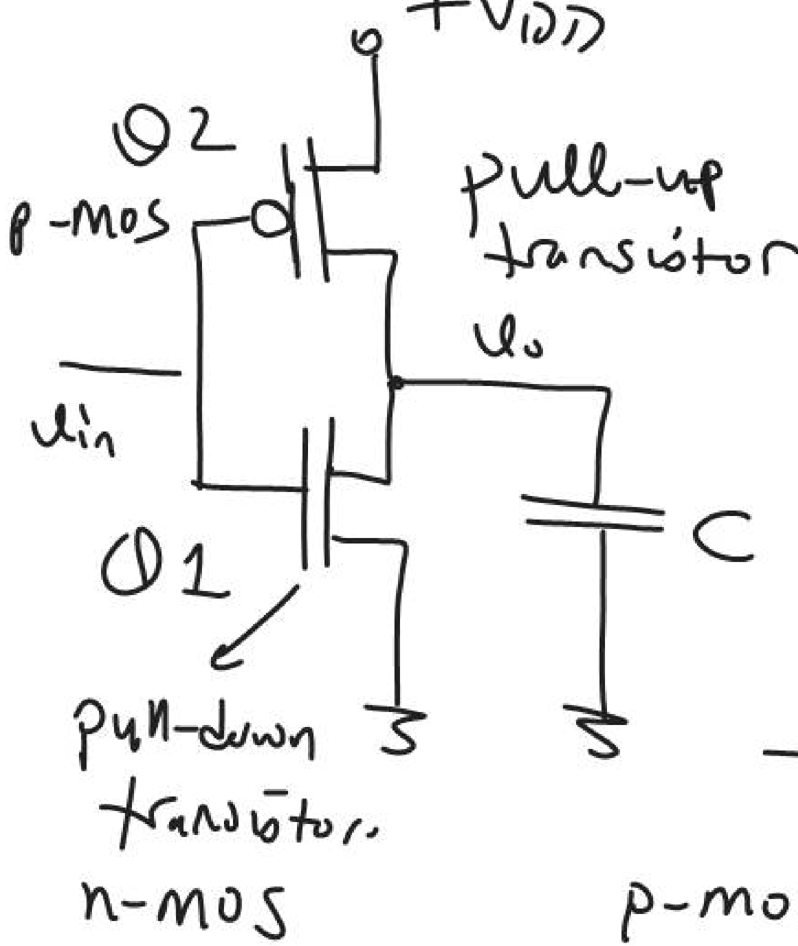
15.10.2010

Power (energy or) consumption :

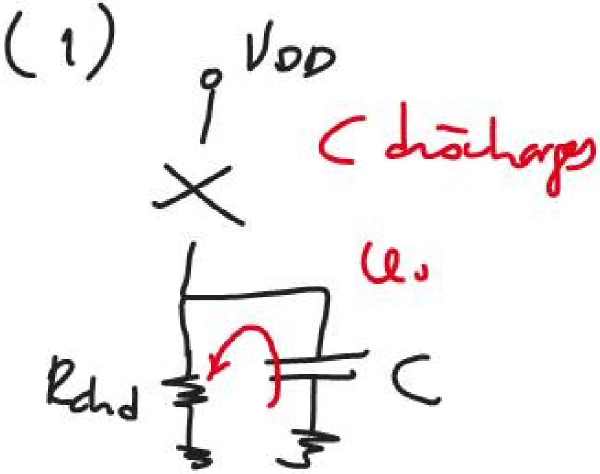


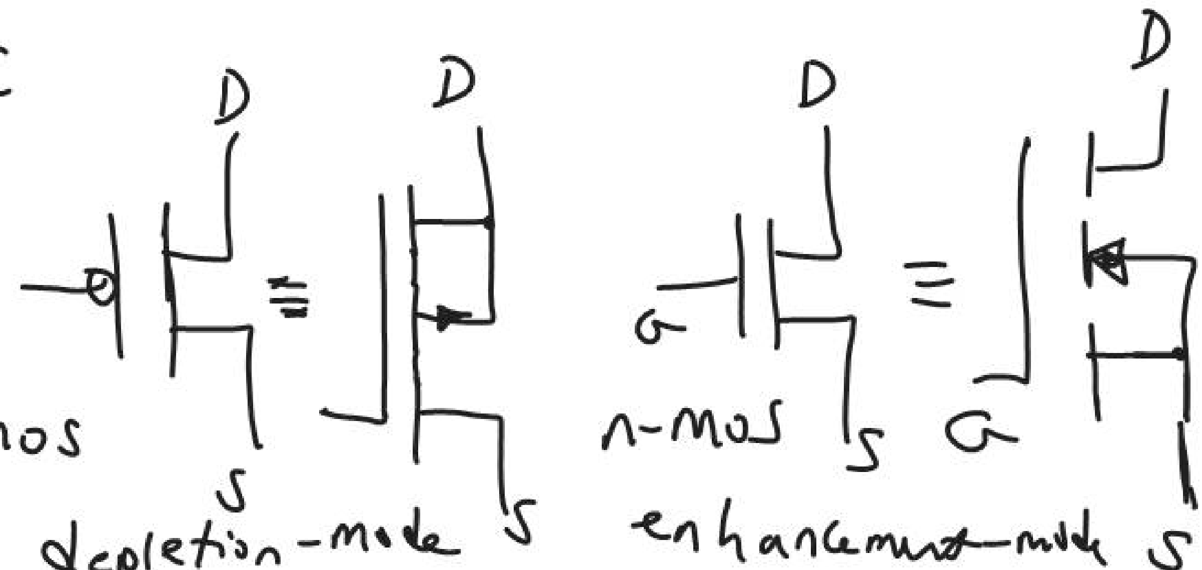
when $V_{in} = V_{DD}$ (1)

