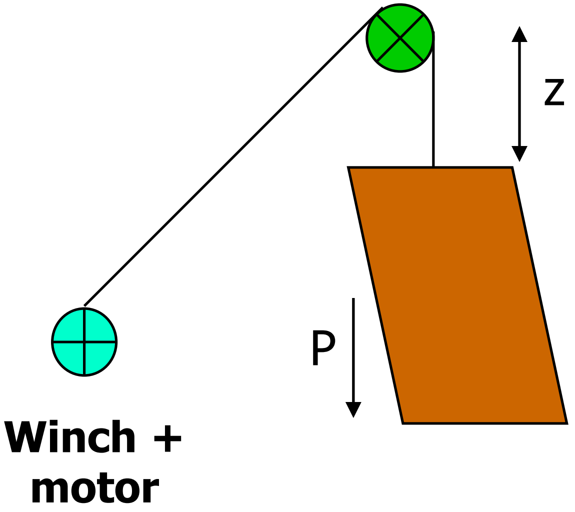
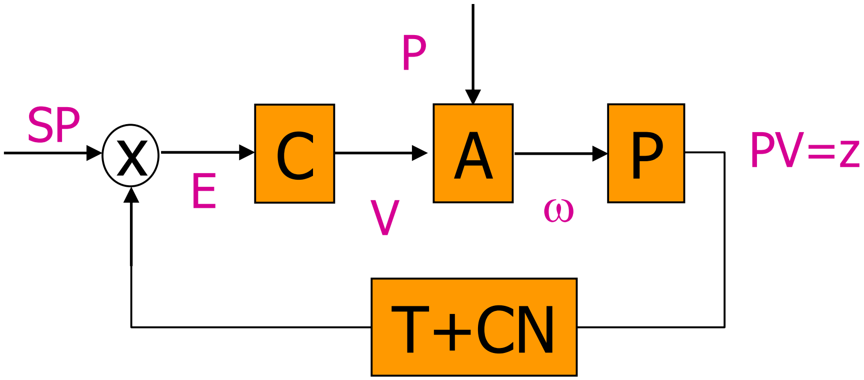
WEIGHT LIFTING CONTROL





P= weight of the object to be lifted

z= coordinate of the hooking point

T=angular position sensor: encoder (accurate and fast, what about a potentiometer?)

A=SCR (or TRIAC) + DC motor. If the rope is tight ω motor = ω pulley

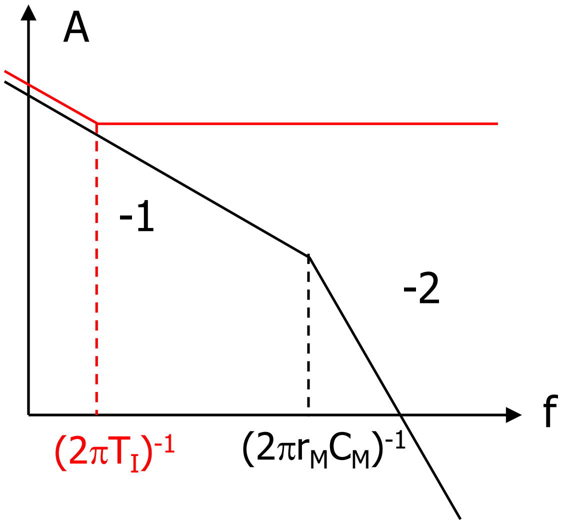
The choice of the transducer affects the process response: since $z = k\rho\theta$ (ρ roll's radius) the process transfer function is $= k'\rho/s$ (ω is the manipulated variable).

A suitable actuator could be a motor with SCR (or TRIAC) regulated power supply.

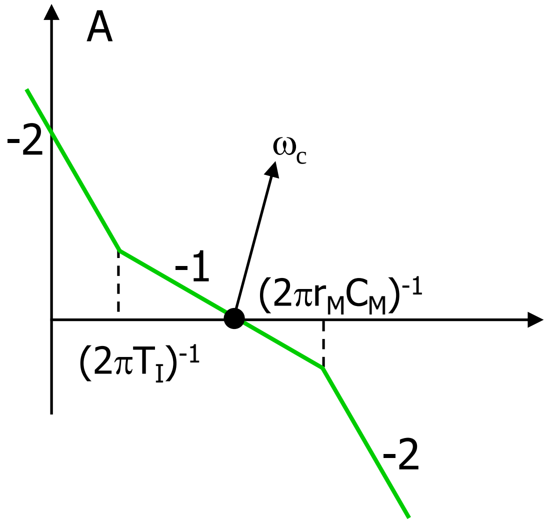
The motor transfer function is an approximated integrator $(1+srC_M)^{-1}$, (neglect L and $r \ll R_M$).

