Q1

Determine the magnitude of common mode voltage gain of the circuit given below. Assume the bias current sources to be practical with current I_{SS} equal to 28 μA and shunt resistance equal to 0.5 MΩ each. Bias voltage V_B, resistors R_D and bias current sources I_{SS} are selected in a way to keep all transistors in saturation.

Other parameters are listed below :

Supply voltage (Vdd) = 3.3 V

$\mu_n c_{ox}$ = 200 μA/V^2 , $\mu_p c_{ox}$ = 100 μA/V^2

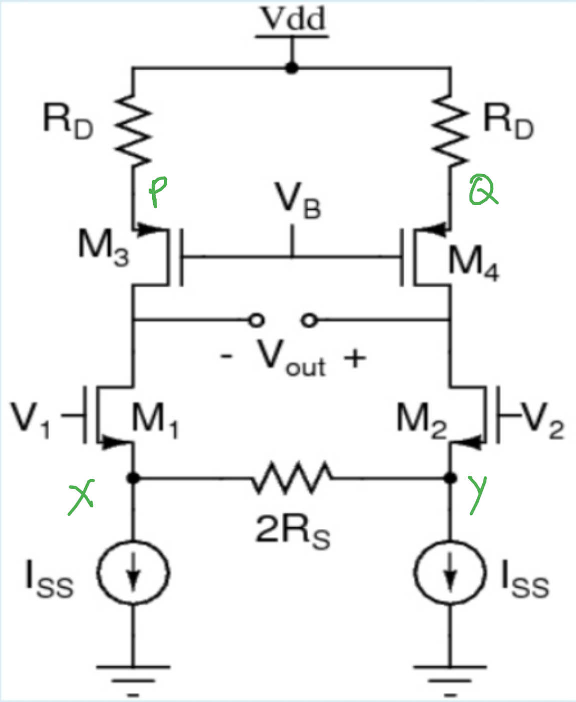
V_{TN} = $|V_{TP}|$ = 0.7 V

$(W/L)_{1,2}$ = 1 , $(W/L)_{3,4}$ = 4

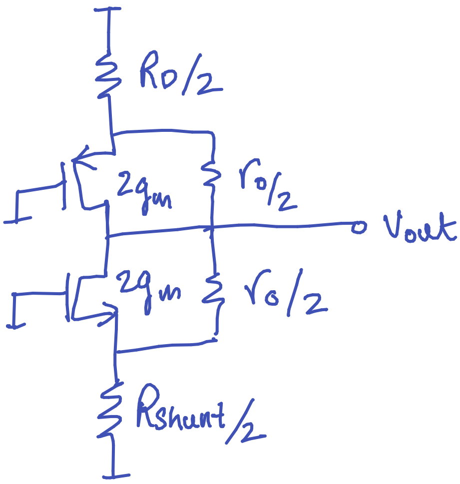
R_D = 3 KΩ , R_S = 10 KΩ

Channel length modulation parameter (λ) = 0.01 V^{-1}

Give your answer correct upto 3 decimal places.



In the common mode scenario, $V_X = V_Y$. $2R_S$ (X)



$$\frac{v_{out}}{v_{CM}} = \left[\frac{2g_{m1}}{1+(2g_{m1})\frac{R_{shunt}}{2}}\right]\left[R_{UP} \,||\, R_{DOWN}\right]$$

$$\because \; R_{UP} = \left[1 + (2g_{m3})(r_o/2)\right]\frac{R_D}{2} + \frac{r_o}{2}$$

$$R_{DOWN} = \left[1 + 2g_{m1}\frac{r_o}{2}\right]\frac{R_{sh}}{2} + \frac{r_o}{2}$$

$$g_{mi} = \sqrt{2 I_{SS}\,\mu_n C_{ox}\left(\frac{W}{L}\right)_i}$$

$$r_{oi} = \frac{1}{\lambda I_{SS}}$$

Q2

Calculate the small signal differential voltage gain v_{out}/v_d of the circuit shown below. The bias current source I_{SS} is ideal and equal to 45 μA.

