Lecture 17.

HW 5 due on Mar 03

HW 6 due on Mar 10

Finals (take home) Mar 12 (midnight) –
Mar 15 (midnight)

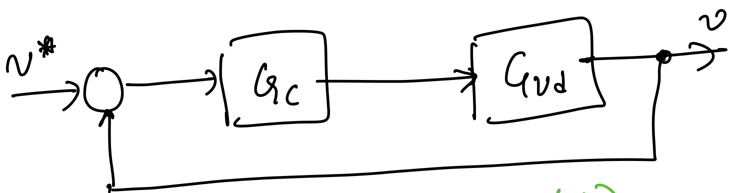
HW 4

Buck boost converter voltage control.

Key takeaway's

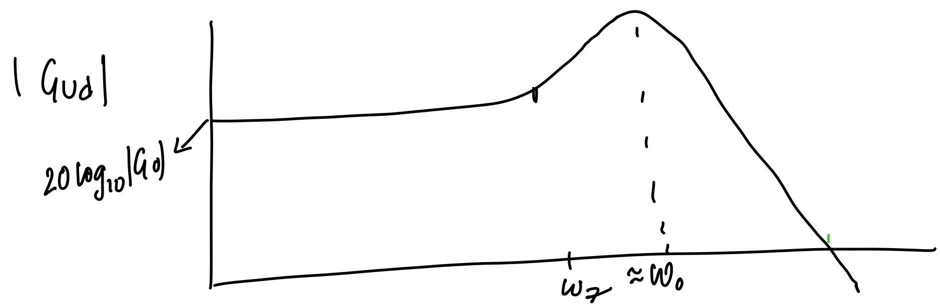
① Right half zero in the transfer function $G_{vd} = \frac{\tilde{v}(s)}{d(s)}$

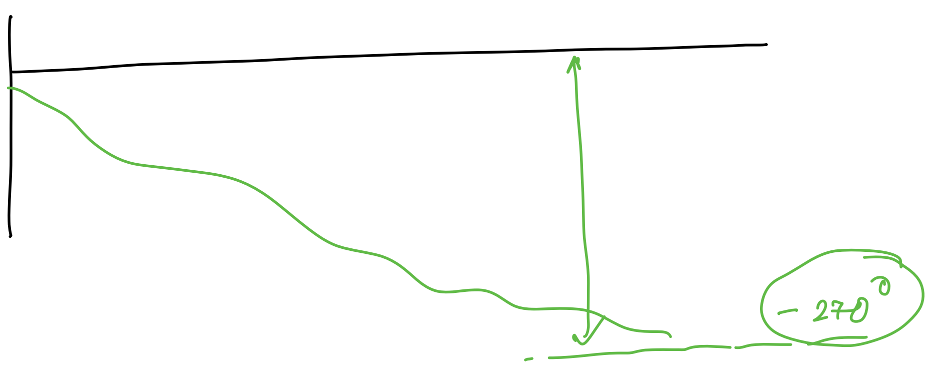
$$G_{vd} = G_0 \frac{\left(1 - s/\omega_z\right)}{\underbrace{\left(\frac{s}{\omega_0}\right)^2 + \frac{s}{Q\omega_0} + 1}} \qquad \begin{matrix} := -90^\circ \\ := -180^\circ \end{matrix}$$



① Perfect dc tracking $\left(\frac{1}{s}\right)$ $:= -90^\circ$

② PM of 52° or more.

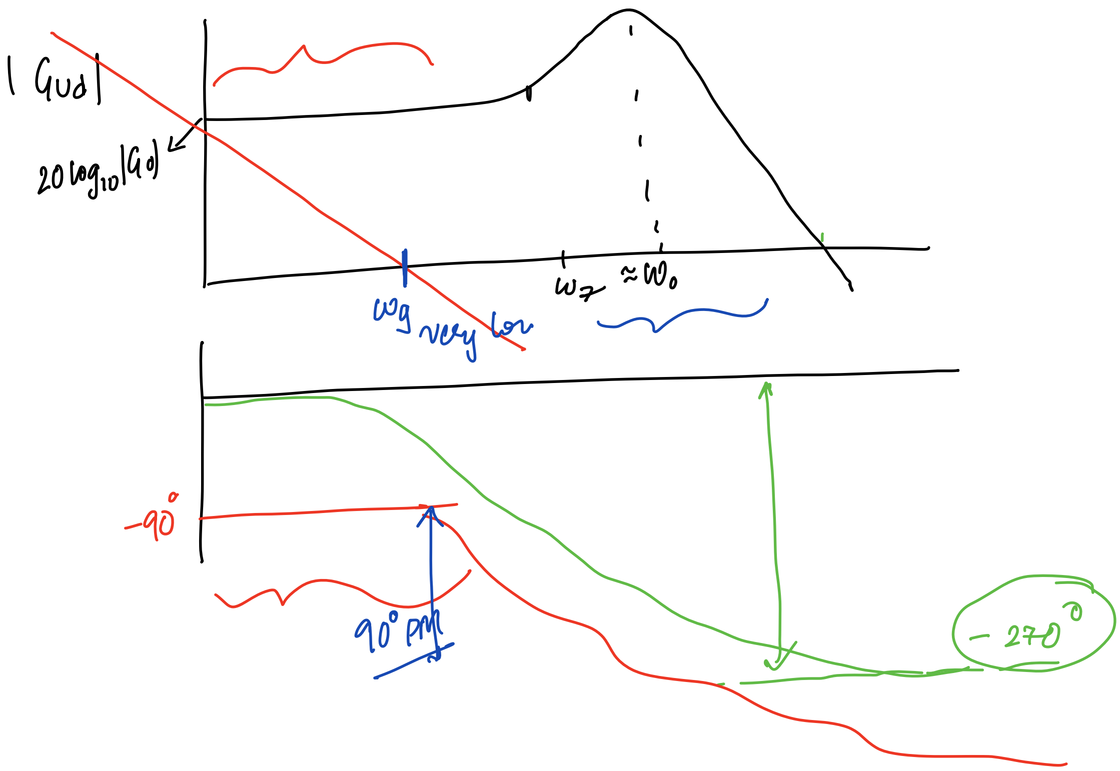




Soln 1 : Integrator & low bandwidth 90° PM.

