< Transconductance Amplifier Design >

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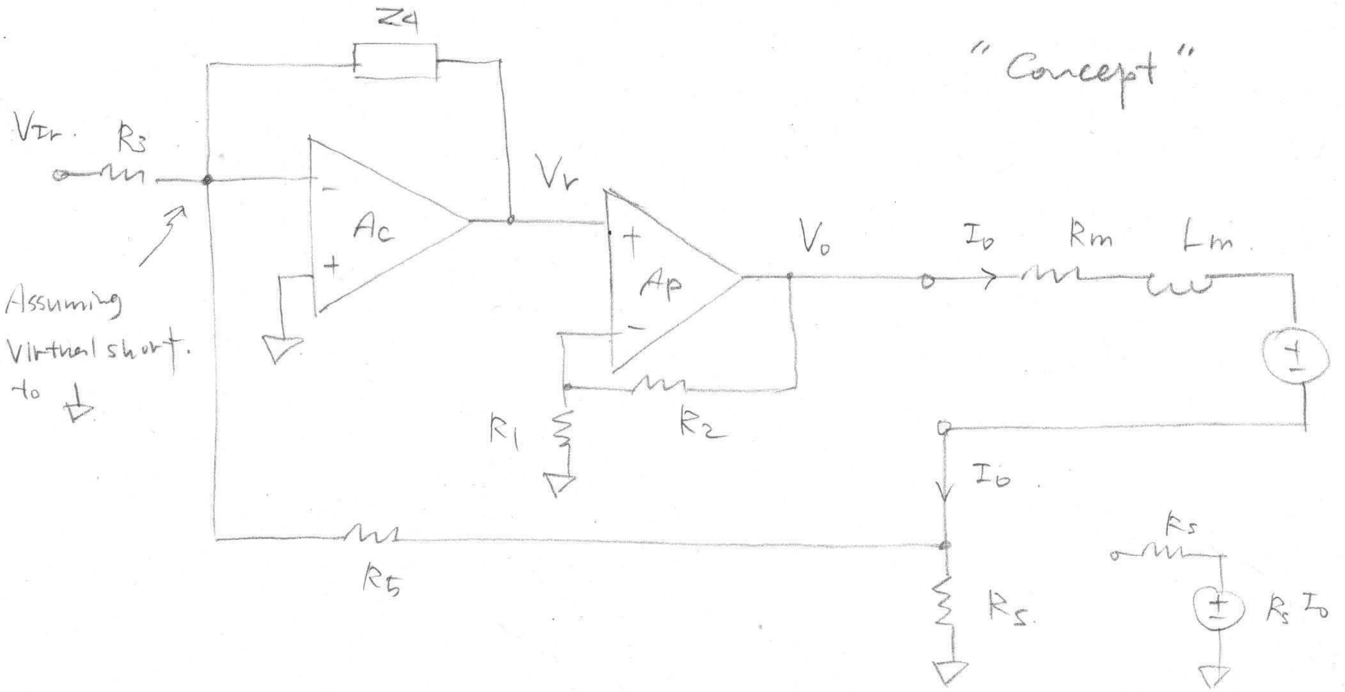
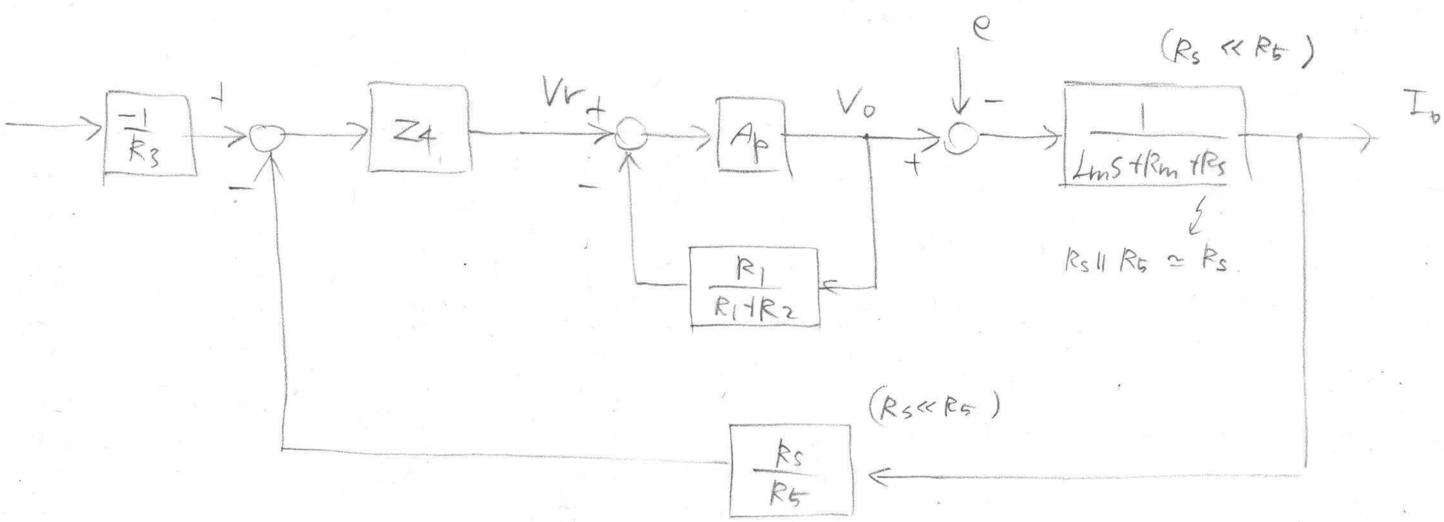
2021 / 2 / 11

