Microelectronic Circuit Design
Sixth Edition Supplement
Solutions to Exercises

CHAPTER S6

Page S6-8

$NM_L = 0.8V - 0.4V = 0.4\ V \quad | \quad NM_H = 3.6V - 2.0V = 1.6\ V$

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$V_{10\%} = V_L + 0.1\left(\Delta V\right) = -2.6V + 0.1\left[-0.6 - \left(-2.6\right)\right] = -2.4\ V$

$\text{Checking: } V_{10\%} = V_H - 0.9\left(\Delta V\right) = -0.6V - 0.9\left[-0.6 - \left(-2.6\right)\right] = -2.4\ V$

$V_{90\%} = V_H - 0.1\left(\Delta V\right) = -0.6V - 0.1\left[-0.6 - \left(-2.6\right)\right] = -0.8\ V$

$\text{Checking: } V_{90\%} = V_L + 0.9\left(\Delta V\right) = -2.6V + 0.9\left[-0.6 - \left(-2.6\right)\right] = -0.8\ \text{V}$

$V_{50\%} = \frac{V_H + V_L}{2} = \frac{-0.6 - 2.6}{2} = -1.6\ V \quad | \quad t_r = t_4 - t_3 = 3\ ns \quad | \quad t_f = t_2 - t_1 = 5\ ns$

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$\text{At } P = 1\ mW: \quad PDP = 1mW\left(1ns\right) = 1\ pJ$

$\text{At } P = 3\ mW: \quad PDP = 3mW\left(1ns\right) = 3\ pJ$

$\text{At } P = 20\ mW: \quad PDP = 20mW\left(2ns\right) = 40\ pJ$

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$Z = \left(A + B\right)\left(B + C\right) = AB + AC + BB + BC = AB + BB + AC + BB + BC$

$Z = AB + B + AC + B + BC = B\left(A + 1\right) + AC + B\left(C + 1\right) = B + AC + B$

$Z = B + B + AC = B + AC$

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$$I_{DD} = \frac{P}{V_{DD}} = \frac{0.4mW}{2.5V} = 160\ \mu A \quad | \quad R = \frac{V_{DD} - V_L}{I_{DD}} = \frac{2.5V - 0.2V}{160\mu A} = 14.4\ k\Omega$$

$$1.6x10^{-4} A = 10^{-4}\frac{A}{V^2}\left(\frac{W}{L}\right)_S\left(2.5 - 0.6 - \frac{0.2}{2}\right)0.2\ V^2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{4.44}{1}$$

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$$I_{DD} = \frac{V_{DD} - V_L}{R} = \frac{3.3V - 0.1V}{102k\Omega} = 31.4\mu A$$

$$31.4x10^{-6} A = 6x10^{-5}\frac{A}{V^2}\left(\frac{W}{L}\right)_S\left(3.3 - 0.75 - \frac{0.1}{2}\right)0.1\ V^2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{2.09}{1}$$

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$$0.15V = \frac{R_{on}}{R_{on} + 28.8k\Omega}2.5V \rightarrow R_{on} = 1.84\ k\Omega$$

$$\left(\frac{W}{L}\right)_S = \frac{1}{10^{-4}\left(2.5 - 0.60 - \frac{0.15}{2}\right)(1.84k\Omega)} \rightarrow \left(\frac{W}{L}\right)_S = \frac{2.98}{1}$$

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$$R_{on} = \frac{1}{6x10^{-5}\left(\frac{1.03}{1}\right)\left(3.3 - 0.75 - \frac{0.2}{2}\right)} = 6.61\ k\Omega \quad | \quad V_L = \frac{6.61k\Omega}{6.61k\Omega + 102k\Omega}3.3V = 0.201\ V$$

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$$\left[\frac{1}{K_n R}\right] = \frac{V^2}{A}\frac{1}{\Omega} = \frac{V^2}{V} = V$$

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$$(a)\ K_n R = \left(6x10^{-5}\right)\left(\frac{1.03}{1}\right)\left(1.02x10^5\right) = \frac{6.30}{V}$$

$$NM_H = 3.3 - 0.75 + \frac{1}{2(6.30)} - 1.63\sqrt{\frac{3.3}{6.30}} = 1.45\ V \qquad NM_L = 0.75 + \frac{1}{6.30} - \sqrt{\frac{2(3.3)}{3(6.30)}} = 0.318\ V$$

(b) $V_{IL} = 0.090$ V, $V_{OH} = 3.22$ V, $V_{IH} = 1.77$ V, $V_{OL} = 0.591$ V

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Using MATLAB:

fzero(@(vh) ((vh-1.9-0.5*sqrt(0.6))^2-0.25(vh+0.6)), 1) | ans = 1.5535

fzero(@(vh) ((vh-1.9-0.5*sqrt(0.6))^2-0.25(vh+0.6)), 4) | ans = 3.2710

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$$V_H = 5 - \left[0.75 + 0.5\left(\sqrt{V_H + 0.6} - \sqrt{0.6}\right)\right] \rightarrow V_H = 3.61\ V$$

fzero(@(vh) (5-0.75-0.5*(sqrt(vh+0.6)-sqrt(0.6))-vh), 1) | ans = 3.61

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$$(a)\quad 80x10^{-6}A = 100x10^{-6}\frac{A}{V^2}\left(\frac{W}{L}\right)_S\left(1.55 - 0.60 - \frac{0.15}{2}\right)0.15\ V^2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{6.10}{1}$$

$$V_{TNL} = 0.6 + 0.5\left(\sqrt{.15 + 0.6} - \sqrt{0.6}\right) = 0.646\ V$$

$$80x10^{-6}A = \frac{100x10^{-6}}{2}\frac{A}{V^2}\left(\frac{W}{L}\right)_L\left(2.5 - 0.15 - 0.646\right)^2 V^2 \rightarrow \left(\frac{W}{L}\right)_L = \frac{0.551}{1} = \frac{1}{1.82}$$

$$(b)\quad 80x10^{-6}A = 100x10^{-6}\frac{A}{V^2}\left(\frac{W}{L}\right)_S\left(1.55 - 0.60 - \frac{0.1}{2}\right)0.1\ V^2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{8.89}{1}$$

$$V_{TNL} = 0.6 + 0.5\left(\sqrt{.1 + 0.6} - \sqrt{0.6}\right) = 0.631\ V$$

$$80x10^{-6}A = \frac{100x10^{-6}}{2}\frac{A}{V^2}\left(\frac{W}{L}\right)_L\left(2.5 - 0.1 - 0.631\right)^2 V^2 \rightarrow \left(\frac{W}{L}\right)_L = \frac{0.511}{1} = \frac{1}{1.96}$$