$C(s) = \frac{1}{s} \cdot K_i$ $\qquad$ $\underline{K_i << 1}$

$l = C(s) \cdot G_{vd}(s)$



Sch-2 Lead compensator based design technique

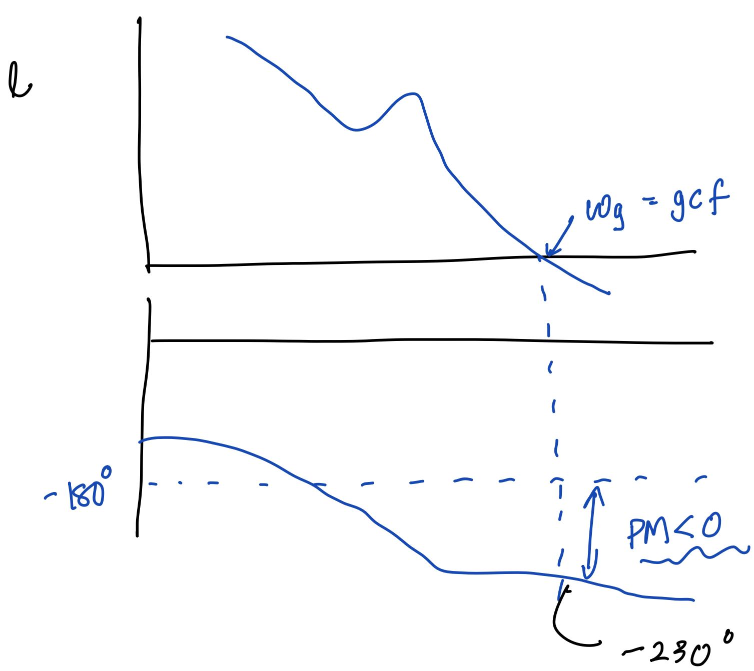
Q: When to use this?

A: When you have already achieved a gain cross over freq (gcf) that you desire.

But at that g.c.f, $\underbrace{\text{your ph} < -180^\circ}$.

So, PM is −ve. → unstable

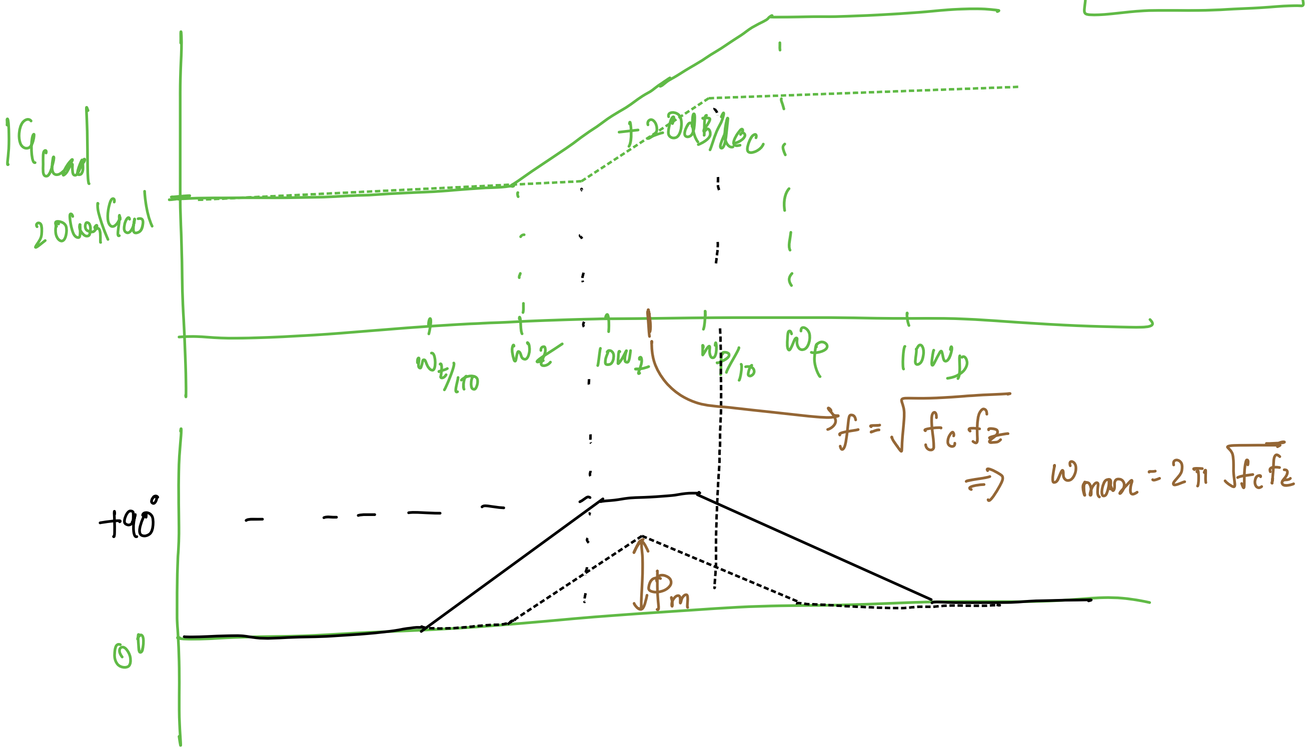
So you want positive phase → lead compensator.

