Solution Tutorial 1

Diode Basics, Application and Special Diodes

1. What is the maximum number of electrons that can exist in the 3rd shell of an atom?

   The third shell of an atom can have $2n^2 = 2(3)^2 =$ **18 electrons**

2. A certain atom has four valence electrons. What type of atom is it?

   An atom with four valence electrons is a **semiconductor**.

3. In a silicon crystal, how many covalent bonds does a single atom form?

   In a silicon crystal, each atom forms **four** covalent bonds.

4. What happens if heat is added to silicon?

   When heat is added to silicon, more free electrons and holes are produced.

5. Name the two energy levels at which current is produced in silicon?

   Current is produced in silicon at the **conduction** band and the **valence** band.

6. Describe the process of doping and explain how it alters the atomic structure of silicon.

   Doping is the carefully controlled addition of trivalent or pentavalent atoms to pure (intrinsic) semiconductor material for the purpose of increasing the number of majority carriers (free electrons or holes).

7. What is antimony? What is boron?

   Antimony is a pentavalent (donor) material used for doping to increase free electrons. Boron is a trivalent (acceptor) material used for doping to increase the holes.

8. How is the electric field across the *pn* junction?

   The electric field across the *pn* junction of a diode is created by donor atoms in the *n* region losing free electrons to acceptor atoms in the *p* region. This creates positive ions in the *n*-region near the junction and negative ions in the *p* region near the junction. A field is then established between the ions.

9. Because of its barrier potential, can a diode be used as a voltage source? Explain.

   The barrier potential of a diode represents an energy gradient that must be overcome by conduction electrons and produces a voltage drop, not a source of energy.

10. To forward-bias a diode, to which region must the positive terminal of a voltage source be connected?

    To forward-bias a diode, the positive terminal of a voltage source must be connected to the ***p* region**.

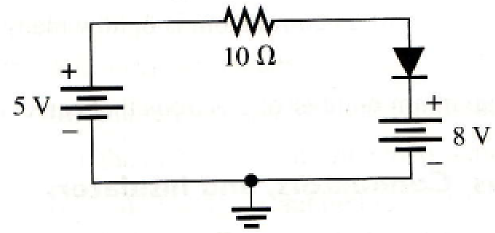
11. Explain why a series resistor is necessary when a diode is forward-biased.

    A series resistor is needed to **limit the current** through a forward-biased diode to a value which will not damage the diode because the diode itself has very little resistance.

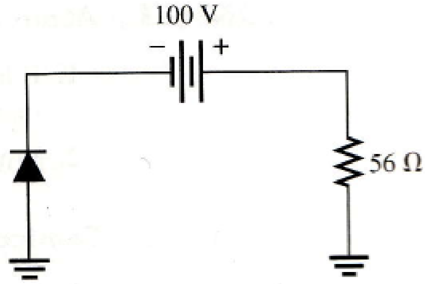
12. Explain how to generate the forward-bias portion of the characteristic curve.

    To generate the forward bias portion of the characteristic curve, connect a voltage source across the diode for forward bias , and place an ammeter in series with the diode and a voltmeter across the diode. Slowly increase the voltage from zero and plot the forward voltage versus the current.

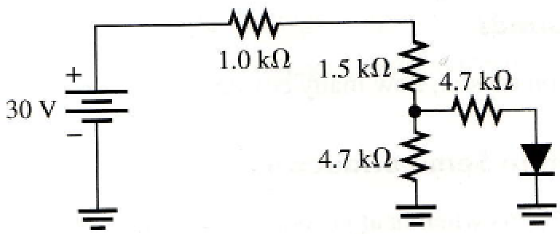
13. Determine whether each diode in Figure 1 is forward-biased or reverse-biased.



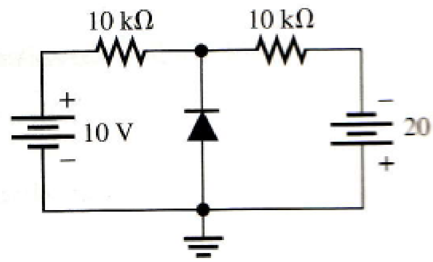
(a) The diode is reverse-biased.



