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MOS DEVICE characteristics

- $I_{D,sat} = \mu C_{ox}\left(\frac{W}{L}\right)\frac{(V_{GS}-V_{th})^2}{2}(1+\lambda V_{DS})$

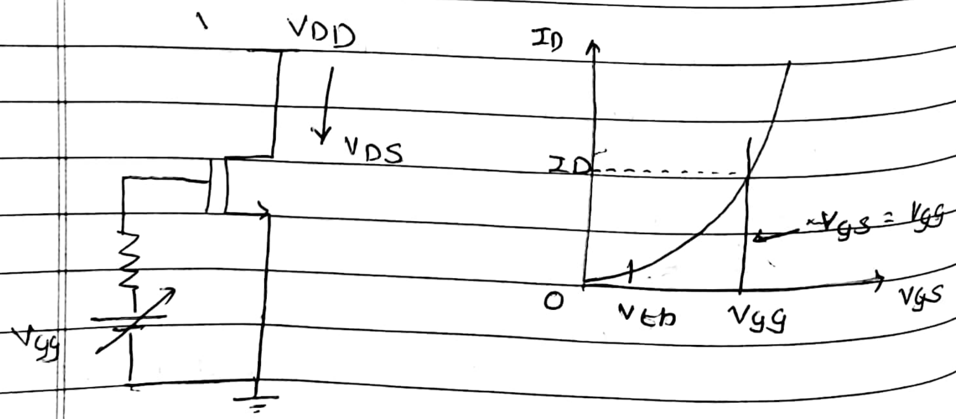
$I_{D,sat} \propto \left(\frac{W}{L}\right)$ linear relationship

$I_{D,sat} \propto (V_{GS}-V_{th})^2$ parabolic relationship

$I_{D,sat} \propto (1+\lambda V_{DS})$ small signal linearity

- Load line equation :- $V_{DS} = V_{DD} - I_D R_D$

- Pinch off voltage :- boundary betn triode region and saturation region
  $V_P = V_{GS} - V_{th}$.
- Slope of load line $= -1/R_D$.



Loop equation, $V_{GS} = V_{GG}$.

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1) Given an operational amp with $R_i = \infty$, $A = 10^4$, $R_o = 0\,\Omega$. Find V_o, if $V_p = 750.25\,mV$, $V_n = 751.75\,mV$

Sol $V_o = A(V_p - V_N)$

$= 10^4(750.25 - 751.75) \times 10^{-3}$

$= -15\ V.$

2) Find V_N if $V_o = -5V$, $V_p = 0$. (op-amp is same)

Sol $V_o = -AV_N$

$V_N = \dfrac{-5}{-10^4}$

$V_N = 5 \times 10^{-4}\ V.$

3) Find V_p, if $V_o = V_N = 5V$

Sol $V_o = A(V_p - V_N)$

$\dfrac{V_o + AV_N}{A} = V_p$

$V_p = 5.0005\ V$

4) Find V_N, $-V_o = V_p = 1V$

Sol $-1 = 10^5(1 - V_N)$

$V_N = \dfrac{10^4 + 1}{10^4}$

$= 1.0001$

5) In the voltage amplifier circuit shown below, let $V_S = 100\,mV$, $R_L = 10\,\Omega$, $R_S = 100\,K\Omega$, $V_i = 75\,mV$,

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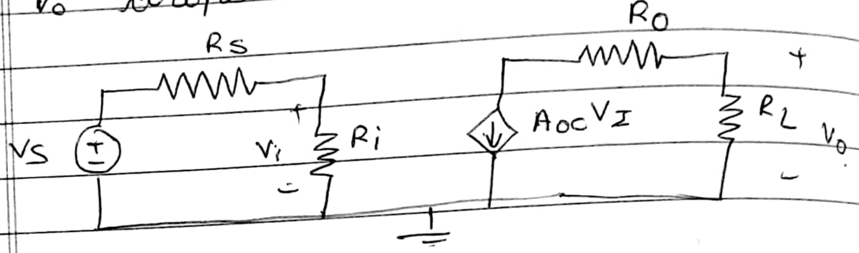
$V_o = 2V$. If connecting a $30\,\Omega$ resistance in parallel will R_L, V_o drops to $1.8\,V$. Find R_i, A_{oc} & R_o



Sol: Given:- $V_S = 100\,mV$ $\quad R_S = 100\,K\Omega$

$V_i = 75\,mV$ $\quad R_L = 10\,\Omega$

Given $I_S = \frac{250 \times 10^{-3}}{100 \times 10^{3}}$

$= \frac{1}{4} \times 10^{-6}$

$= 0.25 \times 10^{-6}\,A$

$R_i = \frac{75 \times 10^{-3}}{0.25 \times 10^{-6}}$

$R_i = 300\,K\Omega$

$V_o - IR_o + A_{oc} V_{I_1} R_L = 0$

$V_o + A_{oc} V_I R_L = IR_o$

$\frac{V_o}{R_L} = I$

$\frac{2}{10} = I$

$0.2\,A = I$

A_{oc}

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0 Ω

U R_L,

A_{oc} & R_o

+

R_L V_o

-

00kΩ

10 Ω

Instead of A_F only A is given, it is feedback gain.

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$$2 + A_{oC}(75\times10^{-3})\overset{R_L}{=} 0.2\,R_o$$

$$2R_o - A_{oc}(75\times10^{-3}) = -20 \quad — ①$$

case ii) :- $R = 30 \parallel R_L$

$$R_{eff} = \frac{30\times10}{40} = 7.5\,\Omega$$

$$V_o = \frac{A_{oc}V_I}{R_o+7.5}(7.5)$$

$$1.8 = \frac{A_{oc}(75\times10^{-3})(7.5)}{R_o+7.5}$$

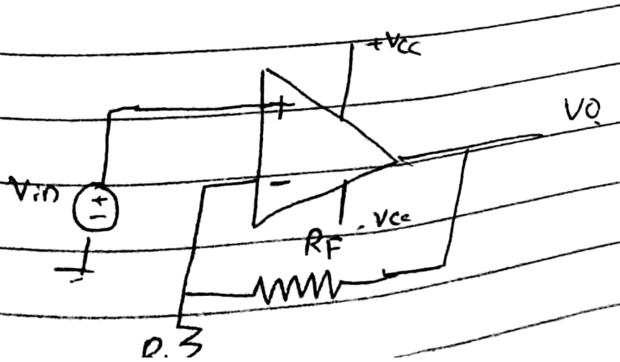
$$1.8R_o + 13.5 = 562.5\,A_{oc}\times10^{-3}$$

$$1.8R_o - 562.5\times10^{-3}A_{oc} = -13.5 \quad — ②$$

$$R_o = 5\ \Omega$$

$$A_{oc} = 40$$

i) Design a non-inverting amplifier who's gain is variable over the range $1V/V \le A_F \le 5V/V$, by the means of 100 kΩ potentiometer.
Repeat the above problem for a gain $0.5V/V \le A_F \le 2V/V$.



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Practical devices will have Voltage divider circuit.

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Sol: i) For minimum gain value = 1

$$A_F = 1 + \frac{R_F}{R_1}$$

$R_F = 0$ (potientometer should be connected across R_F)

$\boxed{A_F = 1}$

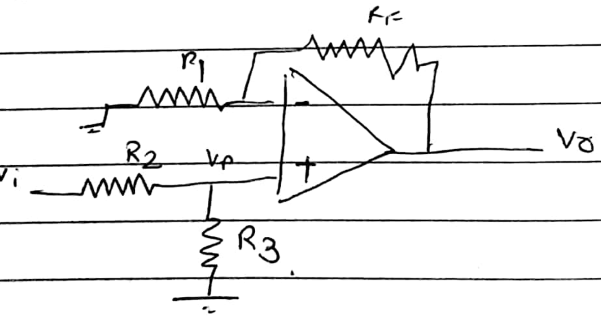
For maximum gain value = 5

$R_F = 100K\Omega$ (it should be maximum)

$$5 = 1 + \frac{100 \times 10^3}{R_1}$$

$R_1 = 25 K\Omega$

ii)



$$V_p = \frac{V_i \times R_3}{R_2 + R_3}$$

$$V_o = \left(1 + \frac{R_F}{R_1}\right) V_p$$

$$= \left(1 + \frac{R_F}{R_1}\right)\left(\frac{R_3}{R_2 + R_3}\right) V_i$$

If $R_F = 0$

$R_2 = R_3$

$$= (1)\left(\frac{1}{2}\right) V_i$$

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$$\frac{V_o}{V_i} = 0.5\,V$$

$$\boxed{R_F = 0\,\Omega \quad R_2 = R_3}$$

Maximum value:-

$R_F = 100\,k\Omega$

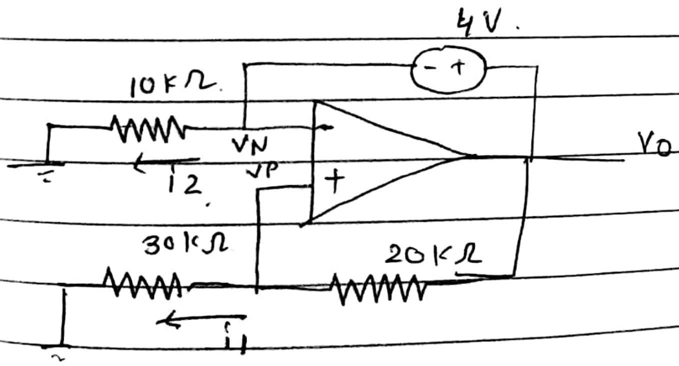
$$A = 1 + \frac{R_F}{R_1}$$

$$2 = \left(1 + \left(\frac{100\times10^3}{R_1}\right)\right)\left(\frac{\cancel{R_3}}{2\cancel{R_3}}\right)$$

$\boxed{\cancel{R_1 = 100\,k\Omega}}$ $R_1 = 33.3\,k\Omega$

$R_1 =$

7) Find V_N, V_P and V_O as well as power released by 4V source.



Sol.- $V_P = (30\times10^3)\,I_1$

Because of virtual same voltage at inputs,

$V_N = V_P$

Voltage drop bet^n

V_N & V_O = V_P & V_O

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$$4 = I_1 \times 20 \times 10^3$$

$$\frac{1}{5 \times 10^3} = I_1$$

$$I_1 = 0.2 \times 10^{-3} \text{ A}$$

$$V_P = 6 \text{ V}$$

$$V_N = 6 \text{ V.}$$

$$V_0 - V_N = 4 \text{ V.}$$

$$V_0 = 10 \text{ V.}$$

$$V_N = I_2 (10 \times 10^3)$$

$$\frac{6}{10^4} = I_2$$

$$6 \times 10^{-4} = I_2$$

$$P_{4V} = (4)(6 \times 10^{-4})$$

$$= 24 \times 10^{-4} \text{ W}$$

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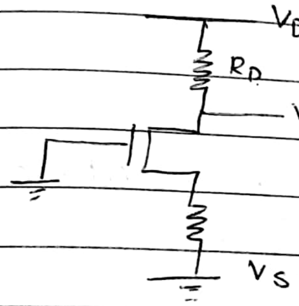
1) Design a circuit shown below, such that the transistor operates at I_D = 0.4 mA, $V_D = 0.5V$ NMOS transistor has $V_t = 0.7V$, $\mu_n C_{ox} = 100 \mu A/V^2$, $W/L = 32$, neglect λ



Sol- $I_D = 0.4 mA$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{2.5 - 0.5}{0.4 \times 10^{-3}} = 5 K\Omega$$

MOS to be saturation $V_t > V_{GD}$

$0.7 > -0.5$

MOSFET is in saturation

$$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$0.4 \times 10^{-3} = \frac{1}{2} \times 100 \times 10^{-6} (32)(V_{GS} - V_t)^2$$

$$1/2 = V_{GS} - 0.7$$

$$V_{GS} = 1.2 V$$

$$V_S = -1.2 V$$

$$R_S = \frac{-V_{SS} + V_S}{I_D}$$

$$= 3.25 K\Omega$$

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2) Redesign the circuit for the same circuit, $V_{DD} = -V_{SS} = 2.5V$, $V_t = 1V$, $\mu_n C_{ox} = 60 \mu A/V^2$, $(W/L) = 40$, $I_D = 0.3 mA$ and $V_D = 0.4 V$.

Sol:- $I_D = 0.3 mA$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{2.5 - 0.4}{0.3 \times 10^{-3}} = 7 k\Omega$$

$V_t > V_{GD}$

$1 > -0.4$

∴ MOSFET is in saturation region

$$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$$

$$0.3 \times 10^{-3} = \frac{1}{2} \times 60 \times 10^{-6} \times 40 \times (V_{GS} - 1)^2$$

$$\frac{1}{4} = (V_{GS} - 1)^2$$

$V_{GS} = 1.5 V$

$V_{SS} = -1.5 V$.

$$R_S = \frac{V_S - V_{SS}}{I_D}$$

$$= \frac{-1.5 + 2.5}{0.3}$$

$R_S = 3.33 k\Omega$

3) Design the circuit shown below, to obtain the current $I_D = 80 \mu A$. Find the value required for R and V_D. (Given $V_t = 0.6V$, $\mu_n C_{ox} = 200 V^2$, $l = 0.8 \mu m$, $W = 4 \mu m$, $\lambda = 0$)

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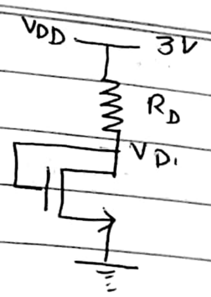

Sol. $V_t = 0.6\,V$ $\quad V_{DD} = 3V \quad V_G = V_D \quad \therefore V_{GD} = 0$

$\therefore V_t > V_{GD}$

$\therefore$ MOSFET is in saturation region

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$80 \times 10^{-6} = \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{4}{0.8}\right)(V_{GS} - 0.6)^2$$

$$0.4 + 0.6 = V_{GS}$$

$$V_{GS} = 1V.$$

$$V_G = V_D = 1V.$$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{3-1}{80 \times 10^{-6}} = 25\,k\Omega$$

4) Redesign the circuit, to double the value of I_D, without changing V_D, give new values for (W/L) and R

Sol. $V_D = 1V$

$$I_D = 2 \times 80$$
$$= 160\,\mu A$$

$$R_D = \frac{V_{DD} - V_D}{I_D}$$

$$= \frac{3-1}{160}$$

$$= 12.5\,k\Omega$$

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$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$

$160 \times 10^{-6} = \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{W}{L}\right)(1 - 0.6)^2$

$(W/L) = 10$

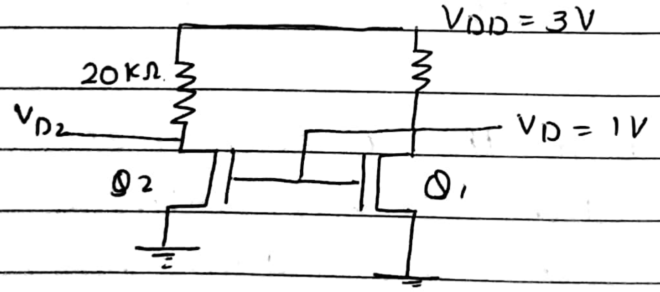
$W = 10 \times L$

$= 10 \times 0.8\ \mu m$

$W = 8\ \mu m$

$\therefore \frac{W}{L} = \frac{8\ \mu m}{0.8\ \mu m}$

5) Consider the circuit shown below, let the voltage V_D be applied to the gate of another transistor shown in fig. Assume Q_2 is identical to Q_1. Find drain current and voltage of Q_2



Sol: $R = 25\ K\Omega$

$I_D = \frac{k'}{2} \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$

$= \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{4}{0.8}\right)(1 - 0.6)^2$

$I_D = 80\ \mu A$

$V_{D2} = V_{DD} - I_D(20)$

$= 3 - (80 \times 10^{-6})(20 \times 10^3)$

$= 1.4\ V$

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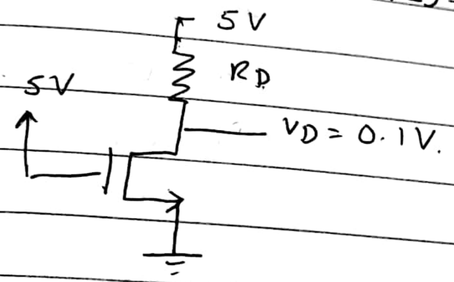
6) Design the foll^n circuit to establish drain voltage of 1V. What is the effective resistance bet^n drain and source at this operating point (Given $V_t = 1V$, $k'_n(W/L) = 1\,mA/V^2$).



