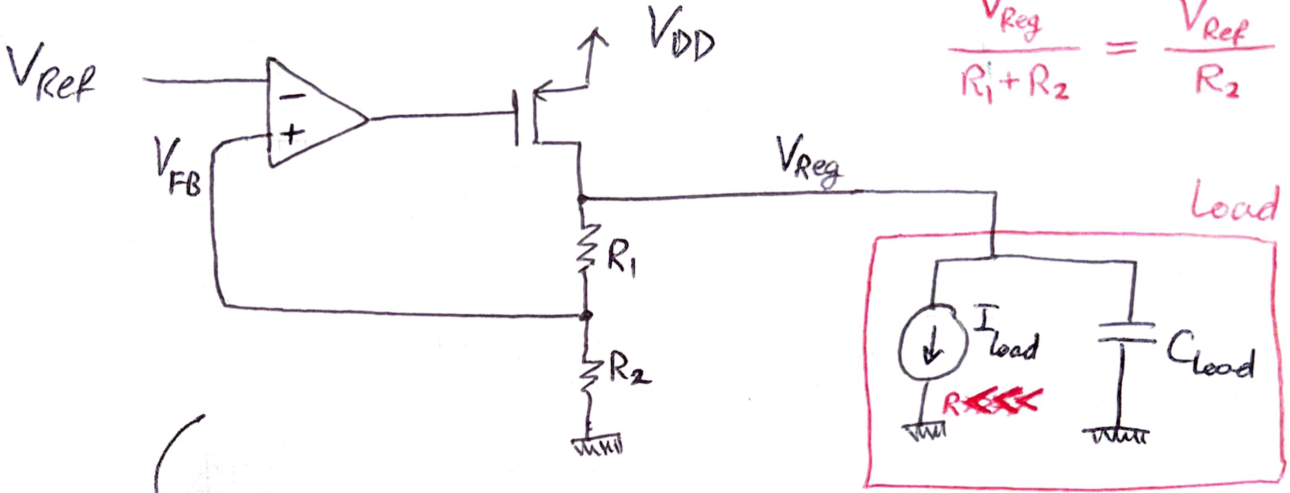
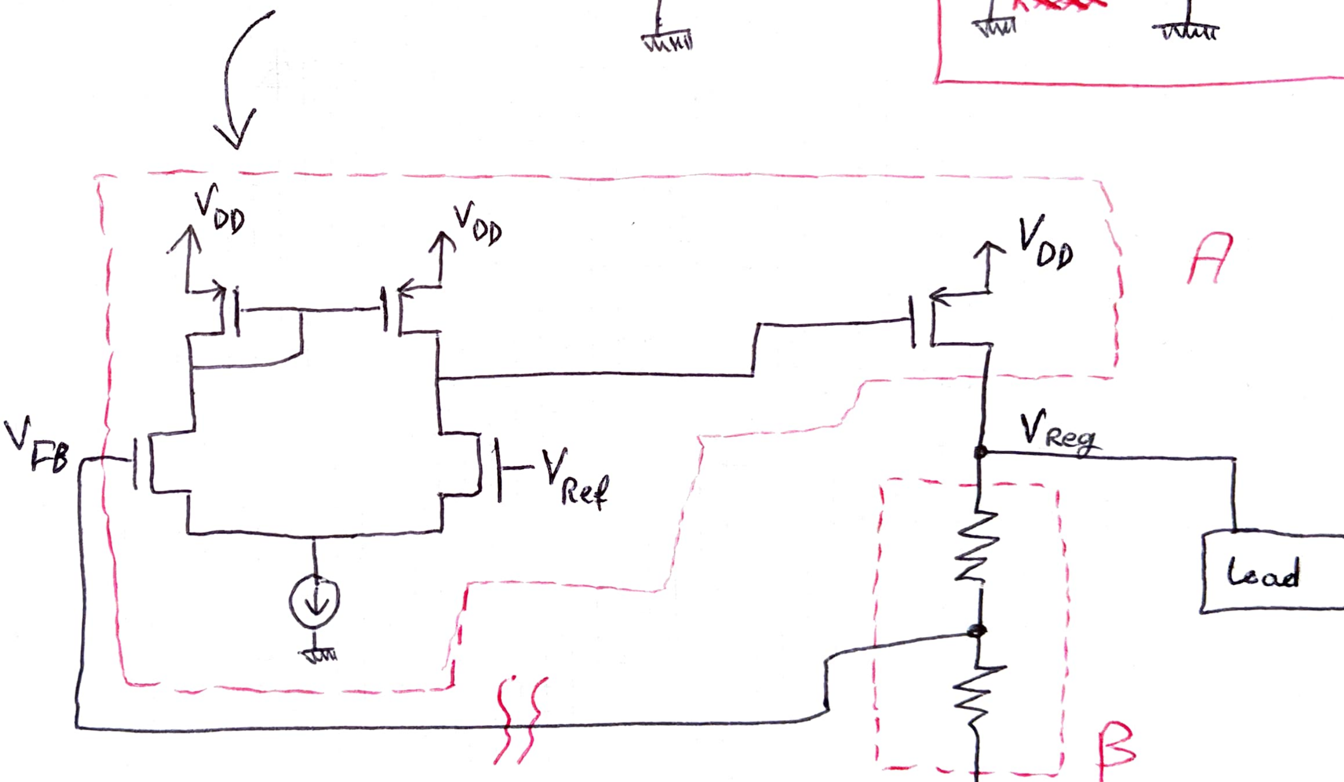