$V_o \cong 0$

Q1 is ON

Q2 is OFF



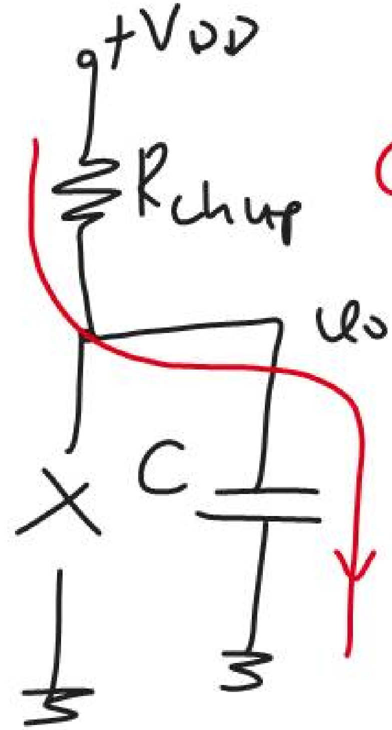


$v_{in} = 0$

$v_o = V_{DD}$

Q2 = ON

Q1 = OFF



C is charged.

The energy (total) consumed from the powersupply:

$$E_{in} = \int_0^{\infty} i(t) \cdot v(t) \cdot dt \qquad v(t) = V_{DD}$$

$i(t)$: instantaneous current drawn from powersupply

$v(t)$: instantaneous voltage of powersupply

Powersupply voltage is assumed to be constant

$$E_{in} = V_{DD} \int_0^\infty i(t)\, dt$$

$$i(t) = C \cdot \frac{dv_{out}}{dt}$$

$$E_{in} = V_{DD}\, C \int_0^\infty \frac{dv_{out}}{\cancel{dt}} \cancel{dt}$$

$$= V_{DD}\, C \int_0^{V_{DD}} dv_{out}$$

x Energy used is not dependent on the R.

$$\boxed{E_{in} = C \cdot V_{DD}^2}$$

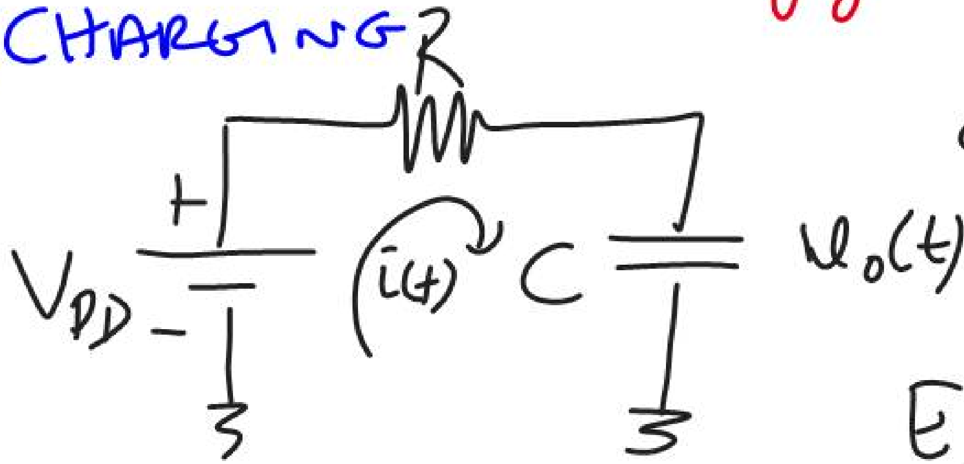
To reduce Energy consumed

① V_{DD} (PS voltage) should be reduced, if possible

② The capacitance (C) should be minimized, if possible

How this energy is dissipated?

(1) CHARGING



Charging

$$E_{dissipated} = \int_0^\infty i(t)\cdot v_o(t)\,dt$$

$$E_{dissipated} = C\int_0^\infty \frac{dv_{out}}{\cancel{dt}}\cdot v_{out}\,\cancel{dt}$$

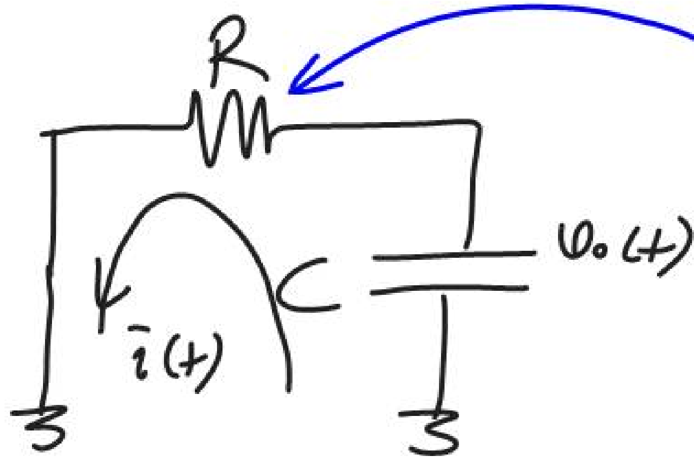
$$= C\int_0^{V_{DD}} v_{out}\cdot dv_{out}$$

This energy is dissipated as HEAT on the R!