Sol:
$$V_{GS} - V_t = 4V$$
$$V_{DS} = 0.1$$
$$V_{GS} - V_t > V_{DS}$$

MOSFET is in triode region

$$I_D = k'_n\left(\frac{w}{l}\right)\left((V_{GS}-V_t)(V_{DS}) - \frac{(V_{DS})^2}{2}\right)$$

$$= 10^{-3}\left((5-1)(0.1) - \frac{(0.1)^2}{2}\right)$$

$$= 3.95 \times 10^{-4}\,A.$$

$$R_D = \frac{5-0.1}{3.95 \times 10^{-4}}$$

$$= 12.405\,k\Omega.$$

$$r_{ds} = \frac{V_{DS}}{I_D} = \frac{0.1 \times 10^3}{0.395}$$

$$= 253\,\Omega$$

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7). In the circuit in ex 6. if the value of R_D is doubled, find the approximate value of I_D & V_D.

Sol:- R_D is doubled

$$V_D = \frac{0.1}{2}$$

$$= 0.05\,V$$

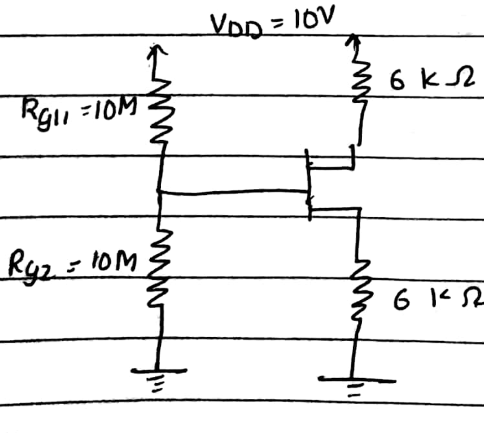
$$I_D = \frac{V_{DD} - V_D}{R_D}$$

$$= \frac{5 - 5.05}{24.8 \times 10^3}$$

$$= 0.199\ mA$$

$$\approx 0.2\ mA$$

8) Analyize the circuit shown below, determine the voltages at all nodes and current through all branches Let $V_t = 1V$, $k'_n(W/L) = 1\,mA/V^2$ Neglect channel length modulation effect



Sol - $I_G = 0$

$$I_1 = I_2 = \frac{V_{DD}}{20M} = \frac{10}{20M} = 0.5 \times 10^{-6}$$

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$V_g = 5V$

assuming Q is in saturation

$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$

$V_D = 10 - I_D(6k)$

$V_S = I_S(6k)$

$V_{GS} = V_g - V_S$

$= 5 - I_S(6k)$

$I_D = (10^{-3})(5 - I_S(6k) - 1)^2$

$I_D = 10^{-3}(16 + 36 I_D^2 k^2 - 48 I_D k)$

$I_D = 0.5 mA$

or $I_D = 0.88 mA$

$V_S = 5.34 V$

$V_{GS} = V_g - V_S = -0.34 X$

$\therefore$ rejecting $0.88 mA$

$\therefore I_D = 0.5 mA$

$V_S = 6 \times 0.5$

$= 3V$

$V_D = 10 - 6(0.5)$

$= 7V$

$V_{GS} = V_g - V_S$

$= 5 - 3 = 2$

$V_{GS} - V_t = 2 - 1 = 1$

$V_{DS} = 7 - 3 = 4 V$

$\therefore V_{DS} > V_{GS} - V_t$

assumption is correct

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9) For the above circuit, what is largest value of R_D that can have while the transistor remains in the saturation mode

Sol: At the edge of saturation

$$V_{DS} = V_{GS} - V_t$$

$$V_{DS(sat)} = 2 - 1 = 1\,V$$

The value of V_D to make $V_{DS} = 1V$

$$V_{DS} = V_D - V_S$$

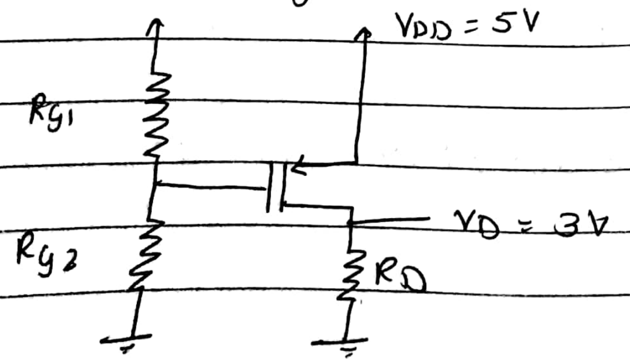
$$V_D = 4$$

$$R_{D(max)} = \frac{V_{DD} - V_D}{I_D}$$

$$= \frac{10-4}{0.5\,mA}$$

$$= 12\,k\Omega$$

10) Design the circuit shown below so that MOSFET operates in saturation region with $I_D = 0.5\,mA$, $V_D = 3V$. Let the enhancement type p-MOS have $V_t = -1V$, $k'_n(W/L) = 1\,mA/V^2$, $\lambda = 0$. What is the largest value that R_D that can have while MOSFET is in sat^n region



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Ans:-

$V_S = 5V$ $\quad V_D = 3V$

$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) V_{ov}^2$

$0.5 = \frac{1}{2} \times 10^{-3} \; V_{ov}^2$

$V_{ov} = -1V.$

$V_{ov} = V_{GS} - V_{tp}$

$V_{GS} = V_G - V_S.$

$V_G = -2 + 5$

$V_G = 3V.$

$R_D = \frac{V_D}{I_D} = \frac{3}{0.5} = 6\,k\Omega$

$V_G = \frac{V_{DD} \cdot R_{G12}}{R_{G11} + R_{G12}}$

$3 = \frac{5(R_{G12})}{R_{G11} + R_{G12}}$

$3R_{G11} + 3R_{G12} = 5R_{G12}$

$3R_{G11} = 2R_{G12}$

$R_{G11} = 2\,M\Omega$

$R_{G12} = 3\,M\Omega.$

$V_{GD} > V_t$

$V_G - V_D = -1$

$V_{D(max)} = 4V$

$R_{D(max)} = \frac{4}{0.5\,mA}$

$= 8\,k\Omega$

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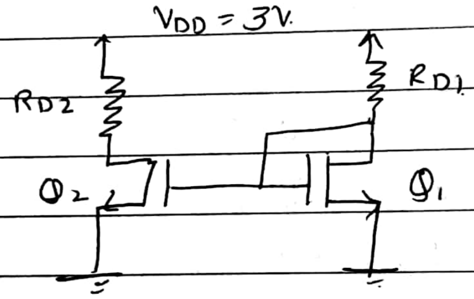
ii) Let Q_1 and Q_2 MOSFET, let $V_t = 0$
$\mu_n C_{ox} = 200\,\mu A/V^2$, $l_1 = l_2 = 0.8\,\mu m$,
$w_1 = 8\,\mu m$ and $\lambda = 0$

i) Find the value of R_{D1} to establish current of 0.2 mA in Q_1.

ii) Find W_2 and the value of R_{D2} so that Q_2 operates in sat^n region with $I_{D2} = 0.5$ mA and $V_{D2} = 1V$.



Sol: Since $V_{GD} = 0$ and

$V_{GD} < V_t$

Q_1 is in saturation region

$$I_{D1} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$0.2 \times 10^{-3} = \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{8}{0.8}\right)(V_{GS} - 0.6)^2$$

$$V_{GS} = 1.047\,V$$

$$R_{D1} = \frac{V_{DD} - V_{GS}}{I_D}$$

$$= \frac{3 - 1.047}{0.2 \times 10^{-3}}$$

$$= 9.765\,K\Omega$$

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ii) For Q_2

$$I_{D2} = 0.5\,mA$$

$$V_{D2} = 1V$$

$$R_{D2} = \frac{V_{DD} - V_{D2}}{I_{D2}}$$

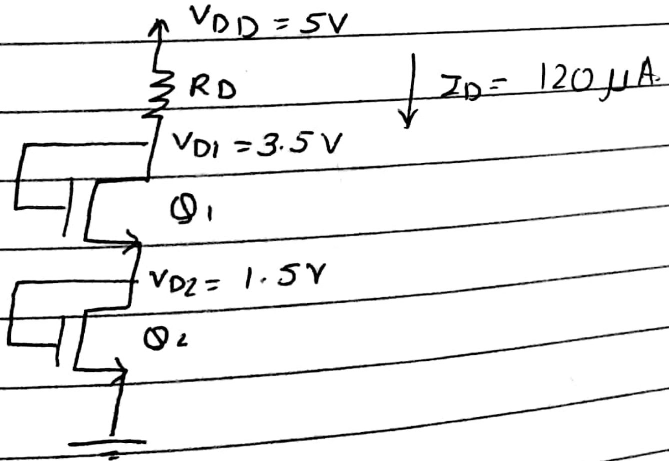
$$= \frac{3-1}{0.5\,mA}$$

$$R_{D2} = 4\,k\Omega$$

$$I_{D2} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$$W_2 = 20.6 \times 10^{-6}\,m.$$

2) N-mos transistor used in fig has $V_{DD} = 5V$, $V_t = 1V$, $\mu_n C_{ox} = 120\mu$, $\lambda = 0$, $l_1 = l_2 = 1\,\mu m$. Find the required values of gate width for each Q_1 and Q_2



$$V_{GS2} = V_G - V_S$$

$$= 1.5\,V$$

$$V_{GS1} = 3.5 - 1.5$$

$$= 2\,V$$

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$$R_D = \frac{V_{DD} - V_{D1}}{I_D}$$

$$= \frac{5 - 3.5}{120 \times 10^{-6}}$$

$$= 12.5\ k\Omega$$

$$I_{D1} = \frac{k'}{2}\left(\frac{W}{L}\right)(V_{GS1} - V_t)^2$$

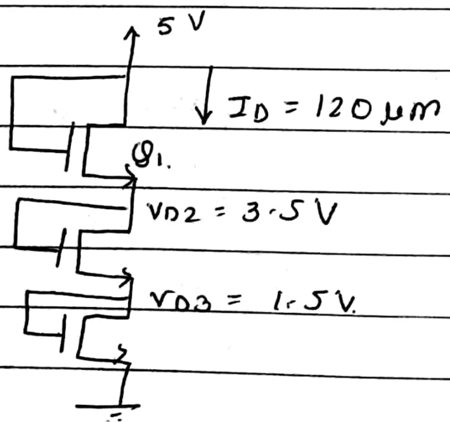
$$120 \times 10^{-6} = \frac{120 \times 10^{-6}}{2}\left(\frac{W_1}{10^{-6}}\right)(2-1)^2$$

$$W_1 = 2\ \mu m$$

$$20 \times 10^{-6} = \frac{1}{2} \times 120 \times 10^{-6}\left(\frac{W_2}{10^{-6}}\right)(1.5-1)^2$$

$$W_2 = 8\ \mu m.$$

13)



Sol:- $V_{GS}(3) = 1.5\ V$

$V_{GS}(2) = 3.5 - 1.5$

$= 2\ V.$

$V_{GS}(1) = 5 - 3.5$

$= 1.5V.$

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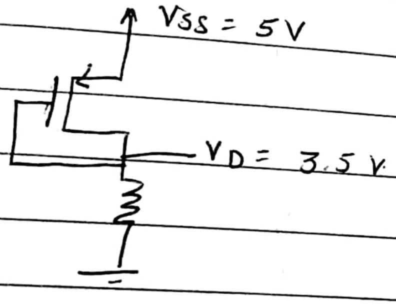
$W_1 = 8 \mu m$
$W_2 = 2 \mu m$
$W_3 = 8 \mu m$

(4) p-mos transistor shown in fig, has $V_t = -0.7V$, $\mu_p C_{ox} = 60 \mu A/V^2$, $l = 0.8 \mu m$ and $\lambda = 0$, Determine W, R in order to establish $I_D = 115 \mu A$ and $V_D = 3.5V$.



$V_{gs} = V_g - V_s$
$= -1.5V.$

$V_{DS} = V_D - V_S$
$= -1.5V.$

$R_D = \dfrac{V_D}{115 \times 10^{-6}}$

$= 30,434 \Omega$

MOS is in saturation region as $V_{gD} > V_t$

$I_D = \frac{1}{2} k' \left(\frac{W}{L}\right) (-2.2)^2$

$W = \dfrac{115 \times 10^{-6} \times 2 \times 0.8 \times 10^{-6}}{60 \times 10^{-6} \times (-2.2)^2}$

$= 6.336 \times 10^{-7}$

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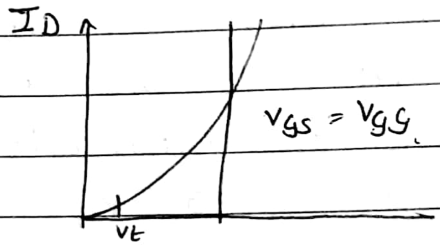
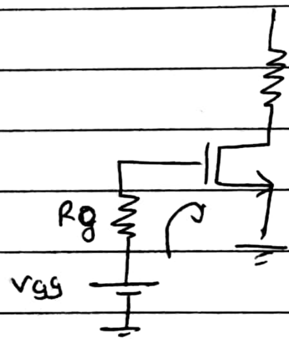
MOS characteristics

$V_{DS} = V_{DD} - I_D R_D$

load line equation



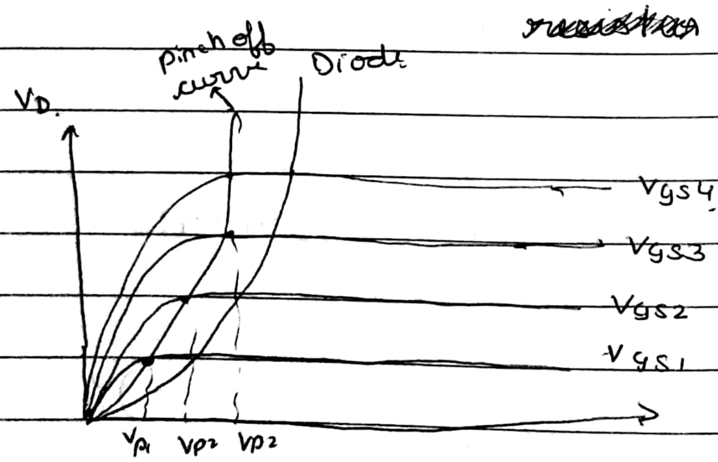


$V_{gg} - I_g R_g = V_{gs}$

$I_g = 0$

$V_{gs} = V_{gg}$

$R_g \rightarrow$ just act as ~~resistor~~ short circuit



$V_{DS} = V_{GS}$

$V_{GS} > V_R$

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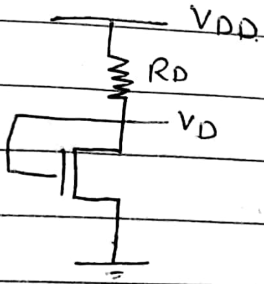
1) For n-mos transistor shown in below fig, $V_t = 0.8V$, $V_D = 1.6V$, $I_D = 0.5\ mA$, neglect channel length modulation, if V_D is adjusted to $2V$ by changing the value of R & V_{DD}, find the new value of I_D



$$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) \left(\frac{V_{GS} - V_t}{2}\right)^2 (1 + \lambda V_{DS})$$

