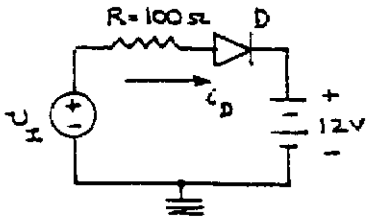
Chapter 2

Exercise Solutions

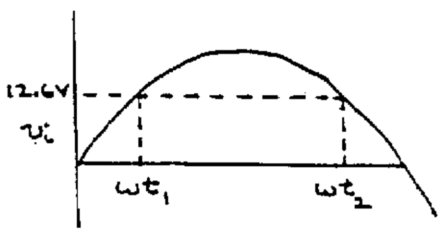
E2.1



a. $i_D(\text{peak}) = \dfrac{24 - 12 - 0.6}{0.10} = 114 \text{ mA}$

b. $V_R(\max) = 24 + 12 = 36 \text{ V}$

c.



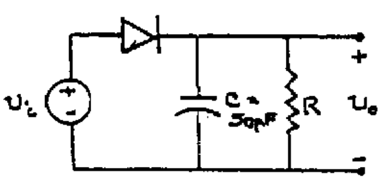
$v_I = 24 \sin \omega t = 12.6$

$\omega t_1 = \sin^{-1}\left(\dfrac{12.6}{24}\right) = 31.7°$

By symmetry, $\omega t_2 = 180 - 31.7 = 148.3°$

$\% = \left(\dfrac{148.3 - 31.7}{360}\right) \times 100\% \Rightarrow \underline{32.4\%}$

E2.2



$v_i = 75 \sin(2\pi 60 t)$

$V_r = \dfrac{V_m}{fRC}$

or $R = \dfrac{V_m}{fCV_r} = \dfrac{75}{(60)(50 \times 10^{-6})(4)}$

$\underline{R = 6.25 \text{ k}\Omega}$

E2.3

$v_i = 120 \sin(2\pi 60 t)$, $V_\gamma = 0.7$, $R = 2.5 \text{ k}\Omega$

Full-wave rectifier

Turns ratio $1:2 \Rightarrow v_S = v_i$

$V_M = 120 - 0.7 = 119.3 \text{ V}$

$V_r = 119.3 - 100 = 19.3 \text{ V}$

So $C = \dfrac{V_m}{2fRV_r} = \dfrac{119.3}{2(60)(2.5 \times 10^3)(19.3)}$

$C = 2.06 \times 10^{-5} = 20.6 \times 10^{-6} \Rightarrow C = 20.6 \ \mu\text{F}$

E2.4

$v_i = 50 \sin(2\pi 60 t)$, $V_\gamma = 0.7$, $R = 10 \text{ k}\Omega$

Full-wave rectifier

$C = \dfrac{V_m}{2fRV_r} = \dfrac{(50 - 1.4)}{2(60)(10 \times 10^3)(2)}$

$C = 2.025 \times 10^{-5} = 20.25 \times 10^{-6} \Rightarrow C = 20.3 \ \mu\text{F}$

E2.5

Using Eq. (2-10)

a. $\omega \Delta t = \sqrt{\dfrac{2V_r}{V_M}} = \sqrt{\dfrac{2(4)}{75}} = 0.327$

$\% = \left(\dfrac{0.327}{2\pi}\right) \times 100\% = \underline{5.2\%}$

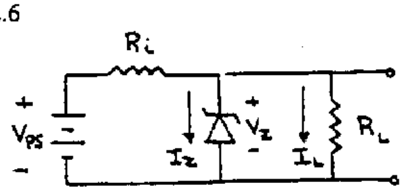
b. $\omega \Delta t = \sqrt{\dfrac{2V_r}{V_M}} = \sqrt{\dfrac{2(19.3)}{119.3}} = 0.569$

$\% = \left(\dfrac{0.569}{\pi}\right) \times 100\% = \underline{18.1\%}$

c. $\omega \Delta t = \sqrt{\dfrac{2V_r}{V_M}} = \sqrt{\dfrac{2(2)}{48.6}} = 0.287$

$\% = \left(\dfrac{0.287}{\pi}\right) \times 100\% = \underline{9.14\%}$

E2.6



$10 \le V_{PS} \le 14 \text{ V}$, $V_Z = 5.6$

$20 \le R_L \le 100$

$I_L(\max) = \dfrac{5.6}{20} = 0.28 \text{ A}$, $I_L(\min) = \dfrac{5.6}{100} = 0.056 \text{ A}$

$I_Z(\max)$

$$= \frac{[V_{PS}(\max) - V_Z]I_L(\max)}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)} - \frac{[V_{PS}(\min) - V_Z]I_L(\min)}{V_{PS}(\min) - 0.9V_Z - 0.1V_{PS}(\max)}$$

$$= \frac{[14 - 5.6](280) - [10 - 5.6](56)}{10 - (0.9)(5.6) - (0.1)(14)}$$

$$= \frac{2352 - 246.4}{3.56}$$

$I_Z(\max) = 591.5$ mA

Power(min) $= I_Z(\max) \cdot V_Z = (0.5915)(5.6)$

<u>Power = 3.31 W</u>

$$R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)} = \frac{14 - 5.6}{0.5915 + 0.056}$$

$$= \frac{8.4}{0.6475}$$

$\underline{R_i \approx 13\Omega}$

E2.7

$$I_Z = \frac{V_{PS} - V_Z}{R_i} - I_L$$

For $V_{PS}(\min)$ and $I_L(\max)$, then

$$I_Z(\min) = \frac{11-9}{20} - 0.1 = 0$$

(Minimum Zener current is zero.)

For $V_{PS}(\max)$ and $I_L(\min)$, then

$$I_Z(\max) = \frac{13.6-9}{20} - 0 \Rightarrow 230\ mA$$

The characteristic of the minimum Zener current being one-tenth of the maximum value is violated. The proper circuit operation is questionable.

E2.8

$$I_Z(\min) = \frac{V_{PS}(\min) - V_Z}{R_i} - I_L(\max)$$

so

$$30 = \frac{10-9}{0.0153} - I_L(\max)$$

Or

$\underline{I_L(\max) = 35.4\ mA}$

E2.9

$$\%\text{ Regulation} = \frac{V_L(\max) - V_L(\min)}{V_L(\text{nominal})}$$

$V_L(\text{nominal}) = 5.6$

$V_L(\max) = V_L(\text{nominal}) + I_Z(\max) r_Z$

$= 5.6 + (0.5915)(1.5) = 6.487$

$V_L(\min) = V_L(\text{nominal}) + I_Z(\min) r_Z$

$= 5.6 + (I_Z(\min))(1.5)$

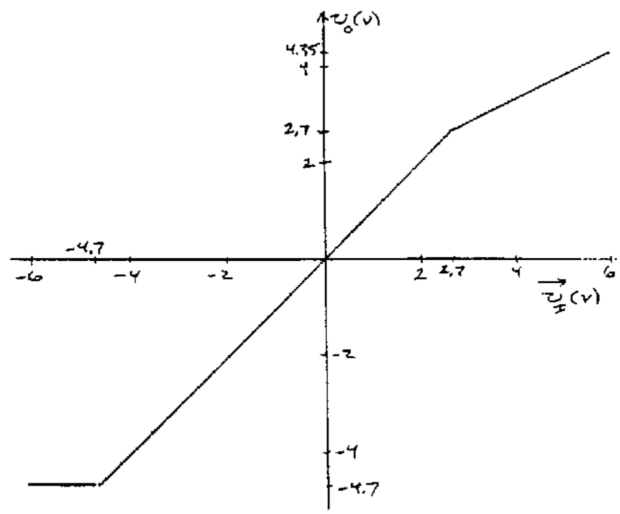
$$I_Z(\min) = \frac{10 - 5.6}{13} - 0.280$$

