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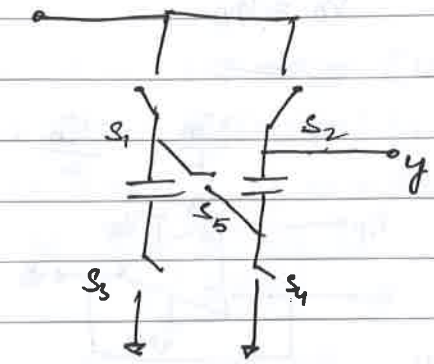
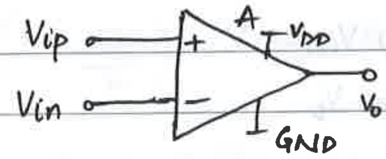
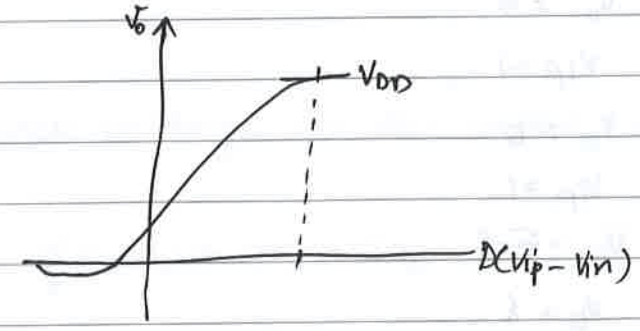
$y = 2x_1 + 4x_2 + 6x_3$



Operational Amplifier



$V_o = A(V_{ip} - V_{in})$



slope = gain / small signal gain

$V_o = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} \cdot \tanh[A(V_{ip} - V_{in})]$

$\frac{e^{Ax} - e^{-Ax}}{e^{Ax} + e^{-Ax}}$

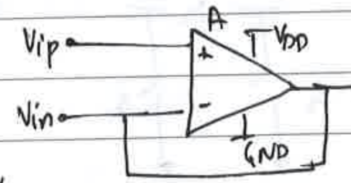
(If x is small) $\approx \frac{(1+Ax) - (1-Ax)}{1+Ax+1-Ax} = Ax$

$$V_0 = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} \tanh(A(x)) \qquad x = V_{ip} - V_{in}$$

$x \to \infty \qquad V_0 = V_{DD}$

$x \to -\infty \qquad V_0 = 0$

$x \to \delta \qquad V_0 = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} \cdot A(x)$



(negative feedback)

(i) $V_{ip} = 1V$

$V_{in} = 0 \Rightarrow V_0 = 5V$

(ii) $V_{ip} = 1V$

$V_{in} = V_0 \Rightarrow V_{in} = 5V$

if the $V_{in} = V_0$

① $V_{ip} = 1$
$V_0 = 5$

② $V_{ip} = 1$
$V_0 = 0$

③ $V_{ip} = 1$
$V_0 = 5 - \delta$

④ $V_0 = \delta$

⑤ $V_0 = 5 - 2\delta$

⑥ 3δ

at steady state $V_0 = 1V$ (close to 1 V)

$$V_0 = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} \tanh[A(V_{ip} - V_0)]$$

let $V_0 = 2.5 + 2.5 \tanh[1000(1 - V_0)]$

$V_0 = 2.5 + 2.5(1000)(1 - V_0)$

$V_0(1 + 2500) = 2.5 + 2500$

$$V_0 = \frac{2502.5}{2501}$$

$V_0 = 1.0006$

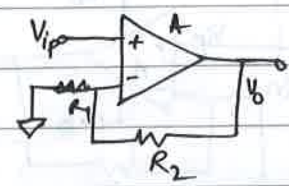
$$V_0 = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} \cdot A(V_{ip} - V_0)$$

$$V_0\left(1 + \frac{AV_{DD}}{2}\right) = \frac{V_{DD}}{2} A \cdot V_{ip}$$

$$V_0 = \frac{A\frac{V_{DD}}{2} \cdot V_{ip}}{1 + A\frac{V_{DD}}{2}}$$

senses voltage at the input and gives output

$$y = 2x_1 + 4x_2 + 6x_3$$



$$V_0 = \frac{\frac{AV_{DD}}{2} \cdot V_{ip}}{1 + \beta \frac{V_{DD}}{2} A}$$

let $\frac{AV_{DD}}{2} = A_0$

$$= \frac{A_0 V_{ip}}{1 + \beta A_0}$$

$$\beta = \frac{R_1}{R_1 + R_2}$$

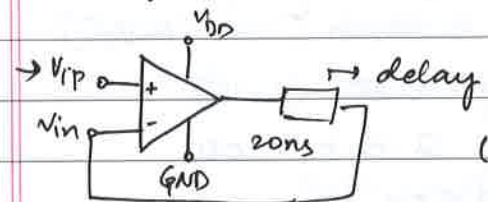
$\approx \frac{V_{ip}}{\beta}$] βA_0 is very large

9/1/18

Application

→ comparing $V_{ip} > V_{in} \to 1$; $V_{ip} < V_{in} \to 0$

→ negative feedback where $V_{out} \simeq V_{ip}$



(virtual short)

	0	20ns	40ns	80ns	100ns
V_{ip}	1	1	1	1	1
V_{in}	0	δ	$V_{DD}-2\delta$	2δ	
V_o	V_{DD}	δ	$V_{DD}-\delta$	2δ	

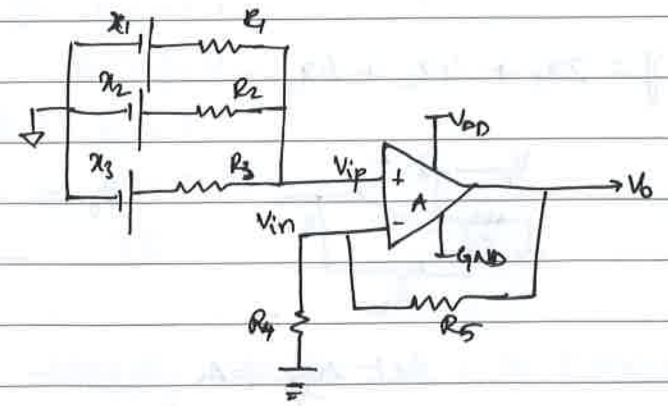
$$V_o = \frac{V_{DD}}{2} + \frac{V_{DD}}{2}\tanh(A\underbrace{(V_{ip}-V_{in})}_{x}) \quad] \text{ if } (Ax)^2 << Ax$$

$$V_o = \frac{V_{DD}}{2} + \frac{V_{DD}}{2} A\,(V_{ip}-V_{in})$$

$$V_o = \frac{\frac{V_{DD}}{2}A}{1+\frac{V_{DD}}{2}A} \cdot V_{ip}$$

Q $\quad y = 2x_1 + 4x_2 + 6x_3$

A1:

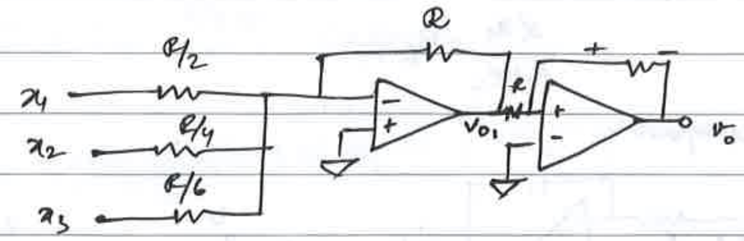


$$V_{ip} = \left(\frac{x_1}{R_1} + \frac{x_2}{R_2} + \frac{x_3}{R_3}\right)\left(\frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_1R_3}\right)$$

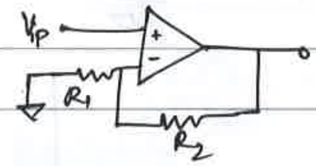
$$= \frac{1}{R}\left(\frac{x_1}{6} + \frac{x_2}{3} + \frac{x_3}{2}\right)\left(\frac{36R^3}{36R^2}\right)$$

$$= \left(\frac{x_1}{6} + \frac{x_2}{3} + \frac{x_3}{2}\right)$$

A2:



→ Input impedance of amplifier is infinite



$$V_o = V_{ip}\frac{A_0}{1+\beta A_0}$$

$$\beta = \frac{R_1}{R_1+R_2}$$

$$V_o = \frac{V_{ip}}{\beta}$$

error in $V_{ip} < 5\%$.

$$V_o \times 0.95 = V_o \frac{A_0}{1+\beta A_0}$$

$$0.95(1+\beta A_0) = A_0$$

$$A_0 = \frac{0.95}{1-0.95\beta}$$

$$A_0 > \frac{0.95}{1-0.95\beta}$$

for error to be less than 5%.