WEIGHT LIFTING CONTROL

In nominal conditions, the hooking point is located at a fixed height. When a weight is hooked to be lifted it determines a rotation torque on the witch and therefore on the motor that drives it. The weight of the object, if variable (i. .e something that lands on the hanging foil can be seen as a «disturbance» on the actuator ⇒ feedforward. If constant it does not affect the frequency response.



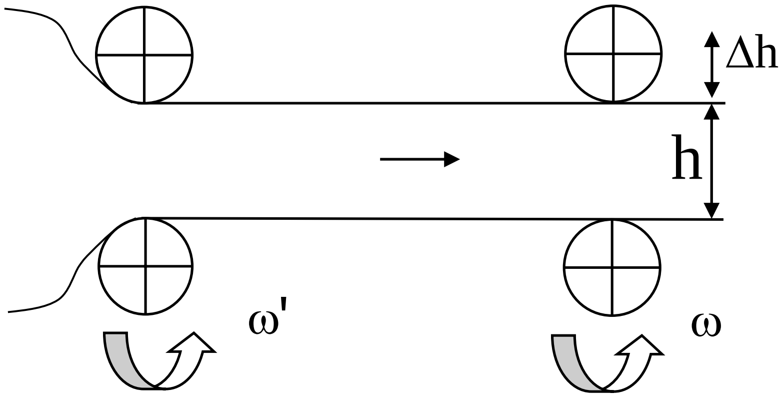
We can use a PI control with $T_I >> rC_M$.



A proportional control could be ok to make the system stable but not to eliminate the error at regime (when the transient is expired).

Also the dynamic compensation is ok (larger bandwidth).

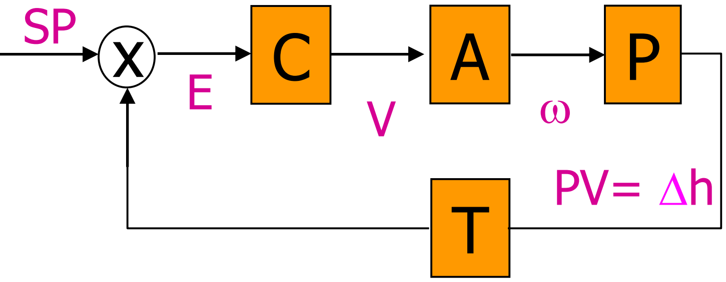
ROLLING MILL



It consists of a couple of reels free to rotate at different velocities, just to determine the thickness of a material (for example «pasta») that gets through each couple of reels; the second couple can rotate at a velocity that is multiple of the first one (this has been fixed): the greater the velocity the finer the foil, the lower the velocity the thicker will be the foil.

The goal is to keep the thickness *h* constant.

$$\omega' = k\omega$$

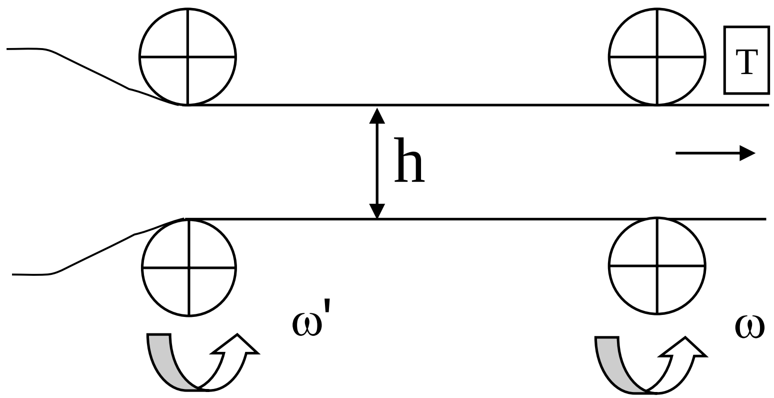


The process will be controlled through the reels rotation velocity that is managed through a DC motor (again transfer function like an approximated integrator).