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The high logic level is unchanged: $V_H = 2.11$

$$60x10^{-6}A = 50x10^{-6}\frac{A}{V^2}\left(\frac{W}{L}\right)_S\left(2.11 - 0.75 - \frac{0.1}{2}\right)0.1\ V^2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{9.16}{1}$$

$$V_{TNL} = 0.75 + 0.5\left(\sqrt{.1 + 0.6} - \sqrt{0.6}\right) = 0.781\ V$$

$$60x10^{-6}A = \frac{50x10^{-6}}{2}\frac{A}{V^2}\left(\frac{W}{L}\right)_L\left(3.3 - 0.1 - 0.781\right)^2 V^2 \rightarrow \left(\frac{W}{L}\right)_L = \frac{0.410}{1} = \frac{1}{2.44}$$

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Using MATLAB:

fzero(@(vh) ((vh - 1.9 - 0.5 * sqrt(0.6))^2 - 0.25(vh + 0.6)), 1) | ans = 1.5535

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$\gamma = 0 \rightarrow V_{TN} = 0.6V \quad | \quad V_H = 2.5 - 0.6 = 1.9\ V \quad | \quad I_{DD} = 0 \text{ for } v_O = V_H$

$$100x10^{-6}\left(\frac{10}{1}\right)\left(1.9 - 0.6 - \frac{V_L}{2}\right)V_L = \frac{100x10^{-6}}{2}\left(\frac{2}{1}\right)\left(2.5 - V_L - 0.6\right)^2$$

$$6V_L^2 - 116.8V_L + 3.61 = 0 \rightarrow V_L = 0.235V \quad | \quad I_{DD} = 100x10^{-6}\left(\frac{10}{1}\right)\left(1.9 - 0.6 - \frac{0.235}{2}\right)0.235 = 278\ \mu A$$

$$\text{Checking:} \quad I_{DD} = \frac{100x10^{-6}}{2}\left(\frac{2}{1}\right)\left(2.5 - 0.235 - 0.6\right)^2 = 277\ \mu A$$

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Using a graph digitizer (Plotdigitizer.com): 0.64 V, 2.42 V, 1.46 V, 0.52 V, 0.12 V, 0.96 V

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$$V_{TNL} = -1.5 + 0.5\left(\sqrt{0.2 + 0.6} - \sqrt{0.6}\right) = -1.44V$$

$$60.6x10^{-6} = 100x10^{-6}\left(\frac{W}{L}\right)_S\left(3.3 - 0.6 - \frac{0.2}{2}\right)0.2 \rightarrow \left(\frac{W}{L}\right)_S = \frac{1.17}{1}$$

$$60.6x10^{-6} = \frac{100x10^{-6}}{2}\left(\frac{W}{L}\right)_L\left(0 - 1.44\right)^2 \rightarrow \left(\frac{W}{L}\right)_L = \frac{0.585}{1} = \frac{1}{1.71}$$

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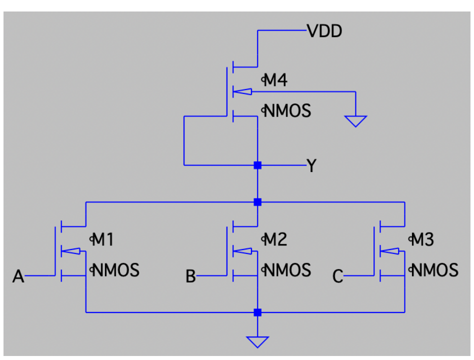
Place a third transistor with $\frac{W}{L} = \frac{2.22}{1}$ in parallel with transistors A and B.

The W/L ratio of the load transistor remains unchanged: $\left(\frac{W}{L}\right)_L = \frac{1.81}{1}$



A, B, C: W/L = 2.22/1

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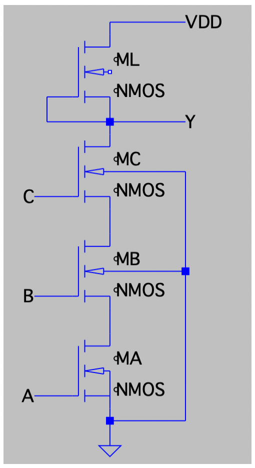
Place a third transistor in series with transistors A and B.

The new W/L ratios of transistors A, B and C are $\left(\frac{W}{L}\right)_{ABC} = 3\frac{2.22}{1} = \frac{6.66}{1}$.

The W/L ratio of the load transistor remains unchanged: $\left(\frac{W}{L}\right)_{L} = \frac{1.81}{1}$



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M_{L1} is saturated for all three voltages. $I_{DD} = \frac{40x10^{-6}}{2}\left(\frac{1.11}{1}\right)_L \left[-2.5-\left(-0.6\right)\right]^2 = 80.1\ \mu A$

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The voltages can be estimated using the on - resistance method.

For the 11000 case, $R_{onA} = \frac{132mV - 64.4mV}{80.1\mu A} = 844\ \Omega \quad R_{onB} = \frac{64.4mV}{80.1\mu A} = 804\ \Omega$

For the 00101 case, $R_{onE} = \frac{64.4mV}{80.1\mu A} = 804\ \Omega$.

For the 01110 case, $R_{onC} = \frac{203mV - 132mV}{80.1\mu A} = 886\ \Omega \quad R_{onD} = \frac{132mV - 64.4mV}{80.1\mu A} = 844\ \Omega$

The voltage across a given conducting device is $I_D R_{on}$. Small variations in R_{on} are ignored.

ABCDE	Y (mV)	2 (mV)	3 (mV)	I_{DD} (uA)	ABCDE	Y (mV)	2 (mV)	3 (mV)	I_{DD} (uA)
00000	2.5 V	0	0	0	10000	2.5 V	2.5 V	0	0
00001	2.5 V	0	0	0	10001	2.5 V	2.5 V	0	0
00010	2.5 V	0	0	0	10010	2.5 V	2.5 V	2.5 V	0
00011	2.5 V	0	0	0	10011	200	130	64	80.1
00100	2.5 V	0	2.5 V	0	10100	2.5 V	2.5 V	2.5 V	0
00101	130	0	64	80.1	10101	130	130	64	80.1
00110	2.5 V	2.5 V	2.5 V	0	10110	2.5 V	2.5 V	2.5 V	0
00111	130	64	64	80.1	10111	100	83	64	80.1
01000	2.5 V	0	0	0	11000	130	64	0	80.1
01001	2.5 V	0	0	0	11001	130	64	0	80.1
01010	2.5 V	0	0	0	11010	130	64	64	80.1
01011	2.5 V	0	0	0	11011	110	43	22	80.1
01100	2.5 V	0	2.5 V	0	11100	130	64	64	80.1
01101	130	0	64	80.1	11101	66	32	32	80.1
01110	200	64	130	80.1	11110	110	64	87	80.1
01111	114	21	43	80.1	11111	65	32	32	80.1

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$$P_{av} = \frac{2.5V(80\mu A)}{2} = 0.100\ mW$$

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$$P_D = 10^{-12}F(2.5V)^2(32x10^6 Hz) = 2x10^{-4}W = 200\ \mu W \quad \text{or} \quad 0.200\ mW$$

$$P_D = 10^{-12}F(2.5V)^2(3.2x10^9 Hz) = 2x10^{-4}W = 0.02\ W \quad \text{or} \quad 20\ mW$$

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The inverter in Fig. 6.33(a) was designed for a power dissipation of 80uA(2.5V) = 0.2 mW.