(b) The diode is forward-biased.



(c) The diode is forward-biased.



(d) The diode is forward-biased.

Figure 1

14. Determine the voltage across each diode in Figure 1, assuming the practical model.

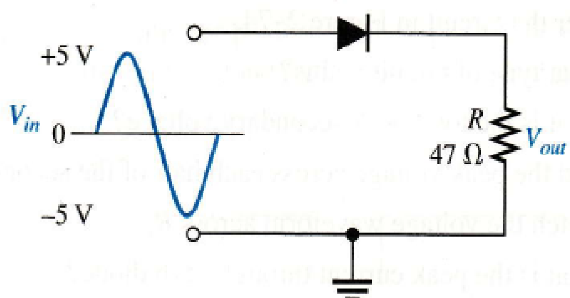
(a) $V_R = \left(\dfrac{50\ \text{M}\Omega}{50\ \text{M}\Omega + 10\ \Omega}\right)(5\ \text{V} - 8\ \text{V}) \cong -3\ \text{V}$

(b) $V_F = 0.7\ \text{V}$

(c) $V_F = 0.7\ \text{V}$

(d) $V_F = 0.7\ \text{V}$

15. Draw the output voltage waveform for the circuit in Figure 2 and include the voltage values. Calculate the peak forward current through the diode.



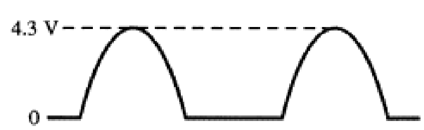


Figure 2

$$I_F = \frac{V_{(p)in} - 0.7\ \text{V}}{R} = \frac{5\ \text{V} - 0.7\ \text{V}}{47\ \Omega} = \frac{4.3\ \text{V}}{47\ \Omega} = \mathbf{91.5\ mA}$$

16. Determine the peak and average power delivered to R_L in Figure 3.

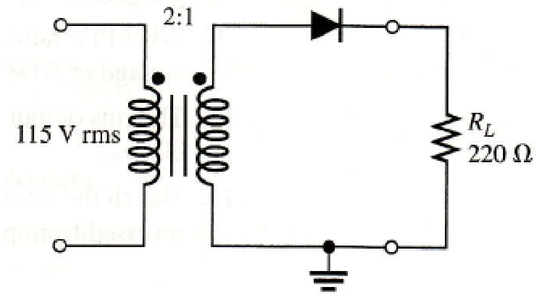


Figure 3

$$V_{sec} = nV_{pri} = (0.5)115\text{ V} = 57.5\text{ V rms}$$

$$V_{p(sec)} = 1.414(57.5\text{ V}) = 81.3\text{ V}$$

$$V_{avg(sec)} = \frac{V_{p(sec)}}{\pi} = \frac{81.3\text{ V}}{\pi} = 25.9\text{ V}$$

$$P_{L(p)} = \frac{(V_{p(sec)} - 0.7\text{ V})^2}{R_L} = \frac{(80.6\text{ V})^2}{220\ \Omega} = \mathbf{29.5\ W}$$

$$P_{L(avg)} = \frac{(V_{avg(sec)})^2}{R_L} = \frac{(25.9\text{ V})^2}{220\ \Omega} = \mathbf{3.05\ W}$$

17. Consider the circuit in Figure 4.

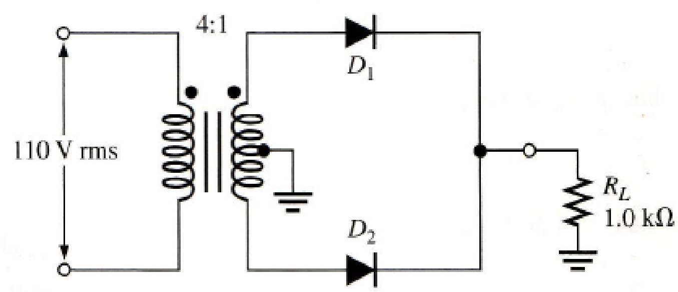


Figure 4

(a) What type if circuit is this? Center-tapped full-wave rectifier

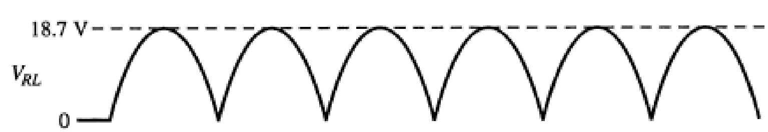
(b) What is the total peak secondary voltage? $V_{p(sec)} = (0.25)(1.414)110\text{ V} = \mathbf{38.9\ V}$