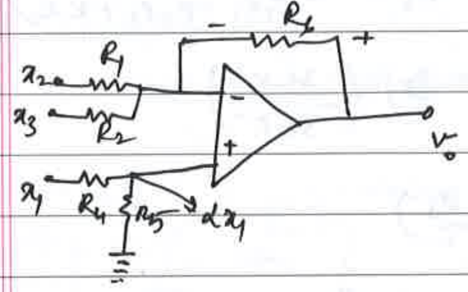
$$\cancel{V_o = 0.95 V_o \frac{A_0}{1+\beta A_0}}$$

$$\cancel{\frac{100}{95} = \frac{A_0}{1+\beta A_0}}$$

$$\cancel{100 + 100\beta A_0 = 95 A_0}$$

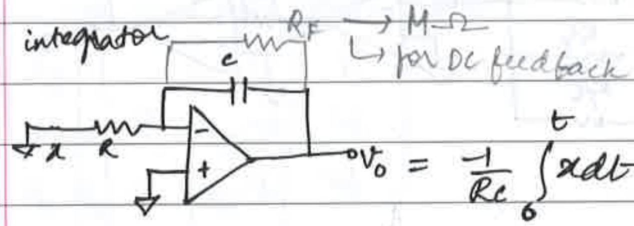
$$\cancel{\therefore A_0 = \frac{100}{95-100\beta} = \frac{1}{0.95-\beta}}$$

Q $\cancel{2x_1 +}\ 2x_1 - 4x_2 - 6x_3$

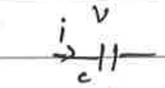


$$\frac{\alpha x_1}{R_1 \| R_2} \cdot R_6$$

integrator



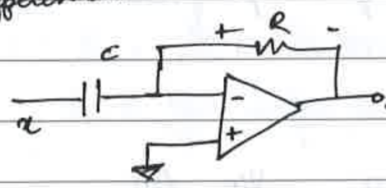
$$V_o = \frac{-1}{Rc} \int_0^t x\,dt$$



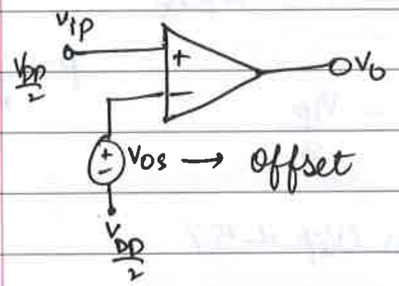
$$v = \frac{1}{c}\int i\,dt$$

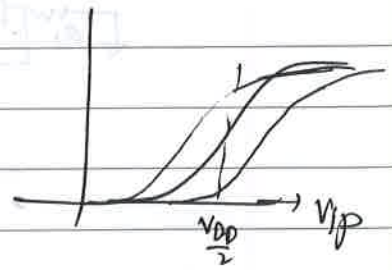
$$i = c\frac{dv}{dt}$$

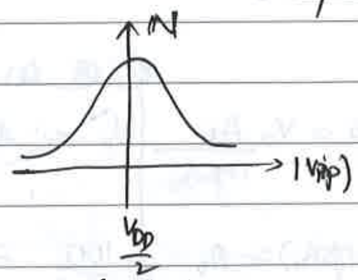
differentiator

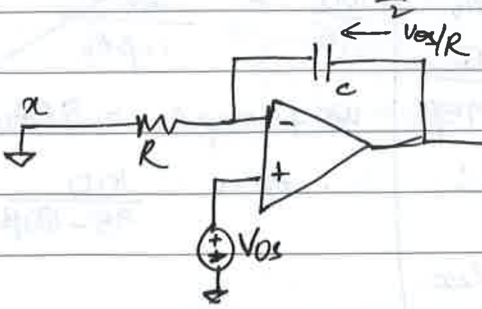


$$V_o = -CR\frac{dv}{dt}$$



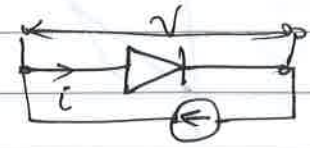






$$v_o = \frac{V_{os}}{R} \cdot \frac{1}{c} \cdot t$$

$$\alpha\frac{d^2x}{dt^2} + \beta\frac{dx}{dt} + \theta = y$$

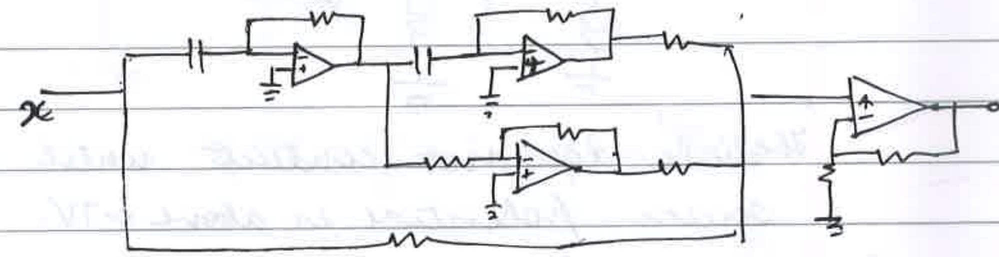


$$I = I_0\left(e^{V/\eta V_T} - 1\right) \quad V_T = 25mV$$

$$I = I_0 e^{V/\eta V_T} \quad \text{(approx.)}$$

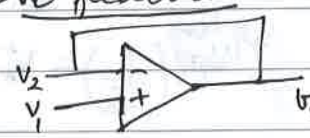
$$V = \eta V_T \log\left(\frac{I}{I_0}\right)$$

10/1/18



$$\alpha\frac{d^2x}{dt^2} + \beta\frac{dx}{dt} + \theta = y.$$

-ve feedback:



$$V_o = \frac{V_{DD}}{2} + \frac{V_{DD}}{2}\tanh[A(V_1 - V_2)]$$

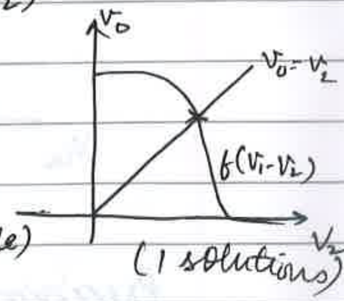
$$V_o = f(V_1 - V_2)$$

$$V_o = V_2$$

$$V_o = f(x)$$

$$= f(0) + f'(0)\cdot x + f''(0)\frac{x^2}{2!} + \cdots$$

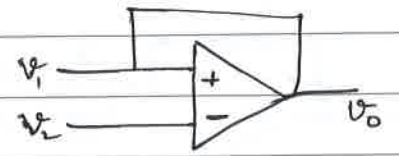
$$= f(0) + f'(0)x \quad \text{(higher order terms are negligible)}$$

