Bode plot analysis (in short)

$s = j\omega$ $\qquad FT(j\omega)$ $\qquad$ then plot $\qquad 20\log\left|FT(j\omega)\right|$

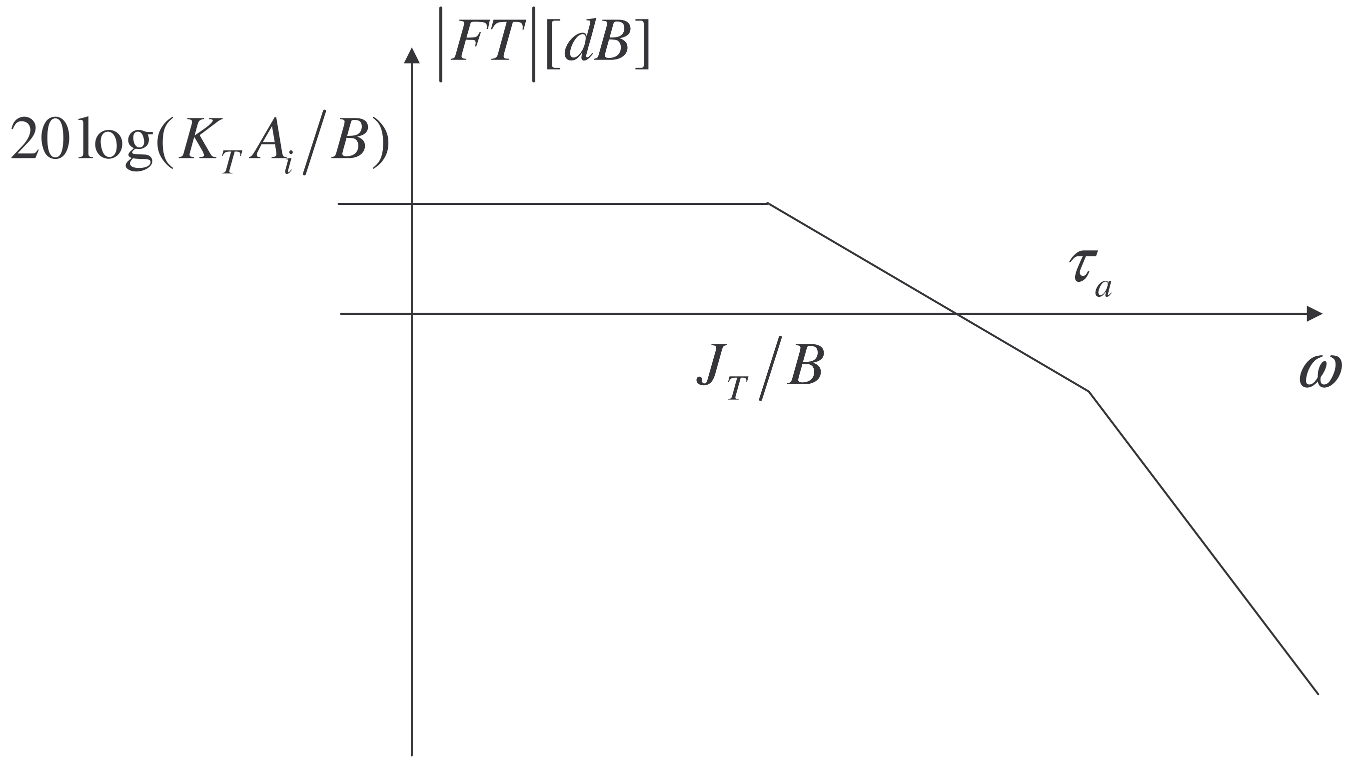
$\angle FT(j\omega)$

$$FT = K\frac{\Pi(1+{}^{j\omega}/_{\omega_{zi}})}{\Pi(1+{}^{j\omega}/_{\omega_{pk}})}$$

$$FT = 20\log K + 20\sum\log(1+\frac{\omega}{\omega_{zi}}) - 20\sum\log(1+\frac{\omega}{\omega_{pk}})$$

Example

$$\frac{\omega(s)}{V_{in}(s)} = \frac{K_T A_i / B}{(1 + s\, {}^{J_T}\!/_{B})(1 + s\tau_a)}$$