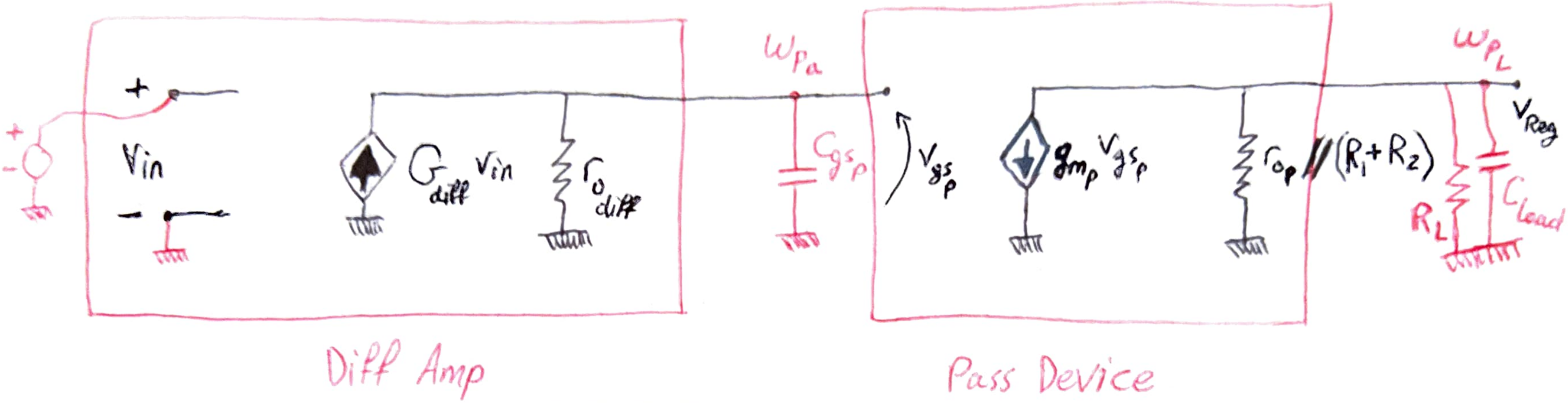
LDO Analysis

