Power Management Integrated Circuits
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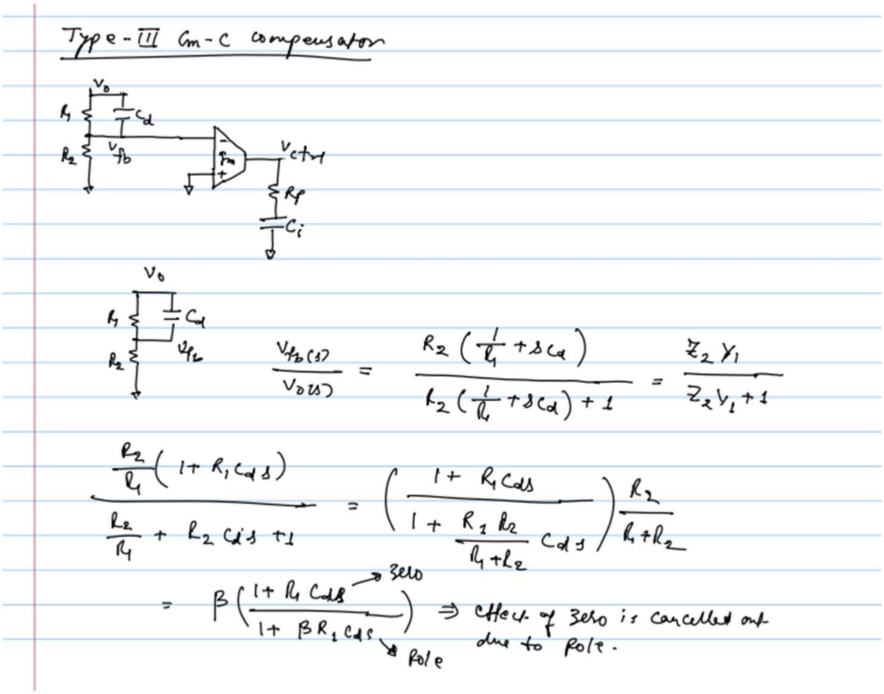
Lecture – 59
Type-III Compensator using Gm-C Architecture

The circuit diagram for type-III compensator using $g_m C$ is shown in below figure. So, for the same PI compensator using $g_m C$, we are adding one more zero by using capacitor C_d. And the transfer function $\frac{V_{fb}}{V_o}$ is derived in below figure.



$$\frac{V_{fb}(s)}{V_o(s)} = \frac{R_2\left(\frac{1}{R_1}+sC_d\right)}{R_2\left(\frac{1}{R_1}+sC_d\right)+1} = \frac{Z_2 Y_1}{Z_2 Y_1 + 1}$$

$$\frac{\frac{R_2}{R_1}(1+R_1C_ds)}{\frac{R_2}{R_1}+R_2C_ds+1} = \left(\frac{1+R_1C_ds}{1+\frac{R_1R_2}{R_1+R_2}C_ds}\right)\frac{R_2}{R_1+R_2}$$

$$= \beta\left(\frac{1+R_1C_ds}{1+\beta R_1C_ds}\right) \Rightarrow \text{effect of zero is cancelled out due to pole.}$$

zero
pole

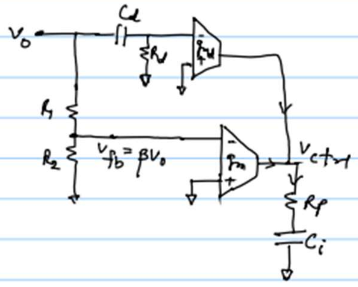
So, the zero is coming at s = $\frac{-1}{R_1 C_d}$ which is same as your op-amp case, but you have a pole which is appearing at s = $\frac{-1}{\beta R_1 C_d}$. Let us say β=1, then the pole and zero will cancel out each other because β=1 means R_2 is gone. And if I remove R_2 then β becomes 1. So, whether you have this cap (C_d) or not, this g_m block will always see input as V_{out}.

But if your feedback factor(β) is much smaller, let us say β=0.01 then you get a 100 times gain advantage there, and the effect of zero will come into picture. So, this is only effective if your β is very small. And we know that this pole should be outside ω_{ugb}. Usually we place this pole 5 to 10 times away from ω_{ugb}.

And we know that ω_{z2} is appearing at ω_o and ω_o is even lower than your ω_{ugb}. So, in order to place this pole outside ω_{ugb}, you may require like 40 or 50 gain here. So, your β should be $\frac{1}{40}$ or $\frac{1}{50}$ kind of number, which is unrealistic because your reference voltage should be order of 10s of millivolt. And we do not want to keep the reference voltage too low, otherwise it will become more sensitive to noise. So, this will not help.

So, this is not the practical way to add second zero. The circuit can be modified as shown in below figure to add the second zero by using one more trans-conductance g_{md} and RC high pass filter. And we have to push the pole due to this RC high pass filter outside ω_{ugb}, otherwise it will reduce your phase margin. Usually this pole is placed at 5 to 10 times of ω_{ugb}. So, to derive the transfer function $\frac{V_{ctrl}}{V_o}$, we considered the assumption $\frac{1}{R_dC_d} \gg \omega_{ugb}$.