$$\Delta\theta r = k'\Delta h \text{ and } \Delta\theta = \Delta\omega/s \Rightarrow \Delta h = \Delta\omega r/sk'$$

A suitable transducer is the differential linear position one (+ a rectifier) since it measures a displacement relative to a rest position. It can be located downstream the reels couple ⇒ $V = j\omega 2nh$

ROLLING MILL

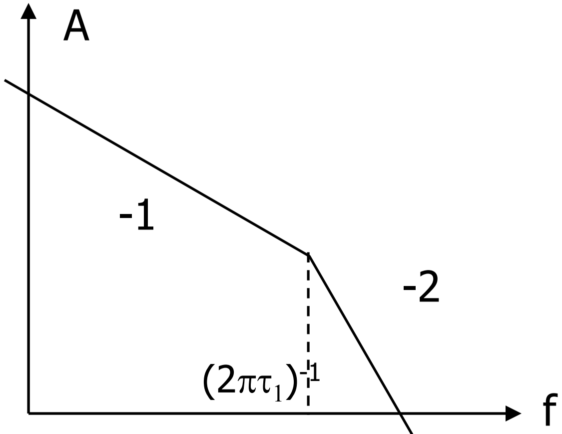


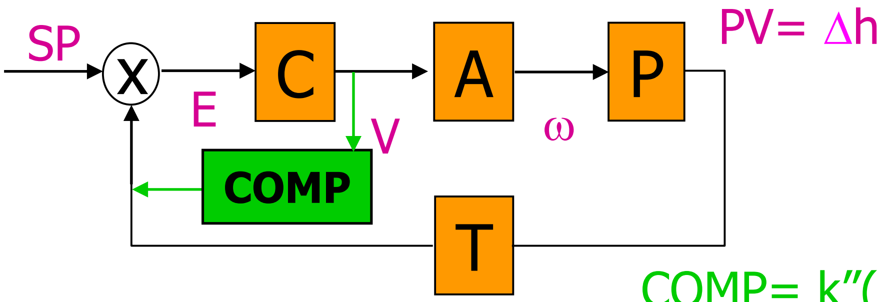
The ring transfer function is therefore

$$\Delta h/\omega = k''/s(1+s\tau_1)$$

We can also suppose the presence of a delay due to the position of the transducer. The final expression is:

$$\Delta h/\omega = k'' e^{-s\tau}/s(1+s\tau_1)$$

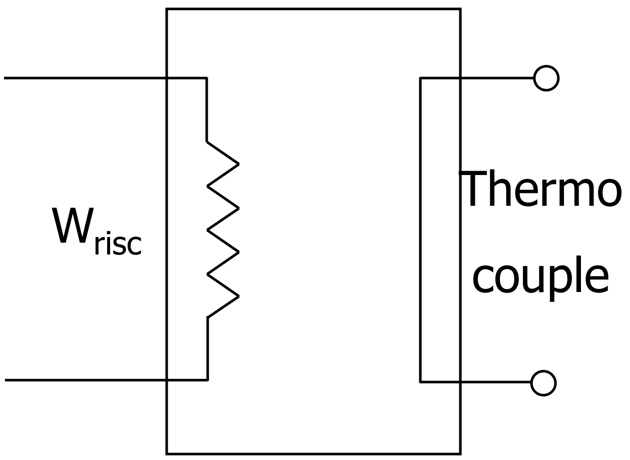




COMP= $k''(1-e^{-s\tau})/s(1+s\tau_1)$

If we are able to compensate the process can be made stable. A numeric controller can generate a delay τ: Smith predictor allows to set n memory cells into which the content of a variable is translated every sampling period T_s : $n=\tau/T_s$. This means that the datum in memory is generated with a fixed delay and transformed in the voltage to be subtracted to the one coming from T+RC through a DAC. At this point we have 2 poles and the dynamic compensation can be used.