Take :

Supply voltage (Vdd) = 3.3 V

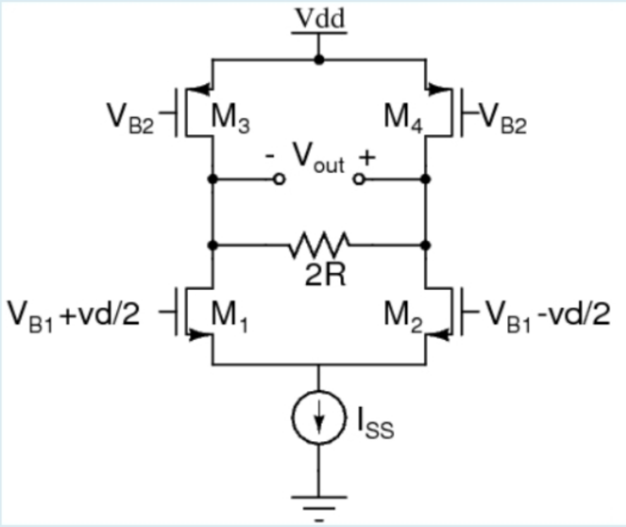
$\mu_n c_{ox}$ = 200 μA/V^2 , $\mu_p c_{ox}$ = 100 μA/V^2

V_{TN} = $|V_{TP}|$ = 0.7 V

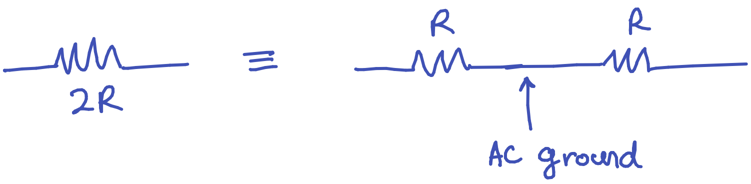
$(W/L)_{1,2}$ = 1 , $(W/L)_{3,4}$ = 4

Resistor R = 117 KΩ

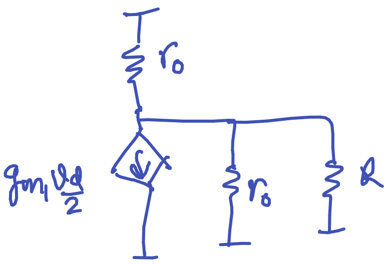
Channel length modulation parameter (λ) = 0.01 V^{-1}



Give your answer correct upto 3 decimal places.



small signal half ckt



$$r_o = r_{on} = r_{op} = \frac{1}{\lambda \frac{I_{SS}}{2}}$$

$$g_{m1} = \sqrt{2\frac{I_{SS}}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1}$$

$$\boxed{\frac{v_{out1}}{\frac{v_d}{2}} = -g_{m1}\left(r_o/2 \,||\, R\right)}$$

Similarly, $v_{out2} = +g_{m1}\left(\frac{r_o}{2}||R\right)\frac{v_d}{2}$

$$\therefore A_{DM} = \frac{V_{out2} - v_{out1}}{v_d} = g_{m1}\left(\frac{r_o}{2}||R\right)$$

Q3

Determine the incremental differential voltage gain v_{out}/v_d of the circuit shown below. Assume the bias current source I_{SS} to be ideal and equal to 26 μA.

Other parameters are listed below:

Supply voltage (Vdd) = 3.3 V

Resistor R = 1 MΩ

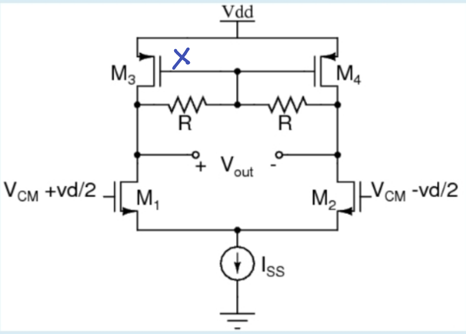
$\mu_n c_{ox}$ = 100 μA/V^2 , $\mu_p c_{ox}$ = 50 μA/V^2

V_{TN} = $|V_{TP}|$ = 0.7 V

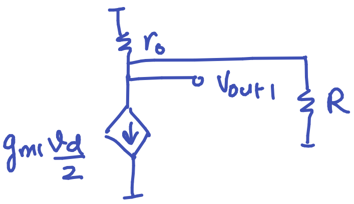
$(W/L)_{1,2}$ = 1 , $(W/L)_{3,4}$ = 2

Channel length modulation parameter (λ) = 0.01 V^{-1}

Give your answer correct upto 3 decimal places.