$= 0.0585$ A

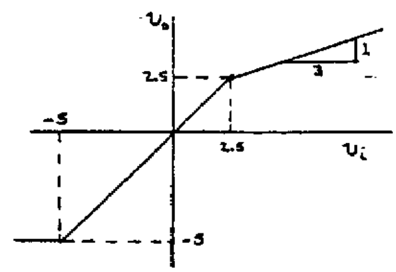
$V_L(\min) = 5.6 + (0.0585)(1.5) = 5.688$

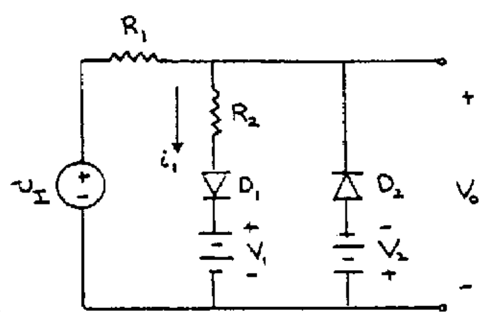
$$\%\text{ Reg} = \frac{6.487 - 5.688}{5.6} = 0.143 \Rightarrow \underline{14.3\%}$$

E2.10



E2.11





$V_\gamma = 0.7$ V

For $v_I < 5$, D_2 on $\Rightarrow V_0 = -5$ V $\Rightarrow \underline{V_2 = 4.3 \text{ V}}$

D_1 turns on when $v_I = 2.5 \Rightarrow \underline{V_1 = 1.8 \text{ V}}$

For $v_I > 2.5$, $\dfrac{\Delta v_0}{\Delta v_I} = \dfrac{1}{3} \Rightarrow \dfrac{R_2}{R_1 + R_2} = \dfrac{1}{3}$

$\Rightarrow R_1 = 2R_2$

E2.12

For $V_\gamma = 0$, $v_O(\max) = -2\,V$

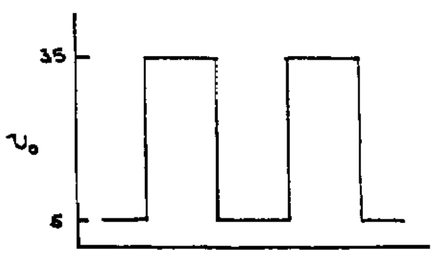
Now, $\Delta v_O = 8\,V$, so that

$v_O(\min) = -10\,V$

E2.13

As v_S goes negative, D turns on and $v_0 = +5$ V.

As v_S goes positive, D turns off.



Output, a square wave oscillating between +5 and +35 volts.

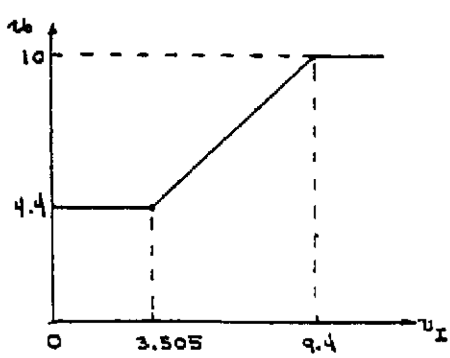
E2.14

$v_0 = 4.4$, $I = \dfrac{10 - 4.4}{9.5} = 0.5895$ mA

Set $I = I_{D_1}$

$v_I = 4.4 - 0.6 - (0.5895)(0.5)$

$v_I = 3.505$



Summary: $0 \le v_I \le 3.5$, $v_0 = 4.4$

For $v_I > 3.5$, $D2$ turns off and when $v_I \ge 9.4$,

$v_0 = 10$

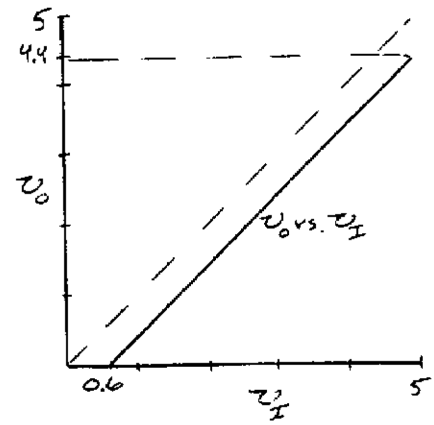
E2.15

$V_0 = -0.6$ V, $I_{D1} = 0$,

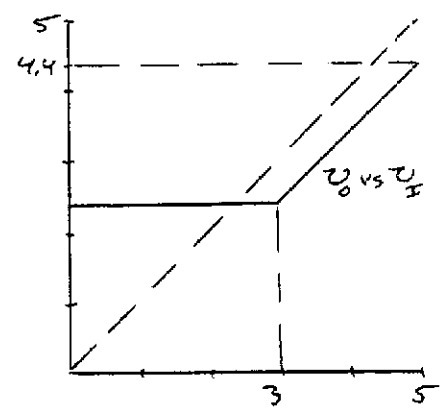
$I_{D2} = I = \dfrac{-0.6 - (-10)}{2.2} \Rightarrow I_{D2} = I = 4.27$ mA

E2.16

(a)



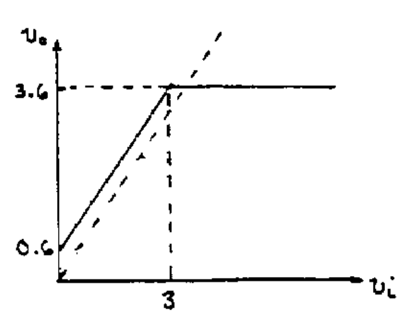
(b)



E2.17

a. $V_0 = 0.6$ V for all V_1

b.



E2.18

a. $I_{Ph} = \eta e \Phi$ A

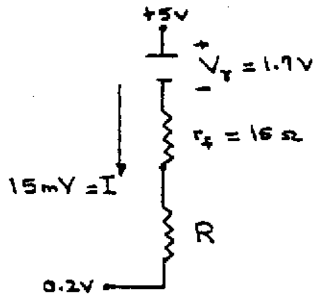
$$I_{Ph} = (0.8)(1.6 \times 10^{-19})\left[\frac{6.4 \times 10^{-2}}{(2)(1.6 \times 10^{-19})}\right](0.5)$$

$\underline{I_{Ph} = 12.8 \text{ mA}}$

b. We have $v_0 = (12.8)(1) = 12.8$ volts.
The diode must be reverse biased so that
$V_{PS} > 12.8$ volts.

E2.19

The equivalent circuit is



$$I = \frac{5 - 1.7 - 0.2}{r_f + R} = 15 \text{ mA}$$

$$r_f + R = \frac{5 - 1.7 - 0.2}{15} = \frac{3.1}{15} = 0.207 \text{ k}\Omega$$

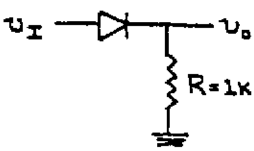
$$= 207\Omega$$

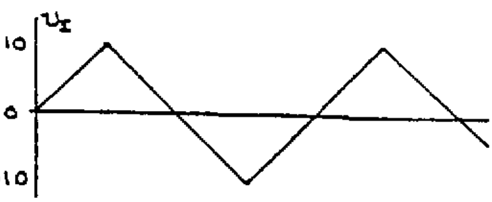
$R = 207 - 15 \Rightarrow \underline{R = 192\Omega}$

