Sensors and Actuators

Control Lab

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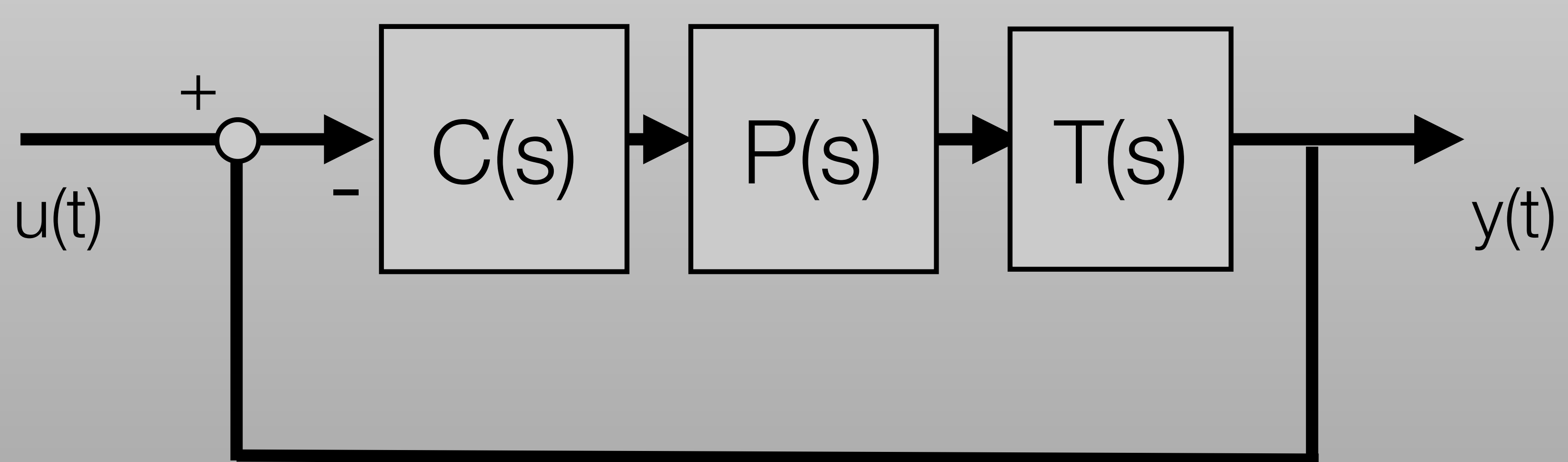
Sensors

> English
>
> **sensor** | ˈsɛnsə | noun
>
> a device which detects or measures a physical property and records, indicates, or otherwise responds to it: *to ensure greater response and surer handling, the engineers used electronic sensors* more

- **Most Important use in Control Systems:**
  Converts the output variable in a quantity compatible with the input of the regulator-compensator.



- Typically translates a **physical quantity into an electrical/logical one,** compatible with the controller.

Sensors

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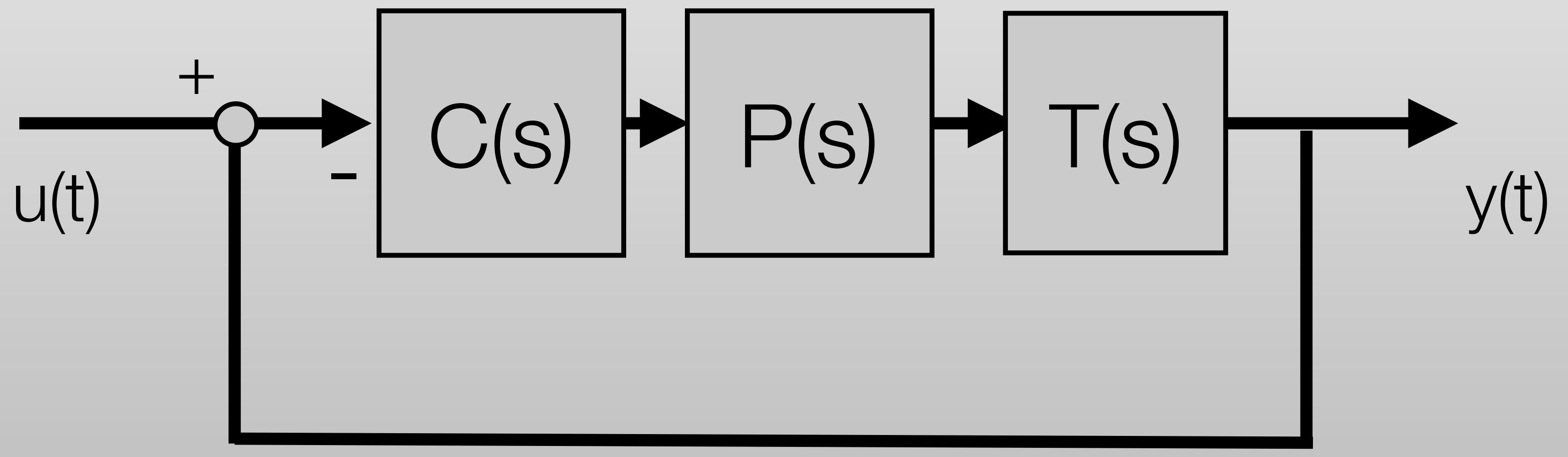
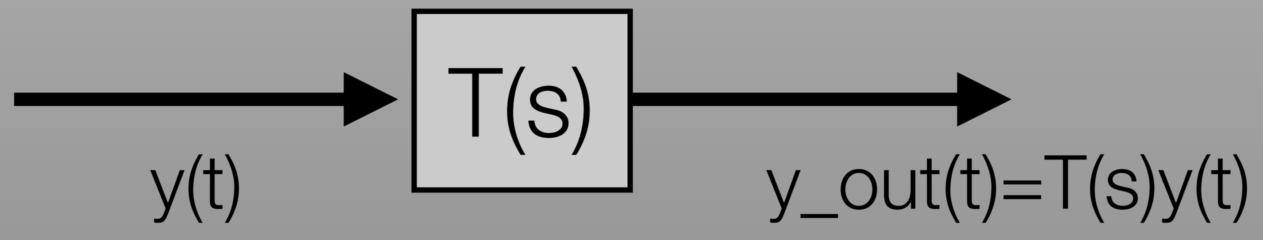