Power dissipated $\Rightarrow i^2\cdot R$, $\dfrac{v^2}{R}$

$$\boxed{E_{dissipated\,(LOST)} = \frac{CV_{DD}^2}{2}}$$

② DISCHARGING



$$E_{dissipated} = \frac{C V_{DD}^2}{2}$$

as heat on the R!

2 M transistors in a chip → dissipate a lot of energy on a very limited area (size of the die)

$C = 10^{-14}$ F $\quad V_{DD} = 5V \quad E_{in} = CV^2 = 10^{-14} \cdot 25 = 25 \times 10^{-14}$ Joule

Total $E_{in} = 2 \times 10^6 \times 10^{-14} \times 25 = 5 \times 10^{-7}$ Joule

If the clock cycle is 2 GHz

$$T = \frac{1}{2\times10^{9}} \cong 0.5\times10^{-9}\ s.$$

$$P = \frac{\cancel{5}^{10}\times10^{-7}\ J}{\cancel{0.5}\times10^{-9}\ sec.}$$

$\underline{P = 1000W}$!

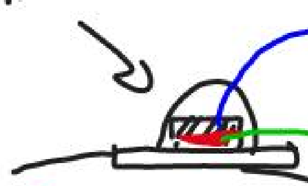
Area of the chip : $1.5\,mm \times 1.5\,mm = 2.25\,mm^2$

$$\frac{E}{Area} = \frac{5\times10^{-2}\ Joules}{2.25\times10^{-6}\ m^2} \cong 0.2\ J/m^2$$

HEAT SINKING

Si transistors Max Junction Temp: 150 - 200°C

metal case



MOS Power transistor

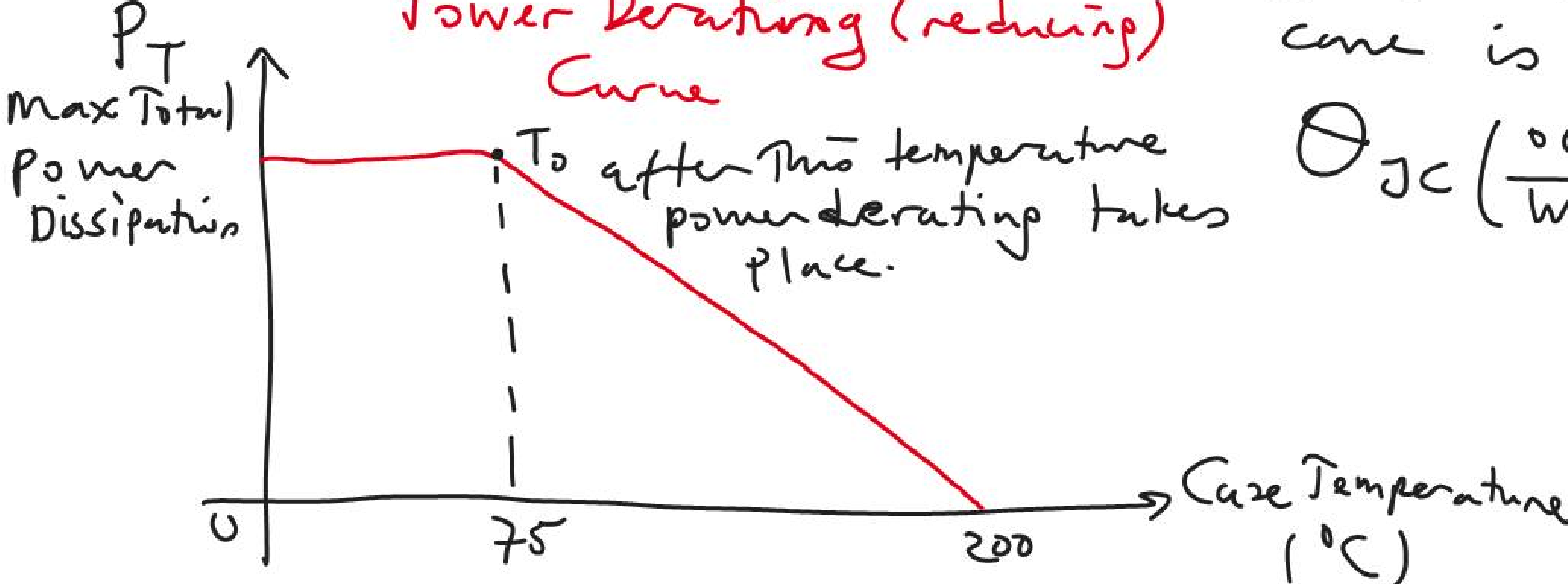
Junction Temperature T_j

Case Temperature T_c

Heat resistance between Junction and case is $\theta_{JC}\left(\frac{°C}{Watt}\right)$

Drain (or source) is connected to the case

Power Derating (reducing) Curve



$$\boxed{T_j - T_c = \theta_{JC} \cdot P_D}$$

another representation of power derating curve.