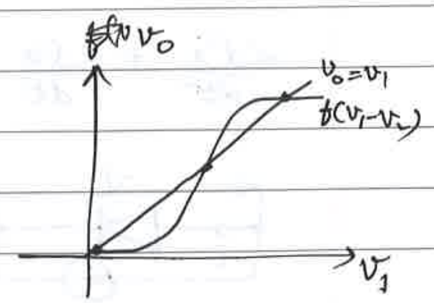


$$v_o = f(0) + f'(0)(v_1 - v_o)$$

$$v_o = \frac{f(0)}{1 + f'(0)} + \frac{f'(0)v_1}{1 + f'(0)}$$

+ve feedback:



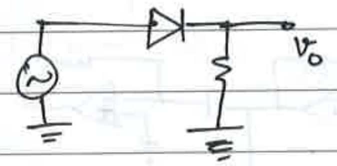


$v_0 = f(v_1 - v_2)$

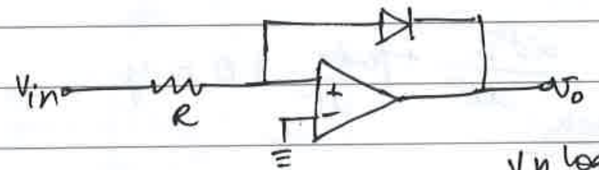
$v_1 = v_0$

(3 solutions)

half wave rectifier



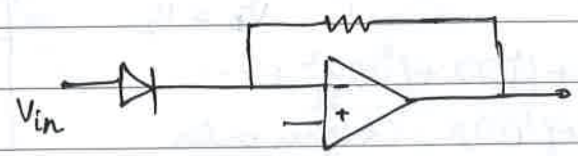
The diode does not conduct until the source potential is above 0.7V.



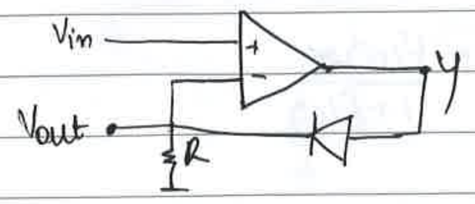
$I = I_0(e^{V/V_T\eta} - 1)$

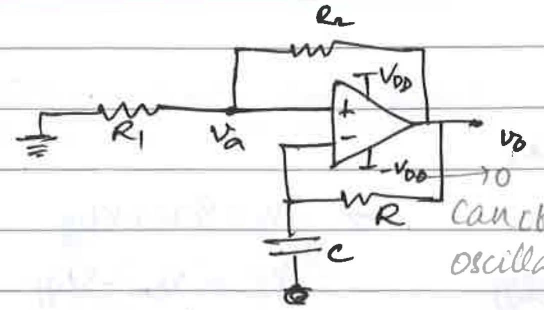
$I = \frac{V_{in}}{R}$

$V_T\eta \log\left(\frac{I}{I_0}\right) = V$ of diode



Precision rectifier → ?

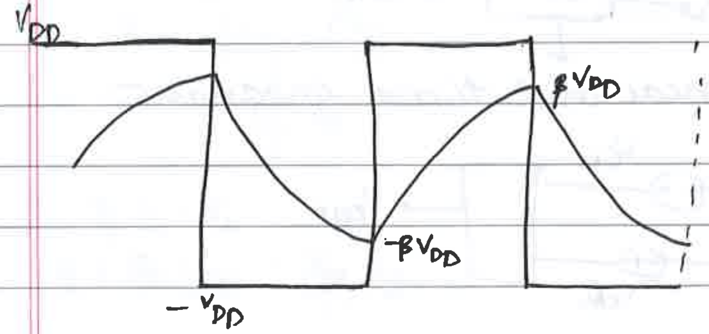




to cause oscillate

$V_a = \beta V_0$

$\frac{R_1}{R_1 + R_2}$



$$v_C(t) = V_f + (V_i - V_f)e^{-t/\tau}$$

$$\beta V_{DD} = V_{DD} + (-\beta V_{DD} - V_{DD})e^{-T_1/\tau}$$

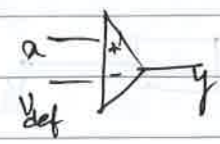
$$\beta - 1 = -(\beta + 1)e^{-T_1/\tau}$$

$$\frac{-T_1}{\tau} = \log\left(\frac{1-\beta}{1+\beta}\right)$$

$$T_1 = \tau \log\left(\frac{\beta+1}{1-\beta}\right)$$

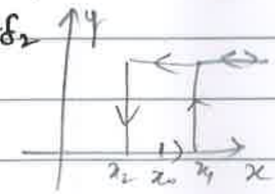
RC causes delay.

Schmitt Trigger



$V_0 = V_{DD}$, $x > V_{def} + \delta_1$

$V_0 = 0$ $\quad x < V_{def} - \delta_2$

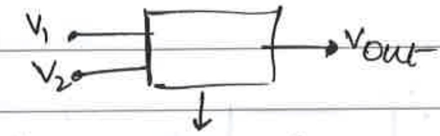


16/1/18 → Ref another book

22/1/18

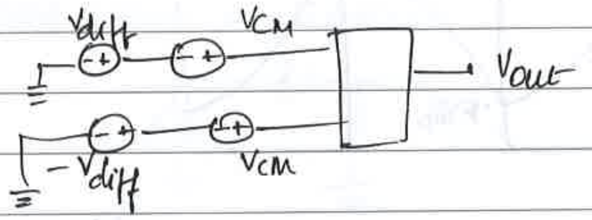
$\frac{V_1+V_2}{2} = V_{CM}$ $\Rightarrow$ $V_1 = V_{CM} + V_{diff}$

$\frac{V_1-V_2}{2} = V_{diff}$ $\quad V_2 = V_{CM} - V_{diff}$

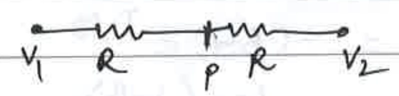


↓

linear and time invariant

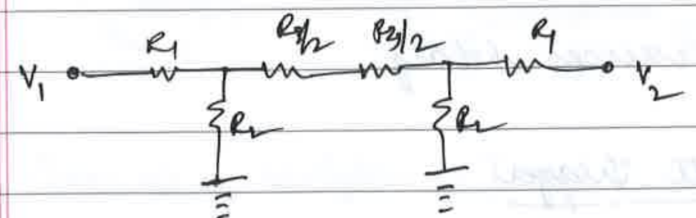


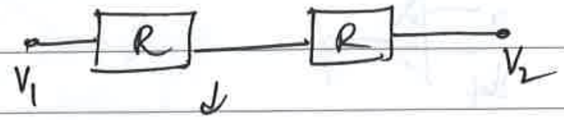
apply V_{CM} first and V_{diff} next and add the individual responses (∵ linear system) = V_{out}.



If $V_1 = V_2 = V_{CM} \Rightarrow I = 0$ and ~~V at pt P = 0~~

If $V_1 = V_{diff} = -V_2 \Rightarrow I = \frac{V_{diff}}{R}$ V at pt P = 0. ~~V at pt P = 0~~.

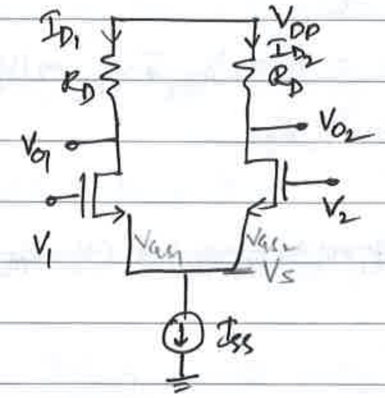


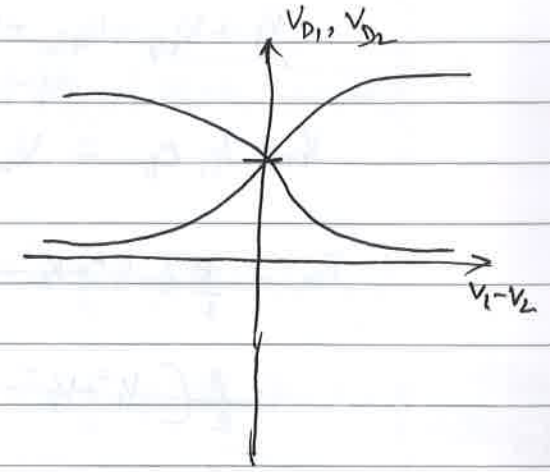
~ 

↓

symmetric network.

