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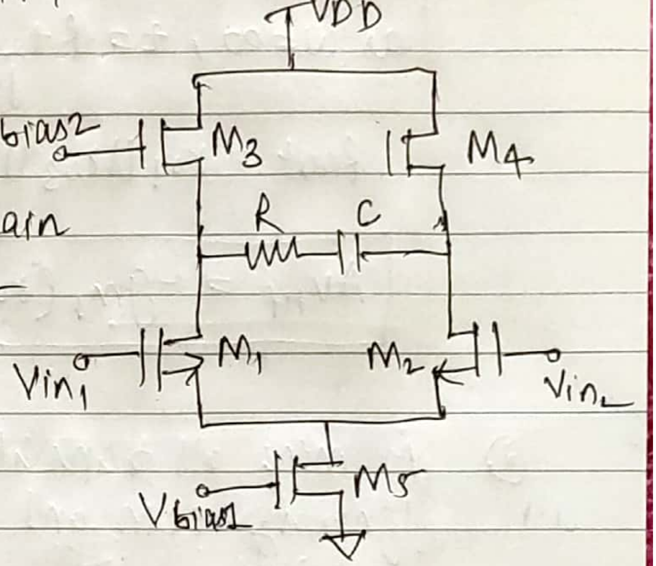
Roll no → 602162015 1st year

Assignment-3

① In the following circuit assume transistors M_1 and M_2, and transistors M_3 and M_4 are identical and $r=0$, $\lambda \neq 0$

(i) Find the expression for the small signal differential voltage gain ($V_{out}/V_{in1} - V_{in2}$) of the circuit



let impedance Z

$$= R + \frac{1}{j\omega C}$$

as Z is parallel to M_2 and to M_1 when AC ground is applied, Rout can be considered as $(r_{o1} \| r_{o3} \| \frac{Z}{2})$ on one side

$$R_{out} = (r_{o1} \| r_{o3} \| Z/2)$$

$$\Rightarrow \boxed{A_v = -g_{m1}(r_{o1} \| r_{o3} \| Z/2)}$$

(ii) What is the gain of the circuit in very low frequencies?

At low frequencies : $\omega \approx 0$

$$Z = R + \frac{1}{j\omega C} = R + \frac{1}{0} = \infty$$

as $Z = \infty$

$$\boxed{A_{v\,LF} = -g_{m1}(r_{o1} \| r_{o3})}$$

(iii) what is the gain of the circuit at very high frequencies ?

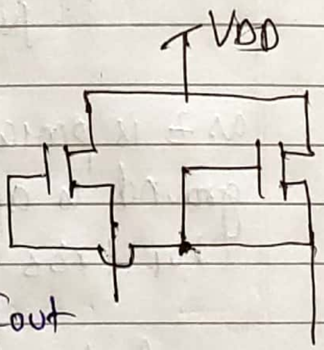
as $\omega = \infty$, $Z = R + \frac{1}{j\omega C} = R + \frac{1}{\infty} = R$

$R_{out} = r_{o1} \| r_{o3} \| R/2$

$$\boxed{A_{V_{HF}} = -g_{m1}(r_{o1} \| r_{o3} \| R/2)}$$

(2) Assuming all transistors in saturation and ignoring CLM and body effect, Also, $(W/L)_3 = (W/L)_4$

(1) find an expression for I_{out}



$\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 \Rightarrow I_1 = I_3 = I_{out}$

$I_{out} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS_2} - V_{th})^2$

$\Rightarrow V_{GS_2} = V_{th_n} \pm \sqrt{\frac{2I_{out}}{\mu_n C_{ox}(W/L)_2}}$