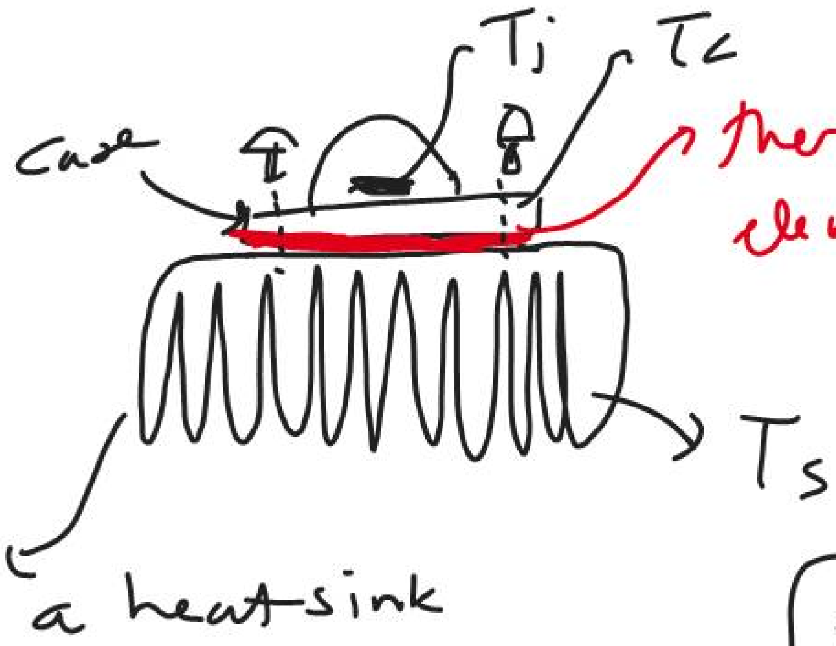
$\theta_{JC} \approx 0.5\,°C/W$

if $P_D = 50W$

$$T_j - T_c = 0.5 \frac{°C}{\cancel{W}} \cdot 50\,\cancel{W}$$

$$\boxed{T_j - T_c = 25\,°C}$$

means if the case is at 50 °C → Then junction is at 75 °C



$$\boxed{\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA}}$$

Ambient T_A

If there were no heat sink $\theta_{JA} = 40\ °C/W$

$P_D = 20W$

$T_j - T_A = 20\cancel{W}\ 40\ °C/\cancel{W} = \underline{800\ °C}$

$P_D = 1W$ $\quad T_j - T_A = 1 \times 40 = \underline{40\ °C}$

If we use heat sink of $\theta_{SA} = 3\,°C/W$

$\theta_{JC} = 0.8\,°C/W$

$\theta_{CS} = 0.5\,°C/W$

$\theta_{SA} = 3\,°C/W$

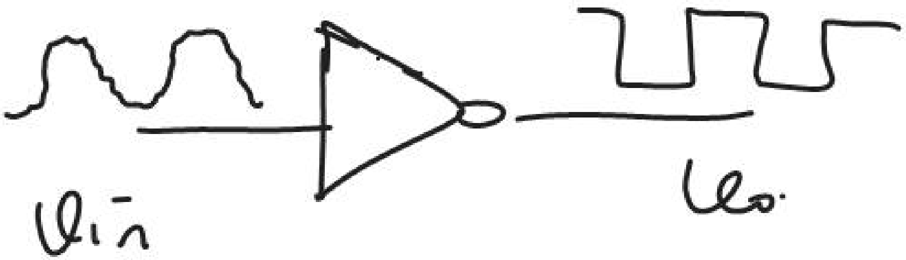
$\theta_{JA} = 0.8 + 0.5 + 3 = 4.3\,°C/W$

for $P_D = 20\,W$

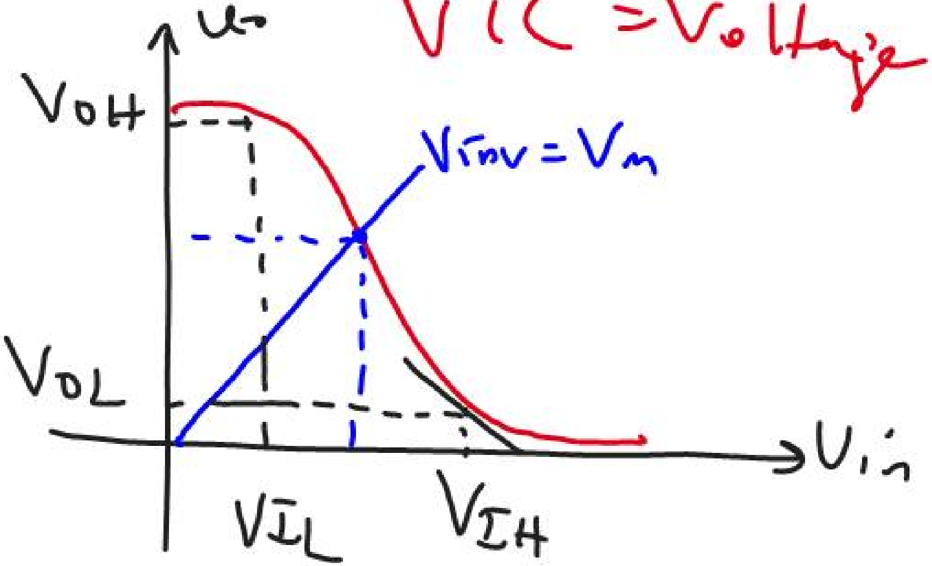
$T_J - T_A = 20 \cdot 4.3\,°C/W \simeq 86\,°C$