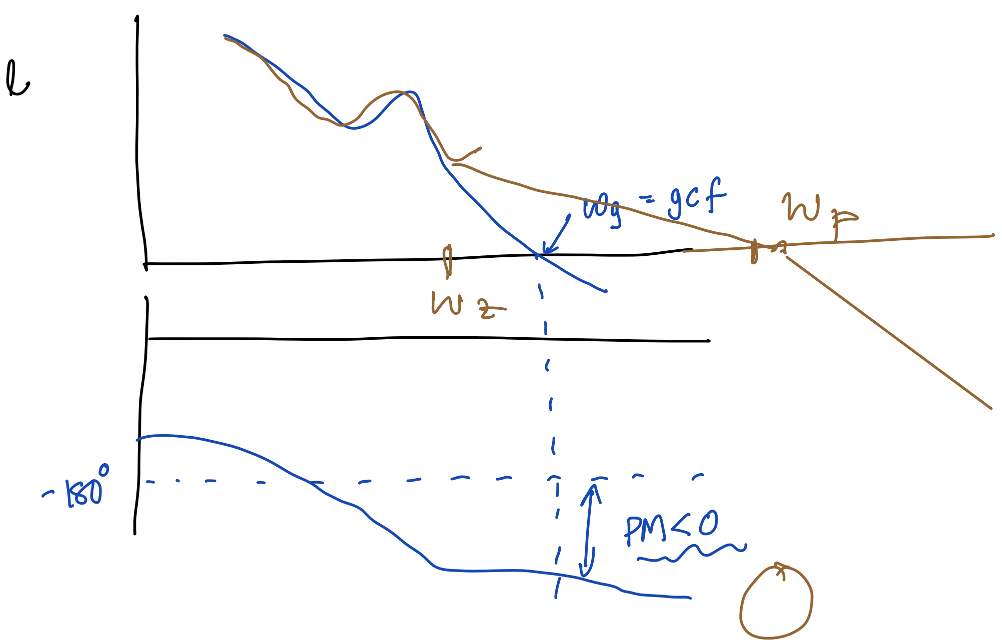


Lead compensator :-

$$\boxed{G_{co}\frac{(1+s/\omega_z)}{(1+s/\omega_p)}} = G_{lead}$$

$$\boxed{\omega_z < \omega_p}$$





f_c = frequency at which you want compensation
= gain crossover freq before you introduce the lead compensator.

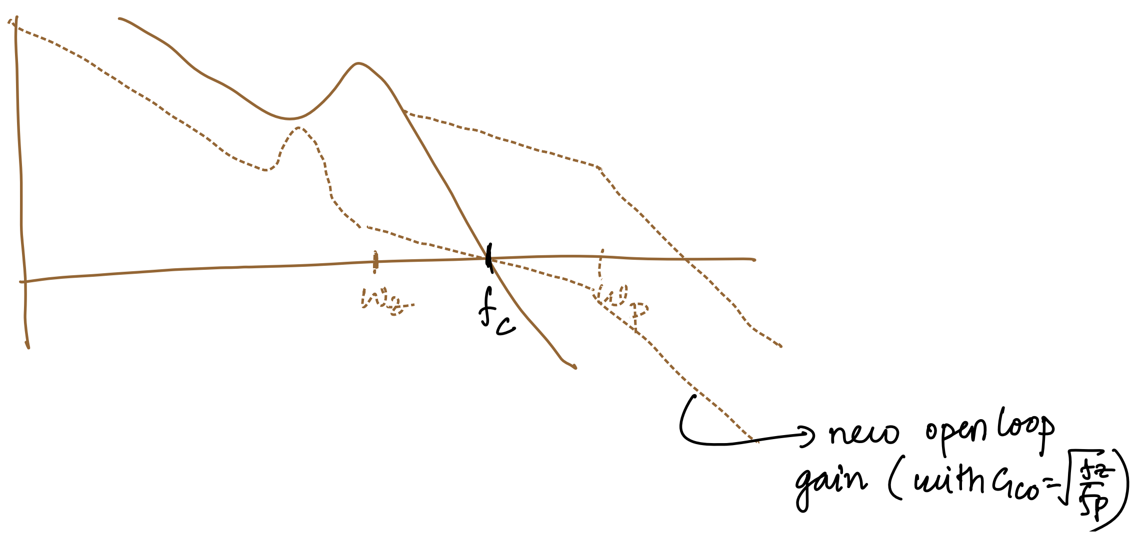
θ = phase 'lead' that you desire.

$$f_z = f_c\sqrt{\frac{1-\sin\theta}{1+\sin\theta}}$$

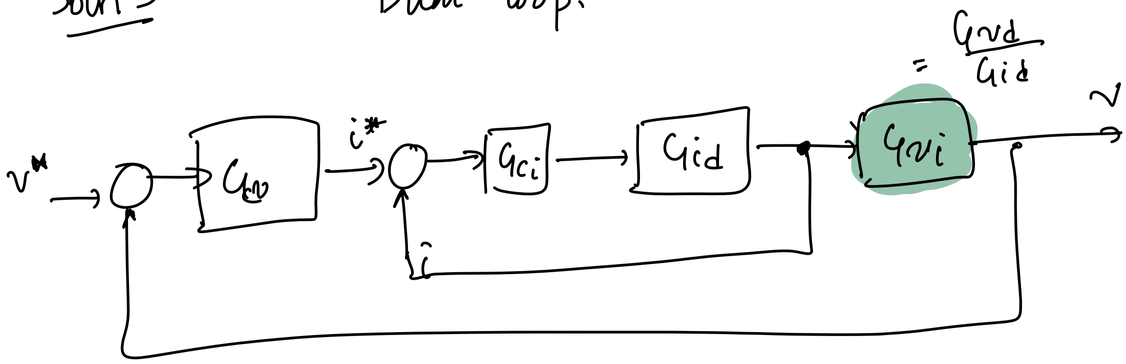
$$f_p = f_c\sqrt{\frac{1+\sin\theta}{1-\sin\theta}}.$$