Differential Amplifier





If $V_1 = V_2$

$V_1 = V_{DD} - \frac{I_{SS}}{2} R_D$

$I_D = \frac{1}{2}\beta(V_{GS} - V_{TH})^2$

If $V_1 - V_S = V_{GS_1}$

$V_S + V_{Th} - V_S = V_{GS_2}$

$V_{GS_1} - V_{GS_2} = V_1 - V_S - V_{Th}$

$\sqrt{2}(V_{GS0} - V_{Th}) = V_1 - V_2$

$V_1 - V_2 = \sqrt{2}\sqrt{\frac{2 I_{SS}/2}{\beta}}$ $\quad \left(\because V_{GS} - V_{TH} = \sqrt{\frac{2 I_D}{\beta}},\ I_D = I_{SS}/2\right)$

23/1/18

$I_{D_1} + I_{D_2} = I_{SS}$

$I_{D_1} = \frac{\beta}{2}(V_1 - V_S - V_{Th})^2$

$I_{D_2} = \frac{\beta}{2}(V_2 - V_S - V_{Th})^2$, $I_{SS} = \frac{\beta}{2}\left[(V_1 - V_S - V_{TH})^2 + (V_2 - V_S - V_{TH})^2\right]$

$V_{o1} = V_{DD} - I_{D1} R_D$

$V_{o2} = V_{DD} - I_{D2} R_D$

$$I_{ss} = \frac{\beta}{2}\left[(V_1 - V_s - V_{th})^2 + (V_2 - V_s - V_{th})^2\right]$$

$$-V_1 + V_{GS_1} - V_{GS_2} + V_2 = 0$$

$$V_1 - V_2 = V_{GS_1} - V_{GS_2} \Rightarrow (V_1 - V_2)^2 = (V_{GS_1} - V_{GS_2})^2$$

$$V_{o1} + I_{D_1} R_D = V_{o2} + I_{D_2} R_D .$$

$$\cancel{I_{ss} = \frac{\beta}{2}\left[V_1^2 + V_2^2 - 2(V_1+V_2)(V_s+V_{th}) + (V_s+V_{th})^2\right]}$$

$$= \frac{\beta}{2}\left[V_1^2 + V_2^2\right.$$

$$\cancel{I_{D_1} = \frac{V_{DD} - V_{o1}}{R_D}}, \quad \cancel{I_{D_2} = \frac{V_{DD} - V_{o2}}{R_D}}$$

$$\cancel{I_{ss} = \frac{2V_{DD} - V_{o1} - V_{o2}}{R_D}}$$

$$\cancel{\frac{\beta}{2}(V_1 - V_s - V_{th})^2 = \frac{V_{DD} - V_{o1}}{R_D}}$$

$$V_1 - V_2 = V_{GS_1} - V_{GS_2} \Rightarrow (V_1 - V_2)^2 = (V_{GS_1} - V_{GS_2})^2$$

$$I_{ss} = \frac{\beta}{2}\left[(V_{GS_1} - V_{th})^2 + (V_{GS_2} - V_{th})^2\right]$$

$$= \frac{\beta}{2}\left[V_{GS_1}^2 + V_{GS_2}^2 - 2(V_{GS_1} + V_{GS_2})V_{th} + 2V_{th}^2\right]$$

$$= \frac{\beta}{2}\left[\right.$$

$$I_{D_1} = \frac{I_{ss}}{2} + \frac{V_1 - V_2}{4}\sqrt{\beta(4I_{ss} - \beta(V_1 - V_2)^2)}$$

$$V_{out_1} = V_{DD} - I_{D_1} R_D$$

$$V_{out_1} = V_{DD} - R_D\left(\frac{I_{ss}}{2} + \left(\frac{V_1 - V_2}{4}\right)\sqrt{\beta(4I_{ss} - \beta(V_1 - V_2)^2}\right)$$

Let $V_1 - V_2 = x$.

$$V_{out_1} = V_{DD} - R_D\left(\frac{I_{ss}}{2} + \frac{x}{4}\sqrt{\beta(4I_{ss} - \beta x^2)}\right)$$

$$\frac{dV_{out_1}}{dx} = 0 - R_D\left(0 + \frac{1}{4}\sqrt{\beta(4I_{ss} - \beta x^2)} + \frac{x}{4}\,\frac{-\beta^2(2x)}{2\sqrt{\beta(4I_{ss} - \beta x^2)}}\right)$$

$$\frac{dV_{out_1}}{dx} = -\frac{R_D}{4}\left(\sqrt{\beta(4I_{ss} - \beta x^2)} - \frac{\beta^2 x^2}{\sqrt{\beta(4I_{ss} - \beta x^2)}}\right)$$

$$\frac{dV_{out}}{dx} \text{ at } x = 0 = \frac{-R_D\sqrt{\beta I_{ss}}}{2}$$

$$+R_D\sqrt{\frac{100\times10^{-6}\times10\times10^{-3}}{2}} = 100$$

$V_{th} = 0.5$

$\beta = 100\mu/V^2$

$I_{ss} = 10mA$.

$$R_D = \frac{+200}{10^{-3}}$$

$$R_D = +2\times10^5$$

$$V_{out_1} = V_{DD} - R_D\left(\frac{I_{ss}}{2}\right) \quad (\because x = 0)$$

$$= V_{DD} - 2\times10^5\left(\frac{10\times10^{-3}}{2}\right)$$

$$= V_{DD} - 1000$$

$$2 = V_{DD} - 2\times10^5\left(\frac{I_{ss}}{2}\right)$$

$$2 = V_{DD} - 2\times10^5 I_{ss}$$

$$\frac{\sqrt{\beta I_{ss}}}{2}R_D = 100, \quad \frac{I_{ss}}{2}R_D = 2; \quad \beta = 100\mu/V^2$$

$$100\times10^{-6}\times 2R_D = 10000$$

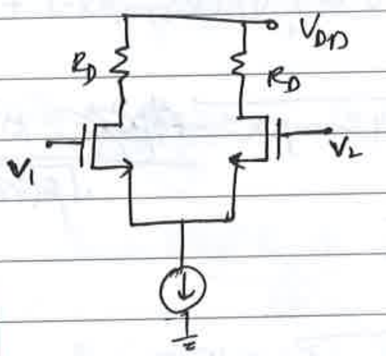
$$R_D = \frac{1}{2}\times10^{8} = 5\times10^{7}$$

$$\sqrt{\frac{\beta\times1\times10^{-3}}{2}(4\times10^{3})} = 100$$

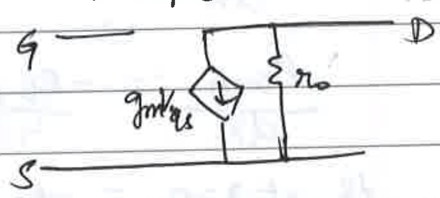
$$I_{D_1} = \frac{I_{SS}}{2} + \frac{V_1-V_2}{4}\sqrt{\beta\left(4I_{SS}-\beta(V_1-V_2)^2\right)}$$

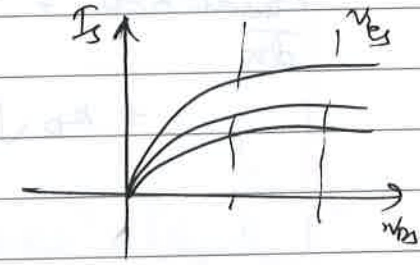
$$I_{D_2} = \frac{I_{SS}}{2} + \frac{V_1-V_2}{4}\sqrt{\frac{4I_{SS}}{\beta}-(V_1-V_2)^2}$$

$$I_{D_1}-I_{D_2} = \frac{\beta}{2}(V_1-V_2)\sqrt{\frac{4I_{SS}}{\beta}-(V_1-V_2)^2}$$



