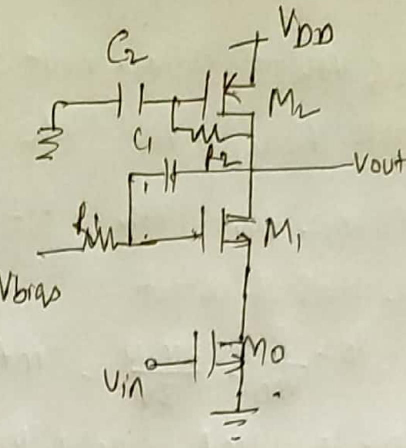
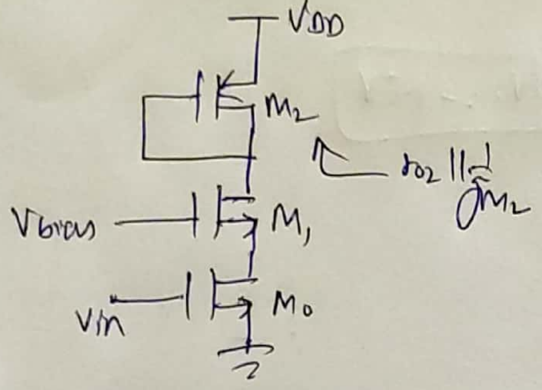
Assignment 2

① Calculate the gain of the following circuit
ⓐ at very low frequencies
ⓑ at very high frequencies
Assume $r = 0$, $\lambda_0 = \lambda_1 = 0$, $\lambda_2 \neq 0$



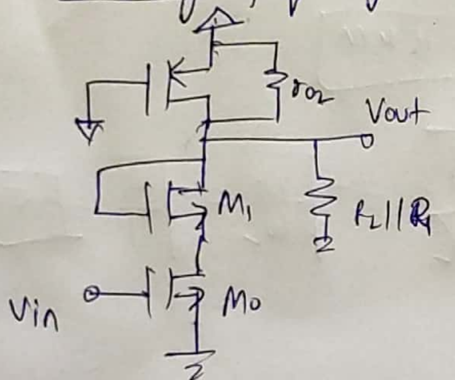
At low frequency

C_1 & C_2 are open circuits



$$\boxed{A_v = -g_{m0}\left(r_{o2} \| \frac{1}{g_{m2}}\right)}$$

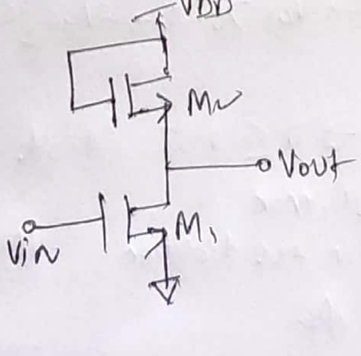
At high frequency



$$\boxed{A_v = -g_{m0}\left(R_1 \| R_2 \| r_{o2}\right)}$$

② Design a common source amplifier with a diode connected load based on the schematic shown below
- Transistor M_1 is in saturation
- The min possible output voltage to keep M_1 in saturation is 0.2 V
- Total power consumption of amplifier is 3 mW
- Both Tx have $L = 0.5\,\mu m$ and for M_2 we have $W_2 = 1\,\mu m$

$\lambda(NMOS) = 0$
$r = 0$
$V_{DD} = 3V$
$V_{th}(NMOS) = 0.5 V$
$\mu_n C_{ox} = 1 mA/V^2$



(a) DC level of the input

M_1 must operate in sat

$V_{GD_1} \le V_{th} \rightarrow V_{bias,1} - V_{out} \le V_{th} \rightarrow V_{bias,1} \le V_{out} + V_{th}$

we choose $V_{bias,1} = V_{out} + V_{th}$

M_1 will operate at edge of saturation at $V_{bias,1} = 0.7V$

$V_{bias,1} = V_{out} + V_{th} = 0.2 + 0.5 = \boxed{0.7V}$

(b) DC level of output

$I_D = \frac{P}{V_{DD}} = \frac{3mW}{3V} = 1mA$

$I_D = I_{D_2} = 1mA = \frac{1}{2}\mu_n C_{ox} \frac{W_2}{L}(V_{GS_2} - V_{th})^2$

$1mA = \frac{1}{2} \times \frac{1mA}{V^2} \times \frac{1}{0.5}(V_{GS_2} - 0.5)^2 \rightarrow \boxed{V_{GS_2} = 1.5V}$

$V_{out\,DC} = V_{DD} - V_{GS_2} = 3 - 1.5$

$\boxed{V_{out\,DC} = 1.5V}$

(c) width (W_1) of tx M_1

$I_D = I_{D1} = 1mA = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS1} - V_{th})^2$

$1mA = \frac{1}{2} \times \frac{1mA}{V^2} \times \frac{W_1}{0.5\mu m}(0.7 - 0.5)^2 \rightarrow \boxed{W_1 = 25\mu m}$

(d) Small signal gain

$A_v = -g_{m_1} \cdot \frac{1}{g_{m_2}} = \frac{-g_{m_1}}{g_{m_2}} = -\sqrt{\frac{2\mu_n C_{ox}\left(\frac{W}{L}\right)_1 I_{D_1}}{2\mu_n C_{ox}\left(\frac{W}{L}\right)_2 I_{D_2}}} = -\sqrt{\frac{W_1}{W_2}} = -\sqrt{\frac{25}{1}} = \boxed{-5}$

