15.36

a. $V_{TH} = \left(\frac{R_1}{R_1 + R_2}\right) V_H = \left(\frac{10}{10 + 40}\right)(10)$

so $\underline{V_{TH} = 2\text{ V}}$

$V_{TL} = \left(\frac{R_1}{R_1 + R_2}\right) V_L = \left(\frac{10}{10 + 40}\right)(-10)$

so $\underline{V_{TL} = -2\text{ V}}$

b. $v_I = 5 \sin \omega t$

15.37

a. Upper crossover voltage when $v_0 = +V_P$.

Now

$$v_B = \left(\frac{R_1}{R_1 + R_2}\right)(+V_P)$$

and

$$v_A = \left(\frac{R_A}{R_A + R_B}\right) V_{REF} + \left(\frac{R_B}{R_A + R_B}\right) V_{TH}$$

$v_A = v_B$ so that

$$\left(\frac{R_1}{R_1 + R_2}\right) V_P = \left(\frac{R_A}{R_A + R_B}\right) V_{REF} + \left(\frac{R_B}{R_A + R_B}\right) V_{TH}$$

or

$$V_{TH} = \left(\frac{R_A + R_B}{R_1 + R_2}\right)\left(\frac{R_1}{R_B}\right) V_P - \left(\frac{R_A}{R_B}\right) V_{REF}$$

Lower crossover voltage when $v_0 = -V_P$

So

$$V_{TL} = -\left(\frac{R_A + R_B}{R_1 + R_2}\right)\left(\frac{R_1}{R_B}\right) V_P - \left(\frac{R_A}{R_B}\right) V_{REF}$$

b. $V_{TH} = \left(\frac{10 + 20}{5 + 20}\right)\left(\frac{5}{20}\right)(10) - \left(\frac{10}{20}\right)(2)$

or $\underline{V_{TH} = 2\text{ V}}$

and

$V_{TL} = -\left(\frac{10 + 20}{5 + 20}\right)\left(\frac{5}{20}\right)(10) - 1 \Rightarrow \underline{V_{TL} = -4\text{ V}}$

15.38

a. $\frac{v_B}{R_1} = \frac{V_{REF} - v_B}{R_3} + \frac{v_0 - v_B}{R_2}$

$v_B\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = \frac{V_{REF}}{R_3} + \frac{v_0}{R_2}$

$V_{TH} = v_B$ when $v_0 = +V_P$ and $V_{TL} = v_B$ when $v_0 = -V_P$

So

$$V_{TH} = \frac{\frac{V_{REF}}{R_3} + \frac{V_P}{R_2}}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

and

$$V_{TL} = \frac{\frac{V_{REF}}{R_3} - \frac{V_P}{R_2}}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

b.

$$V_S = \frac{V_{REF}}{R_3\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$-5 = \frac{-10}{10\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{10}\right)}$$

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{5} - \frac{1}{10} = 0.10$$

$$\Delta V_T = V_{TH} - V_{TL} = \frac{\frac{2V_P}{R_2}}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$0.2 = \frac{2(12)}{R_2(0.10 + 0.10)}$$

So $\underline{R_2 = 600\ \text{k}\Omega}$

Then

$$\frac{1}{R_1} + \frac{1}{R_2} = 0.10$$

$$\frac{1}{R_1} + \frac{1}{600} = 0.10 \Rightarrow \underline{R_1 = 10.17\ \text{k}\Omega}$$

c. $V_{TH} = -5 + 0.1 = -4.9$

$V_{TL} = -5 - 0.1 = -5.1$

15.40

a. Switching point is when $v_0 = 0$. Then

$$v_+ = v_I \equiv V_S = \left(\frac{R_2}{R_1 + R_2}\right) V_{REF}$$

V_{TH} occurs when $v_0 = V_H$, then by superposition

$$v_+ = V_{TH} = \left(\frac{R_1}{R_1 + R_2}\right) V_H + \left(\frac{R_2}{R_1 + R_2}\right) V_{REF}$$

or

$$V_{TH} = V_S + \left(\frac{R_1}{R_1 + R_2}\right) V_H$$

V_{TL} occurs when $v_0 = V_L$, then by superposition

$$v_+ = V_{TL} = \left(\frac{R_1}{R_1 + R_2}\right) V_L + \left(\frac{R_2}{R_1 + R_2}\right) V_{REF}$$

or

$$V_{TL} = V_S + \left(\frac{R_1}{R_1 + R_2}\right) V_L$$

b. For $V_{TH} = 2$ V and $V_{TL} = 1$ V, then $V_S = 1.5$ V

Now

$$2 = 1.5 + \left(\frac{10}{10 + R_2}\right)(10)$$

$$\frac{0.5}{10} = \frac{10}{10 + R_2} \Rightarrow \underline{R_2 = 190\text{ k}\Omega}$$

Now $V_S = 1.5 = \left(\frac{190}{10 + 190}\right) V_{REF}$

so

$$\underline{V_{REF} = 1.579\text{ V}}$$

15.41

a. Switching point when $v_0 = 0$.

Now

$$v_+ = V_{REF} = \left(\frac{R_2}{R_1 + R_2}\right) v_I \text{ where } v_I = V_S.$$

Then

$$V_S = \left(\frac{R_1 + R_2}{R_2}\right) V_{REF} = \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

Now upper crossover voltage for v_I occurs when $v_0 = V_L$ and $v_+ = V_{REF}$. Then

$$\frac{V_{TH} - V_{REF}}{R_1} = \frac{V_{REF} - V_L}{R_2}$$

$$\text{or } V_{TH} = -\frac{R_1}{R_2} \cdot V_L + V_{REF}\left(1 + \frac{R_1}{R_2}\right)$$

$$\text{or } V_{TH} = V_S - \frac{R_1}{R_2} \cdot V_L$$

Lower crossover voltage for v_I occurs when $v_0 = V_H$ and $v_I = V_{REF}$. Then

$$\frac{V_H - V_{REF}}{R_2} = \frac{V_{REF} - V_{TL}}{R_1}$$

$$\text{or } V_{TL} = -\frac{R_1}{R_2} \cdot V_H + V_{REF}\left(1 + \frac{R_1}{R_2}\right)$$

$$\text{or } V_{TL} = V_S - \frac{R_1}{R_2} \cdot V_H$$

b. For $V_{TH} = -1$ and $V_{TL} = -2$, $V_S = -1.5$ V.

Then $V_{TL} = V_S - \frac{R_1}{R_2} \cdot V_H \Rightarrow -2 = -1.5 - \frac{R_1}{20}(12)$

so that $\underline{R_1 = 0.833\ \text{k}\Omega}$

Now

$$V_S = \left(1 + \frac{R_1}{R_2}\right) V_{REF}$$

$$-1.5 = \left(1 + \frac{0.833}{20}\right) V_{REF}$$

which gives

$$\underline{V_{REF} = -1.44\ \text{V}}$$