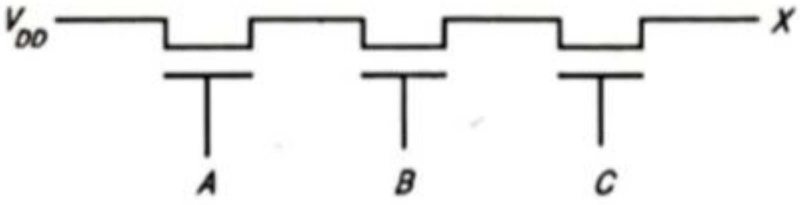
The Pass Transistor



Pass transistor And gate.

$X = A.B.C$ (Logic 1 = $V_{DD} - V_t$)

The output conductance g_{ds} can be expressed by

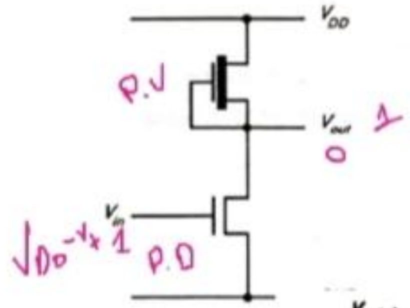
$$g_{ds} = \frac{\delta I_{ds}}{\delta V_{gs}} = \lambda . I_{ds} \, \alpha \left(\frac{1}{L}\right)^2$$

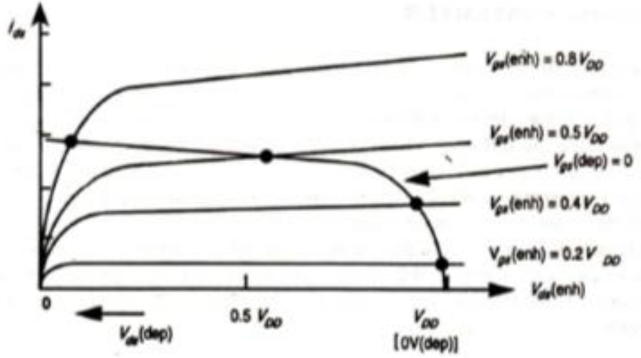
Here the strong dependence on the channel length is demonstrated as

$$\lambda \alpha \left(\frac{1}{L}\right) \text{ and } I_{ds} \, \alpha \left(\frac{1}{L}\right)$$

for the MOS device.

The nMOS Inverter





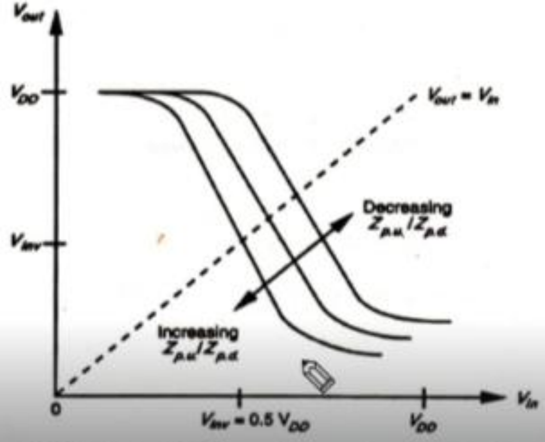


FIGURE 2.7 nMOS inverter transfer characteristic.

$V_{out} = V_{in}$

V_{inv}

$$\text{Gain} = \frac{\delta V_{out}}{\delta V_{in}}$$

DETERMINATION OF PULL-UP TO PULL-DOWN RATIO *(Zp.u} Zp.d.)* FOR AN nMOS INVERTER DRIVEN BY ANOTHER nMOS INVERTER

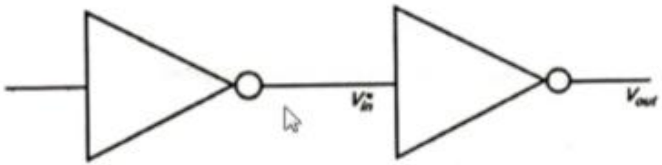


FIGURE 2.8 nMOS inverter driven directly by another inverter.

