VLSI Design (BEC-41)
(Unit-2, Lecture-3)

Presented By:

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Resistive-Load Inverter

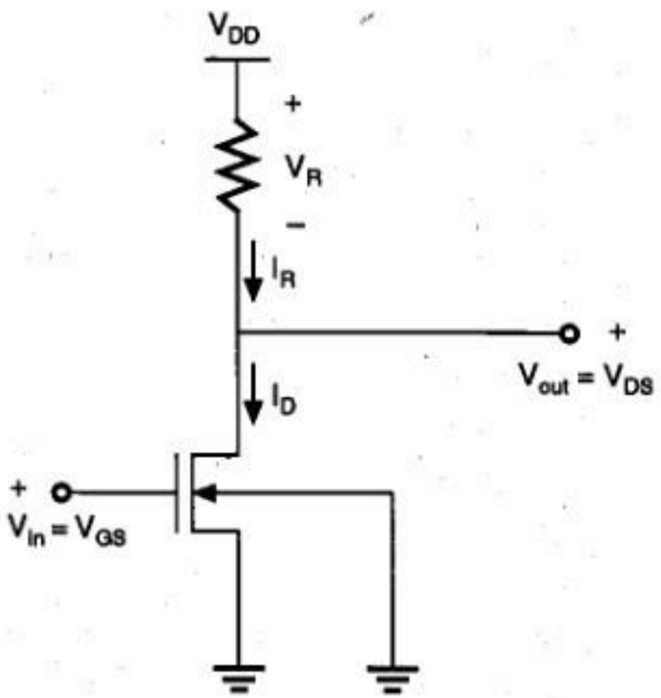

Fig. Resistive load inverter

Table: Operating regions of the driver transistor in the resistive-load inverter.

Input Voltage Range	Operating Mode
$V_{in} < V_{T0}$	cut-off
$V_{T0} \leq V_{in} < V_{out} + V_{T0}$	saturation
$V_{in} \geq V_{out} + V_{T0}$	linear