(c) Find the peak voltage across each half of the secondary.

$$\frac{V_{p(sec)}}{2} = \frac{38.9\text{ V}}{2} = \mathbf{19.4\ V}$$

(d) Sketch the voltage waveform across R_L.

$V_{RL} = 19.4\text{ V} - 0.7\text{ V} = 18.7\text{ V}$



(e) What is the peak current through each diode?

$$I_F = \frac{\frac{V_{p(sec)}}{2} - 0.7\text{ V}}{R_L} = \frac{18.7\text{ V}}{1.0\text{ k}\Omega} = \mathbf{18.7\text{ mA}}$$

(f) What is the PIV for each diode?

$$\text{PIV} = 19.4\text{ V} + 18.7\text{ V} = \mathbf{38.1\text{ V}}$$

18. What PIV rating is required for the diodes in a bridge rectifier that produces an average output voltage of 50V?

$$\text{PIV} = V_p = \frac{\pi V_{avg(out)}}{2} = \frac{\pi(50\text{ V})}{2} = \mathbf{78.5\text{ V}}$$

19. Sketch the output voltage of the bridge rectifier in Figure 5.

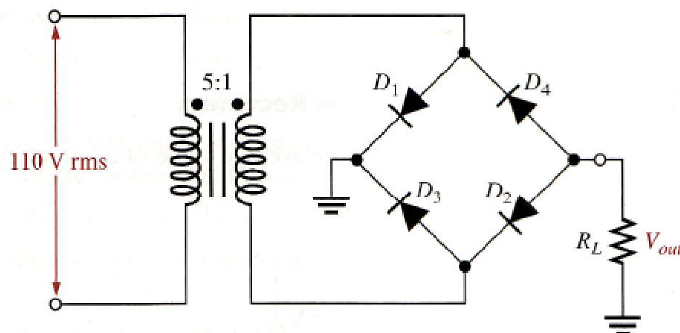
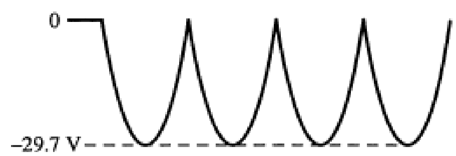


Figure 5



20. A full-wave rectifier produces an 80 V peak rectified voltage from a 60 Hz ac source. If a 10 μF filter capacitor is used, determine the ripple factor for a load resistance of 100 kΩ.

$$V_{r(pp)} = \frac{V_{p(in)}}{fR_LC} = \frac{80\text{ V}}{(120\text{ Hz})(100\text{k}\Omega)(10\ \mu\text{F})} = 0.67\text{ V}$$

$$V_{DC} = \left(1 - \frac{1}{2fR_LC}\right)V_{p(in)} = \left(1 - \frac{1}{(240\text{ Hz})(100\text{k}\Omega)(10\ \mu\text{F})}\right)80\text{ V} = 79.67\text{ V}$$

$$r = \frac{V_{r(pp)}}{V_{DC}} = \frac{0.67\text{ V}}{79.67\text{ V}} = 8.41\text{x}10^{-3}$$