OVEN



$$\frac{k}{(1+s\tau)}e^{-sT_D} \qquad \tau = RC$$

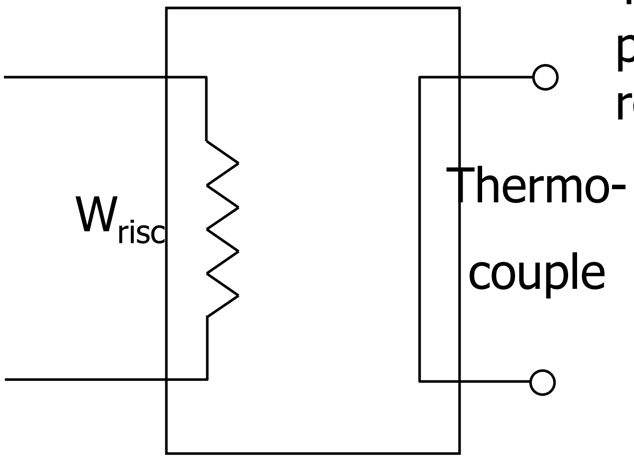
The oven could be considered a pure integrator but this would imply the accumulation of heat without dispersions: not reasonable and in the time this would mean to burn the oven and its content.

Moreover the applied power is not exactly $\propto$ to the obtained T° because at the beginning there is a transient. Therefore the temperature does not augment linearly at the beginning neither immediately when the oven is switched on.

Therefore a delay is associated to this transient.

A RC model (approximated integrator) is the most suitable one since it features a R component modeling the opposition to the heat dispersion and a C component that represents the capability of accumulating the energy.

OVEN



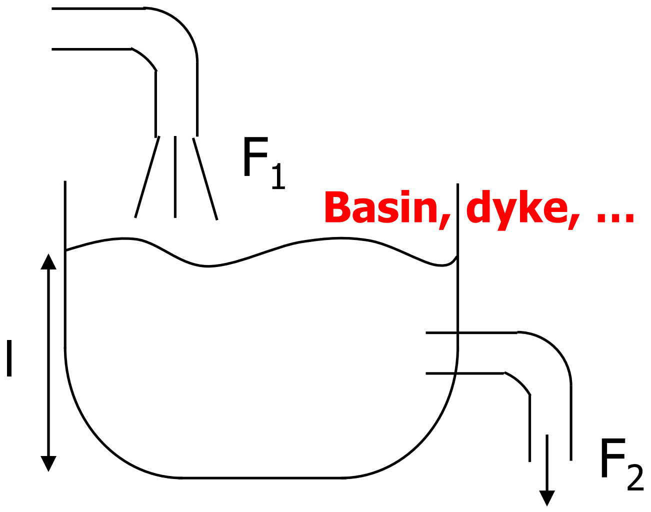
The previous expression takes origin from the following power balance (into which R_t e C represent the thermal resistance and capacity):

$$\underbrace{W_{risc}}_{\text{Input power}} - \underbrace{\frac{T}{R_t}}_{\text{Lost power}} = \underbrace{C\frac{dT}{dt}}_{\text{Accumulated heat}} \Rightarrow T = \frac{W_{risc}R_t}{1+sR_tC}$$

What actuator can be used? Every time a power signal is alternate it is convenient to use a SCR or even a TRIAC to exploit all the available power.

The overall system features only 1 pole and 1 delay: if we compensate the delay with a Smith predictor the system is stable.

LEVEL DETECTION



F_1 = Input flow - F_2 = Output flow

Process transfer function

$$l = \frac{V_{liq}}{A} = \frac{\int_{t_0}^{t}(F_1 - F_2)dt}{A}$$

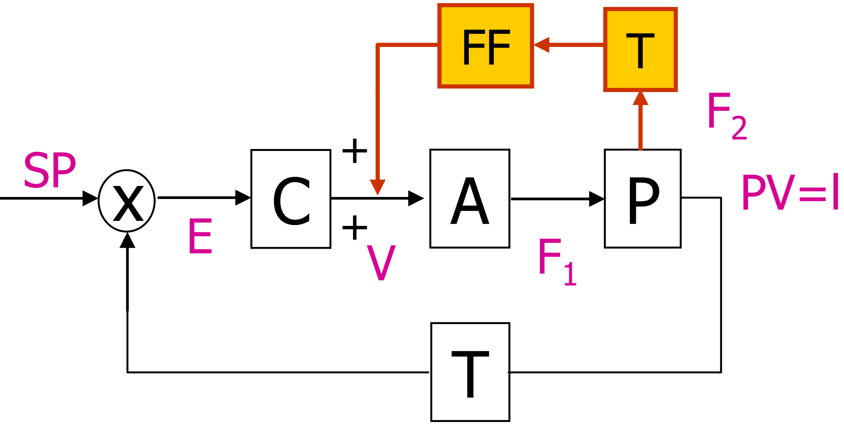
F_1 is regulated through a suitable, actuator i. e. a pump, F_2 can be considered as a disturbance that alters the process since it prevents it to be controlled.