$\lambda = 0$

$$I_D = \frac{1}{2} \times k'_n \left(\frac{W}{L}\right) \left(\frac{V_{GS} - V_t}{2}\right)^2$$

$\Rightarrow V_{GS1} = V_{DS1} = 1.6V$

$I_{D1} = 0.5\ mA$

$\Rightarrow V_{GS2} = V_{DS2} = 2V$

$I_{D2} = ?$

$$I_{D1} = \frac{1}{2} \times k'_n \left(\frac{W}{L}\right) \left(\frac{1.6 - 0.8}{2}\right)^2$$

$$\frac{0.5 \times 10^{-3} \times 2 \times 2}{(0.8)^2} = k'_n \left(\frac{W}{L}\right)$$

$$3 = k'_n \left(\frac{W}{L}\right)$$

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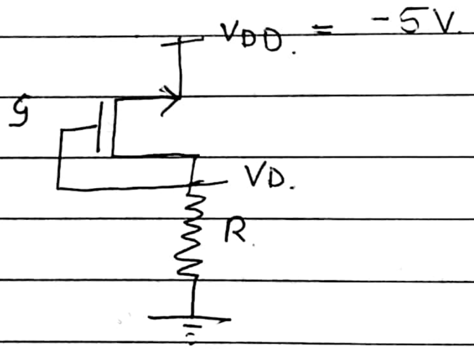
$$I_{D2} = \frac{1}{2} \times 1.56 \times 10^{-3} (2-0.8)^2$$

$= \cancel{2.25 \times 10^{-3}\ A}$

$= \cancel{2.25\ mA}$

$= 1.12\ mA$

2) The mos transistor shown in figure below has $V_t = 0.7V$, $k'_n = 60\ \mu A/V^2$, $l = 0.8\ \mu m$ and $\lambda = 0$ find the value of ω and R in order to establish $I_D = 115\ \mu A$ and $V_D = 3.5\ V$.



Sol:- Given :- $V_t = 0.7V$ $k'_n = 60\mu A/V^2$

$l = 0.8\ \mu m$

$I_D = 115\ \mu A$

$V_D = 3.5\ V$

$V_D = I_D R$

$3.5 = (115 \times 10^{-6}) R$

$$R = \frac{3.5}{115 \times 10^{-6}}$$

$= 30.434\ K\Omega$

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$)^2$

in

and $\lambda = 0$

R

115 μA

μA/V²

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$V_D = V_g = 3.5$ V

$V_S = -5$ V.

$V_{DS} = 3.5 + 5$

$= 8.5$ V.

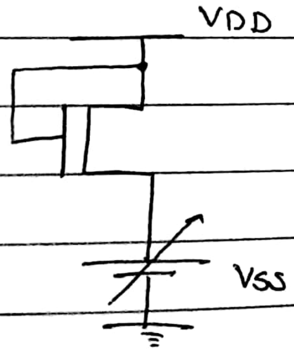
$V_{GS} = 8.5$ V

$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$

$W = \frac{115 \times 10^{-6} \times 2 \times 0.8 \times \cancel{10^{-6}}}{60 \times \cancel{10^{-6}} (8.5 - 0.7)^2}$

$= 5.04 \times 10^{-8}$ m.

) For the n-mos shown in the circuit below, $V_{th} > 0$ and V_{SS} is varied from 0 to V_{DD}. Neglecting channel length modulation, Represent the function of drain current wrt V_{SS}.



MOS is in saturation region

Assume $V_{DD} = 3.3$ V.

case 1 :- $V_{SS} = 0$

$V_D = V_{DD}$

$G = V_{DD}$

$V_S = V_{SS}$

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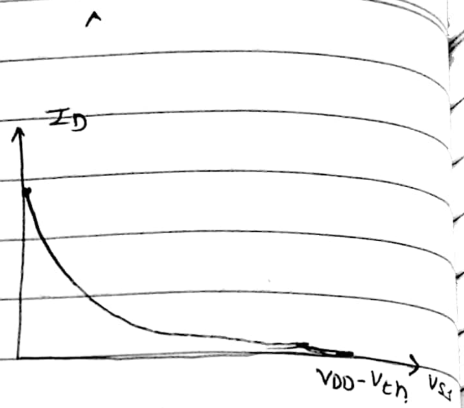
$V_S = 0$

$V_{DS} = V_{DD}$

$V_{gs} = V_{DD}$



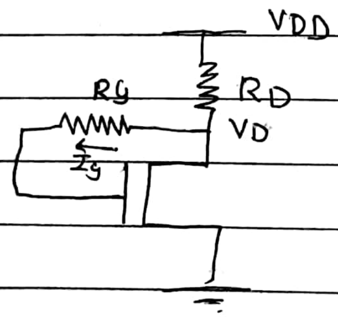
ii) case $V_{SS} = 0.5$

$V_{DS} = V_{DD} - V_{SS}$

$V_{gs} = V_{DD} - V_{SS}$

$I_D \downarrow$

4) It is required to design the circuit shown below to operate at a dc current of 0.5 mA. Assume $V_{DD} = 5V$, $k'_n(W/L) = 1 mA/V^2$, $V_t = 1V$ and $\lambda = 0$. 5)



Sol: $V_{DD} = 5V$

$$I_D = \frac{1}{2} k'_n\left(\frac{W}{L}\right)(V_{gs} - V_t)^2$$

$$\frac{0.5 \times 10^{-3} \times 2}{1 \times 10^{-3}} = (V_{gs} - V_t)^2$$

$$1 = (V_{gs} - 1)^2$$

$$2 = V_{gs}$$

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$V_g = 2V.$

$V_D = 2V.$

$I_g = 0$ because of high impedence

$V_{DD} - I_D R_D = V_D$

$$\frac{V_{DD} - V_D}{I_D} = R_D$$

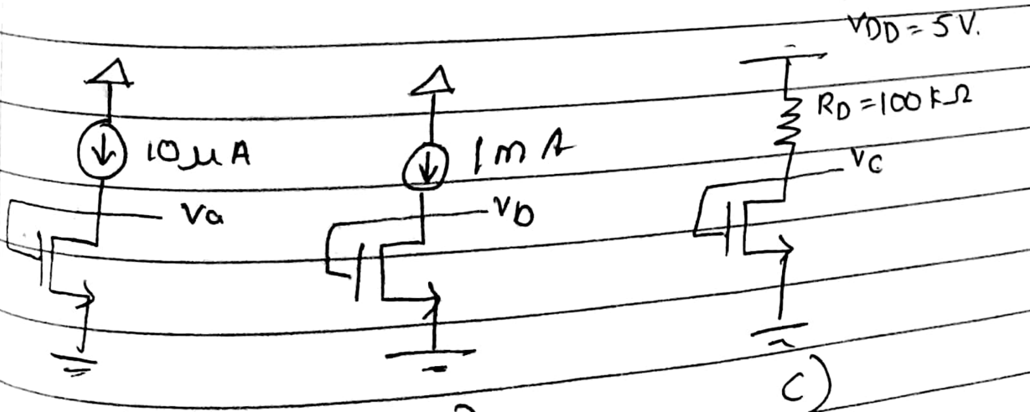
$$\frac{5-2}{0.5 \times 10^{-3}} = R_D$$

$$\frac{30 \times 10^{+3}}{5} = R_D$$

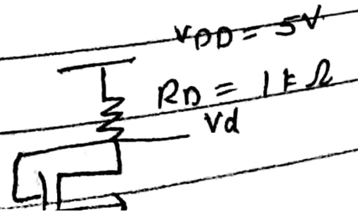
$R_D = 6\ k\Omega.$

5) For each of the following circuit find the labelled node voltages for all transistor. $K'n\left(\frac{W}{L}\right) = 0.4 mA/V^2$

$V_t = 1V$ and $\lambda = 0$



a) b) c)



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Sol: Figure a:-

$V_g = V_D = V_{GS}$

$I_D = \frac{1}{2} k'_n \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$

$10 \times 10^{-6} = \frac{1}{2} \times 0.4 \times 10^{-3} (V_a - V_t)^2$

$V_a = 1.2236\ V.$

⇒ Figure b.

$V_D = \sqrt{\frac{2 \times 1 \times 10^{\cancel{-3}}}{0.4 \times 10^{\cancel{-3}}}} + V_t$

$= 3.2360\ V.$

⇒ Figure c.

$V_{DD} - I_D R_D = V_D$

$V_{DD} - I_D R_D = V_{GS}$

$5 - I_D (100 \times 10^3) = V_{GS}$

$I_D = \frac{1}{2} \times 0.4 \times 10^{-3} (V_{GS} - V_t)^2$

$= \frac{1}{2} \times 0.4 \times 10^{-3} \left(5 - I_D (10^5) - 1\right)^2$

$= 0.2 \times 10^{-3} (4 - I_D (10^5))^2$

$= 0.2 \times 10^{-3} (16 + 10^{10} I_D^2 - 2(4) I_D 10^5)$

$I_D = 3.2 \times 10^{-3} + 0.2 \times 10^7 I_D^2 - 1.6 \times 10^2 I_D$

$3.2 \times 10^{-3} + 0.2 \times 10^7 I_D^2 - 2.61\ I_D = 0$

⇒

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$I_{D1} = 4.47 \times 10^{-5}$

$I_{D2} = 3.5 \times 10^{-5}$

$V_C = V_{DD} - I_D R_D$

$= 5 - (4.47) \times 10^{-5} (100 \times 10^3)$

$= 0.53$

$V_C = V_{DD} - 3.5$

$= 5 - 3.5$

$V_C = 1.5$

$V_g = 1.5$

$V_g > V_t$

$\therefore \boxed{V_g = 1.5\,V}$

$\Rightarrow V_{DD} - I_D R_D = V_{GS}$

$5 - I_D (10^3) = V_{GS}$

$I_D = \frac{1}{2} \times 0.4 \times 10^{-3} (5 - I_D(10^3) - 1)^2$

$= 0.2 \times 10^{-3} (4 - 10^3 I_D)^2$

$= 0.2 \times 10^{-3} (16 + 10^6 I_D^2 - 8 \times 10^3 I_D)$

$= 3.2 \times 10^{-3} + 0.2 \times 10^3 I_D^2 - 1.6 I_D$

$0 = 3.2 \times 10^{-3} + 0.2 \times 10^3 I_D^2 - 2.6 I_D$

$I_{D1} = 0.012$

$V_{C1} = -7$

~~I_{D2}~~

$V_{C2} =$

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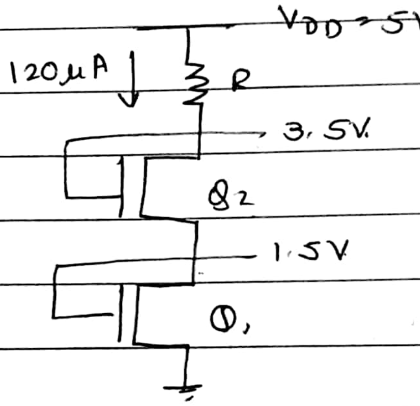
67 The n-mos transistor show below, $V_t = 1V$, $\mu_n C_{ox} = 120\ \mu A/V^2$, $l_1 = l_2 = 1\mu m$. Find the required value of gate widths for Q_1 and Q_2 and also find the value of R.



Sol:- $V_{G1} = V_{D1} = V_{GS1} = V_{DS1} = 1.5V.$

$V_{G2} = 3.5V = V_{D2}$

$V_{S2} = 1.5V$

$V_{GS2} = 2V.$

$$\frac{120\times10^{-6}}{1} = \frac{1}{2}\frac{(W/L)_2\ (V_{GS2}-V_t)^2}{\cancel{(W/L)_1}\ \cancel{(V_{GS1}-V_t)^2}} \times \mu_n C_{ox}$$

$$\cancel{120\times10^{-6}} = \frac{1}{2}\times\frac{W_1}{10^{-6}}\left(1.5-1\right)^2 \times \cancel{120\times10^{-6}}$$

$$\frac{2\times10^{-6}}{(0.5)^2} = W_1$$

$$W_1 = 8\ \mu m$$

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$$120\times\cancel{10^{-6}} = \frac{1}{2}\,\frac{W_2}{10^{-6}} \times 120\times\cancel{10^{-6}}\,(2-1)^2$$

$$2\,\mu m = W_2$$

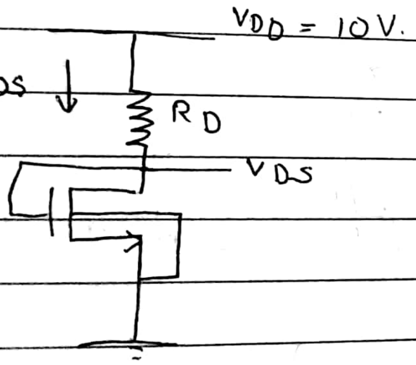
$$W_2 = 2\,\mu m$$

$$R = \frac{V_{DD}-V_D}{I_D} = \frac{5-3.5}{120\times10^{-6}}$$

$$R = 12.5\ K\Omega$$

7) Given a n-mos circuit, $V_{DD} = 10V$, $\mu_n C_{ox} = 10^{-4}\ A/V^2$, $V_t = 1V$. $I_{DS} = 0.5mA$

Evaluate V_{DS} and R_D.



Sol: Assume $W/L = 1$

$$I_D = \frac{1}{2}\times\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_t)^2$$

$$0.5\times10^{-3} = \frac{1}{2}\times 10^{-4}\times 1\,(V_{GS}-1)^2$$

$$\frac{10^{-3}}{10^{-4}} = (V_{GS}-1)^2$$

$$\sqrt{10} = V_{GS}-1$$

$$4.16 = V_{GS}$$

$$V_{GS} = 4.16\ V.$$

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$V_{DS} = 4.16\,V$

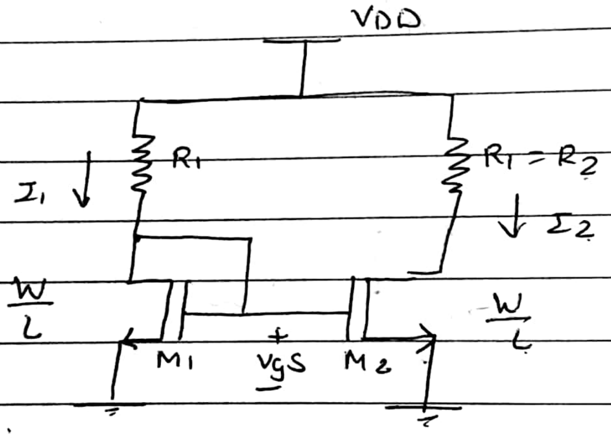
$V_{DD} - I_D R_D = V_{DS}$

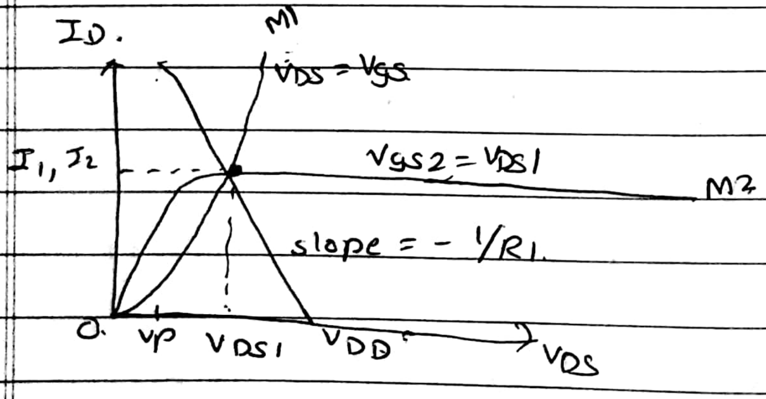
$10 - (0.5 \times 10^{-3}) R_D = 4.16$

$R_D = 11.68\ k\Omega$

Current Mirror Basics and Figures of merit

Current mirror





$V_{DS1} = V_{GS}$

$V_{DS2} = V_{DD} - I_2 R_2$

The entire circuit will have only one load line.