Similarly $V_{GS_1} = V_{th_n} + \sqrt{\frac{2I_{out}}{\mu_n C_{ox}(W/L)_1}}$

Also,

$V_{GS_1} - V_{GS_2} = I_{out} \times R$

$$V_{GS_1} - V_{GS_2} = \left[V_{thn} + \sqrt{\frac{2I_{out}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_1}}\right] - \left[V_{thn} - \sqrt{\frac{2I_{out}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_2}}\right]$$

$$R I_{out} = \sqrt{\frac{2I_{out}}{\mu_n C_{ox}}}\left[\sqrt{\left(\frac{L}{W}\right)_1} - \sqrt{\left(\frac{L}{W}\right)_2}\right]$$

$$R\sqrt{I_{out}} = \sqrt{\frac{2}{\mu_n C_{ox}}}\left(\sqrt{\frac{L_1}{W_1}} - \sqrt{\frac{L_2}{W_2}}\right)$$

$$\boxed{I_{out} = \frac{2}{\mu_n C_{ox} R^2}\left(\sqrt{\frac{L_1}{W_1}} - \sqrt{\frac{L_2}{W_2}}\right)^2}$$

(ii) What would be the percentage change in I_{out} if V_{DD} is increased by 10%.

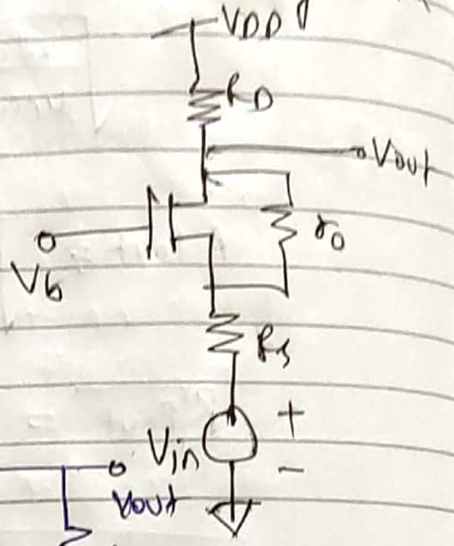
As all transistors are in saturation, the I_{out} is independent of V_{DD}. Hence, there will be no change in I_{out}

(iii) How would the expression for I_{out} derived in part (i) change if $\gamma \neq 0$ and why?

$V_{SB_1} = V_{SB_2} = 0$

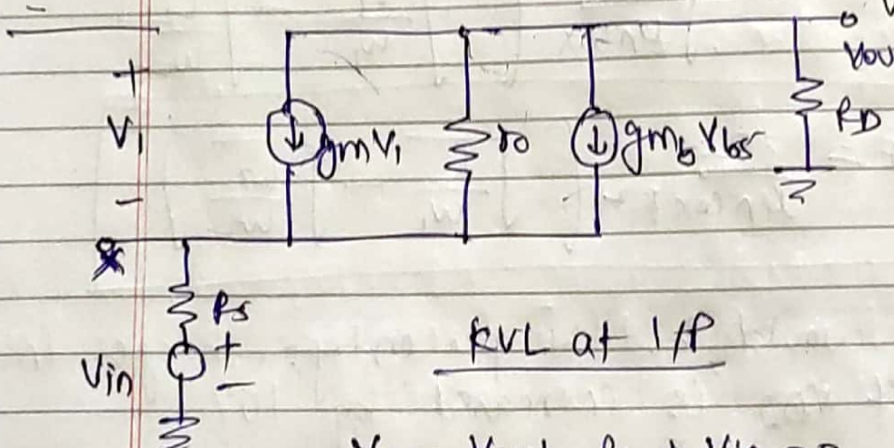
Resultant body effect would not change the I_{out}

(3) Calculate the gain of the common gate amplifier as shown below considering both CLM and Body effect