What is the transfer function of a pump? We could describe it as a pure integrator:

$$l = \frac{F_1 - F_2}{As} = \frac{V}{As^2} - \frac{F_2}{As}$$

We adopt a feed-forward solution so as to eliminate the influence of F_2 on the PV (allowed that we can properly measure it with a flowmeter).

LEVEL DETECTION



How to calculate the feed-forward (FF) function? Let’s evaluate the ring transfer function without FF

$$PV = \frac{F_1 - F_2}{As}$$

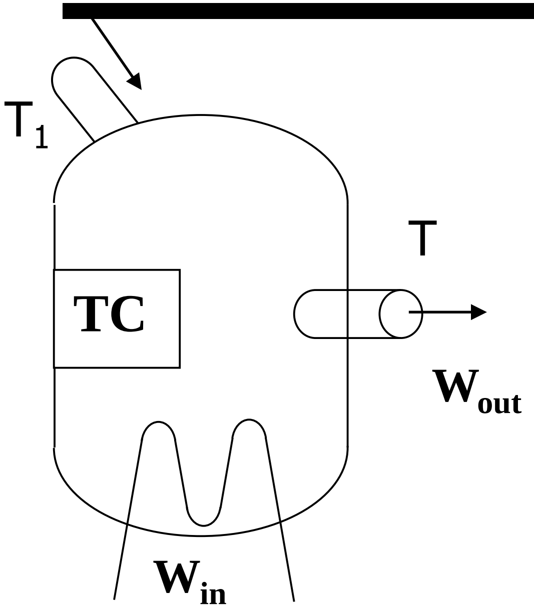
$$F_1 = f_A \left[\mathrm{V} + \mathrm{FF} \bullet F_2 \right]$$

$$PV = \alpha F_2 + \beta F_1 = \beta f_A \mathrm{V} + \left[\alpha + \mathrm{FF} \bullet \beta f_A \right] F_2$$

$$\left[\ldots \right] = 0 \Rightarrow \mathrm{FF} = -\frac{\alpha}{\beta f_A} \quad \text{with} \;\; \alpha = -\beta = \frac{1}{\mathrm{sA}} \;\; \mathrm{e} \;\; f_A = \textit{Actuator transfer function}$$

Therefore in this case FF is not in phase with the disturbance effect onto the process

BOILER



- W_{in} heating power provided by the resistance on which a high current is made to pass
- W_{out} output thermal power supposed to be proportional to temperature difference (T and T_1)
- C_T thermal capacity of the liquid
- TC thermocouple internally to the boiler to monitor the temperature to which we want to bring the liquid.
- Let’s neglect thermal losses and the delay due to the thermal propagation inside the boiler.

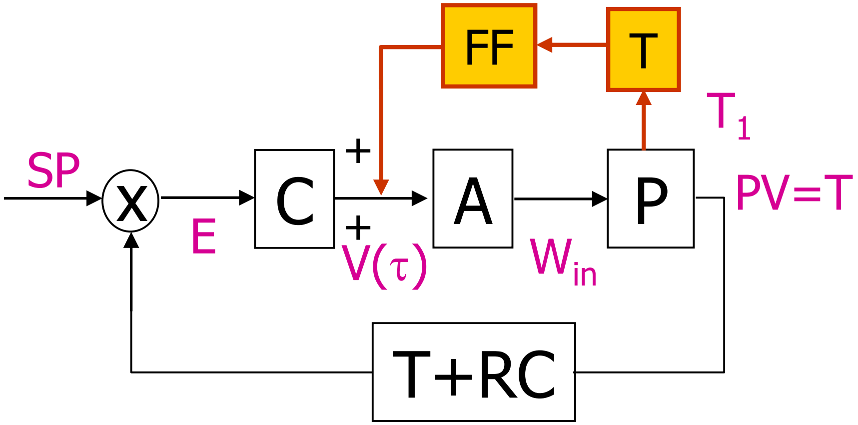
1. **Draw the block scheme of the acquisition/regulation chain identifying the input and output variables in every block and in particular the process variable.**
2. **Calculate the transfer function of the process highlighting what variables must be known.**
3. **Plot the Bode diagram of the loop function (process + actuator) discussing the eventual problems in terms of stability/instability.**
4. **Design the regulator necessary to the stability of the system and its numeric implementation**
5. **Design the electronic circuit that controls the actuator that allows the regulation of the input heating power as a function of the power supply voltage and the resistance R.**
6. **Considering that to read a temperature in the range [0-100]°C the system uses an 8 bit ADC, design a set point circuit that fixes the temperature at 50 °C.**

