

Chapter 4 Digital Hardware

[4.1] $P = (5V)(125mA) = 625 \text{ mW}$.

[4.2] $I = (10W) / (3V) = 3.33A$

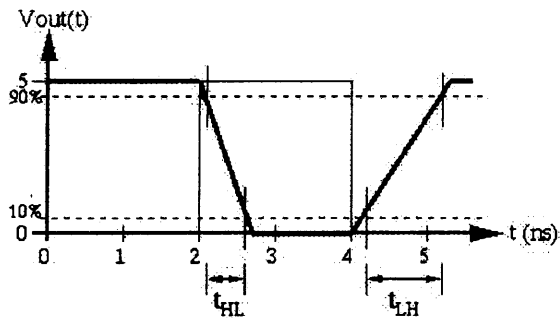
[4.3] (a) $P = (5V)(210mA) = 1.05W$

(b) $P = (3.1V)(1.4A) = 4.34W$

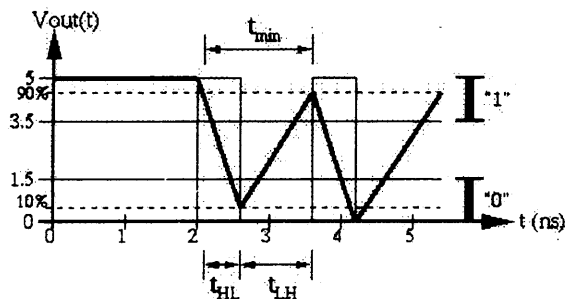
(c) $I = (15W) / (2.6V) = 5.77A$

[4.4]

(a)



(b) $f_{\max} = 1/t_{\min} = 1/(t_{HL} + t_{LH}) = 1/(1.5ns)$
 $= 666.67 \text{ MHz}$



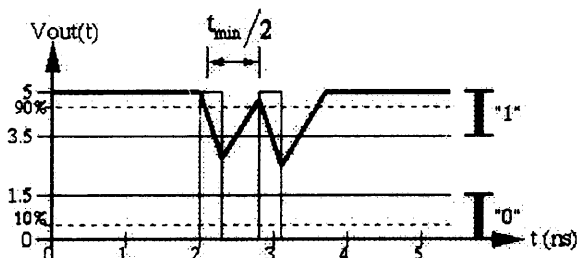
For the discussion purpose in (c), let's assume the following voltage range to represent logic "1" and "0":

$3.5v - 5.0v \Leftrightarrow \text{"1"}$

$0.0v - 1.5v \Leftrightarrow \text{"0"}$

As shown by the sketch above, $V_{out}(t)$ does return the correct logic values with certain delay.

(c) The sketch below shows $V_{out}(t)$ when the input is driven at twice f_{\max} .



The reason that this inverter will not operate properly at this high frequency because there is not enough time for V_{out} to settle down in the right logic value as clearly shown by the sketch.

[4.5] $t_{p,\text{total}} = 3 \times (t_{p0,\text{NOT}} + t_{pL,\text{NOT}})$
 $= 3 \times (0.5 + 0.5) = 3 \text{ ns}$.

[4.6] $t_{p,\text{total}} = 3 \times (t_{p0,\text{NOT}} + 2t_{pL,\text{NOT}})$
 $+ (t_{p0,\text{NOT}} + t_{pL,\text{NOT}})$
 $= 3 \times (0.5 + 0.8) + (0.5 + 0.4) = 4.8 \text{ ns}$.

[4.7] $t_{p,\text{total}} = (t_{p0,\text{NOR}} + t_{pL,\text{NOT}})$
 $+ (t_{p0,\text{NOT}} + t_{pL,\text{NOR}})$
 $= (0.75 + 0.5) + (0.5 + 0.5) = 2.25 \text{ ns}$.

[4.8] $t_{p,\text{total}} = 5 \times (t_{p0,\text{NOT}} + t_{pL,\text{NOT}}) + (t_{p0,\text{NOT}} + t_L)$
 $= 5 \times (1.0 + 0.25) + (1.0 + t_L) = 7.25 \text{ ns}$.
 If the load at the output is an inverter,
 $t_L = 0.25 \text{ ns}$. and thus $t_{p,\text{total}} = 7.5 \text{ ns}$.

[4.9] $V = IR = (25mA)(500\Omega) = 12.5V$.