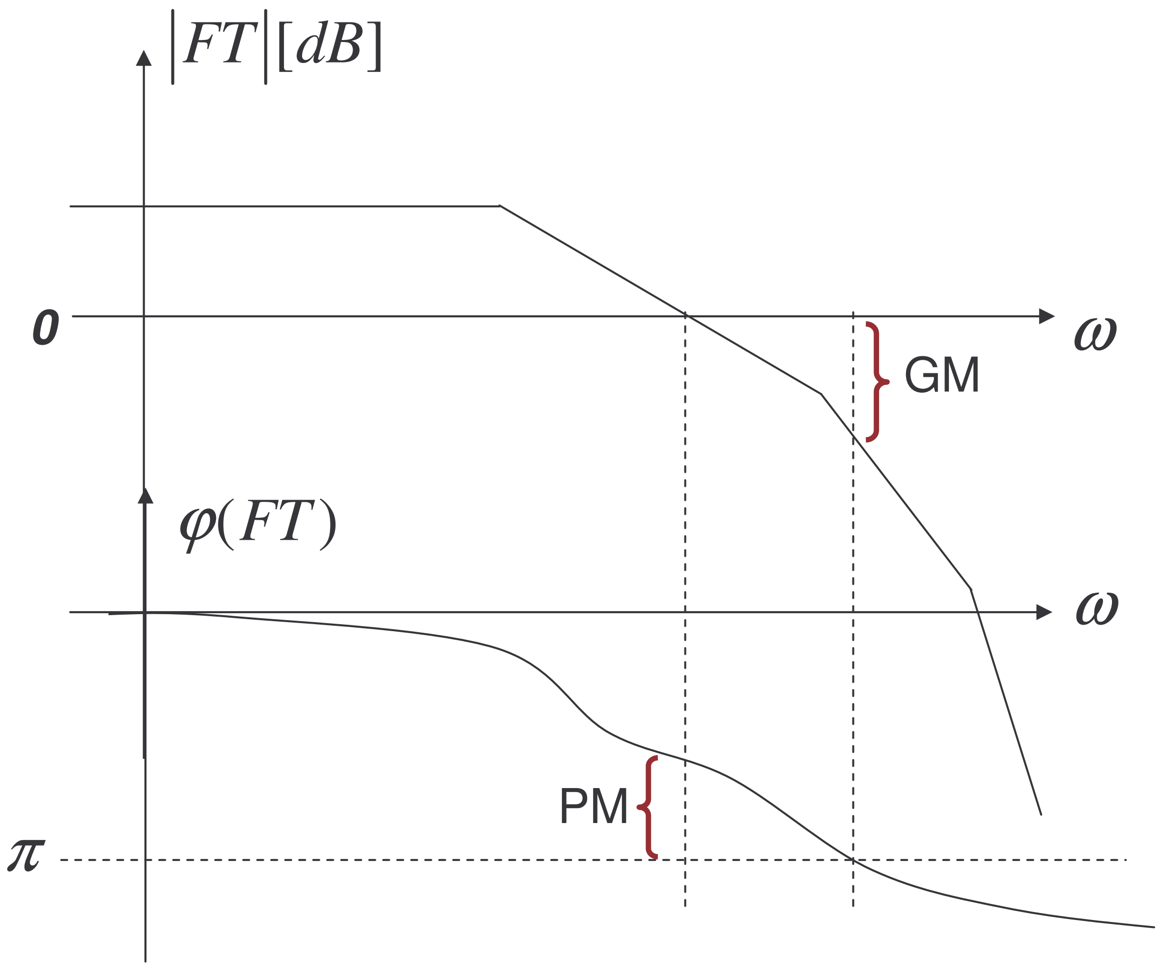
The (asymptotic) plot is accurate for…

- Real valued poles and zeros, no resonance!
- Successive poles/zeros are separate by a factor of 7 or so, they don't interact

Gain and phase margin

$$GM = -20\log(|FT|) \quad @\,\omega_\pi$$
$$PM = \pi - \varphi(FT) \quad @\,\omega_0$$