If you want to add the lead compensator but do not want your gain crossover to change from the previously designed value = f_c,

$$G_{co} = \sqrt{\frac{f_z}{f_p}}.$$



Soln 3 Dual loop.



G_{vi} is a simpler plant transfer function than G_{vd} to design a controller for.

Motor Control

Current Control

$$\left.\begin{array}{l} i_q \\ \\ i_d \end{array}\right\}$$

Q: which one to excite to give a positive torque

A: Method 1:

$$P = \varepsilon_{abc}^T i_{abc}$$

$$= \frac{3}{2} \varepsilon_{dq}^T i_{dq}$$

$$= \frac{3}{2} \begin{bmatrix} \varepsilon_d & \varepsilon_q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix}$$

$$= \frac{3}{2} \left(\varepsilon_d i_d + \varepsilon_q i_q \right)$$

$$\underline{\varepsilon_d = 0} \qquad \underline{\varepsilon_q = -\lambda_{pk} \cdot \omega_e}$$

$$P = -\frac{3}{2} \lambda_{pk} \cdot \omega_e i_q$$

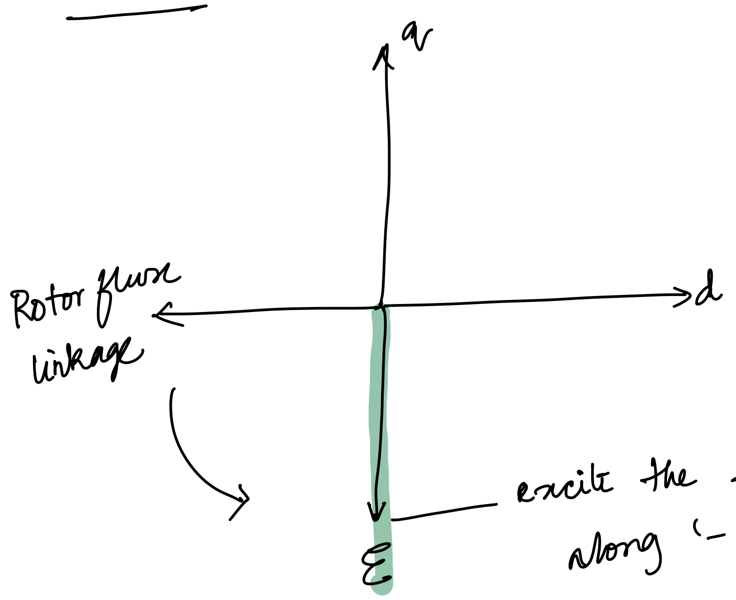
$$= -\frac{3}{2} \frac{P}{2} \lambda_{pk} \omega_m i_q$$

$$\underline{\tau_e = \frac{P}{\omega_m} = -\frac{3}{2} \frac{P}{2} \lambda_{pk} i_q}$$

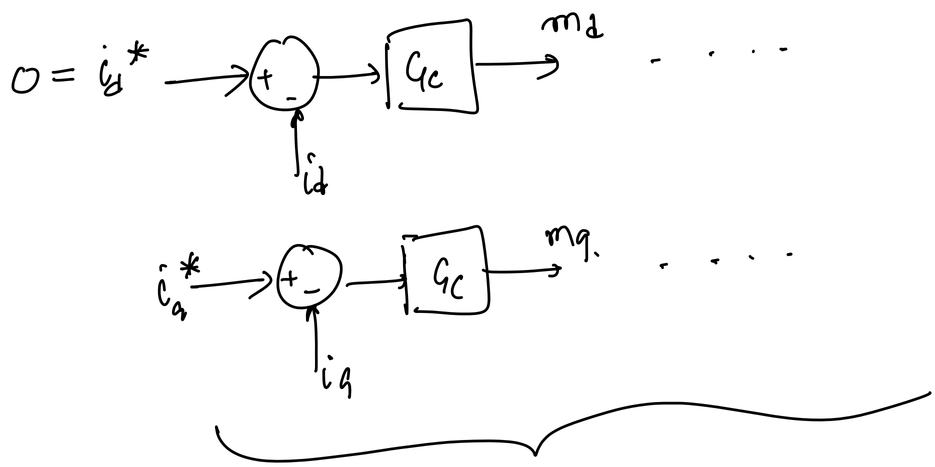
+ve torque $\rightarrow$ negative i_q $\Rightarrow$ i_q^* has to be negative.

i_d has no contribution in τ_e. $\Rightarrow i_d^* = 0$.

Method II



excite the stator current along '$-q$' $\Rightarrow i_q^*$ has to be negative.