- Remember the previous lectures: **It is crucial to have good/fast components at every step of the control loop;**

- **Ideally we want to model it as a LTI system:**



Basic Characteristics

- **Input and Output quantities (e.g. V, i, angles, ...);**

- **Maximum and minimum values**
  (Notice: Saturation! It is already a non-ideality);

  aka (also known as) **Full-Scale Values;**

- **Need of external power?** (e.g. dynamic versus condenser mics)

Static Performances

- The builder/seller should provide performance specification obtained by calibration over a batch of the same sensors.
  Problem: Statistical variation of the characteristics;

- Need for quantifying the **Accuracy**:

  • % FSO: (Full Scale Output) % on the maximum value

  • % Output Value: SNEAKY, they may pick the best input and do not tell you which one they employed (nonlinear behaviors);

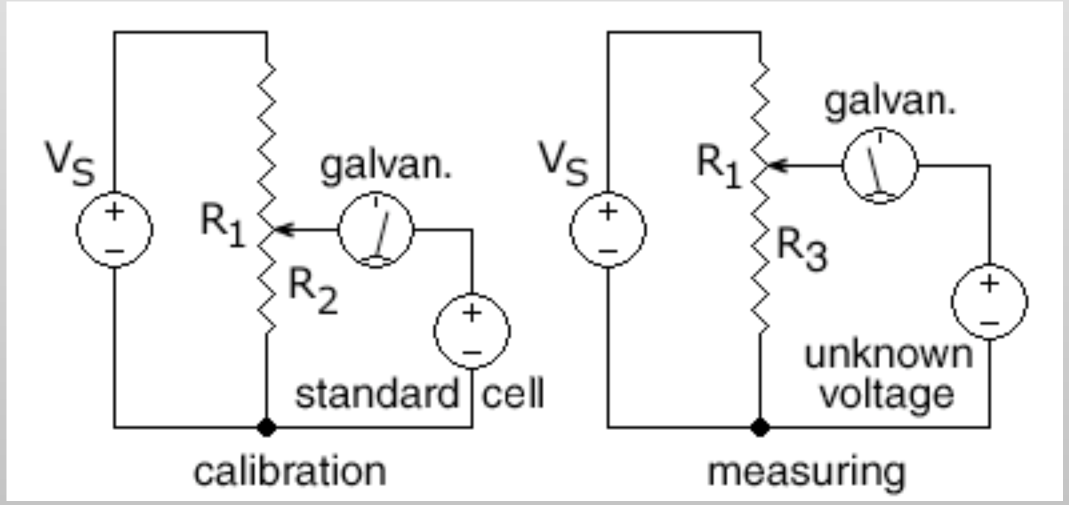
  • Absolute Value;

$$\boxed{\tilde{y}(t) = y(t) + e(t), \quad |e(t)| \leq accuracy}$$

- Also crucial: **Resolution.** It is the smallest input that cause a variation in the output.

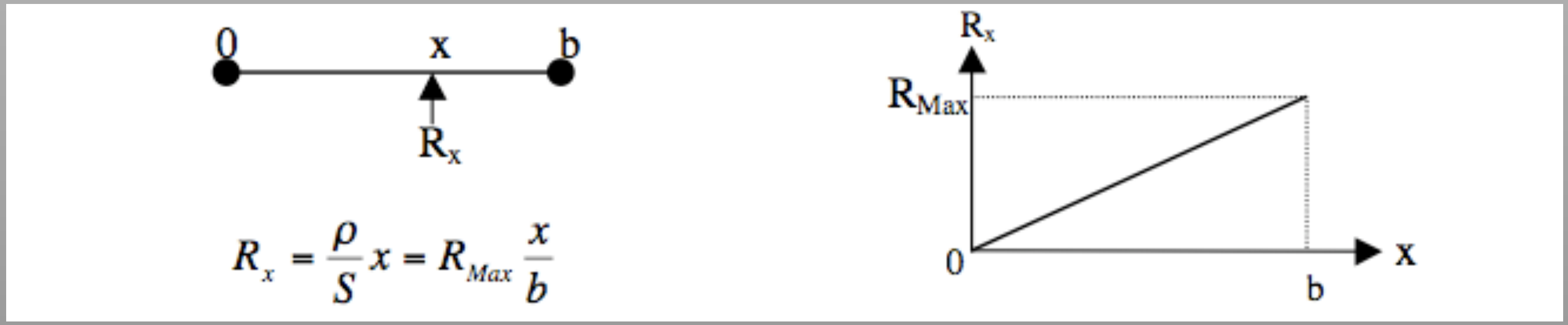
Example: Potentiometer (Old Lab!)

- **Basic Idea: Adjustable (Variable) resistance:** They can be used to measure electric potential, or linear or angular displacement.



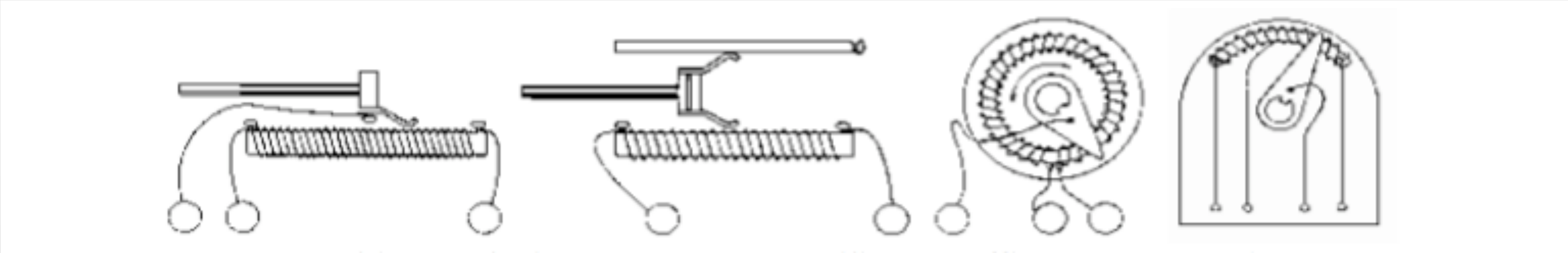
$$\frac{V}{V_S} = \frac{R_{eq}}{R_{max}}$$

- **Ideally**: Linear relation between resistance (Rx) and displacement (x);



Potentiometer

- **In practice:** *Resistivity* (Slope of the curve) too small. Then windings are used.



