Chapter 2

1. The load line will intersect at $I_D = \frac{E}{R} = \frac{12\text{ V}}{750\ \Omega} = 16$ mA and $V_D = 12$ V.

   (a) $V_{D_Q} \cong \mathbf{0.85\ V}$

   $I_{D_Q} \cong \mathbf{15\ mA}$

   $V_R = E - V_{D_Q} = 12\text{ V} - 0.85\text{ V} = \mathbf{11.15\ V}$

   (b) $V_{D_Q} \cong \mathbf{0.7\ V}$

   $I_{D_Q} \cong \mathbf{15\ mA}$

   $V_R = E - V_{D_Q} = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\ V}$

   (c) $V_{D_Q} \cong \mathbf{0\ V}$

   $I_{D_Q} \cong \mathbf{16\ mA}$

   $V_R = E - V_{D_Q} = 12\text{ V} - 0\text{ V} = \mathbf{12\ V}$

   For (a) and (b), levels of V_{D_Q} and I_{D_Q} are quite close. Levels of part (c) are reasonably close but as expected due to level of applied voltage E.

2. (a) $I_D = \frac{E}{R} = \frac{6\text{ V}}{0.2\text{ k}\Omega} = 30$ mA

   The load line extends from $I_D = 30$ mA to $V_D = 6$ V.

   $V_{D_Q} \cong \mathbf{0.95\ V}$, $I_{D_Q} \cong \mathbf{25.3\ mA}$

   (b) $I_D = \frac{E}{R} = \frac{6\text{ V}}{0.47\text{ k}\Omega} = 12.77$ mA

   The load line extends from $I_D = 12.77$ mA to $V_D = 6$ V.

   $V_{D_Q} \cong \mathbf{0.8\ V}$, $I_{D_Q} \cong \mathbf{11\ mA}$

   (c) $I_D = \frac{E}{R} = \frac{6\text{ V}}{0.68\text{ k}\Omega} = 8.82$ mA

   The load line extends from $I_D = 8.82$ mA to $V_D = 6$ V.

   $V_{D_Q} \cong \mathbf{0.78\ V}$, $I_{D_Q} \cong \mathbf{78\ mA}$

   The resulting values of V_{D_Q} are quite close, while I_{D_Q} extends from 7.8 mA to 25.3 mA.

3. Load line through $I_{D_Q} = 10$ mA of characteristics and $V_D = 7$ V will intersect I_D axis as 11.3 mA.

   $I_D = 11.3\text{ mA} = \frac{E}{R} = \frac{7\text{ V}}{R}$

   with $R = \frac{7\text{ V}}{11.3\text{ mA}} = 619.47\text{ k}\Omega \cong \mathbf{0.62\ k\Omega}$ standard resistor

4. (a) $I_D = I_R = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0.7\text{ V}}{1.5\text{ k}\Omega} = \mathbf{19.53\text{ mA}}$

$V_D = \mathbf{0.7\text{ V}}$, $V_R = E - V_D = 30\text{ V} - 0.7\text{ V} = \mathbf{29.3\text{ V}}$

(b) $I_D = \dfrac{E - V_D}{R} = \dfrac{30\text{ V} - 0\text{ V}}{1.5\text{ k}\Omega} = \mathbf{20\text{ mA}}$

$V_D = \mathbf{0\text{ V}}$, $V_R = \mathbf{30\text{ V}}$

Yes, since $E \gg V_T$ the levels of I_D and V_R are quite close.

5. (a) $I = \mathbf{0\text{ mA}}$; diode reverse-biased.

(b) $V_{20\Omega} = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$ (Kirchhoff's voltage law)

$I(20\ \Omega) = \dfrac{19.3\text{ V}}{20\ \Omega} = 0.965\text{ A}$

$V(10\ \Omega) = 20\text{ V} - 0.7\text{ V} = 19.3\text{ V}$

$I(10\ \Omega) = \dfrac{19.3\text{ V}}{10\ \Omega} = 1.93\text{ A}$

$I = I(10\ \Omega) + I(20\ \Omega)$

$= \mathbf{2.895\text{ A}}$

(c) $I = \dfrac{10\text{ V}}{10\ \Omega} = \mathbf{1\text{ A}}$; center branch open

6. (a) Diode forward-biased,

Kirchhoff's voltage law (CW): $-5\text{ V} + 0.7\text{ V} - V_o = 0$

$V_o = \mathbf{-4.3\text{ V}}$

$I_R = I_D = \dfrac{|V_o|}{R} = \dfrac{4.3\text{ V}}{2.2\text{ k}\Omega} = \mathbf{1.955\text{ mA}}$

(b) Diode forward-biased,

$I_D = \dfrac{8\text{ V} + 6\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega + 4.7\text{ k}\Omega} = \mathbf{2.25\text{ mA}}$

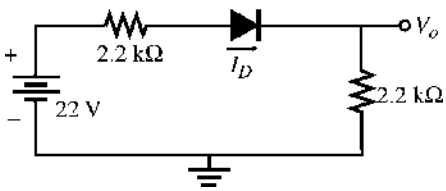
$V_o = 8\text{ V} - (2.25\text{ mA})(1.2\text{ k}\Omega) = \mathbf{5.3\text{ V}}$

7. (a) $V_o = \dfrac{10\text{ k}\Omega(12\text{ V} - 0.7\text{ V} - 0.3\text{ V})}{2\text{ k}\Omega + 10\text{ k}\Omega} = \mathbf{9.17\text{ V}}$

(b) $V_o = \mathbf{10\text{ V}}$

8. (a) Determine the Thevenin equivalent circuit for the 10 mA source and 2.2 kΩ resistor.