For equal margins around the inverter threshold, we set *Vinv* = 0.5 *VDD*· At this point both transistors are in saturation and

$$I_{ds} = K\frac{W}{L}\frac{(V_{gs} - V_t)^2}{2}$$

In the depletion mode

$$I_{ds} = K\frac{W_{p.u.}}{L_{p.u.}}\frac{(-V_{td})^2}{2} \text{ since } V_{gs} = 0$$

and in the enhancement mode

$$I_{ds} = K\frac{W_{p.d.}}{L_{p.d.}}\frac{(V_{inv} - V_t)^2}{2} \text{ since } V_{gs} = V_{inv}$$

Equating (since currents are the same) we have

$$\frac{W_{p.d.}}{L_{p.d.}}(V_{inv} - V_t)^2 = \frac{W_{p.u.}}{L_{p.u.}}(-V_{td})^2$$

$$Z_{p.d.} = \frac{L_{p.d.}}{W_{p.d.}};\ Z_{p.u.} = \frac{L_{p.u.}}{W_{p.u.}}$$

we have

$$\frac{1}{Z_{p.d.}}(V_{inv} - V_t)^2 = \frac{1}{Z_{p.u.}}(-V_{td})^2$$

whence

$$V_{inv} = V_t - \frac{V_{td}}{\sqrt{Z_{p.u.}/Z_{p.d.}}} \qquad (2.9)$$

Now we can substitute typical values as follows:

$$V_t = 0.2V_{DD};\ V_{td} = -0.6V_{DD}$$

$$V_{inv} = 0.5V_{DD} \text{ (for equal margins)}$$

thus, from equation (2.9)

$$0.5 = 0.2 + \frac{0.6}{\sqrt{Z_{p.u.}/Z_{p.d.}}}$$

PULL-UP TO PULL-DOWN RATIO FOR AN nMOS INVERTER DRIVEN THROUGH ONE OR MORE PASS TRANSISTORS

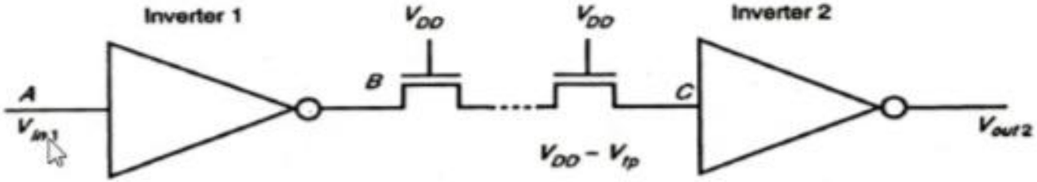


FIGURE 2.9 Pull-up to pull-down ratios for inverting logic coupled by pass transistors.

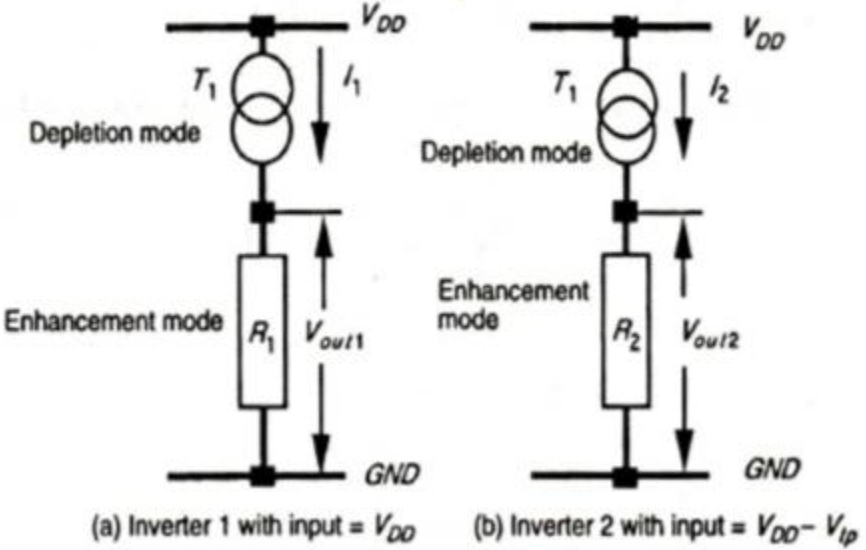


FIGURE 2.10 Equivalent circuits of inverters 1 and 2.