$$\frac{V_{Reg}}{R_1 + R_2} = \frac{V_{Ref}}{R_2}$$





$$A_{CL} = \frac{A}{1 + A\beta} = \frac{A}{1 + L}$$



$$L = \text{Loop Gain} = \frac{G_{diff}\, r_{o_{diff}} \cdot g_{m_p} R_{Load}}{\left(1 + \frac{s}{\omega_{p_a}}\right)\left(1 + \frac{s}{\omega_{p_L}}\right)}$$

$R_{Load} = r_{o_p} // (R_1 + R_2) // R_L$

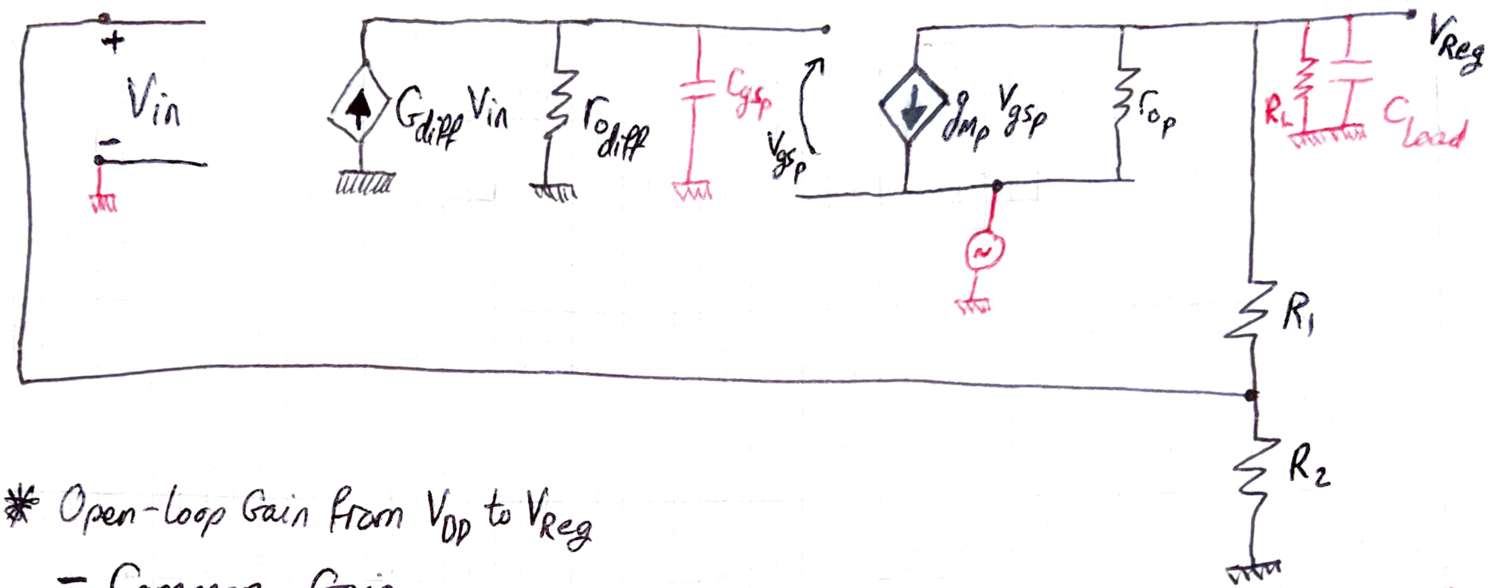
For PM

$$\omega_{p_a} = \frac{1}{r_{o_{diff}} \cdot C_{gs_p}}$$

$\omega_{p_a} < \omega_{p_L}$

dominant

$$\omega_{p_L} = \frac{1}{R_{Load} \cdot C_{Load}}$$



$R_{load} = r_{op} // (R_1 + R_2) // R_L$

$\omega_{out} = \dfrac{1}{C_{load} \cdot R_{load}}$

* Open-loop Gain from V_{DD} to V_{Reg}
= Common-Gain

$$H_{CG} \simeq g_{mp} R_{load} \cdot \frac{1}{\left(1 + \frac{s}{\omega_{out}}\right)}$$