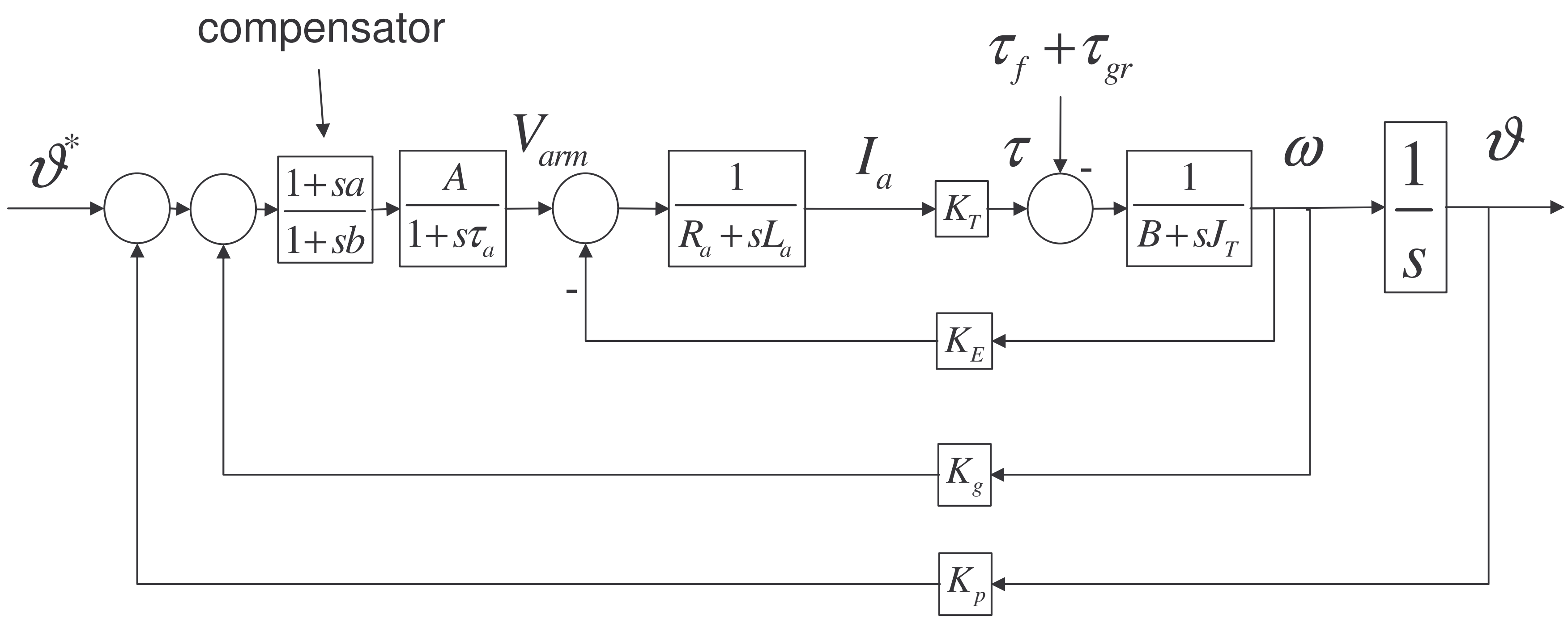
Margins



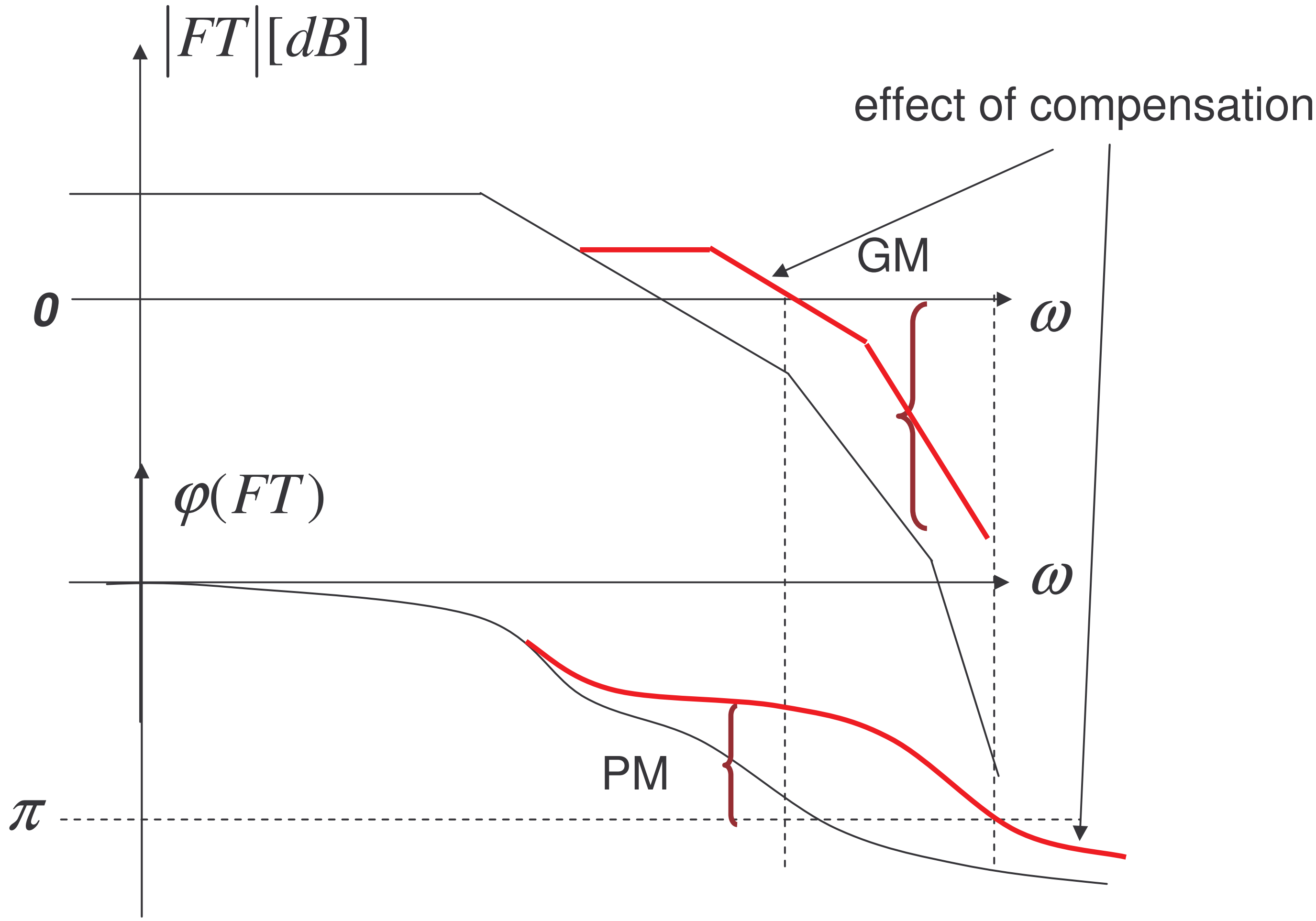
Rule of thumb

- Common design objectives:
  - Gain margin > 20dB
  - Phase margin > 45 degrees

Compensator

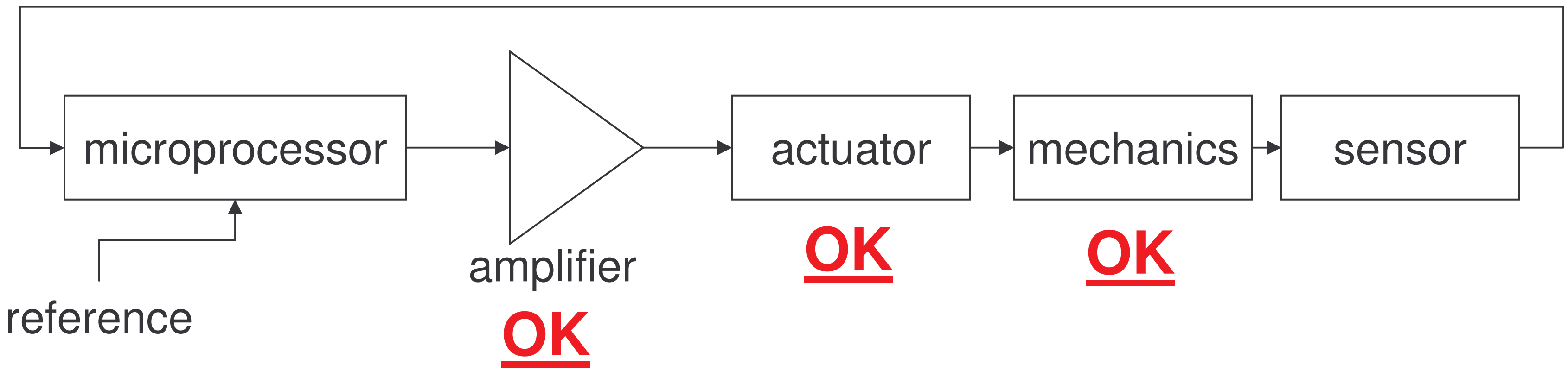


Effects of compensation



This plot is not a real one!

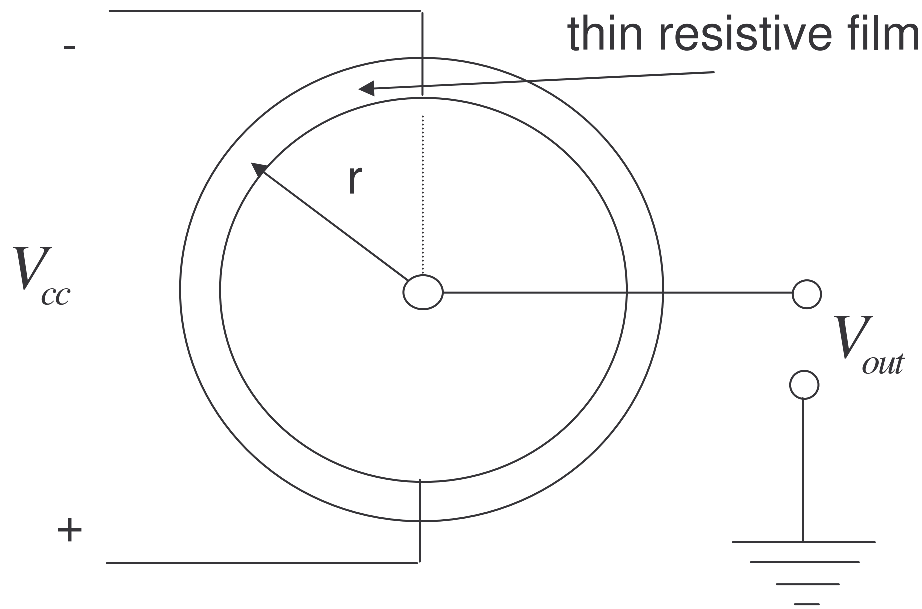
Back to the global view



Sensors

- Potentiometers
- Encoders
- Tachometers
- Inertial sensors
- Strain gauges
- Hall-effect sensors
- and many more…

