Resistive Load Inverter

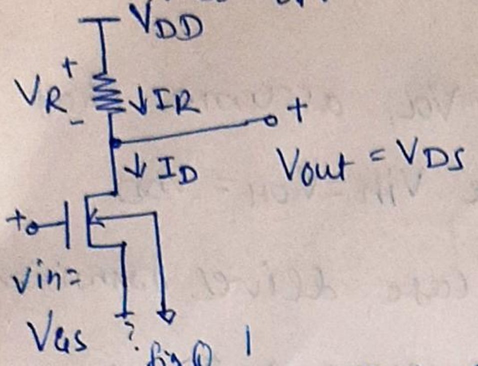

fig: Resistive load inverter.

operating Regions of the driver transistor in the resistive-load inverter.

i/p voltage range	Region
$V_{in} < V_{TO}$	cut-off
$V_{TO} \le V_{in} < V_{out} + V_{TO}$	saturation
$V_{in} \ge V_{out} + V_{TO}$	linear

$$I_{D\,sat} = \frac{k_n}{2}\left(\underset{=V_{in}}{V_{gs}} - V_t\right)^2 \quad \text{— (A)}$$

$$I_{D\,lin} = \frac{k_n}{2}\left[2(V_{gs}-V_t)\cdot V_{ds} - V_{ds}^2\right] \quad \text{— (B)}$$

$$= \frac{k_n}{2}\left[2(V_{in}-V_t)\cdot V_{out} - V_{out}^2\right] \quad \text{— (C)}$$

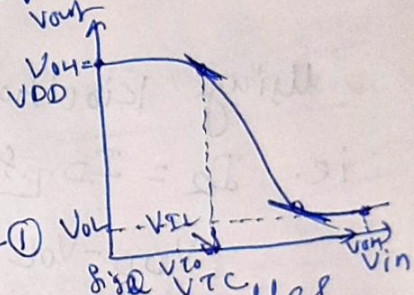

fig 2 VTC

Calculation of V_{OH}

o/p voltage V_{out} is given by

$$V_{out} = V_{DD} - R_L \cdot I_R \quad \text{—— (1)}$$

When the i/p voltage V_{in} is low i.e. smaller than the threshold voltage of the driver MOSFET the driver transistor is cut off. Since the drain current of the driver transistor is equal to the load current $I_R = I_D = 0$

put I_D in eq^n (1), eq^n (1) (2)

$$\boxed{\therefore V_{out} = V_{OH} = V_{DD}} \quad \text{—— (2)}$$

Calculation of V_{OL}

To calculate the o/p low voltage V_{OL}, assume that the i/p voltage is equal to V_{OH}. i.e. $V_{in} = V_{OH} = V_{DD}$.

Since $V_{in} - V_{TO} > V_{out}$ in this case driver transistor operates in the linear region. current I_R is

$$I_R = \frac{V_{DD} - V_{out}}{R_L} \quad \text{--- (3)}$$

Using Kirchhoff current law (KCL) for the o/p node,

i.e. $I_R = I_D$ if $V_{out} = V_{OL}$ --- (4)

$$\frac{V_{DD} - V_{OL}}{R_L} = \frac{k_n}{2}\left[2(V_{DD} - V_{TO}) \cdot V_{OL} - V_{OL}^2\right] \quad \text{--- (5)}$$

$$\therefore \left(\frac{V_{DD} - V_{OL}}{R_L}\right)\frac{2}{k_n} = 2(V_{DD} - V_{TO}) \cdot V_{OL} - V_{OL}^2 \quad \text{--- (6)}$$

$$\therefore V_{OL}^2 - 2(V_{DD} - V_{TO})V_{OL} + \frac{2}{k_n \cdot R_L}(V_{DD} - V_{OL}) = 0 \quad \text{--- (7)}$$

$$V_{OL}^2 - \left[2(V_{DD}-V_{TO}) + \frac{2}{k_n R_L}\right]V_{OL} + \frac{2}{k_n R_L}V_{DD} = 0 \quad (8)$$

in eqn (8)

$$a=1, \quad b = -\left[2(V_{DD}-V_{TO}) + \frac{2}{k_n R_L}\right], \quad c = \frac{2V_{DD}}{k_n R_L}$$

$$\text{Roots} = \frac{-b \pm \sqrt{b^2-4ac}}{2a} \quad (9)$$

$$= \frac{-b \pm \sqrt{4\left\{(V_{DD}-V_{TO}) + \frac{1}{k_n R_L}\right\}^2 - 4(1)\left(\frac{2V_{DD}}{k_n R_L}\right)}}{2(1)}$$

$$= \frac{2\left[(V_{DD}-V_{TO}) + \frac{1}{k_n R_L}\right] \pm 2\sqrt{\left\{(V_{DD}-V_{TO} + \frac{1}{k_n R_L}\right\}^2 - \frac{2V_{DD}}{k_n R_L}}}{2}$$

$$\boxed{V_{OL} = V_{DD}-V_{TO} + \frac{1}{k_n R_L} - \sqrt{\left\{(V_{DD}-V_{TO} + \frac{1}{k_n R_L}\right\}^2 - \frac{2V_{DD}}{k_n R_L}}} \quad (10)$$

Calculation of V_{IL} :=>

V_{IL} is the smaller of the two i/p voltage values at which the slope of the VTC becomes equal (-1) i.e. $\frac{dV_{out}}{dV_{in}} = -1$. from fig (1) when $V_{in} = V_{IL}$, V_{out} is $< V_{OH}$, $V_{out} > V_{in} - V_{TO}$, driver transistor operate in saturation.

By Applying KCL at o/p node

$$I_R = I_D$$

$$\frac{V_{DD}-V_{out}}{R_L} = \frac{k_n}{2}\left(V_{gs}-V_{t0}\right)^2 \quad -(11)$$

$V_{gs} = V_{in}$

$$\frac{V_{DD}-V_{out}}{R_L} = \frac{k_n}{2}\left(V_{in}-V_{T0}\right)^2 \quad -(12)$$

differentiate both sides of eqn (12) w.r.t. V_{in},

$$\frac{d}{dV_{in}}\left(\frac{V_{DD}-V_{out}}{R_L}\right) = \frac{d}{dV_{in}}\left[\frac{k_n}{2}\left(V_{in}-V_{T0}\right)\right]^2 \quad -(13)$$

$$-\frac{1}{R_L}\frac{dV_{out}}{dV_{in}} = \frac{k_n}{2}\left[2\left(V_{in}-V_{t0}\right)\cdot(1)\right]$$

at $V_{in} = V_{IL}$ & $\frac{dV_{out}}{dV_{in}}$ eqn (13) $\Rightarrow$

$$-\frac{1}{R_L}(-1) = \frac{k_n}{\cancel{2}}\left[\cancel{2}\left(V_{IL}-V_{T0}\right)\right]$$

$$+\frac{1}{k_n \cdot R_L} + V_{T0} = V_{IL}$$

$$\boxed{\therefore V_{IL} = V_{T0} + \frac{1}{k_n \cdot R_L}} \quad -(14)$$

by substituting eqn (14) in eqn (11) : eqn 11 $\Rightarrow$

$$V_{out} = V_{DD} - \frac{k_n \cdot R_L}{2}\left(V_{T0} + \frac{1}{k_n \cdot R_L} - V_{T0}\right)^2$$

$$\boxed{V_{out}\Big|_{V_{in}=V_{IL}} = V_{DD} - \frac{1}{2 k_n \cdot R_L}}$$