Resistive-Load Inverter

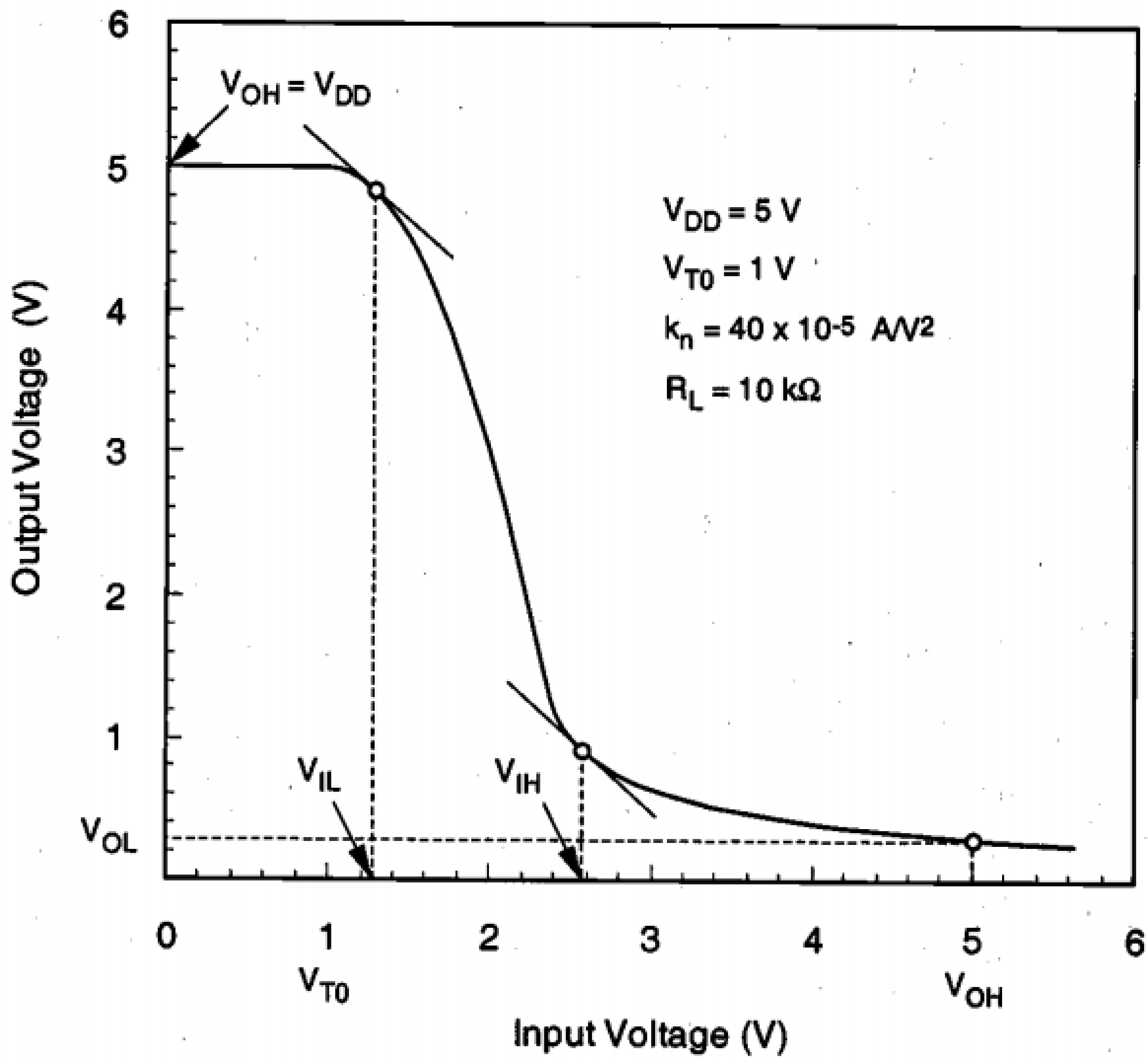

Fig. Typical VTC of a resistive-load inverter circuit. Important design parameters of the circuit are shown in the inset.

Resistive-Load Inverter

Calculation of V_{OH}

- First, we note that the output voltage V_{out} is given by

$$V_{out} = V_{DD} - R_L \cdot I_R$$

- When the input 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, $I_R = I_D = 0$.
- It follows that the output voltage of the inverter under these conditions is:

$$V_{OH} = V_{DD}$$

Resistive-Load Inverter

Calculation of V_{OL}

- To calculate the output low voltage V_{OL}, we assume that the input voltage is equal to V_{OH} i.e., $V_{in} = V_{OH} = V_{DD}$. Since $V_{in} - V_{T0} > V_{OUT}$ in this case, the driver transistor operates in the linear region. Also note that the load current I_R is:

$$I_R = \frac{V_{DD} - V_{out}}{R_L}$$

$$\frac{V_{DD} - V_{OL}}{R_L} = \frac{k_n}{2} \cdot \left[2 \cdot \left(V_{DD} - V_{T0}\right) \cdot V_{OL} - V_{OL}^2\right]$$

$$V_{OL}^2 - 2 \cdot \left(V_{DD} - V_{T0} + \frac{1}{k_n R_L}\right) \cdot V_{OL} + \frac{2}{k_n R_L} \cdot V_{DD} = 0$$

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

Resistive-Load Inverter

Calculation of V_{IL}

- By definition, V_{IL} is the smaller of the two input voltage values at which the slope of the VTC becomes equal to (-1),i.e., $dV_{out}/ dV_{in} = - 1$.
- Simple inspection of VTC that when the input is equal to V_{IL}, the output voltage (V_{out}) is only slightly smaller than V_{OH}.
- Consequently, $V_{out} > V_{in} - V_{T0}$, and the driver transistor operates in saturation.

$$\frac{V_{DD} - V_{out}}{R_L} = \frac{k_n}{2} \cdot (V_{in} - V_{T0})^2$$

- To satisfy the derivative condition, we differentiate both sides of equation with respect to V_{in}, which results in the following equation:

$$-\frac{1}{R_L} \cdot \frac{dV_{out}}{dV_{in}} = k_n \cdot (V_{in} - V_{T0})$$

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

Resistive-Load Inverter

Calculation of V_{IH}

- V_{IH} is the larger of the two voltage points on VTC at which the slope is equal to (-1).
- When the input voltage is equal to V_{IH}, the output voltage V_{out}, is only slightly larger than the output low voltage V_{OL}.
- Hence, $V_{out} < V_{in} - V_{T0}$, and the driver transistor operates in the linear region.

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

- Differentiating both sides with respect to V_{in}, we obtain:

$$-\frac{1}{R_L} \cdot \frac{dV_{out}}{dV_{in}} = \frac{k_n}{2} \cdot \left[2 \cdot (V_{in} - V_{T0}) \cdot \frac{dV_{out}}{dV_{in}} + 2\,V_{out} - 2\,V_{out} \cdot \frac{dV_{out}}{dV_{in}} \right]$$

Resistive-Load Inverter

Calculation of V_{IH} (Continued..)