21. Determine the output voltage waveform for each circuit in Figure 6.

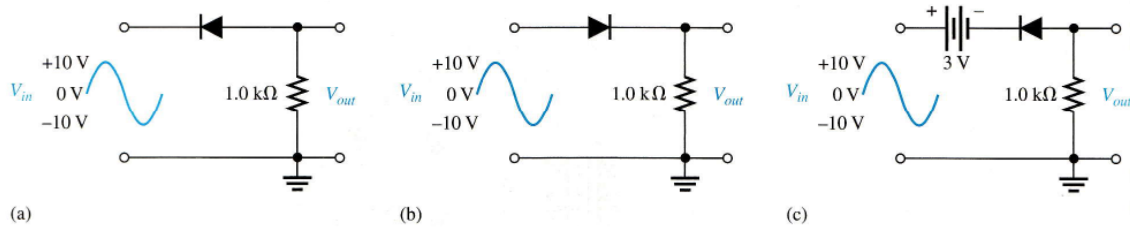
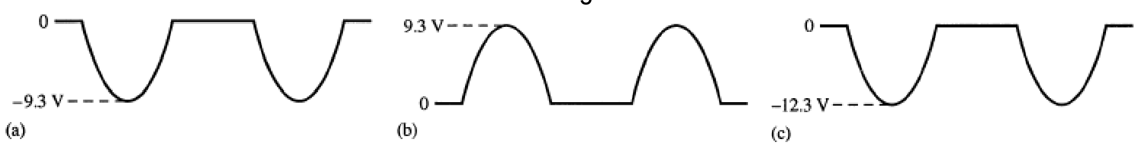


Figure 6



22. Sketch the output voltage waveform for the circuit in Figure 7.

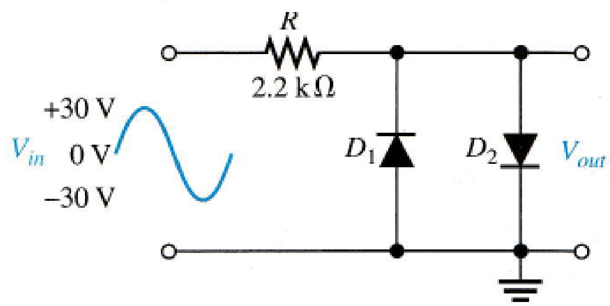
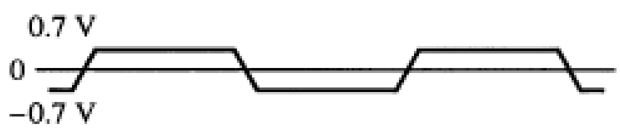
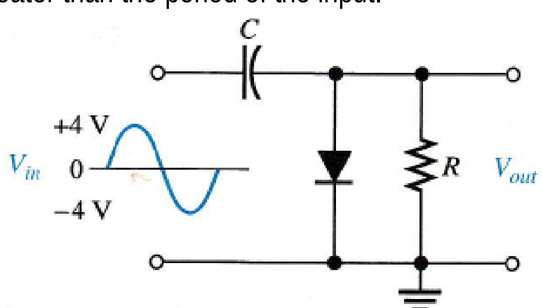


Figure 7

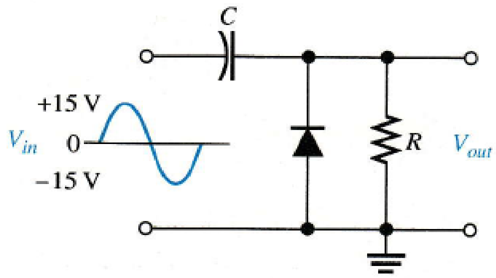


23. Describe the output waveform of each circuit in Figure 8, Assume the RC time constant is much greater than the period of the input.



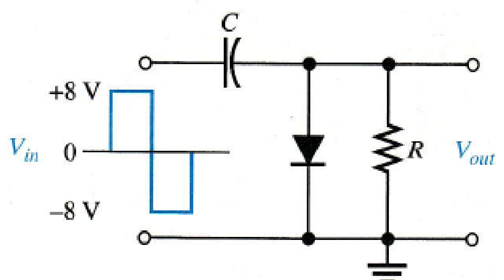
(a)

A sine wave with a positive peak at 0.7 V, a negative peak at −7.3 V, and a dc value of −3.3 V.