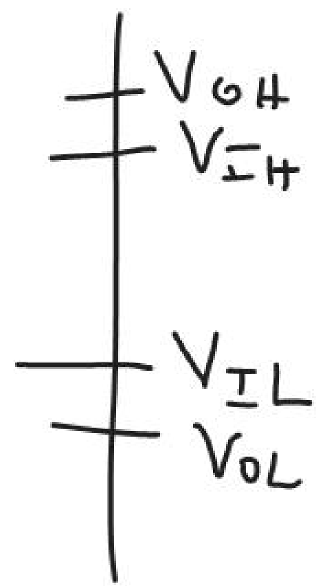
If $\underline{T_A = 20\,°C}$ $\quad$ $\underline{T_J = 106\,°C}$

THE INVERTER



VTC = Voltage Transfer Characteristics

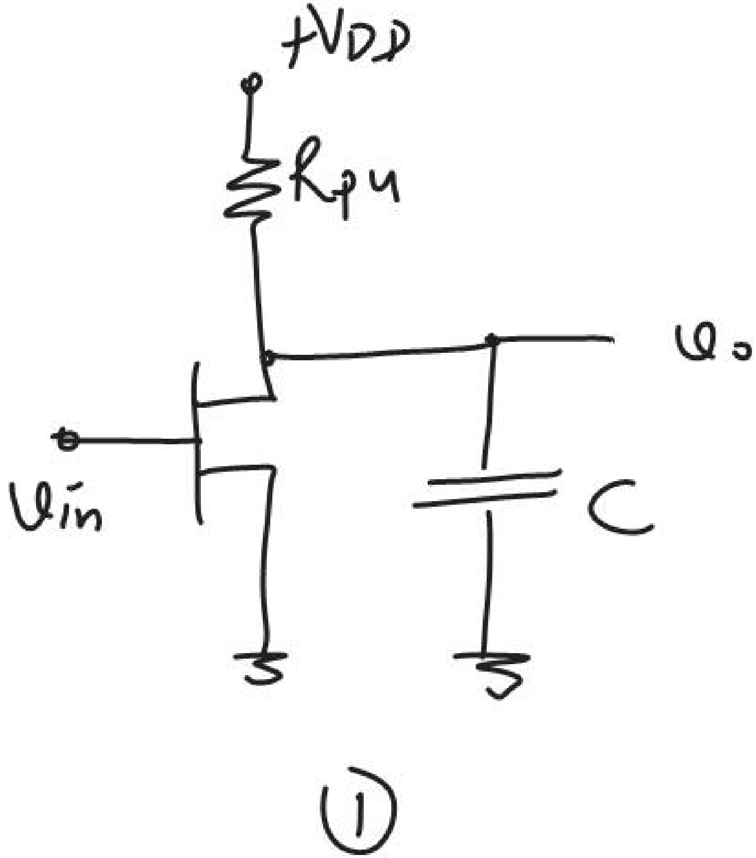


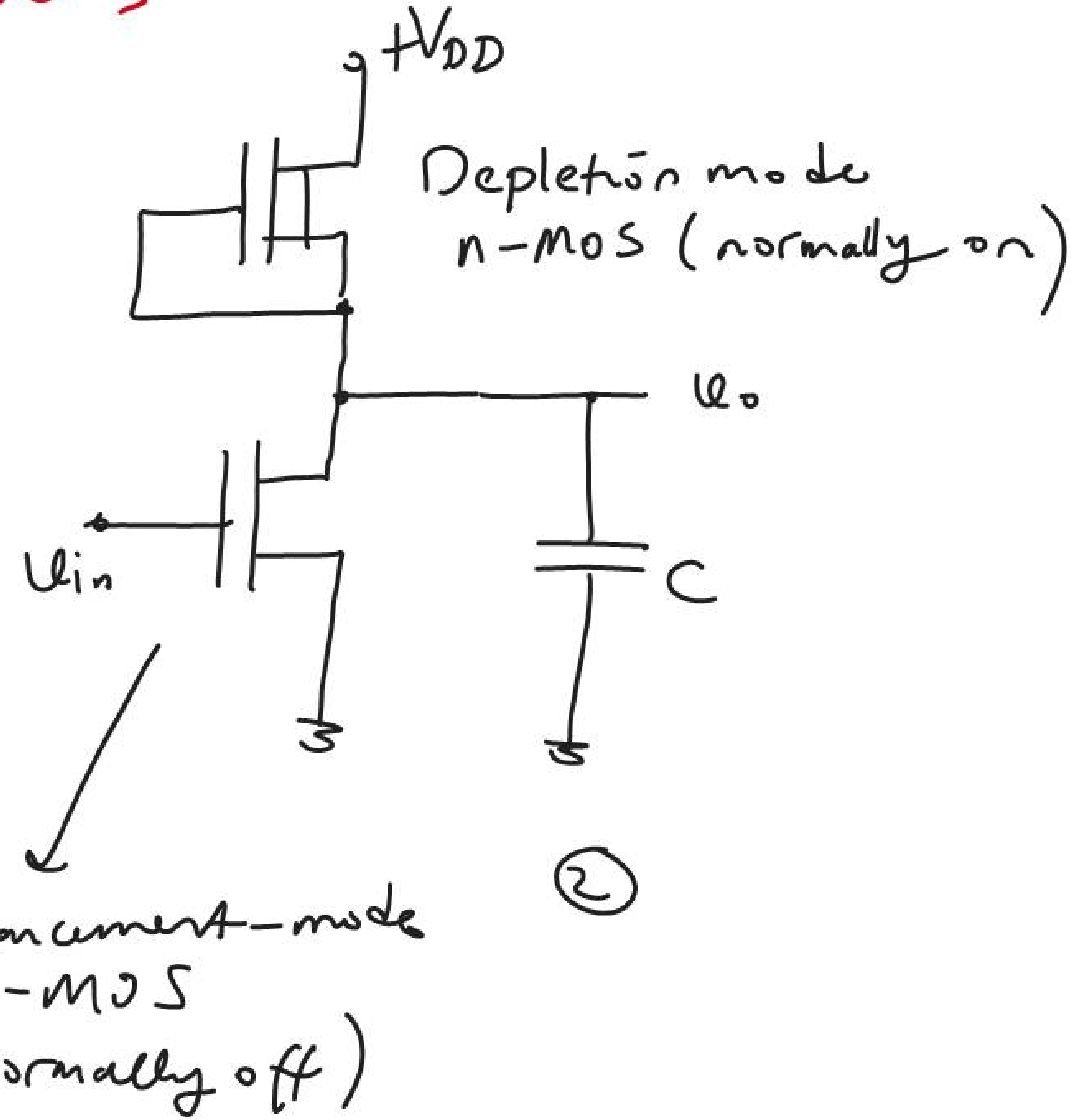


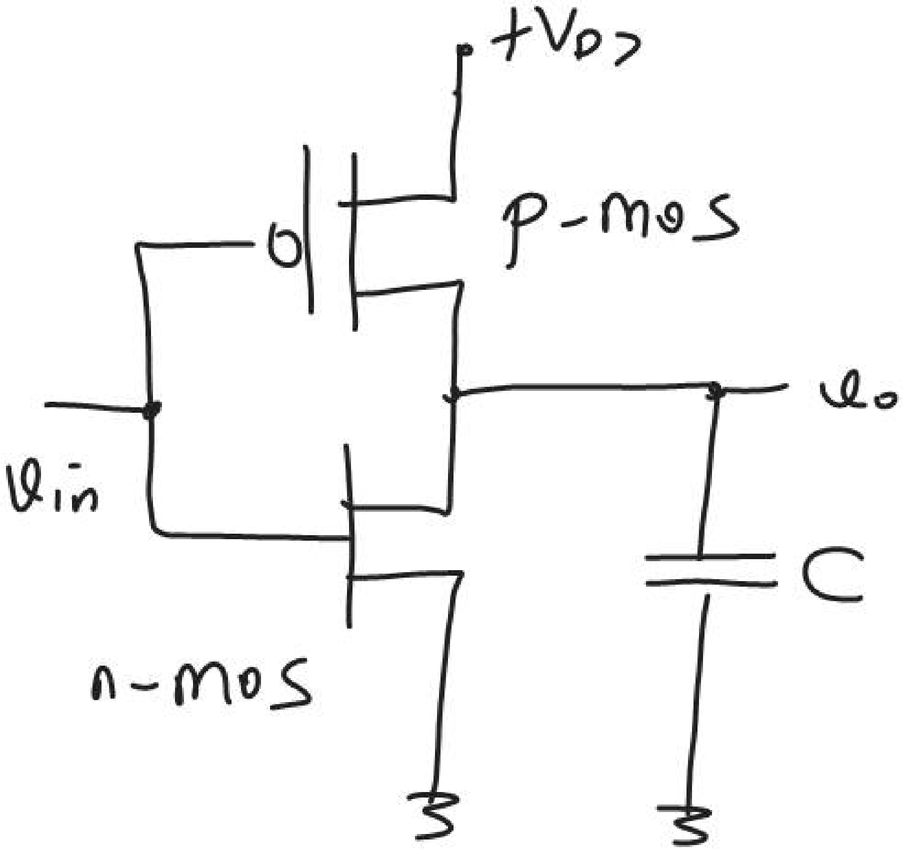
$$N_{MH} = V_{OH} - V_{IH}$$