Design Process (Coarse to Fine)

- Strategy : current sensing & feedback
- Concept : analog implementation
- Details : select discrete components





$$\frac{R_s}{R_5+R_s} \simeq \frac{R_s}{R_5}$$

- Now, we need to work out the details.
- That is, we need to select the "design parameters" to meet the "design specifications"

- Design Specifications
  - DC gain
  - Bandwidth (cross-over frequency) } Loop shaping
  - Resonance peak (phase margin) }

I. Design the dc gain.

- Let's say we want dc transconductance of -1 [A/V].
- This value should be decided by accounting for the max winding current (e.g. 10A) and the DAC output range (e.g. ±10V). Pick the right value that maps the full voltage range to the full current range, so that DAC dynamic range is fully utilized:

we will shape it so

- Assuming $L(j\omega)\big|_{\omega\to 0} \to \infty$, $\dfrac{I_o}{V_{I_L}}\bigg|_{\omega=0} = -\dfrac{1}{R_3}\cdot\dfrac{R_5}{R_S}$.

- If $R_S = 0.2\,\Omega$ $\rightarrow$ $\begin{cases} \text{Pick } R_5 \text{ such that } R_5 \gg R_S & : \underline{R_5 = 1k\Omega} \\ \text{Pick } R_3 \text{ such that } \dfrac{1}{R_3}\cdot\dfrac{R_5}{R_S} = 1A/V & : \underline{R_3 = 5k\Omega} \end{cases}$

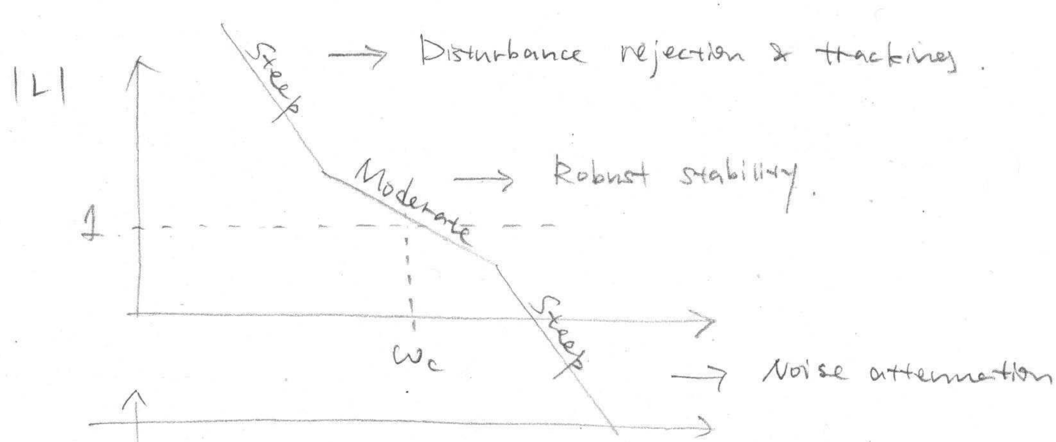
II. Loop shaping

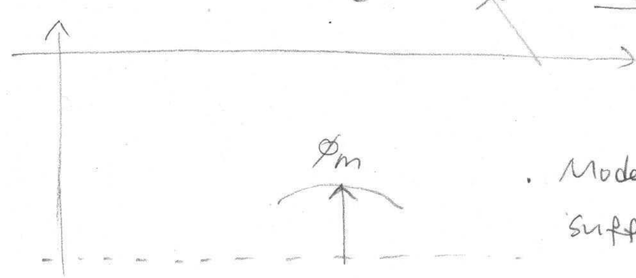
$$L(s) = \underbrace{Z_4(s)}_{C(s)}\ \underbrace{T_p(s)\left(\frac{R_1+R_2}{R_1}\right)\left(\frac{1}{L_m s + R_m + R_s}\right)\left(\frac{R_s}{R_5}\right)}_{p(s)}.$$

- We desing $C(s) = Z_4(s)$ such that $L(s) = C(s) \cdot p(s)$ achieves a "desired loop shape".

- $C(s)$ is also called "Compensator" as it compensates the loop $L(s)$ for some difficiencies, such as magnitude and phase.

∘ Desired Loop shape.