X → signal gnd



$$r_o = r_{o3} = r_{o1} = \frac{1}{\lambda\, I_{SS}/2}$$

$$g_{m1} = \sqrt{2\left(\frac{I_{SS}}{2}\right)\mu_n C_{ox}\left(\frac{W}{L}\right)_1}$$

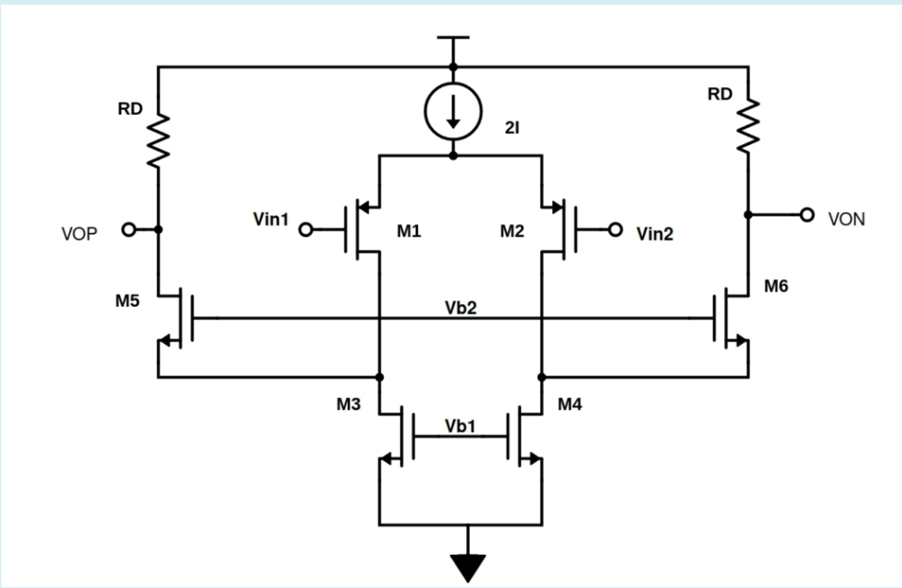
$$v_{out1} = -g_m\left(\frac{r_o}{2} \| R\right)\frac{v_d}{2}$$