- In this way we introduce a minimum resolution, associated to the resistance of a “loop”;

$$Resolution = \frac{R_{max}}{N}$$

- It can also be used to obtain non-linear laws, changing the dimension of the loops along the device.

Typical Problems

1. **Inertia, Friction (static, dynamical), Flexibility of mechanical axial joints and parts (Could generate resonance phenomena);**

2. **Self-Heating: Current generates heat by “Joule’s effect”;**

3. **Linearity: Depends on the intrinsic quality of the device (How refined is the process to lay down the resistive layer), and on the circuit connected to the potentiometer (Load);**

4. **Quantization: Typical for potentiometers that employs resistance wires wit loops;**

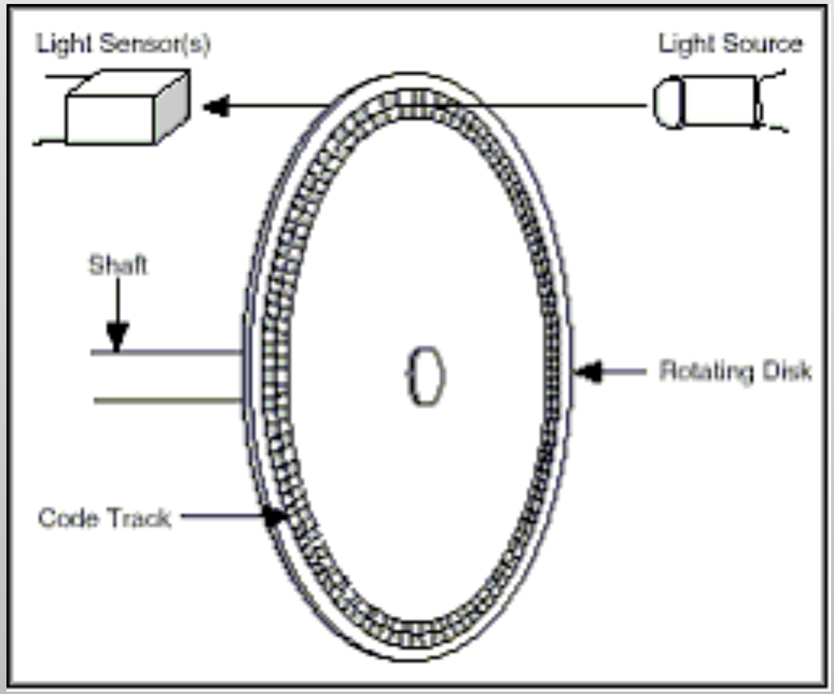
5. **AC features: Parasite components, mainly inductive (especially in wired potentiometers);**

Examples: Digital Encoders

- We will see them soon...
  Incremental Optical Encoder

  N : # holes;

  Resolution = 360 deg/N;

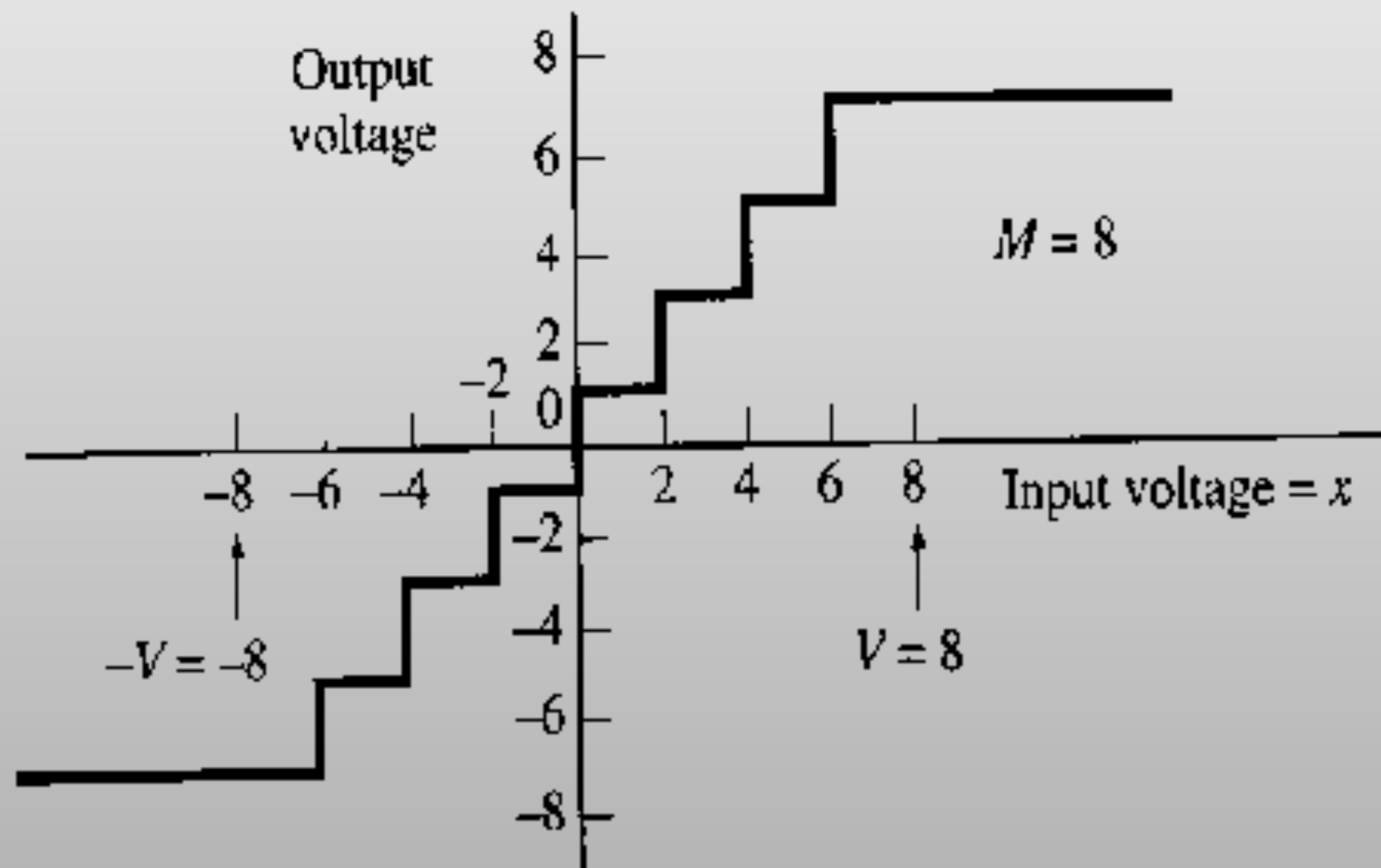


- Also often sensors include or are followed by **A/D converters**:
  e.g. quantization of electric potential V, with (symmetric) full scale V_max, n-bit conversion:

  Resolution = V_max /2^(n-1);

Physical to Logical: We Need Quantization

- **Quantization**:



$$\tilde{y}(t) = y(t) + e(t), \quad |e(t)| \leq resolution$$

Repeatability

- How good they do with repeated measurements:
  In practice same input gives different outputs at different times!