MOSFET





$$I_D = f(V_{GS}, V_{DS})$$

$$I_D + i_d = I_{D,V_{GS},V_{DS}} + f'_{V_{GS}}\,\delta V_{gs} + f'_{V_{DS}}\,\delta V_{ds}$$

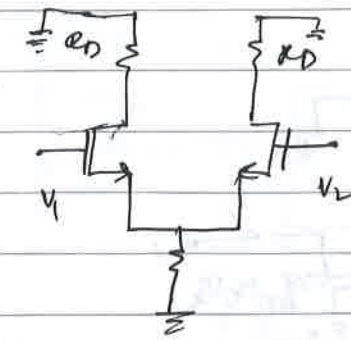
$$I_D = \frac{\beta}{2}(V_{GS}-V_{Th})^2(1+\lambda V_{DS})$$

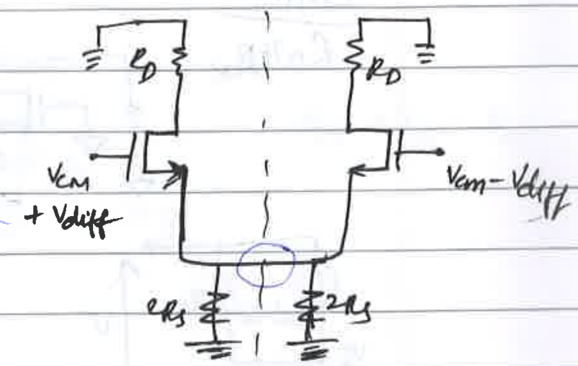
$$\frac{\partial I_D}{\partial V_{GS}} = \beta(V_{GS}-V_{Th})(1+\lambda V_{DS}) = \frac{2I_D}{V_{GS}-V_{Th}} = g_m$$

$$= \frac{2I_D}{\sqrt{\frac{2I_D}{\beta(1+\lambda V_{DS})}}} = \sqrt{2I_D\beta(1+\lambda V_{DS})}$$

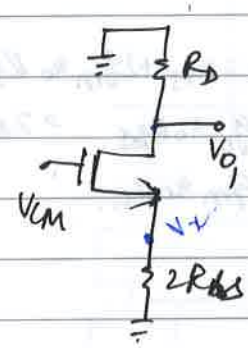
$$\frac{\partial I_D}{\partial V_{DS}} = \frac{\beta}{2}(V_{GS}-V_{Th})^2\lambda \simeq \underline{\underline{I_D\cdot\lambda}}$$

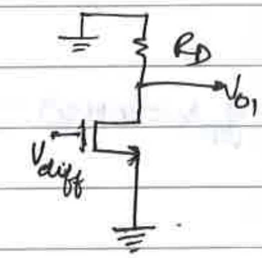
$\lambda = (0.01\ \text{to}\ 0.1)$



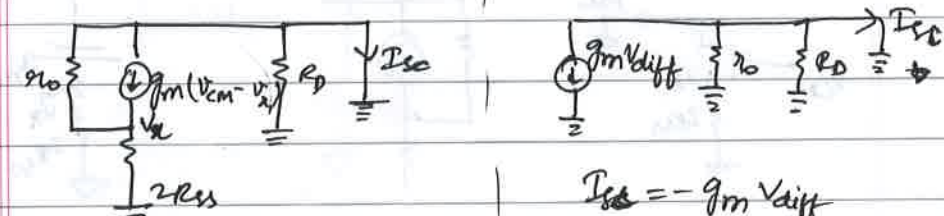


CM Half circuit | Differential Half Circuit



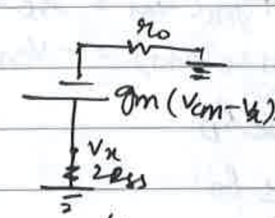


$$v_{o_1} = -g_m(r_o \| R_D)$$



$$I_{SC} = -g_m V_{diff}$$

$$R_o = r_o \| R_D$$



$$\frac{V_x}{2R_{SS}} - \left(\frac{V_x - g_m r_o(V_{cm}-V_x)}{r_o}\right) = 0$$

$$V_x\left(\frac{1}{2R_{SS}} - \frac{1}{r_o} - \frac{g_m r_o}{r_o}\right) + \frac{g_m r_o V_{cm}}{r_o} = 0$$

$$g_m V_{cm} = V_x\left(\frac{(g_m r_o+1)2R_{SS} - r_o}{r_o\,2R_{SS}}\right) \Rightarrow V_{cm} = V_x\left(\frac{(g_m r_o+1)2R_{SS} - r_o}{2R_{SS}\,r_o g_m}\right)$$

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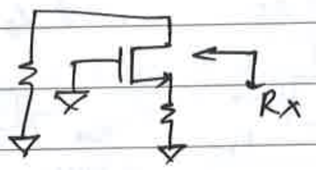
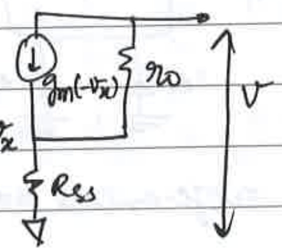
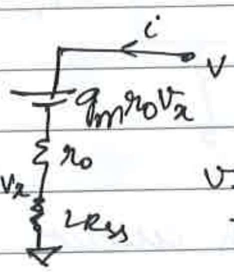
DMHC :

$R_D \| R_x$







$$\frac{v - g_m r_o i(2R_{ss})}{r_o + 2R_{ss}} = i$$

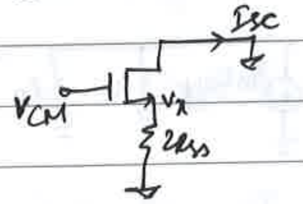
$$\frac{v}{i} = r_o + 2R_{ss} + 2g_m r_o R_{ss}$$

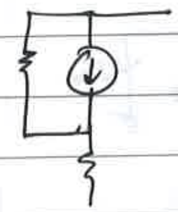
$$\approx 2g_m r_o R_{ss} = 2R_x$$

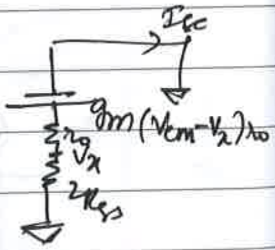
$g_m r_o \approx 20 \text{ to } 30.$

$$R_x = g_m r_o R_{ss}.$$

CMHC :





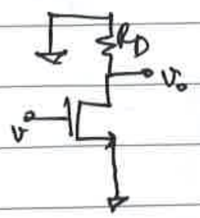


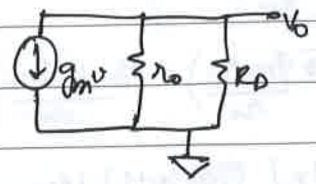
$$I_{sc} 2R_{ss} + I_{sc} r_o + g_m (V_{cm} + I_{sc} 2R_{ss}) r_o = 0$$