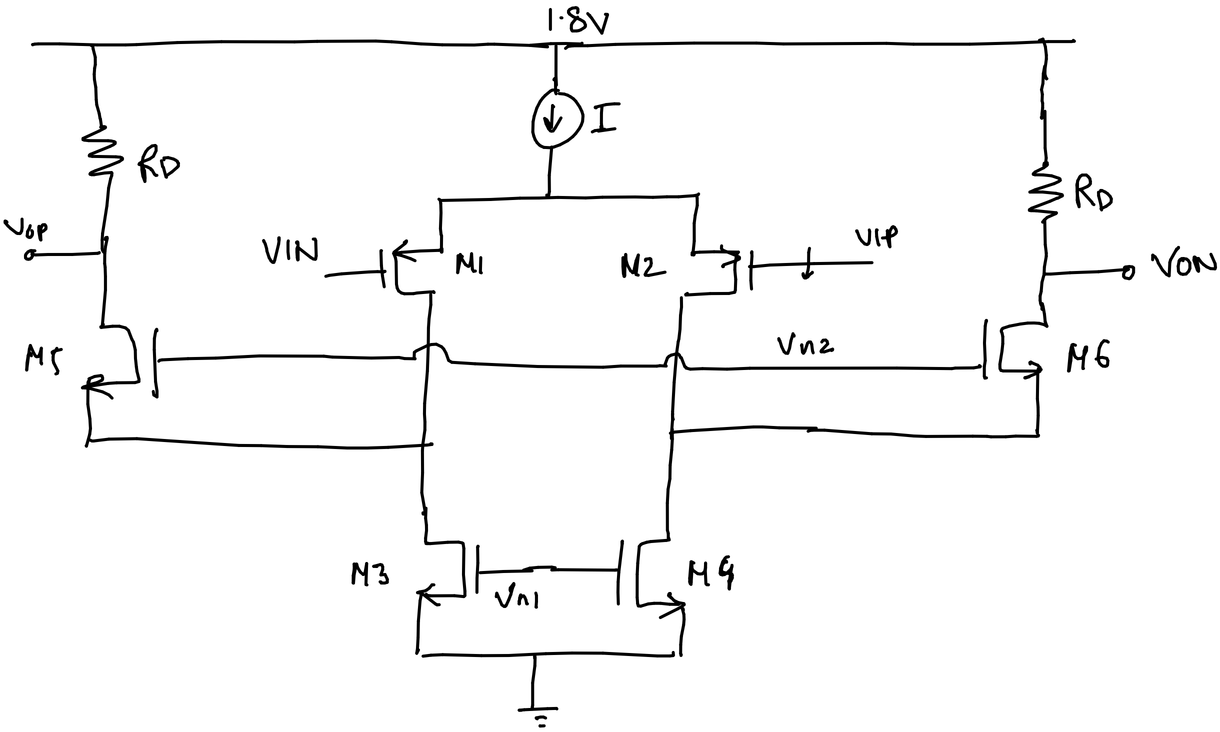
Similarly, $$v_{out2} = +g_{m1}\left(\frac{r_o}{2} \| R\right)\frac{v_d}{2}$$

$$\boxed{A_d = \frac{v_{out1} - v_{out2}}{v_d} = -g_{m1}\left(\frac{r_o}{2} \| R\right)}$$

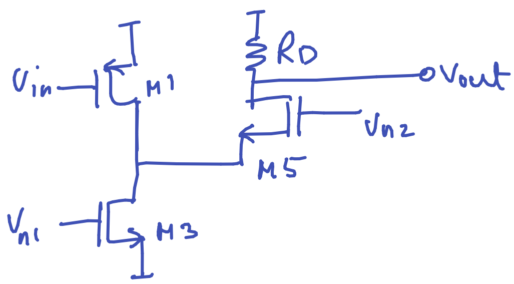
Q4

For the amplifier shown in the given circuit, find the differential mode gain (with polarity) if small signal output impedance due to short channel effects of each MOSFET is 27 kΩ, and gm is 5 mS. The resistance R_D is 227 kΩ. (At least 1% accuracy is expected.)



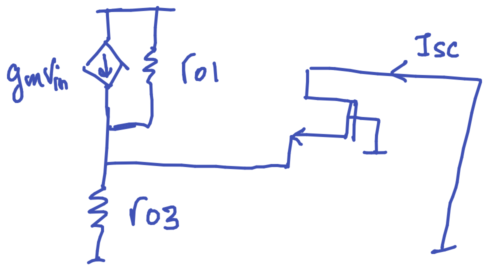


Differential half circuit



$G_M \approx g_{m1}$

For G_M $V_{out} \to 0 \Rightarrow$



$$I_{sc} = -g_{m1} v_{in} \left[\frac{r_{o3} + r_{o1}}{r_{o3} + r_{o1} + 1/g_{m5}} \right] \Rightarrow g_m v_{in} \left[\frac{2 g_m r_o}{2 g_m r_o + 1} \right]$$