- *Repeatability indexes (to be indicated as %)*

$$Rep_1 = \frac{M_{max} - M_{min}}{F.S.}$$

$$Rep_2 = \frac{\Delta_{max}}{F.S.}$$

with respect to the mean value.

$$\tilde{y}(t) = y(t) + e(t), \quad |e(t)| \leq Rep_{1,2}.$$

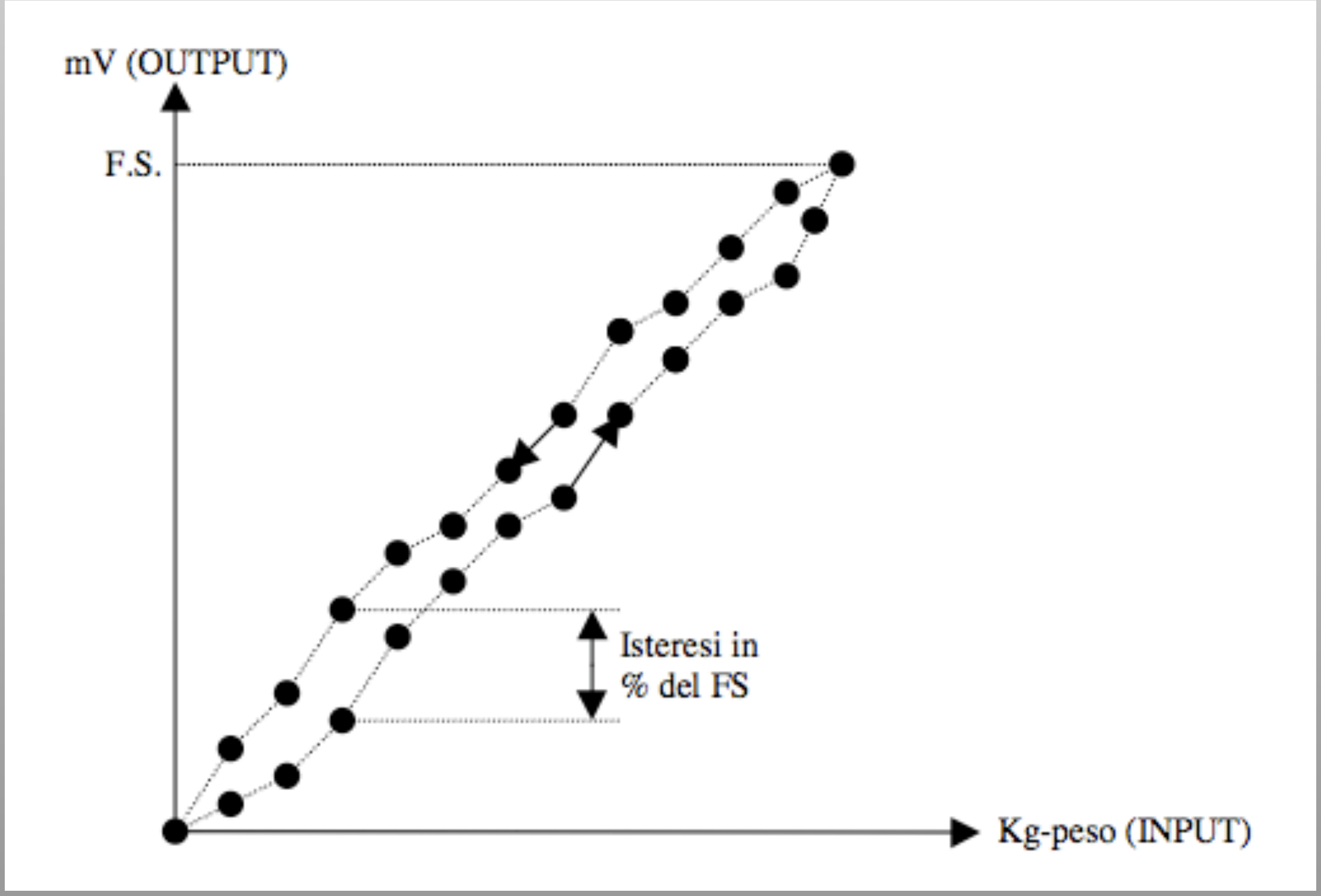
- I can also do some statistical analysis and model: $e(t) \sim \mathcal{N}(0, \sigma)$

Linearity of the Sensor

1. **Ideally, the sensor should to have a linear, static response:**

$$y_{out}(t) = k_s \cdot y_{in}(t)$$

2. **Hystheresis (cycle):** Feeding increasing values (fixed step) first and decreasing next:



Linearity

- **Extreme points linearity:**

  Parameters:

  Line connecting extreme points;

  Maximum % deviations;