Chapter 2

Problem Solutions

2.1



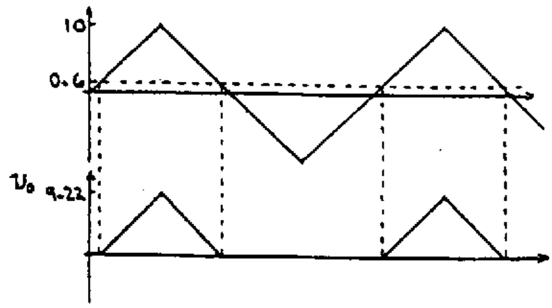


$V_\gamma = 0.6$ V, $r_f = 20\ \Omega$

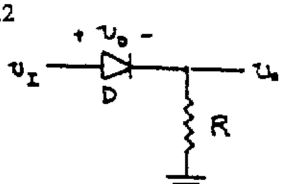
For $v_I = 10$ V, $v_0 = \left(\frac{R}{R + r_f}\right)(10 - 0.6)$

$= \left(\frac{1}{1 + 0.02}\right)(9.4)$

$v_0 = 9.22$



2.2



$v_0 = v_I - v_D$

$v_D = V_T \ln\left(\frac{i_D}{I_S}\right)$ and $i_D = \frac{v_0}{R}$

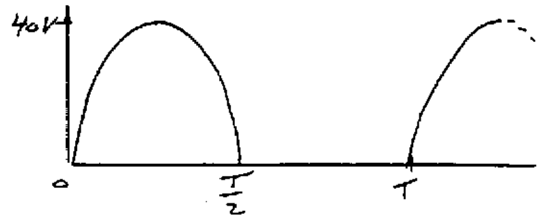
$\underline{v_0 = v_I - V_T \ln\left(\frac{v_0}{I_S R}\right)}$

2.3

(a) $v_s(\max) = \frac{160}{4} = 40\,V$

(b) $PIV = |v_s(\max)| = 40\,V$

(c)



$$v_O(avg) = \frac{1}{T_O}\int_{T_O} v_O(t)dt = \frac{1}{2\pi}\int_0^\pi 40\sin x dx$$

$$= \frac{40}{2\pi}[-\cos x]_0^\pi = \frac{40}{2\pi}[-(-1-1)] = \frac{40}{\pi}$$

or

$\underline{v_O(avg) = 12.7\,V}$

(d) 50%

2.4

$v_0 = v_S - 2V_\gamma \Rightarrow v_S(\max) = v_0(\max) + 2V_\gamma$

a. For $v_0(\max) = 25$ V $\Rightarrow v_S(\max) = 25 + 2(0.7)$
$= 26.4$ V

$\frac{N_1}{N_2} = \frac{160}{26.4} \Rightarrow \underline{\frac{N_1}{N_2} = 6.06}$

b. For $v_0(\max) = 100$ V $\Rightarrow v_S(\max) = 101.4$ V

$\frac{N_1}{N_2} = \frac{160}{101.4} \Rightarrow \underline{\frac{N_1}{N_2} = 1.58}$

From part (a)
$PIV = 2v_s(\max) - V_\gamma = 2(26.4) - 0.7$

or
$\underline{PIV = 52.1\,V}$

or, from part (b)
$PIV = 2(101.4) - 0.7$

or
$\underline{PIV = 202.1\,V}$

2.5

a. $v_O(\max) = 24\text{ V} \Rightarrow v_S(\max) = 24 + 2(0.7)$

$v_S(\max) = 25.4\text{ V}$

$v_S(\text{rms}) = \dfrac{25.4}{\sqrt{2}} \Rightarrow \underline{v_S(\text{rms}) = 17.96\text{ V}}$

b. $V_r = \dfrac{V_M}{2fRC} \Rightarrow C = \dfrac{V_M}{2fV_rR}$

$C = \dfrac{24}{2(60)(0.5)(150)} \Rightarrow \underline{C = 2667\ \mu\text{F}}$

c. $i_{D,\max} = \dfrac{V_m}{R}\left(1 + 2\pi\sqrt{\dfrac{V_M}{2V_r}}\right)$

$i_{D,\max} = \dfrac{24}{150}\left(1 + 2\pi\sqrt{\dfrac{24}{2(0.5)}}\right)$

$\underline{i_{D,\max} = 5.08\text{ A}}$

2.6

(a) $v_S(\max) = 24 + 0.7 = 24.7\,V$

$v_S(rms) = \dfrac{v_S(\max)}{\sqrt{2}} \Rightarrow \quad v_S(rms) = 17.5\,V$

(b) $V_r = \dfrac{V_M}{fRC} \Rightarrow C = \dfrac{V_M}{fRV_r} = \dfrac{24}{(60)(150)(0.5)}$

or

$\underline{C = 5333\ \mu F}$

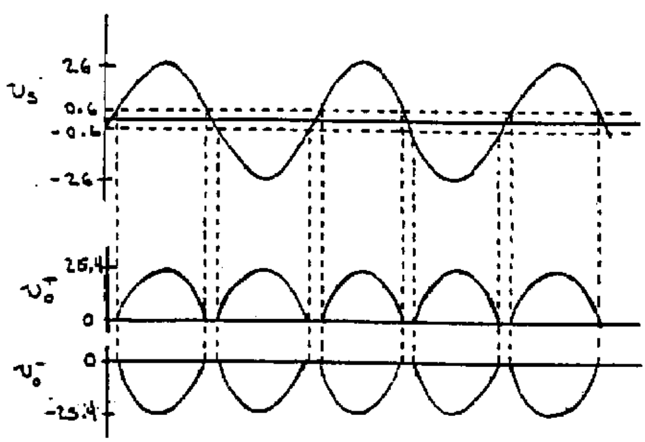
(c) For the half-wave rectifier

$i_{D,\max} = \dfrac{V_M}{R}\left(1 + 4\pi\sqrt{\dfrac{V_M}{2V_r}}\right) = \dfrac{24}{150}\left(1 + 4\pi\sqrt{\dfrac{24}{2(0.5)}}\right)$

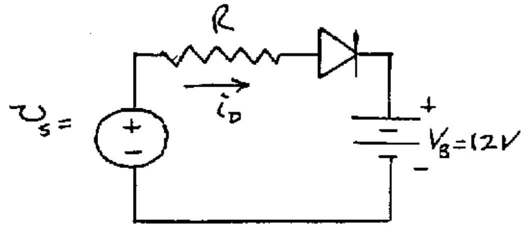
or

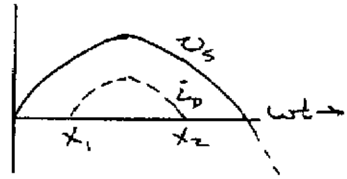
$\underline{i_{D,\max} = 10.0\ A}$

2.7



2.8





$v_S(t) = 24\sin\omega t$

Now

$i_D(avg) = \dfrac{1}{T}\displaystyle\int_0^T i_D(t)\,dt$

We have for $x_1 \le \omega t \le x_2$

$$i_D = \frac{24\sin x - 12.7}{R}$$

To find x_1 and x_2,

$$24\sin x_1 = 12.7$$

$x_1 = 0.558\ rad$

$x_2 = \pi - 0.558 = 2.584\ rad$

Then

$i_D(avg) = 2 = \dfrac{1}{2\pi}\displaystyle\int_{x_1}^{x_2}\left[\dfrac{24\sin x - 12.7}{R}\right]dx$

$= \dfrac{1}{2\pi}\left(\dfrac{24}{R}\right)(-\cos x)\Big|_{x_1}^{x_2} - \dfrac{1}{2\pi}\left(\dfrac{12.7}{R}\right)\cdot x\Big|_{x_1}^{x_2}$

or

$2 = \dfrac{6.482}{R} - \dfrac{4.095}{R} \Rightarrow \quad \underline{R = 1.19\ \Omega}$