$$\therefore \ G_m \approx -g_{m1}$$

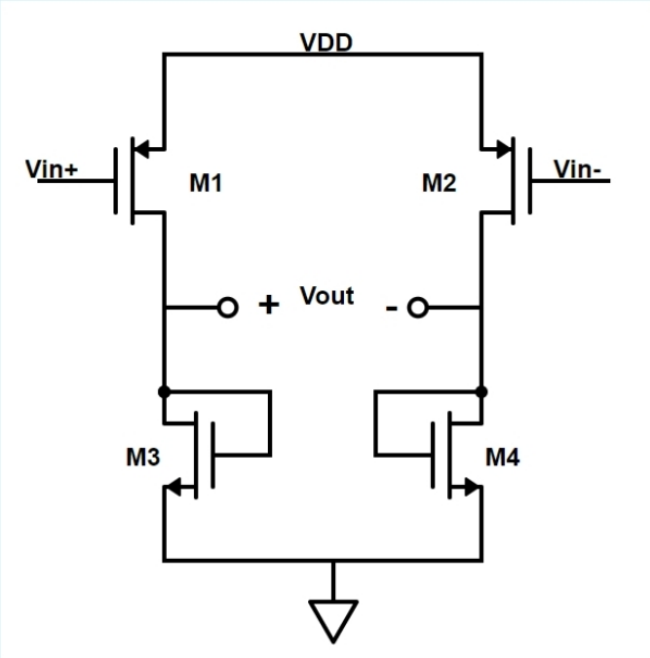
$$R_{out} = R_D \parallel \left[(1 + g_{m5} r_{o5})(r_{o3} \parallel r_{o1}) + r_{o5} \right]$$

$$\approx R_D \parallel \left[g_{m5} r_{o5} \left(r_{o3} \parallel r_{o1} \right) \right] \Rightarrow R_D \parallel g_m r_o^2 / 2$$

$$\therefore \ A_d = -g_m \left[R_D \parallel \frac{g_{m5}}{g_{ds5}(g_{ds3} + g_{ds1})} \right]$$

Q5

Calculate the CMRR (in dB) of the below circuit. Assume gm3=gm4 , gm1=gm2, gm1=2gm3. ro1=r02=r03=r04=49 kΩ.



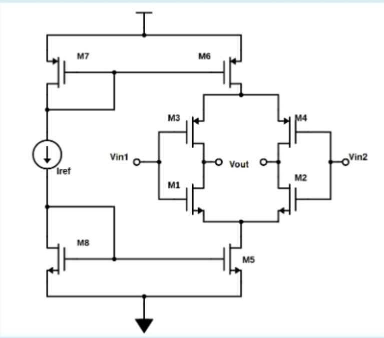
This circuit is a "pseudo-differential pair"

Despite having the same diff. gain, it is incapable of rejecting common mode signals.

$$CMRR = 20 \log_{10}\left(\frac{A_{CM}}{A_d}\right) = 0\,dB$$

Q6

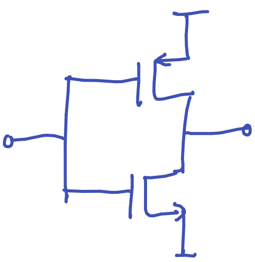
Consider the active load differential amplifier shown in the figure used to enhance the trans-conductance. If I_{ref} is an ideal current source of 247 μA, find the CMRR (|Ad/Acm|) of the arrangement (1% error tolererance) given that $(W/L)_6 = (W/L)_7$; $(W/L)_8=(W/L)_5$; $gm_{1,2} = gm_{1,3}$ = 3 mS. Take Channel length modulation into account (λ=0.1).