Current through Rs is same as $-V_{out}/R_D$

Small signal



KVL at I/P

$$V_1 - \frac{V_{out}}{R_D} R_S + V_{in} = 0 \quad \text{—} (1)$$

KVL at O/P

$$r_0\left(\frac{-V_{out}}{R_D} - g_m V_1 - g_{mb} V_1\right) - \frac{V_{out}}{R_D} \cdot R_S + V_{in} = V_{out}$$
$\hookrightarrow (2)$

from (1)

$$V_1 = V_{out} \cdot \frac{R_S}{R_D} - V_{in}$$

Substituting value of V_1 in (2)

$$r_o\left[\frac{-V_{out}}{R_D} - (g_m+g_{mb})\left(V_{out}\frac{R_S}{R_D} - V_{in}\right)\right] - V_{out}\frac{R_S}{R_D}$$

$$+ V_{in} = V_{out}$$

$$\Rightarrow -V_{out}\cdot\frac{r_o}{R_D} - r_o(g_m+g_{mb})\cdot\frac{R_S}{R_D}V_{out} - V_{out}\frac{R_S}{R_D} -$$

$$V_{out} = -V_{in} - (g_m+g_{mb})r_o V_{in}$$

$$\Rightarrow -V_{in} - (g_m+g_{mb})r_o V_{in} = V_{out}\left(\frac{r_o + (g_m+g_{mb})r_o R_S + R_S + R_D}{R_D}\right)$$

$$\Rightarrow \boxed{\frac{V_{out}}{V_{in}} = \frac{[(g_m+g_{mb})r_o+1]R_D}{r_o+[g_m+g_{mb}]r_oR_S+R_S+R_D}}$$

(4) Explain the working of folded cascode circuit using large-signal analysis.

Simple folded cascode

In order to bias M_1 and M_2, a current source must be added. The small signal operation is as follow. If V_{in} becomes more positive, I_{D1} decreases, forcing I_{D2} to increase, hence decreasing V_{out} to drop.
If V_{in} decreases from V_{DD} to zero, for

$V_{in} > V_{DD} - |V_{th}|$, M_1 is off and M_2 carries all of I_1, yielding $V_{out} = V_{DD} - I_1 R_D$. for $V_{in} < V_{DD} - |V_{th_1}|$, M_1 turns on in saturation,

$$I_{D_2} = I_1 - \frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_1 (V_{DD} - V_{in} - |V_{th_1}|)^2$$

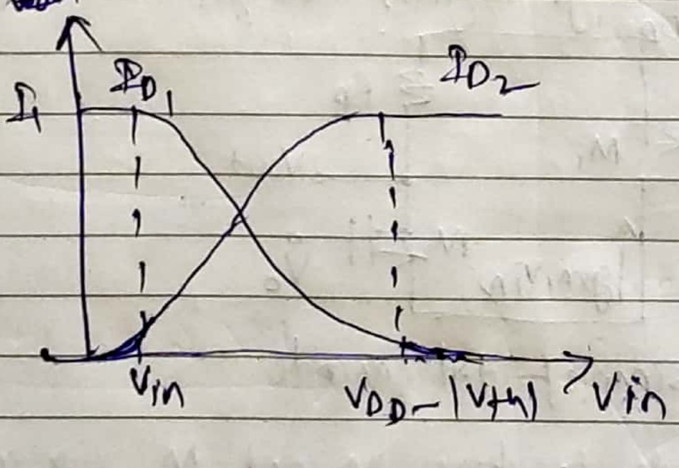
As Vin drops. I_{D_2} decreases further, falling to zero, if $I_{D_1} = I_1$

$$\frac{1}{2} \mu_p C_{ox} \left(\frac{W}{L}\right)_1 (V_{DD} - V_{in_1} - |V_{th_1}|)^2 = I_1$$

