Chapter One

1- Semiconductor Materials

The label semiconductor itself provides a hint as to its characteristics. The prefix semi-is normally applied to a range of levels midway between two limits. The term conductor is applied to any material that will support a generous flow of charge when a voltage source of limited magnitude is applied across its terminals. An insulator is a material that offers a very low level of conductivity under pressure from an applied voltage source. A semiconductor, therefore, is a material that has a conductivity level some-where between the extremes of an insulator and a conductor. The following equation (derived from the basic resistance equation:

$$\rho = \frac{RA}{L} = \frac{\Omega(cm^2)}{cm} = \Omega - cm$$

If the area A=1 cm^2 and the length 1 cm then

$$|\rho| = \rho\frac{1}{A} = \rho\frac{(1cm)}{(cm^2)}|\rho|ohms$$

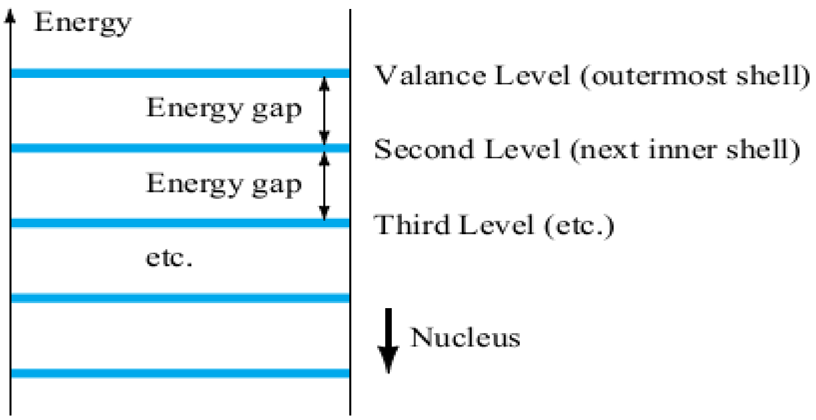
Germanium (Ge) and (Si) have received the attention they have for a number of reasons. One very important consideration is the fact that they can be manufactured to a very high purity level. In fact, recent advances have reduced impurity levels in the pure material to 1 part in 10 billion (1:10,000,000,000). One might ask if these low impurity levels are really necessary. They certainly are if you consider that the addition of one part impurity (of the proper type) per million in a wafer of silicon material can change that material from a relatively poor conductor to a good conductor of electricity.

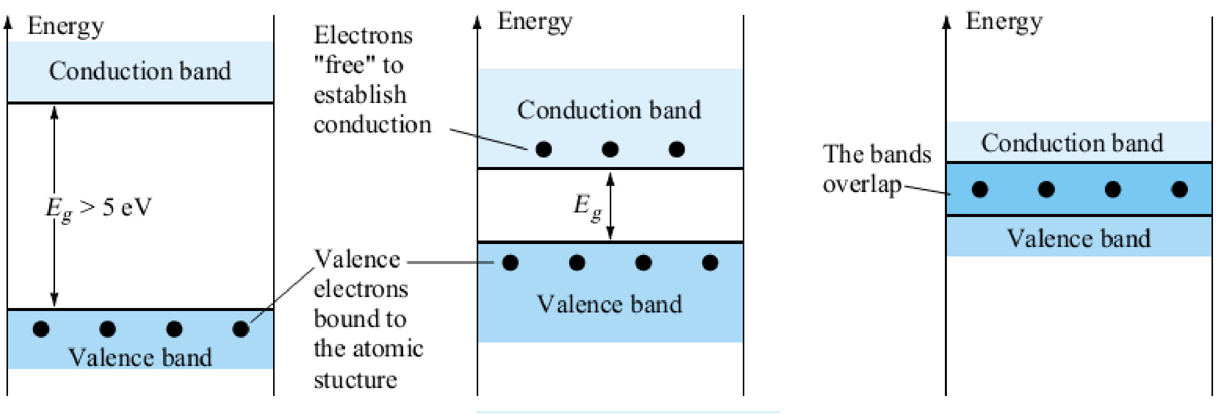
Intrinsic materials are those semiconductors that have been carefully refined to reduce the impurities to a very low level—essentially as pure as can be made available through modern technology.

The free electrons in the material due only to natural causes are referred to as intrinsic carriers. At the same temperature, intrinsic germanium material will have approximately 2.5×10^{13} free carriers per cubic centimeter. The ratio of the number of carriers in germanium to that of silicon is greater than 10^3 and would indicate that germanium is a better conductor at room temperature.

2- Energy Levels:

The more distant the electron from the nucleus, the higher the energy state, and any electron that has left its parent atom has a higher energy state than any electron in the atomic structure.





Insulator　　Semiconductor　　Conductor

Between the discrete energy levels are gaps in which no electrons in the isolated atomic structure can appear.

Recall that ionization is the mechanism whereby an electron can absorb sufficient energy to break away from the atomic structure and enter the conduction band. You will note that the energy associated with each electron is measured in electron volts (eV). The unit of measure is appropriate, since

$$W = QV \qquad eV$$

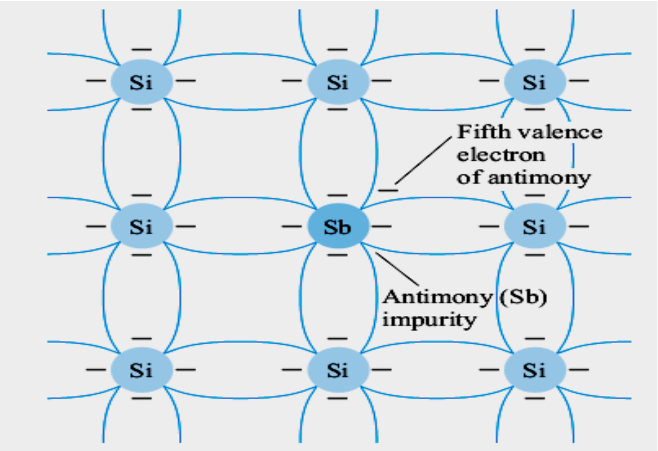
Substituting the charge of an electron and a potential difference of 1volt will result in an energy level referred to as one electron volt. Since energy is also measured in joules and the charge of one electron 1.6×10^{-19} coulomb,

$$W = QV = (1.6 \times 10^{-19}\,C)(1V)$$

$$1eV = 1.6 \times 10^{-19}\,J$$

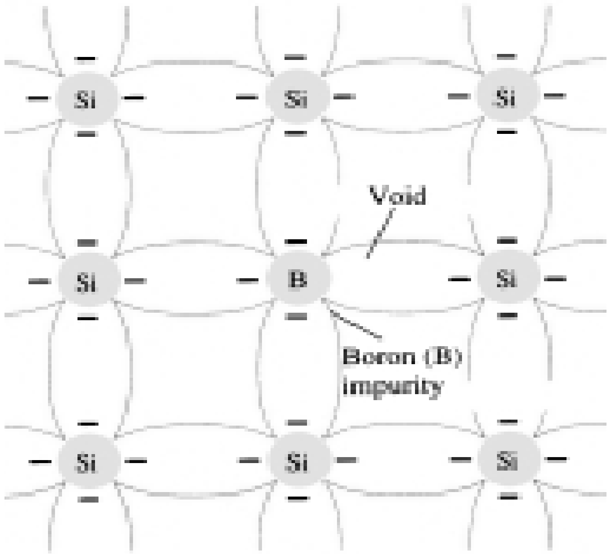
3-Extrinsic Materials N- And P-Type:

Both the n- and p-type materials are formed by adding a predetermined number of impurity atoms into a germanium or silicon base. The n-type is created by introducing those impurity elements that have five valence electrons (pentavalent), such as antimony, arsenic, and phosphorus.



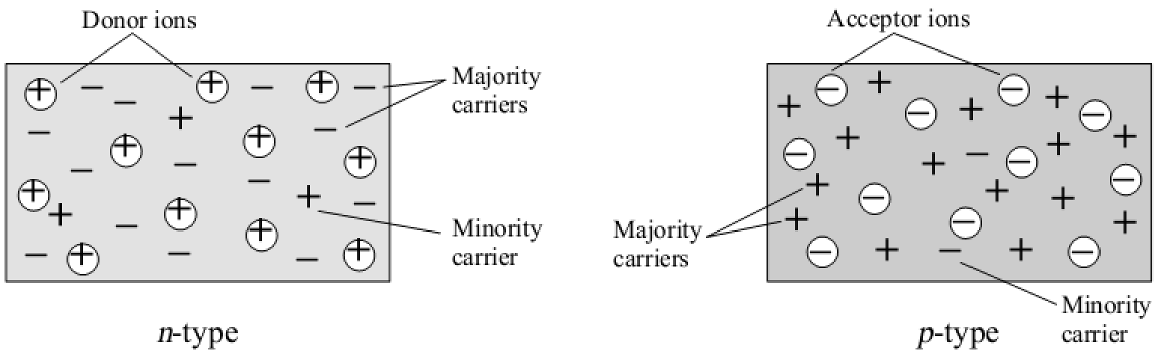
Diffused impurities with five valence electrons are called donor atoms.

The p-type material is formed by doping a pure germanium or silicon crystal with impurity atoms having three valence electrons.



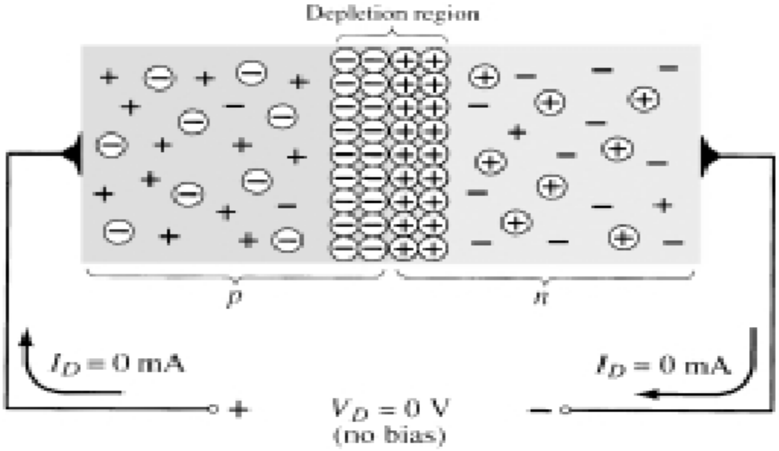
The diffused impurities with three valence electrons are called acceptor atoms.

In an n-type material the electron is called the majority carrier and the hole the minority carrier. In a p-type material the hole is the majority carrier and the electron is the minority carrier.

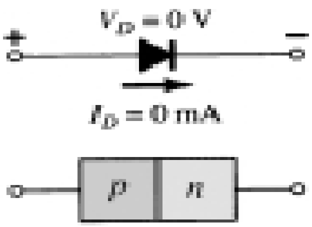


4- **Semiconductor Diode:**

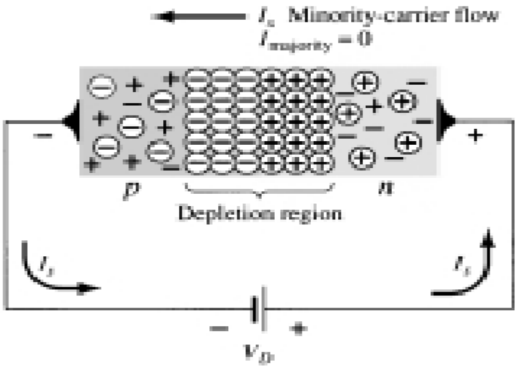
At the instant the two materials are “joined” the electrons and holes in the region of the junction will combine, resulting in a lack of carriers in the region near the junction. This region of uncovered positive and negative ions is called the depletion region due to the depletion of carriers in this region.