$$I_{sc} (2R_{ss} + r_o + g_m r_o 2R_{ss}) = -V_{cm} g_m r_o$$

$$V_o = I_{sc} R_D$$

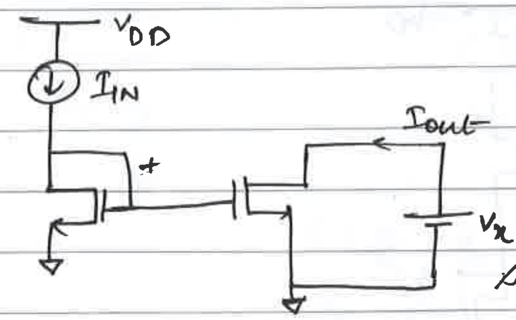
$$= \frac{V_{cm}}{2R_{ss}} R_D.$$





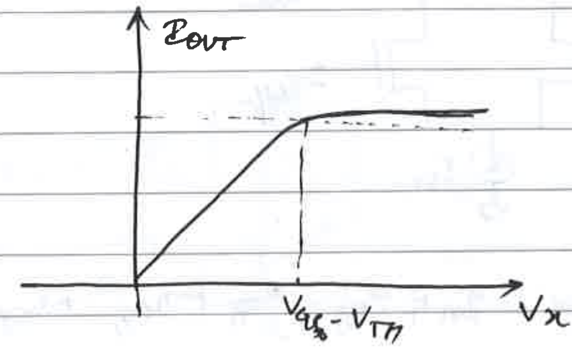
$-g_m v = I_{sc}$

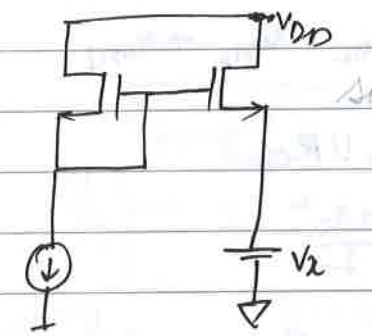
$R_o = r_o \| R_D$



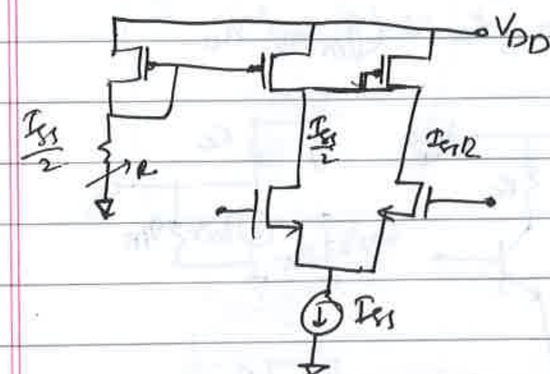
sink

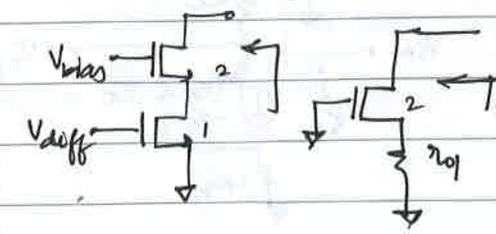
$V_{DS} > V_{GS} - V_{TH}.$



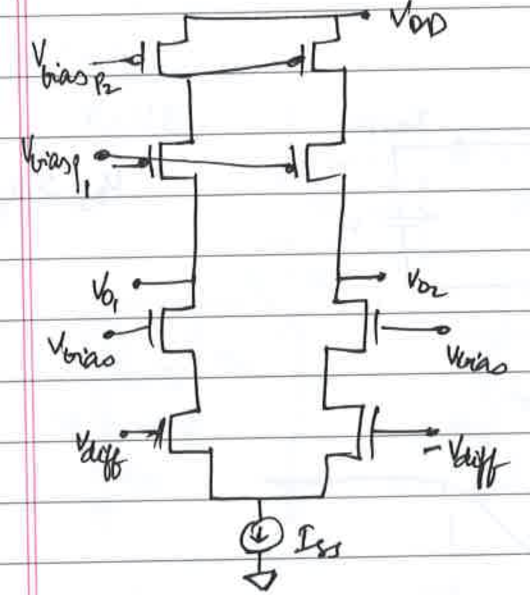


source





$= r_{o1} + r_{o2} + g_{m2} r_{o2} r_{o1}$



$$R_{OV} = g_{mP_1} r_{op_1} r_{op_1} + r_{op_1} + r_{op_2}$$

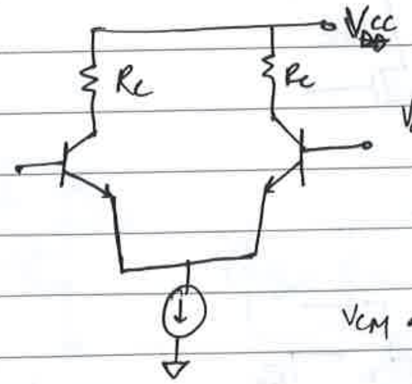
$$R_{OD} = g_{mn_2} r_{on_2} + r_{on_2} + r_{on1}$$

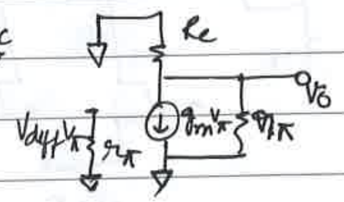
$$R_O = R_{OD} \| R_{OD}$$

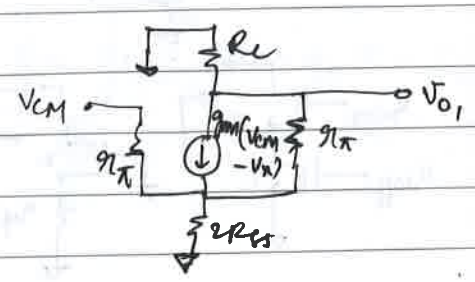
$$= \frac{g_m r_o^2}{2}$$

$$r_{o1} + r_{o2} + g_{m_2} r_{o2} r_{o1} \to R\ \lambda.$$

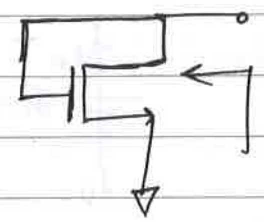
$$R_X + r_{o3} + g_{m_3} r_{o3} R_X \approx (g_m r_o)^2 r_o.$$

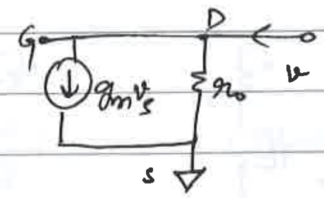






Q

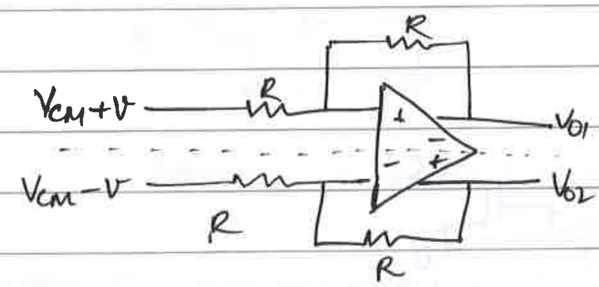




$$i = \frac{v}{r_o} + g_m v$$

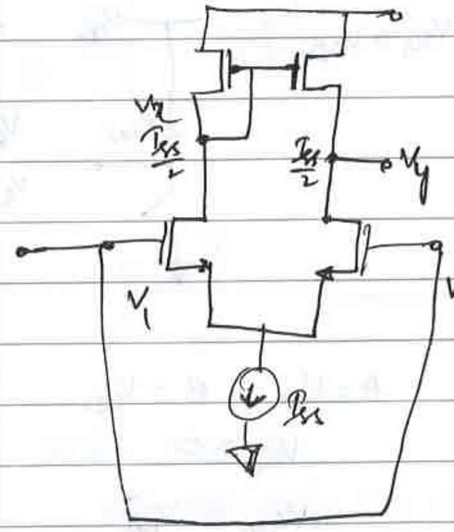
$$g_m r_o = 30$$

$$\frac{v}{i} \quad \frac{i}{v} = \frac{1}{r_o} + g_m$$



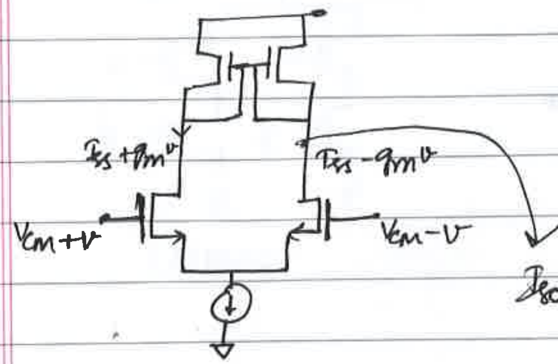
$$\frac{V_x - V_1}{R} + \frac{V_x - V_{O1}}{R} = 0$$

$$\frac{V_x - V_2}{R} + \frac{V_x - V_{O2}}{R} = 0$$



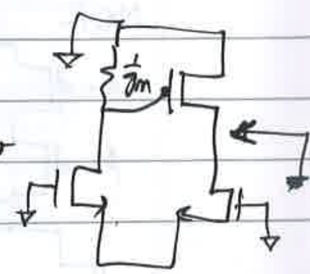
$V_x = V_y$.

