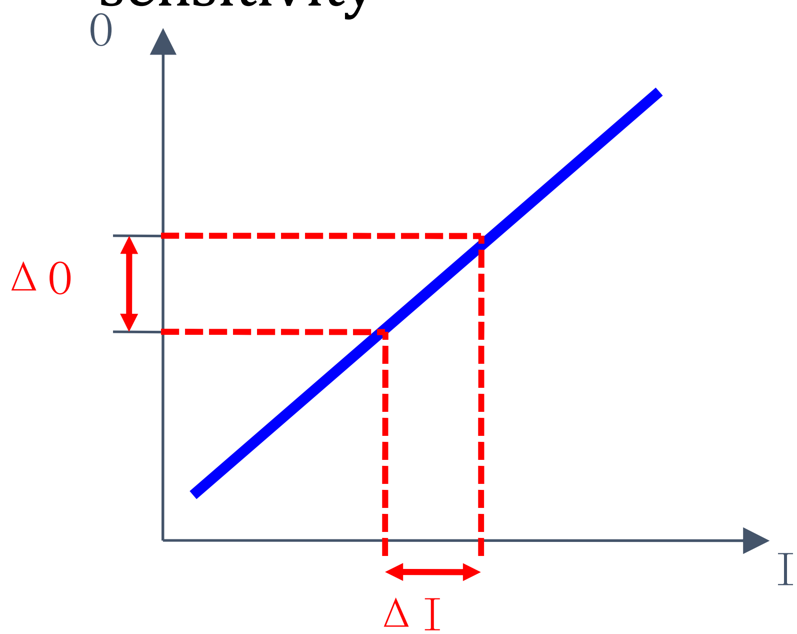
$$\frac{\underset{i}{\mathrm{Max}}\, H(I_i)}{\left|O_{\max} - O_{\min}\right|} \times 100\%$$

# Resolution

- Resolution is the largest change in the input (I) that can occur without any detectable change in the output (O)

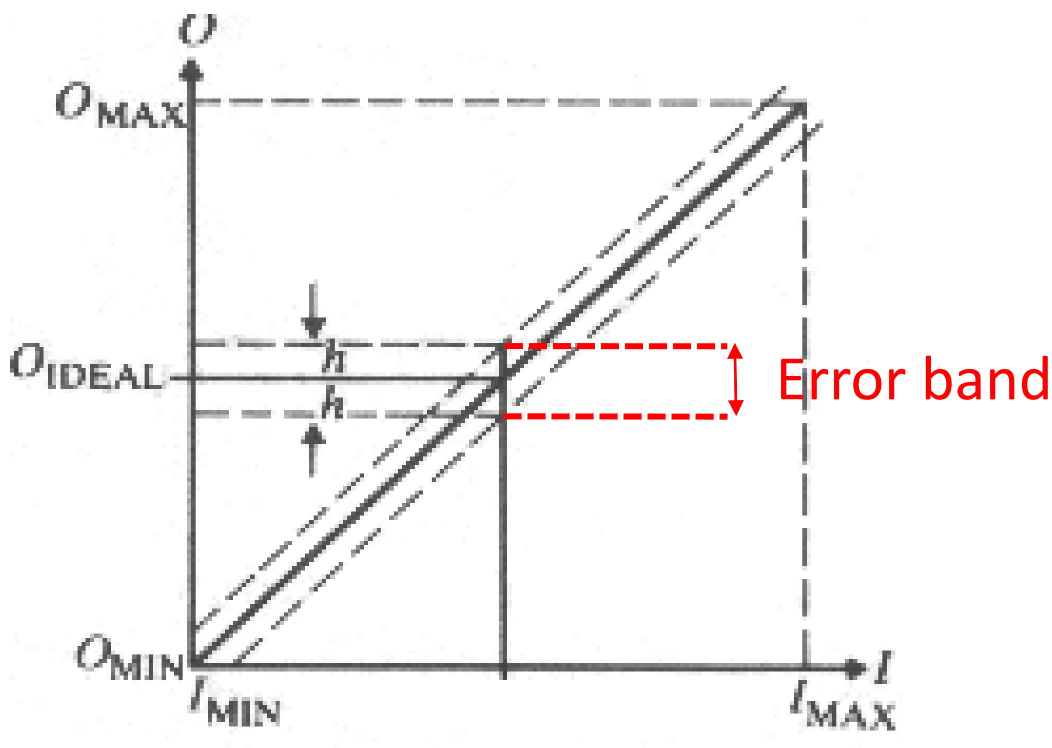
$$\text{Resolution}(\Delta I) = \frac{\Delta O}{K} = \frac{\text{Ouput device resolution}}{\text{sensitivity}}$$