To reduce the power by a factor of two, we must reduce the W/L ratios by a factor of 2.

$$\left(\frac{W}{L}\right)_L = \frac{1}{2}\left(\frac{1}{1.68}\right) = \frac{1}{3.36} \quad | \quad \left(\frac{W}{L}\right)_S = \frac{1}{2}\left(\frac{4.71}{1}\right) = \frac{2.36}{1}$$

To increase the power by a factor of $\frac{4\text{mW}}{0.2\text{mW}}$, we must increase the W/L ratios by a factor of 20.

$$\left(\frac{W}{L}\right)_L = 20\left(\frac{1.81}{1}\right) = \frac{36.2}{1} \quad | \quad \left(\frac{W}{L}\right)_S = 20\left(\frac{2.22}{1}\right) = \frac{44.4}{1}$$

To reduce the power by a factor of three, we must reduce the W/L ratios by a factor of 3.

$$\left(\frac{W}{L}\right)_L = \frac{1}{3}\left(\frac{1.81}{1}\right) = \frac{0.603}{1} = \frac{1}{1.66} \quad | \quad \left(\frac{W}{L}\right)_A = \frac{1}{3}\left(\frac{3.33}{1}\right) = \frac{1.11}{1} \quad | \quad \left(\frac{W}{L}\right)_{BCD} = \frac{1}{3}\left(\frac{6.66}{1}\right) = \frac{2.22}{1}$$

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$$t_r = 2.2RC = 2.2\left(28.8x10^3\Omega\right)\left(2x10^{-13}F\right) = 12.7\ ns$$

$$\tau_{PLH} = 0.69RC = 0.69\left(28.8x10^3\Omega\right)\left(2x10^{-13}F\right) = 3.97\ ns$$

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$$v_O(t) = V_F - \left(V_F - V_I\right)\exp\left(-\frac{t}{RC}\right) \quad | \quad v_O\left(\tau_{PHL}\right) = V_H - 0.5\left(\frac{V_H + V_L}{2}\right) = 2.5 - 1.15 = 1.35\ V$$

$$1.35 = 0.2 - \left(0.2 - 2.5\right)\exp\left(-\frac{\tau_{PHL}}{RC}\right) \rightarrow \tau_{PLH} = -RC\ln 0.5 = 0.69RC$$

$$v_O\left(t_1\right) = V_H - 0.1\left(V_H + V_L\right) = 2.5 + 0.23 = 2.27\ V$$

$$2.27 = 0.2 - \left(0.2 - 2.5\right)\exp\left(-\frac{t_1}{RC}\right) \rightarrow t_1 = -RC\ln 0.9$$

$$v_O\left(t_2\right) = V_L + 0.1\left(V_H + V_L\right) = 0.2 + 0.23 = 0.43\ V$$

$$0.43 = 0.2 - \left(0.2 - 2.5\right)\exp\left(-\frac{t_2}{RC}\right) \rightarrow t_2 = -RC\ln 0.1$$

$$t_f = t_2 - t_1 = -RC\ln 0.1 + RC\ln 0.9 = RC\ln 9 = 2.2RC$$

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$$t_f = 3.7\left(2.37x10^3\Omega\right)\left(2.5x10^{-13}F\right) = 2.19\ ns \quad | \quad \tau_{PHL} = 1.2\left(2.37x10^3\Omega\right)\left(2.5x10^{-13}F\right) = 0.711\ ns$$

$$t_r = 2.2\left(28.8x10^3\Omega\right)\left(2.5x10^{-13}F\right) = 15.8\ ns \quad | \quad \tau_{PLH} = 0.69\left(28.8x10^3\Omega\right)\left(2.5x10^{-13}F\right) = 4.97\ ns$$

$$\tau_P = \frac{0.711\ ns + 4.97\ ns}{2} = 2.84\ ns$$

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$$T = 2N\tau_{P0} = 2\left(401\right)\left(10^{-9}s\right) = 802\ ns \quad | \quad f = \frac{1}{T} = \frac{1}{802ns} = 1.25\ MHz$$

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$$t_{P0} = \frac{L^2}{\mu_n\left(V_{DD} - V_{TN}\right)} = \frac{\left(2.5x10^{-5}cm\right)^2}{500\frac{cm^2}{V-s}\left(0.75\right)\left(3.3V\right)} = 0.505\ ps$$

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The NMOS switching transistor is in the linear region for $v_O = V_L$.

$$I_{DS} = 100x10^{-6}\left(\frac{127}{1}\right)_L\left(2.5-0.6-\frac{0.2}{2}\right)\left[0.2\right] = 4.57\ mA \quad | \quad \text{P}_\text{L} = \text{2.5V(4.51mA) = 11.4 mW}$$

$$P_{av} = \frac{2.5V\left(4.57mA\right)}{2} = 5.72\ mW \quad | \quad P_D = 10x10^{-12}F\left(2.5V-0.2V\right)^2\left(\frac{1}{20x10^{-9}s}\right) = 2.65\ mW$$

From the repetitive waveform, $P_D = 10x10^{-12}F\left(2.4V-0.2V\right)^2\left(\frac{1}{20x10^{-9}s}\right) = 2.42\ mW$

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We must increase the power by a factor of $\left(\frac{20pF}{10pF}\right)\left(\frac{2ns}{1ns}\right) = 4$,

so the W/L ratios must also be increased by a factor of 4.

$$\left(\frac{W}{L}\right)_L = 4\left(\frac{103}{1}\right) = \frac{412}{1} \quad | \quad \left(\frac{W}{L}\right)_S = 4\left(\frac{127}{1}\right) = \frac{508}{1}$$

$$P_D = 20x10^{-12}F\left(2.5V-0.2V\right)^2\left(\frac{1}{10^{-9}s}\right) = 106\ mW$$

CHAPTER S7

Page S7-4

$(a)\ K_p = 40x10^{-6}\left(\frac{20}{1}\right) = 800\ \frac{\mu A}{V^2}$ | $K_n = 100x10^{-6}\left(\frac{20}{1}\right) = 2000\ \frac{\mu A}{V^2} = 2.00\ \frac{mA}{V^2}$

$(b)\ V_{TN} = 0.6 + 0.5\left(\sqrt{2.5+0.6} - \sqrt{0.6}\right) = 1.09\ V$

$(c)\ V_{TP} = -0.6 - 0.75\left(\sqrt{2.5+0.7} - \sqrt{0.7}\right) = -1.31\ V$

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(a) For $v_I = 1\ V,\ V_{GSN} - V_{TN} = 1 - 0.6 = 0.4V$ and $V_{GSP} - V_{TP} = -(2.5-1) + 0.6 = -0.9V$