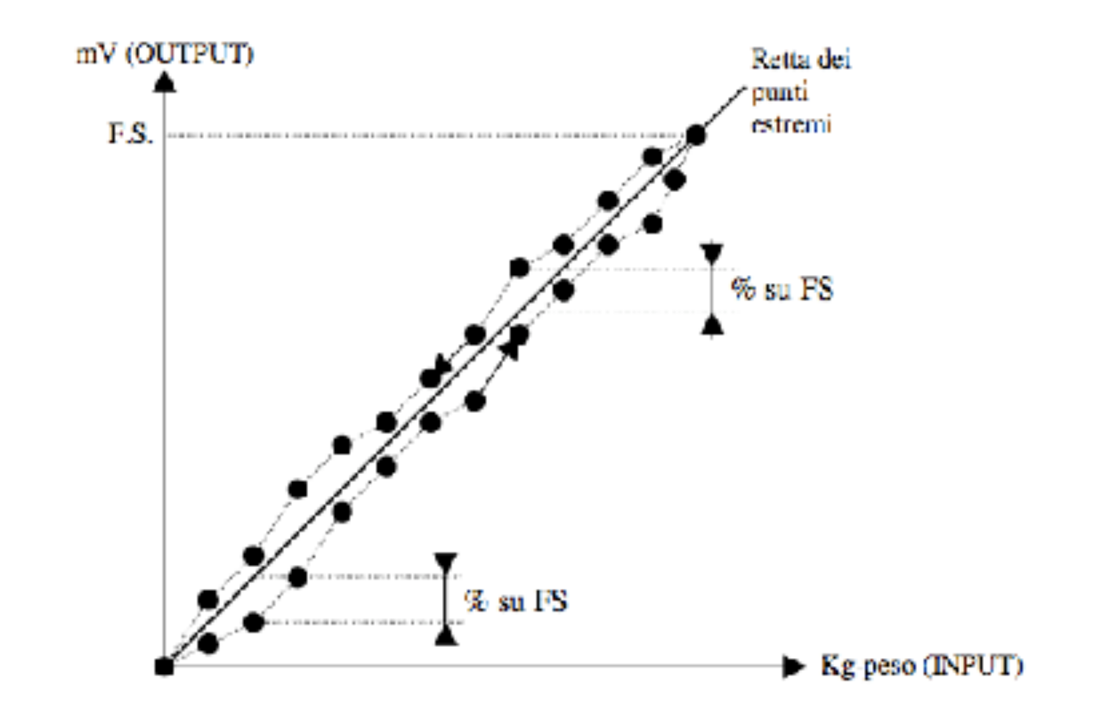


Fig.2.4

- **Least-squares linearity:**

  Parameters:

  LS linear interpolation;

  Maximum % deviations;

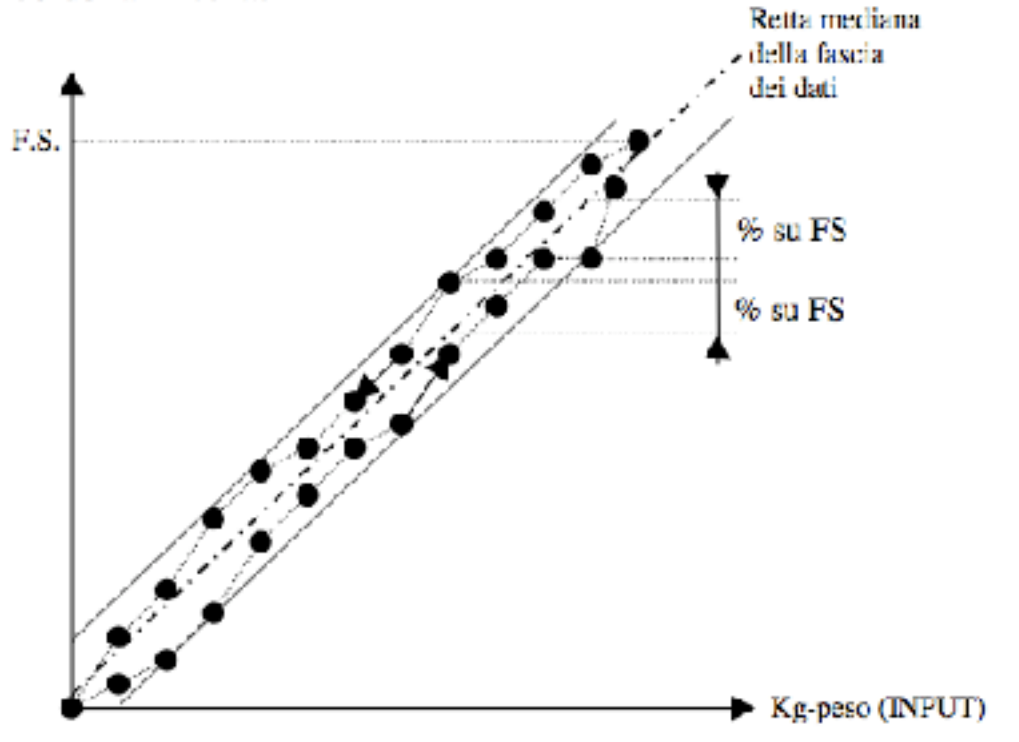


Fig.2.5

Linearity

- **Hysteresis and non-linearities can be also modeled as output (or measurement) noise:**

$$\boxed{\tilde{y}(t) = k \cdot y(t) + e(t), \quad e(t) = f(y(t)) - ky(t).}$$

Dynamical Response of a Sensor

- **The sensor is modeled (approx.) as a (BIBO stable) LTI causal system;**

- **The dynamical behavior is referred to the step response:**

1. **Time-constant** (approx. with 1st order system);

$$T(s) \approx \frac{K}{s + 1/T}$$

2. **Dead time** (e.g. 5%);

3. **Raise time** (time from 10% to 90%);

4. **Damping coefficient** (approx. with 2nd order system);