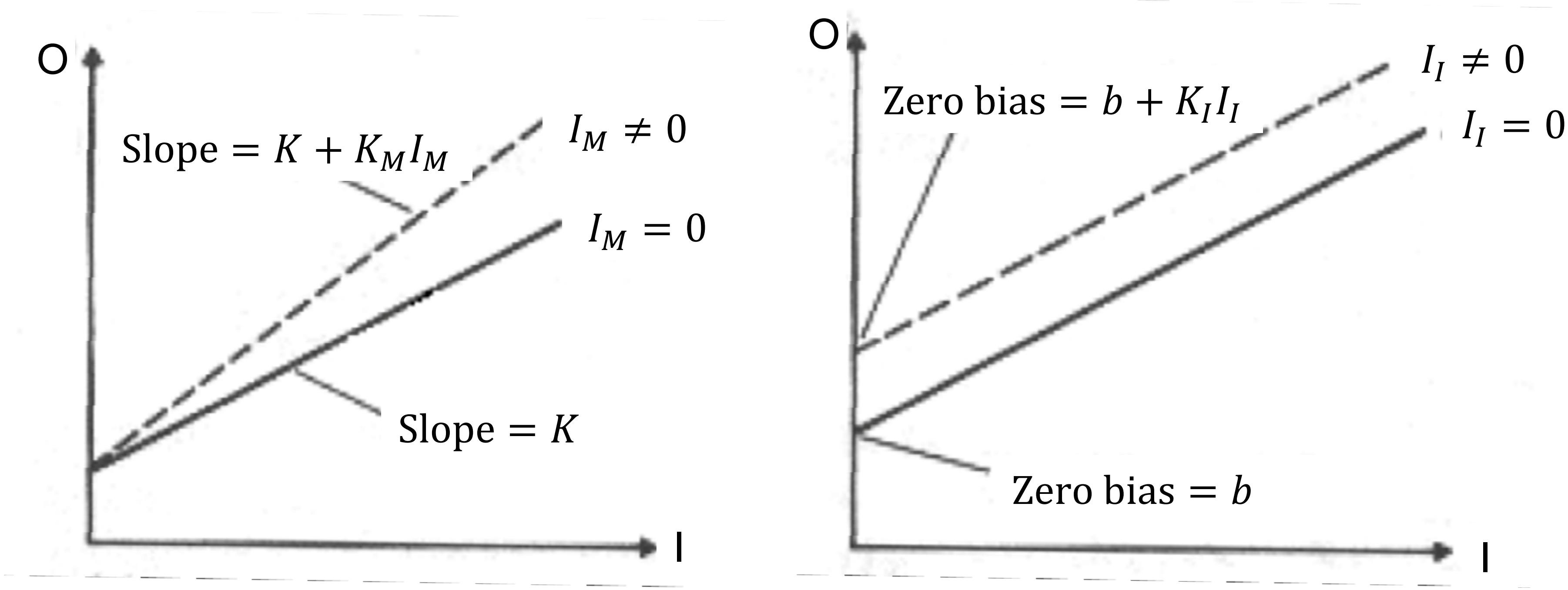
# Error bands

- *Non-linearity*, *hysteresis*, and *resolution* effects in many sensors are so small that it is difficult or not worthwhile to exactly quantify each individual effect.  Often this is reported as an error band