M_N is saturated for $v_O \geq 0.4\ V$. M_P is in the triode region for $v_O \geq 1.6\ V$. $\therefore\ 1.6\ V \leq v_O \leq 2.5\ V$

(b) M_P is saturated for $v_O \leq 1.6\ V$. $\therefore\ 0.4\ V \leq v_O \leq 1.6\ V$

(c) M_N is in the triode region for $v_O \leq 0.4\ V$. M_P is saturated for $v_O \leq 1.6\ V$. $\therefore\ 0 \leq v_O \leq 0.4\ V$

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$$\left(\frac{W}{L}\right)_P = \frac{K_n}{K_p}\left(\frac{W}{L}\right)_N = 2.5\left(\frac{10}{1}\right) = \frac{25}{1}$$

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Both transistors are saturated since $|V_{GS}| = |V_{DS}|$.

$$\frac{K_n}{2}\left(V_{GSN} - V_{TN}\right)^2 = \frac{K_p}{2}\left(V_{GSP} - V_{TP}\right)^2 \qquad K_n = K_p \qquad |V_{TN}| = |V_{TP}|$$

$$V_{GSN} = -V_{GSP} \rightarrow v_I = V_{DD} - v_I \rightarrow v_I = \frac{V_{DD}}{2}$$

$$\frac{10K_p}{2}\left(V_{GSN} - V_{TN}\right)^2 = \frac{K_p}{2}\left(V_{GSP} - V_{TP}\right)^2 \rightarrow \sqrt{10}\left(V_{GSN} - V_{TN}\right) = -V_{GSP} + V_{TP}$$

$$\sqrt{10}\left(v_I - 0.6\right) = 4 - v_I - 0.6 \rightarrow v_I = 1.273\ V$$

$$\frac{K_p}{2}\left(V_{GSN} - V_{TN}\right)^2 = \frac{10K_p}{2}\left(V_{GSP} - V_{TP}\right)^2 \rightarrow \left(V_{GSN} - V_{TN}\right) = \sqrt{10}\left(-V_{GSP} + V_{TP}\right)$$

$$v_I - 0.6 = \sqrt{10}\left(4 - v_I - 0.6\right) \rightarrow v_I = 2.727\ V$$

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$$K_R = \frac{K_n\left(\frac{W}{L}\right)_N}{K_p\left(\frac{W}{L}\right)_P} = \frac{K_n}{K_p} = 2.5$$

$$V_{IH} = \frac{2K_R\left(V_{DD} - V_{TN} + V_{TP}\right)}{\left(K_R - 1\right)\sqrt{1 + 3K_R}} - \frac{\left(V_{DD} - K_R V_{TN} + V_{TP}\right)}{K_R - 1}$$

$$V_{IH} = \frac{2(2.5)(2.5 - 0.6 - 0.6)}{(2.5 - 1)\sqrt{1 + 3(2.5)}} - \frac{\left(2.5 - 2.5(0.6) - 0.6\right)}{2.5 - 1} = 1.22V$$

$$V_{OL} = \frac{\left(K_R + 1\right)V_{IH} - V_{DD} - K_R V_{TN} - V_{TP}}{2K_R} = \frac{(2.5 + 1)1.22 - 2.5 - 2.5(0.6) + 0.6}{2(2.5)} = 0.174V$$

$$V_{IL} = \frac{2\sqrt{K_R}\left(V_{DD} - V_{TN} + V_{TP}\right)}{\left(K_R - 1\right)\sqrt{K_R + 3}} - \frac{\left(V_{DD} - K_R V_{TN} + V_{TP}\right)}{K_R - 1}$$

$$V_{IL} = \frac{2\sqrt{2.5}(2.5 - 0.6 - 0.6)}{(2.5 - 1)\sqrt{2.5 + 3}} - \frac{\left(2.5 - 2.5(0.6) - 0.6\right)}{2.5 - 1} = 0.902V$$

$$V_{OH} = \frac{\left(K_R + 1\right)V_{IL} + V_{DD} - K_R V_{TN} - V_{TP}}{2} = \frac{(2.5 + 1)0.902 + 2.5 - 2.5(0.6) + 0.6}{2} = 2.38V$$

$$NM_H = V_{OH} - V_{IH} = 2.38 - 1.22 = 1.16\ V \quad | \quad NM_L = V_{IL} - V_{OL} = 0.902 - 0.174 = 0.728\ V$$

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Symmetrical Inverter: $\tau_P = 1.2R_{onn}C = 1.2\dfrac{10^{-12}F}{2\left(10^{-4}\right)(2.5 - 0.6)}\Omega = 3.16\ ns \ \ | \ \ \tau_P = \dfrac{3.16ns}{5} = 0.63\ ns$

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Symmetrical Inverter : $R_{onn} = \dfrac{\tau_P}{1.2C} = \dfrac{10^{-9}s}{1.2\left(5x10^{-12}F\right)} = 167\Omega$

$$\left(\frac{W}{L}\right)_N = \frac{1}{R_{onn}K_n^{'}\left(V_{GS} - V_{TN}\right)} = \frac{1}{167\left(10^{-4}\right)(2.5 - 0.6)} = \frac{31.5}{1} \quad | \quad \left(\frac{W}{L}\right)_P = 2.5\left(\frac{W}{L}\right)_N = \frac{78.8}{1}$$

Page S7-13

The inverters need to be increased in size by a factor of $\frac{280\text{ps}}{250\text{ps}} = 1.12$.

$$\left(\frac{W}{L}\right)_N = 1.12\left(\frac{3.77}{1}\right) = \frac{4.22}{1} \quad | \quad \left(\frac{W}{L}\right)_P = 1.12\left(\frac{9.43}{1}\right) = \frac{10.6}{1}$$

$$\left(\frac{W}{L}\right)_N = \left(\frac{3.77}{1}\right)\left(\frac{3.3-0.75}{3.3-0.5}\right) = \frac{3.43}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \left(\frac{9.43}{1}\right)\left(\frac{3.3-0.75}{3.3-0.5}\right) = \frac{8.59}{1}$$

Page S7-14

The current (i. e. the W/L ratios) needs to be scaled by the delay change.

