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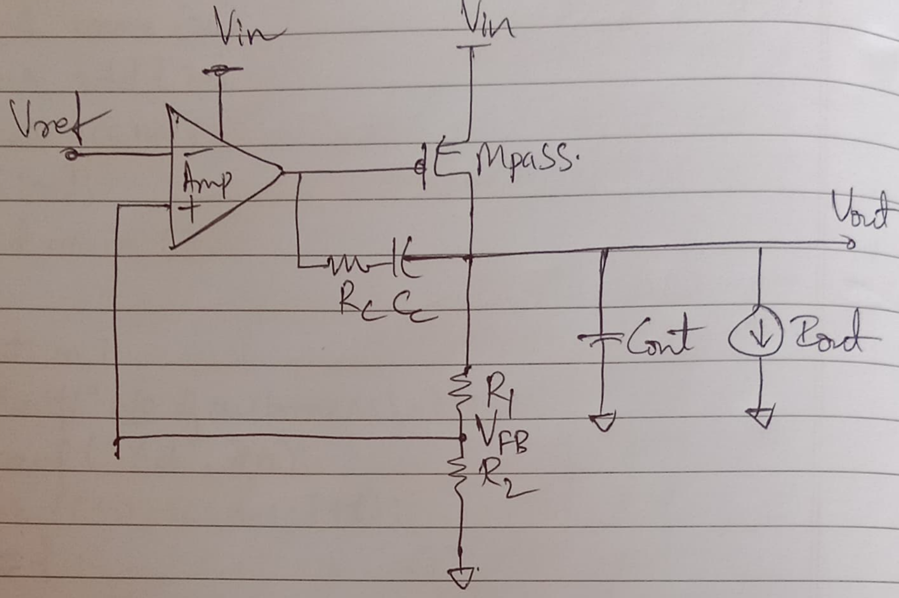
13/05/24

Design of LDO (Low dropout Voltage Regulator)

Overall schematic :-



$$\cancel{V_{out}} = V_{FB} = \frac{V_{out} \times R_2}{R_1 + R_2}$$

$$\frac{V_{out}}{V_{FB}} = \frac{R_1 + R_2}{R_2} = 1 + \frac{R_1}{R_2}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{V_{out}}{V_{FB}} - 1$$

for simplicity lets take $R_1 = R_2$ we get

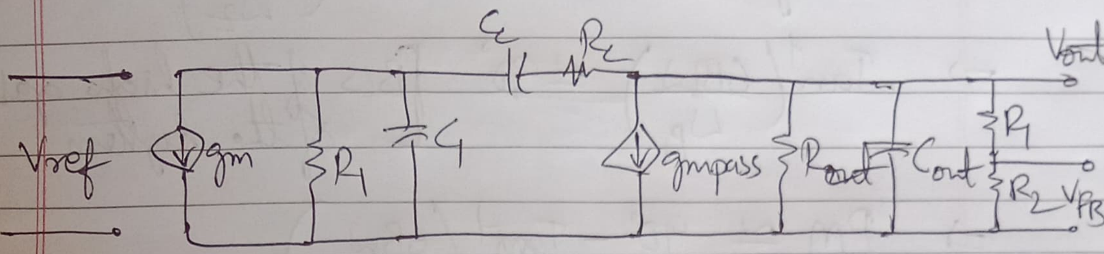
$$\frac{V_{out}}{2} = V_{ref}$$

here $V_{out} = 1.35V$

So $V_{FB} = 0.675V$

⇒ Pole zero Analysis is posted in the other Notes, so kindly Refer that

So from the Pole zero Analysis :



Small Signal Analysis

$$TF = \frac{-A_1 A_2 \left(1 - s/\omega_z\right)}{\left(1+\frac{s}{\omega_{p_1}}\right)\left(1+\frac{s}{\omega_{p_2}}\right)}$$

$$\omega_{p_1} = \frac{1}{R_1\left(C_{gg_{pass}} + C_c(A_2+1)\right)}$$

[We can not neglect C_{gg} bcs its in order of 20–80 pF]

$$\omega_{p_2} = \frac{1}{C_{out} R_{out}}$$

$$A_2 = -g_{mpass} R_{out}$$

$$A_1 = g_{m_1} R_1$$

$$\omega_z = \frac{1}{\left(1/g_{mpass} - R_z\right) C_c}$$

For a Phase Margin (P.M) $\geq 60^\circ$
We need to choose Miller Cap carefully

$$P.M = 180^\circ - \tan^{-1}\left(\frac{GBW}{\omega_z}\right) - \tan^{-1}\left(\frac{GBW}{\omega_{p_1}}\right) - \tan^{-1}\left(\frac{GBW}{\omega_{p_2}}\right)$$

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→ Assuming you ~~to~~ try to neutralize to ω_z with nulling resistor the $\tan^{-1}\left(\frac{GBW}{\omega_z}\right) \simeq 0$

→ $\tan^{-1}\left(\frac{GBW}{\omega_{p_1}}\right) \simeq 90^\circ$ [B/S of the high gain of the system]