Thus,

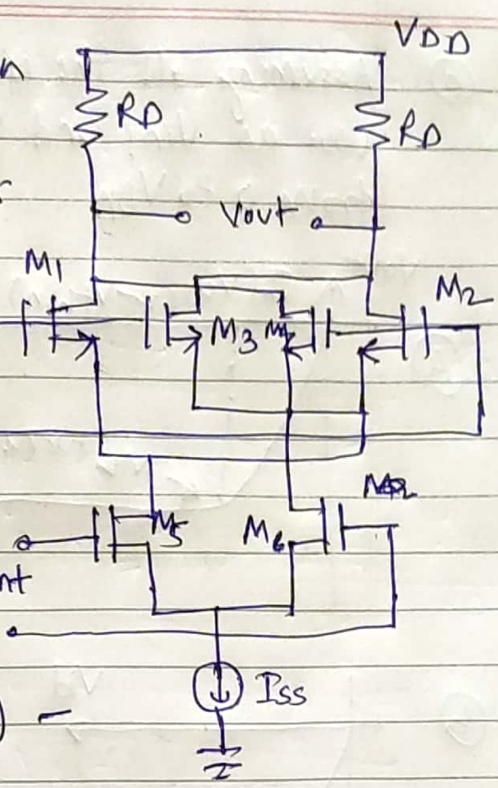
$$V_{in_1} = V_{DD} - \sqrt{\frac{2 I_1}{\mu_p C_{ox} (W/L)_1}} - |V_{th_1}|$$

if Vin falls below this level, I_{D_1} tends to be greater than I_1 and M_1 enter the triode region



⑤ Explain the operation of Gilbert cell. Can Gilbert cell operation as an analog voltage multiplier?

The difference between 2 terminals of Vcont steer a lot part of Iss from Vin to Vout