$E_{Th} = IR = (10\text{ mA})(2.2\text{ k}\Omega) = 22\text{ V}$
$R_{Th} = 2.\ 2\text{k}\Omega$



Diode forward-biased

$$I_D = \frac{22\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega} = \mathbf{4.84\ mA}$$

$V_o = I_D(1.2\text{ k}\Omega)$
$= (4.84\text{ mA})(1.2\text{ k}\Omega)$
$= \mathbf{5.81\ V}$

(b) Diode forward-biased

$$I_D = \frac{20\text{ V} + 20\text{ V} - 0.7\text{ V}}{6.8\text{ k}\Omega} = \mathbf{5.78\ mA}$$

Kirchhoff's voltage law (CW):
$+V_o - 0.7\text{ V} + 20\text{ V} = 0$
$V_o = \mathbf{-19.3\ V}$

9. (a) $V_{o_1} = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\ V}$
$V_{o_2} = \mathbf{1.2\ V}$

(b) $V_{o_1} = \mathbf{0\ V}$
$V_{o_2} = \mathbf{0\ V}$

10. (a) Both diodes forward-biased
Si diode turns on first and locks in 0.7 V drop.

$$I_R = \frac{12\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega} = 2.4\text{ mA}$$

$I_D = I_R = \mathbf{2.4\ mA}$
$V_o = 12\text{ V} - 0.7\text{ V} = \mathbf{11.3\ V}$

(b) Right diode forward-biased:

$$I_D = \frac{20\text{ V} + 4\text{ V} - 0.7\text{ V}}{2.2\text{ k}\Omega} = \mathbf{10.59\ mA}$$

$V_o = 20\text{ V} - 0.7\text{ V} = \mathbf{19.3\ V}$

11. (a) Si diode "on" preventing GaAs diode from turning "on":

$$I = \frac{1\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{0.3\text{ V}}{1\text{ k}\Omega} = \mathbf{0.3\ mA}$$

$V_o = 1\text{ V} - 0.7\text{ V} = \mathbf{0.3\ V}$

(b) $$I = \frac{16\text{ V} - 0.7\text{ V} - 0.7\text{ V} + 4\text{ V}}{4.7\text{ k}\Omega} = \frac{18.6\text{ V}}{4.7\text{ k}\Omega} = \mathbf{3.96\ mA}$$

$V_o = 16\text{ V} - 0.7\text{ V} - 0.7\text{ V} = \mathbf{14.6\ V}$

12. Both diodes forward-biased:

V_{o_1} = **0.7 V**, V_{o_2} = **0.7 V**

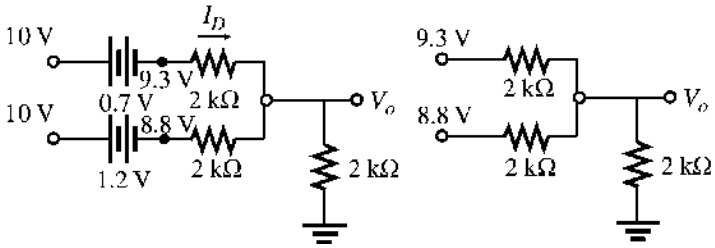
$$I_{1\,k\Omega} = \frac{20\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{19.3\text{ V}}{1\text{ k}\Omega} = 19.3\text{ mA}$$

$I_{0.47\,k\Omega} = 0$ mA

$I = I_{1\,k\Omega} - I_{0.47\,k\Omega} = 19.3\text{ mA} - 0\text{ mA}$

= **19.3 mA**

13.