BOILER

$$W_{in} - W_{out} = c_T \frac{dT}{dt} \xrightarrow{Laplace} W_{in} - k\left(T - T_1\right) = s c_T T$$

$$W_{in} + kT_1 = T\left(k + s c_T\right) \qquad T = \frac{W_{in} + kT_1}{k + s c_T}$$

T_1 acts as a disturbance since it is unknown. As in the previous case we need a FF compensation.



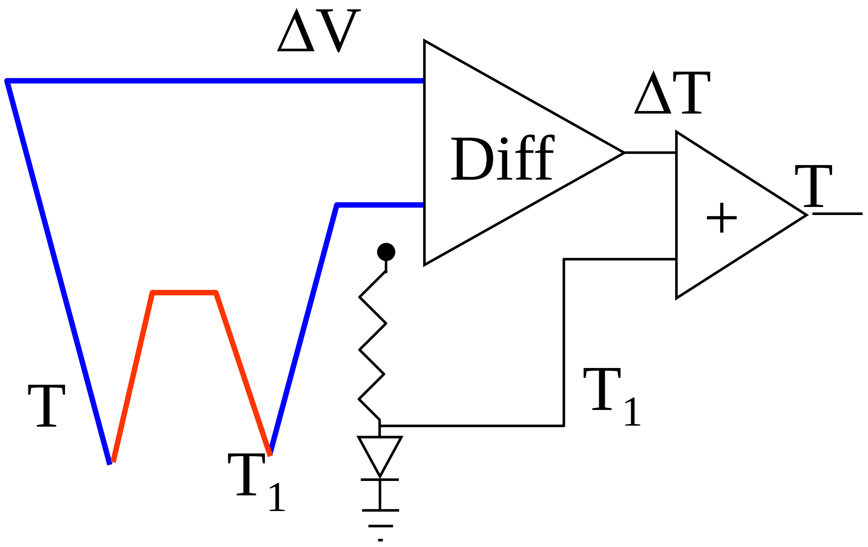
$$\Rightarrow \quad \frac{T}{W_{in}} = \frac{k'}{1 + s\tau}$$ Stable 1 pole only

A delay must be considered due to the distance between the detection point of the liquid temperature and the point where it exits and is really used.

$$\Rightarrow \quad \frac{T}{W_{in}} = \frac{k'}{1 + s\tau} e^{-sT_D}$$

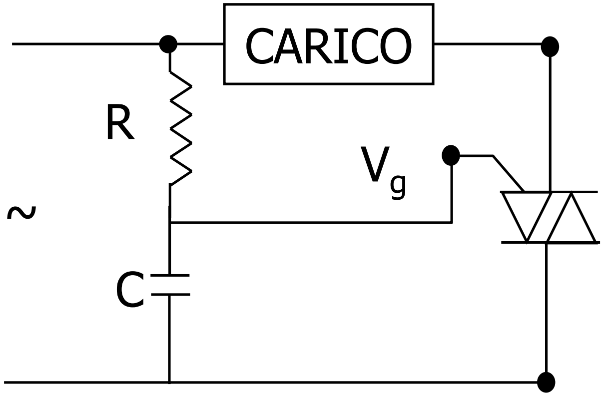
Bode diagram ⇒ process stable but the delay may erode the phase margin ⇒ Smith predictor