To reduce the delay, we need to increase the current.

$$\left(\frac{W}{L}\right)_N = \frac{2}{1}\left(\frac{0.89}{0.71}\right) = \frac{2.51}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \frac{5}{1}\left(\frac{0.89}{0.71}\right) = \frac{6.27}{1}$$

$$\left(\frac{W}{L}\right)_N = \frac{2}{1}\left(\frac{1.74}{1.58}\right) = \frac{2.20}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \frac{5}{1}\left(\frac{1.74}{1.58}\right) = \frac{5.51}{1}$$

Page S7-15

$$\tau_{PHL} = 2.4R_{onn}C = \frac{2.4C}{K_n\left(V_{GS}-V_{TN}\right)} = \frac{2.4C}{K_n\left(2.5-0.6\right)} = 1.26\frac{C}{K_n}$$

$$\tau_{PLH} = 2.4R_{onp}C = \frac{2.4C}{K_p\left(V_{GS}-V_{TN}\right)} = \frac{2.4C}{K_p\left(2.5-0.6\right)} = 1.26\frac{C}{K_p}$$

$$\tau_{PHL} = 2.4R_{onn}C = \frac{2.4C}{K_n\left(V_{GS}-V_{TN}\right)} = \frac{2.4C}{K_n\left(3.3-0.75\right)} = 0.94\frac{C}{K_n}$$

$$\tau_{PLH} = 2.4R_{onp}C = \frac{2.4C}{K_p\left(V_{GS}-V_{TN}\right)} = \frac{2.4C}{K_p\left(3.3-0.75\right)} = 0.94\frac{C}{K_p}$$

Page S7-17

The inverter in Fig. 7.12 is a symmetrical design, so the maximum current occurs for $v_O = v_I = \frac{V_{DD}}{2}$. Both transistors are saturated: $i_{DN} = \frac{10^{-4}}{2}\left(\frac{2}{1}\right)\left(1.25-0.6\right)^2 = 42.3\ \mu A$

Checking: $i_{DP} = \frac{4x10^{-5}}{2}\left(\frac{5}{1}\right)\left(1.25-0.6\right)^2 = 42.3\ \mu A$

Page S7-18

$$(a)\ \ PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13}F\left(2.5V\right)^2}{5} = 0.13\ pJ = 130\ fJ$$

$$(b)\ \ PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13}F\left(3.3V\right)^2}{5} = 0.22\ pJ = 220\ fJ$$

$$(c)\ \ PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13}F\left(1.8V\right)^2}{5} = 0.065\ pJ = 65\ fJ$$

Page S7-23

Remove the NMOS and PMOS transistors connected to input E, and ground the source of the NMOS transistor connected to input D. The are now 4 NMOS transistors in series, and

$$\left(\frac{W}{L}\right)_N = 4\left(\frac{2}{1}\right) = \frac{8}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \frac{5}{1}$$

Page S7-26

The position of PMOS transistors C and D may be interchanged in Fig. S7.27(a) or (b). Another possibility is to interchange the position of the NMOS transistors forming the B(C + D) sub-network.

Page S7-28

(i) Either one or both of the NMOS and PMOS switching networks can be rearranged. In the NMOS network, the positions of transistors A and B and transistors C and E can be interchanged. Note that both of these changes must be done to retain the correct logic function. In the PMOS network, the positions of transistors A and C and transistors B and E can be interchanged. Again, both sets of changes must occur together.

(ii) There are two NMOS transistors in series in the BC and BD NMOS paths and three PMOS transistors in the ADC PMOS path. Therefore:

$$\left(\frac{W}{L}\right)_{N-A} = \frac{2}{1} \quad | \quad \left(\frac{W}{L}\right)_{N-BCD} = 2\left(\frac{2}{1}\right) = \frac{4}{1} \quad | \quad \left(\frac{W}{L}\right)_{P-ADC} = 3\left(\frac{5}{1}\right) = \frac{15}{1} \quad | \quad \left(\frac{W}{L}\right)_{P-B} = \frac{1}{\frac{1}{5}-\frac{1}{15}} = \frac{7.5}{1}$$

(iii) Add a second input labeled F to the lower AND gate in the logic diagram. Add NMOS transistor F in series with transistor E in the NMOS tree and PMOS transistor F in parallel with transistor E in the PMOS network.

Page S7-34

$$\beta = \left(\frac{50\,pF}{50\,fF}\right)^{\frac{1}{2}} = 31.6 \quad \tau_P = 31.6\tau_o + 31.6\tau_o = 63.2\tau_o$$

– – –

$$z = e^{\ln z} \quad | \quad z^{\frac{1}{\ln z}} = \left(e^{\ln z}\right)^{\frac{1}{\ln z}} = e$$

– – –

$$\beta = \left(\frac{50\,pF}{50\,fF}\right)^{\frac{1}{7}} = 2.683$$

$$1,\ 2.68\ ,\ 2.683^2 = 7.20,\ 2.683^3 = 19.3,\ 2.683^4 = 51.8,\ 2.683^5 = 139,\ 2.683^6 = 373$$

$$A_6 = (1 + 3.16 + 10 + 31.6 + 100 + 316)A_o = 462A_o$$

$$A_7 = (1 + 2.68 + 7.20 + 19.3 + 51.8 + 139 + 373)A_o = 594A_o$$

Page S7-35

From the figure, 10/1 devices give a maximum R_{on} of 4 kΩ. The W/L ratios must be 4 times larger in order to reduce the maximum R_{on} to 1 kΩ. $\therefore \left(\frac{W}{L}\right) = 4\left(\frac{10}{1}\right) = \frac{40}{1}$

CHAPTER S8

Page S8-4

$(a)\ NS = \dfrac{2^8 \bullet 2^{20}}{2^7 \bullet 2^{10}} = 2^{11} = 2048 \text{ segments}$ | $(b)\ NS = \dfrac{2^{30}}{2^9 \bullet 2^{10}} = 2^{11} = 2048 \text{ segments}$

Page S8-5

$(a)\ N = 2^8 \bullet 2^{20} = 2^{28} = 268{,}435{,}456$

$(b)\ I_{DD} = \dfrac{0.05W}{3.3V} = 15.2\ mA$ | $\text{Current/cell} = \dfrac{15.2\text{mA}}{2^{28} cells} = 56.4\ pA$

– – –

Reverse the direction of the substrate arrows, and connect the substrates of the PMOS transistors to V_{DD}.

Page S8-8

For M_{A1}, $V_{MIN} = 1\ V$: $i_1 = 60x10^{-6}\left(\dfrac{1}{1}\right)\left(3 - 0.7 - \dfrac{1}{2}\right)(1) = 108\ \mu A$

For M_{A2}, $V_{MIN} = 0.46\ V$: $i_1 = 60x10^{-6}\left(\dfrac{1}{1}\right)\left(1.5 - 1.04 - \dfrac{0.46}{2}\right)0.46 = 6.35\ \mu A$

– – –

M_{A1}: At $t = 0^+$, $V_{GS} - V_{TN} = 4\ V$ and $V_{DS} = 2.5V$, so transistor M_{A1} is operating in the triode region.

$$i_1 = 60x10^{-6}\left(\frac{1}{1}\right)\left(5 - 1 - \frac{2.5}{2}\right)2.5 = 413\ \mu A$$

M_{A2}: At $t = 0^+$, $V_{GS} = V_{DS}$, so transistor M_{A2} is operating in the saturation region.

$$V_{TN2} = 1 + 0.6\left(\sqrt{2.5 + 0.6} - \sqrt{0.6}\right) = 1.592V \qquad i_2 = \frac{60x10^{-6}}{2}\left(\frac{1}{1}\right)\left(5 - 2.5 - 1.592\right)^2 = 24.7\ \mu A$$