Superposition: $V_{o_1}(9.3\text{ V}) = \dfrac{1\text{ k}\Omega(9.3\text{ V})}{1\text{ k}\Omega + 2\text{ k}\Omega} = 3.1\text{ V}$

$$V_{o_2}(8.8\text{ V}) = \frac{16\text{ k}\Omega(8.8\text{ V})}{1\text{ k}\Omega + 2\text{ k}\Omega} = 2.93\text{ V}$$

$V_o = V_{o_1} + V_{o_2}$ = **6.03 V**

$$I_D = \frac{9.3\text{ V} - 6.03\text{ V}}{2\text{ k}\Omega} = \mathbf{1.635\text{ mA}}$$

14. Both diodes "off". The threshold voltage of 0.7 V is unavailable for either diode.

V_o = **0 V**

15. Both diodes "on", $V_o = 10\text{ V} - 0.7\text{ V}$ = **9.3 V**

16. Both diodes "on".

V_o = **0.7 V**

17. Both diodes "off", V_o = **10 V**

18. The Si diode with −5 V at the cathode is "on" while the other is "off". The result is

$V_o = -5\text{ V} + 0.7\text{ V}$ = **−4.3 V**

19. 0 V at one terminal is "more positive" than −5 V at the other input terminal. Therefore assume lower diode "on" and upper diode "off".
The result:

$V_o = 0\text{ V} - 0.7\text{ V}$ = **−0.7 V**

The result supports the above assumptions.

20. Since all the system terminals are at 10 V the required difference of 0.7 V across either diode cannot be established. Therefore, both diodes are "off" and

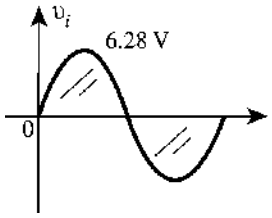
V_o = **+10 V**

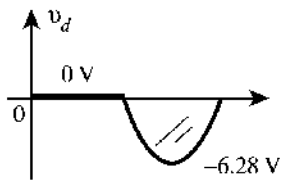
as established by 10 V supply connected to 1 kΩ resistor.

21. The Si diode requires more terminal voltage than the Ge diode to turn "on". Therefore, with 5 V at both input terminals, assume Si diode "off" and Ge diode "on".

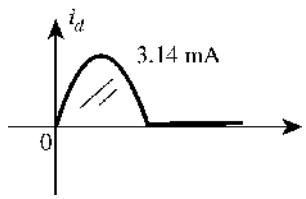
The result: $V_o = 5\text{ V} - 0.3\text{ V} = \mathbf{4.7\ V}$
The result supports the above assumptions.

22. $V_{dc} = 0.318\ V_m \Rightarrow V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\ V}$

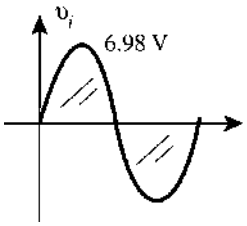


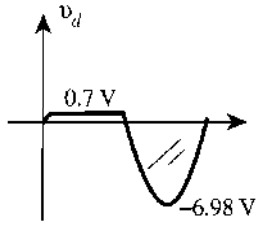


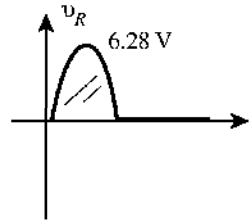
$I_m = \dfrac{V_m}{R} = \dfrac{6.28\text{ V}}{2\text{ k}\Omega} = \mathbf{3.14\ mA}$

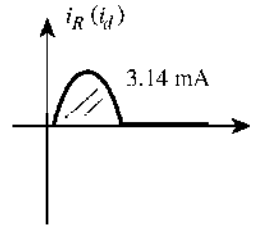


23. Using $V_{dc} \cong 0.318(V_m - V_T)$
$2\text{ V} = 0.318(V_m - 0.7\text{ V})$
Solving: $V_m = \mathbf{6.98\ V} \cong 10{:}1$ for $V_m{:}V_T$

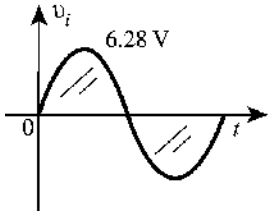


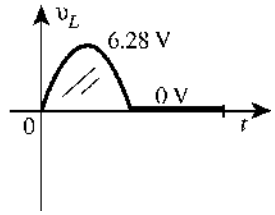




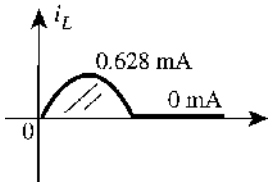


24. $V_m = \dfrac{V_{dc}}{0.318} = \dfrac{2\text{ V}}{0.318} = \mathbf{6.28\ V}$



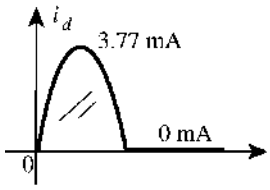


$I_{L_{max}} = \dfrac{6.28\text{ V}}{10\text{ k}\Omega} = \mathbf{0.628\ mA}$

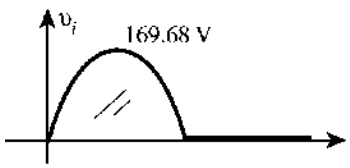


$I_{\max}(2\ \text{k}\Omega) = \dfrac{6.28\ \text{V}}{2\ \text{k}\Omega} = \mathbf{3.14\ mA}$

$I_{D_{\max}} = I_{L_{\max}} + I_{\max}(2\ \text{k}\Omega) = 0.678\ \text{mA} + 3.14\ \text{mA} = \mathbf{3.77\ mA}$