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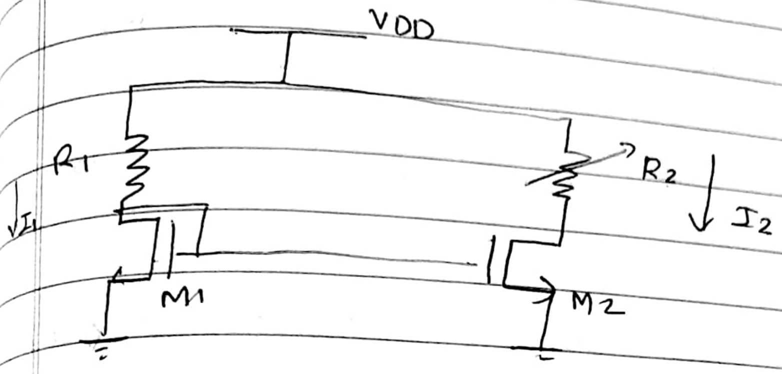
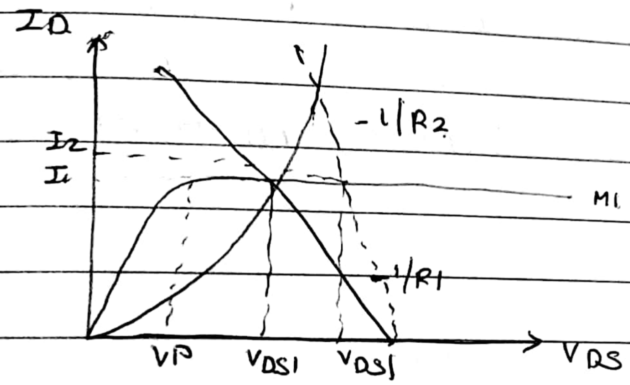
W/L is same

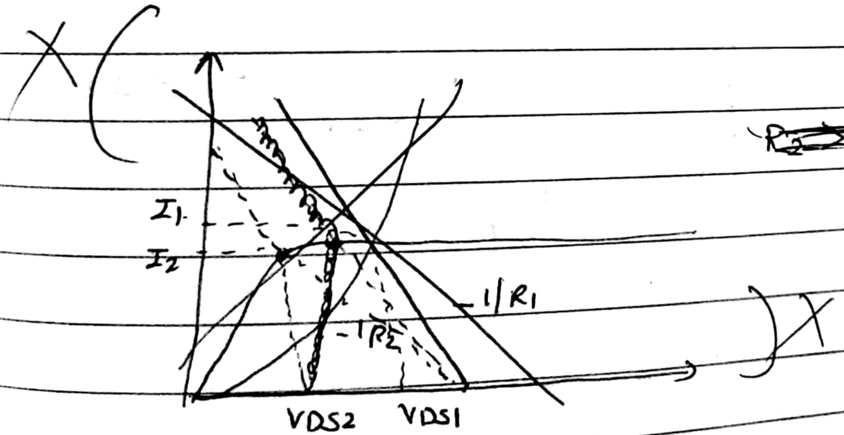
VGS, VDS is same

$I_1 = I_2$





$R_2 < R_1$



~~$R_2 > R_1$~~

If M2 is maintained in saturation region, there is slight change in I_2 because in saturation region, I_D doesn't depend on V_{DS}.

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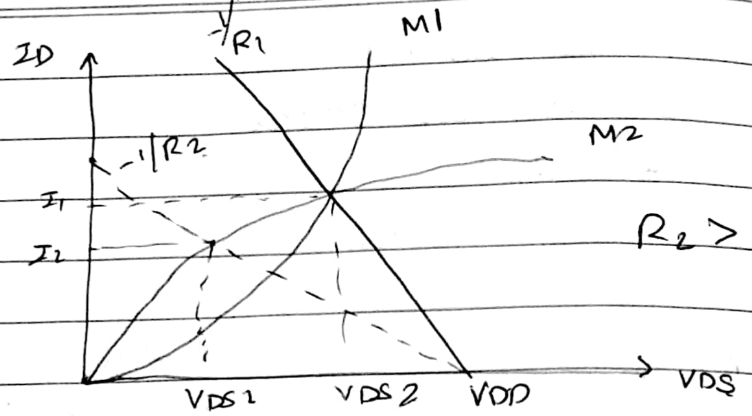
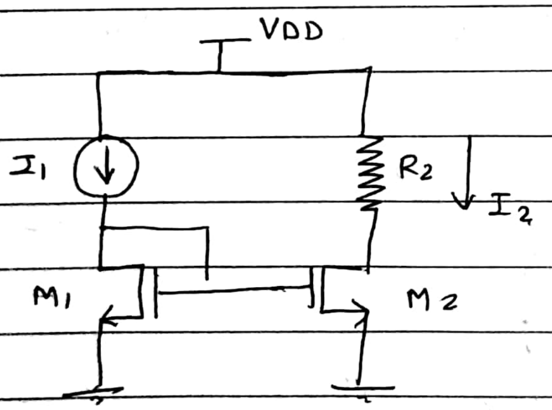


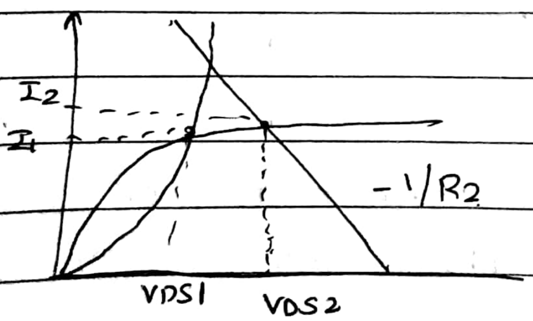
$R_2 > R_1$

Now MOS is in triode region, I_2 is different from I_1 (difference is large), as in triode region, current depends on VDS.

*



$I_1 \approx I_2$



$\therefore I_1 \approx I_2$

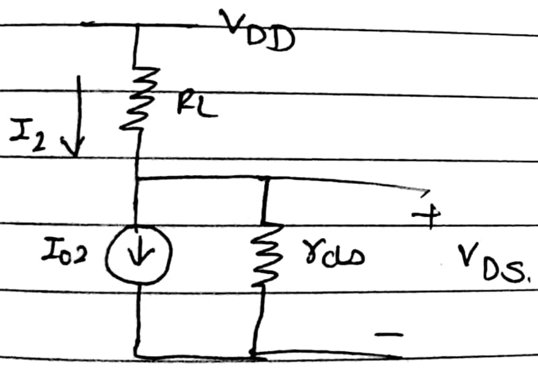
$I_1 = f(V_{GS1})$ — ①
$I_2 = f(V_{GS2})$ — ② $\Big\}$ non linear fun^n.
$V_{GS1} = V_{GS2}$

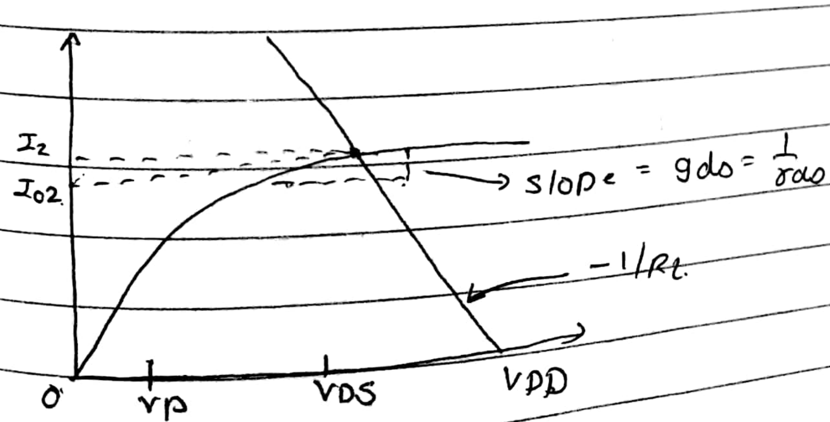
$I_2 = f(V_{GS1})$
$V_{GS1} = f^{-1}(I_1) \rightarrow$ inverse nonlinear fun^n.

$I_2 = f(f^{-1}(I_1))$
$\boxed{I_2 = I_1} \rightarrow$ linear fun^n

non-linearity is cancelled, only linearity is present.

current source model.





Because of rds
$I_2 \neq I_{02}$.

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Figure of merit :-

Ideal current source :- It is the current which does not ~~have~~ change with change in voltage drop across it.

High value of r_{ds}, make current source, ideal.

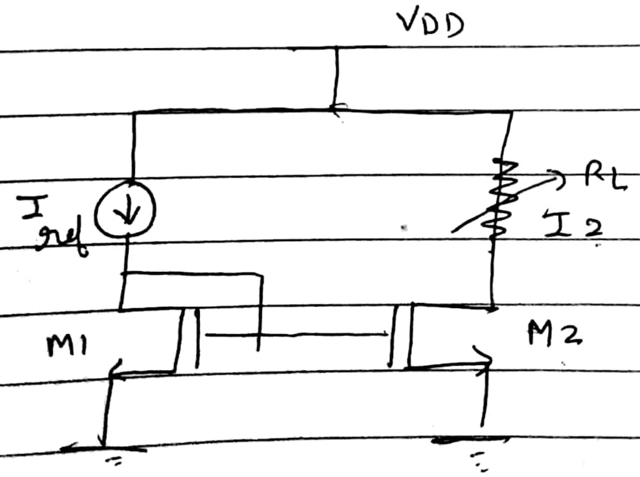
1) If R_o is very high, $I_o = I_{o1}$
2) Output swing $= 0.2 \sim 5.0\,V$.
(assuming $V_{GS1} = V_{GS2} = 0.7V$ (diode)

$\therefore V_{DS2} \geq V_{GS2} - V_t$

$\therefore V_{DS2(min)} = 0.2$

$V_{DS2(max)} = V_{DD} = 5V$)

Derivation of Mirror Ratio:



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case 1:- When the aspect ratio of M1 and M2 same $\left(\frac{W_1}{L_1} = \frac{W_2}{L_2}\right)$.

$$I_{ref} = \mu_n C_{ox} \left(\frac{W}{L}\right)_1 \left(\frac{V_{GS1} - V_t}{2}\right)^2 (1 + \lambda V_{DS1})$$

$$I_2 = \mu_n C_{ox} \left(\frac{W}{L}\right)_2 \left(\frac{V_{GS2} - V_t)^2 (1 + \lambda V_{DS2}}{2}\right)$$

MOSFETS are of the same family

∴ $\mu_n C_{ox}$ is same

(or MOSFET's are matched).

$V_{GS1} = V_{GS2}$

$$\frac{I_2}{I_{ref}} = \frac{(W/L)_2 (1 + \lambda V_{DS2})}{(W/L)_1 (1 + \lambda V_{DS1})}$$

∴ $\left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_1$

$$\frac{I_2}{I_{ref}} = \frac{1 + \lambda V_{DS2}}{1 + \lambda V_{DS1}}$$

a) If $\lambda = 0$

$\boxed{I_2 = I_{ref}}$

b) ~~case 2~~ When $V_{DS1} = V_{DS}$

$$\frac{I_2}{I_{ref}} = 1$$

case 2: When aspect ratios are not matched.

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$$\frac{I_2}{I_{ref}} = \frac{(W/L)_2 (1 + \lambda V_{DS2})}{(W/L)_1 (1 + \lambda V_{DS1})}$$

a) when $\lambda = 0$

$$\frac{I_2}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1}$$

b) when $V_{DS2} = V_{DS1}$

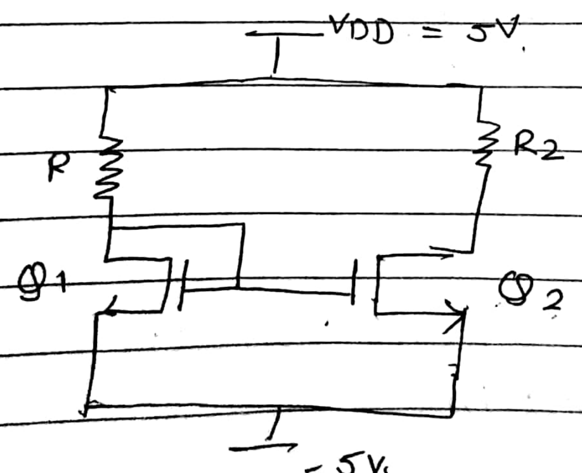
$$\frac{I_2}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1}.$$

Problems :-

1) In a basic current mirror circuit shown below, Q_1 & Q_2 has $V_t = 0.6V$. $\mu_n C_{ox}$ $200\mu A/V^2$, $l_1 = l_2 = 0.8\mu m$, $W_1 = 8\mu m$, $\lambda = 0$

a) Find the value of R required to establish a current of 0.2mA in Q_1 transistor.

b) Find W_2 and R_2 so that Q_2 operates in saturation region with $I_2 = 0.5mA$. $V_D = 1V$.



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a) $I_{D1} = 0.2\,mA$

$$I_{D1} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)_1 (V_{GS1} - V_t)^2$$

$$0.2 \times 10^{-3} = \frac{1}{2} \times 200 \times 10^{-6} \left(\frac{8}{0.8}\right)(V_{GS1} - 0.6)^2$$

$$0.2 = (V_{GS1} - 0.6)^2$$

$$V_{GS1} = 1.047\ V$$

$$V_{G1} - V_{S1} = 1.047$$

$$V_{G1} = 1.047 - 5$$

$$V_{G1} = \cancel{\ } -3.953\ V. = V_{D1}$$

$$V_{DD} - I_1 R = V_{G1}$$

$$5 - (0.2 \times 10^{-3}) R = \cancel{\ } -3.953$$

$$R = 44.76\ k\Omega$$

b) $V_{GS1} = 1.047\ V.$

$V_{GS2} = 1.047\ V.$

$$I_{D2} = \frac{1}{2} \times 200 \times \cancel{10^{-6}} \left(\frac{W_2}{0.8 \times \cancel{10^{-6}}}\right)(1.047 - 0.6)^2$$

$$\frac{0.5 \times 10^{-3} \times 2 \times 0.8}{200 \times (1.047 - 0.6)^2} = W_2$$

$$W_2 = 0.2001 \times 10^{-4}\ m$$

$$= 20\,\mu m.$$

$$V_{DD} - I_2 R_2 - V_{DS2} - V_{SS} = 0$$

$$5 - (0.5 \times 10^{-3}) R_2 - (V_D) = 0$$

$$= R_2 = 8\ k\Omega$$

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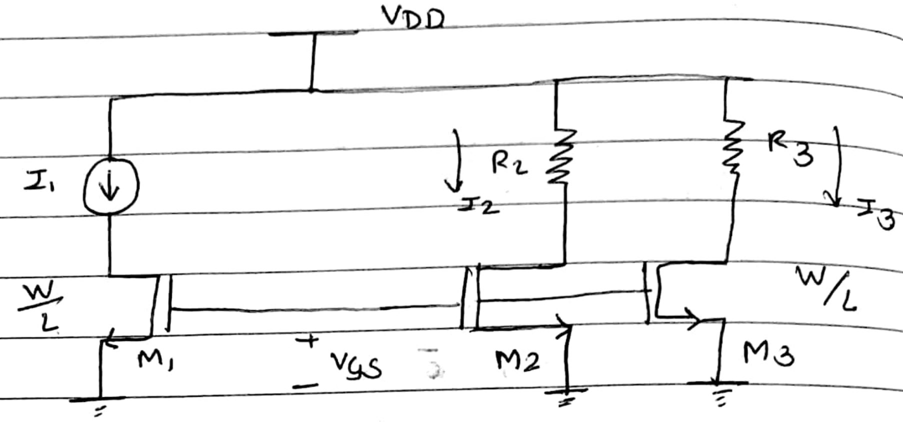
Current Mirror Applications

1) Multiple current mirrors



$V_{DS,1} = V_{GS}$ — V_{GS} of all 3 are same

$V_{DS,2} = V_{DD} - I_2 R_2$ — w/L of all 3 are same

$V_{DS,3} = V_{DD} - I_3 R_3$

$\Rightarrow I_2 \approx I_1 \qquad I_3 \approx I_1$

$\Rightarrow$ I_2 is not same as I_1 because V_{DS} of M_2 is not same as V_{DS} of M_1.