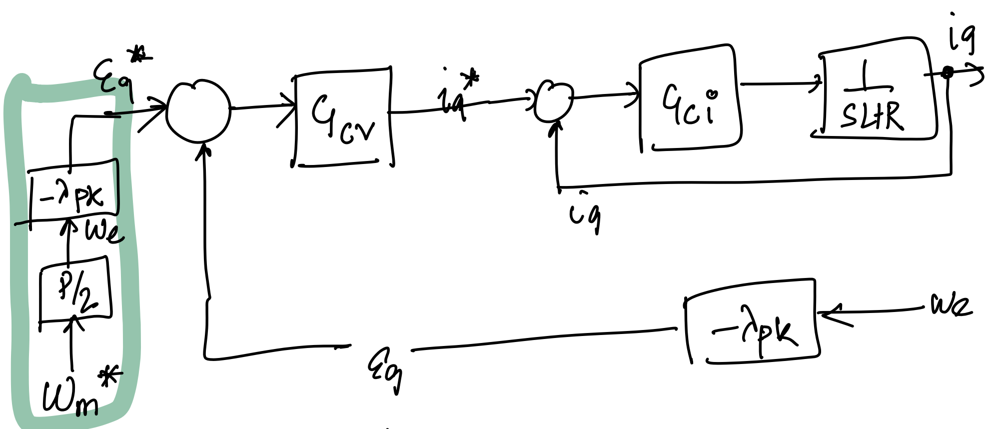
Current control.

$$\mathcal{E}_q = -\lambda_{pk}\cdot\omega_e$$

$$\tau_e = -\frac{3}{2}\frac{P}{2}\lambda_{pk}\, i_q$$

Electrical		Mechanical	
$\mathcal{E}_q$ (voltage)	$\longleftrightarrow$	$= \underbrace{-\lambda_{pk}\,\omega_e}$	(ω_e)
i_q (current)	$\longleftrightarrow$	$= \dfrac{\tau_e}{-\frac{3}{2}\frac{P}{2}\lambda_{pk}}$	(τ_e)

$$\omega_e = \frac{P}{2}\omega_m$$



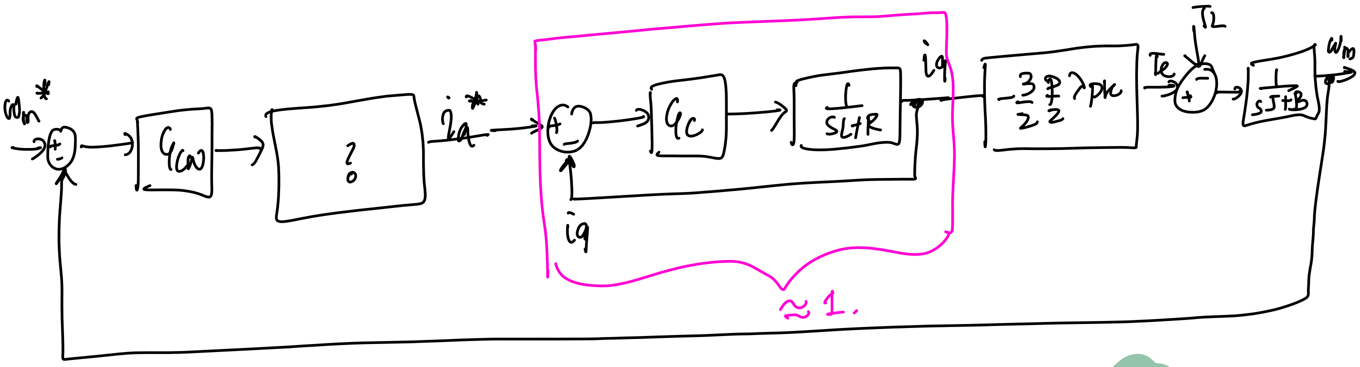
$$\mathcal{E}_q^* = -\lambda_{pk}\,\omega_e^*$$
$$= -\lambda_{pk}\frac{P}{2}\omega_m^*$$

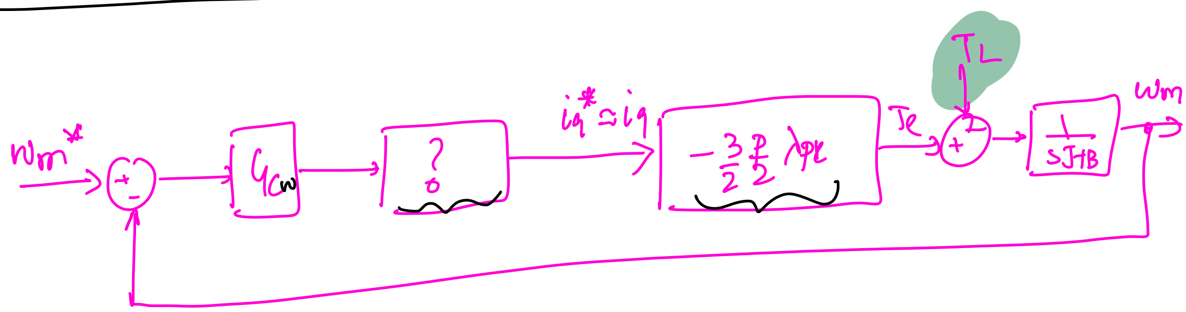
$$J\dot{\omega}_m + B\omega_m = T_e - T_L$$