Under no-bias (no applied voltage) ($V_D = 0\ V$) conditions, any minority carriers (holes) in the n-type material that find themselves within the depletion region will pass directly into the p-type material. Similar discussion can be applied to the minority carriers (electrons) of the p-type material. As indicated, for($V_D = 0\ V$), the current in any direction is 0 mA.

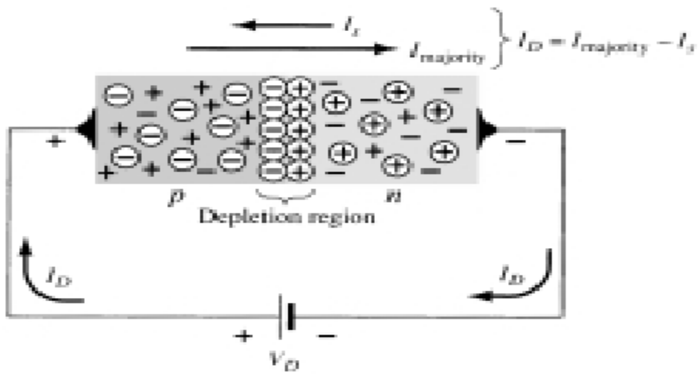


Reverse-Bias Condition ($V_D < 0$): If an external potential of V volts is applied across the p-n junction. Such that the positive terminal is connected to the n-type material and the negative terminal is connected to the p-type material as shown below, the number of uncovered positive ions in the depletion region of the n-type material will increase due to the large number of “free” electrons drawn to the positive potential of the applied voltage. For similar reasons, the number of uncovered negative ions will increase in the p-type material. The net effect, therefore, is a widening of the depletion region.



The current that exists under reverse-bias conditions is called the reverse saturation current and is represented by Is.

Forward-Bias Condition ($V_D > 0$): A forward-bias or “on” condition is established by applying the positive potential to the p-type material and the negative potential to the n-type material. A semiconductor diode is forward-biased when the association p-type and positive and n-type and negative has been established.

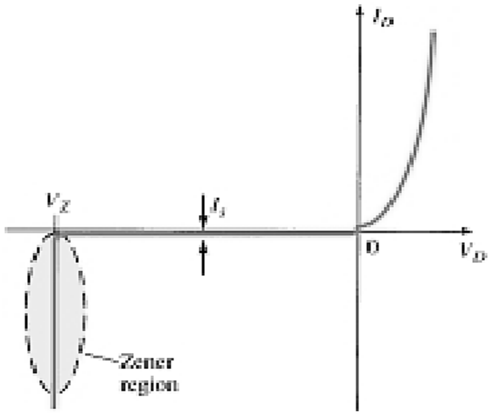


5- Characteristics of a semiconductor diode:

The general characteristics of a semiconductor diode can be defined by the following equation for the forward and reverse bias regions:

$$I_D = I_s(e^{kV_D/T_K} - 1)$$

where Is reverse saturation current k = 11,600/η with η = 1 for Ge and 2 for Si for relatively low levels of diode current (at or below the knee of the curve) and 1 for Ge and Si for higher levels of diode current (in the rapidly increasing section of the curve) $T_K = T_C + 273$



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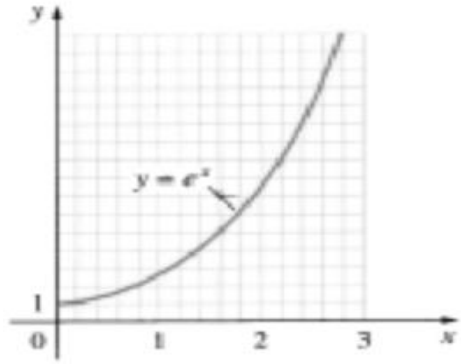
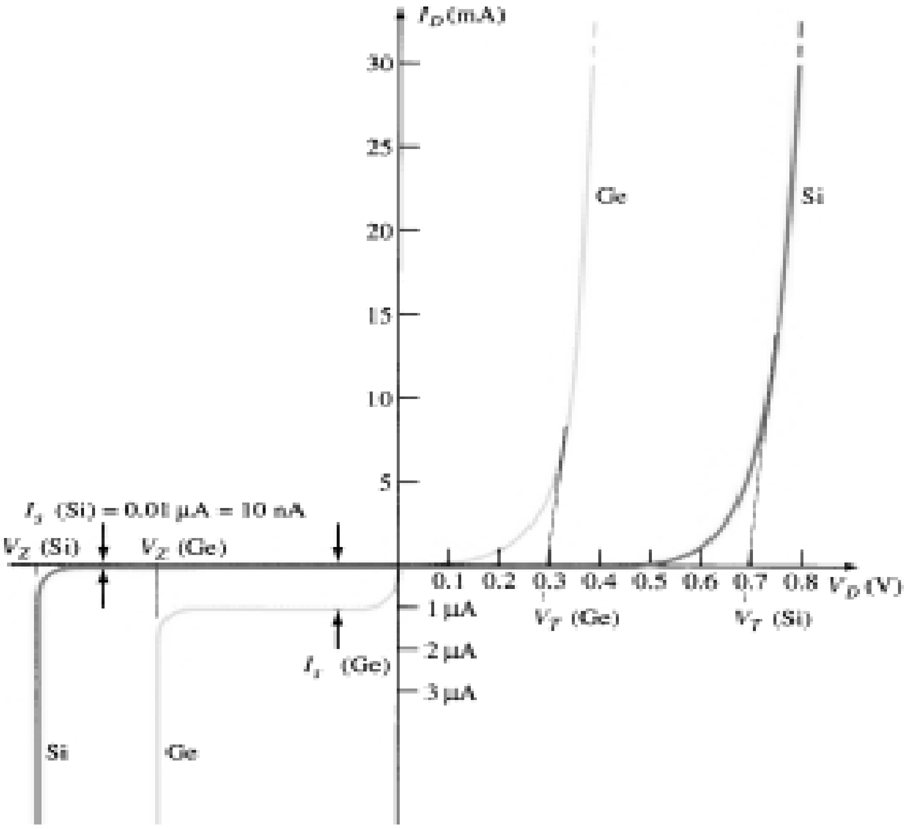


The maximum reverse-bias potential that can be applied before entering the Zener region is called the peak inverse voltage (referred to simply as the PIV rating) or the peak reverse voltage (denoted by PRV rating). Silicon diodes have, in general, higher PIV and current rating and wider temperature ranges than germanium diodes.



6- Resistance Levels:

As the operating point of a diode moves from one region to another the resistance of the diode will also change due to the nonlinear shape of the characteristic curve.

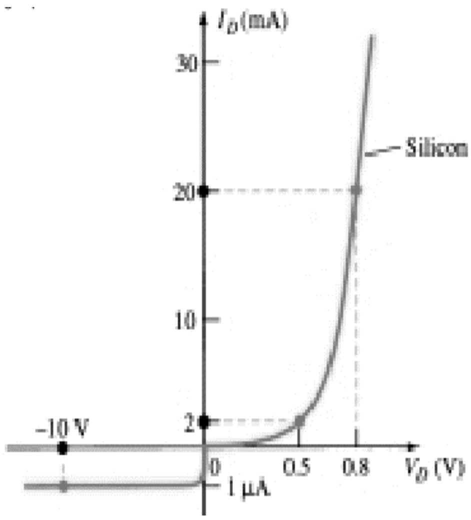
DC or Static Resistance: The resistance of the diode at the operating point can be found simply by finding the corresponding levels of V_D and I_D and applying the following equation:

$$R_D = \frac{V_D}{I_D}$$

The dc resistance levels at the knee and below will be greater than the resistance levels obtained for the vertical rise section of the characteristics. In general, therefore, the lower the current through a diode the higher the dc resistance level.

Example 1: *Determine the dc resistance levels for the diode of Figure below at*

$$a)\ I_D = 2mA, b)\ I_D = 20mA, c)\ V_D = -10V$$



(a) At $I_D = 2$ mA, $V_D = 0.5$ V (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{0.5\text{ V}}{2\text{ mA}} = \mathbf{250\ \Omega}$$

(b) At $I_D = 20$ mA, $V_D = 0.8$ V (from the curve) and

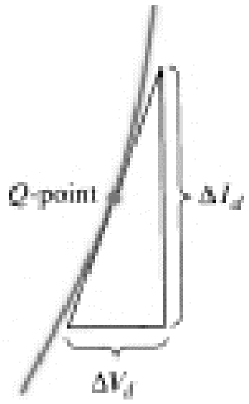
$$R_D = \frac{V_D}{I_D} = \frac{0.8\text{ V}}{20\text{ mA}} = \mathbf{40\ \Omega}$$

(c) At $V_D = -10$ V, $I_D = -I_s = -1\ \mu$A (from the curve) and

$$R_D = \frac{V_D}{I_D} = \frac{10\text{ V}}{1\ \mu\text{A}} = \mathbf{10\ M\Omega}$$

AC or Dynamic Resistance: If a sinusoidal rather than dc input is applied, the situation will change completely. The varying input will move the instantaneous operating point up and down a region of the characteristics. A straight line drawn tangent to the curve through the Q-point will define a particular change in voltage and current that can be used to determine the ac or dynamic resistance for this region of the diode characteristics.

$$r_d = \frac{\Delta V_d}{\Delta I_d}$$ where Δ signifies a finite change in the quantity.



Example 2: *For the characteristics of Fig. below:*

(a) Determine the ac resistance at I_D =2 mA.

(b) Determine the ac resistance at I_D = 25 mA.

(c) Compare the results of parts (a) and (b) to the dc resistances at each current level.

(a):

$$\Delta I_d = 4\text{ mA} - 0\text{ mA} = 4\text{ mA}$$

and $$\Delta V_d = 0.76\text{ V} - 0.65\text{ V} = 0.11\text{ V}$$

and the ac resistance:

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11\text{ V}}{4\text{ mA}} = \mathbf{27.5\ \Omega}$$

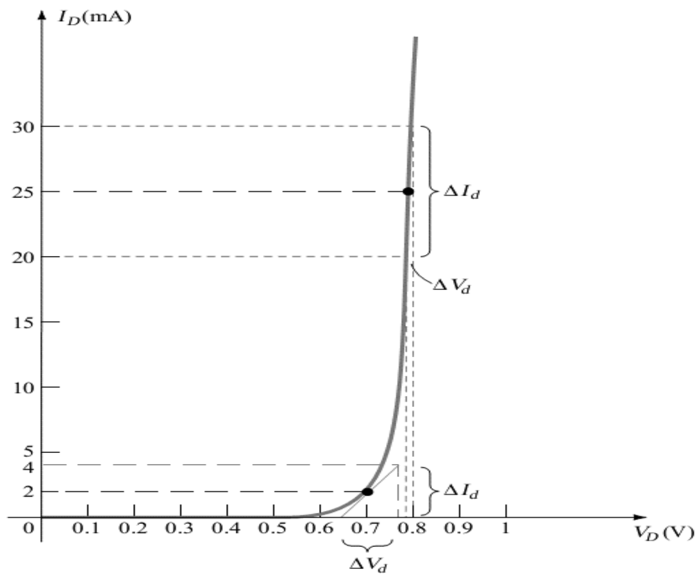
(b)

$$\Delta I_d = 30\text{ mA} - 20\text{ mA} = 10\text{ mA}$$

and $$\Delta V_d = 0.8\text{ V} - 0.78\text{ V} = 0.02\text{ V}$$

and the ac resistance is

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02\text{ V}}{10\text{ mA}} = \mathbf{2\ \Omega}$$



(c) For $I_D = 2$ mA, $V_D = 0.7$ V and

$$R_D = \frac{V_D}{I_D} = \frac{0.7 \text{ V}}{2 \text{ mA}} = \mathbf{350\ \Omega}$$

which far exceeds the r_d of 27.5 Ω.