$\Rightarrow$ Ensure M_2 and M_3 are in sat^n.

2) Current mirror multiplier

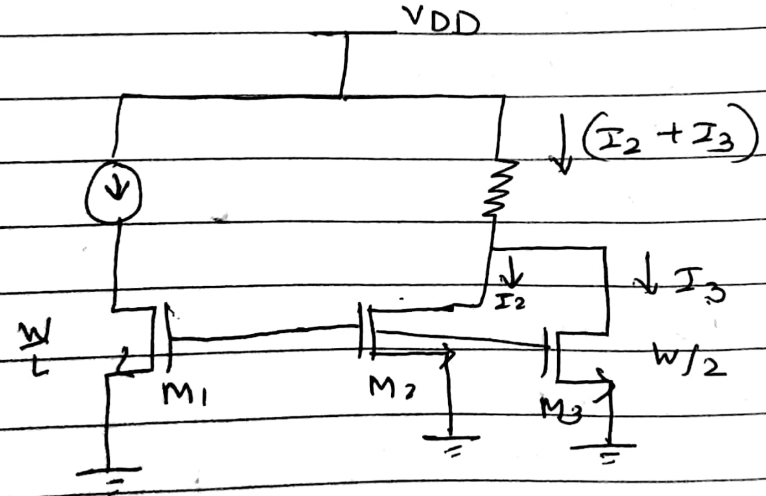


Fig 2:

In this $V_{DS2} = V_{DS3}$
(MOSFET, when considered wrt vertical field, it acts as capacitor). ∴ M_2, M_3 are like capacitor.

$V_{DS} = V_{GS}$

$V_{DS(2)} = V_{DD} - (I_2 + I_3)R_2$

$I_2 = I_3$, if M_2 and M_3 are of same size.
current through $R_2 = 2I_2$

$I_2 = I_1$

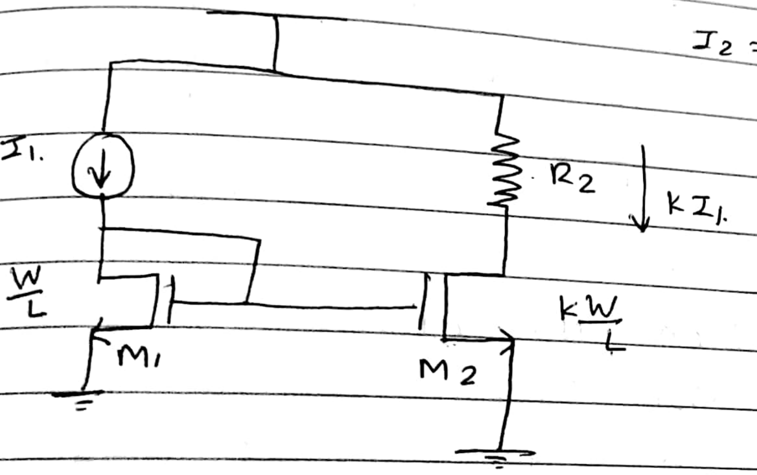


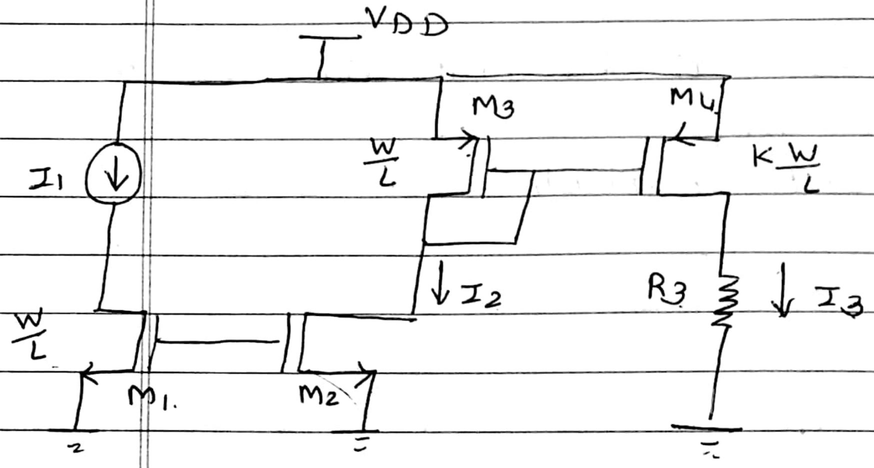
Fig 3

In fig 2, M_2, M_3 are parallel as gate are shorted, drains are shorted and source terminal is grounded

In fig 2, M_2, M_3 have same length but different width

In fig 3, the current is scaled
Relation between I_1 & kI_1 is linear

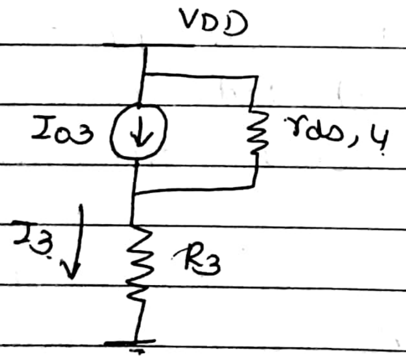
Current sink and current source

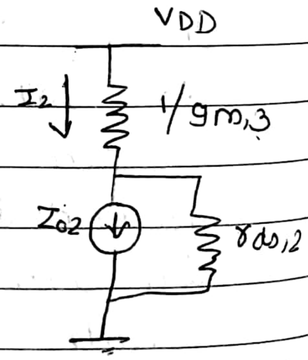


From the above figure

$V_{GS1} = V_{GS2}$ $\qquad I_1 = I_2$

$V_{GS3} = V_{GS4}$ $\qquad I_3 = k I_2$





current source $\qquad$ current sink

M3 is p-mos

$V_{SD3} = 0.7V$ which is very small

∴ M2 is in saturation

∴ M2 is mirror version of M1

current source → p mos (load is connected to ground)

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current sink → n mos, (if mosfet is connected to ground) load is connected to VDD.

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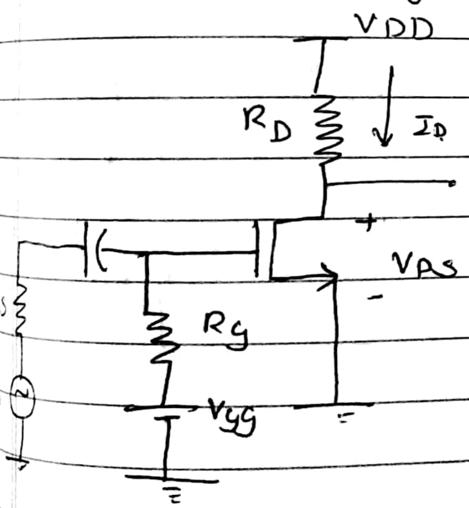
Now I_2 is a current source
M_4 is a current source.

⇒ If M_1 and M_2 are of same size
∴ $I_1 = I_2$.

One is current source i,e M_4, as it is droping current from VDD and other is current sink.
In both the circuit, the current is in downward direction

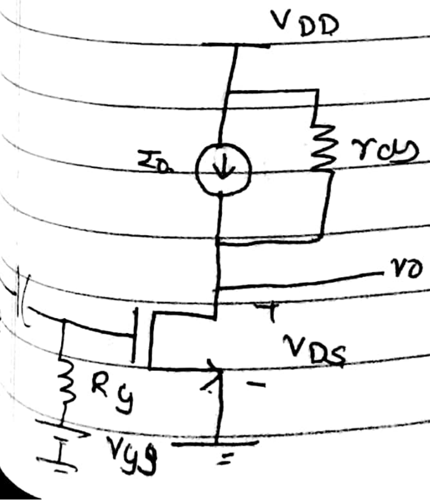
Active load
(application of current mirror)



R_D is restricting factor

$V_{DD} - I_D R_D\uparrow = V_{DS}\downarrow$

$A = -g_m R_D \uparrow$



The gain will be boosted, if R_D will be replaced by current source and mosfet will be in saturation current mirror as active load

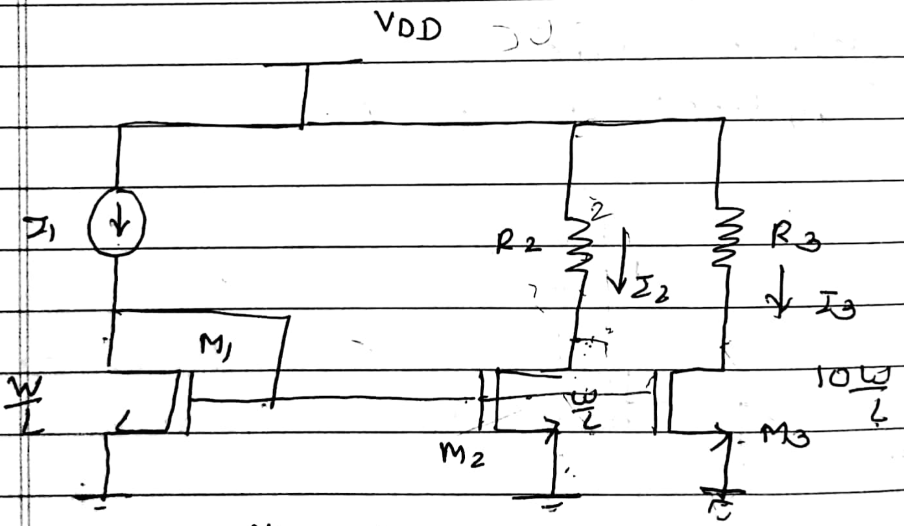
→ Diode connected MOS is fed from a well stabilized current reference

→ The stability of mirrored currents depends upon stability of Iref

→ Active load defines Q point

Numericals

1)



given $V_{DD} = 5V$

$I_1 = 10\mu A$ $R_2 = 200\ k\Omega$

i) compute voltage accross M_2

ii) $V_{GS} \approx 1V$, $r_{ds} = 2M\Omega$, I_2 ?

iii) Compute the value of R_3 for which current in M_3 exactly = $100\ \mu A$

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4. i) Assume, $I_1 = I_2$

$I_1 = 10\,\mu A$ $\quad$ $I_2 = 10\,\mu A$ (on the basis of w/L)

Voltage drop across $R_2 = 2V$

$\therefore V_{D2} = 3V$.

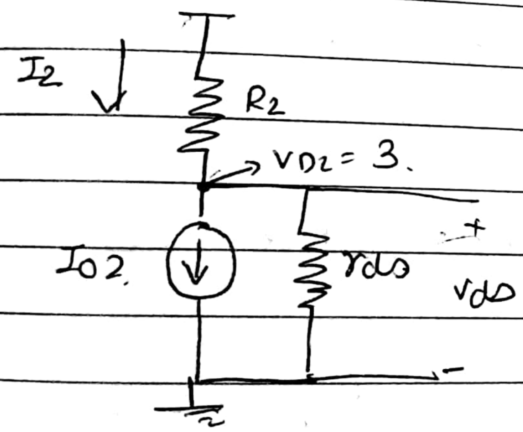
$\therefore M_2$ is in saturation region

$\therefore$ our assumption is correct

voltage across M_2 is 3V.

) $V_{GS} = 2V$.

$$I_{D2} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)(V_{GS} - V_t)^2 ($$



current across rds $= \frac{3}{r_{ds}} = \frac{3}{2} = 1.5\,\mu A$

$\therefore I_2 = 10 + 1.5$
$= 11.5\,\mu A$

$I_3 = 100\,\mu A$ $\quad$ For exact mirroring

$V_{DS3} = V_{DS1}$.

$$R_3 = \frac{V_{DD} - V_{DS3}}{I_3} = \frac{5-1}{100 \times 10^{-6}} = 4 \times 10^4\,\Omega \approx 40\,k\Omega$$

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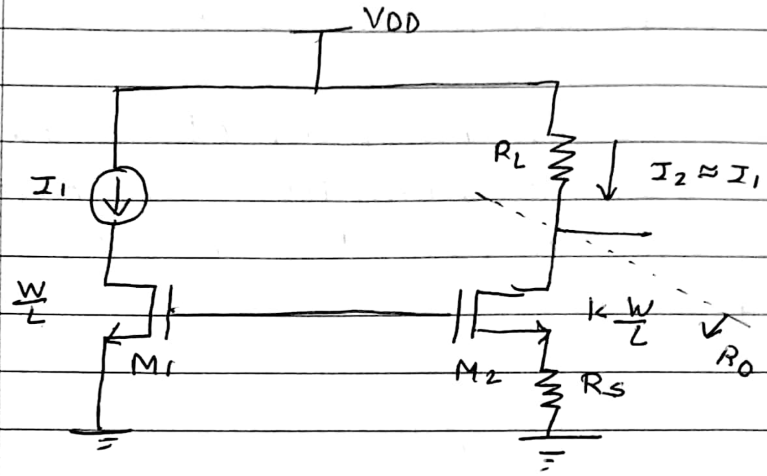
Current mirror Topologies

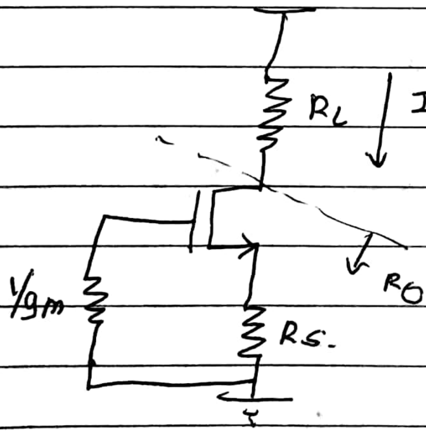
1. Widlar current mirrors



$V_{GS1} = V_{GS,2} + I_2 R.$

$\therefore V_{GS1} > V_{GS2} \quad \therefore I_2 < I_1$

Rs is degenerative resi



$R_O = r_{ds} + R_S + g_m r_{ds} R_S$

$R_2\uparrow \to I_2R_2\uparrow \to V_{DS2}\uparrow \to I_2\downarrow \to I_2R_2\downarrow \to V_{GS2}\uparrow \to I_2\uparrow$

$\therefore$ Rs is a degenerative resistor.