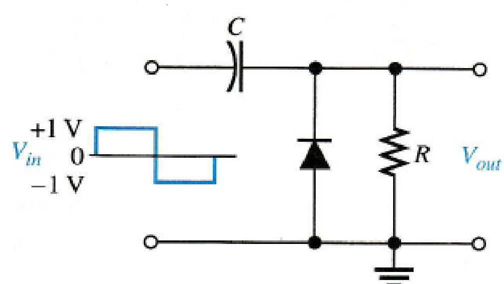
(b)

A sine wave with a positive peak at 29.3 V, a negative peak at −0.7 V, and a dc value of +14.3 V.



(c)

A square wave varying from +0.7 V to −15.3 V with a dc value of −7.3 V.



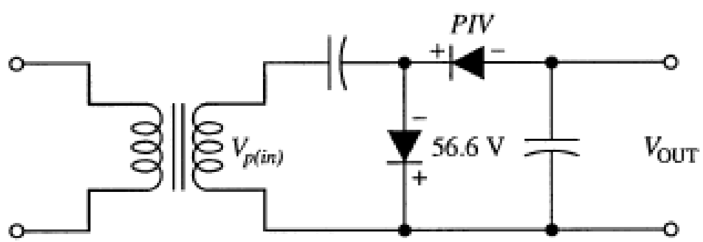
(d)

A square wave varying from +1.3 V to −0.7 V with a dc value of +0.3 V.

Figure 8

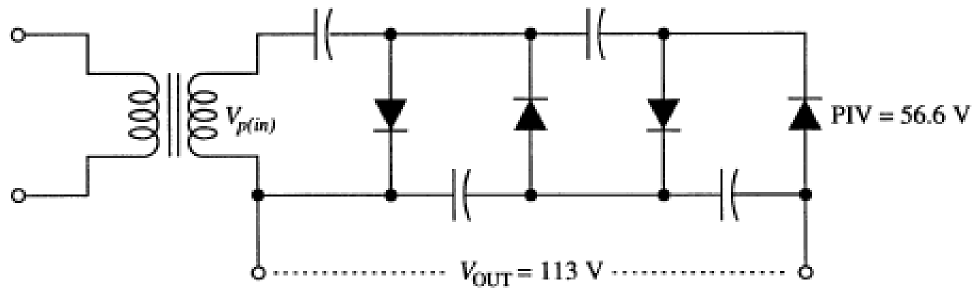
24. A certain voltage doubler has 20 V rms on its input. What is the output voltage? Sketch the circuit, indicating the output terminals and PIV rating for the diode.

$V_{OUT} = 2V_{p(in)} = 2(1.414)(20\text{ V}) = \mathbf{56.6\ V}$



25. Repeat problem above for a voltage quadrater.

$V_{OUT(quad)} = 4V_{p(in)} = 4(1.414)(20\text{ V}) = \mathbf{113\text{ V}}$



26. Based on the value given, would you expect the circuit in Figure 9 to fail? If so, why?

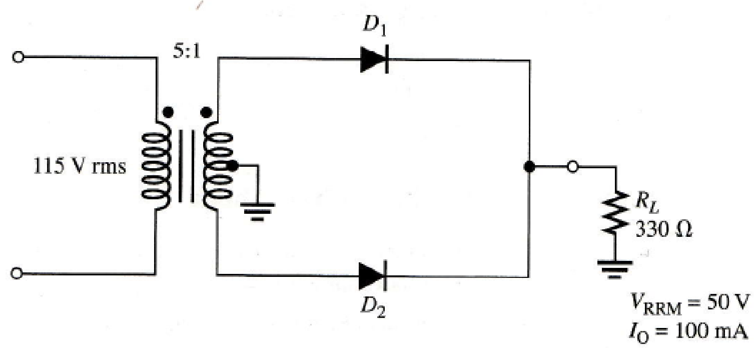


Figure 9

$$V_{sec} = \frac{115\text{ V}}{5} = 23\text{ V rms}$$

$V_{p(sec)} = 1.414(23\text{ V}) = 32.5\text{ V}$

The peak voltage for each half of the secondary is

$$\frac{V_{p(sec)}}{2} = \frac{32.5\text{ V}}{2} = 16.3\text{ V}$$

The peak inverse voltage for each diode is PIV = 2(16.3 V) + 0.7 V = 33.2 V

The peak current through each diode is

$$I_p = \frac{\frac{V_{p(sec)}}{2} - 0.7\text{ V}}{R_L} = \frac{16.3\text{ V} - 0.7\text{ V}}{330\ \Omega} = 47.3\text{ mA}$$

The diode ratings exceed the actual PIV and peak current.