Fraction of time diode is conducting

$= \dfrac{x_2 - x_1}{2\pi} \times 100\% = \dfrac{2.584 - 0.558}{2\pi} \times 100\%$

or

$\underline{\text{Fraction} = 32.2\%}$

Power rating

$P_{avg} = R \cdot i_{rms}^2 = \dfrac{R}{T}\displaystyle\int_0^T i_D^2\,dt = \dfrac{R}{2\pi}\int_{x_1}^{x_2}\left[\dfrac{24\sin x - 12.7}{R}\right]^2 dx$

$= \dfrac{1}{2\pi R}\displaystyle\int_{x_1}^{x_2}\left[(24)^2\sin^2 x - 2(12.7)(24)\sin x + (12.7)^2\right]dx$

$= \dfrac{1}{2\pi R}\left[(24)^2\left[\dfrac{x}{2} - \dfrac{\sin 2x}{4}\right]_{x_1}^{x_2} - 2(12.7)(24)(-\cos x)\Big|_{x_1}^{x_2} + (12.7)^2\, x\Big|_{x_1}^{x_2}\right]$

For $R = 1.19\ \Omega$, then

$\underline{P_{avg} = 17.9\ W}$

2.9

$R = \frac{15}{0.1} = 150\,\Omega$

$v_S(\max) = v_O(\max) + V_\gamma = 15 + 0.7$

or

$\underline{v_S(\max) = 15.7\ V}$

Then

$\underline{v_S(rms) = \frac{15.7}{\sqrt{2}} = 11.1\ V}$

Now

$\frac{N_1}{N_2} = \frac{120}{11.1} \Rightarrow \quad \underline{\frac{N_1}{N_2} = 10.8}$

$V_r = \frac{V_M}{2fRC} \Rightarrow C = \frac{V_M}{2fRV_r} = \frac{15}{2(60)(150)(0.4)}$

or

$\underline{C = 2083\ \mu F}$

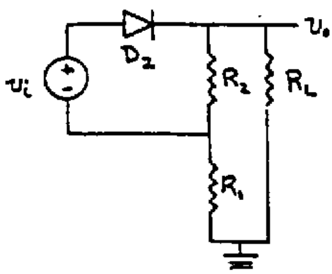
$PIV = 2v_S(\max) - V_\gamma = 2(15.7) - 0.7$

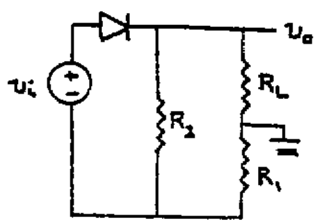
or

$PIV = 30.7\ V$

2.10

For $v_i > 0$

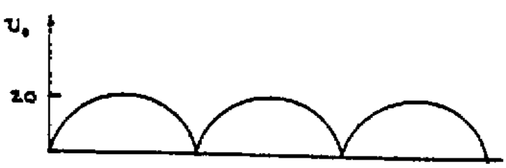




$V_\gamma = 0$

Voltage across $R_L + R_1 = v_i$

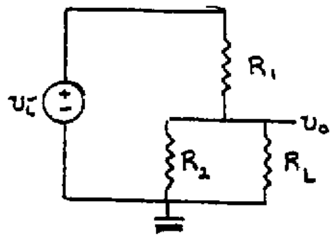
Voltage Divider $\Rightarrow v_0 = \left(\frac{R_L}{R_L + R_1}\right) v_i = \frac{1}{2} v_i$



2.11

For $v_i > 0$, $(V_\gamma = 0)$

a.



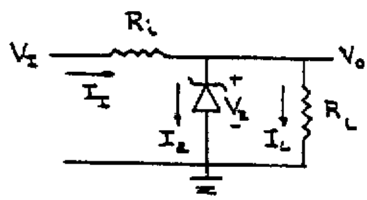
$v_0 = \left(\frac{R_2 \| R_L}{R_2 \| R_L + R_1}\right) v_i$

$R_2 \| R_L = 2.2 \| 6.8 = 1.66\ \text{k}\Omega$

$v_0 = \left(\frac{1.66}{1.66 + 2.2}\right) v_i = 0.43 v_i$

b. $\quad v_0(\text{rms}) = \frac{v_0(\max)}{\sqrt{2}} \Rightarrow \underline{v_0(\text{rms}) = 3.04\ \text{V}}$

2.12



$V_I = 6.3\ \text{V}, \quad R_i = 12\Omega, \quad V_Z = 4.8$

a. $\quad I_I = \frac{6.3 - 4.8}{12} \Rightarrow 125\ \text{mA}$

$I_L = I_I - I_Z = 125 - I_Z$

$\underline{25 \le I_L \le 120\ \text{mA}} \Rightarrow \underline{40 \le R_L \le 192\Omega}$

b. $\quad P_Z = I_Z V_Z = (100)(48) \Rightarrow \underline{P_Z = 480\ \text{mW}}$

$P_L = I_L V_0 = (120)(4.8) = \underline{P_L = 576\ \text{mW}}$

2.13

a. $\quad I_I = \frac{20 - 10}{222} \Rightarrow \underline{I_I = 45.0\ \text{mA}}$

$I_L = \frac{10}{380} \Rightarrow \underline{I_L = 26.3\ \text{mA}}$

$I_Z = I_I - I_L \Rightarrow \underline{I_Z = 18.7\ \text{mA}}$

b. $P_Z(\max) = 400 \text{ mW} \Rightarrow I_Z(\max) = \frac{400}{10} = 40 \text{ mA}$

$\Rightarrow I_L(\min) = I_I - I_Z(\max) = 45 - 40$

$\Rightarrow I_L(\min) = 5 \text{ mA} = \frac{10}{R_L}$

$\Rightarrow \underline{R_L = 2 \text{ k}\Omega}$

For $R_i = 175\Omega$

$\underline{I_I = 57.1 \text{ mA}}$ $\underline{I_L = 26.3 \text{ mA}}$ $\underline{I_Z = 30.8 \text{ mA}}$

$I_Z(\max) = 40 \text{ mA} \Rightarrow I_L(\min) = 57.1 - 40 = 17.1 \text{ mA}$

$R_L = \frac{10}{17.1} \Rightarrow \underline{R_L = 585\Omega}$

2.14

a. From Eq. (2-23)

$$I_Z(\max) = \frac{500[20 - 10] - 50[15 - 10]}{15 - (0.9)(10) - (0.1)(20)}$$

$$= \frac{5000 - 250}{4}$$

$I_Z(\max) = 1.1875 \text{ A}$

$I_Z(\min) = 0.11875 \text{ A}$

From Eq. (2-21(b))

$$R_i = \frac{20 - 10}{1187.5 + 50} \Rightarrow \underline{R_i = 8.08\Omega}$$

b. $P_Z = (1.1875)(10) \Rightarrow \underline{P_Z = 11.9 \text{ W}}$
$P_L = I_L(\max)V_0 = (0.5)(10) \Rightarrow \underline{P_L = 5 \text{ W}}$

2.15

(a) As approximation, assume $I_Z(\max)$ and $I_Z(\min)$ are the same as in problem 2-14.