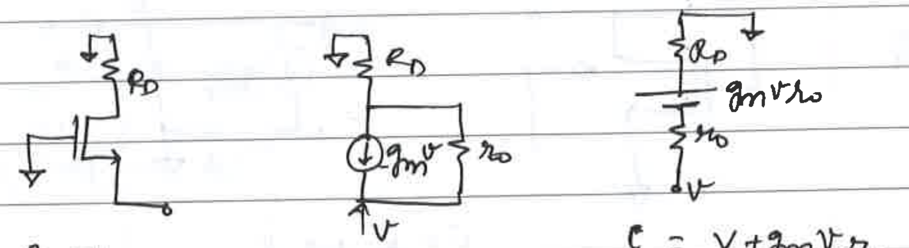
current through both the branches is equal



$$I_{SC} = 2 g_m v$$

$$i = g_m v$$



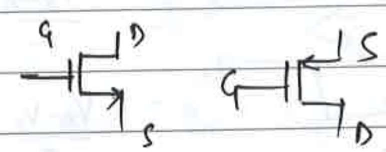


$$\frac{R_D + r_o}{1 + g_m r_o} = R$$

$R_D << r_o$

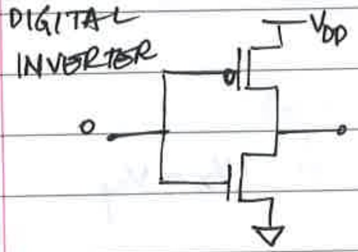
$= \frac{1}{g_m}$.

$C = \frac{V + g_m v r_o}{R_D + r_o}$

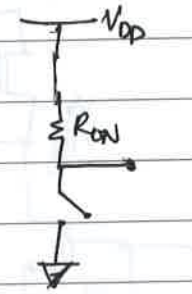


$V_{GS} > V_{Th}$ $|V_{SG}| > V_{Th}$

DIGITAL INVERTER



$V_{SG} = V_{DD}$

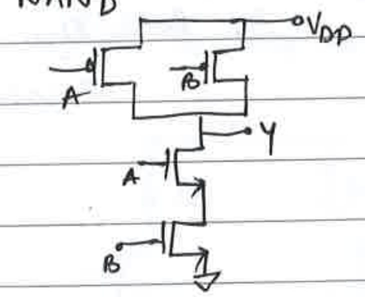


A	Y
0	1

$V_{SG_P} = 0$

$V_{GS_N} = V_{DD}$

NAND

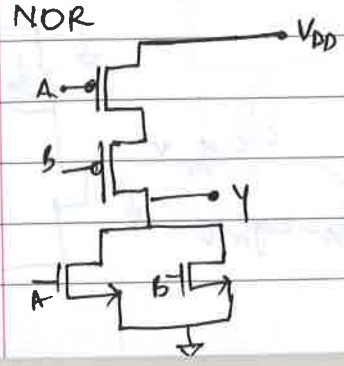


$A = V_{DD}$, $B = V_{DD}$

$V_{SG_1} = 0$

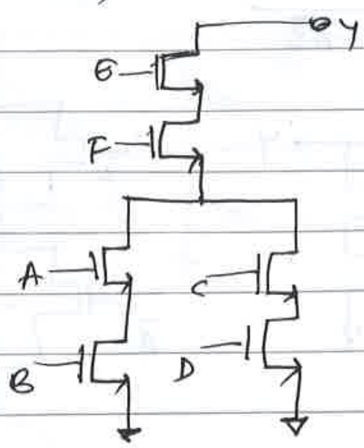
$V_{GSN} = V_{DD}$

NOR



20/1/18

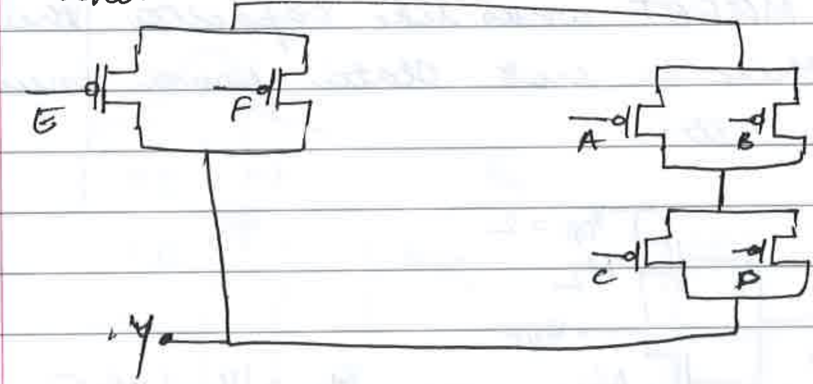
$f = \overline{(AB+CD)EF}$



(NMOS)

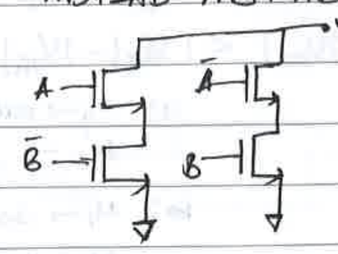
NMOS ⟷ PMOS (series connection → parallel and parallel connection → series)

→ The function under the bar '(AB+CD)EF' is inverted when NMOS & PMOS is used.

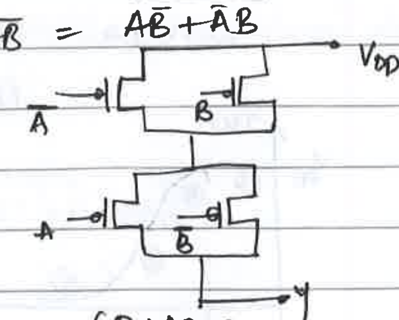


~~XOR~~ XNOR

~~$A\bar{B}+\bar{A}B$~~ ~~$A\bar{B}+\bar{A}B$~~ $AB+\bar{A}\bar{B}$ $= \overline{A\bar{B}+\bar{A}B}$



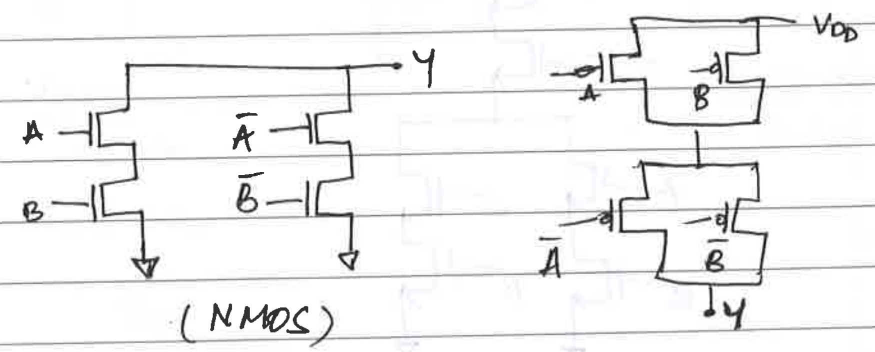
(NMOS)



(PMOS)