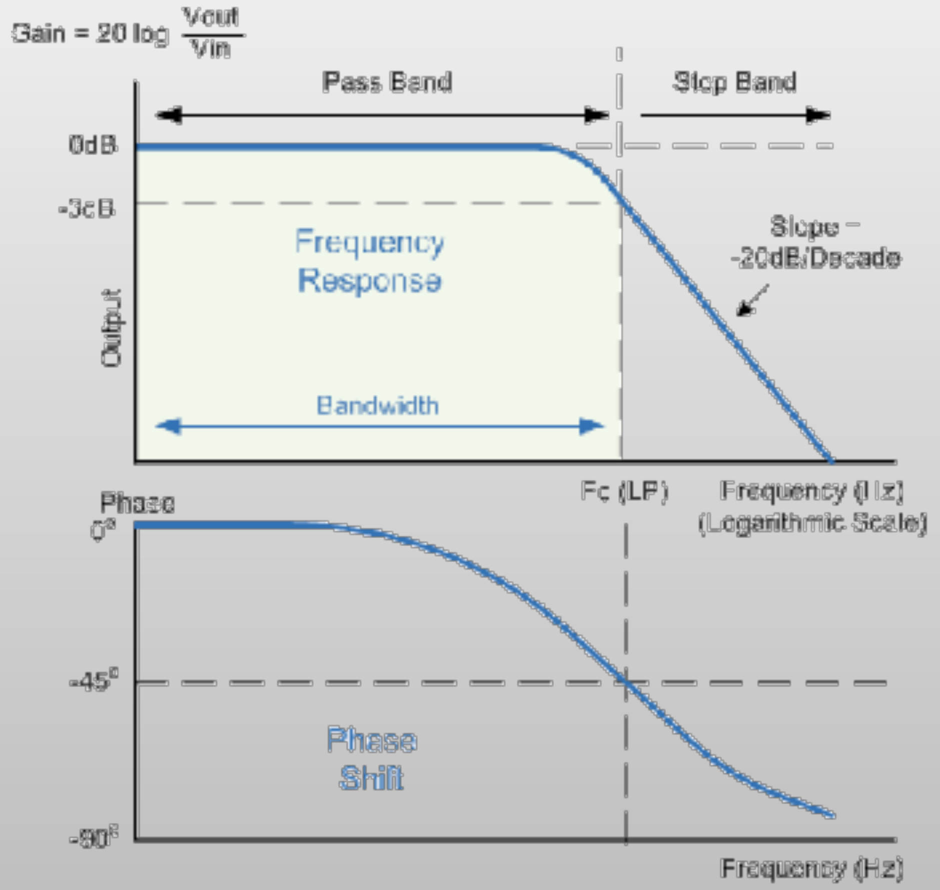
$$T(s) \approx \frac{K}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

5. **Settling time** (e.g. up to 5%);

6. **Overshoot** (%);

Frequency response of a Sensor

- **Typically a Low-Pass system:** (well-modeled by a first order one)



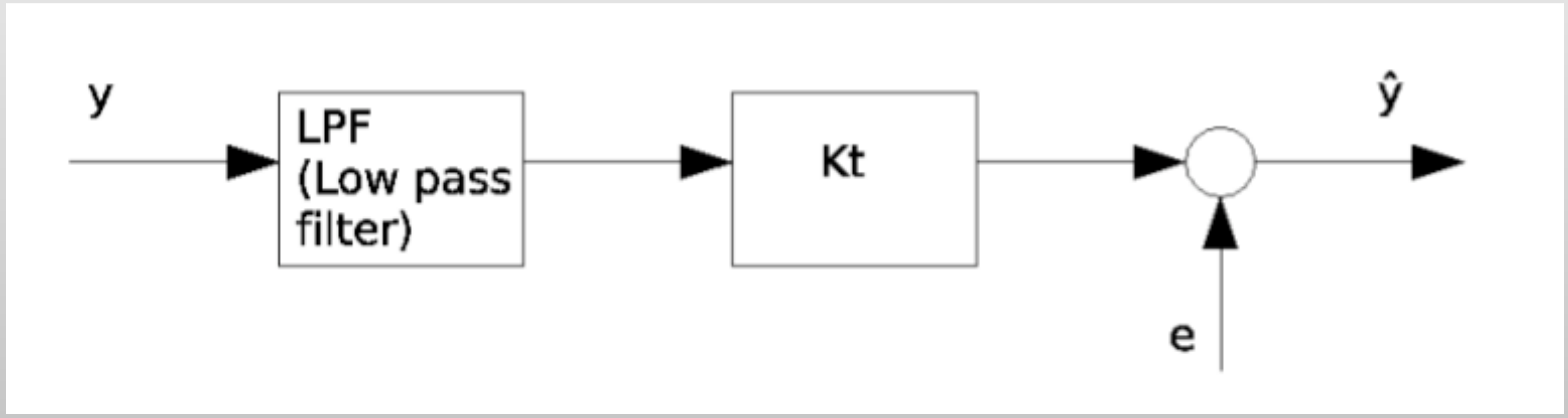
- **The relevant parameter is the cutoff frequency** (first point at -3dB);

- Related to transfer function's pole:

$$\omega_c \approx \frac{2\pi}{T}$$

Model of the Sensor

- Putting things together: **Typical Model of a Sensor**



$$\boxed{\tilde{y}(t) = \frac{k}{1+sT} \cdot y(t) + e(t);}$$

$$\omega_c \approx \frac{2\pi}{T}$$

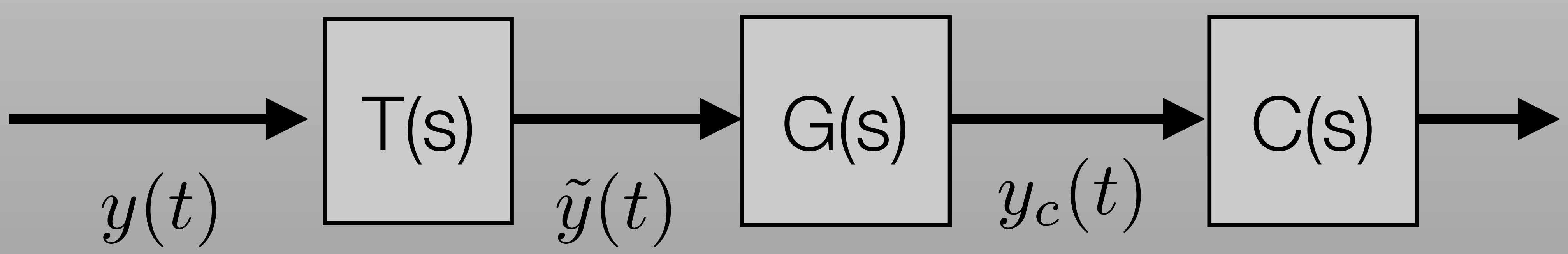
If there is a risk to hit max/min values: also saturation block.

From the Sensor to the Controller

- **The next step is to send the signal from the sensor to the controller;**
  Not a big problem for us…

- **In many industrial cases sensors and controllers are at large distances (e.g. centralized control):**
  Non trivial problems related to noise;

- **In many case it is necessary to go through an intermediate signal processing block:**



Conditioning the Signal

Signal Processing Typical Steps

1. **Adapting the signal levels and adjusting offsets;**
2. **Filtering:**
   - **Limiting the signal bandwidth** (necessary for sampling and HF noise)**;**
   - **Eliminating or reducing known noise sources** e.g. 50Hz disturbance**;**
3. **Adapting the impedance to attain optimal output power;**

A Few Things To Take Care Of...

