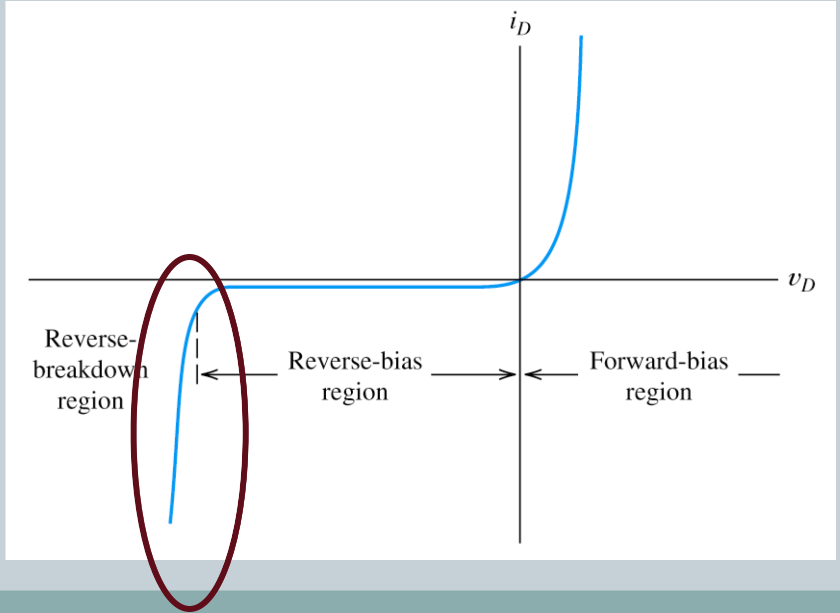
Semiconductor Diode

The Zener Diode

* *Zener diode* is designed for operation in the reverse-breakdown region.
* The *breakdown voltage* is controlled by the doping level *(-1.8 V to -200 V)*.
* The major application of Zener diode is to provide an output reference that is stable despite changes in input voltage – power supplies, voltmeter,…



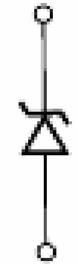
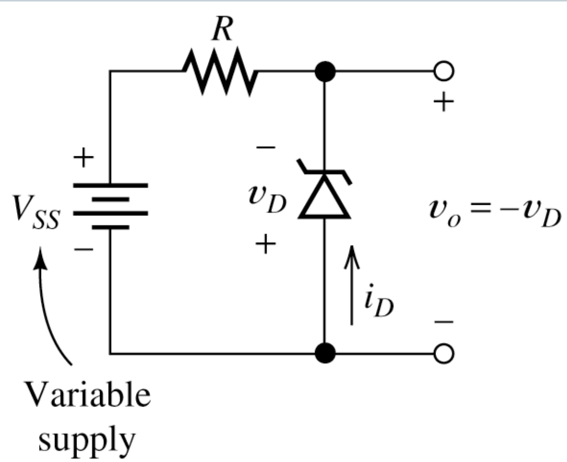


Figure 7.3 Zener diode symbol.

Zener Diode

* Sometimes, a circuit that produces constant output voltage while operating from a variable supply voltage is needed. Such circuits are called *voltage regulator*.
* The Zener diode has a breakdown voltage equal to the desired output voltage.
* The resistor limits the diode current to a safe