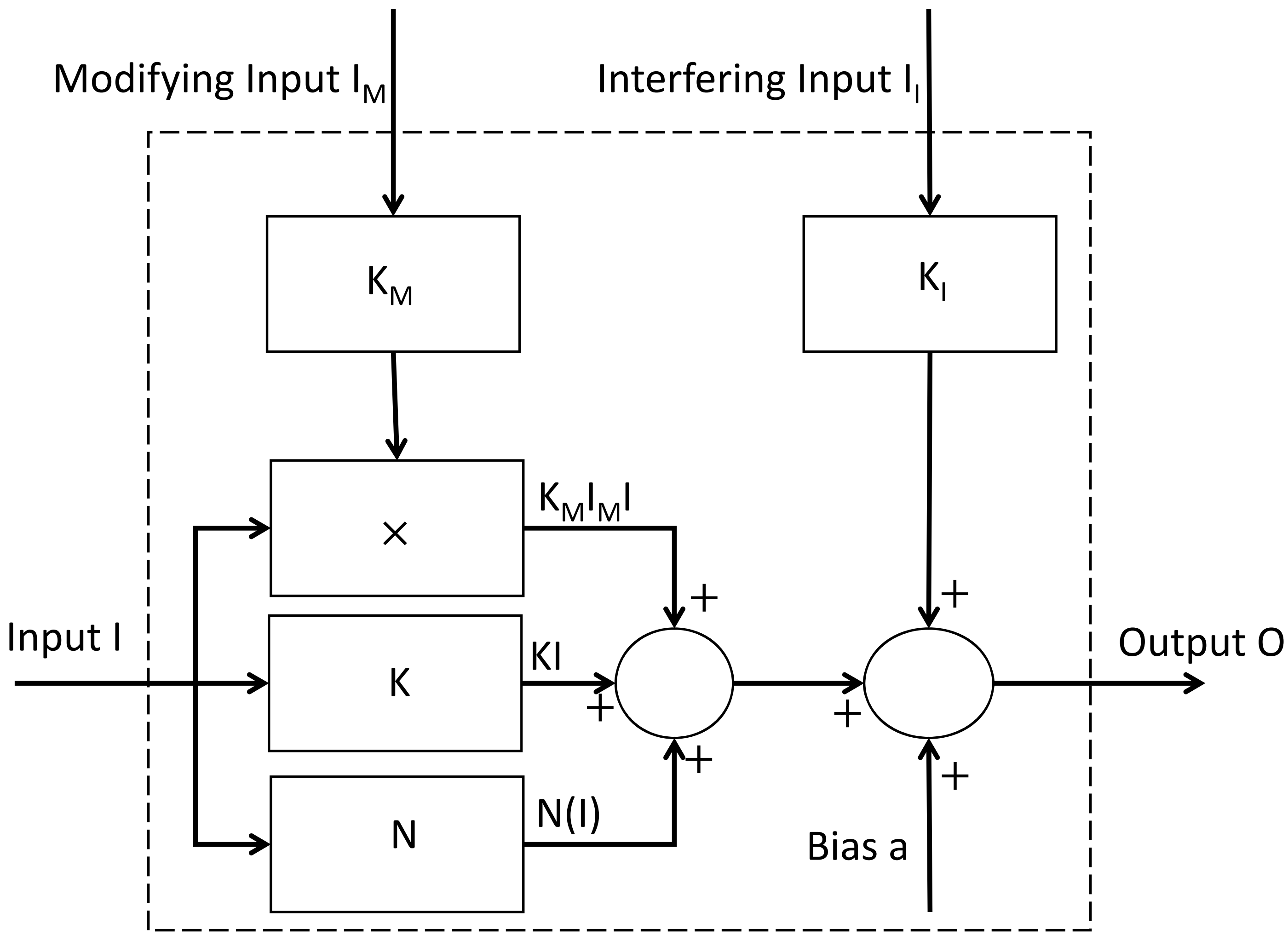


# Environmental effects

- **Modifying effects**: change sensitivity (slope)
- **Interfering effects**: change bias (intercept)



# Generalized model of a static system element




Dependable readings require calibrating your instruments with known references and calibrating at the beginning, middle, and end use of your instruments!

# Standards hierarchy


- Primary Standard (e.g., see http://physics.nist.gov/cuu/Units/)
  - Not calibrated by other standards (NIST or ISO)
- Inter-laboratory Standard http://www.astmnewsroom.org/default.aspx?pageid=1840
  - Calibrated against primary standard
- Local Standard https://strategis.gc.ca/eic/site/mc-mc.nsf/eng/lm00111.html
  - Usually most accurate device within lab, calibrated against secondary (inter-laboratory) standard
- Working Instrument

Product Folder | Sample & Buy | Technical Documents | Tools & Software | Support & Community

TEXAS INSTRUMENTS

**LM35**



# LM35 Precision Centigrade Temperature Sensors

## FEATURES

- Calibrated Directly in ° Celsius (Centigrade)
- Linear + 10 mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at +25°C)
- Rated for Full −55°C to +150°C Range
- Suitable for Remote Applications
- Low Cost Due to Wafer-Level Trimming
- Operates from 4 to 30 V
- Less than 60-μA Current Drain
- Low Self-Heating, 0.08°C in Still Air
- Nonlinearity Only ±¼°C Typical
- Low Impedance Output, 0.1 Ω for 1 mA Load

What does this tell us about this sensor's actual response?

## DESCRIPTION

The LM35 series are precision integrated-circuit temperature sensors, with an output voltage linearly proportional to the Centigrade temperature. Thus the LM35 has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The low output impedance, linear output, and precise inherent calibration of the LM35 make interfacing to readout or control circuitry especially easy. The device is used with single power supplies, or with plus and minus supplies. As the LM35 draws only 60 μA from the supply, it has very low self-heating of less than 0.1°C in still air. The LM35 is rated to operate over a −55°C to +150°C temperature range, while the LM35C is