Page S8-10

For both M_{A1} and M_{A2}, $V_{MIN} = 1\ V$: $i = 60x10^{-6}\left(\dfrac{1}{1}\right)\left(3 - 0.7 - \dfrac{1}{2}\right)(1) = 108\ \mu A$

Page S8-11

M_{A1}: At $t = 0^+$, $V_D = 5\ V,\ V_G = 5\ V,\ V_S = 2.5\ V\ |\ V_{GS} = V_{DS}$, so transistor M_{A1} is operating in the saturation region: $i_1 = \frac{60x10^{-6}}{2}\left(\frac{1}{1}\right)(5-1)^2 = 480\ \mu A$

M_{A2}: At $t = 0^+$, $V_D = 2.5\ V,\ V_G = 5\ V,\ V_S = 0\ V\ |\ V_{GS} - V_{TN} = 5-1 = 4$ V, $V_{DS} = 2.5$, so transistor M_{A2} is operating in the triode region: $i_1 = 60x10^{-6}\left(\frac{1}{1}\right)\left(5-1-\frac{2.5}{2}\right)2.5 = 413\ \mu A$

Page S8-13

(a) At $t = 0^+$, $V_{GS} - V_{TN} = 3\text{-}0.7 = 2.3\ V$ and $V_{DS} = 1.9\ V$, so transistor M_A is operating in the triode region. $i_1 = 60x10^{-6}\left(\frac{1}{1}\right)\left(3-0-0.7-\frac{1.9}{2}\right)1.9 = 154\ \mu A$

(b) From S7.18 and S7.19: $t_f = 2.4R_{on}C = 2.4\frac{50x10^{-15}F}{60x10^{-6}(3-0.7)} = 0.87\ ns$

(c) $V_{MIN} = 1\ V\ \ |\ \ i_1 = 60x10^{-6}\left(\frac{1}{1}\right)\left(3-0-0.7-\frac{1}{2}\right)1 = 108\ \mu A$

Page S8-14

$V_C = V_{BL} - V_{TN}\ \ |\ \ V_C = 3-\left[0.7+0.5\left(\sqrt{V_C+0.6}-\sqrt{0.6}\right)\right] \rightarrow V_C = 1.89\ V\ \ |\ \ V_C = 3-0.7 = 2.3\ V$

– – –

$$n = \frac{CV}{q} = \frac{25x10^{-15}F(1.89V)}{1.60x10^{-19}C} = 2.95 \text{ x } 10^5 \text{electrons}$$

Page S8-15

(a) $\Delta V = \frac{V_C - V_{BL}}{\frac{C_{BL}}{C_C}+1} = \frac{1.9-0.95}{\frac{49C_C}{C_C}+1}V = 19.0\ \text{m}V\ \ |\ \ \Delta V = \frac{V_C - V_{BL}}{\frac{C_{BL}}{C_C}+1} = \frac{0-0.95}{\frac{49C_C}{C_C}+1}V = -19.0\ \text{m}V$

(b) $\tau = R_{on}\frac{C_C}{\frac{C_C}{C_{BL}}+1} = 5k\Omega\frac{25fF}{\frac{1}{49}+1} = 0.123\ ns$ or $\tau \cong R_{on}C_C = 5k\Omega(25fF) = 0.125\ ns$

Page S8-16

(a) At $t = 0^+$, $V_{GS} - V_{TN} = (3\text{-}0)\text{-}0.7 = 2.3\ V$ and $V_{DS} = 1.5\ V$, so transistor M_{A2} is operating in the triode region. $i_D = 60x10^{-6}\left(\frac{2}{1}\right)\left(3-0.7-\frac{1.5}{2}\right)1.5 = 279\ \mu A$

(b) $V_{MIN} = 1\ V\ \ |\ \ i_D = 60x10^{-6}\left(\frac{2}{1}\right)\left(3-0.7-\frac{1}{2}\right)1 = 216\ \mu A$

Page S8-19

(a) In setting the drain currents equal, we see that the change in W/L cancels out, and the voltages remain the same.

$$\therefore i_D = \frac{1}{2}\left(60x10^{-6}\right)\left(\frac{5}{1}\right)\left(1.33-0.7\right)^2 = 59.5\ \mu A \quad | \quad P_D = 2\left(59.5\mu A\right)\left(3V\right) = 0.357\ mW$$

As a check, the current should scale with W/L: $i_D = \frac{5}{2}\left(23.5\mu A\right) = 58.8\ \mu A$

(b) $V_{DS} = 1.33\ V,\ V_{GS} - V_{TN} = 1.33 - 0.7 = 0.63\ V,\ V_{SAT} = 1\ V \rightarrow V_{MIN} = 0.67\ V$

$$i_D = \left(60x10^{-6}\right)\left(\frac{5}{1}\right)\left(0.63 - \frac{0.63}{2}\right)\left(0.63\right) = 59.5\ \mu A \quad | \quad P_D = 2\left(59.5\mu A\right)\left(3V\right) = 0.357\ mW$$

Equating drain currents: $\frac{1}{2}\left(25x10^{-6}\right)\left(\frac{2}{1}\right)\left(2.5 - V_O - 0.6\right)^2 = \frac{1}{2}\left(60x10^{-6}\right)\left(\frac{2}{1}\right)\left(V_O - 0.6\right)^2$

$$1.4V_O^2 + 0.92V_O - 2.746 = 0 \rightarrow V_O = 1.11V$$

$$i_D = \frac{1}{2}\left(25x10^{-6}\right)\left(\frac{2}{1}\right)\left(2.5-1.11-0.6\right)^2 = 15.6\ \mu A \quad | \quad P_D = 2\left(15.6\mu A\right)\left(2.5V\right) = 78.0\ \mu W$$

Checking: $\frac{1}{2}\left(60x10^{-6}\right)\left(\frac{2}{1}\right)\left(1.11-0.6\right)^2 = 15.6\ \mu A$

Page S8-20

$$R_{on} = \frac{1}{60x10^{-6}\left(3-1.3-1\right)} = 23.8\ k\Omega \quad | \quad \tau = 23.8k\Omega\left(25fF\right) = 0.595\ ns$$

Page S8-23

(i) Depletion-mode load devices: 1.81/1 NMOS switching devices: 2.22/1

(ii) For all possible input combinations there will be two inverters and 3 output lines in the low state for a total of 5 conducting paths. $P_D = 5\left(0.2mW\right) = 1.0\ mW$

Page S8-24

$$\left(\frac{W}{L}\right)_L = \frac{2}{2.22}\left(\frac{1.81}{1}\right) = \frac{1.63}{1}$$

Page S8-26

For a 0-V input, all transistors will be on and the input nodes will all discharge to 0 V.

For the 3-V input, the nodes will all charge to 3 V as long as $V_{TN} \le 2\ V$.