For the p.d. transistor

$$I_{ds} = K\frac{W_{p.d.1}}{L_{p.d.1}}\left((V_{DD} - V_t)V_{ds1} - \frac{V_{ds1}^2}{2}\right) \qquad \text{(from 2.4)}$$

Therefore

$$R_1 = \frac{V_{ds1}}{I_{ds}} = \frac{1}{K}\frac{L_{p.d.1}}{W_{p.d.1}}\left(\frac{1}{V_{DD} - V_t - \frac{V_{ds1}}{2}}\right)$$

Note that V_{ds1} is small and $V_{ds1}/2$ may be ignored.
Thus

$$R_1 \doteqdot \frac{1}{K}Z_{p.d.1}\left(\frac{1}{V_{DD} - V_t}\right)$$

Now, for depletion mode p.u. in saturation with $V_{gs} = 0$

$$I_1 = I_{ds} = K\frac{W_{p.u.1}}{L_{p.u.1}}\frac{(-V_{td})^2}{2} \qquad \text{(from 2.5)}$$

The product

$$I_1R_1 = V_{out\,1}$$

Thus

$$V_{out1} = I_1R_1 = \frac{Z_{p.d.1}}{Z_{p.u.1}}\left(\frac{1}{V_{DD} - V_t}\right)\frac{(V_{td})^2}{2}$$

Consider inverter 2 (Figure 2.10(b)) when input = $V_{DD} - V_{tp}$. As for inverter 1

$$R_2 \doteqdot \frac{1}{K}Z_{p.d.2}\frac{1}{((V_{DD} - V_{tp}) - V_t}$$

$$\frac{V_{ds1}}{K\frac{W_{pd1}}{L_{pd1}}\left((V_{DD}-V_t)-\frac{V_{ds}}{2}\right)V_{ds1}}$$

$$(V_{inv}-V_t)^2 = \frac{Z_{pd}}{Z_{pu}}(-V_{td})^2$$

$$V_{inv}-V_t = \frac{V_{td}}{\sqrt{Z_{p.u}/Z_{p.d}}}$$

$$K\frac{W_{pu1}}{L_{pu1}}\frac{(-V_{td})^2}{2}\times\frac{1}{K}Z_{pd1}\left(\frac{1}{V_{DD}-V_t}\right)$$

$$\frac{Z_{pd1}}{Z_{pu1}}\left(\frac{1}{V_{DD}-V_t}\right)\left(\frac{V_{td}^2}{2}\right)$$

$$I_2 = K \frac{1}{Z_{p.u.2}} \frac{(-V_{td})^2}{2}$$

whence

$$V_{out\,2} = I_2 R_2 = \frac{Z_{p.d.2}}{Z_{p.u.2}} \left(\frac{1}{V_{DD} - V_{tp} - V_t} \right) \frac{(-V_{td})^2}{2}$$

If inverter 2 is to have the same output voltage under these conditions then $V_{out\,1} = V_{out\,2}$. That is

$$I_1 R_1 = I_2 R_2$$

Therefore

$$\frac{Z_{p.u.2}}{Z_{p.d.2}} = \frac{Z_{p.u.1}}{Z_{p.d.1}} \frac{(V_{DD} - V_t)}{(V_{DD} - V_{tp} - V_t)}$$

$$\frac{Z_{pd1}}{Z_{pu1}}\left(\frac{1}{V_{DD}-V_t}\right)\frac{(V_t)^2}{2} = \frac{Z_{pd2}}{Z_{pu2}}\left(\frac{1}{V_{DD}-V_{tp}-V_t}\right)\left(\frac{V_{td}^2}{2}\right)$$

Taking typical values

$$V_t = 0.2 V_{DD}$$

$$V_{tp} = 0.3 V_{DD}^{*}$$

$$\frac{Z_{p.u.2}}{Z_{p.d.2}} = \frac{Z_{p.u.1}}{Z_{p.d.1}} \frac{0.8}{0.5}$$

Therefore

$$\frac{Z_{p.u.2}}{Z_{p.d.2}} \doteqdot 2 \frac{Z_{p.u.1}}{Z_{p.d.1}} = \frac{8}{1}$$