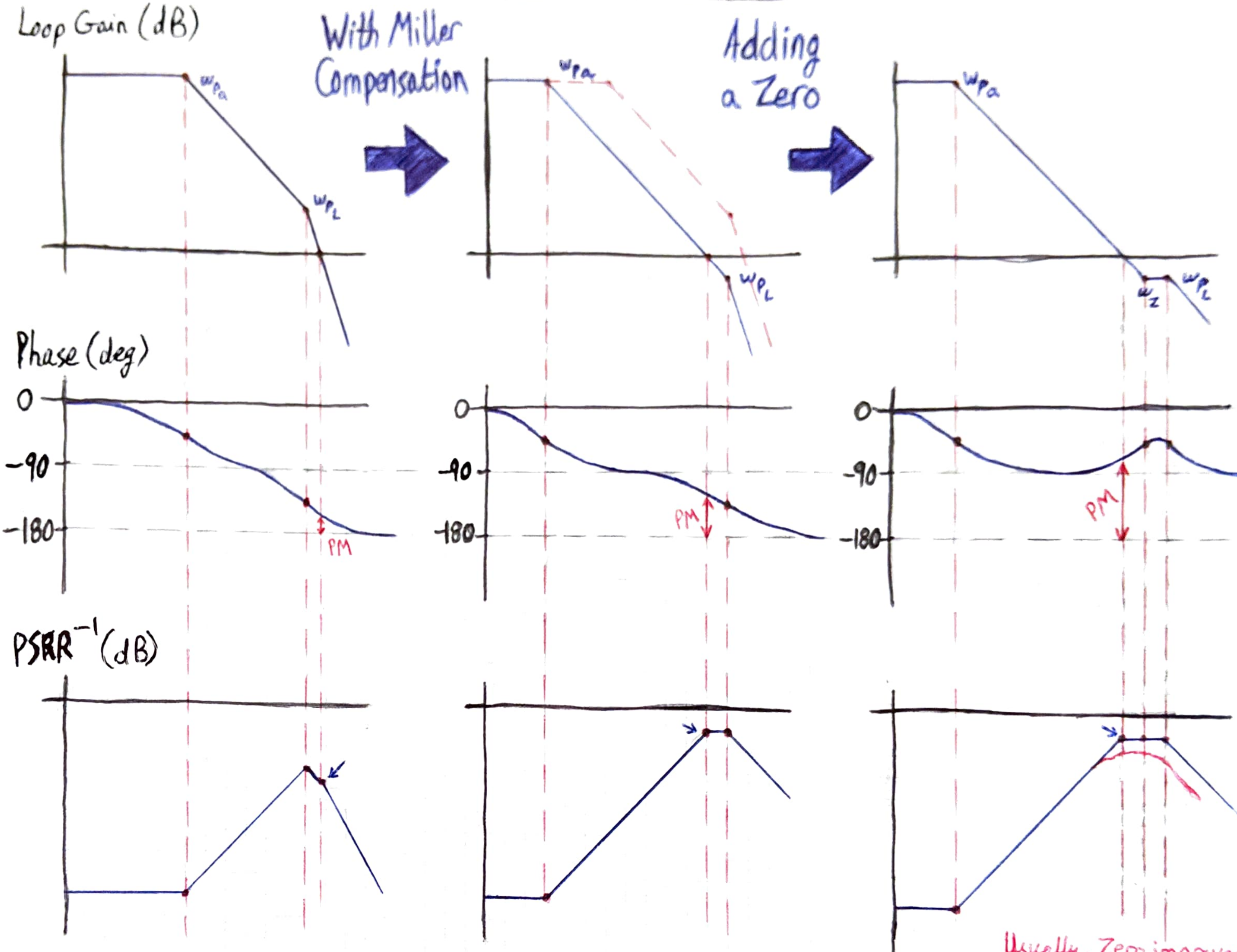
* Closed-loop Gain from V_{DD} to V_{Reg}

$$H = \frac{V_{Reg}}{V_{DD}} = PSRR^{-1} = \frac{H_{CG}(s)}{1 + L(s)}$$

For PSRR

* Usually: @ low $I_{Load} \rightarrow PM_{min}$
@ high $I_{Load} \rightarrow PSRR_{min}$

Loop Gain & PSRR (Assume ω_{p_a} dominant)



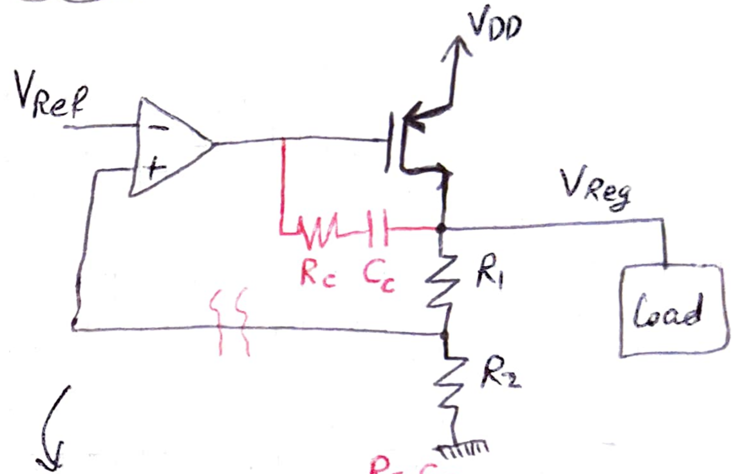
Usually, Zero improves both PM & PSRR

Phase Margin Improves
PSRR Worsens (Max PSRR^{-1} Increases)
} Tradeoff

* Note: ① ω_{p_L} < UGB ⟶ PM << (Unstable loop)
② As ω_{p_L} >> UGB ⟶ PM ↑ but PSRR^{-1} ↑

LDO Compensation

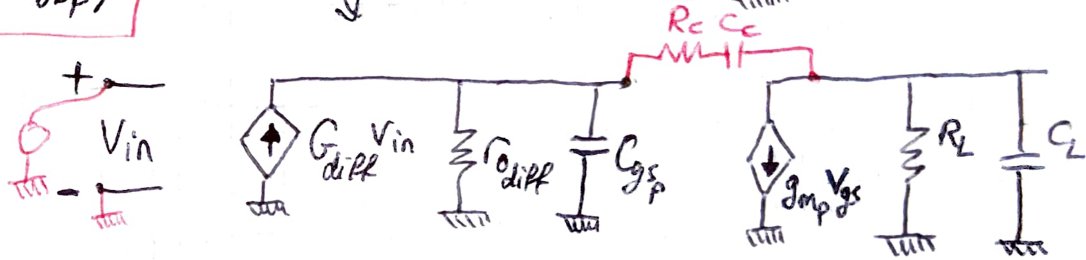
① Miller Compensation:



Assuming $R_c = 0$ for now:

1 dominant pole

$$\boxed{\omega_{p_a} = \frac{1}{r_{o_{diff}}\left((g_{m_p} R_L) C_c + C_{gs_p}\right)}}$$



2 Non dominant pole

$$\boxed{\omega_{p_L} = \frac{g_{m_p}}{C_{gs_p} + C_L}}$$

3 Zero

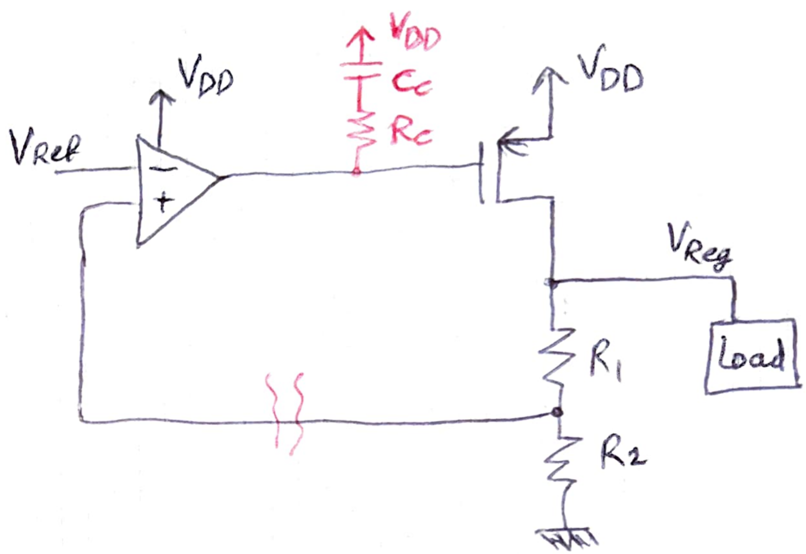
$$\omega_Z = \frac{g_{m_p}}{C_c} \xrightarrow{\text{if } R_c \neq 0} \boxed{\omega_Z = \frac{1}{C_c\left(\frac{1}{g_{m_p}} - R_c\right)}}$$

RHP zero, reduces PM (undesirable)

$\rightarrow R_c > \frac{1}{g_{m_p}}$ to give phase lead (improve PM)

$$\boxed{UGB = \omega_0 = \frac{G_{diff}}{C_c}}$$

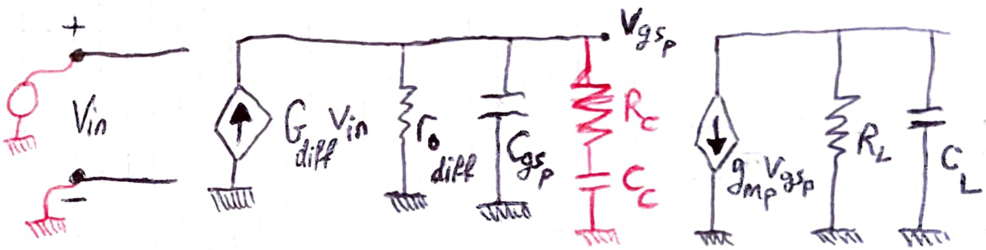
② RC Compensation:



Assume $C_c \ggg C_{gs_p}$ (ignore C_{gs_p} for now)

↳ To find the zero, find the condition where $V_{gs_p} = 0$:

$$V_{gs_p} = G_{diff} V_{in} \left(r_o \, // \, R_c + \frac{1}{sC_c} \right) = 0$$



$$\therefore \frac{r_o \cdot \left(R_c + \frac{1}{sC_c} \right)}{r_o + R_c + \frac{1}{sC_c}} = 0$$

$$\frac{(1 + sR_cC_c)}{(1 + s(r_o + R_c)C_c)} = 0$$

↳ 1 dominant pole

$$\boxed{\omega_{p_1} = \frac{1}{(r_o + R_c)C_c}}$$

2 Zero

$$\boxed{\omega_z = \frac{1}{R_cC_c}}$$

3 Non dominant poles

$$\boxed{\omega_2 = \frac{1}{C_{gs_p}(r_o // R_c)}}$$

at higher frequencies, C_c ~ as a short

$$\boxed{\omega_3 = \frac{1}{C_L R_L}}$$