$V_0(\max) = V_0(\text{nom}) + I_Z(\max)r_Z$
$= 20 + (0.453)(2) = 20.906$

$V_0(\min) = V_0(\text{nom}) + I_Z(\min)r_Z$
$= 20 + (0.0453)(2) = 20.0906$

b. $\% \text{ Reg} = \frac{20.906 - 20.0906}{20} \times 100\%$

$\Rightarrow \underline{\% \text{ Reg} = 4.08\%}$

2.16

$$\%\text{Reg} = \frac{V_L(\max) - V_L(\min)}{V_L(nom)} \times 100\%$$

$$= \frac{V_L(nom) + I_Z(\max)r_z - (V_L(nom) + I_Z(\min)r_z)}{V_L(nom)}$$

$$= \frac{[I_Z(\max) - I_Z(\min)](3)}{6} = 0.05$$

So

$I_Z(\max) - I_Z(\min) = 0.1 \; A$

Now

$I_L(\max) = \frac{6}{500} = 0.012 \; A$, $I_L(\min) = \frac{6}{1000} = 0.006 \; A$

Now

$$R_i = \frac{V_{PS}(\min) - V_Z}{I_Z(\min) + I_L(\max)}$$

or

$$280 = \frac{15 - 6}{I_Z(\min) + 0.012} \Rightarrow I_Z(\min) = 0.020 \; A$$

Then

$I_Z(\max) = 0.1 + 0.02 = 0.12 \; A$

and

$$R_i = \frac{V_{PS}(\max) - V_Z}{I_Z(\max) + I_L(\min)}$$

or

$$280 = \frac{V_{PS}(\max) - 6}{0.12 + 0.006} \Rightarrow \underline{V_{PS}(\max) = 41.3 \; V}$$

2.17

Using Figure 2.17

a. $V_{PS} = 20 \pm 25\% \Rightarrow 15 \le V_{PS} \le 25 \text{ V}$

For $V_{PS}(\min)$:

$I_I = I_Z(\min) + I_L(\max) = 5 + 20 = 25 \text{ mA}$

$R_i = \frac{V_{PS}(\min) - V_Z}{I_I} = \frac{15 - 10}{25} \Rightarrow \underline{R_i = 200\Omega}$

b. For $V_{PS}(\max)$

$\Rightarrow I_I(\max) = \frac{25 - 10}{R_i} \Rightarrow I_I(\max) = 75 \text{ mA}$

For $I_L(\min) = 0 \Rightarrow I_Z(\max) = 75 \text{ mA}$

$V_{Z0} = V_Z - I_Z r_Z = 10 - (0.025)(5) = 9.875 \text{ V}$

$V_0(\max) = 9.875 + (0.075)(5) = 10.25$

$V_0(\min) = 9.875 + (0.005)(5) = 9.90$

$\underline{\Delta V_0 = 0.35 \text{ V}}$

c. $\% \text{ Reg} = \frac{\Delta V_0}{V_0(\text{nom})} \times 100\% \Rightarrow \underline{\% \text{ Reg} = 3.5\%}$

2.18

From Equation (2.21(a))

$$R_i = \frac{V_{PS}(\min) - V_Z}{I_Z(\min) + I_L(\max)} = \frac{24 - 16}{40 + 400}$$

or

$\underline{R_i = 18.2 \; \Omega}$

Also

$$V_r = \frac{V_M}{2fRC} \Rightarrow C = \frac{V_M}{2fRV_r}$$

$R \cong R_i + r_z = 18.2 + 2 = 20.2 \; \Omega$

Then

$$C = \frac{24}{2(60)(1)(20.2)} \Rightarrow \underline{C = 9901 \; \mu F}$$

2.19

$V_Z = V_{Z0} + I_Z r_Z \quad V_Z(\text{nom}) = 8 \text{ V}$

$8 = V_{Z0} + (0.1)(0.5) \Rightarrow V_{Z0} = 7.95 \text{ V}$

$I_i = \dfrac{V_S(\max) - V_Z(\text{nom})}{R_i} = \dfrac{12-8}{3} = 1.333 \text{ A}$

For $I_L = 0.2 \text{ A} \Rightarrow I_Z = 1.133 \text{ A}$

For $I_L = 1 \text{ A} \Rightarrow I_Z = 0.333 \text{ A}$

$V_L(\max) = V_{Z0} + I_Z(\max) r_Z$

$= 7.95 + (1.133)(0.5) = 8.5165$

$V_L(\min) = V_{Z0} + I_Z(\min) r_Z$

$= 7.95 + (0.333)(0.5) = 8.1165$

$\Delta V_L = 0.4 \text{ V}$

$\% \text{ Reg} = \dfrac{\Delta V_L}{V_0(\text{nom})} = \dfrac{0.4}{8} \Rightarrow \underline{\% \text{ Reg} = 5.0\%}$

$V_r = \dfrac{V_M}{2fRC} \Rightarrow C = \dfrac{V_M}{2fRV_r}$

$R = R_i + r_z = 3 + 0.5 = 3.5\,\Omega$

Then

$C = \dfrac{8}{2(60)(3.5)(0.8)} \Rightarrow \underline{C = 0.0238\,F}$

2.20

(a) For $-10 \le v_I \le 0$, both diodes are conducting $\Rightarrow v_O = 0$

For $0 \le v_I \le 3$, Zener not in breakdown, so

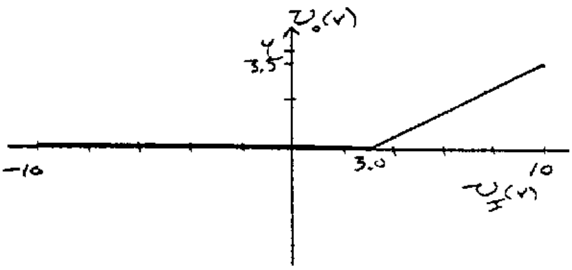
$\underline{i_1 = 0, \quad v_O = 0}$

For $v_I > 3$

$i_1 = \dfrac{v_I - 3}{20}\, mA$

$v_O = \left(\dfrac{v_I - 3}{20}\right)(10) = \dfrac{1}{2} v_I - 1.5$

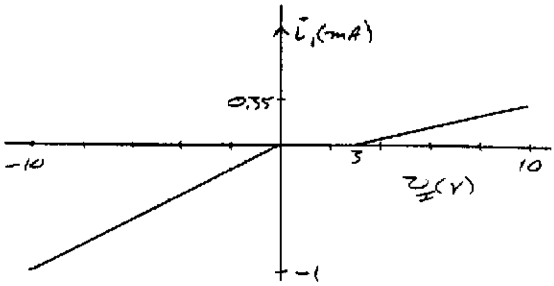
At $v_I = 10\,V$, $v_O = 3.5\,V$, $i_1 = 0.35\,mA$



(b) For $v_I < 0$, both diodes forward biased

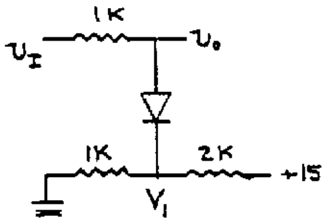
$-i_1 = \dfrac{0 - v_I}{10}$. At $v_I = -10\,V, i_1 = -1\,mA$

For $v_I > 3$, $i_1 = \dfrac{v_I - 3}{20}$. At $v_I = 10\,V, i_1 = 0.35\,mA$



2.21

(a)



$V_1 = \dfrac{1}{3} \times 15 = 5 \text{ V} \Rightarrow$ for $v_I \le 5.7$, $v_0 = v_I$

$\dfrac{v_I - (V_1 + 0.7)}{1} + \dfrac{15 - V_1}{2} = \dfrac{V_1}{1}$, $v_0 = V_1 + 0.7$

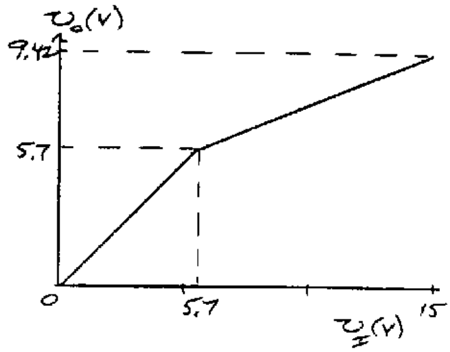
$\dfrac{v_I - v_0}{1} + \dfrac{15 - (v_0 - 0.7)}{2} = \dfrac{v_0 - 0.7}{1}$

$\dfrac{v_I}{1} + \dfrac{15.7}{2} + \dfrac{0.7}{1} = v_0\left(\dfrac{1}{1} + \dfrac{1}{2} + \dfrac{1}{1}\right) = v_0(2.5)$