And the transfer function $\frac{V_{ctrl}}{V_o}$ is derived in below figure.



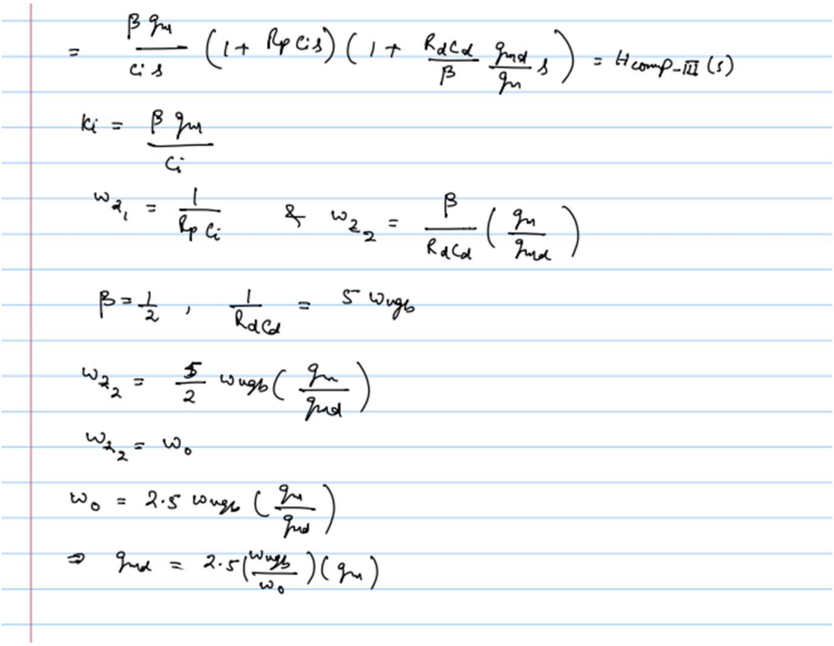
$$-\left(\frac{R_dC_ds}{1+R_dC_ds}\right)V_o \times g_{md} - \beta V_o g_m - \frac{V_{ctrl}}{R_p+\frac{1}{C_is}} = 0$$

$$\frac{C_is}{1+R_pC_is}V_{ctrl} = -V_o\left(\frac{R_dC_ds}{1+R_dC_ds}g_{md} + \beta g_m\right)$$

$$\frac{1}{R_dC_d} \gg \omega_{ugb}$$

$$\frac{V_{ctrl}(s)}{V_o(s)} = \frac{1}{C_is}(1+R_pC_is)(R_dC_ds\,g_{md} + \beta g_m)$$

This compensator transfer function $\frac{V_{ctrl}}{V_o}$ is looking quite similar to what we had in op-amp case.



$$= \frac{\beta g_m}{C_i s}\left(1 + R_p C_i s\right)\left(1 + \frac{R_d C_d}{\beta}\frac{g_{md}}{g_m} s\right) = H_{comp\text{-}III}(s)$$

$$k_i = \frac{\beta g_m}{C_i}$$

$$\omega_{z_1} = \frac{1}{R_p C_i} \quad \& \quad \omega_{z_2} = \frac{\beta}{R_d C_d}\left(\frac{g_m}{g_{md}}\right)$$

$$\beta = \frac{1}{2}, \quad \frac{1}{R_d C_d} = 5\,\omega_{ugb}$$

$$\omega_{z_2} = \frac{5}{2}\,\omega_{ugb}\left(\frac{g_m}{g_{md}}\right)$$

$$\omega_{z_2} = \omega_o$$

$$\omega_o = 2.5\,\omega_{ugb}\left(\frac{g_m}{g_{md}}\right)$$

$$\Rightarrow g_{md} = 2.5\left(\frac{\omega_{ugb}}{\omega_o}\right)(g_m)$$

Once you choose the g_m, then we get g_{md}. And this g_{md} is going to be high because, we know that ω_{ugb} is at higher frequency than ω_o.

From the previous example f_{ugb} is at 100 KHz, so ω_{ugb} is at 628 Krad/sec and ω_o is at 174 Krad/sec. So,

$$g_{md} = 2.5 \text{ x } \frac{628}{174} \text{ x } g_m$$

$$g_{md} = 9.023\ g_m$$

So, g_{md} is close to 10 times of g_m. So, if I choose g_m = 1 mS then g_{md} should be 10 mS.

The advantage here is g_{md} will independently control the zero. It will not affect anything. If I change the g_{md} it will only move my zero, and it will not affect any of the other factors. So, independently you can control both the zeros here. And we know that first zero ω_{z1} is coming at $s = \frac{-1}{R_p C_i}$.

So, if I change R_p then zero will change, but it will also change my proportional gain because proportional gain is $g_m R_p$. So, if I increase the R_p to change the zero location then I can reduce the g_m proportionally so that the $g_m R_p$ product will remain same. So, it will not affect my loop gain.

So, the advantage is you can tune both the zeros independently here, which is not possible in case of op-amp, until unless you design your integral, proportional and derivative components separately and add them together. But here you can do that quite easily. And g_m can be controlled by simply controlling your bias current.