$$N_{ML} = V_{IL} - V_{OL}$$

Types of Inverters

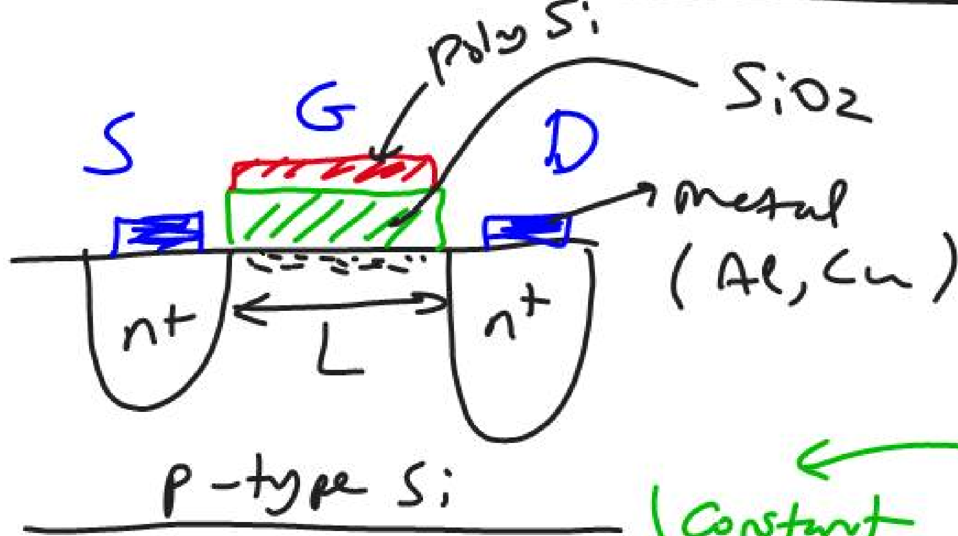


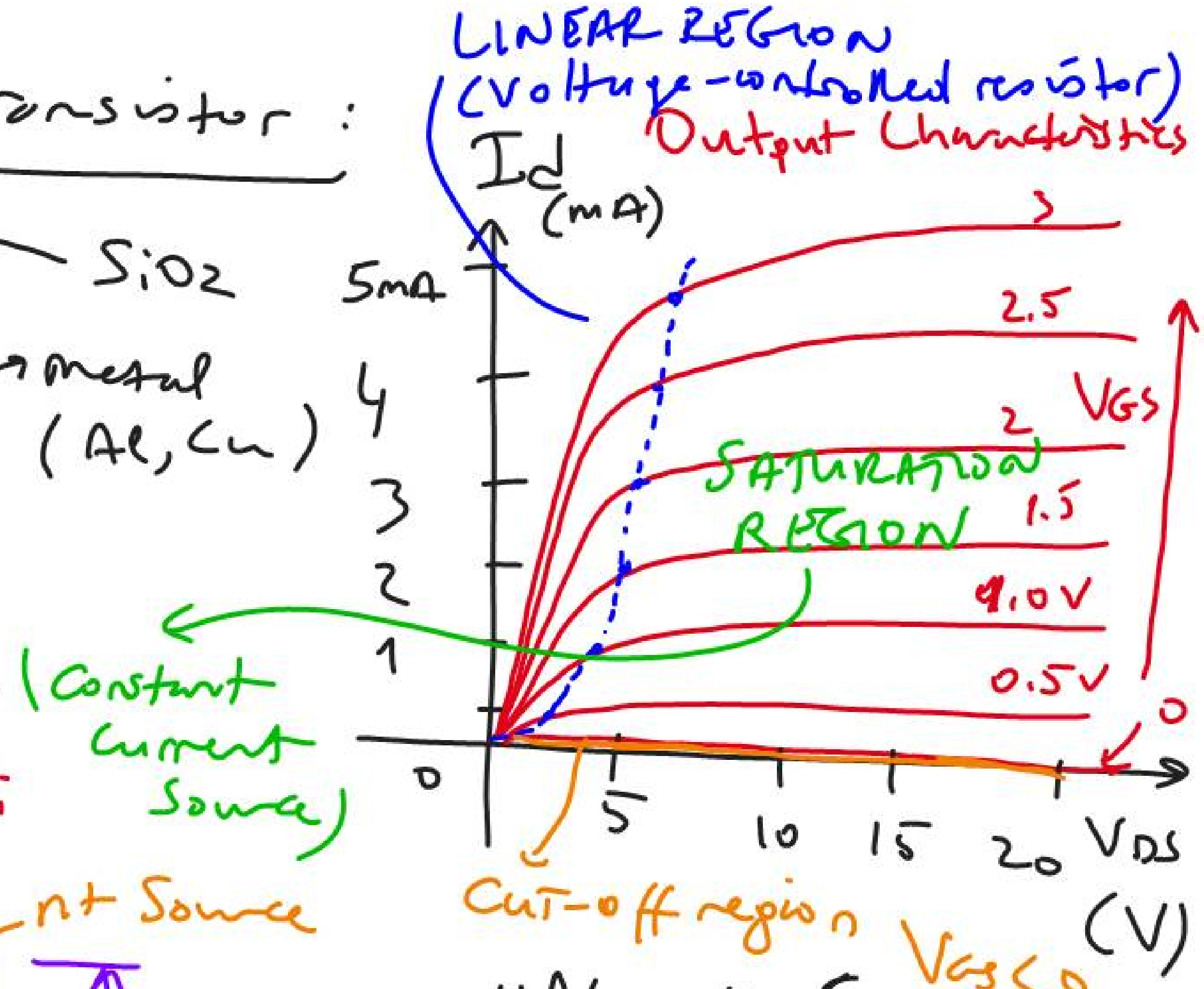


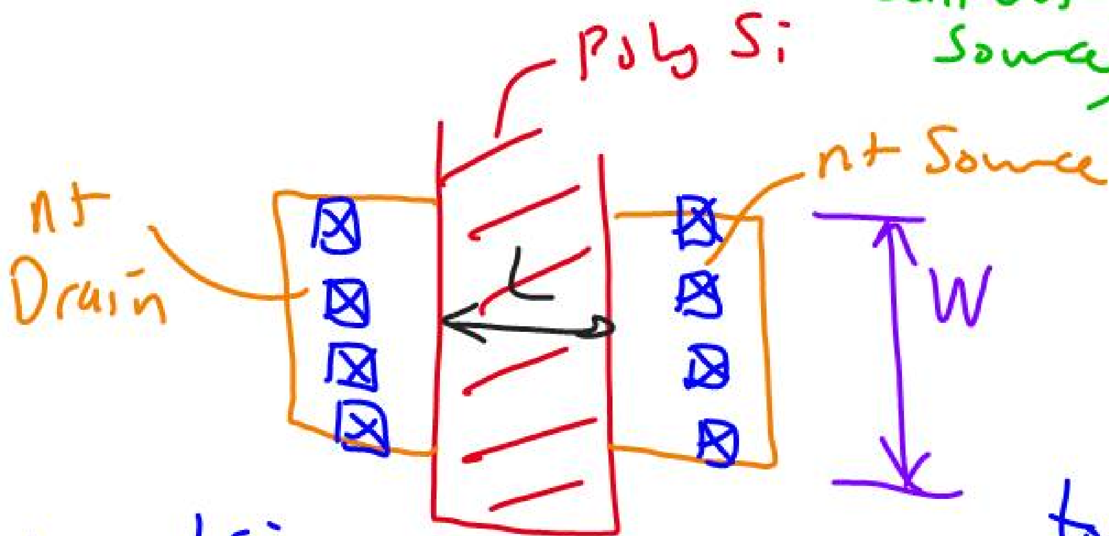


③ CMOS inverter

an-n MOS transistor:







$$\beta = \left(\frac{W}{L}\right)\frac{\mu \cdot \epsilon}{t_{ox}}$$

