

Solutions

University of New Mexico
Department of Electrical and Computer Engineering

ECE 520 - VLSI Design

1. The circuit in Figure 1 is a *level shift* circuit. It achieves a DC level shift between the input and the output. The value of this shift is determined by the current I_o . Assume $X_d=0$, $\gamma=0.4$, $2|\phi_f|=0.6V$, $V_{T0}=0.43V$, $k_n'=115\mu A/V^2$ and $\lambda=0$.

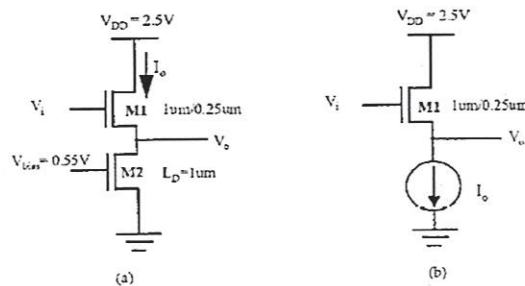
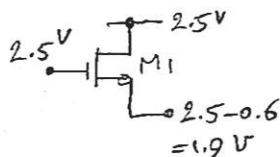


Figure 1 - NMOS Level Shifter

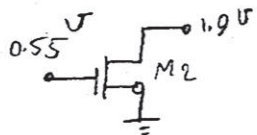
- a. Suppose we want the nominal level shift between V_i and V_o to be $0.6V$ in the circuit in Figure 1-a. Neglecting the body effect, calculate the width of M2 to provide this level shift (Hint: first relate V_i to V_o in terms of I_o).

Assume $V_{in} = V_{dd} = 2.5V$, then



$$M1: \begin{cases} V_{DS} = 0.6V \\ V_{GS} = 0.6V \end{cases}$$

$$\frac{V_{DS}}{0.6V} > \frac{V_{GS} - V_T}{0.17V} \Rightarrow M1 \text{ is in Saturation}$$



$$M2: \begin{cases} V_{DS} = 1.9V \\ V_{GS} = 0.55V \end{cases}$$

$$\frac{V_{DS}}{1.9V} > \frac{V_{GS} - V_T}{0.12V} \Rightarrow M2 \text{ is in Saturation}$$

$$\begin{cases} I_{DS1} = \frac{k_n'}{2} \left(\frac{W}{L}\right) (V_{GS1} - V_T)^2 = \frac{115 \mu A/V^2}{2} \left(\frac{1}{0.25}\right) (0.6 - 0.43)^2 = 6.647 \mu A \\ I_{DS2} = \frac{k_n'}{2} \left(\frac{W}{L}\right) (V_{GS2} - V_T)^2 = \frac{115 \mu A/V^2}{2} \left(\frac{W}{1\mu}\right) (0.55 - 0.43)^2 = 0.828 \times \left(\frac{W}{1\mu}\right) \mu A \end{cases}$$

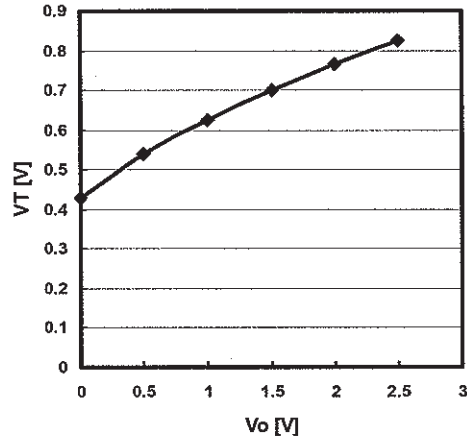
$$I_{DS2} = I_{DS1} \Rightarrow 0.828 \left(\frac{W}{1\mu}\right) = 6.647 \mu A \Rightarrow \underline{W_2 = 8\mu}$$

- b. Now assume that an ideal current source replaces M2 (Figure 1-b). The NMOS transistor M1 experiences a shift in V_T due to the body effect. Find V_T as a function of V_o for V_o ranging from 0 to 2.5V with 0.5V intervals. Plot V_T vs. V_o .

$$\begin{cases} V_T = V_{T0} + \gamma (\sqrt{|2\phi_f| + V_{SB}} - \sqrt{|2\phi_f|}) \\ V_{SB} = V_o \end{cases}$$

$$\Rightarrow V_T = 0.43 + 0.4 (\sqrt{0.6 + V_o} - \sqrt{0.6})$$

V_o	V_T
0	0.43
0.5	0.54
1	0.63
1.5	0.70
2	0.76
2.5	0.82



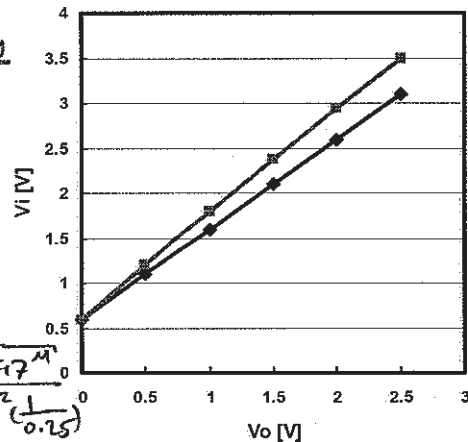
- c. Plot V_o vs. V_i as V_o varies from 0 to 2.5V with 0.5 V intervals. Plot two curves: one neglecting the body effect and one accounting for it. How does the body effect influence the operation of the level converter?

M1: Saturation

$$\begin{aligned} \Rightarrow I_D &= \frac{K'_n}{2} \left(\frac{W}{L}\right) (V_{GS} - V_T)^2 \\ &= \frac{K'_n}{2} \left(\frac{W}{L}\right) (V_i - V_o - V_{Tn})^2 \end{aligned}$$

$$\Rightarrow V_i = V_o + V_T + \sqrt{\frac{2I_D}{K'_n(W/L)}}$$

V_o	V_{in} ideal	V_{in} with body
0	0.6	0.6
0.5	1.1	1.21
1	1.6	1.79
1.5	2.1	2.36
2	2.6	2.93
2.5	3.1	3.49



$$\Rightarrow V_i = V_o + 0.43 + 0.4 (\sqrt{0.6 + V_o} - \sqrt{0.6}) + \sqrt{\frac{2 \times 6.647 \mu A}{115 \frac{\mu A/V^2}{0.25}}}$$

$$\Rightarrow V_i = V_o + 0.6 + 0.4 (\sqrt{0.6 + V_o} - \sqrt{0.6})$$

- d. At V_o (with body effect) = 2.5V, find V_o (ideal) and thus determine the maximum error introduced by the body effect.

$$V_i = 2.5 \Rightarrow V_o(\text{ideal}) = 2.5 - 0.6 = 1.9$$

From equation in Part 1.c: $V_o(\text{with body effect}) = 1.615$

$$\Rightarrow \text{ERROR} = V_o(\text{ideal}) - V_o(\text{with body effect}) = 1.9 - 1.615$$

$$\Rightarrow \text{ERROR} = 0.285 \text{ V}$$