25. $V_m = \sqrt{2}\ (120\ \text{V}) = 169.68\ \text{V}$
$V_{\text{dc}} = 0.318V_m = 0.318(169.68\ \text{V}) = \mathbf{53.96\ V}$



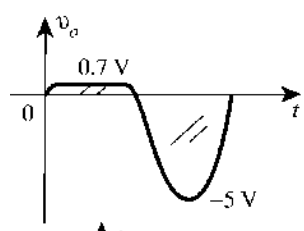
26. Diode will conduct when $v_o = 0.7$ V; that is,

$$v_o = 0.7\ \text{V} = \frac{1\ \text{k}\Omega(v_i)}{1\ \text{k}\Omega + 1\ \text{k}\Omega}$$

Solving: $v_i = \mathbf{1.4\ V}$

For $v_i \geq 1.4$ V Si diode is "on" and $v_o = \mathbf{0.7\ V}$.
For $v_i < 1.4$ V Si diode is open and level of v_o is determined by voltage divider rule:

$$v_o = \frac{1\ \text{k}\Omega(v_i)}{1\ \text{k}\Omega + 1\ \text{k}\Omega} = 0.5\ v_i$$

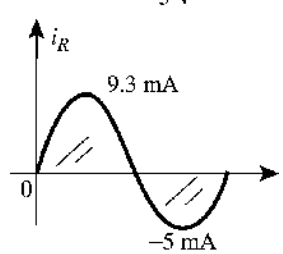


For $v_i = -10$ V:

$v_o = 0.5(-10\ \text{V})$
$= \mathbf{-5\ V}$

When $v_o = 0.7$ V, $v_{R_{\max}} = v_{i_{\max}} - 0.7\ \text{V}$
$= 10\ \text{V} - 0.7\ \text{V} = 9.3\ \text{V}$

$$I_{R_{\max}} = \frac{9.3\ \text{V}}{1\ \text{k}\Omega} = 9.3\ \text{mA}$$



$$I_{\max}(\text{reverse}) = \frac{10\ \text{V}}{1\ \text{k}\Omega + 1\ \text{k}\Omega} = \mathbf{0.5\ mA}$$

27. (a) $P_{max} = 14\text{ mW} = (0.7\text{ V})I_D$

$$I_D = \frac{14\text{ mW}}{0.7\text{ V}} = \mathbf{20\ mA}$$

(b) $I_{max} = 2 \times 20\text{ mA} = \mathbf{40\ mA}$

(c) $4.7\text{ k}\Omega \,||\, 68\text{ k}\Omega = 4.4\text{ k}\Omega$

$V_R = 160\text{ V} - 0.7\text{ V} = 159.3\text{ V}$

$$I_{max} = \frac{159.3\text{ V}}{4.4\text{ k}\Omega} = 36.2\text{ mA}$$

$$I_d = \frac{I_{max}}{2} = \mathbf{18.1\ mA}$$

(d) Total damage, **36.2 mA > 20 mA**

28. (a) $V_m = \sqrt{2}\,(120\text{ V}) = 169.7\text{ V}$

$V_{L_m} = V_{i_m} - 2V_D$

$= 169.7\text{ V} - 2(0.7\text{ V}) = 169.7\text{ V} - 1.4\text{ V}$

$= 168.3\text{ V}$

$V_{dc} = 0.636(168.3\text{ V}) = \mathbf{107.04\ V}$

(b) PIV = V_m(load) + V_D = 168.3 V + 0.7 V = **169 V**

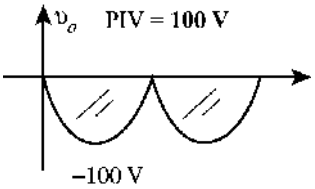
(c) $I_D(\text{max}) = \dfrac{V_{L_m}}{R_L} = \dfrac{168.3\text{ V}}{1\text{ k}\Omega} = \mathbf{168.3\ mA}$

(d) $P_{max} = V_D I_D = (0.7\text{ V})I_{max}$

$= (0.7\text{ V})(168.3\text{ mA})$

$= \mathbf{117.81\ mW}$

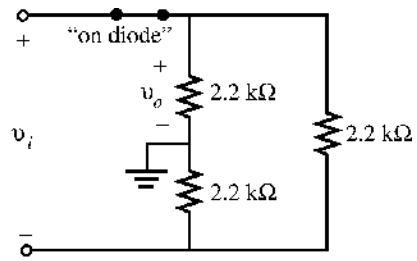
29.



$$I_{max} = \frac{100\text{ V}}{2.2\text{ k}\Omega} = \mathbf{45.45\ mA}$$

30. Positive half-cycle of v_i:

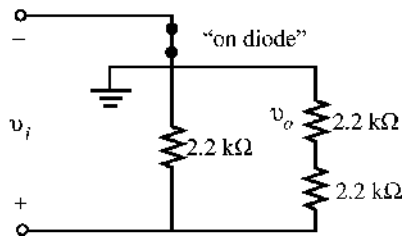
Network redrawn:



Voltage-divider rule:

$$V_{o_{max}} = \frac{2.2\text{ k}\Omega(V_{i_{max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{1}{2}(V_{i_{max}}) = \frac{1}{2}(100\text{ V}) = \mathbf{50\ V}$$

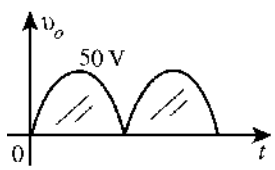
Negative half-cycle of v_i:



Polarity of v_o across the 2.2 kΩ resistor acting as a load is the same.