$V_{TN} = 0.7 + 0.5\left(\sqrt{3+0.6} - \sqrt{0.6}\right) = 1.26\ V$. Thus the nodes will all be a 3 V.

$2 \ge 0.7 + \gamma\left(\sqrt{3+0.6} - \sqrt{0.6}\right) \rightarrow \gamma \le 1.158\ V^{0.5}$

– – –

The output will drop below $V_{DD}/2$. For the PMOS device, $\left|V_{GS} - V_{TP}\right| = 3 - 1.9 - 0.7 = 0.4V$.

The PMOS transistor will be saturated. For the NMOS device, $\left|V_{GS} - V_{TP}\right| = 1.9 - 0.7 = 1.2V$.

Assume linear region operation.

$$\frac{40x10^{-6}}{2}\left(\frac{5}{1}\right)\left(-1.1+0.7\right)^2 = 100x10^{-6}\left(\frac{2}{1}\right)\left(1.9 - 0.7 - \frac{V_O}{2}\right)V_O$$

$V_O^2 - 2.4V_O + 0.16 = 0 \rightarrow V_O = 68.6\ mV$

Page S8-28

(i) An NMOS transistor is connected to B_5, B_4 and B_1.

(ii) W_0: 0010 W_1: 0100 W_2: 1011 W_3: 0100

CHAPTER S9

Page S9-4

$$\frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.2V}{0.025V}\right) = 2.98\ x\ 10^3 \ \ | \ \ \frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.3V}{0.025V}\right) = 1.63\ x\ 10^5 \ \ | \ \ \frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.4V}{0.025V}\right) = 8.89\ x\ 10^6$$

Page S9-5

The current must be reduced by 5 while the voltages remain the same.

$$I_{EE} = \frac{300\mu A}{5} = 60\ \mu A \quad | \quad R_C = 5(2k\Omega) = 10\ k\Omega$$

Page S9-6

$$I_B = \frac{I_E}{\beta_F + 1} \quad | \quad I_{B3} = \frac{92.9\mu A}{21} = 4.42\ \mu A \quad | \quad I_{B4} = \frac{107\mu A}{21} = 5.10\ \mu A$$

$$I_{B3}R_C = 4.42\mu A(2k\Omega) = 8.84\ mV << 0.7\ V \quad | \quad I_{B4}R_C = 5.10\mu A(2k\Omega) = 10.2\ mV << 0.7\ V$$

Page S9-8

$$V_H = 0 - 0.7 = -0.7\ V \quad | \quad V_L = 0 - 0.2mA(2k\Omega) - 0.7V = -1.1\ V$$

$$V_{REF} = \frac{-0.7V + (-1.10V)}{2} = -0.9\ V \quad | \quad \Delta V = \text{-}0.7V \text{ - } (1.1V) - 0.4\ V$$

Page S9-10

$$NM_H = NM_L = \frac{0.4V}{2} - 0.025V\left[1 + \ln\left(\frac{0.4}{0.025} - 1\right)\right] = 0.107\ V$$

Page S9-12

$P = 3.3V\left(0.3mA + 0.2mA\right) = 1.65\ mW \quad | \quad P = 3.3V\left(0.357mA + 0.2mA\right) = 1.84\ mW$

$$NM_H = NM_L = \frac{0.6V}{2} - 0.025V\left[1 + \ln\left(\frac{0.6}{0.025} - 1\right)\right] = 0.20\ V$$

– – –

From the graph, the VTC slope is-1 for $V_{IL} = -1.08\ V,\ V_{OH} = -0.71\ V$ and $V_{IH} = -0.91\ V,\ V_{OL} = -1.28\ V.\ \ NM_H = -0.71 - \left(-0.91\right) = 0.20\ V.\ \ NM_L = -1.08 - \left(-1.28\right) = 0.20\ V$

– – –

The voltages remain the same. Thus the currents must be reduced by a factor of 3, and the resistor values must be increase by a factor of 3.

$$R_{EE} = \frac{-1.7V - \left(-5.2V\right)}{0.20mA} = 17.5\ k\Omega \rightarrow 18\ k\Omega$$

$$I_E = \frac{-1.4V - \left(-5.2V\right)}{18\ k\Omega} = 0.211\ mA \ \mid\ R_{C1} = \frac{0.4V}{0.211mA} = 1.90\ k\Omega$$

Page S9-13

For all inputs low: $I_{EE} = \frac{-1 - 0.7 - \left(-5.2\right)}{11.7}\frac{V}{k\Omega} = 299\mu A$

$\frac{\Delta V}{2} = V_H - V_{REF} = -0.7 - \left(-1\right) = 0.3\ V \ \mid\ \Delta V = 0.6\ V \ \mid\ R_{C2} = \frac{0.6V}{299\mu A} = 2.00\ k\Omega$

For an inputs high: $I_{EE} = \frac{-0.7 - 0.7 - \left(-5.2\right)}{11.7}\frac{V}{k\Omega} = 325\mu A \ \mid\ R_{C1} = \frac{0.6V}{325\mu A} = 1.85\ k\Omega$

Based upon analysis above, $R_C = \frac{0.6V}{325\mu A} = 1.85\ k\Omega$

– – –

For all inputs low: $I_{EE} = \frac{-1 - 0.7 - \left(-5.2\right)}{11.7}\frac{V}{k\Omega} = 299\mu A$

$\frac{\Delta V}{2} = V_H - V_{REF} = -0.7 - \left(-1\right) = 0.3\ V \ \mid\ \Delta V = 0.6\ V \ \mid\ R_C = \frac{0.6V}{299\mu A} = 2.00\ k\Omega$

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$$R_E = \frac{V_E - \left(-V_{EE}\right)}{0.3mA} = \frac{0 - 0.7 - \left(-5.2V\right)}{0.3}\frac{V}{mA} = 15.0\ k\Omega$$

Page S9-16

(a) For $I_E = 0,\ v_O = -5.2\ V.$ (b) For $I_E = 0,\ v_O = --5.2V\dfrac{10k\Omega}{10k\Omega + 15k\Omega} = -2.08\ V$

Page S9-17

The transistor's power dissipation is

$$P = V_{CB}I_C + V_{BE}I_E = 5V\left(2.55mA\frac{50}{51}\right) + 0.7V\left(2.55mA\right) = 14.3\ mW$$

The total power dissipation in the circuit is

$$P = V_{CC}I_C + V_{EE}I_E = 5V\left(2.55mA\frac{50}{51}\right) + 5V\left(2.55mA\right) = 25.3\ mW$$

For $v_O = -3.7V,\ \ I_E = \dfrac{-3.7-(-5)}{1300} - \dfrac{3.7}{5000} = 260\ \mu A.$

At the Q-point, $I_E = \dfrac{-0.7-(-5)}{1300} - \dfrac{0.7}{5000} = 3.17\ mA$

The transistor's power dissipation is

$$P = V_{CB}I_C + V_{BE}I_E = 5V\left(3.17mA\frac{50}{51}\right) + 0.7V\left(3.17mA\right) = 17.8\ mW$$

- - -

(a) $-4V = -5.2V\dfrac{10k\Omega}{10k\Omega + R_E} \rightarrow R_E = 3.00\ k\Omega$

(b) $I_E = \dfrac{5.2V}{3k\Omega} = 1.73\ mA$ | $I_E = \dfrac{-4-(-5.2)}{3000} - \dfrac{4}{10000} = 0$ | $I_E = \dfrac{4-(-5.2)}{3000} + \dfrac{4}{10000} = 3.47\ mA$

Page S9-19

Increase the value of each resistor by a factor of 10.