Typical Sources of Problems:

1. **For electrical signals, wire and components resistance** (deteriorate the signal)**;**

2. **External and Internal Noise;**

    - **The environment contains significant sources of EM fields;**

    - **The components of the devices are far from ideal;**

3. **Bad insulation of the wires;** It is also *dangerous:* A few micro-ampere can be lethal in medical applications;

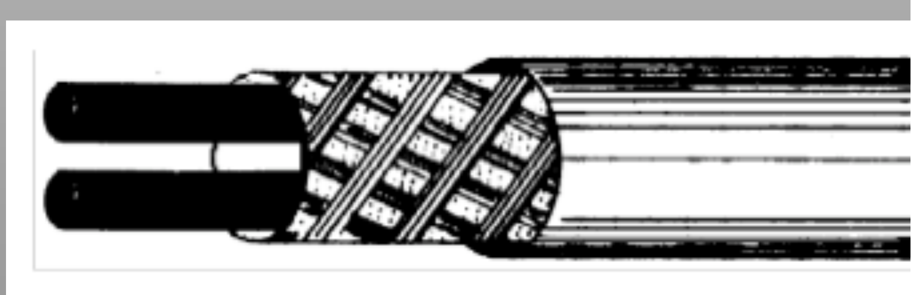
4. **Ground connection and reference** (Difficult to use the same)**;**

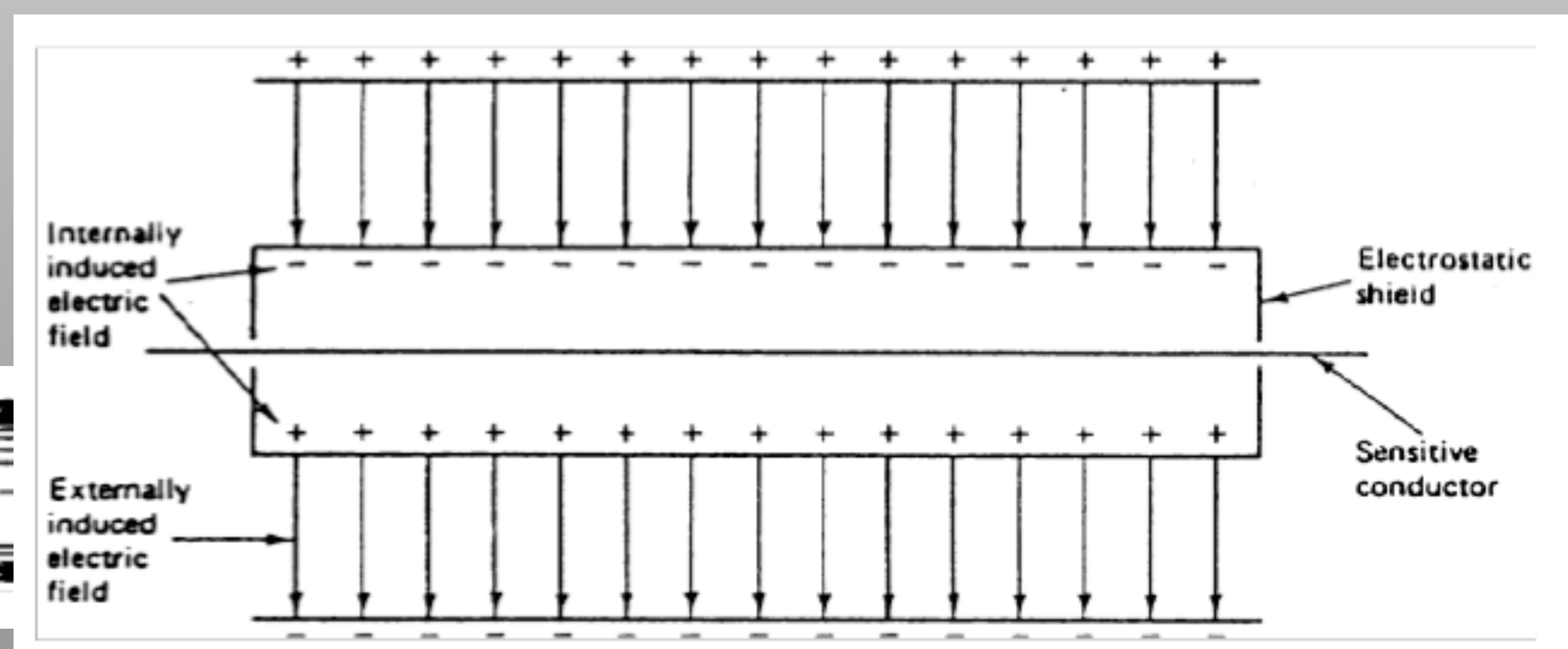
Insulation and EM Shielding

Losses due to EM absorbing properties (Low and High Freq):

		Material		
Frequency	Thickness (in.)	Aluminum (dB)	Copper (dB)	Steel (dB)
Audio	0.020	2	3	10
	0.125		10	40
100 kHz	0.020	25	35	>150
	0.125		130	>150

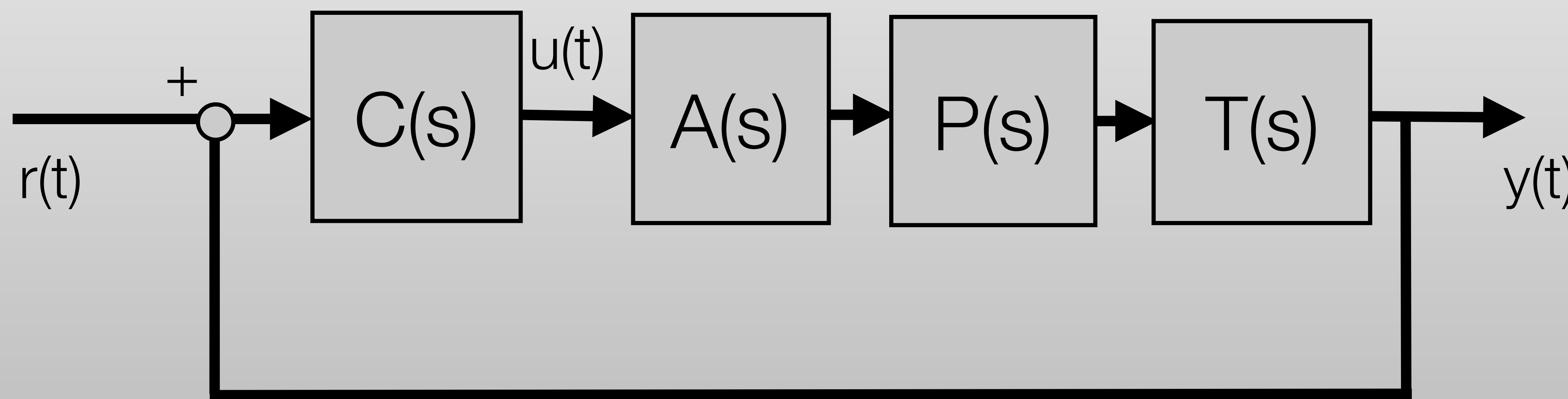
Need for Ground Connection!