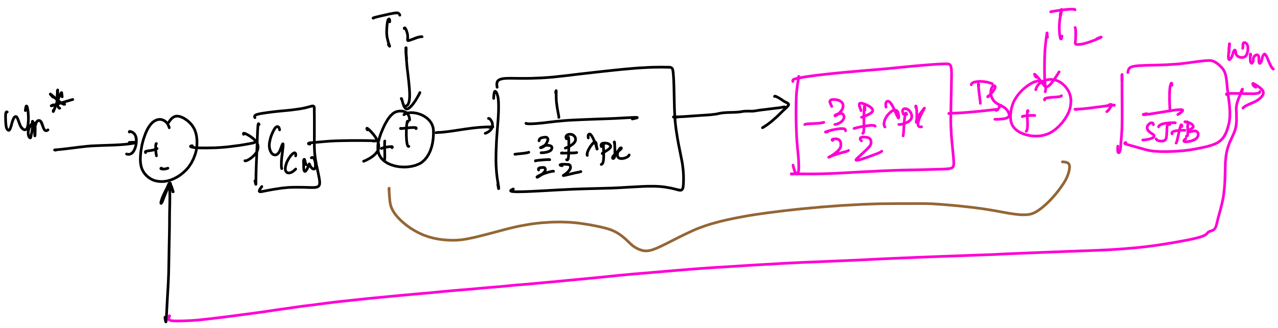
$$sJ\,\omega_m(s) + B\omega_m(s) = T_e(s) - T_L(s)$$

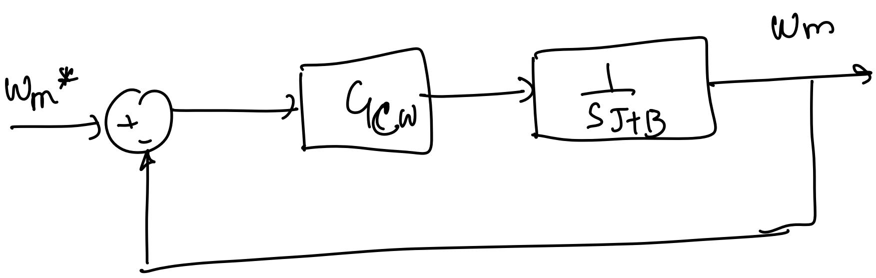
$$\boxed{\omega_m(s) = \frac{T_e(s) - T_L(s)}{sJ + B}}$$

$$\tau_e = -\frac{3}{2}\frac{P}{2}\lambda_{pk}\, i_q$$









$$G_{cw} = K_{pw} + \frac{K_{iw}}{s}$$

BW of the speed control loop $= \omega_w = \frac{1}{10}$ BW of current control loop

$$= \frac{1}{10}\omega_c$$

$$\left(K_{pw} + \frac{K_{iw}}{s}\right) \cdot \frac{1}{sJ+B} = \frac{\omega_{\Omega w}}{s}$$

$$\boxed{\begin{aligned} K_{pw} &= \omega_{\Omega w} J \\ K_{iw} &= \omega_{\Omega w} B \end{aligned}}$$

$J \rightarrow$ net moment of inertia of rider + bike $\rightarrow M \cdot r^2$

$B \rightarrow$ friction in road, friction in machine shaft.

$$C(s) = K_p + \frac{K_i}{s}.$$

$$P(s) = \frac{1}{as+b}$$

① Design your controller for a nominal a^0 & b^0.

$$K_p = a^0 . \omega_g$$

$$K_i = b^0 \omega_g$$

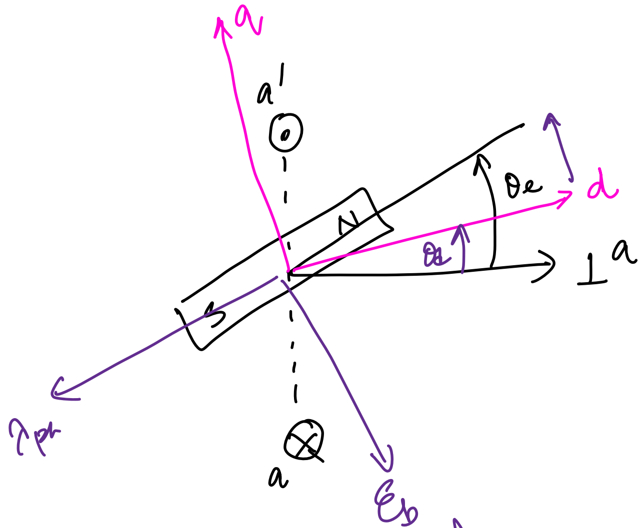
ω_g = desired band width.

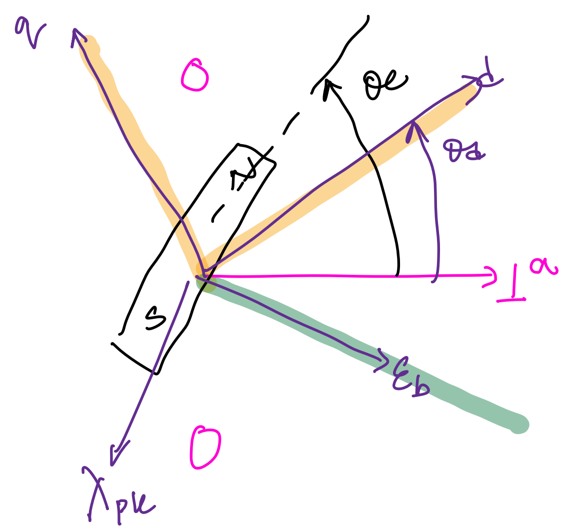
② Now find bode plots of following transfer fn.