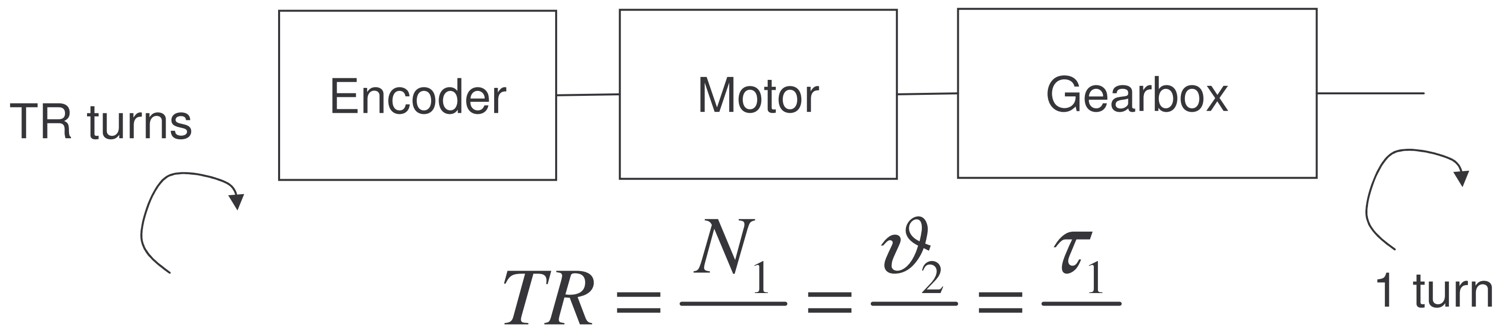
Potentiometer



$$V_{out} = \frac{r}{R} V_{cc}$$

- Simple but noisy
- Requires A/D conversion
- Absolute position (good!)

Note



$$TR = \frac{N_1}{N_2} = \frac{\vartheta_2}{\vartheta_1} = \frac{\tau_1}{\tau_2}$$

$$\tau_2 = \frac{N_2}{N_1}\tau_1 \Rightarrow \text{(most of the time)}\, N_2 > N_1$$

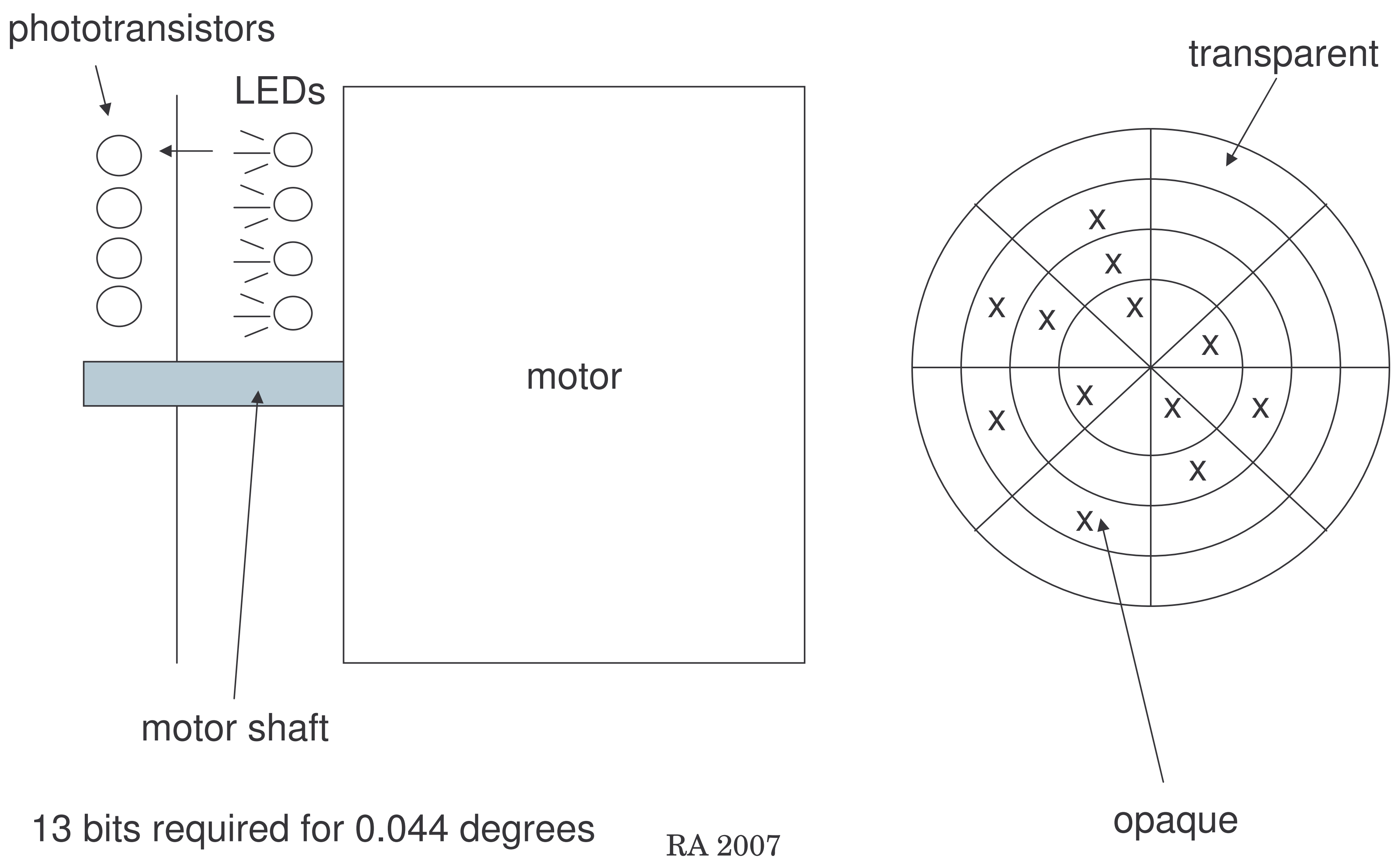
$$\vartheta_2 = \frac{N_1}{N_2}\vartheta_1$$