The circuit should not fail.

27. A loaded zener regulator is shown in Figure 10. V_Z=5.1 V at I_{ZT}=49mA, I_{ZK}=1 mA, Z_Z=7 and I_{ZM}=70mA. Determine the minimum and maximum permissible load currents.

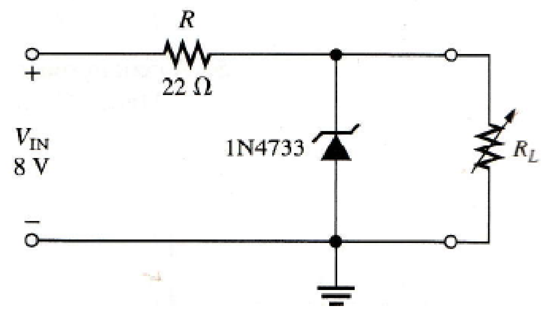


Figure 10

$$V_{Z(min)} = V_Z - \Delta I_Z Z_Z = 5.1\text{ V} - (49\text{ mA} - 1\text{ mA})(7\ \Omega)$$
$$= 5.1\text{ V} - (48\text{ mA})(7\ \Omega) = 5.1\text{ V} - 0.336 = 4.76\text{ V}$$
$$V_R = 8\text{ V} - 4.76\text{ V} = 3.24\text{ V}$$
$$I_T = \frac{V_R}{R} = \frac{3.24\text{ V}}{22\ \Omega} = 147\text{ mA}$$
$$I_{L(max)} = 147\text{ mA} - 1\text{ mA} = \mathbf{146\text{ mA}}$$
$$V_{Z(max)} = 5.1\text{ V} + (70\text{ mA} - 49\text{ mA})(7\ \Omega) = 5.1\text{ V} + 0.34\text{ V} = 5.44\text{ V}$$
$$V_R = 8\text{ V} - 5.44\text{ V} = 2.56\text{ V}$$
$$I_T = \frac{2.56\text{ V}}{22\ \Omega} = 116\text{ mA}$$
$$I_{L(min)} = 116\text{ mA} - 70\text{ mA} = \mathbf{46\text{ mA}}$$

28. Find the load regulation expressed as a percentage in Problem 27.

$$\%\text{ Load regulation} = \frac{V_{Z(max)} - V_{Z(min)}}{V_{Z(min)}} \times 100\% = \frac{5.44\text{ V} - 4.76\text{ V}}{4.76\text{ V}} \times 100\% = \mathbf{14.3\%}$$

29. Analyze the circuit in Figure 10 for percent line regulation using an input voltage from 6V to 12V with no load.

With no load and $V_{IN} = 6$ V:

$$I_Z \cong \frac{V_{IN} - V_Z}{R + Z_Z} = \frac{6\text{ V} - 5.1\text{ V}}{29\ \Omega} = 31\text{ mA}$$
$$V_{OUT} = V_Z - \Delta I_Z Z_Z = 5.1\text{ V} - (35\text{ mA} - 31\text{ mA})(7\ \Omega) = 5.1\text{ V} - 0.028\text{ V} = 5.07\text{ V}$$

With no load and $V_{IN} = 12$ V:

$$I_Z \cong \frac{V_{IN} - V_Z}{R + Z_Z} = \frac{12\text{ V} - 5.1\text{ V}}{29\ \Omega} = 238\text{ mA}$$
$$V_{OUT} = V_Z + \Delta I_Z Z_Z = 5.1\text{ V} + (238\text{ mA} - 35\text{ mA})(7\ \Omega) = 5.1\text{ V} + 1.42\text{ V} = 6.52\text{ V}$$
$$\%\text{ Line regulation} = \frac{\Delta V_{OUT}}{\Delta V_{IN}} \times 100\% = \frac{6.52\text{ V} - 5.07\text{ V}}{12\text{ V} - 6\text{ V}} \times 100\% = \mathbf{24.2\%}$$