BOILER



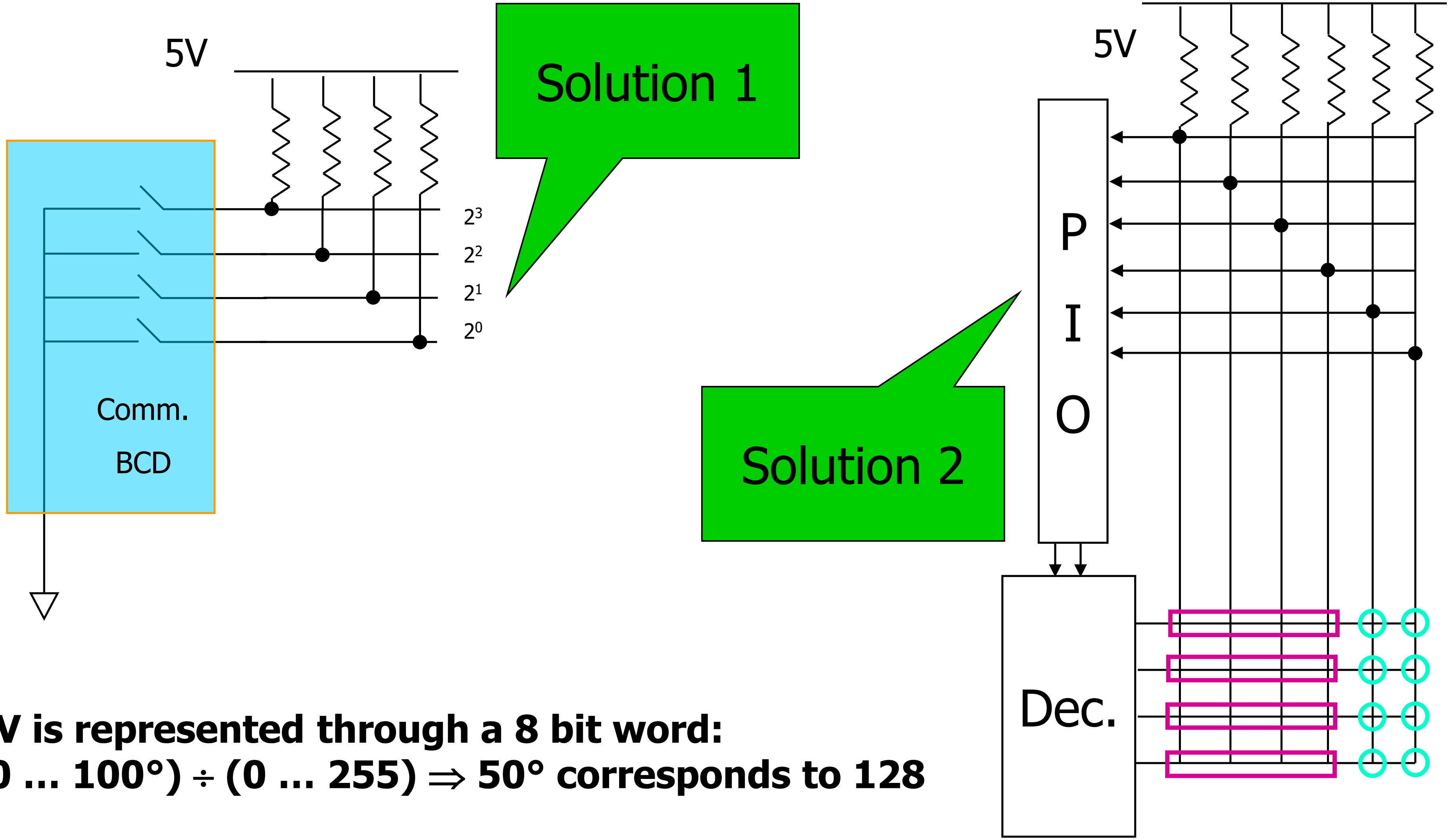
The transducer and its conditioning network

A possible control for the actuator



- **Triac to exploit all the available power;**
- **Also the SCR can be used since the phenomenon is slow**
- **Period selection instead of partialisation is ok always de to the slowness of the thermal process**
- **The circuit shown is not the optimal one because the regulation of the switching delay depends on the manual tuning of R (not automatic). Better to use the circuit with the UJT transistor and the control from the μP.**

BOILER



PV is represented through a 8 bit word:
(0 … 100°) ÷ (0 … 255) ⇒ 50° corresponds to 128