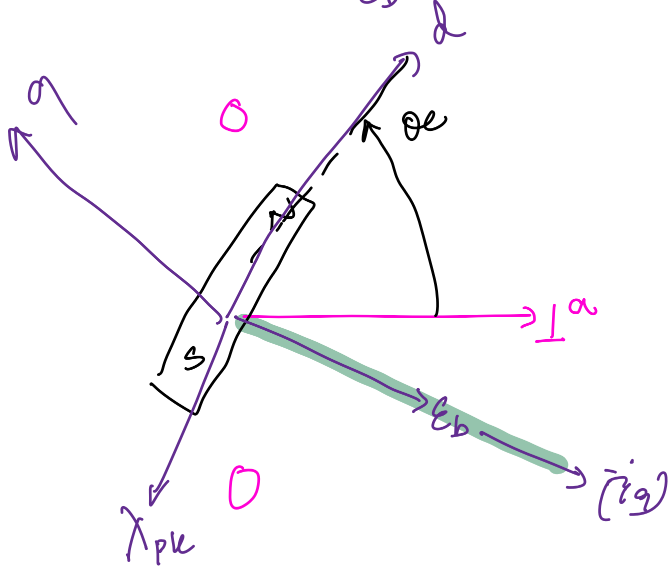
$$\underbrace{\begin{aligned} l_1 &= \left(K_p + \frac{K_i}{s}\right) \frac{1}{(a^0+\Delta a)s + (b^0+\Delta b)} \\ l_2 &= \left(K_p + \frac{K_i}{s}\right) \frac{1}{(a^0-\Delta a)s + (b^0-\Delta b)} \end{aligned}}$$

Design for the worst plant to have the minimum PM & ωg that you want to design for.

Question: What do you mean by locking the d axis?



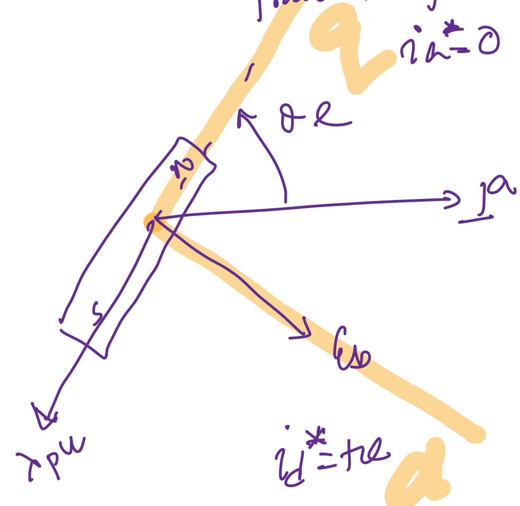




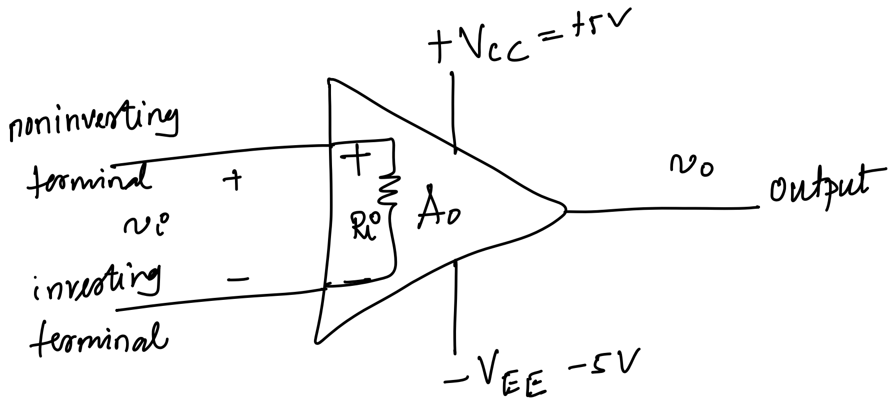
$$\boxed{\theta_e = \theta_d + \frac{\pi}{2}}$$

$$\boxed{\theta_e = \theta_d}$$

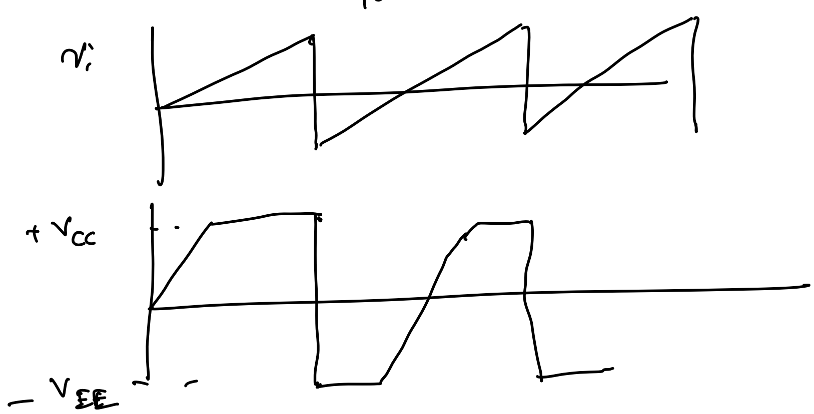
frame transformation

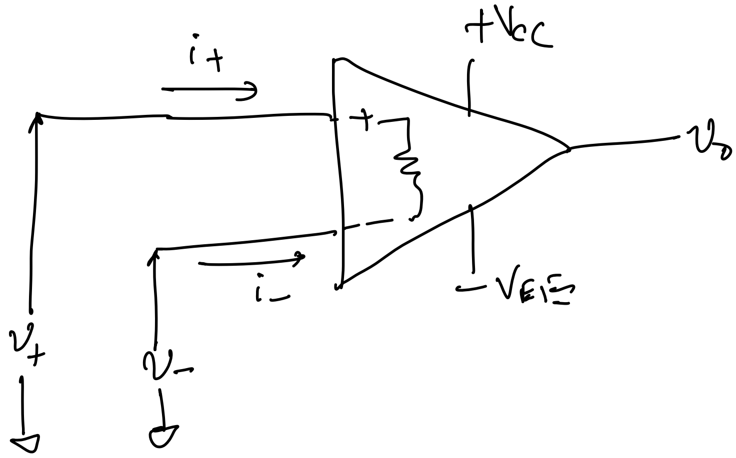


Op Amp (Revision)