- The resolution of the sensor multiplied by TR

Encoder

- Absolute
- Incremental

Absolute encoder

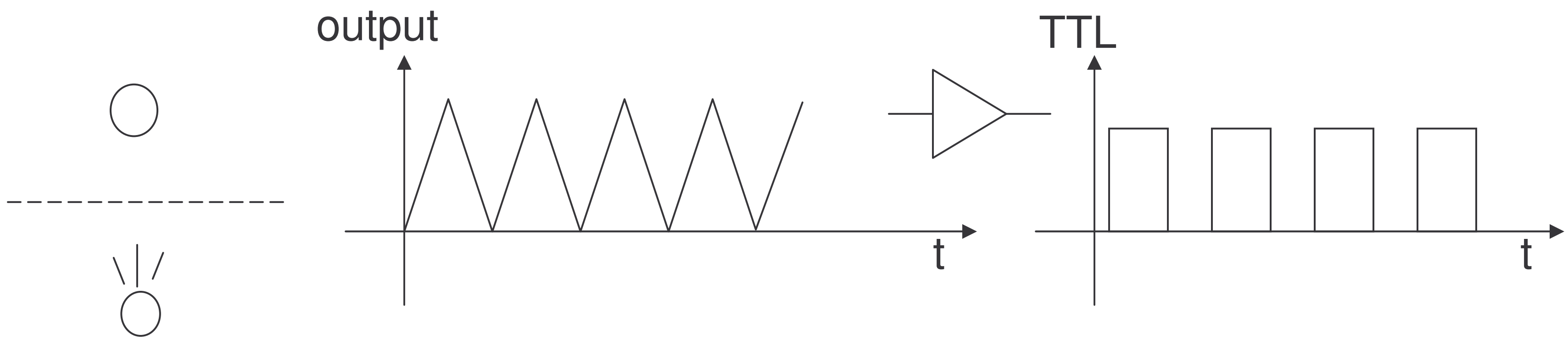


13 bits required for 0.044 degrees

Incremental encoder

- Disk single track instead of multiple
- No absolute position
- Usually an index marks the beginning of a turn

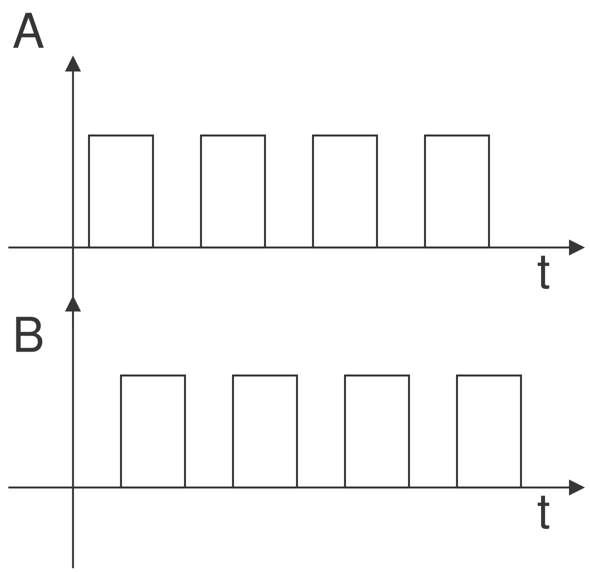
Incremental encoder

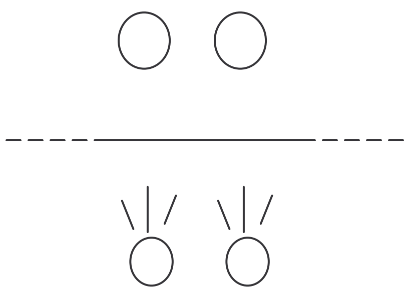


- Sensitive to the amount of light collected
- The direction of motion is not measured

Two-channel encoder

- 2 channels 90 degrees apart (quadrature signals) allow measuring the direction of motion





Moreover

- There are “differential” encoders
  - Taking the difference of two sensors 180 degrees apart
- Typically
  - A, B, Index channel
  - A, B, Index (differential)
- A “counter” is used to compute the position from an incremental encoder

Increasing resolution

- Counting UP and DOWN edges
  - X2 or X4 circuits

Absolute position

- A potentiometer and incremental encoder can be used simultaneously: the pot for the “absolute” reference, and the encoder because of good resolution and robustness to noise

Analog locking

- Use digital encoder as much as possible
  - Get to zero error or so using the digital signal
- When close to zeroing the error:
  - Switch to analog: use the analog signal coming from the photodetector (roughly sinusoidal/triangular)
  - Much higher resolution, precise positioning