Page S9-22

$R_C = \dfrac{\Delta V}{I_{EE}} = \dfrac{0.6V}{0.5mA} = 1.2\ k\Omega$ | $\tau_P = 0.69\left(1.2k\Omega\right)\left(2\,pF\right) = 1.66\ ns$

$P = 5.2V\left(0.5 + 0.1 + 0.1\right)mA = 3.64\ mW$ | $PDP = 6.0\ pJ$

Page S9-25

$R_{C2} = R_{C1} = \dfrac{0 - V_L}{I_{EE}} = \dfrac{0.4V}{0.5mA} = 800\ \Omega$ | $P = I_{EE}V_{EE} = 0.5mA(2.8V) = 1.40\ mW$

$PDP = 1.4mW(50ps) = 70\ fJ$

– – –

$I_{EF} = \dfrac{I_{EE}}{2} = 250\ \mu A$ | $P = I_{EE}V_{EE} = 0.25mA(2.8V) = 0.70\ mW$

– – –

$V_H = 0$ | $V_L = -0.2\ V$ | $V_{Bias} = -0.1\ V$ | $V_{BH} = -0.7$ | $V_{BL} = -0.9\ V$ | $V_{BiasB} = -0.8\ V$

$V_{AH} = -1.4$ | $V_{AL} = -1.6\ V$ | $V_{BiasA} = -1.5\ V$

$-V_{EE} = V_{AH} - 0.7V - 0.7V = -1.4 - 0.7 - 0.7 = -2.8\ V$ | $-V_{EE} = -2.8\ V$

– – –

$V_H = 0\ V$, $V_L = -0.4\ V$, : The C-level bias is $V_{BiasC} = \dfrac{V_H + V_L}{2} = -0.2\ V$

Using the level shifter in Fig. 9.27,

$V_{BH} = -0.7$ | $V_{BL} = -1.1\ V$ | $V_{BiasB} = -0.9\ V$

$V_{AH} = -1.4$ | $V_{AL} = -1.8\ V$ | $V_{BiasA} = -1.6\ V$

$-V_{EE} = V_{emitterA} - 0.7V = -0.7 = -2.8\ V$ | $-V_{EE} = -2.8\ V$

Page S9-30

For $v_O = V_H, I_C = 0$, and $P = 0$. $P = V_{DD}I_{DD} = 5V(2.43mA) = 12.1\ mW$

Increase R by a factor of 10: $R = 10(2k\Omega) = 20k\Omega$.

Page S9-32

$$\Gamma = \exp\left(\frac{0.1}{0.0258}\right) = 48.2 \quad | \quad I_B \geq \frac{10A}{20}\left[\frac{1+\dfrac{20}{0.1(48.2)}}{1-\dfrac{11}{48.2}}\right] = 3.34\ A \quad | \quad \beta_{FOR} = \frac{10A}{3.34A} = 3.00$$

– – –

$$\alpha_R = \frac{0.2}{0.2+1} = \frac{1}{6} \quad | \quad I_B \geq \frac{10A}{20}\left[\frac{1+\dfrac{20}{0.2(54.6)}}{1-\dfrac{6}{54.6}}\right] = 1.59\ A$$

– – –

$$\Gamma = \exp\left(\frac{0.15}{0.025}\right) = 403 \quad | \quad I_B \geq \frac{10A}{20}\left[\frac{1+\dfrac{20}{0.1(403)}}{1-\dfrac{11}{403}}\right] = 0.769\ A$$

– – –

$$V_T = \frac{1.38x10^{-23}(273+150)}{1.60x10^{-19}} = 36.5\ mV \quad | \quad V_{CEMIN} = 36.5mV\ \ln\left(\frac{0.05+1}{0.05}\right) = 111\ mV$$

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$$\Gamma = \exp\left(\frac{0.1}{0.025}\right) = 54.6 \quad | \quad \alpha_R = \frac{0.25}{1+0.25} = \frac{1}{5}$$

$$I_B \geq \frac{10mA}{40}\left[\frac{1+\dfrac{40}{0.25(54.6)}}{1-\dfrac{5}{54.6}}\right] = 1.08\ \text{mA} \quad | \quad \beta_{FOR} = \frac{10mA}{1.08mA} = 9.24$$

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$$1ns = 6.4ns \ln\left(\frac{1mA - I_{BR}}{\dfrac{2.5mA}{40.7} - I_{BR}}\right) \quad | \quad 1.169 = \frac{1mA - I_{BR}}{0.0614mA - I_{BR}} \rightarrow I_{BR} = -5.49\ mA$$

– – –

$$i_{CMAX} = \frac{V_{CC} - V_{CE}}{\beta_F} \cong \frac{5-0}{2500} = 2.5mA \quad | \quad Q_{XS} = 6.4ns\left(1mA - \frac{2.5mA}{40.7}\right) = 6.01\ pC$$

$$Q_F = i_F \tau_F = 2.5mA(0.25ns) = 0.625\ pC \quad | \quad Q_{XS} >> Q_F$$

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$$v_I = V_L \text{ and } v_O = 0: \quad I_{B4} = \frac{5 - V_{B4}}{1600} = \frac{5 - (0 + 0.7 + 0.7)}{1600} = 2.25\ mA \quad | \quad I_L = 41 I_{B4} = 92.3\ mA$$

$$5 - 1600\frac{I_L}{41} - 0.7 - 0.7 \geq 3 \rightarrow I_L \leq 15.4\ mA$$

$$I_{B4} = \frac{5 - (3 + 0.7 + 0.7)}{1600} = 0.375\ mA \quad | \quad I_L = 41 I_{B4} = 15.4\ mA$$

$$V_{CE} = 5 - 130\Omega I_C - V_O = 5V - 130\Omega(15.4mA) - 3.7 = -0.702\ V$$

Oops! - the transistor is not in the forward-active region. Assume saturation with $V_{CESAT} = 0.15V$.

$$I_L = I_B + I_C = \frac{5 - (0.8 + 0.7 + 3.0)}{1600} + \frac{5 - (0.15 + 0.7 + 3)}{130} = 9.16\ mA$$

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BiCMOS NAND gate: Replace the CMOS NOR-gate with a two-input CMOS NAND-gate, and connect its output to the bases of Q_1 and Q_2.