

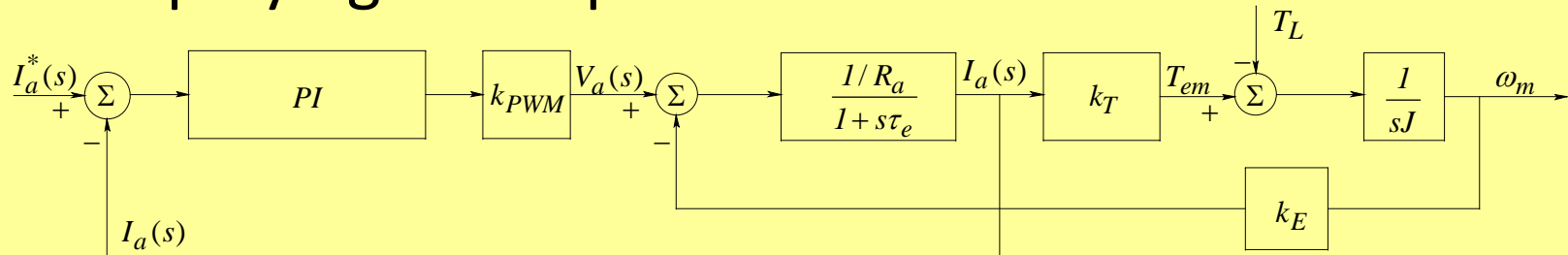
Controller Design

- Procedure

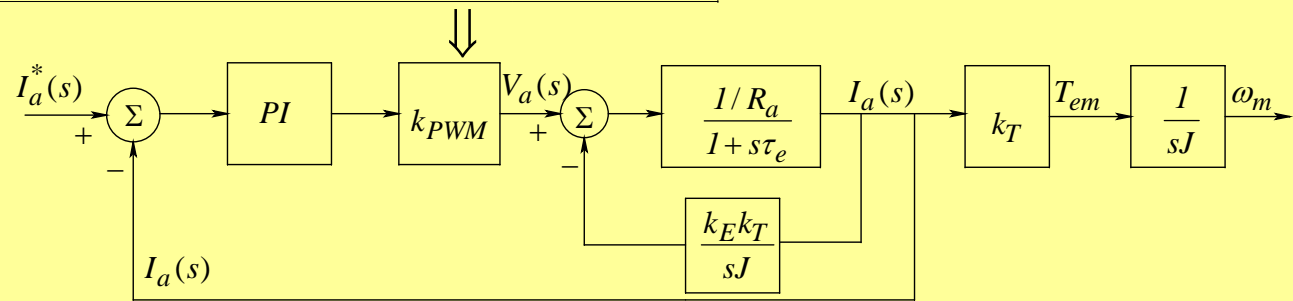
- ◆ Design torque loop (fastest) first
- ◆ Design speed loop assuming torque loop to be ideal
- ◆ Design position loop (slowest) assuming speed loop to be ideal