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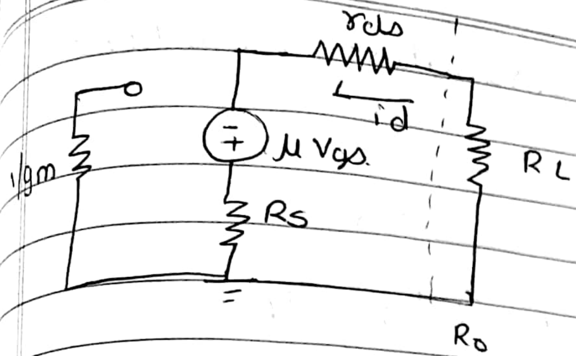


small signal model of M_2

Remove R_L, connect a voltage source

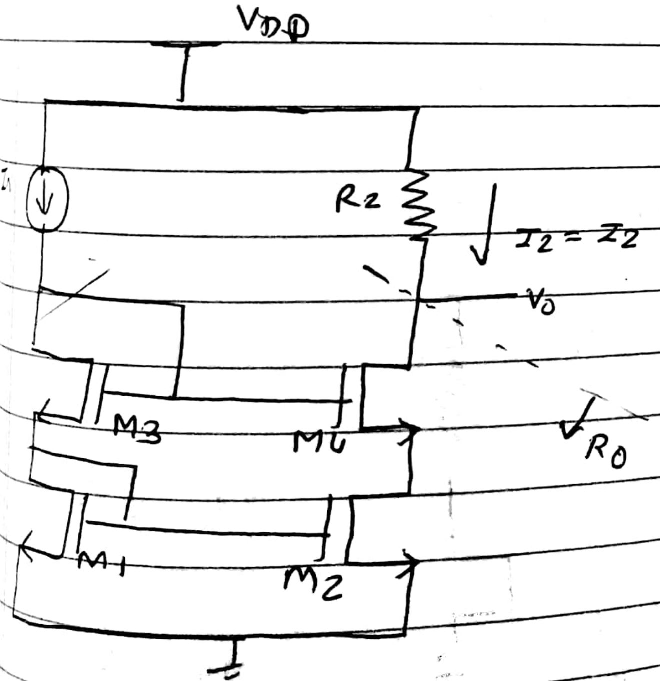
$V_{gs} = -i_d R_s$

$$i_d = \frac{V_0 - \mu i_d R_s}{r_{ds} + R_s}$$

$$i_d(r_{ds} + R_s + \mu R_s) = V_0$$

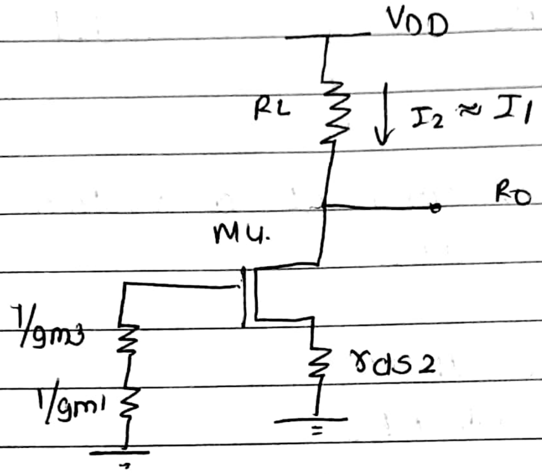
$$R_0 = r_{ds} + R_s + \mu R_s$$

ii) Cascode current mirror



$M_1 M_2$ are current mirror, whose role is used to provide source degenerative resistance

Model.



$R_o = r_{ds4} + r_{ds2} + g_{m4} r_{ds4} \cdot r_{ds}$

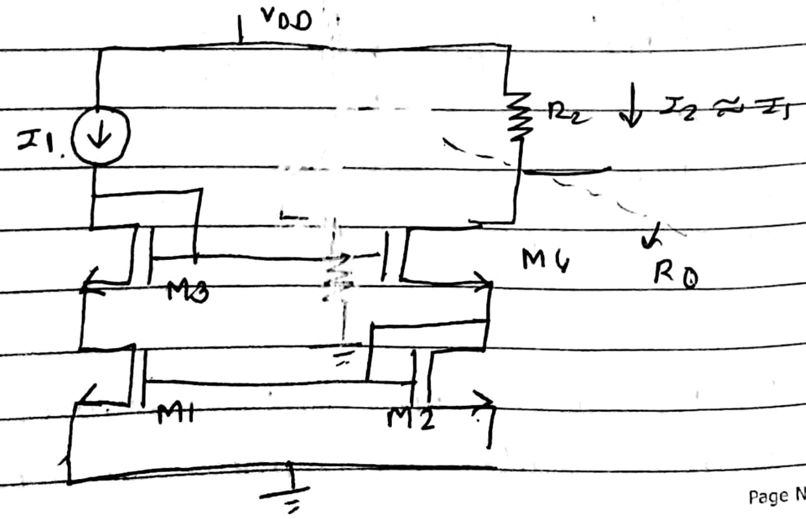
$R_o = (2+\mu) r_{ds}$

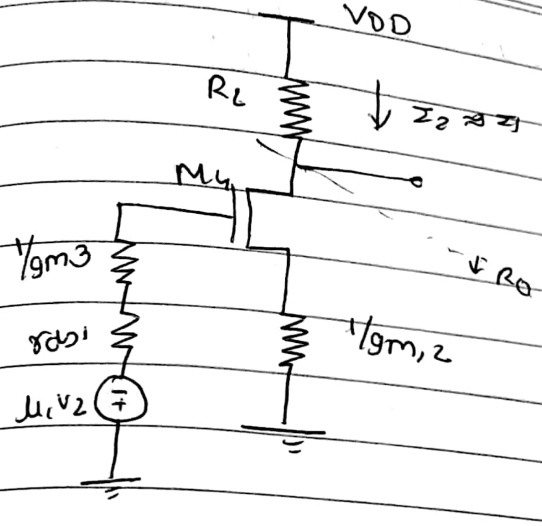
$V_{gs1} = V_{gs} = 0.7V$

$V_{g3} = V_{g4} = 1.4V$

Drop across $M_4 = 0.7V$

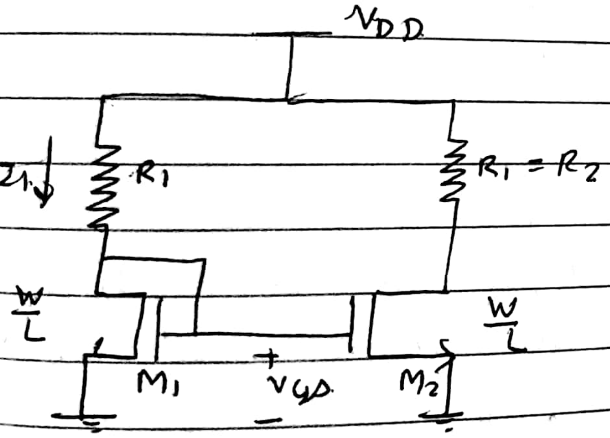
Wilson current mirror





Current Mirror Basics & Figures of merit :-

Current mirror



M1 is diode connected device

$V_{DS1} = V_{GS1}$

$V_{GS1} = V_{GS2}$

case 1 :-

$R_1 = R2$

$V_{DS1} = V_{DD} - I_1 R_1$

$V_{DS2} = V_{DD} - I_2 R_2$

$V_{DS2} = V_{DS1} \Rightarrow I_1 = I_2$

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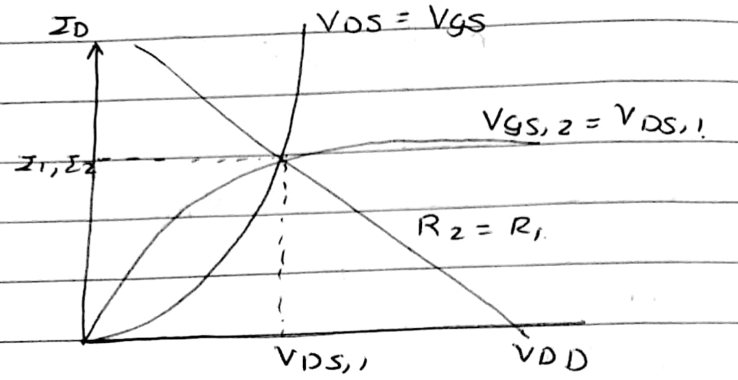
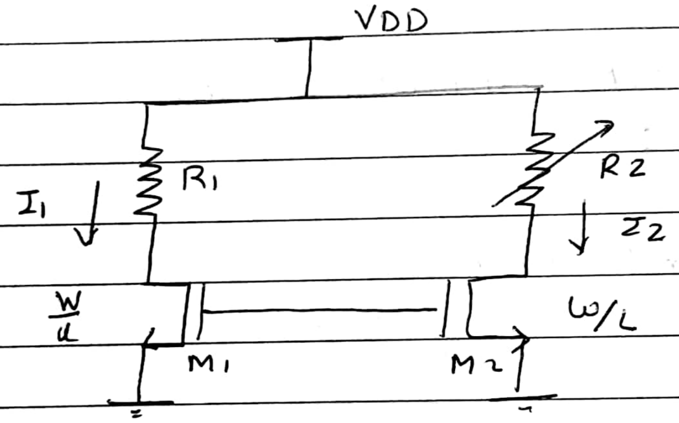
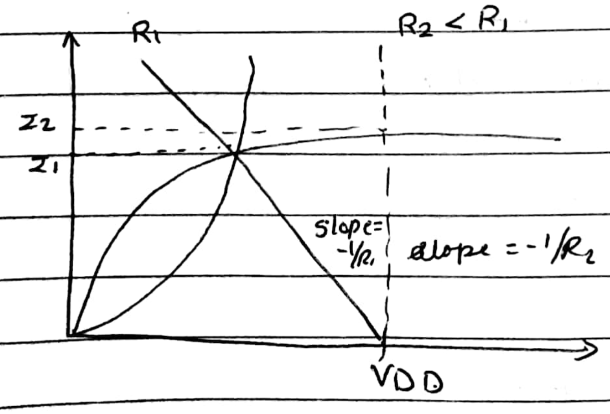
$\therefore$ I_2 will be mirrored value of I_1



case 2 :-



$\rightarrow$ When $R_1 \neq R_2$ and $R_2 < R_1$
The slope of load line of M_2 is larger than that of M_1.



The device is still in saturation region and $I_1 \approx I_2$

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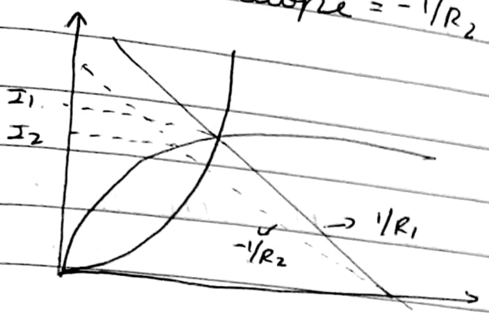
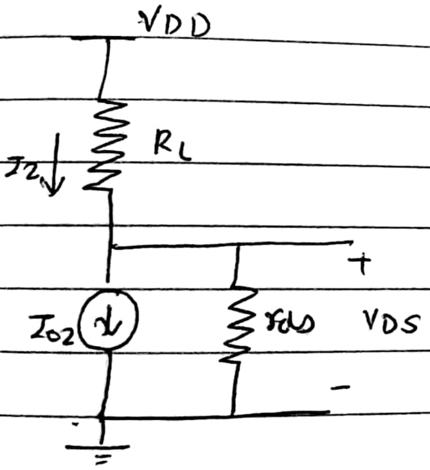
when $R2 > R1$, slope $= -1/R_2$ decreases



In this case, the mosfet will be saturation region.

Current source Model



The characteristic line in saturation region has a slope $1/r_{ds}$

$\therefore I_2 \neq I_{O2}$

$$I_2 = I_{O2} + \frac{V_{ds}}{r_{ds}}$$

Figures of merit
The current source has 2 performance parameters
→ The R_O which accounts for the load current variation with R_L

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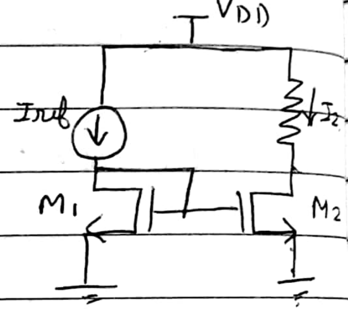
- The o/p voltage during

Q) Calculate the o/p current I_o, for the basic current mirror, if $k'n = 250\mu A/V^2$, $V_t = 1V$, $V_{DD} = 10V$, $\lambda = 0.0133/V$, $I_{ref} = 150\mu A$, $V_{DS} = 10V$.

Sol:-



~~$V_{DS} = V_{GS1} = V_{GS2} = 10V$.~~

~~$I_{ref} = 150\mu A$~~

$\cancel{V_{DS2}} = \cancel{V_{GS2} - V_t}$

$= \cancel{10 - 1}$ $\quad V_{DS2} = 10V$

$= \cancel{9V}$ (min) $\quad$ assume $\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2$

$$\frac{I_D}{I_{ref}} = \frac{\cancel{(W/L)_2}(1 + \lambda V_{DS2})}{\cancel{(W/L)_1}(1 + \lambda V_{DS1})}$$

$$\frac{I_O}{I_{ref}} = \frac{1 + \lambda V_{DS2}}{1 + \lambda V_{DS1}}$$

$$I_{ref} = \frac{1}{2} \times 250 \times 10^{-6} (V_{GS_1} - 1)^2$$

[$(1+\lambda V_{DS})$ is not considered as it's very small]

$$\sqrt{\frac{150 \times 2}{250}} = V_{GS} - 1$$

$$V_{GS1} = 2.095\ V. = V_{DS1}$$

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$$I_o = (150\times10^{-6})\,\frac{(1 + (0.0133)(10))}{1 + (0.0133)(2.095)}$$

$$I_o = 165.34\ \mu A$$

Q) calculate the mirror ratio for a mos current mirror.

a) $\lambda = 0$

b) $\lambda = 0.02\ V^{-1}$

given $V_t = 1V$, $k'_n = 25\ \mu A/V^2$,
$I_{ref} = 50\ \mu A$, $V_{DS2} = 10\ V$.

(i) a) aspect ratio of $M_2 = 25/1$
aspect ratio of $M_1 = 3/1$

(ii) a) aspect ratio of $M_2 = 2/1$
aspect ratio of $M_1 = 5/1$.

a) considering $\lambda = 0$

i) $(W/L)_2 = 25/1$ & $(W/L)_1 = 3/1$

$$\frac{I_o}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1} = \frac{25/1}{3/1} = \frac{25}{3} = 8.33$$

ii) $(W/L)_2 = 2/1$ & $(W/L)_1 = 5/1$

$$\frac{I_o}{I_{ref}} = \frac{2/1}{5/1} = \frac{2}{5} = 0.4$$

b) considering $\lambda = 0.02\ V^{-1}$.

$I_{ref} = 50\ \mu A$

$50\times10^{-6} = \frac{1}{2}\times 25\times10^{-6}\times\frac{3}{1}(V_{GS} - V_t)^2$

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$V_{GS1} = 2.15\,V = V_{DS1}$

$$\frac{I_o}{I_{ref}} = \frac{(W/L)_2}{(W/L)_1} \frac{(1+\lambda V_{DS2})}{(1+\lambda V_{DS1})}$$

$$= \frac{(25/1)}{(3/1)} \frac{(1+(0.02)(10))}{1+(0.02)(2.15)}$$

$$= 9.58$$

ii) $I_{ref} = \frac{1}{2} \times 250 \times 10^{-6} \times \frac{5}{1} (V_{GS1} - V_t)^2$

$0.89 = V_{GS1} - V_t$

$V_{GS1} = 1.89\ V.$

$$\frac{I_o}{I_{ref}} = \frac{(2/1)}{(5/1)} \frac{(1+(0.02)(10))}{(1+(0.02)(2.89))}$$

$$= 0.4628$$

Q) Calculate the mirror ratio when $V_{GS} = 2V$, $V_A = 50\,V$, $V_{DS2} = V$.