For $I_D = 25$ mA, $V_D = 0.79$ V and

$$R_D = \frac{V_D}{I_D} = \frac{0.79 \text{ V}}{25 \text{ mA}} = \mathbf{31.62\ \Omega}$$

which far exceeds the r_d of 2 Ω.

We have found the dynamic resistance graphically, but there is a basic definition in differential calculus which states: The derivative of a function at a point is equal to the slope of the tangent line drawn at that point. If we find the derivative of the general equation for the semiconductor diode with respect to the applied forward bias and then invert the result, we will have an equation for the dynamic or ac resistance in that region.

$$\frac{d}{dV_D}(I_D) = \frac{d}{dV}[I_s(e^{kV_D/T_K} - 1)]$$

and

$$\frac{dI_D}{dV_D} = \frac{k}{T_K}(I_D + I_s)$$

$$\text{If } I_D \gg I_s \qquad then \ \frac{dI_D}{dV_D} \cong \frac{k}{T_K}$$

Substituting $\eta = 1$ for Ge and Si in the vertical-rise section of the characteristics, we obtain

$$k = \frac{11{,}600}{\eta} = \frac{11{,}600}{1} = 11{,}600$$

and at room temperature,

$$T_K = T_C + 273^\circ = 25^\circ + 273^\circ = 298^\circ$$

so that $\qquad \frac{k}{T_K} = \frac{11{,}600}{298} \cong 38.93$

and $\qquad \frac{dI_D}{dV_D} = 38.93 I_D$

Flipping the result to define a resistance ratio ($R = V/I$) gives us

$$\frac{dV_D}{dI_D} \cong \frac{0.026}{I_D}$$

or $\qquad \boxed{r_d = \frac{26 \text{ mV}}{I_D}}$ $_{\text{Ge,Si}}$

All the resistance levels determined thus far have been defined by the p-n junction and do not include the resistance of the semiconductor material itself (called body resistance) and the resistance introduced by the connection between the semiconductor material and the external metallic conductor (called contact resistance).

$$\boxed{r'_d = \frac{26 \text{ mV}}{I_D} + r_B} \qquad \text{ohms}$$

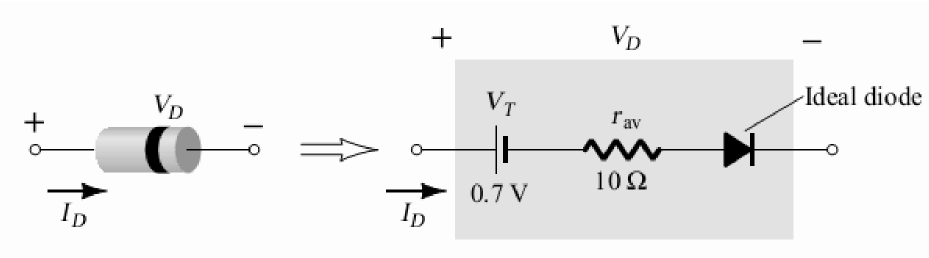
The factor r_B can range from typically 0.1 Ω for high-power devices to 2 Ω for some low-power, general-purpose diodes. If the input signal is sufficiently large to produce a broad swing, the resistance associated with the device for this region is called the average ac resistance.

Homework: *Repeat example 2 and solve using new equation.*

7- Diode Equivalent Circuits:

An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device, system, or such in a particular operating region.

The ideal diode is included to establish that there is only one direction of conduction through the device, and a reverse-bias condition will result in the open-circuit state for the device. Since a silicon semiconductor diode does not reach the conduction state until V_D reaches 0.7 V with a forward bias, a battery V_T opposing the conduction direction must appear in the equivalent circuit.



8- Diode Specification Sheets:

Data on specific semiconductor devices are normally provided by the manufacturer in one of two forms. They include:

1. The forward voltage V_F (at a specified current and temperature)
2. The maximum forward current I_F (at a specified temperature)
3. The reverse saturation current I_R (at a specified voltage and temperature)
4. The reverse-voltage rating [PIV or PRV or V(BR), where BR comes from the term "breakdown"(at a specified temperature)]
5. The maximum power dissipation level at a particular temperature
6. Operating temperature range

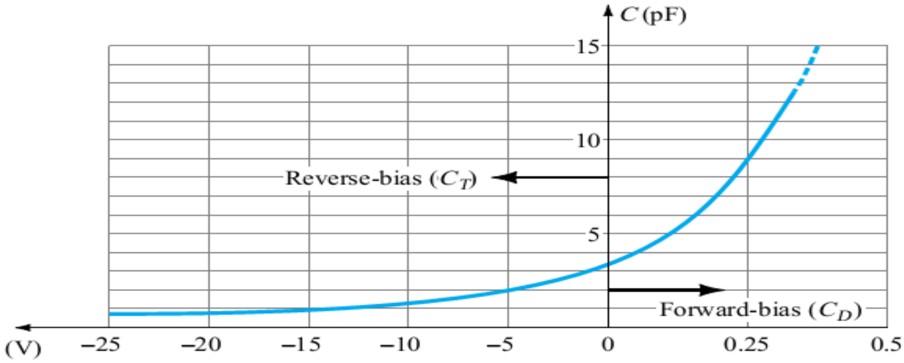
Depending on the type of diode being considered, additional data may also be provided, such as frequency range, noise level, switching time, thermal resistance levels, and peak repetitive values. If the maximum power or dissipation rating is also provided, it is understood to be equal to the following product: $P_{Dmax} = V_D \times I_D$. we can substitute $V_D = V_T = 0.7V$ for a silicon diode, so that:

$$P_{dissipated} \cong (0.7V)I_D$$

9- Transition And Diffusion Capacitance:

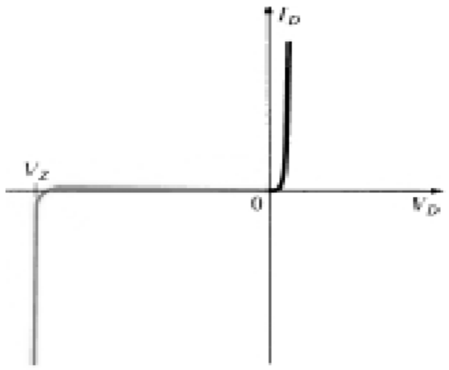
In the reverse-bias region we have the transition- or depletion-region capacitance (C_T), while in the forward-bias region we have the diffusion (C_D) or storage capacitance. Recall that the basic equation for the capacitance of a parallel-plate capacitor is defined by $C = \varepsilon A/d$, where is the permittivity of the dielectric (insulator) between the plates of area A separated by a distance d. In the reverse-bias region there is a depletion region (free of carriers) that behaves essentially like an insulator between the layers of opposite charge. Since the depletion width

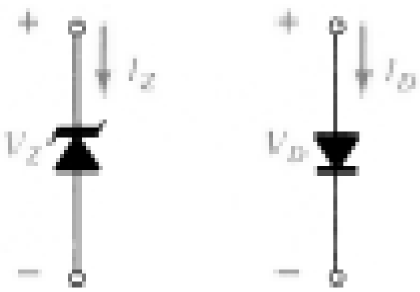
(d) will increase with increased reverse-bias potential, the resulting transition capacitance will decrease. The fact that the capacitance is dependent on the applied reverse-bias potential has application in a number of electronic systems.



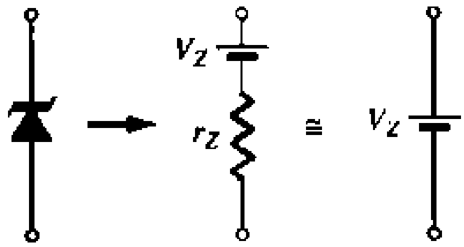
10- Zener Diodes:

In the Zener region the characteristic drops in an almost vertical manner at a reverse bias potential denoted V_Z. For the semiconductor diode the "on" state will support a current in the direction of the arrow in the symbol. For the Zener diode the direction of conduction is opposite to that of the arrow in the symbol. Note also that the polarity of V_D and V_Z are the same as would be obtained if each were a resistive element.





The location of the Zener region can be controlled by varying the doping levels. An increase in doping, producing an increase in the number of added impurities, will decrease the Zener potential. Zener diodes are available having Zener potentials of 1.8 to 200 V with power ratings from 1/4 W to 50 W.



11- Light-Emitting Diodes (LED):

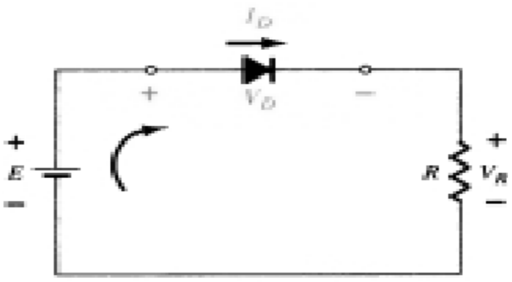
As the name implies, the light-emitting diode (LED) is a diode that will give off visible light when it is energized. In all semiconductor p-njunctions some of energy will be given off as heat and some in the form of photons. In silicon and germanium the greater percentage is given up in the form of heat and the emitted light is insignificant. In other materials, such as gallium arsenide phosphide (GaAsP) or gallium phosphide (GaP), the number of photons of light energy emitted is sufficient to create a very visible light source.