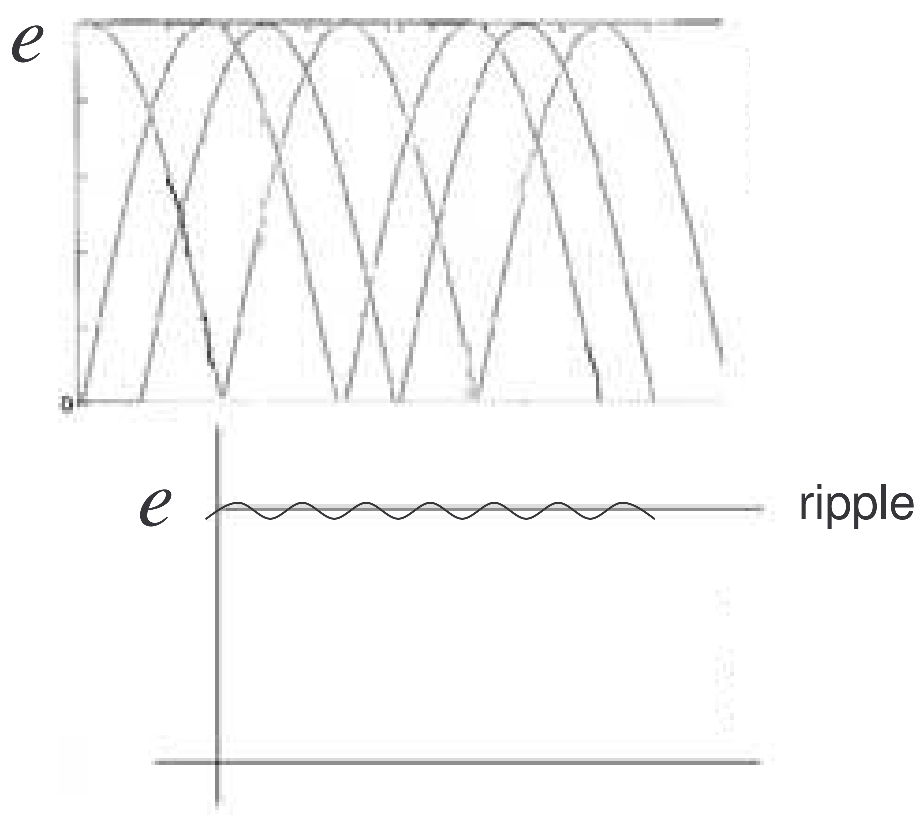
Tachometer

- Use a DC motor
  - The moving coils in the magnetic field will get an induced EMF

$$c\oint_{\delta s} \overline{E} \bullet d\overline{l} = \frac{d}{dt}\iint_{s} \overline{B} \bullet d\overline{S}$$

- In practice is better to design a special purpose "DC motor" for measuring velocity
- Ripple: typ. 3%

As already seen…



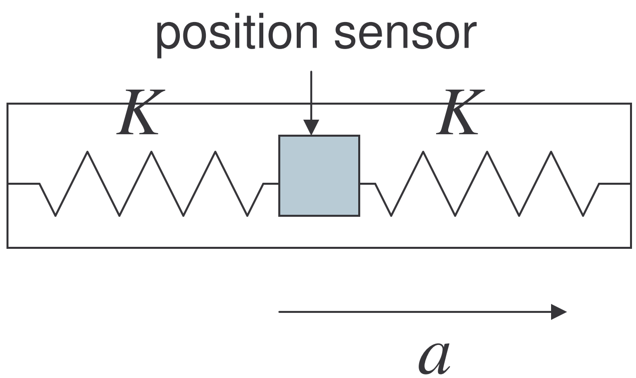
Measuring speed with digital encoders

- Frequency to voltage converters
  - Costly (additional electronics)
- Much better: in software
  - Take the derivative (for free!)

$$v(kT) = \frac{p(kT) - p((k-1)T)}{T}$$

Inertial sensors

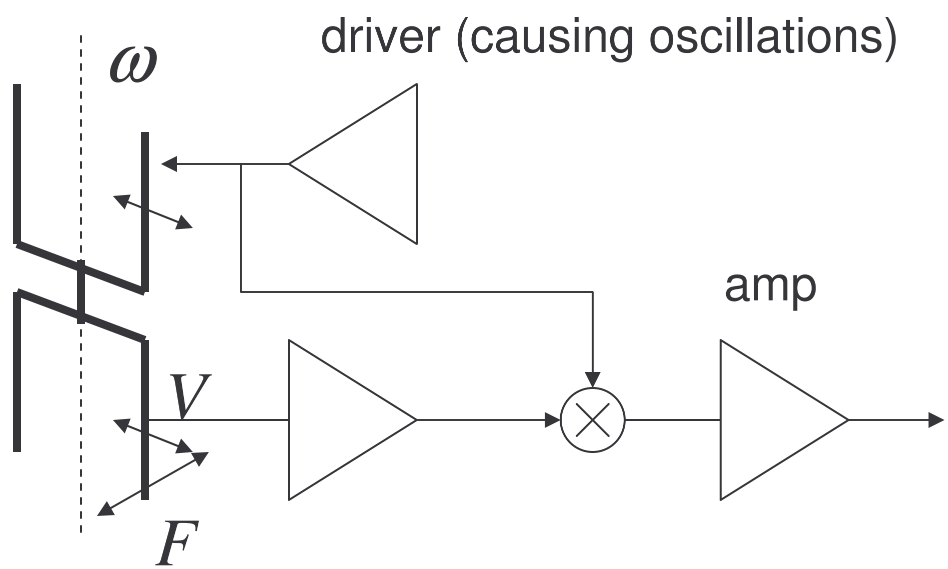
- Accelerometers:



$$Ma = 2Kx \Rightarrow a = \frac{2Kx}{M}$$

Gyroscopes

- Quartz forks



$$F = 2m\omega \times V$$

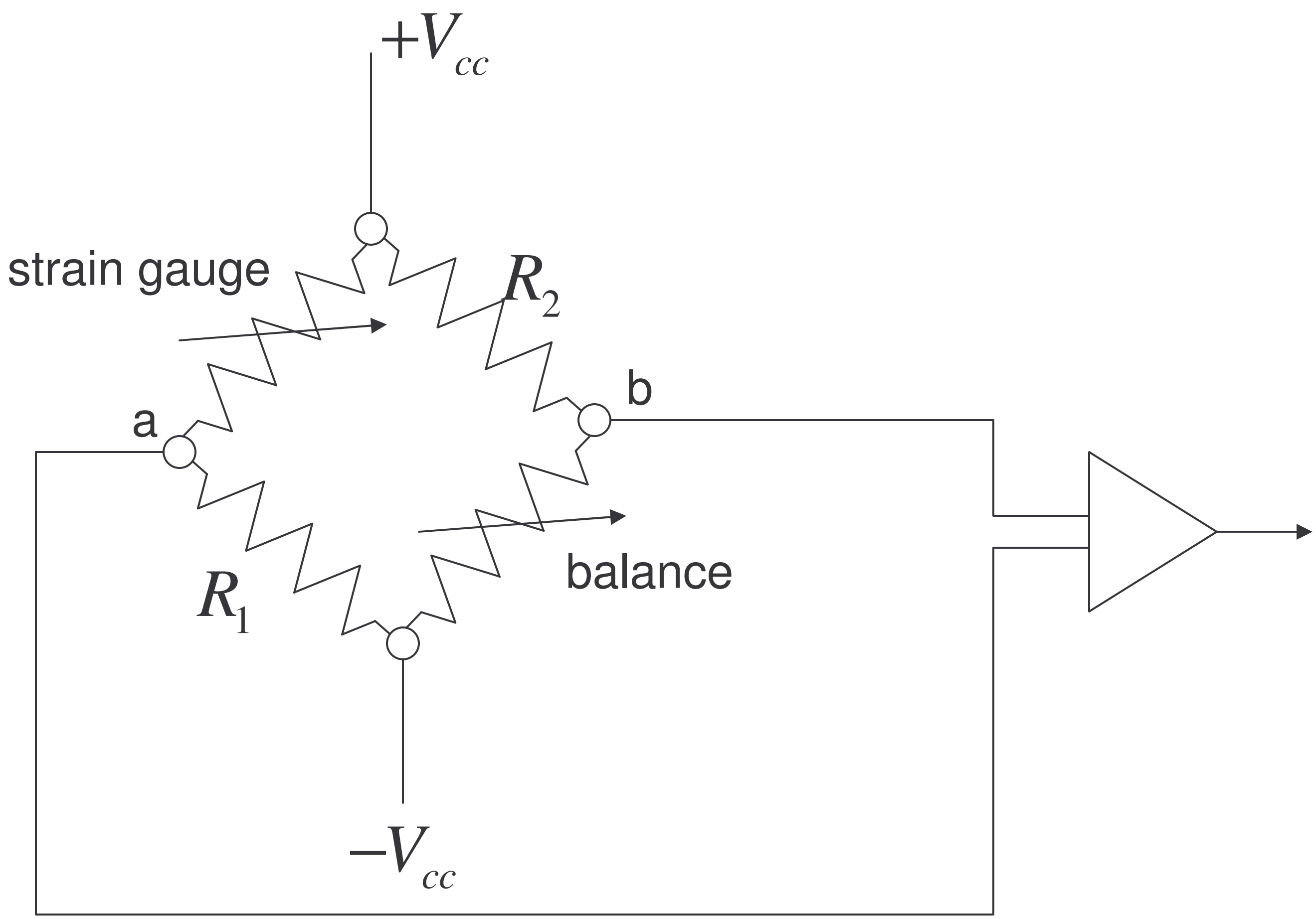
Strain gauges

- Principle: deformation $\rightarrow \Delta R$ (resistance)
  - Example: conductive paint (Al, Cu)
  - The paint covers a deformable non-conducting substrate

$$R = \frac{L}{\sigma A} \Rightarrow \Delta L, A = const \Rightarrow \Delta R$$

conductivity

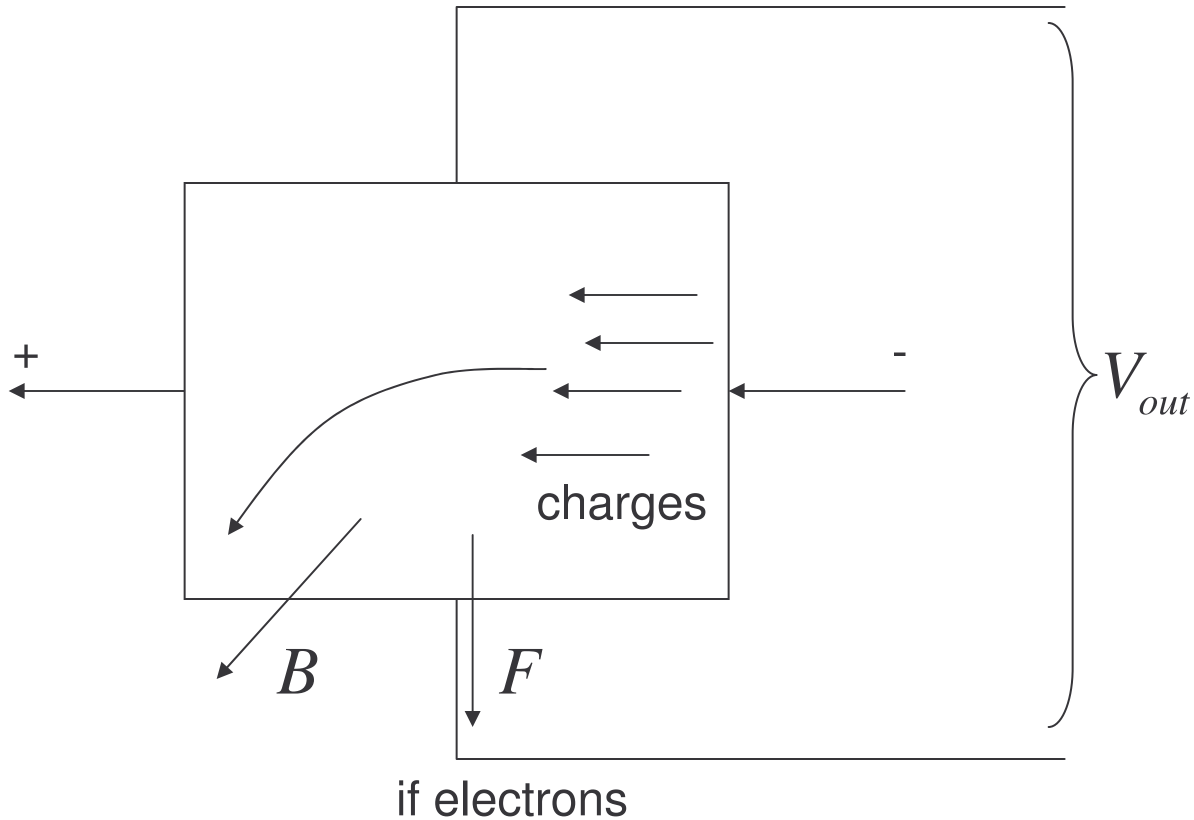
Reading from a strain gauge



$$R_1 R_2 = R_g R_b \Rightarrow V_{ab} = 0$$

$$\Delta V_{ab} = f(\Delta R_g)$$

Hall-effect sensors



$$F_{lorentz} = q\vec{v} \times \vec{B}$$

Example

- Measuring angles (magnetic encoders)