Design of the Torque (Current) Loop

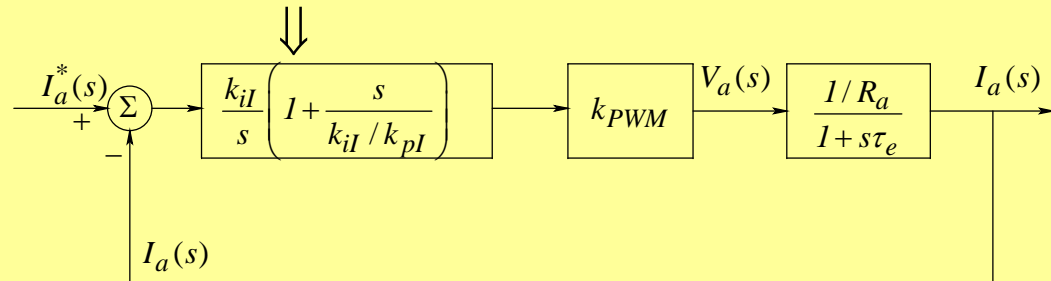
Simplifying assumptions



- Interleaved loops redrawn as nested loops



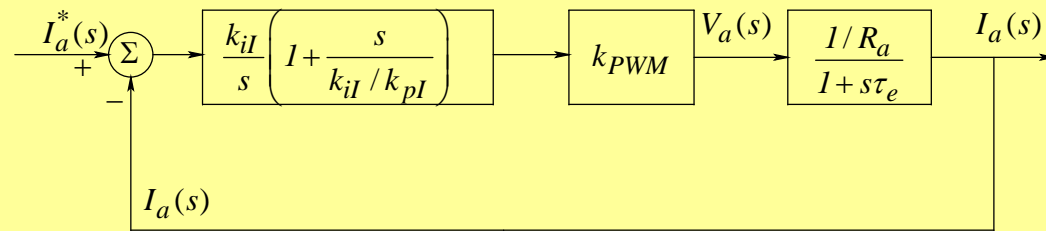
- Assuming J high enough, inner loop can be ignored



$$G_{I,OL}(s) = \underbrace{\frac{k_{il}}{s} \left(1 + \frac{s}{k_{il}/k_p} \right)}_{PI \text{ controller}} \underbrace{k_{PWM}}_{PPU} \underbrace{\frac{1/R_a}{1+s\tau_e}}_{\text{motor}}$$

Design of the Torque (Current) Loop

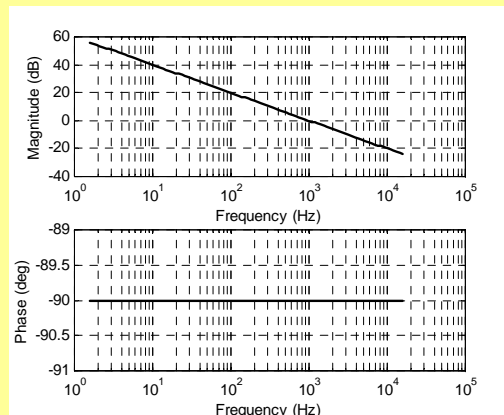
Selecting Parameters



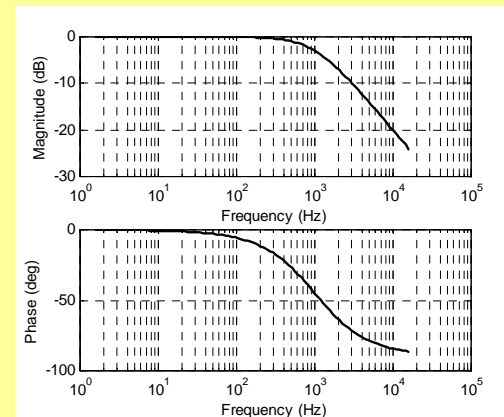
- Select zero of PI to cancel motor pole ;

$$\Rightarrow G_{I,OL} = \frac{k_{I,OL}}{s}; \quad k_{I,OL} = \frac{k_{iI} k_{PWM}}{R_a} \quad \frac{k_{pI}}{k_{iI}} = \tau_e$$