12- Diode Applications:

The applied load will normally have an important impact on the point or region of operation of a device. If the analysis is performed in a graphical manner, a line can be drawn on the characteristics of the device that represents the applied load. The intersection of the load line with the characteristics will determine the point of operation of the system. Consider the network of Figure below employing a diode with its characteristics. Applying Kirchhoff's voltage law to the series circuit will result in

$$E - V_D - V_R = 0$$

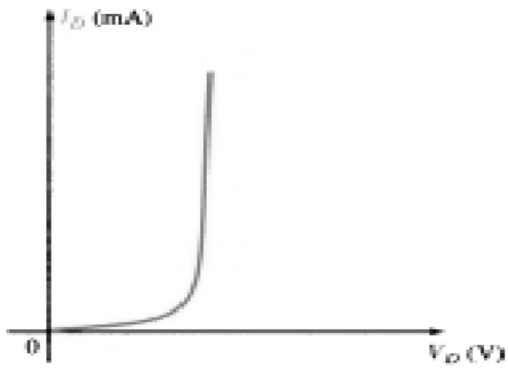
$$\boxed{E = V_D + I_D R}$$



If we set $V_D = 0V$

$$E = V_D + I_D R$$
$$= 0\text{ V} + I_D R$$

$$\boxed{I_D = \frac{E}{R}\bigg|_{V_D = 0\text{ V}}}$$



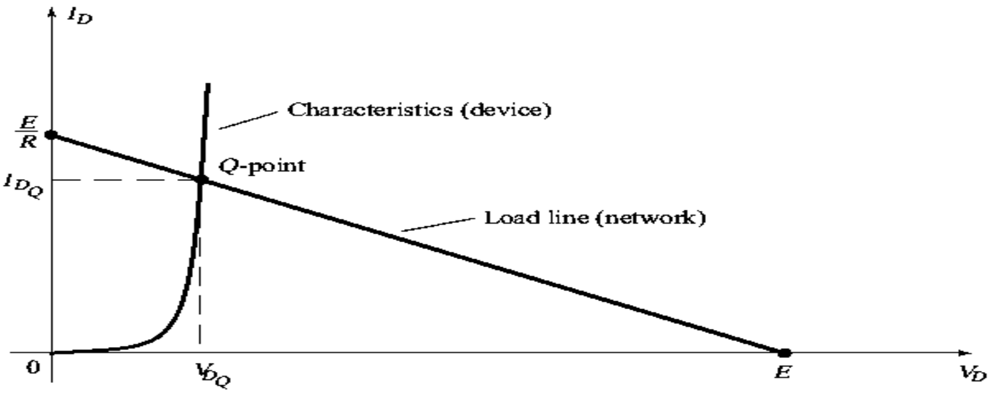
If we set $I_D = 0A$

$$E = V_D + I_D R$$

$$= V_D + (0\text{ A})R$$

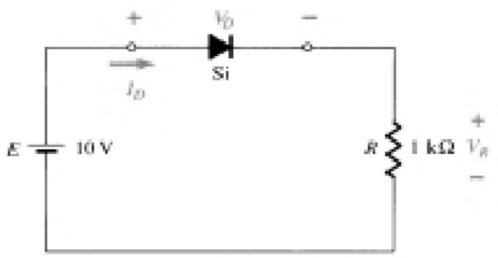
$$\boxed{V_D = E|_{I_D = 0\text{ A}}}$$

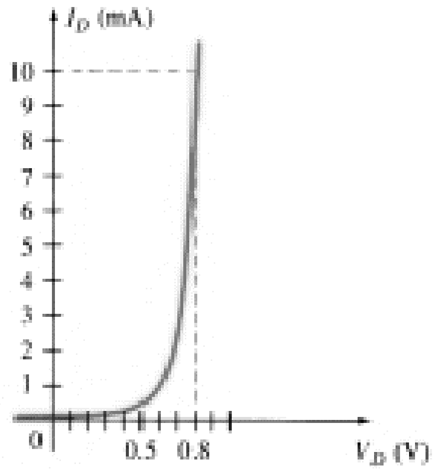
We now have a load line defined by the network and a characteristic curve defined by the device. The point of operation is usually called the quiescent point (abbreviated "Q pt.") to reflect its "still, unmoving" qualities as defined by a dc network.

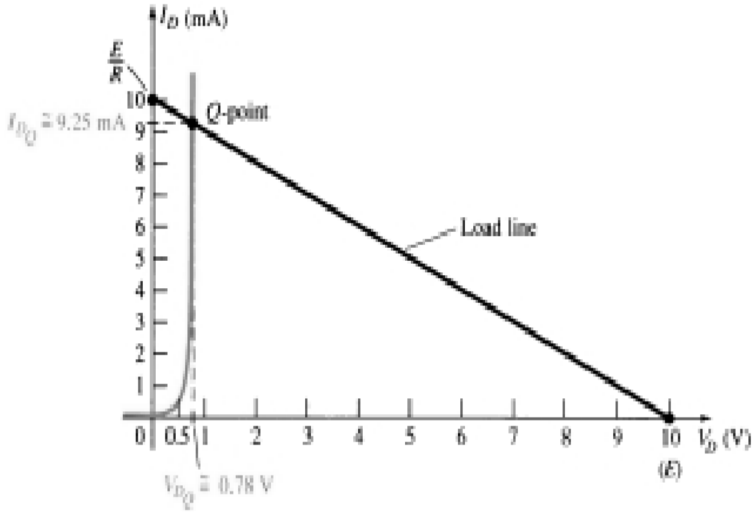


Example: *For the series diode configuration of Fig. 2.3a employing the diode characteristics of Figure below, determine:*

(a) V_{D_Q} and I_{D_Q}.
(b) V_R.







$$I_D = \frac{E}{R}\bigg|_{V_D = 0\text{ V}} = \frac{10\text{ V}}{2\text{ k}\Omega} = 10\text{ mA}$$

$$V_D = E|_{I_D = 0\text{ A}} = 10\text{ V}$$

The intersection between the load line and the characteristic curve defines the Q-point as

$$V_{DQ} \cong 0.78V$$

$$I_{DQ} \cong 9.25mA$$

(b) $V_R = I_R R = I_{D_Q} R = (9.25\text{ mA})(1\text{ k}\Omega) = \mathbf{9.25\text{ V}}$

or $V_R = E - V_D = 10\text{ V} - 0.78\text{ V} = \mathbf{9.22\text{ V}}$

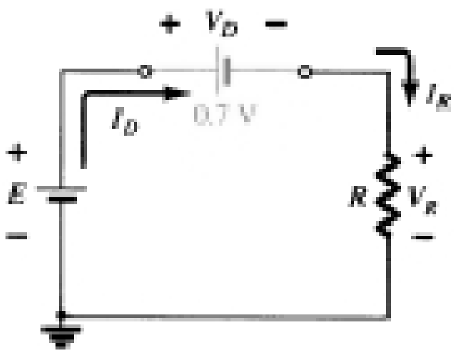
12-1 Series Diode Configurations with DC Inputs:

In general, a diode is in the "on" state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and V_D= 0.7 V for silicon and V_D =0.3 V for germanium.

$$V_D = V_T$$

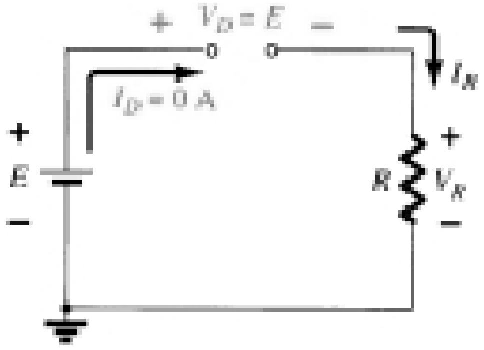
$$V_R = E - V_T$$

$$I_D = I_R = \frac{V_R}{R}$$

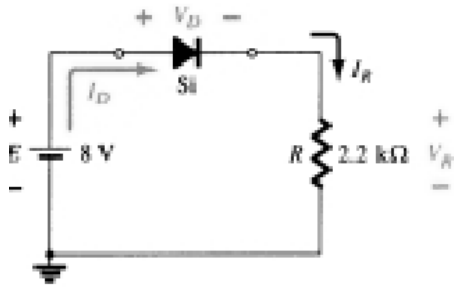


The diode is in the "off" state, resulting in the equivalent circuit. Due to the open circuit, the diode current is 0 A and the voltage across the resistor R is the following:

$$V_R = I_R R = I_D R = (0\text{ A})R = \mathbf{0\ V}$$



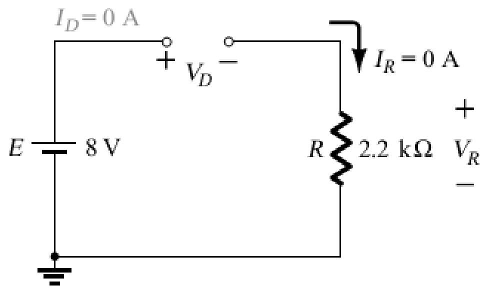
***Example**: For the series diode configuration of Figure below, determine V_D, V_R , and I_D. And repeat with the diode reversed.*



$$V_D = \mathbf{0.7\ V}$$

$$V_R = E - V_D = 8\text{ V} - 0.7\text{ V} = \mathbf{7.3\ V}$$

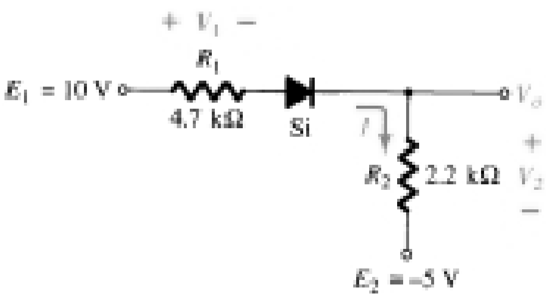
$$I_D = I_R = \frac{V_R}{R} = \frac{7.3\text{ V}}{2.2\text{ k}\Omega} \cong \mathbf{3.32\ mA}$$



$$E - V_D - V_R = 0$$

$$V_D = E - V_R = E - 0 = E = \mathbf{8\ V}$$

***Example:** Determine I, V_1, V_2 , and V_o for the series dc configuration of Figure below.*



$$I = \frac{E_1 + E_2 - V_D}{R_1 + R_2} = \frac{10\text{ V} + 5\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{14.3\text{ V}}{6.9\text{ k}\Omega}$$

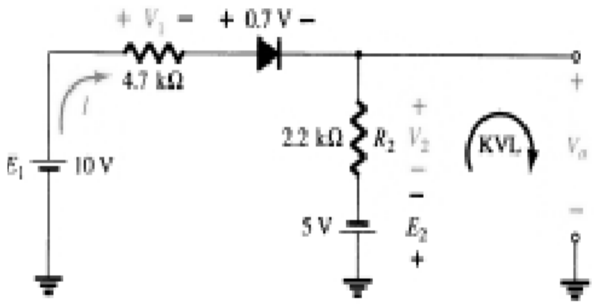
$$\cong \mathbf{2.072\ mA}$$

$$V_1 = IR_1 = (2.072 \text{ mA})(4.7 \text{ k}\Omega) = \mathbf{9.74\ V}$$

$$V_2 = IR_2 = (2.072 \text{ mA})(2.2 \text{ k}\Omega) = \mathbf{4.56\ V}$$

$$-E_2 + V_2 - V_o = 0$$

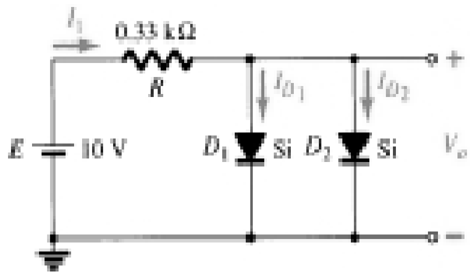
$$V_o = V_2 - E_2 = 4.56 \text{ V} - 5 \text{ V} = \mathbf{-0.44\ V}$$



12-2 Parallel and Series–Parallel Configurations:

Example: *Determine Vo, I_1, I_{D1}, and I_{D2} for the parallel diode configuration of Figure below:*