Voltage-divider rule:

$$V_{o_{max}} = \frac{2.2\text{ k}\Omega(V_{i_{max}})}{2.2\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{1}{2}(V_{i_{max}}) = \frac{1}{2}(100\text{ V}) = \mathbf{50\ V}$$



$V_{dc} = 0.636V_m = 0.636\ (50\text{ V}) = \mathbf{31.8\ V}$

31. Positive pulse of v_i:

Top left diode "off", bottom left diode "on"
2.2 kΩ || 2.2 kΩ = 1.1 kΩ

$$V_{o_{peak}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

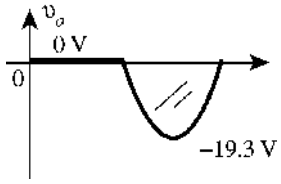
Negative pulse of v_i:

Top left diode "on", bottom left diode "off"

$$V_{o_{peak}} = \frac{1.1\text{ k}\Omega(170\text{ V})}{1.1\text{ k}\Omega + 2.2\text{ k}\Omega} = 56.67\text{ V}$$

$V_{dc} = 0.636(56.67\text{ V}) = \mathbf{36.04\ V}$

32. (a) Si diode open for positive pulse of v_i and $v_o = \mathbf{0\ V}$
For $-20\text{ V} < v_i \le -0.7\text{ V}$ diode "on" and $v_o = v_i + 0.7\text{ V}$.
For $v_i = -20\text{ V}$, $v_o = -20\text{ V} + 0.7\text{ V} = \mathbf{-19.3\ V}$
For $v_i = -0.7\text{ V}$, $v_o = -0.7\text{ V} + 0.7\text{ V} = \mathbf{0\ V}$



(b) For $v_i \le 8$ V the 8 V battery will ensure the diode is forward-biased and $v_o = v_i - 8$ V.

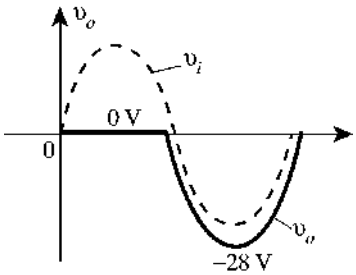
At $v_i = 8$ V

$v_o = 8\text{ V} - 8\text{ V} = \mathbf{0\ V}$

At $v_i = -20$ V

$v_o = -20\text{ V} - 8\text{ V} = \mathbf{-28\ V}$

For $v_i > 8$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

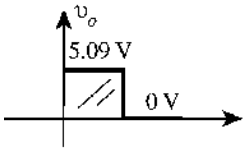


33. (a) Positive pulse of v_i:

$$V_o = \frac{1.8\text{ k}\Omega(12\text{ V} - 0.7\text{ V})}{1.8\text{ k}\Omega + 2.2\text{ k}\Omega} = \mathbf{5.09\ V}$$

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$

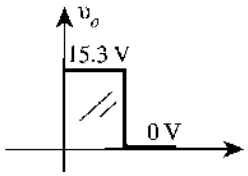


(b) Positive pulse of v_i:

$V_o = 12\text{ V} - 0.7\text{ V} + 4\text{ V} = \mathbf{15.3\ V}$

Negative pulse of v_i:

diode "open", $v_o = \mathbf{0\ V}$

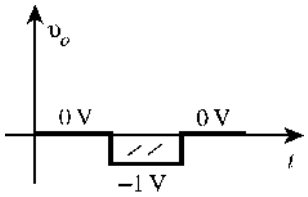


34. (a) For $v_i = 20$ V the diode is reverse-biased and $v_o = \mathbf{0\ V}$.

For $v_i = -5$ V, v_i overpowers the 4 V battery and the diode is "on".

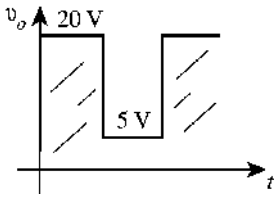
Applying Kirchhoff's voltage law in the clockwise direction:

$$-5\text{ V} + 4\text{ V} - v_o = 0$$
$$v_o = \mathbf{-1\ V}$$

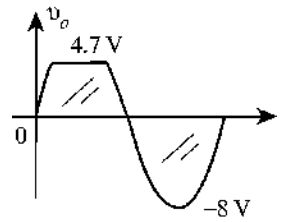


(b) For $v_i = 20$ V the 20 V level overpowers the 5 V supply and the diode is "on". Using the short-circuit equivalent for the diode we find $v_o = v_i = \mathbf{20\ V}$.