$v_I + 8.55 = v_0(2.5) \Rightarrow v_0 = \dfrac{1}{2.5} v_I + 3.42$

$v_I = 5.7 \Rightarrow v_0 = 5.7$

$v_I = 15 \Rightarrow v_0 = 9.42$



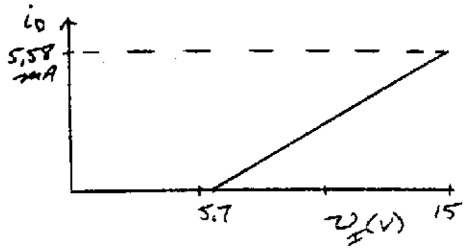
(b) $i_D = 0$ for $0 \le v_I \le 5.7$

Then

$i_D = \dfrac{v_I - v_O}{1} = \dfrac{v_I - \left(\dfrac{v_I}{2.5} + 3.42\right)}{1}$

or

$i_D = \dfrac{0.6 v_I - 3.42}{1} \qquad$ For $v_I = 15$, $i_D = 5.58\,mA$



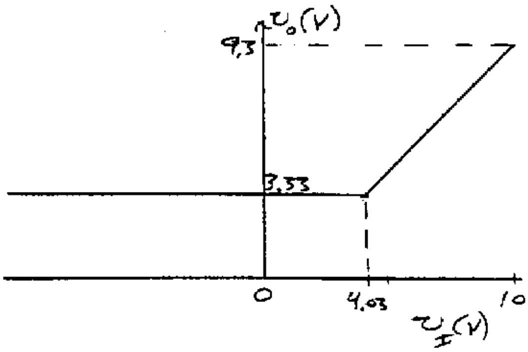
2.22

(a) For D off, $v_O = \left(\frac{20}{30}\right)(20) - 10 = 3.33\,V$

Then for $v_I \le 3.33 + 0.7 = 4.03\,V \Rightarrow v_O = 3.33\,V$

For $v_I > 4.03$, $v_O = v_I - 0.7$;

For $v_I = 10$, $v_O = 9.3$

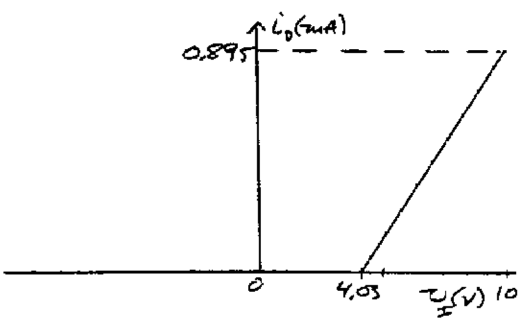


(b) For $v_I \le 4.03\,V$, $i_D = 0$

For $v_I > 4.03$, $i_D + \frac{10 - v_O}{10} = \frac{v_O - (-10)}{20}$

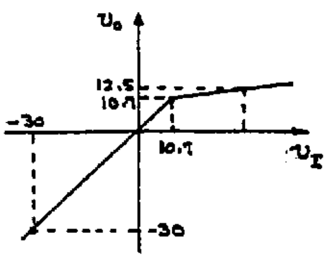
Which yields $i_D = \frac{3}{20} v_I - 0.605$

For $v_I = 10$, $i_D = 0.895\,mA$



2.23

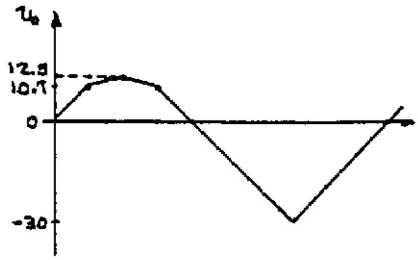
a.



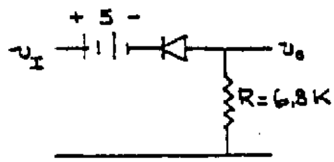
For $v_I = 30$ V, $i = \frac{30 - 10.7}{100 + 10} = 0.175$ A

$v_0 = i(10) + 10.7 = 12.5$ V

b.

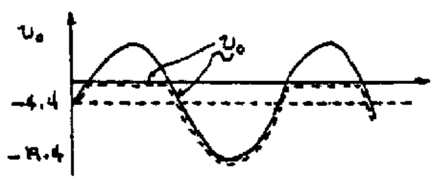


2.24



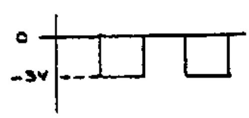
$V_\gamma = 0.6$ V

$v_I = 15 \sin \omega t$

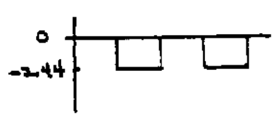


2.25

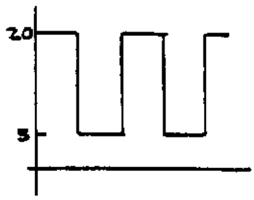
a. $V_\gamma = 0$



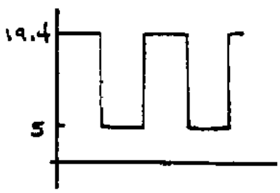
$V_\gamma = 0.6$



b. $V_\gamma = 0$

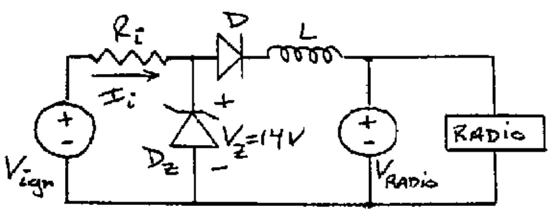


$V_\gamma = 0.6$



2.26

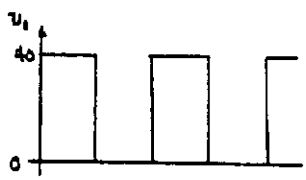
One possible example is shown.



L will tend to block the transient signals
D_Z will limit the voltage to +14 V and –0.7 V.
Power ratings depends on number of pulses per second and duration of pulse.

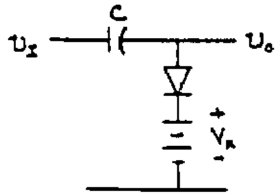
2.27
$V_\gamma = 0$

a.



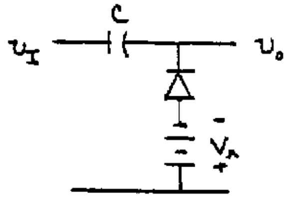
b.

2.28



a. For $V_\gamma = 0 \Rightarrow V_I = 2.7$ V
b. For $V_\gamma = 0.7$ V $\Rightarrow V_I = 2.0$ V

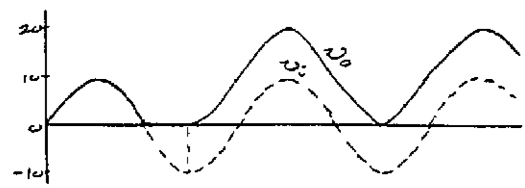
2.29



For $V_\gamma = 0$; $V_I = 10$ V

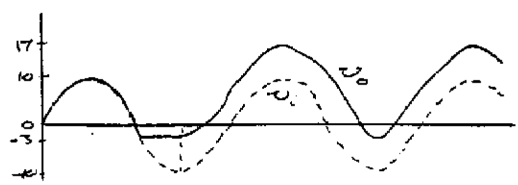
2.30

For circuit in Figure P2.27(a)

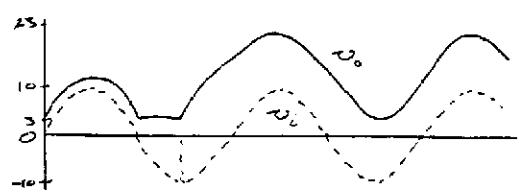


For circuit in Figure P2.27(b)