30. The no-load output voltage of a certain zener regulator is 8.23V and the full-load ouput is 7.98V. Calculate the load regulation expressed as a percentage.

$$\% \text{ Load regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\% = \frac{8.23\text{ V} - 7.98\text{ V}}{7.98\text{ V}} \times 100\% = \mathbf{3.13\%}$$

31. What capacitance value is required for each of the varactors in Figure 11 to produce a resonant frequency of 1 MHz.

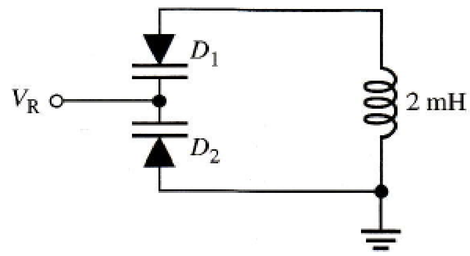


Figure 11

$$f_r = \frac{1}{\sqrt{2\pi L C_T}}$$

$$C_T = \frac{1}{4\pi^2 L f_r^2} = \frac{1}{4\pi^2 (2\text{ mH})(1\text{MHz})^2} = 12.7\text{ pF}$$

Since they are in series, each varactor must have a capacitance of $2C_T$ = **25.4 pF**

32. The LED in Figure 12 has a light-producing characteristic as shown in Figure (b). Neglecting the forward voltage drop of the LED, determine the amount of radiant (light) power produced in mW.

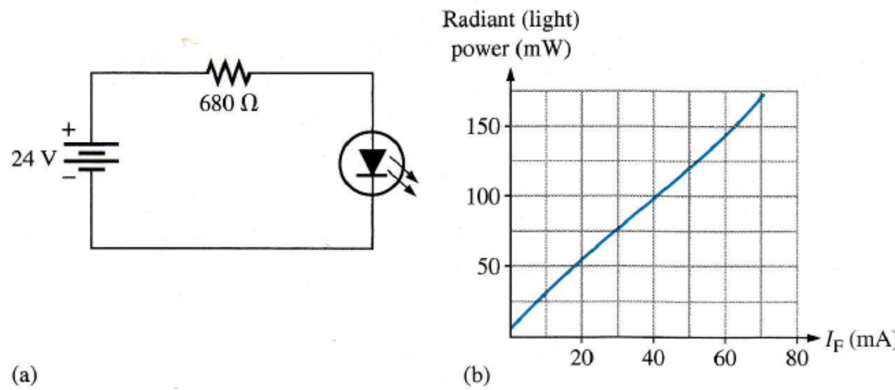


Figure 12

Assuming $V_F = 1.2$ V,

$$I_F = \frac{24\text{ V} - 1.2\text{ V}}{680\,\Omega} = 33.5\text{ mA}$$

From the graph, the radiant power is approximately **80 mW**.

33. Determine how to connect the seven-segment display in Figure 13 to display '5'. The maximum comtinous forward current for each LED is 30mA and a +5V dc source is to be used.

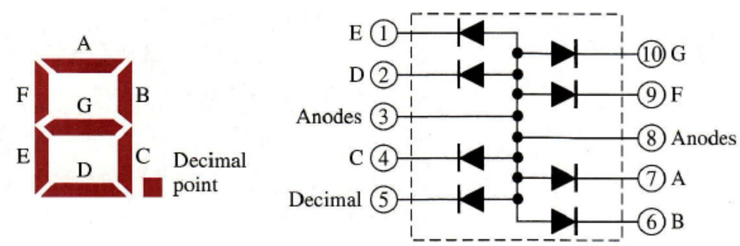


Figure 13

$$R = \frac{5\text{ V} - 0.7\text{ V}}{30\text{ mA}} = 143\ \Omega$$

Use nearest standard 1% value of 147 Ω or 5% value of 150 Ω.