For $v_i = -5$ V, both v_i and the 5 V supply reverse-bias the diode and separate v_i from v_o. However, v_o is connected directly through the 2.2 kΩ resistor to the 5 V supply and $v_o = \mathbf{5\ V}$.



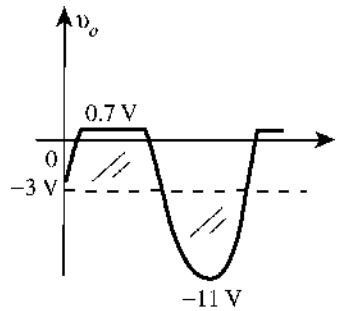
35. (a) Diode "on" for $v_i \geq 4.7$ V
For $v_i > 4.7$ V, $V_o = 4$ V + 0.7 V = **4.7 V**
For $v_i < 4.7$ V, diode "off" and $v_o = \boldsymbol{v_i}$



(b) Again, diode "on" for $v_i \geq 3.7$ V but v_o now defined as the voltage across the diode
For $v_i \geq 3.7$ V, v_o = **0.7 V**

For $v_i < 3.7$ V, diode "off", $I_D = I_R = 0$ mA and $V_{2.2\,\text{k}\Omega} = IR = (0\text{ mA})R = 0$ V

Therefore, $v_o = v_i - 3$ V
At $v_i = 0$ V, v_o = **−3 V**
$v_i = -8$ V, $v_o = -8$ V − 3 V = **−11 V**

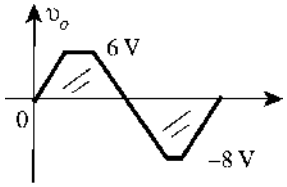


36. For the positive region of v_i:
The right Si diode is reverse-biased.
The left Si diode is "on" for levels of v_i greater than 5.3 V + 0.7 V = 6 V. In fact, v_o = **6 V** for $v_i \geq 6$ V.

For $v_i < 6$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.

For the negative region of v_i:
The left Si diode is reverse-biased.
The right Si diode is "on" for levels of v_i more negative than 7.3 V + 0.7 V = 8 V. In fact, v_o = **−8 V** for $v_i \leq -8$ V.

For $v_i > -8$ V both diodes are reverse-biased and $v_o = \boldsymbol{v_i}$.

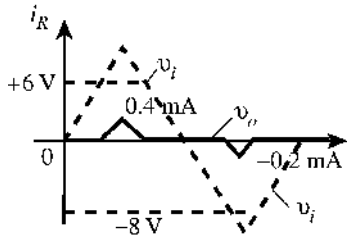


i_R: For -8 V $< v_i < 6$ V there is no conduction through the 10 kΩ resistor due to the lack of a complete circuit. Therefore, $i_R = 0$ mA.
For $v_i \geq 6$ V
$v_R = v_i - v_o = v_i - 6$ V
For $v_i = 10$ V, $v_R = 10$ V − 6 V = 4 V
and $i_R = \dfrac{4\text{ V}}{10\text{ k}\Omega}$ = **0.4 mA**
For $v_i \leq -8$ V
$v_R = v_i - v_o = v_i + 8$ V

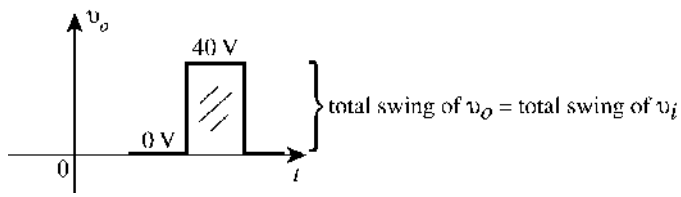
For $v_i = -10$ V

$v_R = -10\text{ V} + 8\text{ V} = -2\text{ V}$

and $i_R = \dfrac{-2\text{ V}}{10\text{ k}\Omega} = \mathbf{-0.2\ mA}$

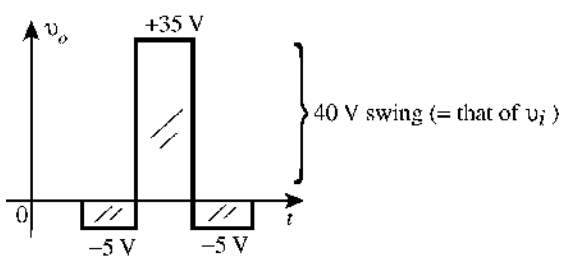


37. (a) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges to −20 V+. During this interval of time v_o is across the "on" diode (short-current equivalent) and $v_o = 0$ V.
When v_i switches to the +20 V level the diode enters the "off" state (open-circuit equivalent) and $v_o = v_i + v_C = 20\text{ V} + 20\text{ V} = +40\text{ V}$