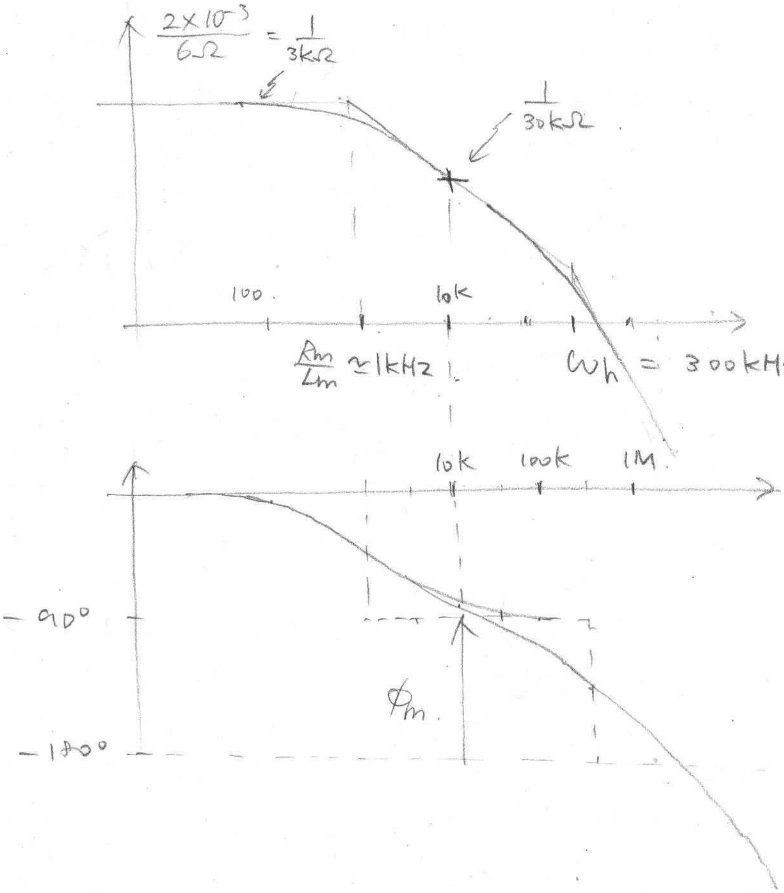
- Moderate slope around ω_c is needed for sufficient ϕ_m.
- Recall Bode's gain-phase relation for min-phase systems

$$\phi \simeq 90° \cdot n$$

- Loop shape before compensation

$$P(s) = \cancel{T_p(s)}^{\text{1 upto 300kHz}} \cdot \underbrace{\frac{R_1+R_2}{R_1}}_{10} \frac{1}{L_m s + R_m + R_s} \cdot \underbrace{\frac{R_s}{R_5}}_{0.2\times10^{-3}}$$

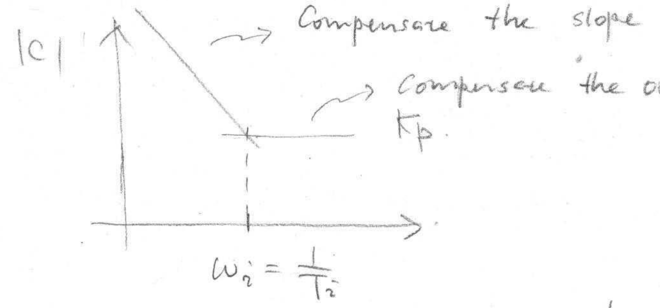
$$\begin{cases} L_m = 1mH \\ R_m = 6\Omega \\ R_1 = 1k\Omega \\ R_2 = 9k\Omega \\ R_s = 0.2\Omega \\ R_5 = 1k\Omega \end{cases}$$



- Difficiencies $\begin{cases} \text{Low overall loop gain} \\ \text{Flat dc loop gain} \rightarrow \text{we want steep slope.} \end{cases}$

< Loop Shaping Steps >

① Decide on the compensator (Controller) topology for the desired loop shape. : $C(s) = K_p\left(1+\frac{1}{T_i s}\right) = K_p\left(1+\frac{\omega_i}{s}\right)$



Analog implementation : $\frac{1}{C_4 s}$ R_4

$\Rightarrow Z_4(s) = R_4\left(1+\frac{1}{R_4 C_4 s}\right)$.

② Select the crossover frequency ω_c by considering the phase margin. ϕ_m (e.g. set $\phi_m > 60°$)

e.g. $\omega_c = 10\,\text{kHz} \rightarrow \phi_m \approx 90°$.

Don't need to push it too high. Then, you amplifies the H.F. noise.

③ Raise the proportional gain K_p to set $|L(j\omega)| = 1$ at $\omega = \omega_c$.

e.g. $\frac{R_4}{30\,k\Omega} = 1 \rightarrow R_4 = 30\,k\Omega$.

④ Introduce the integral action by specifying the PI controller break frequency ω_i (or the integral time constant T_i).

e.g. $\frac{1}{R_4 C_4} = 1\,\text{kHz} \rightarrow C_4 \simeq \frac{1}{R_4 \cdot 6\times10^3\,\text{rad/s}} = \frac{1}{30\times6\times10^6}$

$= \frac{1000}{180}\,\text{nF}$

$\simeq 5.5\,\text{nF}$

"Trade-off" $\begin{cases} \text{Low } \omega_i \rightarrow \text{Weak disturbance reject, poor tracking} \\ \text{High } \omega_i \rightarrow \text{sacrifice } \phi_m \end{cases}$