$$r_{o6} = \frac{1}{\lambda I_{ref}} = r_o$$

$$r_{o3} = r_{o1} = 2r_{o6} = 2r_o$$

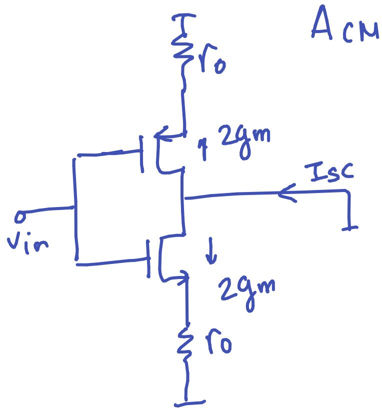
I) A_{dm}

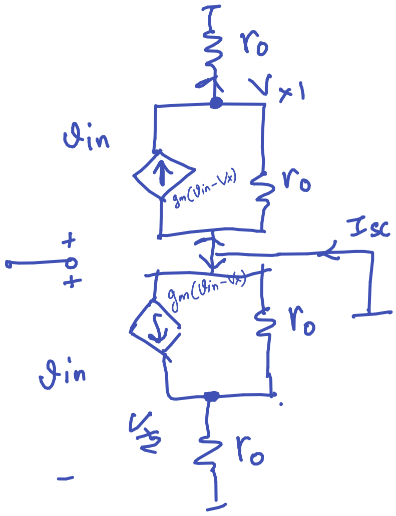


$$\Rightarrow (g_{mn} + g_{mp})(r_{on} \,||\, r_{op})$$

$$\Rightarrow \frac{g_{mn} + g_{mp}}{g_{dsn} + g_{dsp}} \approx g_m r_o$$

II) A_{CM}





$$V_{x1} = V_{x2} = V_x \quad \text{(by symmetry)}$$

$$\frac{I_{sc}}{2} = \frac{V_x}{r_o} \Rightarrow V_x = \frac{I_{sc} r_o}{2}$$

Also,

$$\frac{I_{sc}}{2} = 2g_m(v_{in} - v_x) - \frac{v_x}{r_o}$$

$$\frac{I_{sc}}{2} = 2g_m v_{in} - V_x\left(2g_m + \frac{1}{r_o}\right)$$

$$\frac{I_{sc}}{2} = 2g_m v_{in} - \frac{I_{sc}}{2}\left(2g_m r_o + 1\right)$$

$$\frac{I_{sc}}{2}\left(1 + 2g_m r_o + 1\right) = 2g_m v_{in}$$

$$I_{sc}(1 + g_m r_o) = 2g_m v_{in}$$

$$G_M = \frac{2g_m}{1 + g_m r_o} \approx \frac{2}{r_o}$$

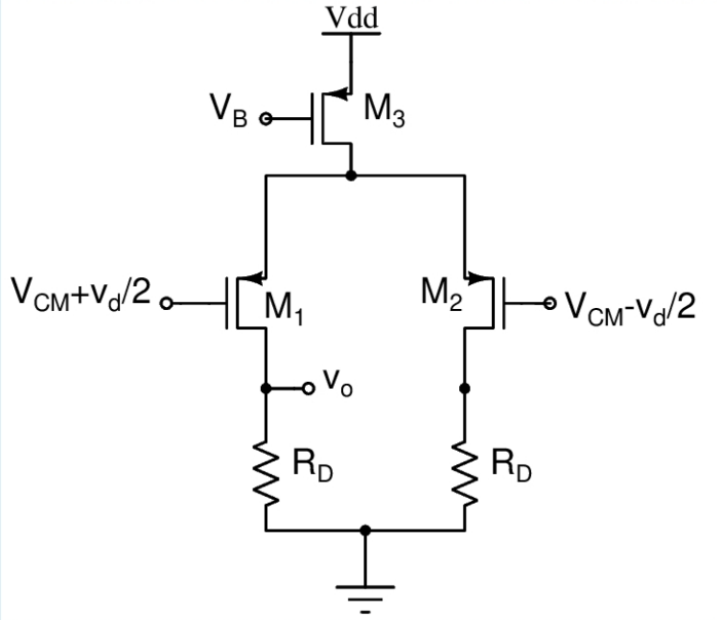
$$R_{out} = \frac{(1 + 2g_m r_o) r_o}{2} \approx g_m r_o^2$$

$$\therefore A_{CM} = 2g_m r_o$$

$$\boxed{CMRR = \frac{A_{CM}}{A_d} = 2}$$

Q7

In the circuit shown below, Find Maximum single ended peak to peak output swing. Given Vdd=8.6 V, Overdrive voltage of all transistors is 0.2 V.