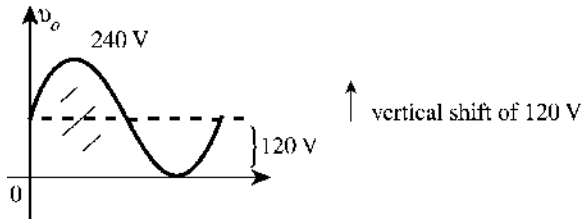


(b) Starting with $v_i = -20$ V, the diode is in the "on" state and the capacitor quickly charges up to −15 V+. Note that $v_i = +20$ V and the 5 V supply are additive across the capacitor. During this time interval v_o is across "on" diode and 5 V supply and $v_o = -5$ V.

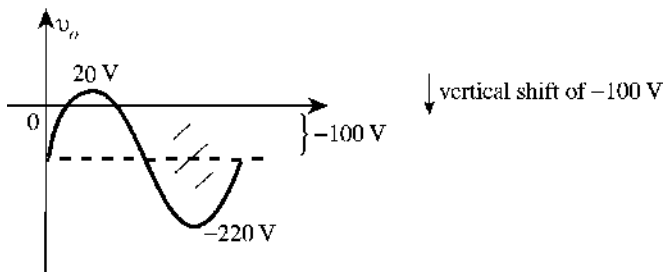
When v_i switches to the +20 V level the diode enters the "off" state and $v_o = v_i + v_C = 20\text{ V} + 15\text{ V} = 35\text{ V}$.



38. (a) For negative half cycle capacitor charges to peak value of 120 V = 120 V with polarity $(- \dashv\vdash +)$. The output v_o is directly across the "on" diode resulting in v_o = **0 V** as a negative peak value.
For next positive half cycle $v_o = v_i$ + 120 V with peak value of
v_o = 120 V + 120 V = **240 V**.



(b) For positive half cycle capacitor charges to peak value of 120 V − 20 V = 100 V with polarity $(+ \dashv\vdash -)$. The output v_o = 20 V = **20 V**
For next negative half cycle $v_o = v_i$ − 100 V with negative peak value of
v_o = −120 V − 100 V = **−220 V**.

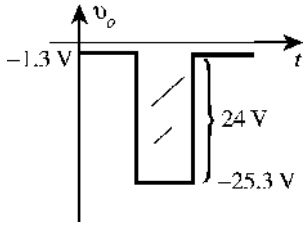


39. (a) $\tau = RC$ = (56 kΩ)(0.1 μF) = 5.6 ms
5τ = **28 ms**

(b) $5\tau = 28 \text{ ms} \gg \dfrac{T}{2} = \dfrac{1 \text{ ms}}{2}$ = **0.5 ms**, 56:1

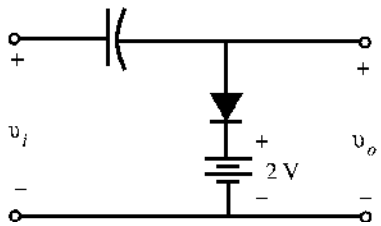
(c) Positive pulse of v_i:
Diode "on" and v_o = −2 V + 0.7 V = −1.3 V
Capacitor charges to 12 V + 2 V − 0.7 V = 13.3 V

Negative pulse of v_i:
Diode "off" and v_o = −12 V − 13.3 V = −25.3 V



40. Solution is network of Fig. 2.181(b) using a 10 V supply in place of the 5 V source.

41. Network of Fig. 2.178 with 2 V battery reversed.



42. (a) In the absence of the Zener diode

$$V_L = \frac{180\,\Omega(20\text{ V})}{180\,\Omega + 220\,\Omega} = 9\text{ V}$$

$V_L = 9\text{ V} < V_Z = 10\text{ V}$ and diode non-conducting

Therefore, $I_L = I_R = \dfrac{20\text{ V}}{220\,\Omega + 180\,\Omega} = \mathbf{50\ mA}$

with $I_Z = \mathbf{0\ mA}$
and $V_L = \mathbf{9\ V}$

(b) In the absence of the Zener diode

$$V_L = \frac{470\,\Omega(20\text{ V})}{470\,\Omega + 220\,\Omega} = 13.62\text{ V}$$

$V_L = 13.62\text{ V} > V_Z = 10\text{ V}$ and Zener diode "on"

Therefore, $V_L = \mathbf{10\ V}$ and $V_{R_s} = 10\text{ V}$

$I_{R_s} = V_{R_s} / R_s = 10\text{ V}/220\,\Omega = \mathbf{45.45\ mA}$

$I_L = V_L/R_L = 10\text{ V}/470\,\Omega = \mathbf{21.28\ mA}$

and $I_Z = I_{R_s} - I_L = 45.45\text{ mA} - 21.28\text{ mA} = \mathbf{24.17\ mA}$

(c) $P_{Z_{max}} = 400\text{ mW} = V_Z I_Z = (10\text{ V})(I_Z)$

$$I_Z = \frac{400\text{ mW}}{10\text{ V}} = 40\text{ mA}$$

$I_{L_{min}} = I_{R_s} - I_{Z_{max}} = 45.45\text{ mA} - 40\text{ mA} = 5.45\text{ mA}$

$$R_L = \frac{V_L}{I_{L_{min}}} = \frac{10\text{ V}}{5.45\text{ mA}} = \mathbf{1{,}834.86\ \Omega}$$

Large R_L reduces I_L and forces more of I_{R_s} to pass through Zener diode.

