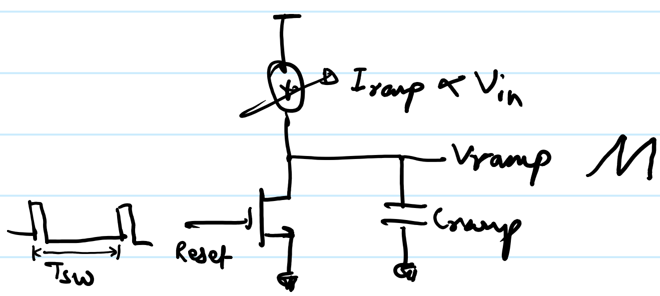
Variation in Loop Gain

$$K_{MO} = \beta \frac{V_{in}}{V_M}$$

Loop gain varies with V_{in} if β & V_M are constant.

Make V_M function of V_{in} to keep V_{in}/V_M constant

$V_M \propto V_{in} \Rightarrow V_M = K V_{in}$ (feed-forward compensation)



$V_M \propto V_{in}$ $\longrightarrow$ K_{MO} remains constant
& line transient is improved.

Variation in K_{uo} due to β can be cancelled by programming V_o directly through V_{ref} instead of changing feedback factor (β).

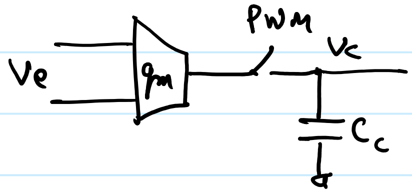
$$K_{uo} = \frac{V_{ref}}{V_o} \times \frac{V_{in}}{V_M} \qquad \beta = \frac{V_{ref}}{V_o}$$

However, if V_{ref} is constant then above equation can be written as:

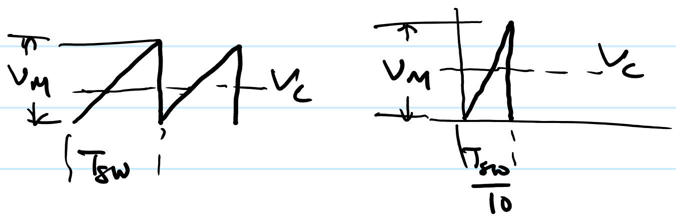
$$K_{uo} = \frac{V_{ref}}{V_M} \cdot \frac{1}{D} \qquad \left(\frac{V_{in}}{V_o} = \frac{1}{D} \right)$$

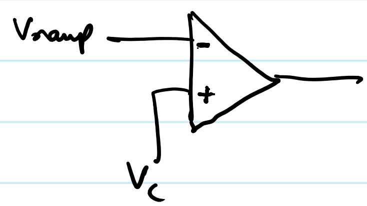
we can cancel variation in loop gain due to β and V_{in} by making the gain proportional to D while keeping V_{ref} and V_M constant.

Following example shows how integrator gain in type-I converter can be made constant by modulating g_m with PWM.



$$\frac{V_c(s)}{V_e(s)} = \frac{g_m}{C_c s} \cdot D$$





same duty cycle at $10\times F_{sw}$ (we can switch g_m at higher frequency to reduce ripple in V_c)

Type-III Compensation

Also called PID (Proportional - Integral - Derivative)

type-II = type I + Prop.

type-III = type-II + deriv

$$H_{comp}(s) = \left(K_p + \frac{K_i}{s}\right)\left(1 + s/\omega_{z_2}\right)$$

$$= \frac{K_i}{s}\left(1 + \frac{K_p}{K_i} s\right)\left(1 + s/\omega_{z_2}\right)$$

$$\omega_{z_1} = \frac{K_i}{K_p}$$

$$\triangleq K_p + \frac{K_p}{\omega_{z_2}} s + \frac{K_i}{s} + \frac{K_i}{\omega_{z_2}}$$

$$= \underbrace{\left(K_p + \frac{K_i}{\omega_{z_2}}\right)}_{P} + \underbrace{\frac{K_i}{s}}_{I} + \underbrace{\frac{K_p}{\omega_{z_2}} s}_{D}$$

$$K_p' = K_p\left(1 + \frac{\omega_{z_1}}{\omega_{z_2}}\right)$$

$K_p' = K_p$ if $\omega_{z_1} << \omega_{z_2}$

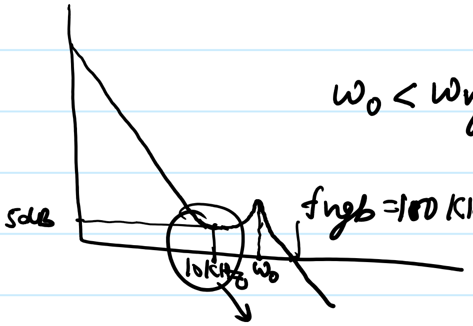
Rules of PID Compensation

Rule-1

$$\omega_{ugb} > \omega_o$$

$\omega_o = \omega_{ugb}$

gain also crosses at $\omega << \omega_o$ due to high Q



slow response due to low gain

$\omega_o < \omega_{ugb}$

ω_o should be significantly lower than ω_{ugb} to ensure enough gain in mid-band (between ω_{z_1} and ω_o).