(i) For $V_B = +3V$

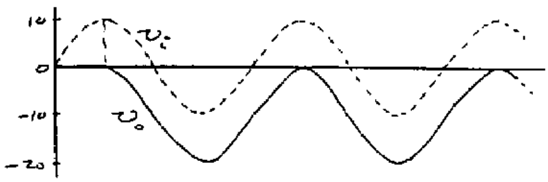


(ii) For $V_B = -3V$



2.31

For Figure P2.27(a)



2.32

a. $I_{D1} = \frac{10-0.6}{9.5+0.5} \Rightarrow \underline{I_{D1} = 0.94 \text{ mA}}$ $\underline{I_{D2} = 0}$

$V_0 = I_{D1}(9.5) \Rightarrow \underline{V_0 = 8.93 \text{ V}}$

b. $I_{D1} = \frac{5-0.6}{9.5+0.5} \Rightarrow \underline{I_{D1} = 0.44 \text{ mA}}$ $\underline{I_{D2} = 0}$

$V_0 = I_{D1}(9.5) \Rightarrow \underline{V_0 = 4.18 \text{ V}}$

c. Same as (a)

d. $10 = \frac{(I)}{2}(0.5) + 0.6 + I(9.5) \Rightarrow I = 0.964 \text{ mA}$

$V_0 = I(9.5) \Rightarrow \underline{V_0 = 9.16 \text{ V}}$

$I_{D1} = I_{D2} = \frac{I}{2} \Rightarrow \underline{I_{D1} = I_{D2} = 0.482 \text{ mA}}$

2.33

a. $\underline{I = I_{D1} = I_{D2} = 0}$ $\underline{V_0 = 10}$

b. $10 = I(9.5) + 0.6 + I(0.5) \Rightarrow$

$\underline{I = I_{D2} = 0.94 \text{ mA}}$ $\underline{I_{D1} = 0}$

$V_0 = 10 - I(9.5) \Rightarrow \underline{V_0 = 1.07 \text{ V}}$

c. $10 = I(9.5) + 0.6 + I(0.5) + 5 \Rightarrow$

$\underline{I = I_{D2} = 0.44 \text{ mA}}$ $\underline{I_{D1} = 0}$

$V_0 = 10 - I(9.5) \Rightarrow \underline{V_0 = 5.82 \text{ V}}$

d. $10 = I(9.5) + 0.6 + \frac{I}{2}(0.5) \Rightarrow \underline{I = 0.964 \text{ mA}}$

$I_{D1} = I_{D2} = \frac{I}{2} \Rightarrow \underline{I_{D1} = I_{D2} = 0.482 \text{ mA}}$

$V_0 = 10 - I(9.5) \Rightarrow \underline{V_0 = 0.842 \text{ V}}$

2.34

a. $V_1 = V_2 = 0 \Rightarrow D_1,\ D_2,\ D_3,$ on $\underline{V_0 = 4.4 \text{ V}}$

$I = \frac{10-4.4}{9.5} \Rightarrow$ $\underline{I = 0.589 \text{ mA}}$

$I_{D1} = I_{D2} = \frac{4.4-0.6}{0.5} \Rightarrow \underline{I_{D1} = I_{D2} = 7.6 \text{ mA}}$

$I_{D3} = I_{D1} + I_{D2} - I = 2(7.6) - 0.589 \Rightarrow$

$\underline{I_{D3} = 14.6 \text{ mA}}$

b. $V_1 = V_2 = 5$ V D_1 and D_2 on, D_3 off

$10 = I(9.5) + 0.6 + \frac{I}{2}(0.5) + 5 \Rightarrow \underline{I = 0.451 \text{ mA}}$

$I_{D1} = I_{D2} = \frac{I}{2} \Rightarrow \underline{I_{D1} = I_{D2} = 0.226 \text{ mA}}$

$\underline{I_{D3} = 0}$

$V_0 = 10 - I(9.5) = 10 - (0.451)(9.5) \Rightarrow$

$\underline{V_0 = 5.72 \text{ V}}$

c. $V_1 = 5$ V, $V_2 = 0$ D_1 off, D_2, D_3 on

$\underline{V_0 = 4.4 \text{ V}}$

$I = \frac{10-4.4}{9.5} \Rightarrow$ $\underline{I = 0.589 \text{ mA}}$

$I_{D2} = \frac{4.4-0.6}{0.5} \Rightarrow$ $\underline{I_{D2} = 7.6 \text{ mA}}$

$\underline{I_{D1} = 0}$

$I_{D3} = I_{D2} - I = 7.6 - 0.589 \Rightarrow \underline{I_{D3} = 7.01 \text{ mA}}$

d. $V_1 = 5$ V, $V_2 = 2$ V D_1 off, D_2, D_3 on

$\underline{V_0 = 4.4 \text{ V}}$

$I = \frac{10-4.4}{9.5} \Rightarrow$ $\underline{I = 0.589 \text{ mA}}$

$I_{D2} = \frac{4.4-0.6-2}{0.5} \Rightarrow$ $\underline{I_{D2} = 3.6 \text{ mA}}$

$\underline{I_{D1} = 0}$

$I_{D3} = I_{D2} - I = 3.6 - 0.589 \Rightarrow \underline{I_{D3} = 3.01 \text{ mA}}$

2.35

(a) D_1 *on*, D_2 *off*, D_3 *on*

So $\underline{I_{D2} = 0}$

Now $\underline{V_2 = -0.6\,V}$, $I_{D1} = \frac{10-0.6-(-0.6)}{R_1+R_2} = \frac{10}{2+6} \Rightarrow$

$\underline{I_{D1} = 1.25\,mA}$

$V_1 = 10 - 0.6 - (1.25)(2) \Rightarrow$ $\underline{V_1 = 6.9\,V}$

$I_{R3} = \frac{-0.6-(-5)}{2} = 2.2\,mA$

$I_{D3} = I_{R3} - I_{D1} = 2.2 - 1.25 \Rightarrow$ $\underline{I_{D3} = 0.95\,mA}$

(b) D_1 *on*, D_2 *on*, D_3 *off*

So $\underline{I_{D3} = 0}$

$\underline{V_1 = 4.4\,V}$, $I_{D1} = \frac{10-0.6-4.4}{R_1} = \frac{5}{6}$

or

$\underline{I_{D1} = 0.833\,mA}$

$I_{R2} = \frac{4.4-(-5)}{R_2+R_3} = \frac{9.4}{10} = 0.94\,mA$

$I_{D2} = I_{R2} - I_{D1} = 0.94 - 0.833 \Rightarrow$ $\underline{I_{D2} = 0.107\,mA}$

$V_2 = I_{R2}R_3 - 5 = (0.94)(5) - 5 \Rightarrow$ $\underline{V_2 = -0.3\,V}$

(c) All diodes are on

$V_1 = 4.4\,V\,,\quad V_2 = -0.6\,V$

$$I_{D_1} = 0.5\,mA = \frac{10-0.6-4.4}{R_1} \Rightarrow \quad R_1 = 10\,k\Omega$$

$$I_{R2} = 0.5 + 0.5 = 1\,mA = \frac{4.4-(-0.6)}{R_2} \Rightarrow$$

$R_2 = 5\,k\Omega$

$$I_{R3} = 1.5\,mA = \frac{-0.6-(-5)}{R_3} \Rightarrow \quad R_3 = 2.93\,k\Omega$$