$$v_o = \underbrace{A_o}_{10^8} \cdot v_i \rightarrow mV$$

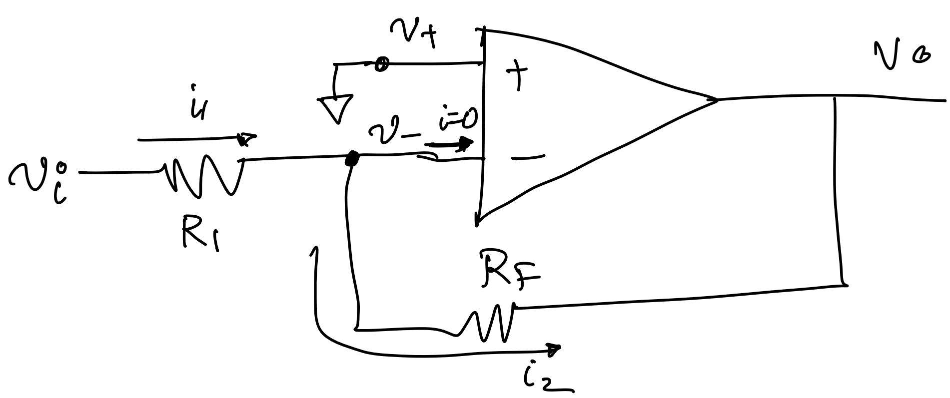




$$i_+ + i_- = 0$$

$$\boxed{v_+ = v_-}$$

① Inverting opamp



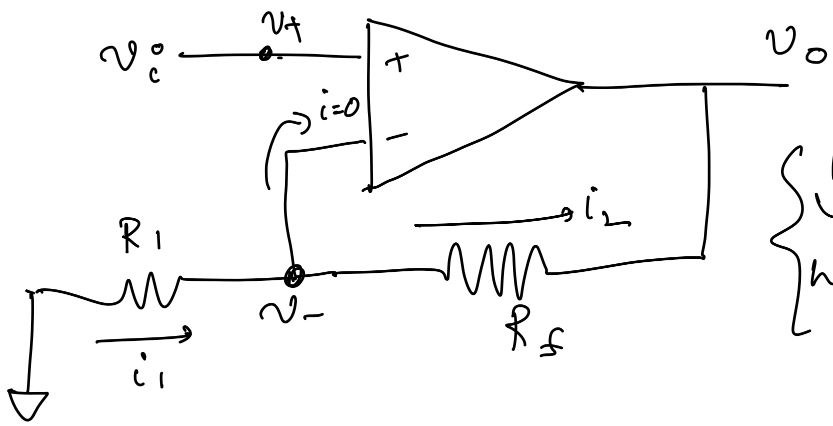
$$v_+ = v_- = 0$$

$$i_1 = i_2$$

$$\frac{v_i - \cancel{v_-}^{\,0}}{R_1} = \frac{\cancel{v_-}^{\,0} - v_0}{R_F}$$

$$\therefore \quad v_0 = -\frac{R_F}{R_1} v_i$$

② Non inverting op-amp.



high CMRR
high BW

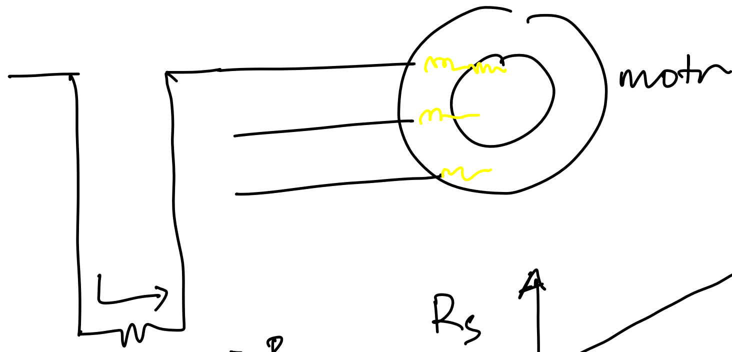
$$\frac{0 - v_-}{R_1} = \frac{v_- - V_0}{R_f}$$

$$v_- = v_+ = v_i$$

$$-\frac{v_i}{R_1} = \frac{v_i - v_o}{R_f}$$

$$\frac{v_o}{R_f} = v_i\left(\frac{1}{R_1} + \frac{1}{R_f}\right)$$

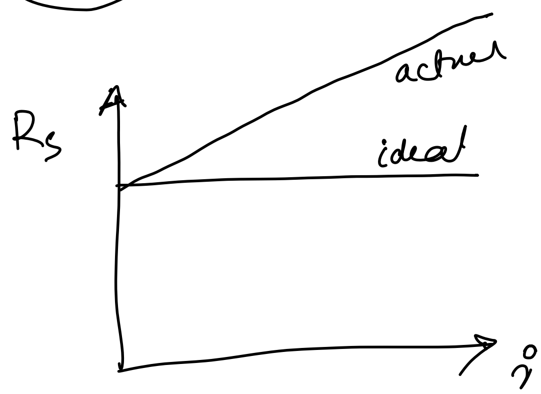
$$v_o = v_i\left(\frac{R_1 + R_f}{R_1}\right)$$



1 mΩ − 5 mΩ = R_s

\+ −

$i \cdot R_s$



current sensor $3 − $8.00 → Hall effect sensors

LEM sensors $25