- Choose k_{iI} to achieve desired cross-over frequency $k_{I,OL} = \omega_{CI}$

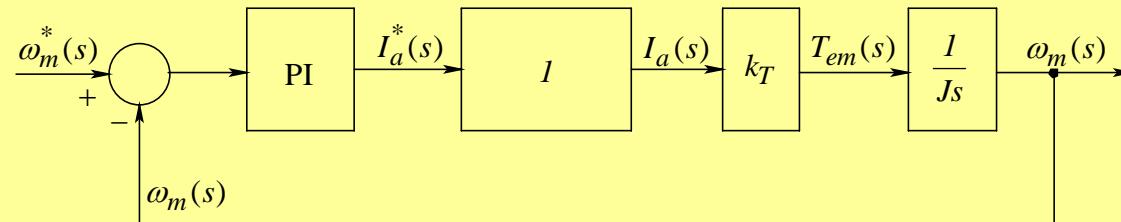


open loop



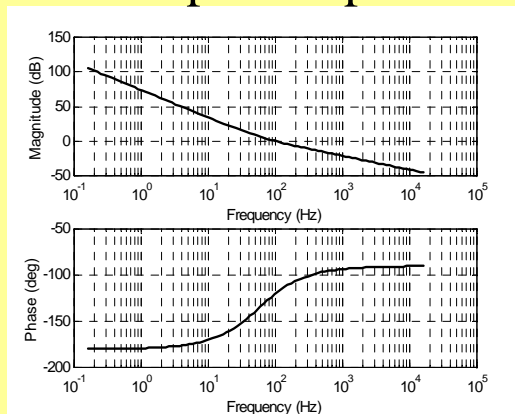
closed loop

Design of the Speed Loop

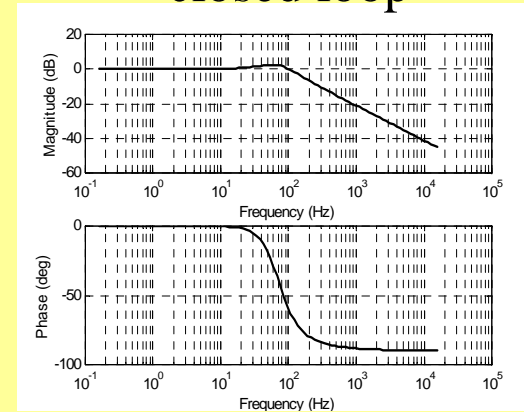


- ❑ Assume current loop to be ideal; represent by unity
- ❑ Choose crossover frequency $\omega_{C\omega}$ an order of magnitude lower than ω_{CI}
- ❑ Choose a reasonable phase margin $\phi_{PM,\omega}$

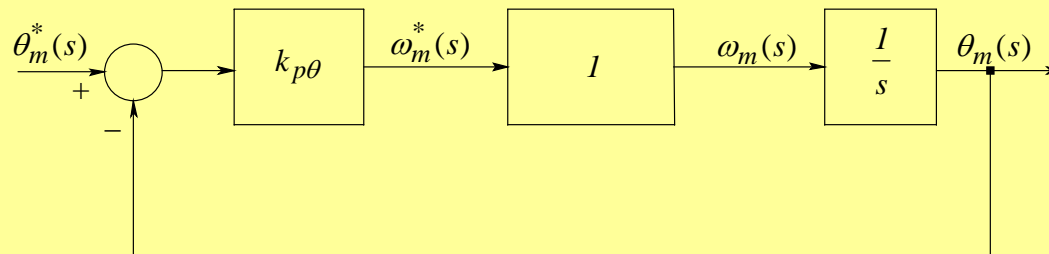
open loop



closed loop

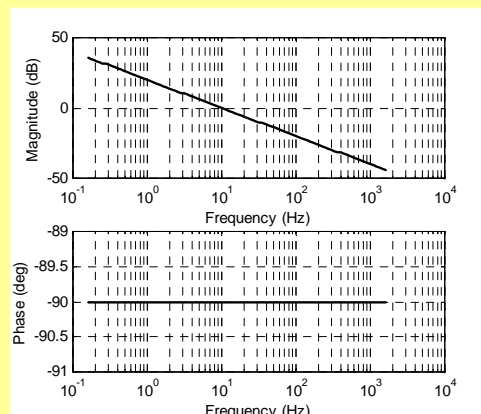


Design of the Position Loop

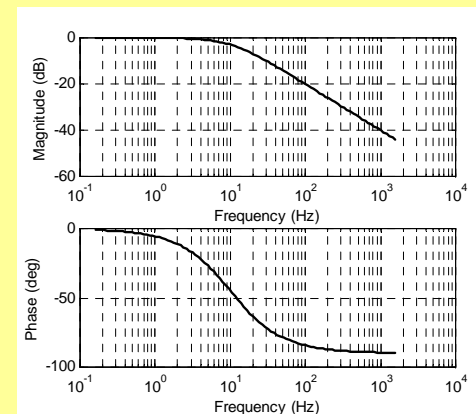


- Assume speed loop to be ideal
- Proportional gain ($k_{P\theta}$) alone is adequate due to presence of pure integrator

$$G_{\theta,OL} = \frac{k_{P\theta}}{s} \quad \Rightarrow \quad k_{P\theta} = \omega_{CP}$$



