Dynamic Characteristics

Inverted output with delay

t_r - Rise time
t_f - Fall time
t_{pd} - Propagation Delay

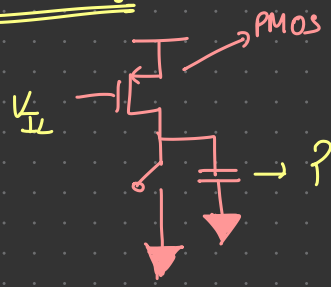
} Based on output

$$t_{pd} = \frac{t_r + t_f}{2}$$ [Average of both]

Assumptions:

① At a time, only one transistor is ON and other is OFF

Rise-time:



[Assume NMOS is OFF]

We use it because one-logic gate will drive one to others

With finite sizes, they will give some gate capacitance which will act as load capacitance to the drives

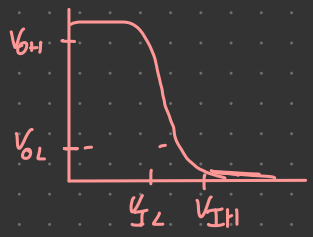
Essentially corresponds to time taken to charge capacitor

V_{IL} - used as it is considered as max limit till which we can consider as low level

$T_{rise} \rightarrow 0$ to V_{OH}

For capacitor

This is the recognised level for logic high



Initially capacitor voltage increases roughly behaving like RC Ideally we should get

$$V_o = V_1\left[1 - e^{-t/RC}\right]$$

↳ ∞ time to reach $V_o = V_1$

5τ time to reach 99% etc

Due to this ∞ time issue, we find the time taken reach V_{OH}

Derivation:

Drain current = Capacitor current $V_{o,1}$

$$I_{dp} = C\frac{dV_o}{dt} \Rightarrow \int_0^{T_2} \frac{dt}{C} = \int_0^{} \frac{dV_o}{I_{dp}}$$

$$\frac{T_r}{C} = \int_0^{V_{OH}} \frac{dV_o}{I_{dp}}$$

→ Initially when PMOS was ON, it was in saturation

→ After a while due to capacitor charging when

$V_o \leq V_i + |V_{Tp}|$ → In saturation initially

$V_o > V_i + |V_{Tp}|$ → Goes into linear region

$$\frac{T_r}{C} = \int_0^{V_i+|V_{Tp}|} \frac{dV_o}{I_{dp_{sat}}} + \int_{V_i+|V_{Tp}|}^{V_{OH}} \frac{dV_o}{I_{dp_{lin}}}$$

Do the full derivation for above as its important for quiz

$$T_{rise} = \frac{2C\left[V_i + |V_{Tp}|\right]}{K_p\left(V_{DD} - V_{IL} - |V_{Tp}|\right)^2} + \frac{C}{K_p\left(V_{DD} - V_{IL} - |V_{Tp}|\right)} \ln\left[\frac{V_{DD} + V_{OH} - 2V_{IL} - 2|V_{Tp}|}{V_{DD} - V_{OH}}\right]$$

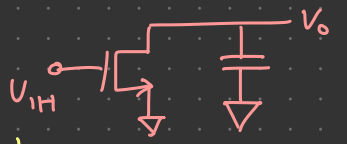
Saturation — Linear

Saturation region – Acts like constant current source

Linear region – Acts like resistor in PMOS

Fall Time:

↳ NMOS - ON
PMOS - OFF



↳ Minimum value of voltage which can be considered logic High

T_f defined for drop from:

$V_{dd} \rightarrow V_{OL}$

$$I_{dn} = -C\frac{dV_o}{dt}$$

- Initially in saturation region
- Once it changes, it will eventually go into linear region
- ↳ Break integral into two parts - saturation, linear

$V_o \geq V_i - V_{tn} \rightarrow$ Saturation

$V_o < V_i - V_{tn} \rightarrow$ Linear

$$\frac{T_f}{C} = -\int_{V_{DD}}^{V_i - V_{tn}} \frac{dV_o}{I_{d\,sat}} - \int_{V_i - V_{tn}}^{V_{OL}} \frac{dV_o}{I_{d\,lin}}$$

$$T_{fall\,tn} = \underbrace{\frac{2C\left[V_{DD} - V_{IH} - V_{tn}\right]}{K_n\left[V_{IH} - V_{Tn}\right]^2}}_{Sat} + \underbrace{\frac{C}{K_n\left[V_{IH} - V_{tn}\right]} \ln\left[\frac{2(V_{IH} - V_{Tn}) - V_{OL}}{V_{OL}}\right]}_{Linear}$$

In general,

$$\frac{\gamma K}{C} = f\left(V_{DD}, V_{IL}, V_{Th}, V_{OL}, V_{IL}, V_{OH}, V_{th}\right)$$

$\frac{\gamma K}{C}$ → Function

↳ Function of voltages that are technology dependent

$\frac{K^n \gamma}{C}$ = constant for given technology, supply voltage

IMP

If noise margin parameters are given $\frac{K^n \gamma}{C}$ can be calculated

→ If C is increased, keeping K constant ⟶ γ will also increase

→ If C is increased, to have same γ ⟶ Increase K [Adjust $\frac{W}{L}$]

↳ $\mu_n C_{ox}\left[\frac{W}{L}\right]$

Usually L - const so only W is scaled up/down