- Next, we can substitute $dV_{out}/dV_{in} = -1$ into previous equation, since the slope of the VTC is equal to (-1) also at $V_{in} = V_{IH}$

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

$$V_{IH} = V_{T0} + 2V_{out} - \frac{1}{k_n R_L}$$

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

$$V_{out}\left(V_{in}=V_{IH}\right) = \sqrt{\frac{2}{3}\cdot\frac{V_{DD}}{k_n R_L}} \qquad V_{IH} = V_{T0} + \sqrt{\frac{8}{3}\cdot\frac{V_{DD}}{k_n R_L}} - \frac{1}{k_n R_L}$$

Resistive-Load Inverter

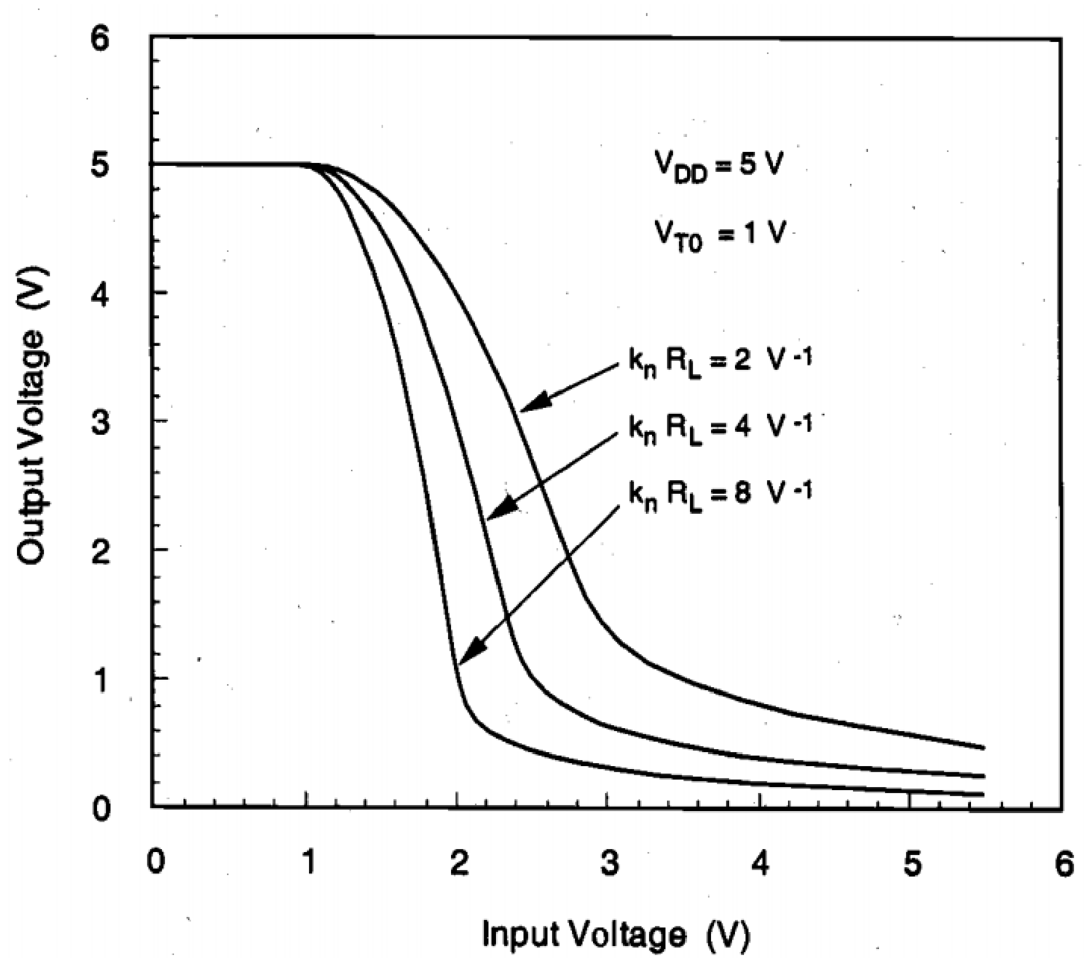

Fig. Voltage transfer characteristics of the resistive-load inverter, for different values of the parameter (k_n,R_L)