PASS-TRANSISTOR LOGIC

INEL 4207 - Spring 2012
Figure 15.5 Conceptual pass-transistor logic gates. (a) Two switches, controlled by the input variables \( B \) and \( C \), when connected in series in the path between the input node to which an input variable \( A \) is applied and the output node (with an implied load to ground) realize the function \( Y = ABC \). (b) When the two switches are connected in parallel, the function realized is \( Y = A(B + C) \).
Figure 15.6 Two possible implementations of a voltage-controlled switch connecting nodes A and Y: (a) single NMOS transistor and (b) CMOS transmission gate.
Figure 15.7 A basic design requirement of PTL circuits is that every node have, at all times, a low resistance path to either ground or $V_{DD}$. Such a path does not exist in (a) when $B$ is low and $S_1$ is open. It is provided in (b) through switch $S_2$. 
Figure 15.9 Operation of the NMOS switch as the input goes low ($v_i = 0$ V). Note that the drain of an NMOS transistor is always higher in voltage than the source; correspondingly, the drain and source terminals interchange roles in comparison to the circuit in Fig. 15.8.
Example

Consider the NMOS switch shown in figs. 15.8 and 15.9 for which $\mu_n C_{ox} = 50 \mu A/V^2$, $\mu_p C_{ox} = 20 \mu A/V^2$, $|V_{t0}| = 1V$, $\gamma = 0.5\sqrt{V}$, $2\phi_f = 0.6V$ and $V_{DD} = 5V$. Let the transistor have $W/L = 4\mu m/2\mu m$, and assume $C = 50fF$.

1. For $v_i$ high, (fig. 15.8) find $V_{OH}$.

2. If the output feeds a CMOS inverter whose $(W/L)_p = 2.5(W/L)_n$, find the static current in the inverter and its power dissipation when its input is the value found in (1). Find the inverter output voltage.

3. Find $t_{PLH}$.

4. Find $t_{PHL}$ for the case with $v_i$ going low (fig. 15.9).

5. Find $t_p$. 
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1. For $v_i$ high, (fig. 15.8) find $V_{OH}$.

2. If the output feeds a CMOS inverter whose $(W/L)_p = 2.5(W/L)_n = 10\mu m/2\mu m$, find the static current in the inverter and its power dissipation when its input is the value found in (1). Find the inverter output voltage.

3. Find $t_{PLH}$.

4. Find $t_{PHL}$ for the case with $v_i$ going low (fig. 15.9).

5. Find $t_p$.

Answer: (1) $V_{OH} = 3.4V$. (2) $i_{DP} = 18\mu A$, $P_D = 90\mu W$, $v_O = 0.08$. (3) $i_D(0) = 800\mu A$, $i_D(t_{PLH}) = 50\mu A$, $i_{D, AV} = 425\mu A$, $t_{PLH} = C(V_{DD}/2)/i_{D, AV} = 0.29ns$. (4) $t_{PHL} = 0.17ns$. (5) $t_p = 0.23ns$. 
Figure 15.10 The use of transistor $Q_R$ connected in a feedback loop around the CMOS inverter, to restore the $V_{OH}$ level, produced by $Q_1$, to $V_{DD}$. 
Figure 15.11 The CMOS transmission gate and its circuit symbol.
Transmission gate resistance empirical formula (for submicron technologies) (eq. 15.36)

\[ R_{TG} = \frac{12.5}{(W/L)^n} \text{k}\Omega \]

*Figure 15.13* Plot of the equivalent resistances of the two transistors of the transmission gate in Fig. 15.12(a) and the overall resistance \( R_{TG} \) versus \( v_O \). The data apply to the situation specified in Exercise 15.5.
Figure 15.14  (a) A transmission gate connects the output of a CMOS inverter to the input of another.  (b) Equivalent circuit for the purpose of analyzing the propagation delay of the circuit in (a).
Elmore delay formula (eq. 15.37):

\[ t_p = 0.69 \left[ C_1 R_1 + C_2 (R_1 + R_2) + C_3 (R_1 + R_2 + R_3) \right] \]
For the circuit if fig. 15.14, fabricated using 0.13\(\mu\)m technology, \(Q_p\) of the first inverter has \(W/L = 2\), and both transistors in the t.g. have \(W/L = 1\). The caps are \(C_{\text{out1}} = 10\, fF\), \(C_{\text{TG1}} = C_{\text{TG2}} = 5\, fF\), and \(C_{\text{in2}} = 10\, fF\). Use empirical formulas to obtain \(R_{P1}\) and \(R_{TG}\); then find \(t_p\).
2. The following diagram shows an NMOS transistor operating as a switch.

Assuming that $\mu_n C_{ox} = 300 \mu A/V^2$, $W/L = 1.5$, $V_{t0} = 1V$, $\gamma = 0.5V^{1/3}$, and $2\phi_F = 0.6V$, find

(a) the maximum voltage across the capacitor, $v_Y$, if $v_A = v_C = 5V$. (15 pts)
(b) the voltage that must be applied to $v_C$ so that the voltage across the capacitor, $v_Y$, reaches 5V if $v_A = 5V$. (10 pts)
(c) an estimate of the fall time $t_f$ that it takes for $v_Y$ to drop from 90% to 10% of its initial value of 5V, using the average current method. Assume $C = 1pF$, $v_A = 0V$ and $v_C = 5V$. (10 pts)
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Ans.: (a) $v_Y = 3.4 V$; (b) $v_C = 6.8 V$; (c) $i_{D1} = 3.6 mA; i_{D2} = 0.84 mA; t_f = 1.8 ns$
Figure 15.16 Realization of a two-to-one multiplexer using pass-transistor logic.
Figure 15.17 Realization of the XOR function using pass-transistor logic.
Figure 15.18 An example of a pass-transistor logic gate utilizing both the input variables and their complements. This type of circuit is therefore known as complementary pass-transistor logic, or CPL. Note that both the output function and its complement are generated.
Probs. 13, 16, 21
Figure 15.19 (a) Basic structure of dynamic-MOS logic circuits. (b) Waveform of the clock needed to operate the dynamic logic circuit. (c) An example circuit.