Since the resulting current direction matches that of the arrow in each diode symbol and the applied voltage is greater than 0.7 V, both diodes are in the "on" state. The voltage across parallel elements is always the same and $V_O = 0.7V$



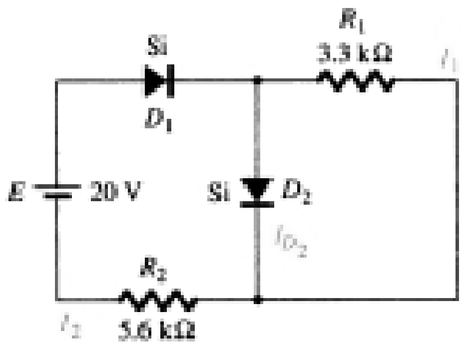
The current

$$I_1 = \frac{V_R}{R} = \frac{E - V_D}{R} = \frac{10 \text{ V} - 0.7 \text{ V}}{0.33 \text{ k}\Omega} = \mathbf{28.18\ mA}$$

Assuming diodes of similar characteristics, we have

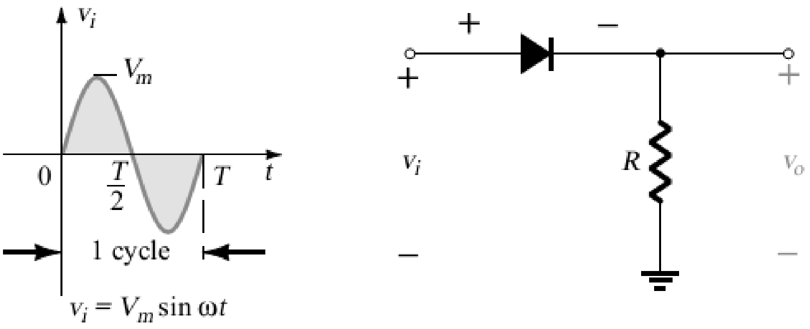
$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18 \text{ mA}}{2} = \mathbf{14.09\ mA}$$

H.W. *Determine the currents I_1, I_2, and I_{D2} for the network of Figure shown.*



12-3 Sinusoidal Inputs; Half-Wave Rectification

For the moment we will use the ideal model (note the absence of the Si or Ge label to denote ideal diode) to ensure that the approach is not clouded by additional mathematical complexity.

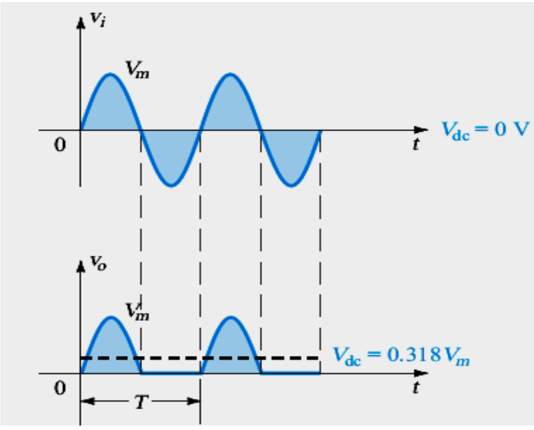


During the interval t=0→T/2 the polarity of the applied voltage v_i is such as to establish “pressure” in the direction indicated and turn on the diode with the polarity appearing above the diode.

For the period T/2→T, the polarity of the input v_i and the resulting polarity across the ideal diode produces an “off” state with an open-circuit equivalent.

The output signal v_o now has a net positive area above the axis over a full period and an average value determined by

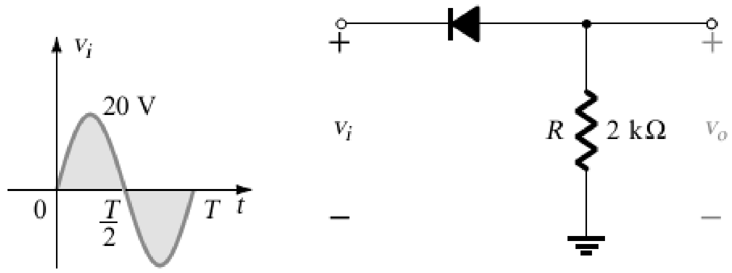
$$V_o = 0.318 V_m$$



The effect of using a silicon diode with V_T = 0.7 V for the forward-bias region. The applied signal must now be at least 0.7 V before the diode can turn “on.” For levels of v_i less than 0.7 V, the diode is still in an open-circuit state and v_o = 0 V as shown in the same figure. For situations where $V_m \geq V_T$ can be applied to determine the average value with a relatively high level of accuracy.

$$V_o = 0.318(V_m - V_T)$$

Example: *(a) Sketch the output v_o and determine the dc level of the output for the network of Figure Below (b) Repeat part (a) if the ideal diode is replaced by a silicon diode. (c) Repeat parts (a) and (b) if V_m is increased to 200 V and compare solutions*



(a) In this situation the diode will conduct during the negative part of the input

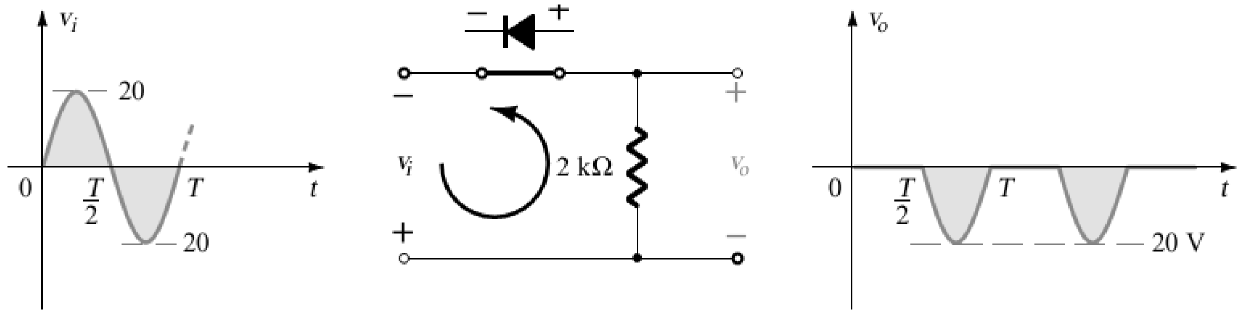
$$V_{dc} = -0.318V_m = -0.318 \times 20 = -6.36V$$

(b) Using a silicon diode:

$$V_{dc} \cong -0.318(V_m - V_T) \cong -0.318(20 - 0.7) = -0.318 \times 19.3 \cong -6.14V$$

(c) $V_{dc} = -0.318V_m = -0.318 \times 200 = -63.6V$

$$V_{dc} = -0.318(V_m - V_T) = -0.318(200 - 0.7) = -0.318 \times 190.3 = -63.38V$$

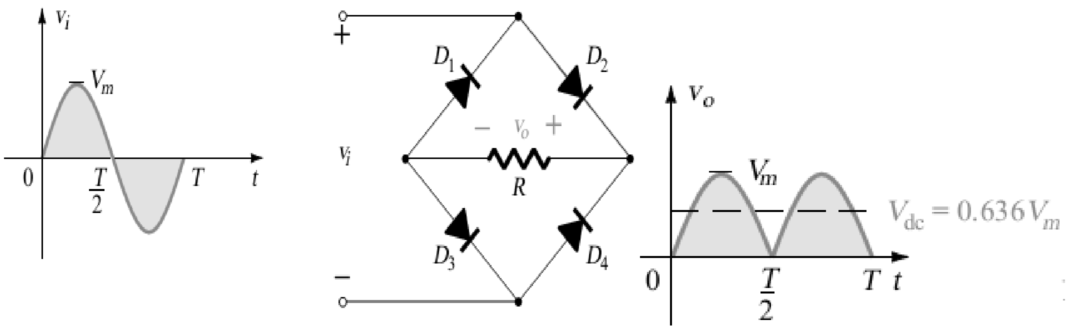


(d) $PIVrating \geq V_m$ for Half-wave rectifier

$$PIV \geq 20V$$

12-4 Full-Wave Rectification:

(a) **Bridge Network:** The dc level obtained from a sinusoidal input can be improved 100% using a process called full-wave rectification. The most familiar network for performing such a function with its four diodes in a bridge configuration. During the period t = 0 to T/2 the polarity of the input is reveal that D_2 and D_3 are conducting while D_1 and D_4 are in the “off” state.



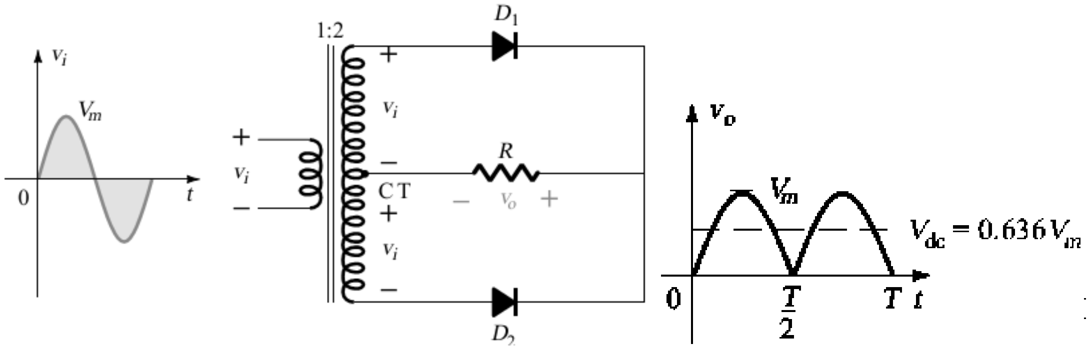
$$V_o = 2(0.318V_m) = 0.636V_m$$

If silicon rather than ideal diodes are employed:

$$V_o \cong 0.318(V_m - 2V_T)$$

$PIVrating \geq V_m$ for Full-wave bridge rectifier

(b) **Center-Tapped Transformer:** A second popular full-wave rectifier with only two diodes but requiring a center-tapped (CT) transformer to establish the input signal across each section of the secondary of the transformer.
During the positive portion of v_i applied to the primary of the transformer. D1 assumes the short-circuit equivalent and D_2 the open-circuit equivalent, as determined by the secondary voltages and the resulting current directions.