Since,

$V_{out1} = R_D I_{D1} - R_D I_{D2}$
$V_{out2} = R_D I_{D4} - R_D I_{D3}$

$V_{out} = R_D(I_{D1} + I_{D4}) - R_D(I_{D2} + I_{D3})$

where,

$$\frac{V_{out1}}{V_{in}} = -g_m R_D,$$

$$\frac{V_{out2}}{V_{in}} = g_m R_D$$

Analog voltage multiplier

Since gain of ckt is

$$V_{cont} = V_{cont1} - V_{cont2}$$

we have

$$V_{out} = V_{in} f(V_{cont}).$$

Expand $f(V_{cont})$ in a Taylor series

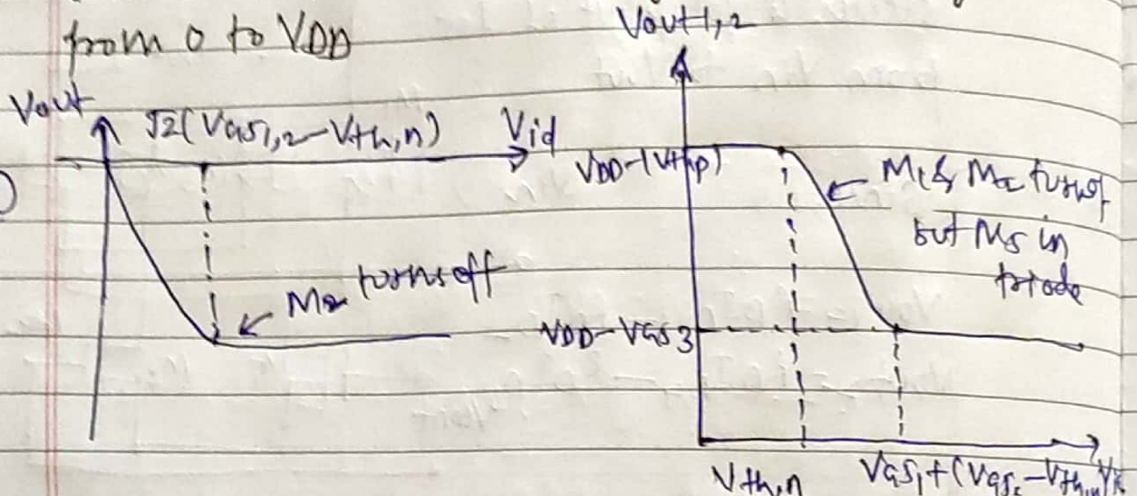
we have,

$$V_{out} = \alpha V_{in} V_{cont}$$

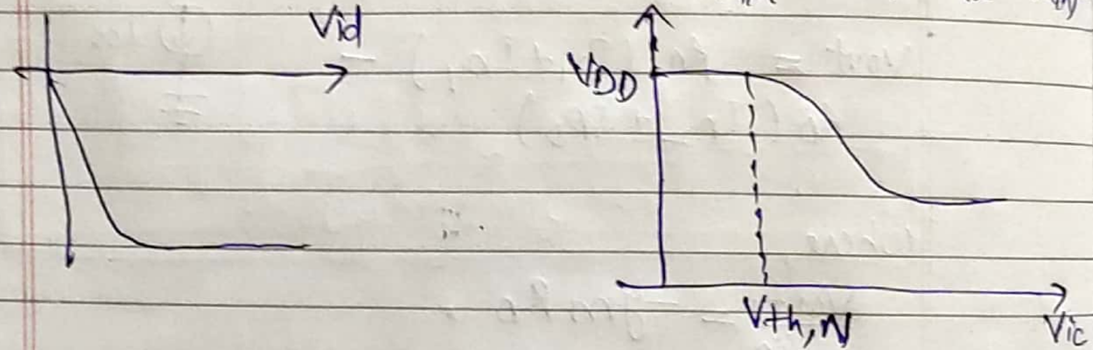
Thus the ckt can multiply voltages.

(b) Assuming all the circuits to be symmetric, plot Vout as Vin1 and Vin2 vary differentially from 0 to VDD

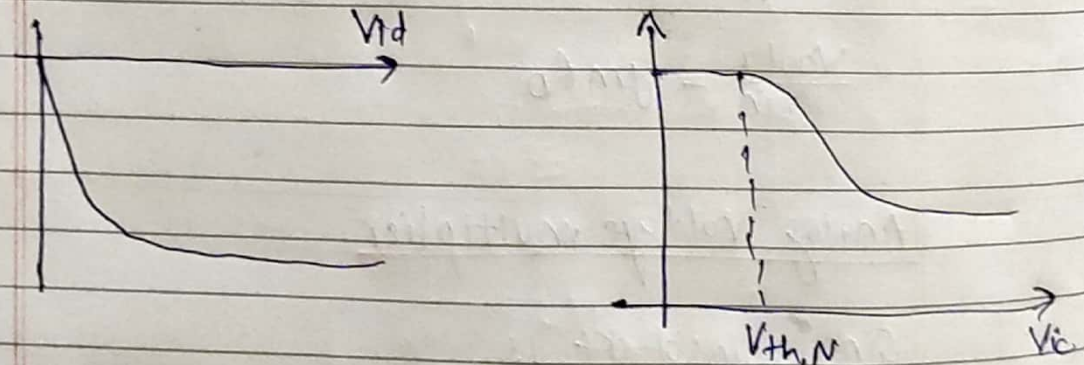
(a)



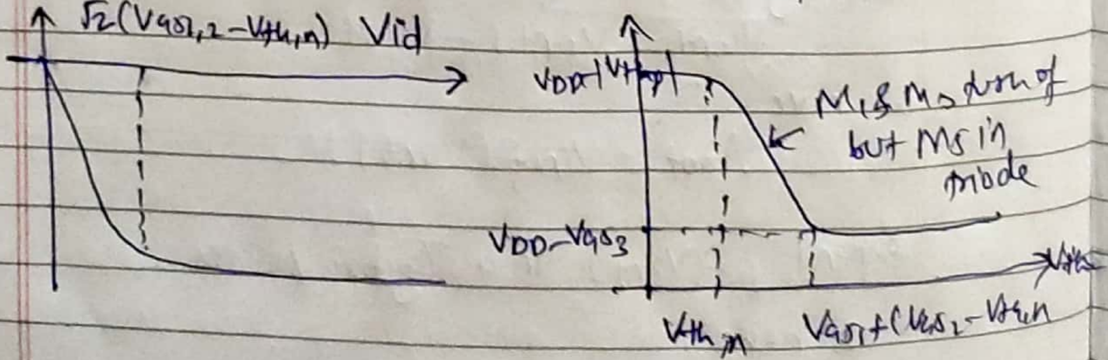
(b)



(c)



(d)



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