Keeping ω_o closer to ω_{ugb} reduces mid-band gain and degrades the transient response.

Rules of PID Compensation

Rule-2

$$\omega_{z_1} < \omega_0$$

phase lag due to integrator must be cancelled before ω_0 to ensure stability.

$$\boxed{\omega_{z_1} \text{ controls } \omega_{ugb}}$$

Rule-3

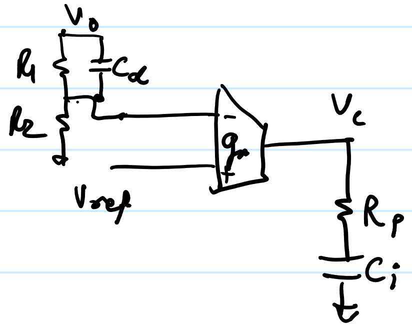
ω_{z_2} should be placed around ω_0 based on Q

high Q $\rightarrow$ $\omega_{z_2} \leq \omega_0$

Low Q $\rightarrow$ $\omega_{z_2} \geq \omega_0$

$$\boxed{\omega_{z_2} \text{ controls phase margin}}$$

Implementing Type-III Compensator



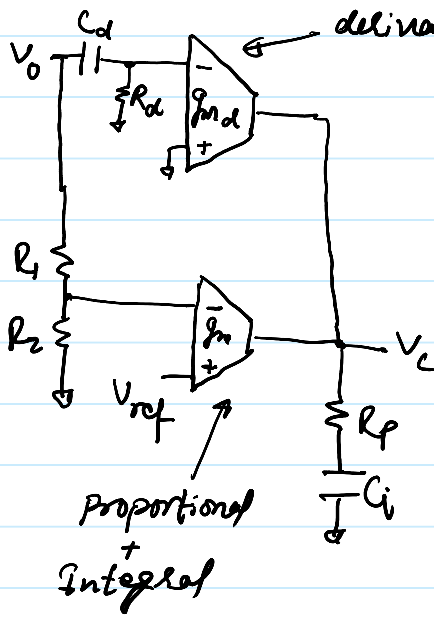
$$H_{comp}(s) = -\beta \frac{(1+R_1C_ds)}{(1+\beta R_1C_ds)} \left(g_mR_p + \frac{g_m}{C_is}\right)$$

$$= -\beta \frac{g_m}{C_is} \frac{(1+R_1C_ds)(1+R_pC_is)}{(1+\beta R_1C_ds)}$$

$$\omega_{z_1} = \frac{1}{R_pC_i}, \quad \omega_{z_2} = \frac{1}{R_1C_d}, \quad \omega_p = \frac{1}{\beta R_1C_d}$$

ω_{z_2} and ω_p are close to each other for $\beta \approx 1$. hence only works if $\beta << 1$ which is quiet unusual as V_{ref} is usually 0.6 to 1.2V.

derivative portion can be implemented using another g_m.



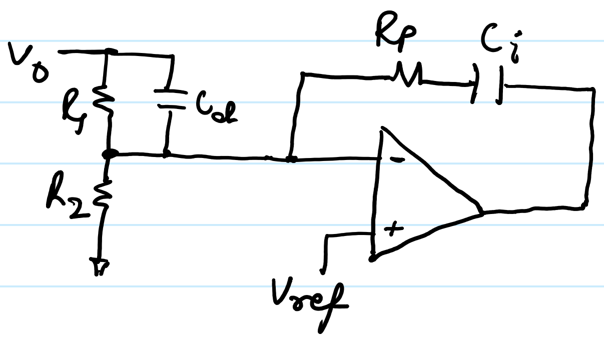
$$H_{comp}(s) = \frac{-\beta R_p g_m}{C_i} \frac{(1+s/\omega_{z_1})(1+s/\omega_{z_2})}{s(1+s/\omega_p)}$$

$$\omega_{z_1} = \frac{1}{R_pC_i}; \quad \omega_{z_2} = \frac{1}{R_dC_d} \beta \frac{g_m}{g_{md}}$$

$$\omega_p = \frac{1}{R_dC_d}$$

if R_dC_d is chosen low enough such that $\omega_p >> \omega_{ugb}$ then ω_{z_2} can be controlled by g_m/g_{md} ratio.

Implementing Type-III Compensator



$$H_{comp}(s) = -Z_2 \times Y_1$$

$$-\left(R_p + \frac{1}{sC_i}\right)\left(\frac{1}{R_1} + sC_d\right)$$

$$= -\frac{1}{R_1 C_i s}\left(1 + R_p C_i s\right)\left(1 + R_1 C_d s\right)$$

$$\omega_{z_1} = \frac{1}{R_p C_i} \quad ; \quad \omega_{z_2} = \frac{1}{R_1 C_d}$$