Q) Calculate the mirror ratio when $V_{GS} = 2.5V$, $\lambda = 0.01\,/V$, $V_{DS_2} = 10V$ & $(W/L)_2 = 20$ & $(W/L)_1 = 10$.

$i_g = 0$

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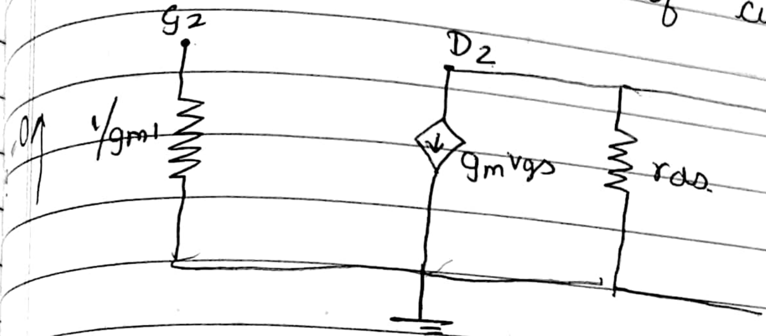
Current Mirror Topologies

small signal model of current mirror

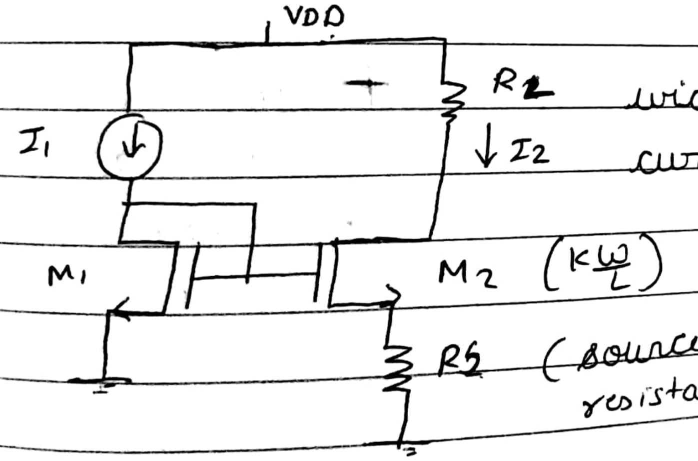


drop across $1/g_{m1} = 0$

$\therefore V_S = 0$

$\therefore V_{GS} = 0$

$\therefore$ output resistance $= r_{ds}$



widlar current mirror

$V_{GS1} = V_{GS2} + I_2 R_S$

$V_{GS2} = (V_{GS1} - I_2 R_S)$

$\therefore V_{GS2} < V_{GS1}$

$I_2 < I_1$

Inorder to make I_2 same as I_1

$(W/L)_2 = K(W/L)_2$

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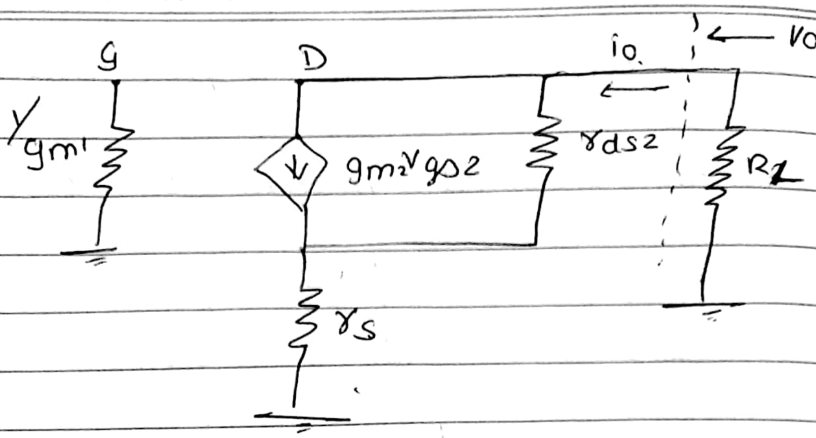

$$V_o - i_o r_{ds2} + g_m v_{gs2} r_{ds2} - i_o r_s = 0$$

$$i_o = \frac{+g_m v_{gs2} r_{ds2} + V_o}{r_{ds2} + r_s}$$

$$i_o = \frac{+g_m v_{gs2} \cdot r_{ds2} + V_o}{r_{ds} + r_s}$$

$$i_o = \frac{V_o + g_m r_{ds2}(V_{g2} - V_{s2})}{r_{ds} + r_s}$$

$$= \frac{V_o + g_m r_{ds2}(-V_{s2})}{r_{ds} + r_s}$$

$$= \frac{V_o - g_m r_{ds} I_o r_s}{r_{ds} + r_s}$$

$$i_o\left(\frac{r_{ds} + r_s + g_m r_{ds} r_s}{\cancel{r_{ds} + r_s}}\right) = \frac{V_o}{\cancel{r_{ds} + r_s}}$$

$$\frac{V_o}{i_o} = \frac{r_{ds} + r_s + g_m r_{ds} r_s}{\cancel{r_{ds} + r_s}}$$

output resistance is increased ~~because~~, inorder to make the mosfet to behave like ideal current source.

cascode][ ][in series
][one above other.

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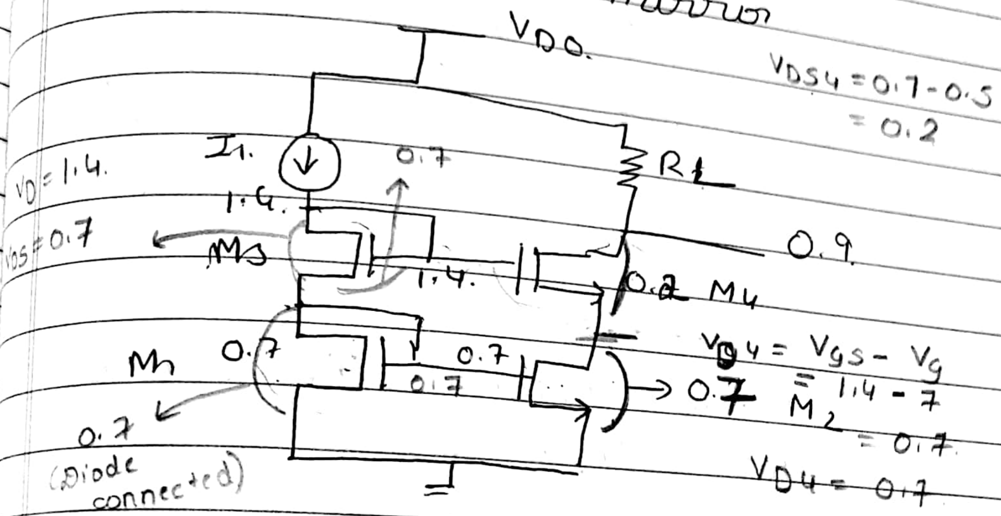
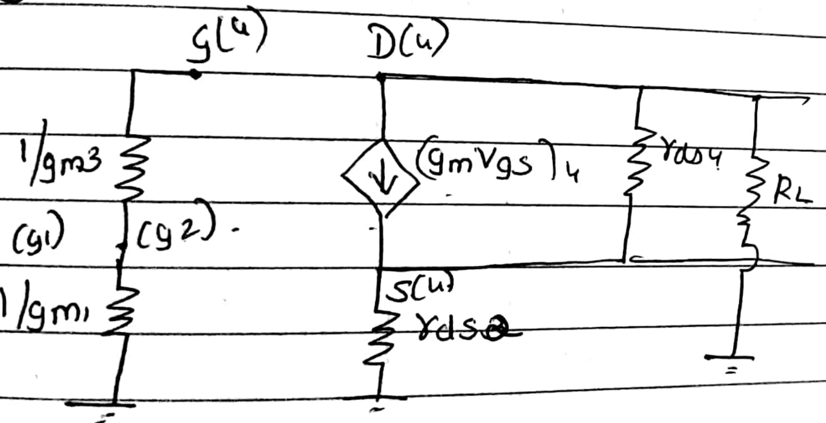
$V_{min} = V_{DS2(min)} + i_o R_s$

but the swing decreased.

Cascode current mirror



model



Applying KVL

$$V_o - i_o r_{ds4} + (g_m v_{gs})_4 r_{ds4} - i_o r_{ds2} = 0$$

$$\frac{V_o + (g_m V_{gs})_4 r_{ds4}}{r_{ds4} + r_{ds2}} = i_o$$

$$\frac{V_o}{i_o} = i_o(r_{ds4} + r_{ds2}) - g_m V_{gs4} r_{ds4}$$

$$V_o = i_o(r_{ds4} + r_{ds2}) + g_m(i_o r_{ds2}) r_{ds4}$$

$$\frac{V_o}{i_o} = r_{ds4} + r_{ds2} + g_m r_{ds2} r_{ds4}$$

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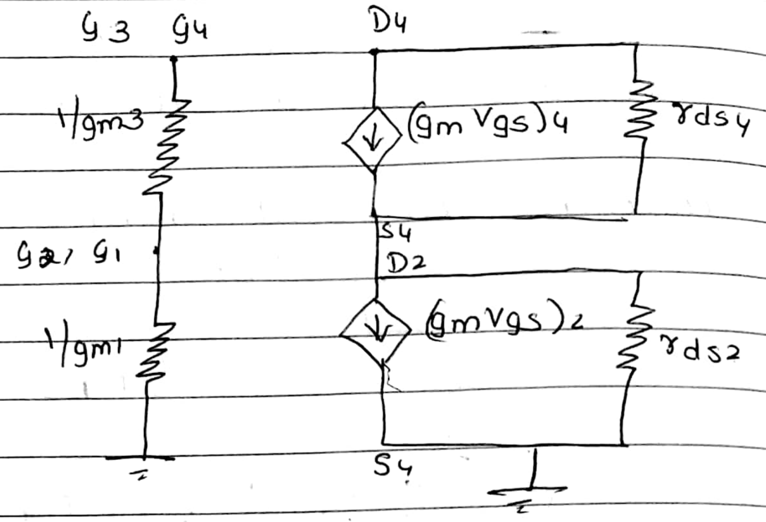
$\Rightarrow r_{ds4} = r_{ds2}$

$\Rightarrow 2r_{ds} + g_m r_{ds}^2$

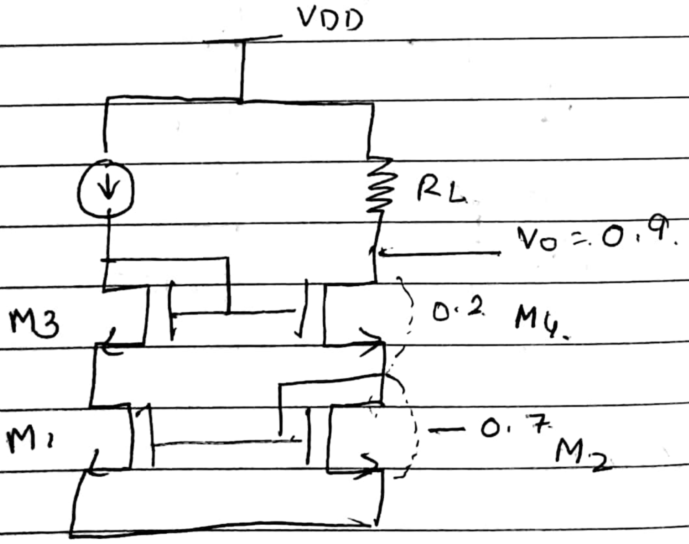
$\Rightarrow r_{ds}(2 + g_m r_{ds}) = r_{ds}(2+\mu)$

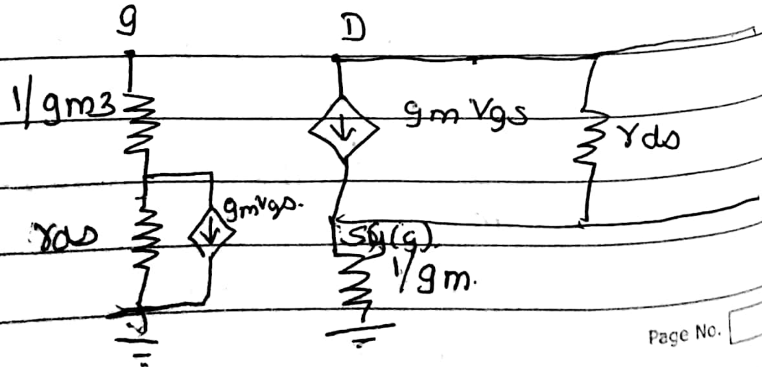


$v_{gs2} = 0$

M_2 is acting like source degenrating resistor.

→ Wilson current mirror :





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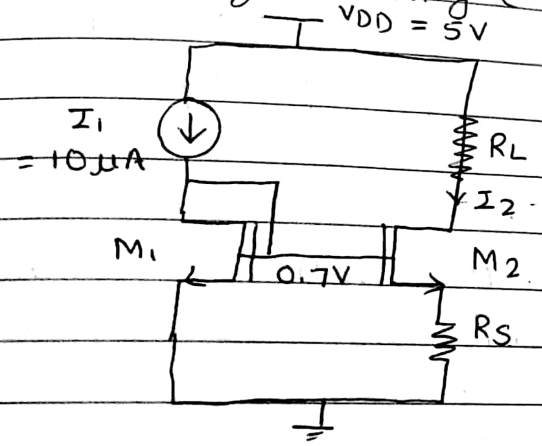
$R_o = (2+\mu) r_{ds}$

$V_o = 0.9 - V_{DD}$

1) For the widlar current mirror, $V_{DD} = 5V$, $V_{GS1} = 0.7V$, $V_{GS2} = 0.4V$, $I_1 = I_2 = 10\mu A$, $V_t = 0.2V$. Determine the value of R_S, range of R_L & output voltage swing ($V_{DS min} = 0.2V$)



Draw a neat ckt diagram with labelled values.

sol. Given :- $V_{GS1} = 0.7V$ $\quad V_{DD} = 5V$

$V_{DS1} = 0.7V$.

$V_{GS2} = 0.4V$.

$(V_{DS\,min})_2 = 0.2V$.