⇒ $PM \simeq 90^\circ - \tan^{-1}\left(\frac{GBW}{\omega_{p_2}}\right)$

So we use Miller Compensation to split the ω_{p_1} & ω_{p_2} far apart

From this we try to estimate C_c

For spec of $P.M \geq 60^\circ$

$$60^\circ = 90^\circ - \tan^{-1}\left(\frac{GBW}{\omega_{p_2}}\right)$$

$$\tan^{-1}\left(\frac{GBW}{\omega_{p_2}}\right) \simeq 30^\circ$$

for ~~GBW~~ $\frac{GBW}{\omega_{p_2}} = 0.577$

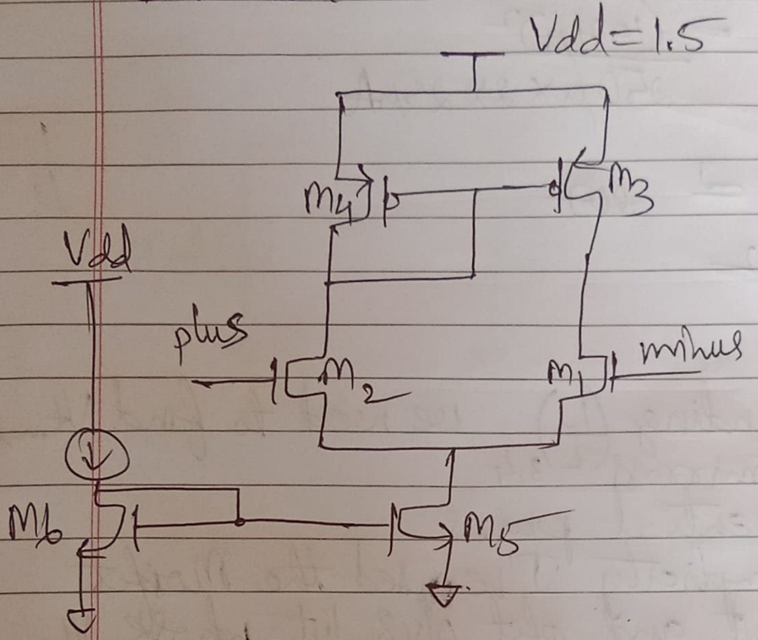
$GBW = \frac{g_{m1}}{C_c}$ & $\omega_{p_2} = \frac{g_{mpass}}{C_{out}}$ [This is approximation needs tuning]

we get $C_c \geq 0.3 C_L$

So for simplicity lets Consider $C_c \simeq 30pF$

Error Amplifier :-

I've used 5T-OTA



→ **Note :** I've not used gm/Id

Gain :- $\geq 40dB$
Vdd :- 1.5V
ICMR- : 0.75
ICMR+ : 1.2
$PM \geq 60^\circ$
$C_L = 50pF$ (I'm considering $(C_{gs,pass} + C_L)$)
$SR = 1V/\mu sec$
$I_{ss} = 50\mu A$

M_1, M_2

$$g_{m1,2} = 2\pi(GBW \times C_L)$$
$$= 2\pi(5\times10^6 \times 50\times10^{-12})$$
$$g_{m1,2} \simeq 1571\mu S$$

$$\left(\frac{W}{L}\right)_{1,2} \simeq \frac{g_{m1,2}^2}{\mu_n C_{ox}\, 2 I_D}$$

$$= \frac{(157\mu)^2}{250\mu \times 2 \times 25\mu A}$$

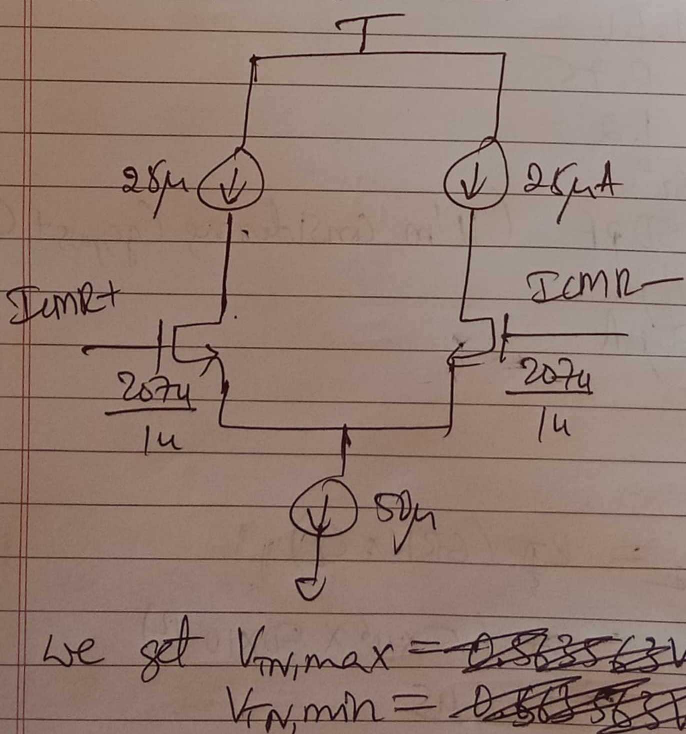
$$\left(\frac{W}{L}\right)_{1,2} \simeq 207$$

M_3, M_4

⟹ Before finding $\left(\frac{W}{L}\right)_{3,4}$ we need to find $V_{t\,max}$ of current mirrors and differential pairs.