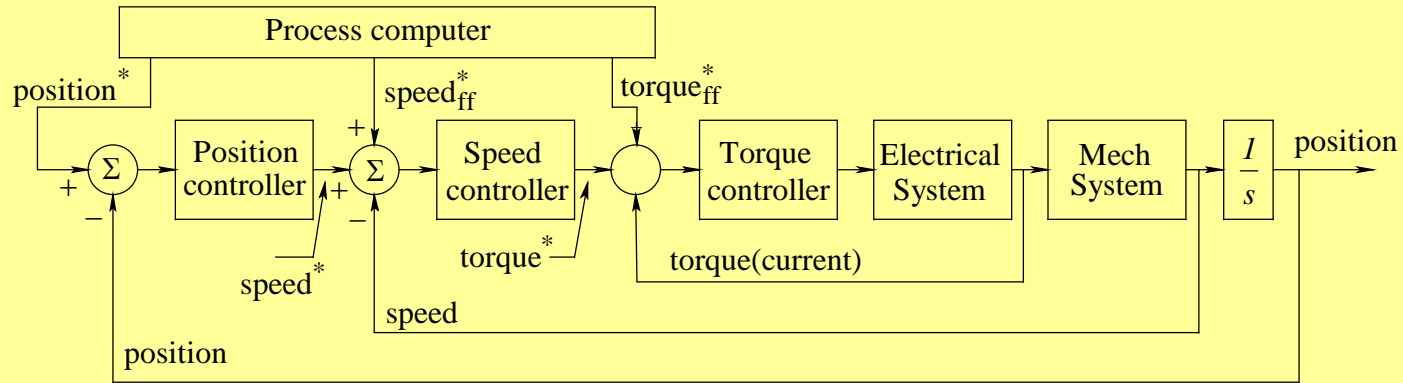
open loop



closed loop

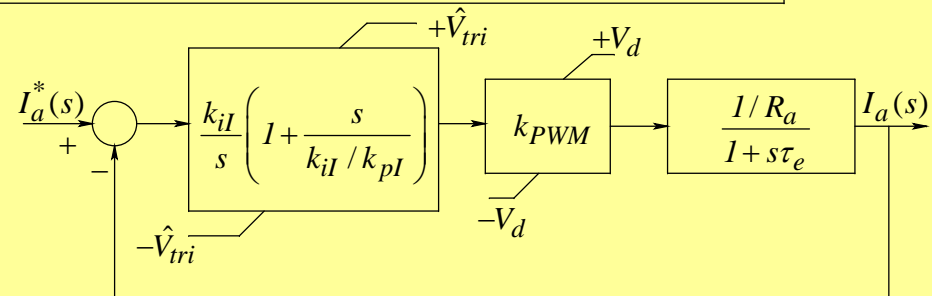
Further Issues

□ Feed-forward: To improve dynamic response



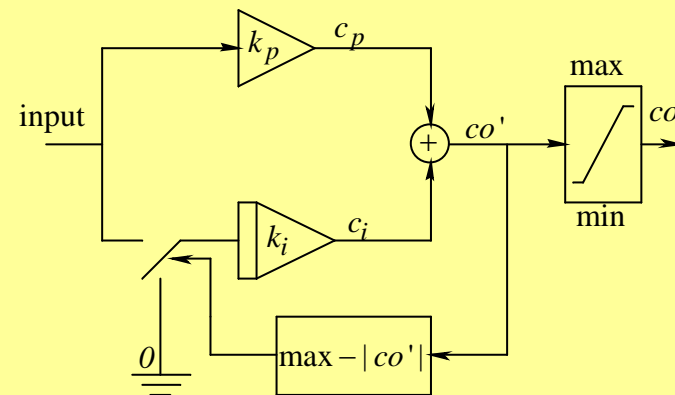
□ Effect of limits

- nonlinearity



□ Anti-windup integration

- suspend integration when output saturates



Summary

Controller Design

□ Procedure

- ◆ Design torque loop (fastest) first
- ◆ Design speed loop assuming torque loop to be ideal
- ◆ Design position loop (slowest) assuming speed loop to be ideal