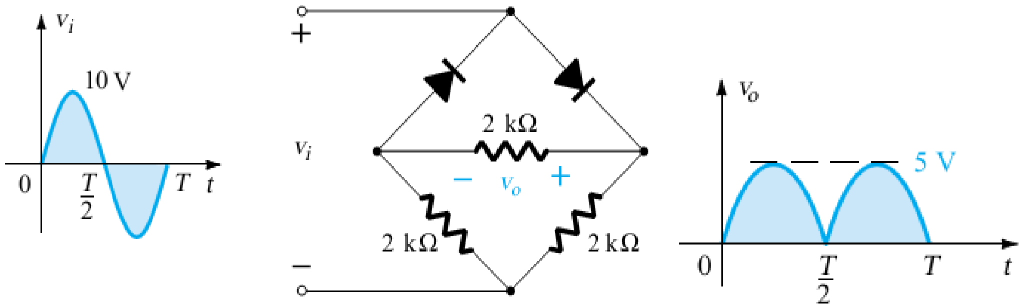


The net effect is the same output as that appearing in bridge rectifier with the same dc levels.

$$PIV = V_{Secondary} + V_R = V_m + V_m = 2V_m$$

$$PIVrating \geq 2V_m \text{ for Full-wave CT rectifier}$$

Example: *Determine the output waveform for the fallowing network and calculate the output dc level and the required PIV of each diode.*



Type equation here.

$$V_o = 0.636V_m = 0.636 \times 5 = 3.18V$$

$PIVrating \geq V_m$ for Full-wave bridge rectifier, PIV=5V

12-5 Clippers:

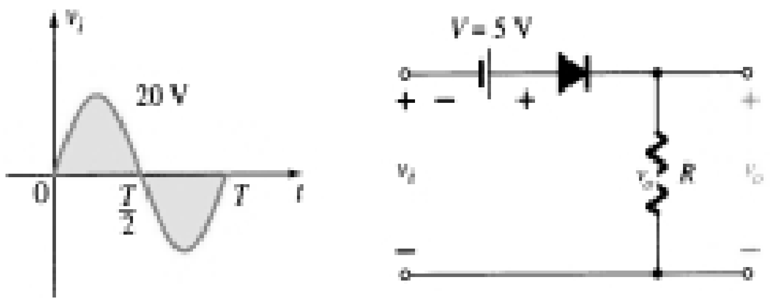
There are a variety of diode networks called clippers that have the ability to "clip" off a portion of the input signal without distorting the remaining part of the alternating waveform.

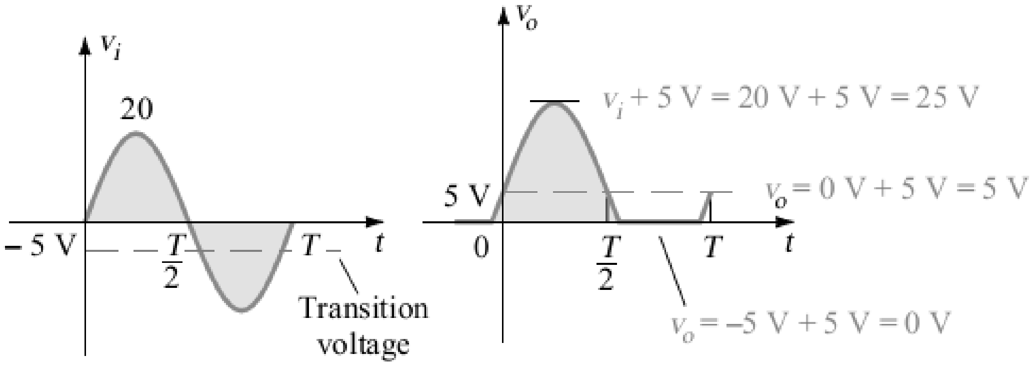
There is no general procedure for analyzing networks such but there are a few thoughts to keep in mind as you work toward a solution.

1- Make a mental sketch of the response of the network based on the direction of the diode and the applied voltage levels.
2- Determine the applied voltage (transition voltage) that will cause a change in state for the diode.
3- Be continually aware of the defined terminals and polarity of v_o.
4- It can be helpful to sketch the input signal above the output and determine the output at instantaneous values of the input.

Example: *Determine the output waveform for the fallowing network:*

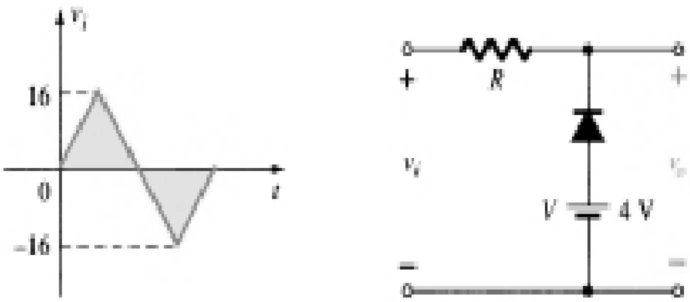
Past experience suggests that the diode will be in the "on" state for the positive region of v_i —especially when we note the aiding effect of V = 5 V. For v_i more negative than -5 V the diode will enter its open-circuit state, while for voltages more positive than -5 V the diode is in the short-circuit state.





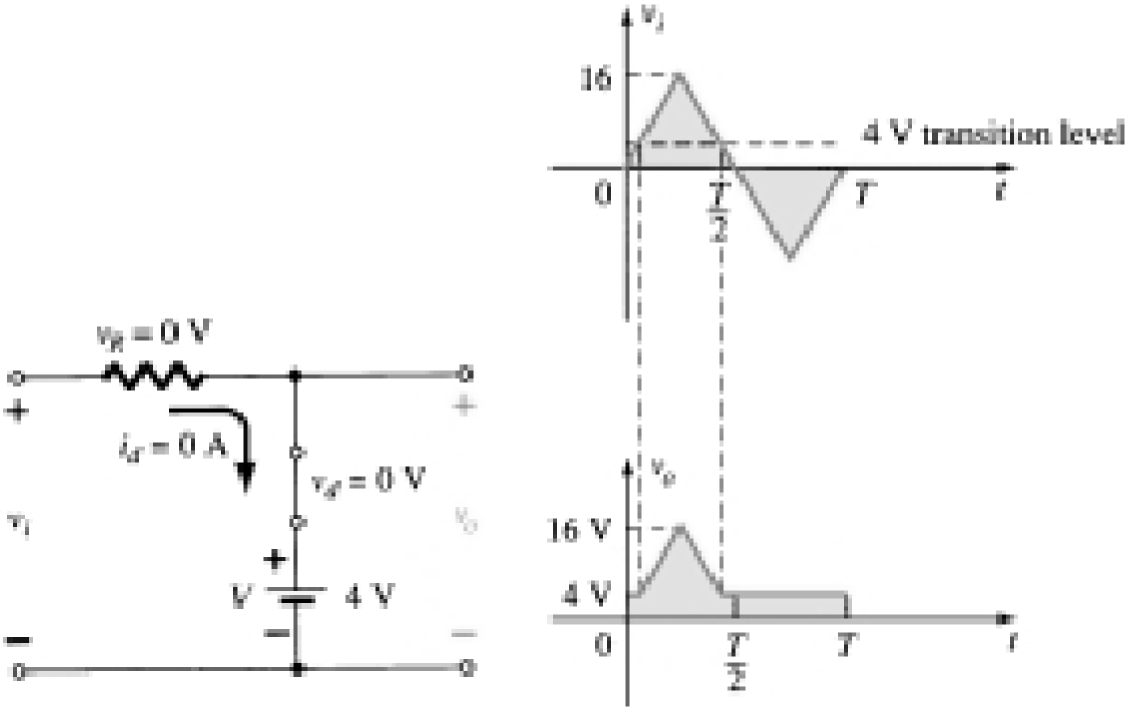
The analysis of parallel configurations is very similar to that applied to series configurations.

Example: *Determine v_o for the network of the fallowing network:*

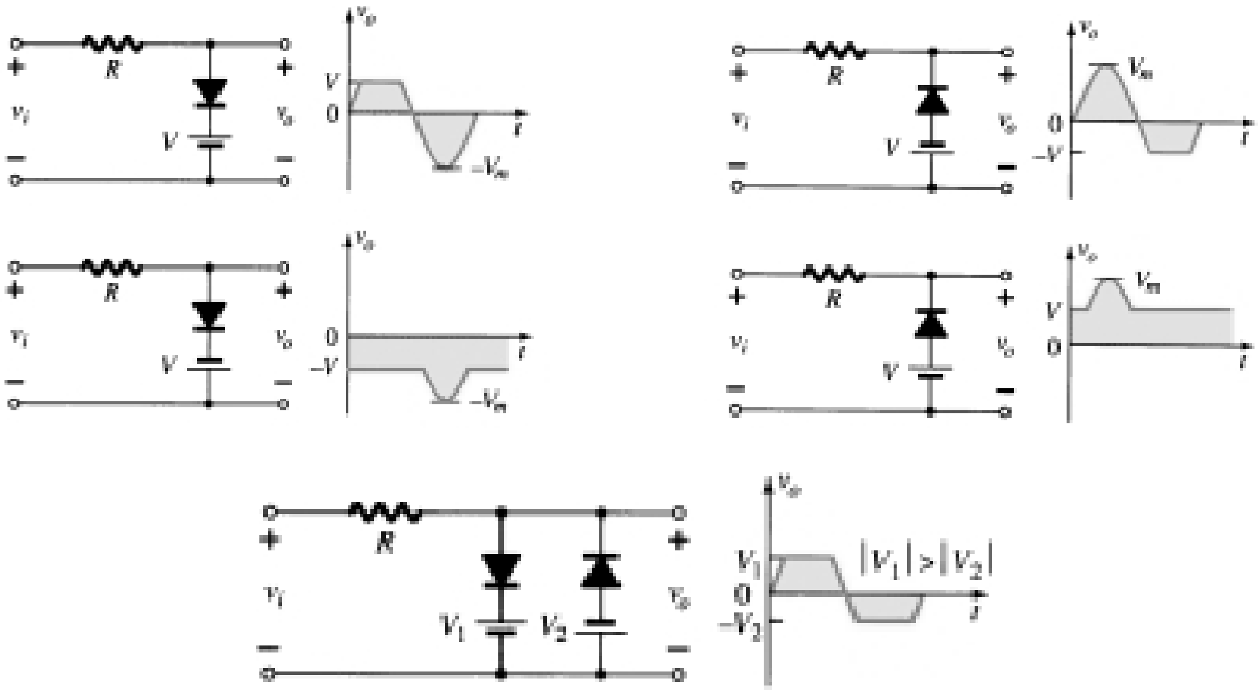


The polarity of the dc supply and the direction of the diode strongly suggest that the diode will be in the "on" state for the negative region of the input signal.

Since the dc supply is obviously "pressuring" the diode to stay in the short-circuit state, the input voltage must be greater than 4 V for the diode to be in the "off" state. Any input voltage less than 4 V will result in a short-circuited diode.