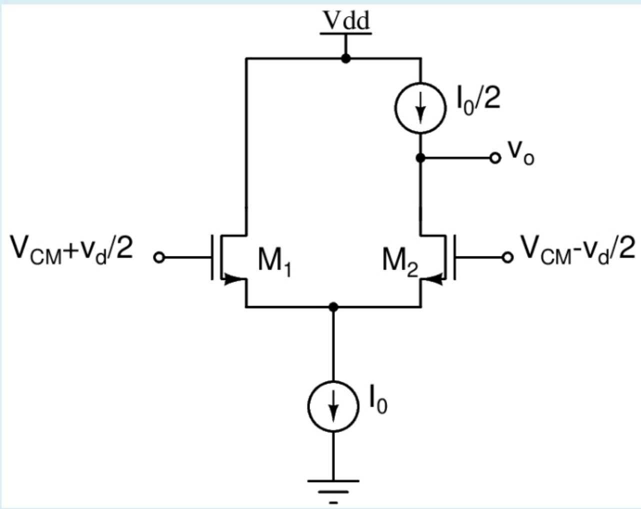
$$V_{o,max} = V_{DD} - V_{SD,sat3} - V_{SD,sat1}$$
$$= V_{DD} - 2V_{SD,sat}$$

$$V_{o,min} = 0V$$

single - ended $V_{PP,out} = V_{DD} - 2V_{SD,sat}$

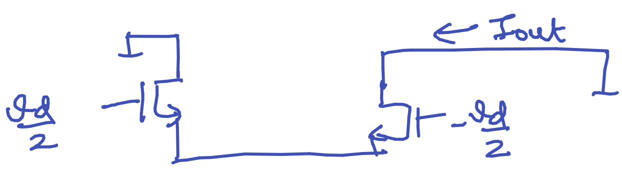
Q8

In the circuit shown below, Calculate single ended gain. I0=163 μA, λ=0.01 v^{-1}, Given Vdd = 1.8 V, aspect ratio of transistors is 2, Mos parameters are $\mu_n C_{ox}$ = 100 μA/V^2, V_{TH}=0.5 V. (Accuracy= ±0.001)



$$A_v = G_M R_{out}$$

G_M:



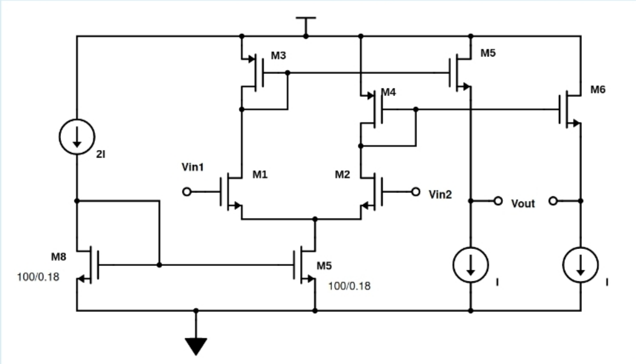
$$\frac{i_{out}}{v_d} = \frac{g_m}{2}$$

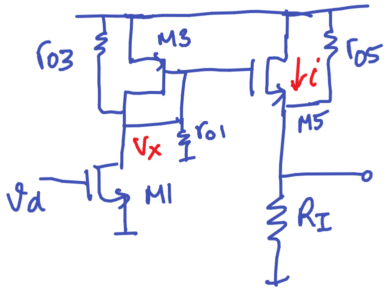
R_{out} : $(1+g_m r_o)\frac{1}{g_m} + r_o \cong 2r_o$

$\therefore$ gain $= \left(\frac{g_m}{2}\right)(2r_o) = g_m r_o$

Q9

Find the magnitude of small signal differential gain, $|A_d|$, of the circuit below assuming all transistors are biased in saturation region. The current sources are non-ideal with shunt resistance of 1250 Ω. $(W/L)_{5,6}$ = $1\times(W/L)_{3,4}$. $g_{m1}=g_{m2}$ = 1 mS. Small signal output impedance of all transistors is same, 1428.5714285714 Ω. [+/- 1% error tolerated].





$\longrightarrow$ Differential Half ckt

$V_{out} = g_m v_d R_I$

$\therefore$ Gain $= g_m R_I$

I) $$\frac{V_x}{v_d} = \frac{g_{m1}}{g_{m3} + g_{ds1} + g_{ds3}} \qquad \left[\, g_{dsi} = \frac{1}{r_{oi}} \right]$$