t_{ox} is the thickness of Gate oxide :
$(SiO_2) \approx 50 - 150\ \text{Å}$

μ : mobility $\left(\frac{cm^2}{V\text{-}s}\right)$
ϵ = permittivity $\rightarrow$ F/cm

① Cut-off region

$I_{ds} = 0$ when $V_{GS} \leq V_T$ ($V_T = 0$ in the figure above)

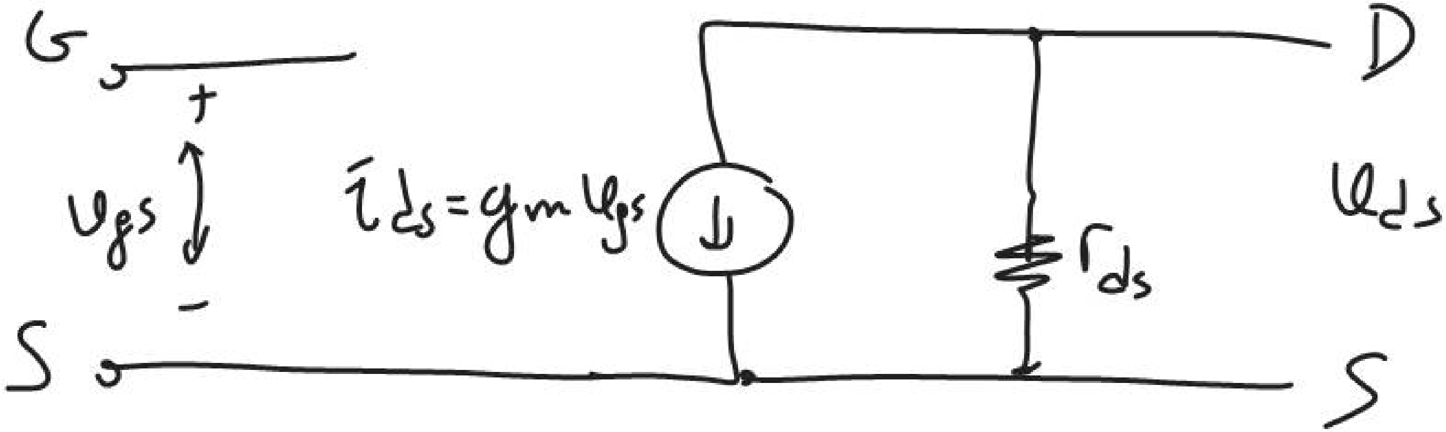
② Linear Region

$$I_{ds} = \beta\left(V_{GS} - V_T - \frac{V_{DS}}{2}\right)V_{DS}$$ when $V_{GS} - V_T \geq V_{DS}$

③ Saturation Region

$$I_{ds} = \frac{\beta}{2}\left(V_{GS} - V_T\right)^2$$ when $V_{GS} - V_T < V_{DS}$

I_{ds} is not a function of V_{DS}.


G
D
+
v_{gs}
−
$i_{ds} = g_m v_{gs}$
v_{ds}
r_{ds}
S
S