⟹ For simplicity I've used the Mosfet nfet_01v8_lvt and pfet_01v8_lvt whose V_t doesnt change ~~the~~ much over Width or length

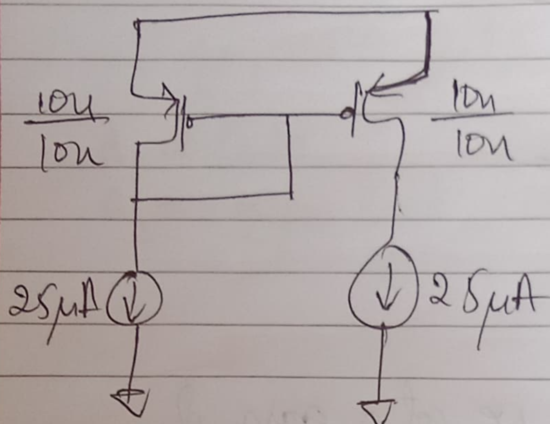
⟹ V_{TN}max simulation



we get $V_{TN,max}$ = ~~0.5635563V~~ 0.48221

$V_{TN,min}$ = ~~0.5635583V~~ 0.482106

$V_{TP_3 max}$



[I've put $\frac{10u}{10u}$ to avoid short channel effects

$V_{TP_3 max} = \underline{0.424058}$

$V_{SG_3} = V_{DD} - ICMR_{max} + V_{TN, min}$
$= 1.5 - 1.2 + \cancel{0.583}\ 0.482106$
$V_{SG_3} \simeq \cancel{0.863}\ 0.8$

$$\left(\frac{W}{L}\right)_{3,4} = \frac{2I_3}{\mu_p C_{ox}(V_{SG_3} - V_{TP_3 max})^2}$$

$$= \frac{50\mu}{55\mu(0.8 - 0.424058)^2}$$

$$\left(\frac{W}{L}\right)_{3,4} \simeq 7$$

M5, M6

$V_{dsat_5} = ICMR(-) - \sqrt{\frac{I_5}{\beta}} - V_{Tn\,min}$

$V_{dsat_5} \simeq 0.3$

$$\left(\frac{W}{L}\right)_{5,6} \simeq \frac{50\mu \times 2}{250\mu (0.3)^2} \simeq 5$$

$\left(\frac{W}{L}\right)_{1,2} \simeq 207$

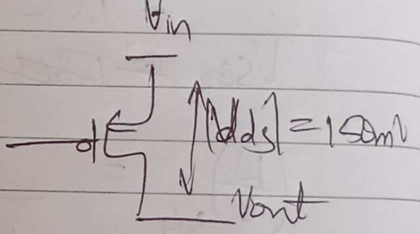
$\left(\frac{W}{L}\right)_{3,4} \simeq 7$

$\left(\frac{W}{L}\right)_{5,8} \simeq 5$

Simulating we got a gain of.

Gain : $\simeq$ 40dB
GBW : 7MHz

~~Mpass~~



$V_{drop} = |V_{ds}| = 150\ mV$

So we target for $V_{ov} \simeq 100mV$

$$I_d = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_{pass}[V_{ov}]^2$$

$$\left(\frac{W}{L}\right)_{pass} \simeq \frac{2I_D}{\mu_p C_{ox}[V_{ov}]^2}$$

$$\left(\frac{W}{L}\right)_{pass} \simeq \frac{2 \times 40 \times 10^{-3}}{55 \times 10^{-6} \times (0.1)^2}$$

$$\left(\frac{W}{L}\right)_{pass} \simeq 145455$$

$C_{gg\,pass} \simeq 20pF$

Calculating

$gm_{pass} \simeq \underline{\underline{0.85}}$

$A_1 \simeq 40dB$
$A_2 = gm_{pas} R_{out} \simeq 12 = \underline{\underline{20dB}}$

Total Gain $\simeq$ 60dB

observed Gain $\simeq$ 62dB.

<u>Calculate pole</u>

$$f_1 = \frac{1}{R_1(C_{gg} + (A_2+1)C_c)} \simeq \underline{\underline{4\,KHz}}\ (\text{dom})$$

$$f_2 = \frac{1}{R_2 C_{out}} \simeq \underline{\underline{100\,MHz}}\ (\text{non dom})$$

$GBW = ADC \times Pole$

$GBW \simeq \underline{\underline{4.8\,MHz}}$

$P.M \simeq \underline{\underline{82^\circ}}$

$\underline{\underline{\text{Efficiency} \simeq 89.77\%}}$