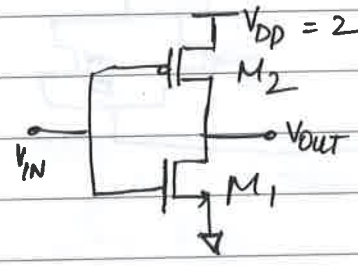
XOR

$\bar{A}B + A\bar{B} = \overline{AB + \bar{A}\bar{B}}$



~~The function use~~

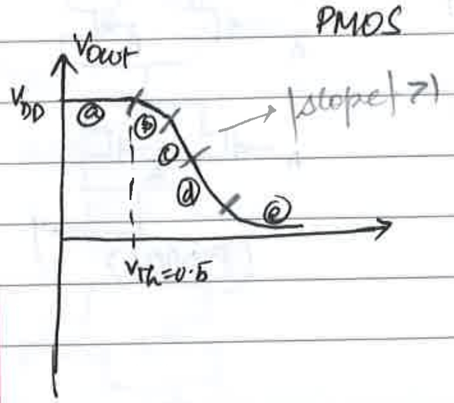
→ BJTs need base current to be turned on.
→ MOSFET works like capacitor therefore there is not static power consumption in it.



$V_{thn} = |V_{thp}| = 0.5$

linear NMOS $|V_{DS}| < |V_{GS} - V_{th}|$

PMOS $|V_{DS}| < |V_{GS}| - |V_{th}|$



a: $M_1 \to$ cutoff
$M_2 \to$ linear

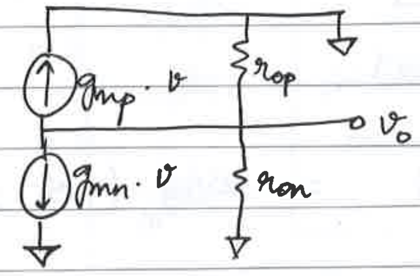
b: $M_1 \to$ saturation
$M_2 \to$ linear

c: $M_1 = M_2 =$ saturation

d: $M_1 -$ linear
$M_2 -$ saturation

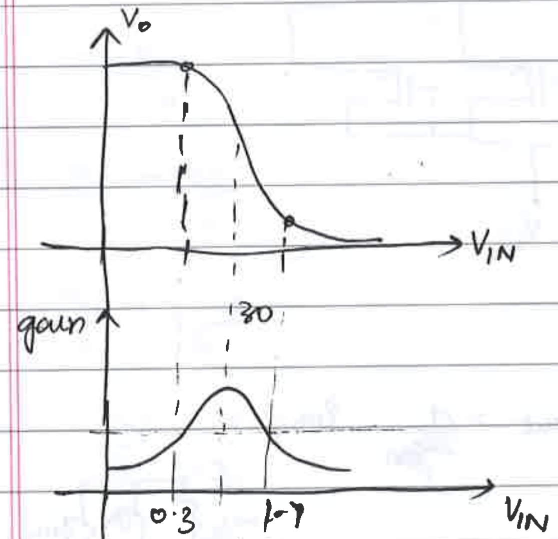
e: M_1 - linear, M_2 - cutoff

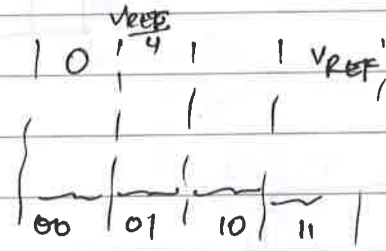
small signal model:

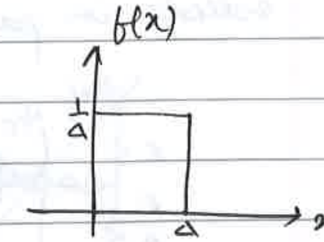


$v_o = -(g_{mp} + g_{mn})(r_{op} \| r_{on}) v$

$= -g_m r_o v$



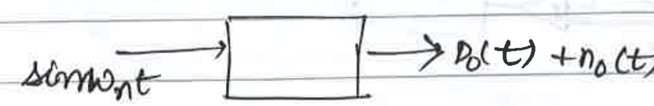




$x \to$ random variable

$f(x) \Rightarrow$ pdf → uniform distribution

$\sigma^2 = \frac{\Delta^2}{12}$



rms

Power of sin wave $= \frac{V_{REF}^2}{2}$, $\Delta = \frac{V_{REF}}{2^n}$

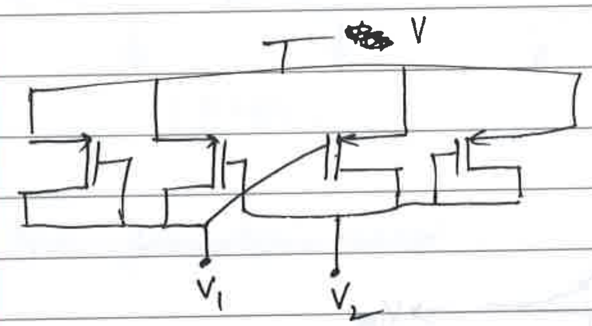
peak to peak → V_{REF}

$2V_{max} = V_{REF}$

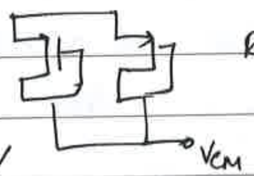
$$\frac{\frac{V_m^2}{2}}{\frac{\Delta^2}{12}} = \frac{\frac{V_{REF}^2}{2\times 4}}{\frac{V_{REF}^2}{2^{2N}(12)}} = 3(2^{2N}-1)$$

$$10\log_{10}\left(\frac{3\cdot 2^{2N}}{2}\right) = 10\log_{10}(1.5\cdot 2^{2N})$$

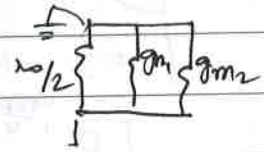
Q



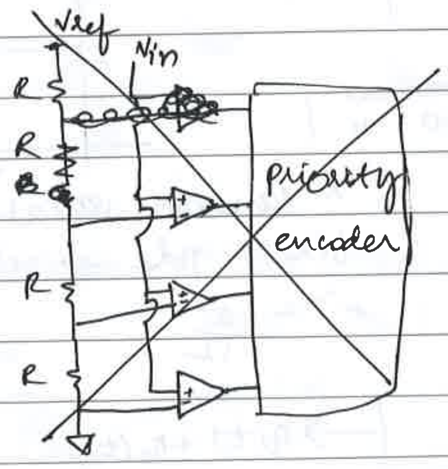
common mode

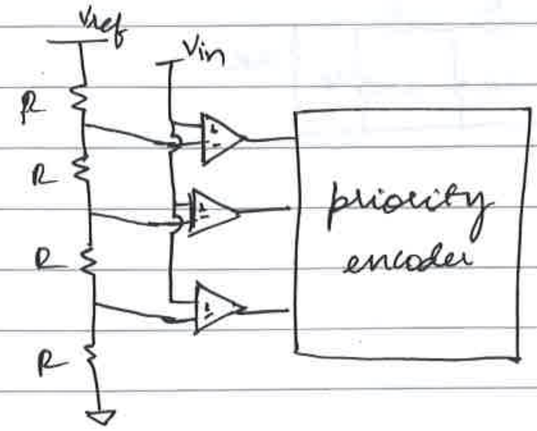


$R_{out} = \frac{1}{2g_m}$ $\quad g_{m_1}$



2diodes in parallel





	V_{O3}	V_{O2}	V_{O1}
$0 - \frac{V_{Ref}}{4}$	0	0	0
$\frac{V_{Ref}}{4} \to \frac{V_{Ref}}{2}$	0	0	1
$\frac{V_{ref}}{2} \to \frac{3V_{ref}}{4}$	0	1	1
$\frac{3V_{ref}}{4} \to V_{ref}$	1	1	1