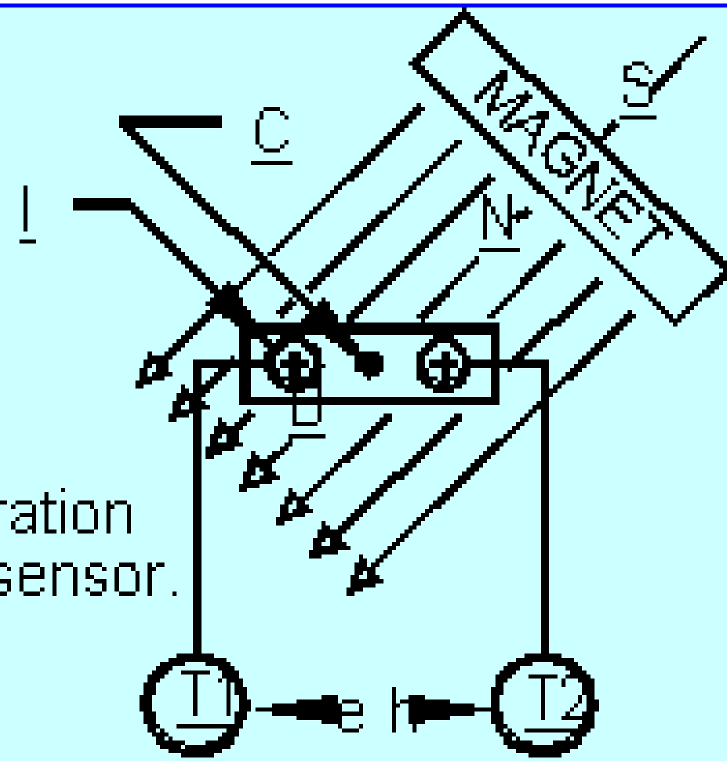
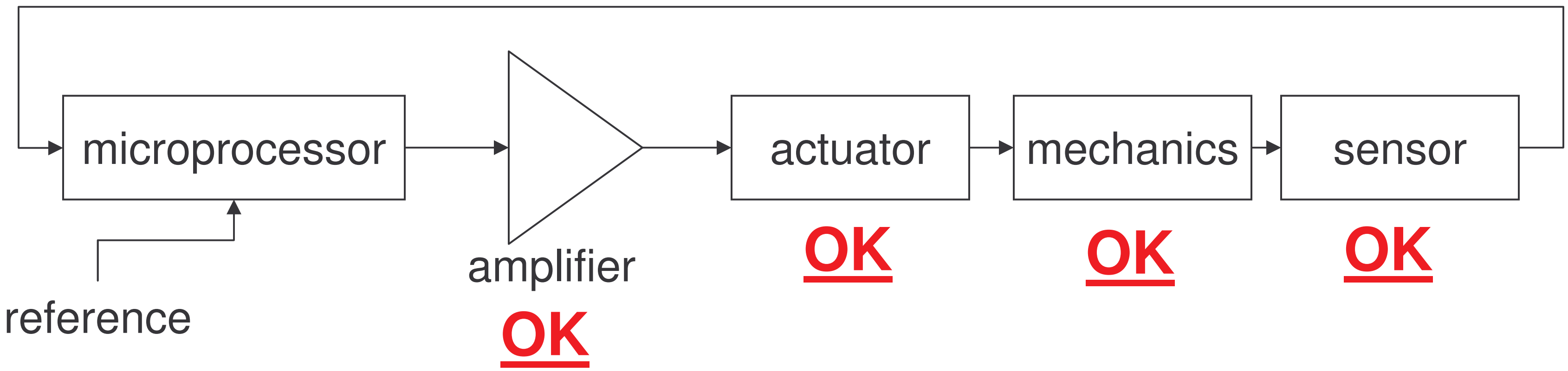


FIGURE 1--Basic Configuration of magnet and hall effect sensor. Edge views are shown.

Back to the global view



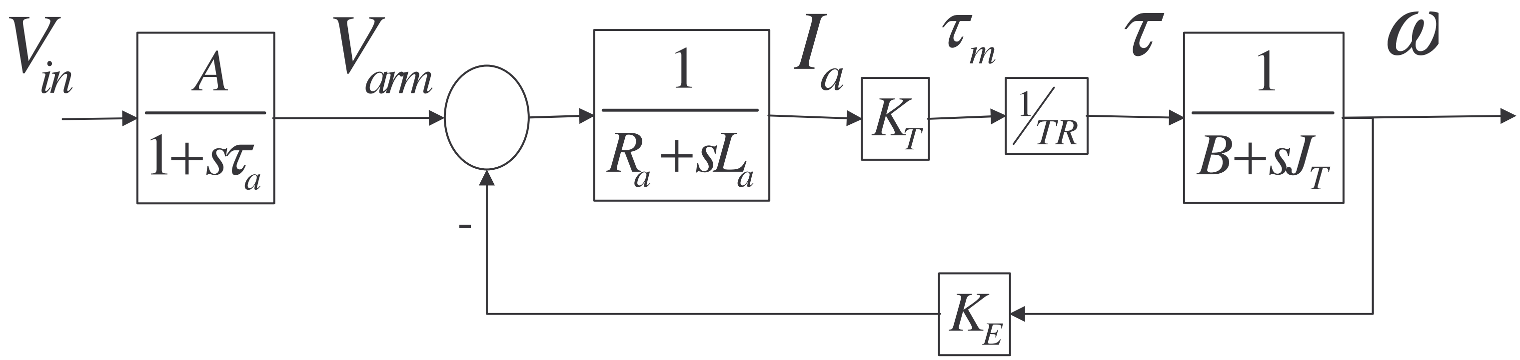
Microprocessors

- Special DSPs for motion control
  - Some are barely programmable (the control law is fixed)
  - Others are general purpose and they are mixed mode (analog and digital in a single chip)

Example

- DSP 16 bit ALU and instruction set
- PWM generator (simply attach this to either T or H amplifier)
- A/D conversion
- CAN bus, Serial ports, digital I/O
- Encoder counters
- Flash memory and RAM on-board
- Enough of all these to control two motors (either brush- or brushless)

Problem set



Simulate the following situation and build a controller for it.

-B = 10*Bm

-J = a thin bar 0.2m long and 0.2kg in weigth

-Motor: 1331

-A=1

-ta=3ms

-Add blocks as needed