(d) In the absence of the Zener diode

$$V_L = 10\text{ V} = \frac{R_L(20\text{ V})}{R_L + 220\,\Omega}$$

$10R_L + 2200 = 20R_L$
$10R_L = 2200$
$R_L = \mathbf{220\ \Omega}$

43. (a) $V_Z = 12\text{ V}, R_L = \dfrac{V_L}{I_L} = \dfrac{12\text{ V}}{200\text{ mA}} = \mathbf{60\ \Omega}$

$$V_L = V_Z = 12\text{ V} = \frac{R_L V_i}{R_L + R_S} = \frac{60\ \Omega(16\text{ V})}{60\ \Omega + R_s}$$

$$720 + 12R_s = 960$$
$$12R_s = 240$$
$$R_s = \mathbf{20\ \Omega}$$

(b) $P_{Z_{\max}} = V_Z I_{Z_{\max}}$
$= (12\text{ V})(200\text{ mA})$
$= \mathbf{2.4\ W}$

44. Since $I_L = \dfrac{V_L}{R_L} = \dfrac{V_Z}{R_L}$ is fixed in magnitude the maximum value of I_{R_s} will occur when I_Z is a maximum. The maximum level of I_{R_s} will in turn determine the maximum permissible level of V_i.

$$I_{Z_{\max}} = \frac{P_{Z_{\max}}}{V_Z} = \frac{400\text{ mW}}{8\text{ V}} = 50\text{ mA}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{8\text{ V}}{220\ \Omega} = 36.36\text{ mA}$$

$$I_{R_s} = I_Z + I_L = 50\text{ mA} + 36.36\text{ mA} = 86.36\text{ mA}$$

$$I_{R_s} = \frac{V_i - V_Z}{R_s}$$

or $V_i = I_{R_s} R_s + V_Z$
$= (86.36\text{ mA})(91\ \Omega) + 8\text{ V} = 7.86\text{ V} + 8\text{ V} = \mathbf{15.86\ V}$

Any value of v_i that exceeds 15.86 V will result in a current I_Z that will exceed the maximum value.

45. At 30 V we have to be sure Zener diode is "on".

$$\therefore\ V_L = 20\text{ V} = \frac{R_L V_i}{R_L + R_s} = \frac{1\text{ k}\Omega(30\text{ V})}{1\text{ k}\Omega + R_s}$$

Solving, $R_s = \mathbf{0.5\ k\Omega}$

At 50 V, $I_{R_S} = \dfrac{50\text{ V} - 20\text{ V}}{0.5\text{ k}\Omega} = 60\text{ mA}$, $I_L = \dfrac{20\text{ V}}{1\text{ k}\Omega} = 20\text{ mA}$

$I_{ZM} = I_{R_S} - I_L = 60\text{ mA} - 20\text{ mA} = \mathbf{40\ mA}$

46. For $v_i = +50$ V:
Z_1 forward-biased at 0.7 V
Z_2 reverse-biased at the Zener potential and $V_{Z_2} = 10$ V.

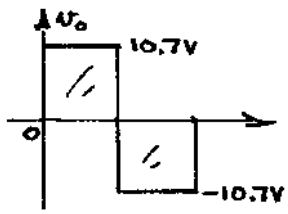
Therefore, $V_o = V_{Z_1} + V_{Z_2} = 0.7\text{ V} + 10\text{ V} = \mathbf{10.7\ V}$

For $v_i = -50$ V:

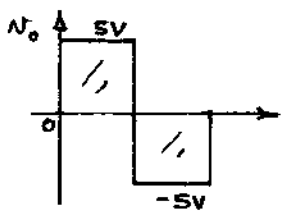
Z_1 reverse-biased at the Zener potential and $V_{Z_1} = -10$ V.

Z_2 forward-biased at -0.7 V.

Therefore, $V_o = V_{Z_1} + V_{Z_2}$ = **−10.7 V**



For a 5 V square wave neither Zener diode will reach its Zener potential. In fact, for either polarity of v_i one Zener diode will be in an open-circuit state resulting in $v_o = v_i$.



47. $V_m = 1.414(120\text{ V}) = 169.68$ V

$2V_m = 2(169.68\text{ V})$ = **339.36 V**

48. The PIV for each diode is $\mathbf{2V_m}$

$\therefore \text{PIV} = 2(1.414)(V_{\text{rms}})$