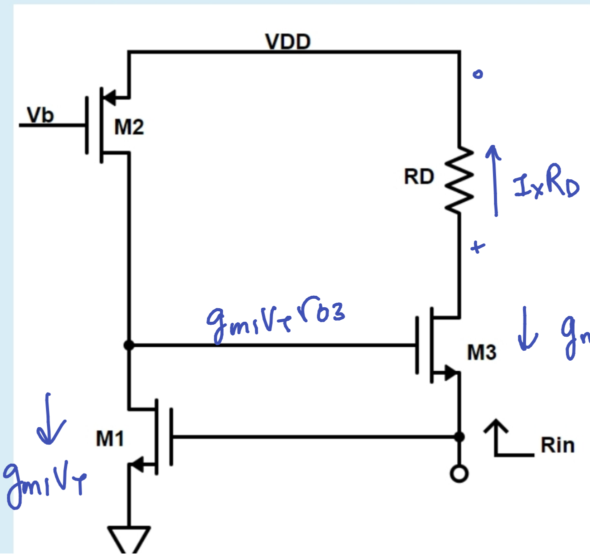
$$\frac{v_{out}}{V_x} = \frac{g_{m5}}{G_I + g_{ds5} + g_{m5}}$$

$$\therefore \text{gain} = \frac{g_{m1}\, g_{m5}}{(g_{m3} + g_{ds1} + g_{ds3})(G_I + g_{ds5} + g_{m5})}$$

$$= \frac{\sqrt{\alpha}\, g_m^2}{(g_m + 2g_{ds})(G_I + g_{ds} + \sqrt{\alpha}\, g_m)}$$

Q10

Calculate the equivalent Thevenin resistance Rin in Ω . [Given RD= 1.1 KΩ gm1=gm2=gm3= 1.37 ms, ro1= ro2= 2ro3, ro3= 1.1 MΩ. Accuracy required +/- 0.05]



$\downarrow$ $$g_{m3}(g_{m1}r_{o3} - 1)V_x + \frac{I_xR_D - V_x}{r_{o3}} = -I_x$$

$$\left(g_{m1}g_{m3}r_{o3} - \frac{1}{r_{o3}}\right)V_x = -I_x(1+R_D)$$

$$R_{in} = \frac{R_D + r_{o3}}{1 + (g_{m1}(r_{o1} \| r_{o2}) + 1)\, g_{m3} r_{o3}}$$

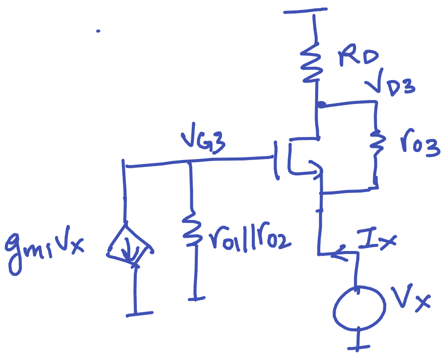
$$= \frac{R_D + r_{o3}}{1 + \left(g_m \frac{r_{o1}}{2} + 1\right) g_m r_{o3}}$$

$$= \frac{R_D + r_{o3}}{1 + (g_m r_{o3} + 1) g_m r_{o3}}$$

$$r_{o3} \gg R_D, \quad g_m r_{o3} \gg 1$$

$$= \frac{r_{o3}}{1 + g_m^2 r_{o3}^2} \Rightarrow \frac{1}{g_m^2 r_{o3}}$$

Alternatively,



$$V_{G3} = g_{m1} V_x (r_{o1} \| r_{o2})$$

$$I_x = \frac{V_{D3}}{R_D}$$

$$-I_x = -g_{m3}(V_{G3} - V_x) + \frac{(V_{D3} - V_x)}{r_{o3}}$$

$$-I_x = -g_{m3}(g_{m1}(r_{o1} \| r_{o2}))V_x + \frac{I_x R_D - V_x}{r_{o3}}$$

$$V_x\left(-g_{m3} g_{m1} \frac{r_o}{2} - \frac{1}{r_{o3}}\right) + I_x\left(\frac{R_D}{r_{o3}} + 1\right) = 0$$

$$R_{in} = \frac{\frac{R_D}{r_{o3}} + 1}{g_{m3} g_{m1} \frac{r_o}{2} - \frac{1}{r_{o3}}}$$

$$\approx \frac{1}{g_m^2 r_{o3}}$$