2.36

For v_I small, both diodes off

$$v_O = \left(\frac{0.5}{0.5+5}\right)v_I = 0.0909 v_I$$

When $v_I - v_O = 0.6$, D_1 turns on. So we have

$v_I - 0.0909 v_I = 0.6 \Rightarrow v_I = 0.66\,,\quad v_O = 0.06$

For D_1 on

$$\frac{v_I - 0.6 - v_O}{5} + \frac{v_I - v_O}{5} = \frac{v_O}{0.5} \quad \text{which yields}$$

$$v_O = \frac{2v_I - 0.6}{12}$$

When $v_O = 0.6$, D_2 turns on. Then

$$0.6 = \frac{2v_I - 0.6}{12} \Rightarrow v_I = 3.9\,V$$

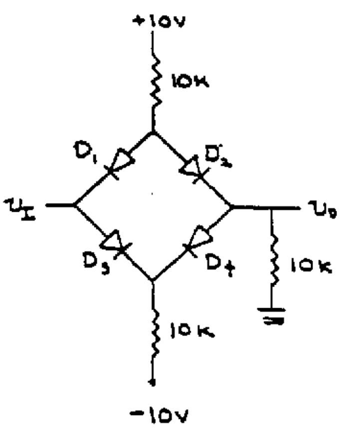
Now for $v_I > 3.9$

$$\frac{v_I - 0.6 - v_O}{5} + \frac{v_I - v_O}{5} = \frac{v_O}{0.5} + \frac{v_O - 0.6}{0.5}$$

Which yields

$$v_O = \frac{2v_I + 5.4}{22}\,;\ For\ \ v_I = 10 \Rightarrow v_O = 1.15\,V$$

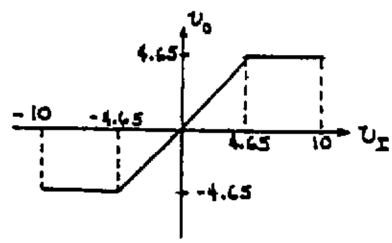
2.37



For $v_I > 0$. when D_1 turns off

$$I = \frac{10-0.7}{20} = 0.465\ \text{mA}$$

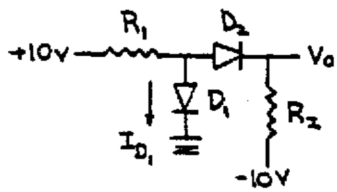
$$v_O = I(10\ \text{k}\Omega) = 4.65\ \text{V}$$



$v_O = v_I$ for $-4.65 \le v_I \le 4.65$

2.38

a.



$R_1 = 5\ \text{k}\Omega,\ R_2 = 10\ \text{k}\Omega$

D_1 and D_2 on $\Rightarrow \underline{V_0 = 0}$

$$I_{D1} = \frac{10-0.7}{5} - \frac{0-(-10)}{10} = 1.86 - 1.0$$

$\underline{I_{D1} = 0.86\ \text{mA}}$

b. $R_1 = 10\ \text{k}\Omega,\ R_2 = 5\ \text{k}\Omega,\ D_1$ off, D_2 on

$\underline{I_{D1} = 0}$

$$I = \frac{10-0.7-(-10)}{15} = 1.287$$

$V_0 = IR_2 - 10 \Rightarrow \underline{V_0 = -3.57\ \text{V}}$

2.39

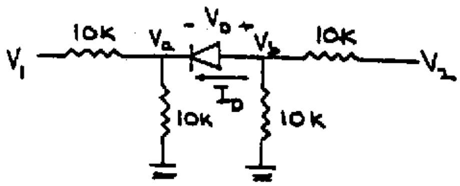
$$\frac{15-(V_0+0.7)}{10} = \frac{V_0+0.7}{20} + \frac{V_0}{20}$$

$$\frac{15}{10} - \frac{0.7}{10} - \frac{0.7}{20} = V_0\left(\frac{1}{10} + \frac{1}{20} + \frac{1}{20}\right) = V_0\left(\frac{4.0}{20}\right)$$

$V_0 = 6.975\ \text{V}$

$$I_D = \frac{V_0}{20} \Rightarrow \underline{I_D = 0.349\ \text{mA}}$$

2.40



a. $V_1 = 15$ V, $V_2 = 10$ V Diode off

$V_a = 7.5$ V, $V_b = 5$ V $\Rightarrow \underline{V_D = -2.5\text{ V}}$

$\underline{I_D = 0}$

b. $V_1 = 10$ V, $V_2 = 15$ V Diode on

$$\frac{V_2 - V_b}{10} = \frac{V_b}{10} + \frac{V_a}{10} + \frac{V_a - V_1}{10} \Rightarrow V_a = V_b - 0.6$$

$$\frac{15}{10} + \frac{10}{10} = V_b\left(\frac{1}{10} + \frac{1}{10}\right) + V_b\left(\frac{1}{10} + \frac{1}{10}\right)$$

$$- 0.6\left(\frac{1}{10} + \frac{1}{10}\right)$$

$$2.62 = V_b\left(\frac{4}{10}\right) \Rightarrow V_b = 6.55\text{ V}$$

$$I_D = \frac{15 - 6.55}{10} - \frac{6.55}{10} \Rightarrow \underline{I_D = 0.19\text{ mA}}$$

$\underline{V_D = 0.6\text{ V}}$

2.41

$v_I = 0$, D_1 off, D_2 on

$$I = \frac{10 - 2.5}{15} = 0.5\text{ mA}$$

$v_0 = 10 - (0.5)(5) \Rightarrow \underline{v_0 = 7.5\text{ V for } 0 \le v_I \le 7.5}$

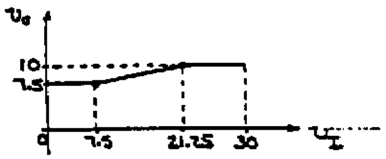
For $v_I = 30$ V, D_2 off, $v_0 = 10$ V

Determine v_I when $V_x = 10$

$$I = \frac{v_I - 2.5}{25}$$

$V_x = 10 = I(10) + 2.5 \Rightarrow I = 0.75$ mA

$v_I = (0.75)(25) + 2.5 = 21.25$



2.42

a. $\underline{V_{01} = V_{02} = 0}$
b. $\underline{V_{01} = 4.4\text{ V}}$, $\underline{V_{02} = 3.8\text{ V}}$
c. $\underline{V_{01} = 4.4\text{ V}}$, $\underline{V_{02} = 3.8\text{ V}}$

Logic "1" level degrades as it goes through additional logic gates.

2.43

a. $\underline{V_{01} = V_{02} = 5\text{ V}}$
b. $\underline{V_{01} = 0.6\text{ V}}$, $\underline{V_{02} = 1.2\text{ V}}$
c. $\underline{V_{01} = 0.6\text{ V}}$, $\underline{V_{02} = 1.2\text{ V}}$

Logic "0" signal degrades as it goes through additional logic gates.

2.44

$$(V_1\ AND\ V_2)\ OR\ (V_3\ AND\ V_4)$$

2.45

$$I = \frac{10 - 1.5 - 0.2}{R + 10} = 12\text{ mA} = 0.012$$

$$R + 10 = \frac{8.3}{0.012} = 691.7\Omega$$

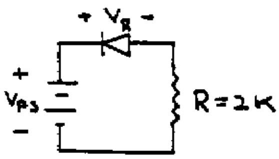
$\underline{R = 681.7\Omega}$

2.46

$$I = \frac{10 - 1.7 - V_I}{0.75} = 8$$

$V_I = 10 - 1.7 - 8(0.75) \Rightarrow \underline{V_I = 2.3\text{ V}}$

2.47



$V_R = 1$ V, $I = 0.8$ mA

$V_{PS} = 1 + (0.8)(2)$

$\underline{V_{PS} = 2.6\text{ V}}$

2.48

$I_{Ph} = \eta e \Phi A$

$0.6 \times 10^{-3} = (1)(1.6 \times 10^{-19})(10^{17})A$

$\underline{A = 3.75 \times 10^{-2}\text{ cm}^2}$