[4.10] $I = V/R = 0.86V / 1500\Omega = 0.57 \text{ mA}$.

[4.11] $t_{p,\text{total}} = (t_{p0,\text{NAND}} + t_{pL,\text{NOT}} + t_{pL,\text{NOR}})$
 $+ (t_{p0,\text{NOR}} + t_{pL,\text{NOT}} + t_{pL,\text{NOR}})$
 $+ (t_{p0,\text{NOT}} + t_{pL,\text{NOT}})$
 $= (0.85 + 0.4 + 0.9)$
 $+ (0.75 + 0.4 + 0.9)$
 $+ (0.5 + 0.4) = 5.1 \text{ ns}$.

[4.12] $P = V^2 / R = (0.35V)^2 / (1200\Omega) = 0.1 \text{ mW}$

[4.13] (a) $R_{xz} = R_1 + R_2 = 200 + 450 = 650\Omega$

(b) $R_{yw} = R_2 + R_3 = 450 + 80 = 530\Omega$

(c) $R_{xw} = R_1 + R_2 + R_3 = 200 + 450 + 80 = 730\Omega$

[4.14] (a) $I(t=2ns) = V_R(t=2ns) / R$
 $= 3.03V / 1200\Omega = 2.53 \text{ mA}$

(b) $I(t=4ns) = V_R(t=4ns) / R$
 $= 1.84V / 1200\Omega = 1.53 \text{ mA}$

(c) $I(t=6ns) = V_R(t=6ns) / R$
 $= 1.12V / 1200\Omega = 0.93 \text{ mA}$

The plot on the next page shows the exponential decline of current with time.

	ABCDE	F1 F1(E)	F2 F2(E)	F3 F3(E)	F4 F4(E)	F5 F5(E)
0	00000	0 E	0 0	0 \bar{E}	0 $E+\bar{E}$	X $\bar{E}x+E$
1	00001	1	0 0	1 \bar{E}	X $\bar{E}x+E$	X $\bar{E}x+E$
2	00010	0 0	0 E	0 \bar{E}	1 $\bar{E}x+E$	1 $\bar{E}x+E$
3	00011	0 0	1 0	0 \bar{E}	X $\bar{E}x+E$	X $\bar{E}x+E$
4	00100	0 0	0 0	0 \bar{E}	1	1
5	00101	1	0 0	1 \bar{E}	0 0	0 0
6	00110	0 0	0 E	0 \bar{E}	0 0	0 0
7	00111	0 0	1 $E+\bar{E}$	1 \bar{E}	0 0	0 0
8	01000	0 E	1	0 \bar{E}	0 0	0 0
9	01001	1	0 E	0 0	1 \bar{E}	0 0
10	01010	0 E	1	0 \bar{E}	0 $\bar{E}+Ex$	0 $\bar{E}+Ex$
11	01011	1 0	1 $E+\bar{E}$	1 \bar{E}	X	X
12	01100	0 E	1	0 $E+\bar{E}$	0 Ex	0 Ex
13	01101	1	0 E	1 \bar{E}	X $\bar{E}+Ex$	X $\bar{E}+Ex$
14	01110	0 0	1	0 \bar{E}	1 \bar{E}	1 \bar{E}
15	01111	0 0	1 $E+\bar{E}$	1 \bar{E}	X $\bar{E}+Ex$	X $\bar{E}+Ex$
16	10000	0 0	1	0 \bar{E}	1 \bar{E}	1 \bar{E}
17	10001	0 0	0 E	1 \bar{E}	0 E	0 0
18	10010	0 0	1	0 \bar{E}	X X	X X
19	10011	0 0	0 E	1 \bar{E}	0 0	0 0
20	10100	1 $E+\bar{E}$	1 \bar{E}	0 \bar{E}	1 \bar{E}	1 \bar{E}
21	10101	1	0 $E+\bar{E}$	1 \bar{E}	0 0	0 0
22	10110	0 0	0 E	1 \bar{E}	X X	X X
23	10111	0 0	0 0	0 0	0 0	0 0
24	11000	0 0	0 0	0 0	1 \bar{E}	1 \bar{E}
25	11001	0 0	0 E	0 0	0 0	0 0
26	11010	1 $E+\bar{E}$	1	0 0	0 0	0 0
27	11011	1	0 $E+\bar{E}$	0 0	1 $\bar{E}+Ex$	1 $\bar{E}+Ex$
28	11100	1 $E+\bar{E}$	1	0 0	0 0	0 0
29	11101	1	0 $E+\bar{E}$	0 0	X $\bar{E}+Ex$	X $\bar{E}+Ex$
30	11110	1 $E+\bar{E}$	1 $E+\bar{E}$	1 $E+\bar{E}$	X $\bar{E}+Ex$	X $\bar{E}+Ex$
31	11111	1	1	1	X	X