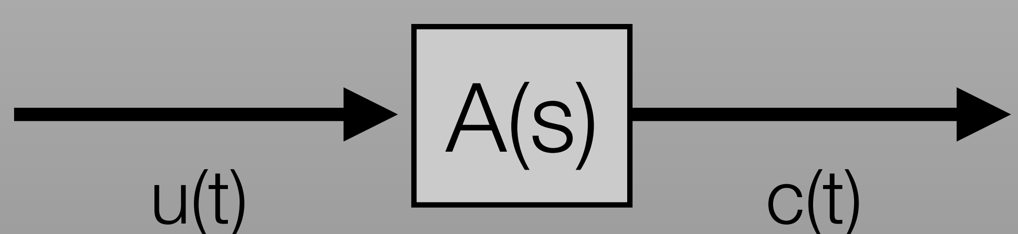


Actuator

- **Most Important use in Control Systems:**
  Converts the control variable in a quantity compatible with the input of the plant..

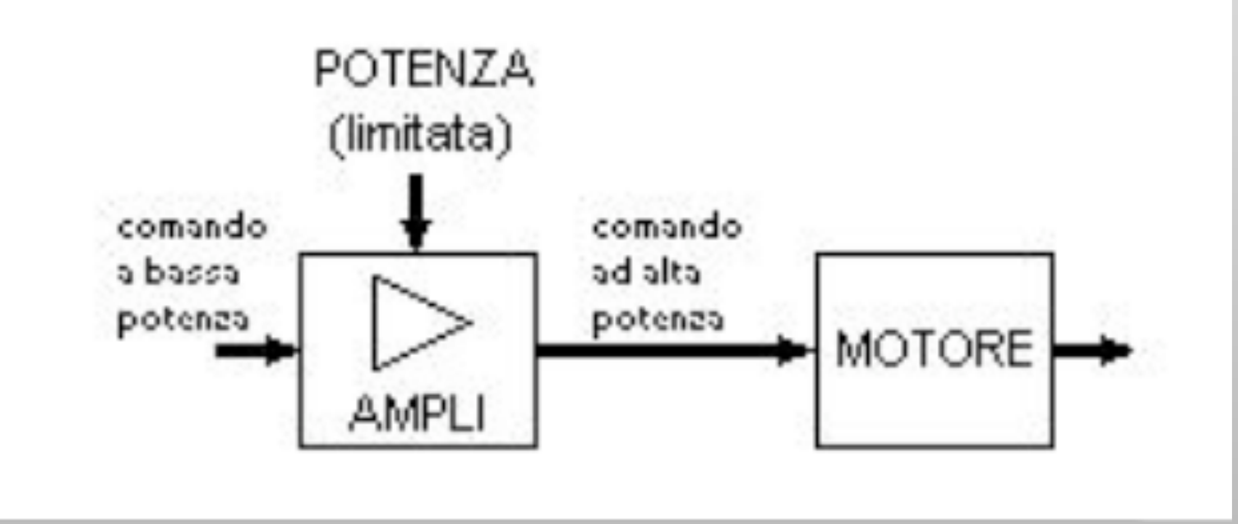


- Ideally a known LTI system:



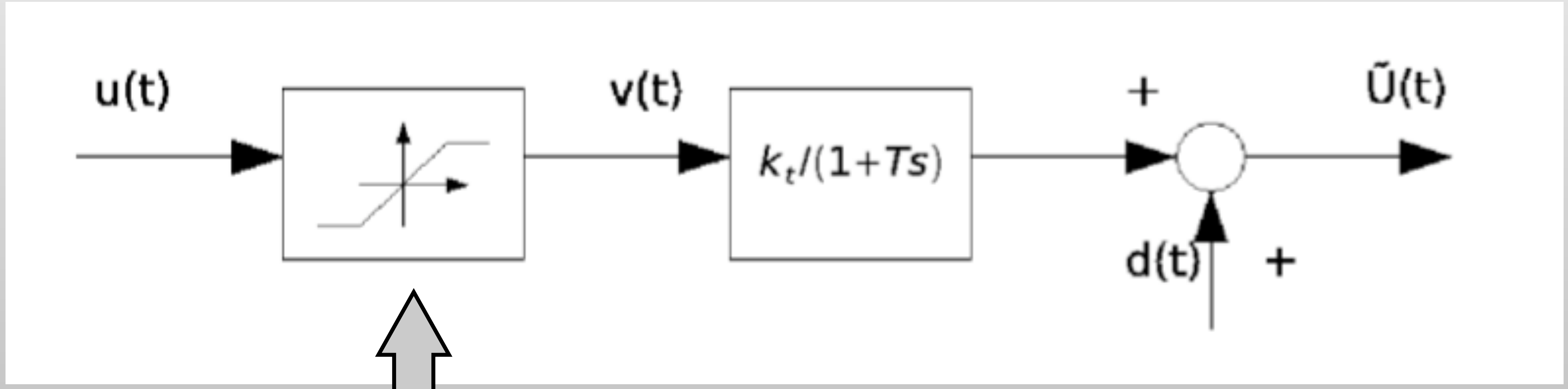
Actuator

- **For our Lab:**
  Converts the electrical reference signal (ouput of the terminal board) in a tension, the input of the engine..



Model of the Actuator

- **Similar to what we have seen before:**



Fundamental Component: **Saturation**

We shall see what kind of problems this may cause, and how to solve/reduce it in certain cases (LAB1)