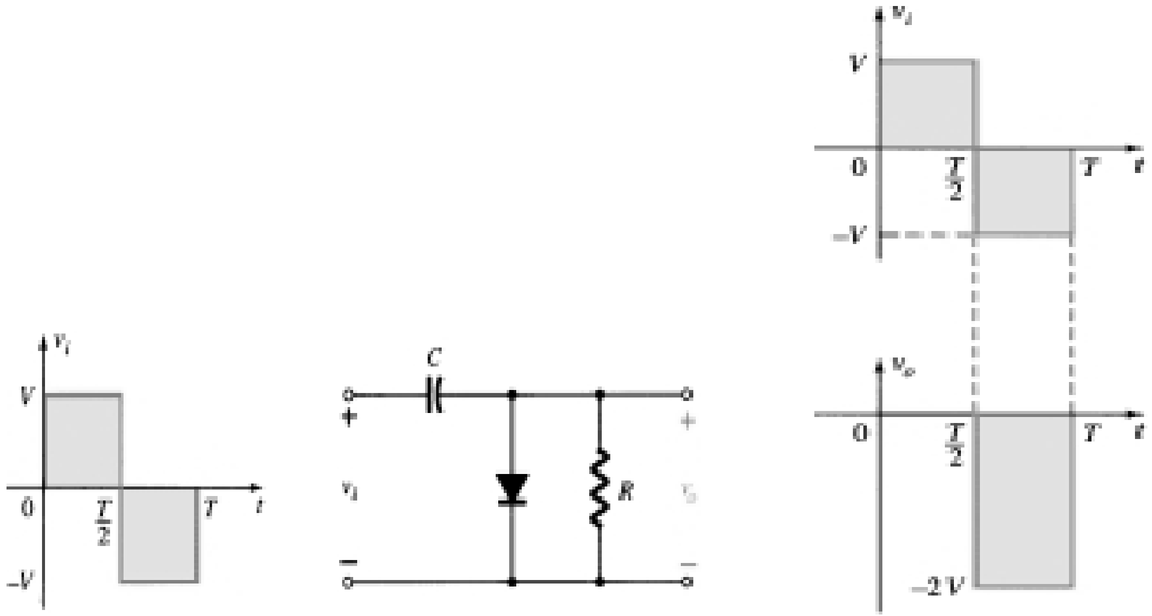


H.W: Repeat the above example using a silicon diode with V_T = 0.7 V

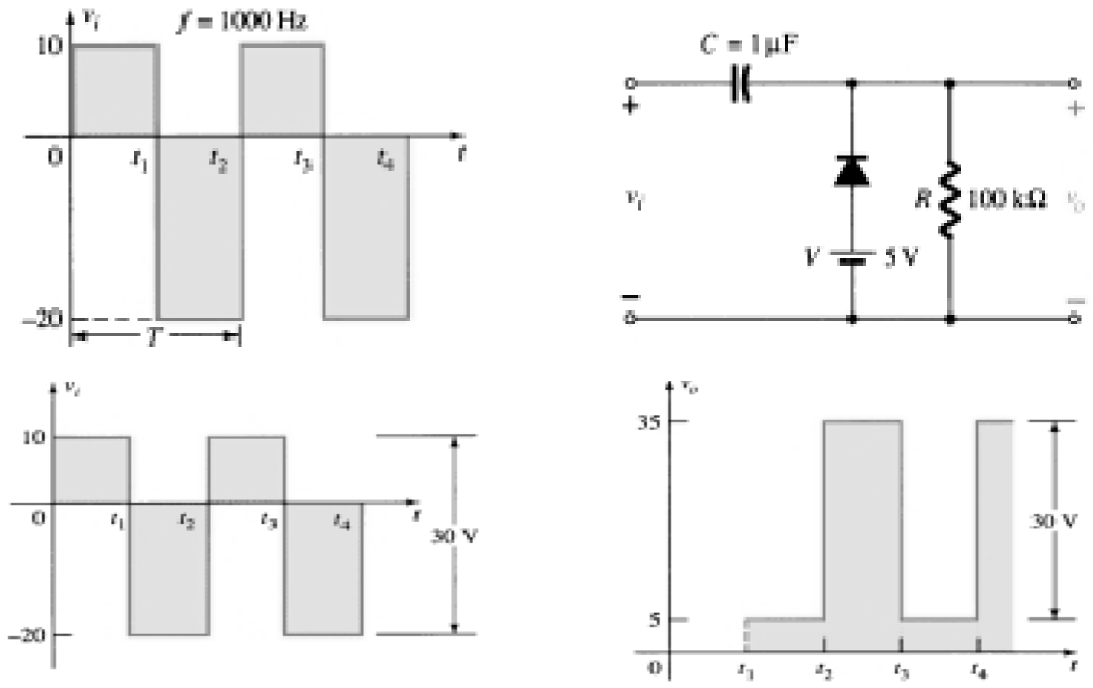


12-6 Clampers:

The clamping network is one that will “clamp” a signal to a different dc level. The network must have a capacitor, a diode, and a resistive element, but it can also employ an independent dc supply to introduce an additional shift. The magnitude of R and C must be chosen such that the time constant RC is large enough to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is non-conducting.



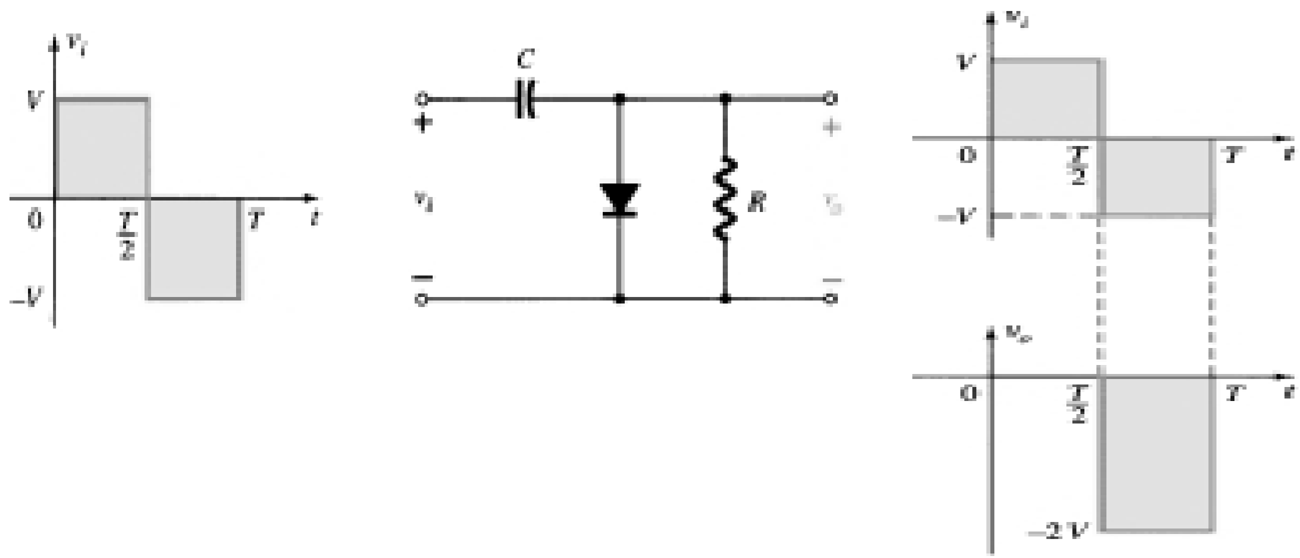
Example: *Determine v_o for the network of the fallowing Figure for the input indicated:*



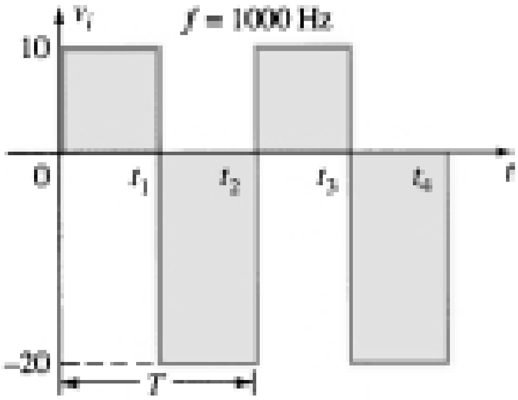
H.V: *Repeat the above example using a silicon diode with V_T = 0.7.*

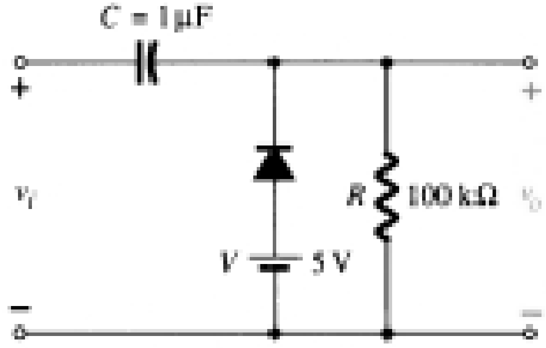
12-7 Clampers

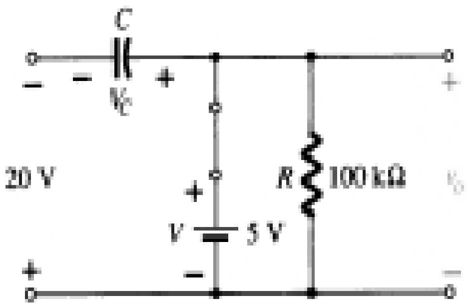
The clamping network is one that will "clamp" a signal to a different dc level. The network must have a capacitor, a diode, and a resistive element, but it can also employ an independent dc supply to introduce an additional shift. The magnitude of R and C must be chosen such that the time constant $\tau = RC$ is large enough to ensure that the voltage across the capacitor does not discharge significantly during the interval the diode is non-conducting. During the interval 0→T/2 the diode in the "on" state effectively "shorting out" the effect of the resistor R. The resulting RC time constant is so small (R determined by the inherent resistance of the network) that the capacitor will charge to V volts very quickly. When the input switches to the -V state, with the open-circuit equivalent for the diode determined by the applied signal and stored voltage across the capacitor—both "pressuring" current through the diode from cathode to anode. Now that R is back in the network the time constant determined by the RC product is sufficiently large to establish a discharge period 5 τ much greater than the period T/2→T.

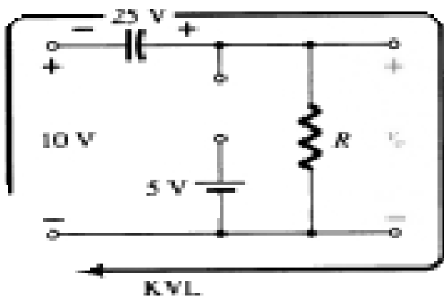


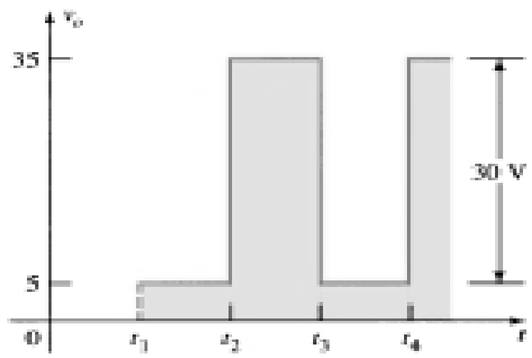
Example: *Determine v_o for the Fallowing network for the input indicated*:



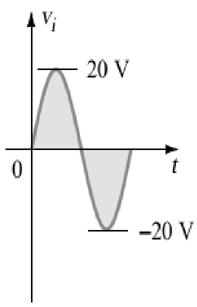


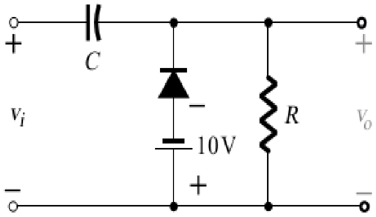


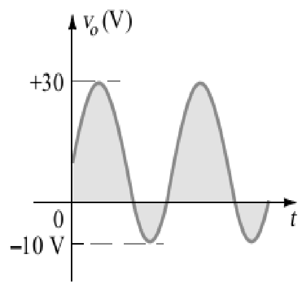


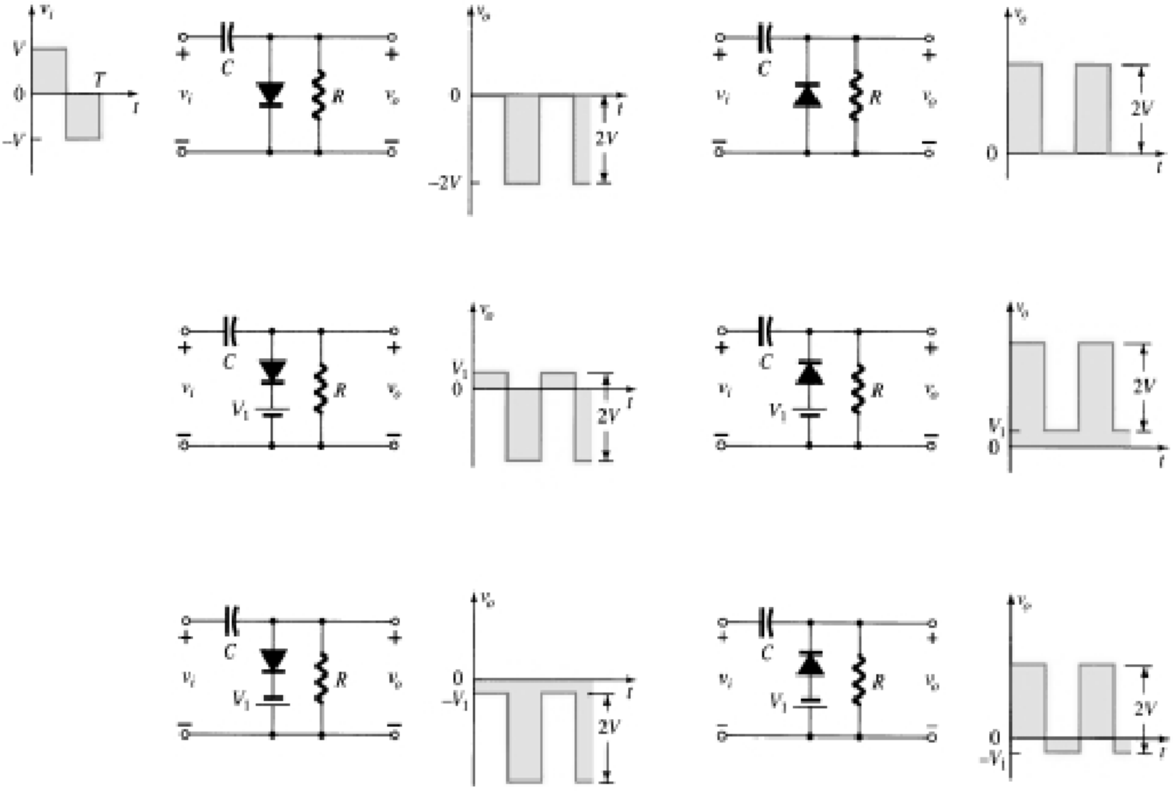


H.W: *Repeat the above Example using a silicon diode with V_T = 0.7 V.*







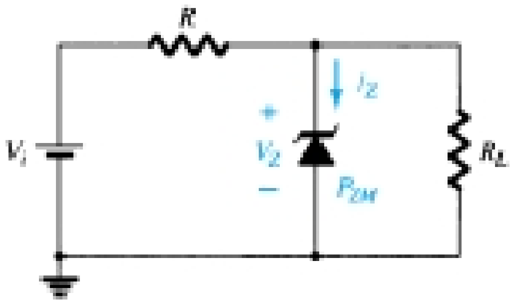


12-8 Zener Diodes

The analysis of networks employing Zener diodes is quite similar to that applied to the analysis of semiconductor diodes. The simplest of Zener diode networks appears in Figure below. The applied dc voltage is fixed, as is the load resistor. The analysis can fundamentally be broken down into two steps.

1- Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.
2- Substitute the appropriate equivalent circuit and solve for the desired unknowns.

If $V_i < V_Z$ then $V_L = \frac{R_L V_i}{R_L + R}$



If $V_i \geq V_Z$, the Zener diode is "on" and

$$V_L = V_Z$$

The Zener diode current must be determined by an application of Kirchhoff's current law. That is,

$$I_R = I_Z + I_L$$

$$I_Z = I_R - I_L$$

Where $I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$ and $I_L = \frac{V_L}{R_L}$

The power dissipated by the Zener diode is determined by: $P_Z = V_Z I_Z$

Fixed V_i, Variable R_L: Due to the offset voltage V_Z, there is a specific range of resistor values (and therefore load current) which will ensure that the Zener is in the "on" state**.**

To determine the minimum load resistance:

$$V_L = \frac{R_L V_i}{R_L + R} \rightarrow V_L R_L + V_L R = R_L V_i$$

$$V_L = V_Z$$

$$R_{Lmin} = \frac{V_Z R}{V_i - V_Z}$$

Any load resistance value greater than the R_L obtained from will ensure that the Zener diode is in the "on" state and the diode can be replaced by its V_Z source equivalent. But in turn specifies the maximum I_L as

$$I_{Lmax} = \frac{V_L}{R_L} = \frac{V_Z}{R_{Lmin}}$$

Once the diode is in the "on" state, the voltage across R remains fixed at

$$V_R = V_i - V_Z$$

and I_R remains fixed at

$$I_R = \frac{V_R}{R}$$

The Zener current

$$I_Z = I_R - I_L$$

To find the range of R_L:

$$I_{Lmin} = I_R - I_{ZM}$$

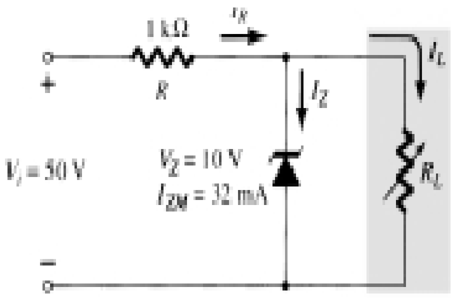
And

$$R_{Lmax} = \frac{V_Z}{I_{Lmin}}$$

Example: (a) for the fallowing network, determine the range of R_L and I_L that will result in V_{RL} being maintained at 10 V.

(b) Determine the maximum wattage rating of the diode.

(a) $R_{Lmin} \frac{RV_Z}{V_i - V_Z} = \frac{(1k)(10V)}{50V - 10V} = \frac{10k}{40}$



$V_R = V_i - V_Z = 50V - 10V = 40V$

$I_R = \frac{V_R}{R} = \frac{40V}{1k} = 40mA$

$I_{Lmin} = I_R - I_{ZM} = 40 - 32 = 8mA$

$$R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{10V}{8mA} = 1.25k\Omega$$

: $P_Z = V_Z I_Z = (10V)(32mA) = 320mW$

Fixed R_L, Variable V_i

For fixed values of R_L, the voltage V_i must be sufficiently large to turn the Zener diode on. The minimum turn-on voltage $V_i = V_{imin}$ is determined by

$$V_L = V_Z = \frac{R_L V_i}{R_L + R}$$

$$V_{i_{min}} = \frac{(R_L + R)V_Z}{R_L}$$

The maximum value of V_i is limited by the maximum Zener current I_{ZM}. Since

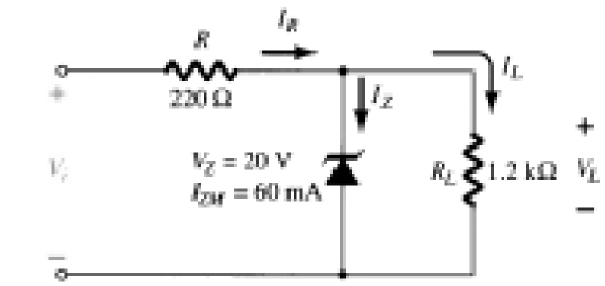
$$I_L = I_R - I_{ZM}$$

$$I_{Rmax} = I_{ZM} + I_L$$

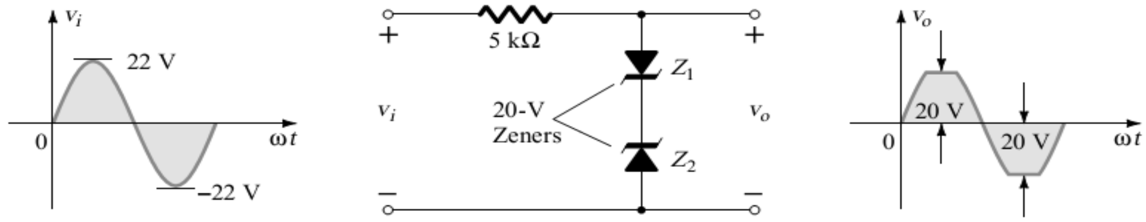
$$V_{imax} = V_{Rmax} + V_Z$$

$$V_{imax} = I_{Rmax} R + V_Z$$

H.W: *Determine the range of values of Vi that will maintain the Zener diode of Fig. below in the "on" state.*



Two back-to-back Zeners can also be used as an ac regulator as shown in Fig. below. The input and output will continue to duplicate each other until v_i reaches 20 V. Z_2 will then "turn on"(as a Zener diode), while Z_1 will be in a region of conduction with a resistance level sufficiently small compared to the series 5-kΩ resistor to be considered a short circuit.

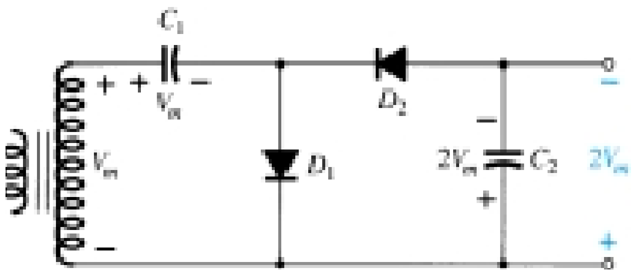


12-9 Voltage-Multiplier Circuits:

Voltage-multiplier circuits are employed to maintain a relatively low transformer peak voltage while stepping up the peak output voltage to two, three, four, or more times the peak rectified voltage.

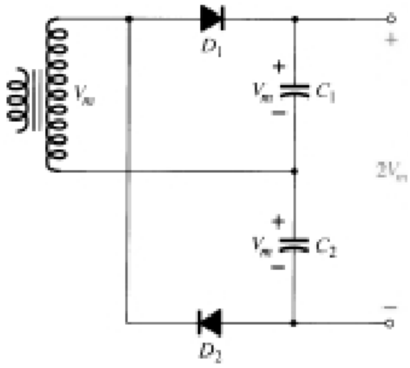
Voltage Doubler: The network of Figure below is a half-wave voltage doubler. we can sum the voltages around the outside loop**.**

$$-V_m - V_{C1} + V_{C2} = 0 \quad \Rightarrow \quad -V_m - V_m + V_{C2} = 0 \quad \Rightarrow \quad V_{C2} = 2V_m$$



The peak inverse voltage across each diode is 2Vm.

Another doubler circuit is the full-wave doubler of Fig. below. The peak inverse voltage across each diode is 2Vm, as it is for the filter capacitor circuit.



Voltage Tripler and Quadrupler: The Figure shows an extension of the half-wave voltage doubler, which develops three and four times the peak input voltage**.** It should be obvious from the pattern of the circuit connection how additional diodes and capacitors may be connected so that the output voltage may also be five, six, seven, and so on, times the basic peak voltage (Vm).