$V_{GS1} = V_{GS2} + I_2 R_S$

$R_S = \dfrac{0.7 - 0.4}{10 \times 10^{-6}}$

$= 0.3 \times 10^5$

$= 30\ k\Omega$

$I_2 R_S = 10 \times 10^{-6} \times 30 \times 10^3 = 0.3$

$(V_o)_{min} = 0.2 + 0.3 = 0.5$

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$$V_{DD} - I_2 R_L = V_O$$

$$V_{DD} - (V_O)_{min} = I_2 R_L$$

$$(R_L)_{max} = \frac{5 - 0.5}{10 \times 10^{-6}}$$

$$= 4.5 \times 10^5$$

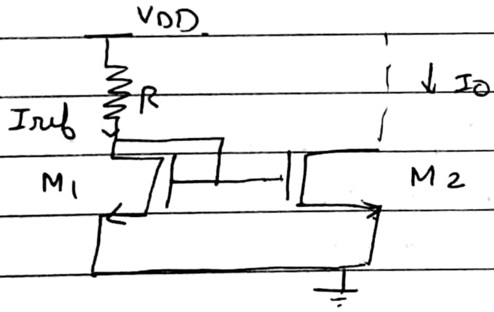
$$= 450\ k\Omega$$

$$(V_O)_{max} = V_{DD} = 5\ V.$$

$$\therefore (R_L)_{min} = 0\ \Omega$$

Range of R_L $0\,\Omega$ to $450\ k\Omega$ for range of o/p voltage $0.5 - 5V$

2) Design the foll^n CM shown in below fig. $I_O = 100\,\mu A$, $V_{DD} = 3V$ $(\lambda = 0)$, $V_t = 1V$, $k_n'(W/L) = 90\,mA/V^2$



Sol. Given $I_O = 100\,\mu A$ $V_{DD} = 3V$.

$$V_t = 1V$$

$$I_O = \frac{1}{2} k_n' \left(\frac{W}{L}\right) (V_{gs} - V_t)^2$$

$$\frac{100 \times 10^{-6} \times 2}{90 \times 10^{-3}} = (V_{gs} - V_t)^2$$

$$2.22 \times 10^{-3} = (V_{gs} - V_t)^2$$

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$(V_{GS})_2 - V_t = 0.047$

$(V_{GS})_2 = 1.047\text{ V}$

$\therefore I_0 = I_{ref} = 100\,\mu A$

$(V_{DS})_1 = 1.047\text{ V}$

$$\therefore \frac{V_{DD} - (V_{DS})_1}{I_{ref}} = R$$

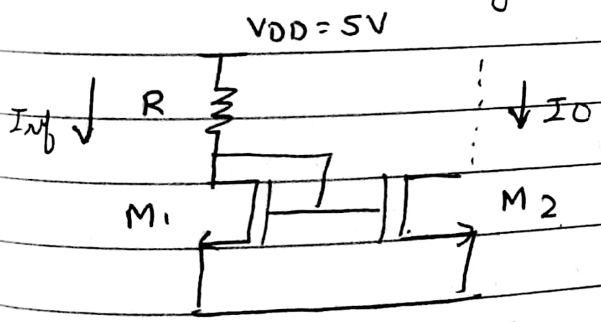
$$\frac{3 - 1.047}{100\times10^{-6}} = R$$

$R = 19.53\text{ k}\Omega$

3) For ckt shown below $V_{DD} = 5V$, $V_t = 1V$, $k'_n = 20\,\mu A/V^2$, $R = 1k\Omega$

a) What is $(W/L)_1$ needed to obtain $I_{ref} = 1mA$

b) What is $(W/L)_2$ for $I_0 = 7mA$



Sol- a) Given $I_{ref} = 1mA$

$V_{DD} - I_{ref}R = (V_{DS})_1$

$(V_{DS})_1 = 5 - (1\times10^{-3})(1\times10^{3})$

$= 4\text{ V}$

$(V_{DS})_1 = (V_{GS})_1 = 4V$

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$$I_{ref} = \frac{1}{2} k'_n \left(\frac{W}{L}\right)_1 (V_{GS1} - V_t)^2$$

$$\frac{1\times10^{-3} \times 2}{20\times10^{-6} \times (4-1)^2}$$

$$\frac{100}{9} = \left(\frac{W}{L}\right)_1$$

b) $(V_{GS})_1 = (V_{GS})_2 = 4\,V.$

$$I_0 = \frac{1}{2} k'_n \left(\frac{W}{L}\right)_2 (V_{GS2} - V_t)^2$$

$$\frac{7\times10^{-3} \times 2}{20\times10^{-6} \times (4-1)^2} = \left(\frac{W}{L}\right)_2$$

$$\frac{700}{9} = \left(\frac{W}{L}\right)_2$$

4) In widlar C.M $V_{GS1} = 0.7\,V$, $V_{GS2} = 0.4\,V$, $(V_{DS})_{2\,min} = 0.2\,V$, $V_{DD} = 5V$, $I_1 = 10\,\mu A$, $R_L = 200\,k\Omega$. Determine the value of I_2 for $(V_o)_{max} = 4V$,

a) also determine the value of R_S

b) If $(k'_n)_1 = (k'_n)_2 = 80\,\mu A/V^2$. Then to get $I_2 = I_1 = 10\,\mu A$ what should be aspect ratio of M_2, if $(W/L)_1 = 1$ $(V_t = 0.2\,V)$.

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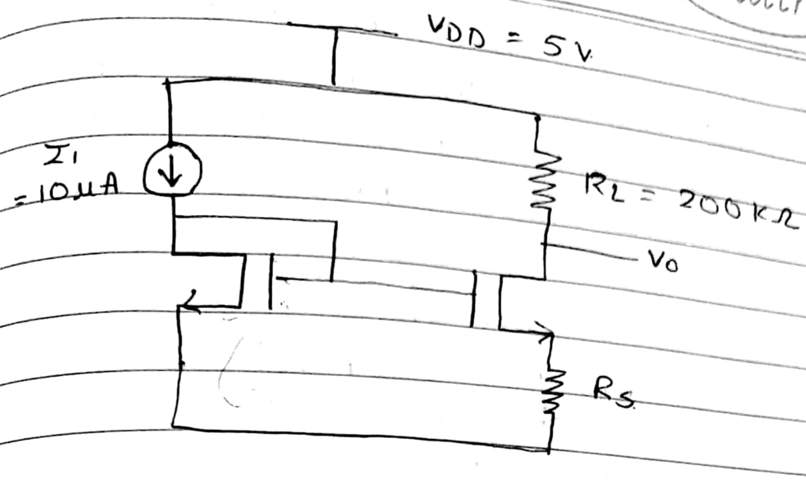

a) Given $(V_{GS1}) = (V_{DS1}) = 0.7V$

$(V_{GS})_2 = 0.4V$

$(V_{DS})_2\ min = 0.2V$

$I_O R_L = V_{DD} - (V_O)_{max}$

$I_o = \dfrac{5-4}{200\times10^{+3}}$

$I_O = 5\mu A$

$V_{GS1} = V_{GS2} + I_O R_S$

$\cancel{(10/5)\times10^{-6}}$ $\dfrac{0.7-0.4}{5\times10^{-6}} = R_S$

$\dfrac{0.3}{5}\times10^{6} = R_S$

$\boxed{60\ k\Omega = R_S}$

b) $I_2 = I_1$

$\frac{1}{2}k'\left(\frac{W}{L}\right)_2 (V_{GS2}-V_t)^2 = \frac{1}{2}k'\left(\frac{W}{L}\right)_1 (V_{GS1}-V_t)^2$

$\left(\frac{W}{L}\right)_2 = \dfrac{(0.7-0.2)^2}{(0.4-0.2)^2} = \dfrac{25}{4} = 6.25$

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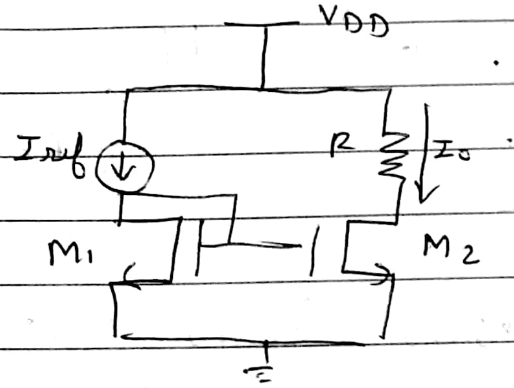
5) In a basic current mirror. Determine the mirror ratio when $V_{GS} = 2V$, $(V_{DS})_2 = 10V$, $\lambda = 0.02/V$. Assume both mosfet's are identical.

Sol:



$$\frac{I_o}{I_{ref}} = \frac{(W/L)_2 (1+\lambda V_{DS2})}{(W/L)_1 (1+\lambda V_{DS1})}$$

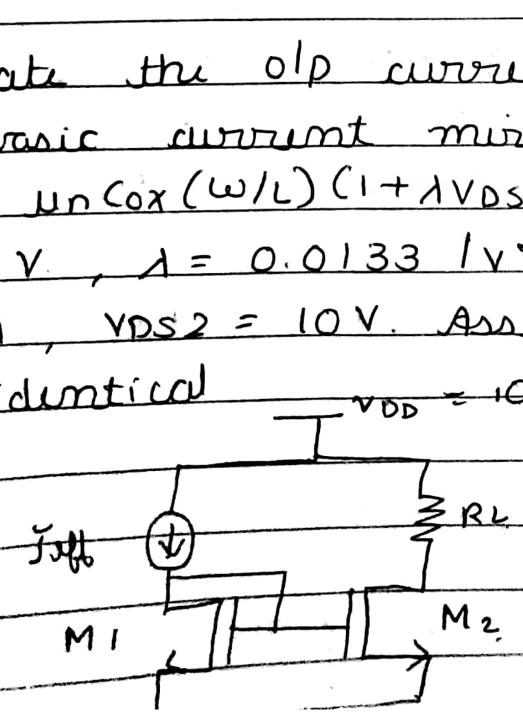
$(V_{GS})_1 =$
$(V_{DS})_1 = 2V$

$$= \frac{1+(0.02)(10)}{1+(0.02)(2)}$$

$$= \frac{1+0.2}{1+0.04}$$

$$= 1.15$$

6). Calculate the o/p current I_2 for the basic current mirror, if $V_{DD} = 10V$, $\mu_n C_{ox}(W/L)(1+\lambda V_{DS}) = 250\mu A/V^2$, $V_t = 1V$, $\lambda = 0.0133/V$. $I_{ref} = 150\mu A$, $V_{DS2} = 10V$. Assume mosfet's are identical



$\mu_n C_{ox}\left(\frac{W}{L}\right)(1+\lambda V_{DS})$

$$I_{ref} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(1+\lambda V_{DS})(V_{GS1}-V_t)^2$$

$$\frac{150\times\cancel{10^{-6}}\times 2}{250\times\cancel{10^{-6}}} = (V_{GS1}-V_t)^2$$

$$1.2 = (V_{GS1}-V_t)^2$$

$$1.095 = V_{GS1}-V_t$$

$$V_{GS1} = 2.095\ V.$$

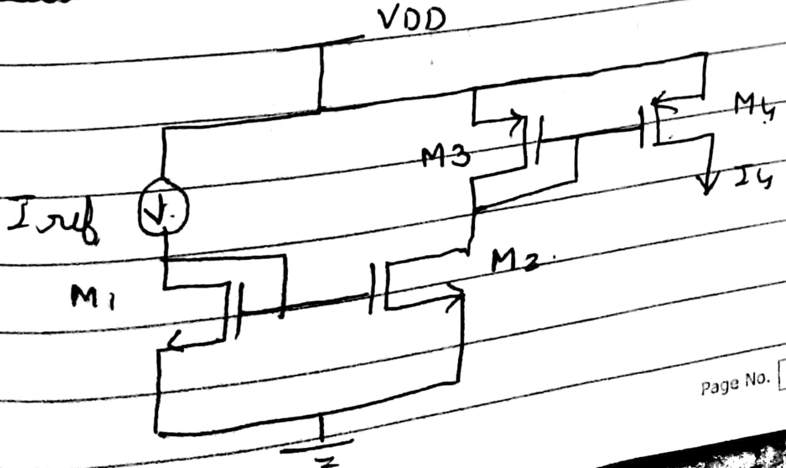
$$V_{GS1} = V_{GS2} = 2.095$$

$$\frac{I_o}{I_{ref}} = \cancel{\frac{1}{2}}\times\frac{1+\lambda V_{DS2}}{1+\lambda V_{DS1}}$$

$$= \frac{1+(0.0133)(\overset{10}{\cancel{2.095}})}{1+(0.0133)(2.095)}$$

$$I_o = 165.34\ \mu A.$$

7) Find the drain current of M_4 in the foll^n circuit, where all transistors are in saturation region



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Sol:- $\frac{I_2}{I_{ref}} = \frac{(W/L)_2 \cdot (1+\lambda V_{DS2})}{(W/L)_1 \cdot (1+\lambda V_{DS1})}$

assume $\lambda = 0$

$I_2 = I_{ref} \left(\frac{(W/L)_2}{(W/L)_1} \right)$ — ①

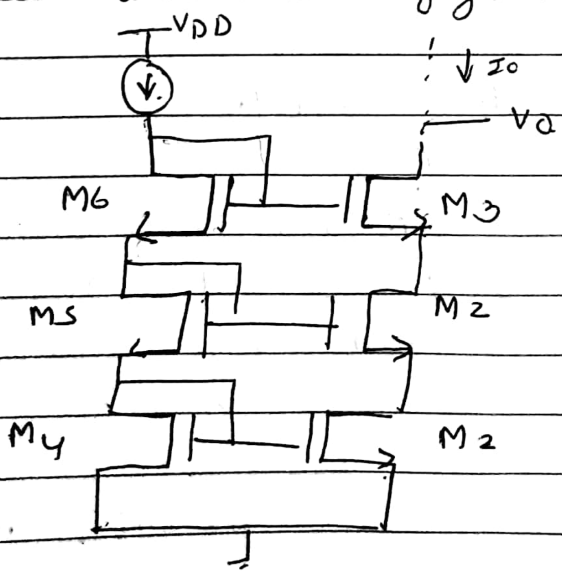
WKT $I_2 = I_3$

$\frac{I_4}{I_3} = \frac{(W/L)_4}{(W/L)_3}$

$I_4 = \frac{(W/L)_4}{(W/L)_3} I_3$

$I_4 = \frac{(W/L)_4}{(W/L)_3} \times \frac{(W/L)_2}{(W/L)_1} \times I_{ref}$

Imp 8) Determine the o/p resistance of double cascode current mirror shown in below figure



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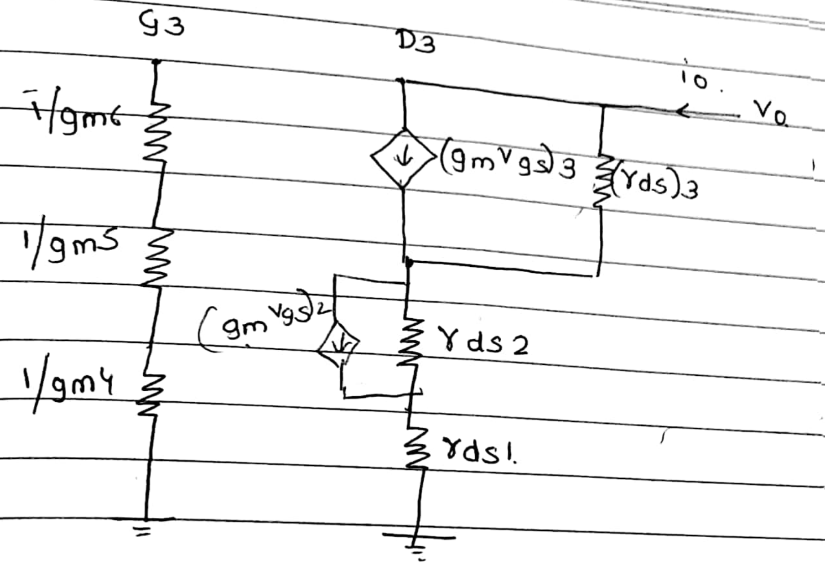

$$V_o - i_o(r_{ds})_3 + (g_m v_{gs})_3^{r_{ds3}} - i_o(r_{ds})_2 - i_o(r_{ds})_1 + (g_m v_{gs2})\, r_{ds2} = 0$$

$$v_o - \cancel{i_o(r_{ds3} + r_{ds2} + r_{ds1}) + (g_m v_{gs})_3\, r_{ds3} = 0}$$

$$v_{gs3} = (v_g - v_s)_3$$
$$= v_g - ($$

$$v_{gs2} = v_g - v_s$$
$$= 0 - I_o r_{ds1}.$$

$$v_{gs3} = v_g - [(g_m v_{gs})_2 r_{ds} + I_o r_{ds2} + I_o r_{ds1}]$$

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