(e) Max o/p signal swing for a symmetric o/p signal

$V_{out\,min} = 0.2V$

$V_{out\,DC} = 1.5V$

$V_{out\,max} = ?$

As o/p voltage increases, the overdrive voltage of M_2 decreases up to the point where $V_{GS_2} = V_{th}$. If V_{out} increases any further, M_2 will turn off. M_2 is a diode connected device & operates in saturation as long as $V_{GS_2} > V_{th}$

M_2 in saturation: $V_{GS} > V_{th} \rightarrow V_{GS} > 0.5 \rightarrow -V_{GS_2} < -0.5 \rightarrow V_{DD} - V_{GS_2} < V_{DD} - 0.5 \rightarrow V_{out} < 2.5$

$\boxed{V_{out,max} = 2.5V}$

$V_{GD_2} \le V_{th} \rightarrow 0 \le 0.5$ (diode connected device)

2.5V — $V_{out,max}$

↑ 1V swing in +ve direction

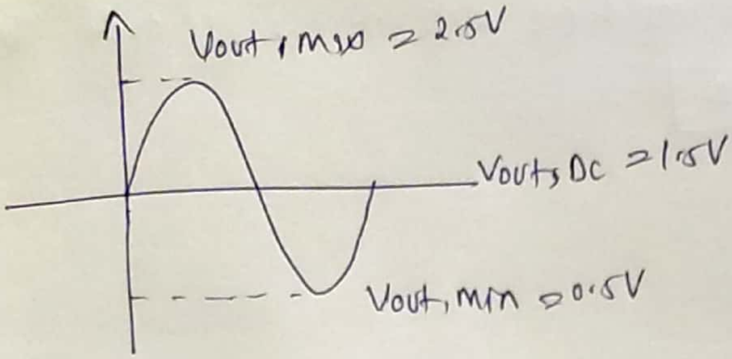
1.5V → $V_{out,DC}$

↓

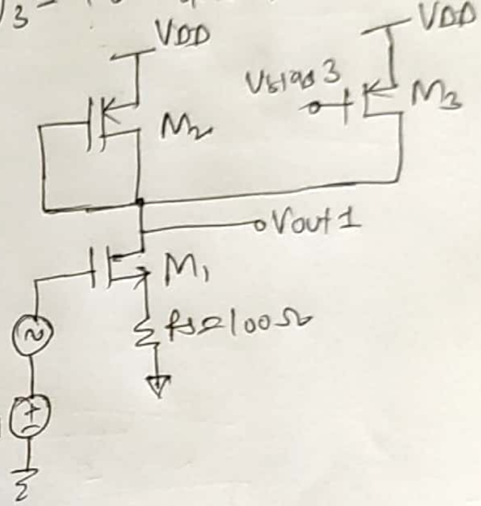
0.2V → $V_{out,min}$

max. symmetric swing $= 2 \times \min(1V, 1.3V)$

$= 2V$



③ In following ckt assume that all transistors are operating in saturation region. Also assume that $\lambda = \gamma = 0$, $V_{DD} = 1.8V$, $V_{bias3} = 1.15V$, $V_{th}(n) = 0.4V$ and $V_{th}(P) = -0.4V$, $\mu_n C_{ox} = 800\mu A/V^2$, $(W/L)_1 = 40$, $\mu_p C_{ox} = 400\mu A/V^2$, $(W/L)_2 = 40$, $(W/L)_3 = 40$ and $R_s = 100\Omega$



ⓐ find V_{bias1} such that bias current of M_1 is $I_1 = 1mA$

ⓑ ~~Calculat~~

$I_{D1} = 1mA = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{th})^2$

$= \frac{1}{2} \times 800\frac{\mu A}{V^2} \times 40 (V_{GS1} - 0.4)^2$

$\boxed{V_{GS1} = 0.65V}$

$V_{bias1} = V_{GS1} + R_s I_1 = 0.65 + 0.1 \times 1 = \boxed{0.75V}$

ⓑ Calculate small signal voltage gain $A_{v1} = V_{out1}/V_{in}$

$\lambda = 0 \Leftrightarrow r_o = \infty$, $\quad A_v = \frac{-g_{m1}R_D}{1+g_{m1}R_s}$

$R_D = \frac{1}{g_{m2}}$, $R_s = 0.1k\Omega$

$I_{D3} = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)_3 (V_{DD} - V_{bias3} - |V_{thp}|)^2$

$= \frac{1}{2} \times 400 \times 40 (1.8 - 1.15 - 0.4)^2 = \boxed{500\mu A}$

$I_{D2} = I_{D1} - I_{D3} = 1000\mu A - 500\mu A = 500\mu A$

$g_{m2} = \sqrt{2K_p I_{D2}} = \sqrt{2 \times 400 \times 40 \times 500} = \boxed{4mA/V}$

$g_{m1} = \sqrt{2K_n I_{D1}} = \sqrt{2 \times 800 \times 40 \times 1000} = \boxed{8mA/V}$

$R_D = \frac{1}{g_{m2}} = \frac{1}{4mA/V} = 250\Omega = \boxed{0.25k\Omega}$

$A_v = \frac{-g_{m1}R_D}{1+g_{m1}R_s} = \frac{-8 \times 0.25}{1+8 \times 0.1} = \boxed{-1.11\ V/V}$

(c) Calculate the small-signal o/p impedance seen at the o/p node V_{out} |

$$R_{out} = \frac{1}{g_m} = R_D = \boxed{250\,\Omega}$$