F1

AB \ CD	00	01	11	10
00	E	0	0	E
01	E	E	0	E
11	0	E + \bar{E}	E + \bar{E}	E + \bar{E}
10	0	0	0	E + \bar{E}

$\bar{A}B\bar{C}E$ (points to cell 01, 00)
 $\bar{A}\bar{B}E$ (points to cell 00, 10)
 $AC\bar{D}$ (points to cell 11, 11)
 ABD (points to cell 10, 10)

$$F1 = ABD + \bar{A}B\bar{C}E + AC\bar{D} + \bar{A}\bar{B}E$$

F2

AB \ CD	00	01	11	10
00	0	E	E	0
01	E + \bar{E}	E	E	E + \bar{E}
11	0	E	E + \bar{E}	0
10	E + \bar{E}	E	E	\bar{E}

$\bar{A}B\bar{C}\bar{D}$ (points to cell 10, 00)
 $\bar{A}B\bar{D}$ (points to cell 00, 10)
 $ABCD$ (points to cell 01, 10)
 DE (points to cell 01, 01)
 $\bar{A}B\bar{D}\bar{E}$ (points to cell 10, 10)

$$F2 = \bar{A}B\bar{C}\bar{D} + DE + \bar{A}B\bar{D}\bar{E} + ABCD + \bar{A}B\bar{D}$$

F3

		CD			
		00	01	11	10
AB	00	\bar{E}	\bar{E}	\bar{E}	\bar{E}
	01	\bar{E}	0	$E + \bar{E}$	\bar{E}
	11	0	0	$E + \bar{E}$	0
	10	\bar{E}	\bar{E}	\bar{E}	\bar{E}

$\bar{A}\bar{D}\bar{E}$ (points to cell 01, 00)
 BCD (points to cell 01, 11)
 $\bar{B}\bar{E}$ (points to cell 10, 00)

$$F3 = \bar{A}\bar{D}\bar{E} + \bar{B}\bar{E} + BCD$$

F4

		CD			
		00	01	11	10
AB	00	$E + \bar{E}$	$E + EX$	0	$\bar{E}X + E$
	01	0	\bar{E}	EX	$\bar{E} + EX$
	11	0	\bar{E}	$\bar{E} + EX$	0
	10	$\bar{E} + EX$	\bar{E}	X	E

$\bar{A}\bar{B}\bar{C}$ (points to cell 00, 00)
 $\bar{C}D\bar{E}$ (points to cell 01, 01)
 $\bar{A}C\bar{D}$ (points to cell 00, 10)
 $\bar{B}D\bar{E}$ (points to cell 11, 10)
 $A\bar{D}\bar{E}$ (points to cell 01, 01)
 $\bar{B}\bar{C}\bar{D}$ (points to cell 00, 00)

$$F4 = \bar{B}\bar{C}\bar{D} + A\bar{D}\bar{E} + \bar{B}D\bar{E} + \bar{A}C\bar{D} + \bar{C}D\bar{E} + \bar{A}\bar{B}\bar{C}$$

FS

AB \ CD		00	01	11	10	
$\overline{A}\overline{B}\overline{C}$	00	$\overline{E}X+E$	$\overline{E}X+E$	0	$\overline{E}X+E$	$\rightarrow \overline{A}\overline{C}\overline{D}$
	01	0	0	EX	$\overline{E}+EX$	
	11	EX	$\overline{E}+E$	$\overline{E}+EX$	0	$\rightarrow AB\overline{D}$
	10	EX	\overline{E}	X	0	
						$\downarrow A\overline{D}\overline{E}$

$$FS = \overline{A}\overline{B}\overline{C} + A\overline{D}\overline{E} + AB\overline{D} + \overline{A}\overline{C}\overline{D}$$