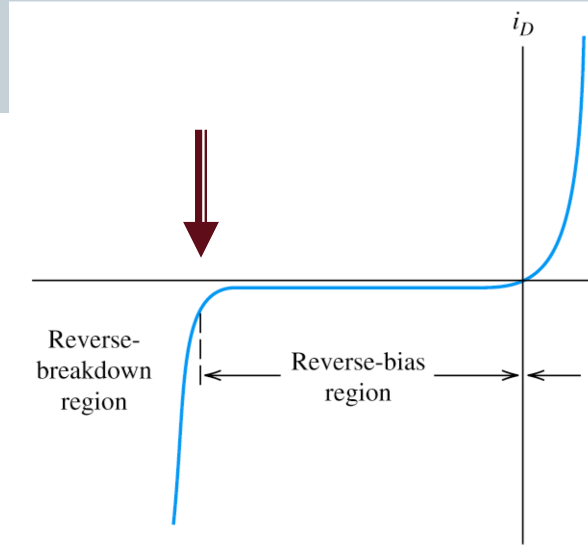
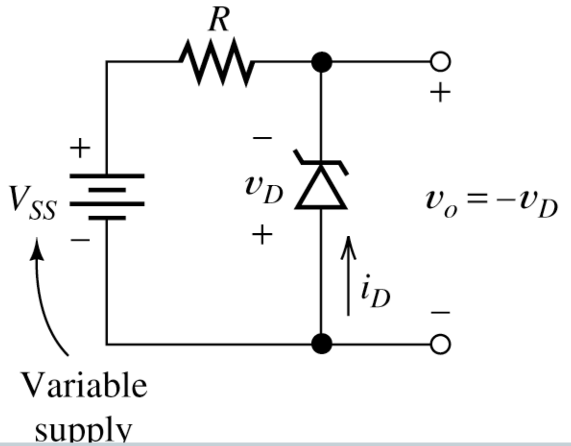


Figure 10.9 A simple regulator circuit that provides a nearly constant output voltage v_o from a variable supply voltage.

Example Zener-Diode Voltage-Regulator Circuits

$$Given: \text{the Zener diode } I\text{-}V \text{ curve}, R = 1k\Omega$$

$$Find: \text{the output voltage for } V_{SS} = 15\,V \text{ and } V_{SS} = 20\,V$$



KVL gives the load line:

$$V_{SS} + R\,i_D + v_D = 0$$

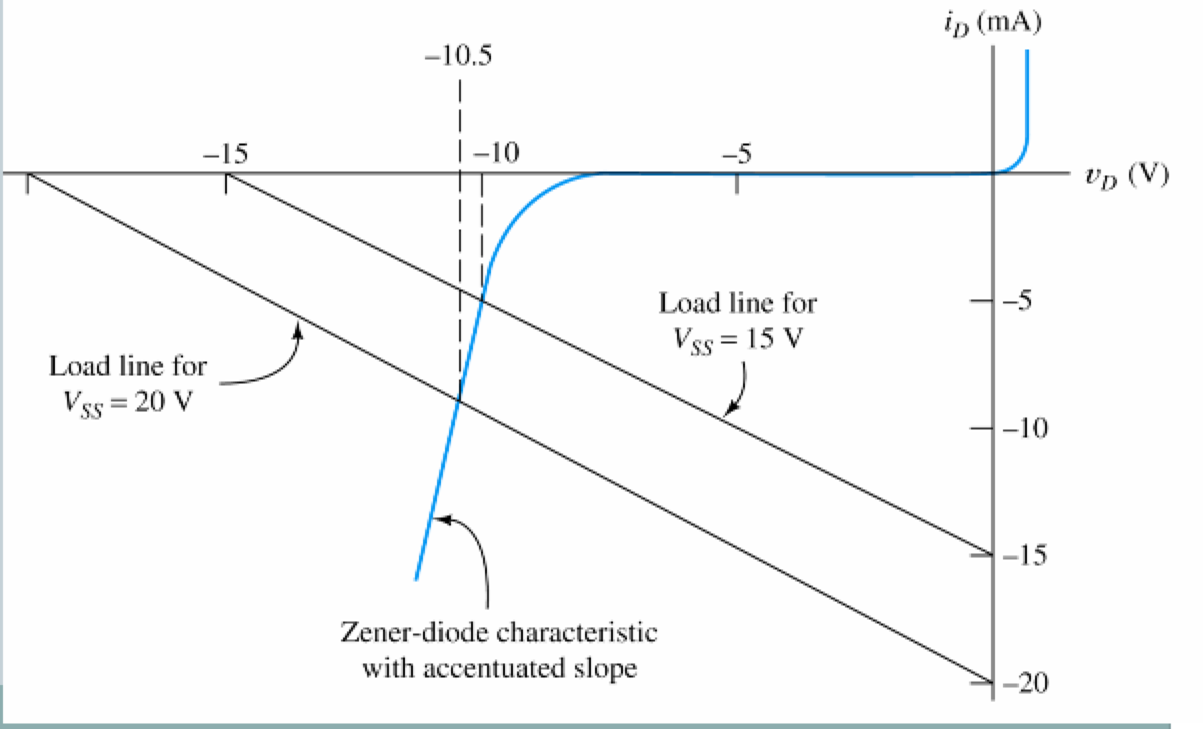
From the Q-point we have:

$$v_o = 10.0\,V \text{ for } V_{SS} = 15\,V$$

$$v_o = 10.5\,V \text{ for } V_{SS} = 20\,V$$

5V change in input

$\Rightarrow 0.5V$ change in v_o



Actual Zener diode performs much better!

Load-Line Analysis of Complex Circuits

* Use the Thevenin Equivalent

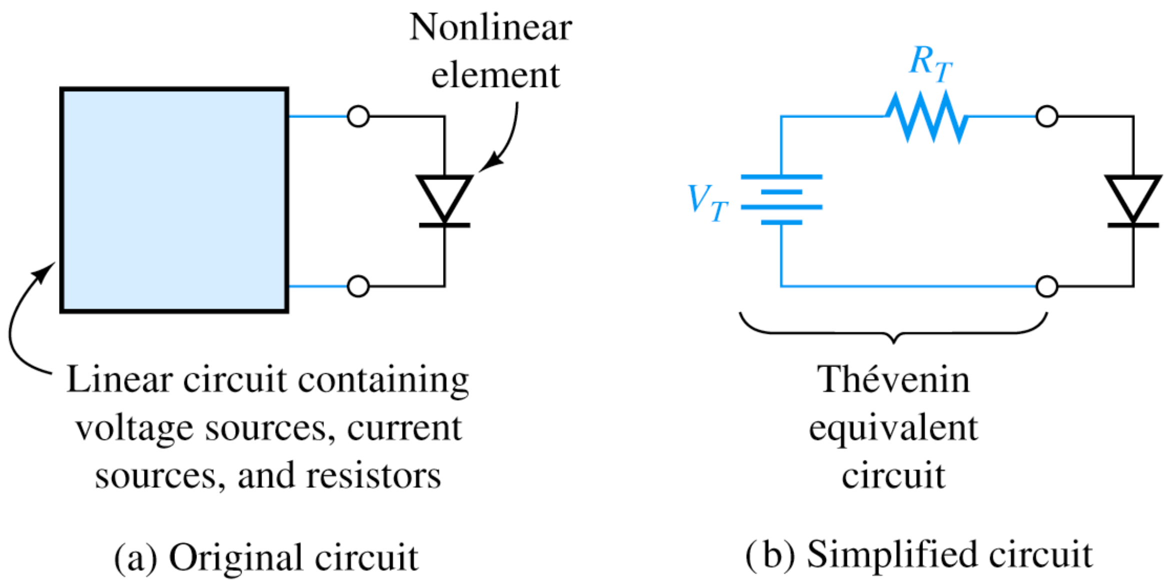


Figure 10.11 Analysis of a circuit containing a single nonlinear element can be accomplished by load-line analysis of a simplified circuit.

Example – Zener-Diode Voltage-Regulator with a Load

$Given: Zener\ diode\ I\text{-}V\ curve,\ V_{SS} = 24V,\ R = 1.2k\Omega,\ R_L = 6k\Omega$

$Find:\ the\ load\ voltage\ v_L\ and\ source\ currents\ I_S$

$$Applying\ Thevenin\ Equivalent \Rightarrow V_T = V_{SS}\frac{R_L}{R+R_L} = 20V,\ R_T = \frac{R\,R_L}{R+R_L} = 1k\,\Omega$$

$$\Rightarrow V_T + R_T\,i_D + v_D = 0$$

$$\Rightarrow v_L = -v_D = 10.0\,V$$

$$I_S = (V_{SS} - v_L)/R = 11.67\ mA$$

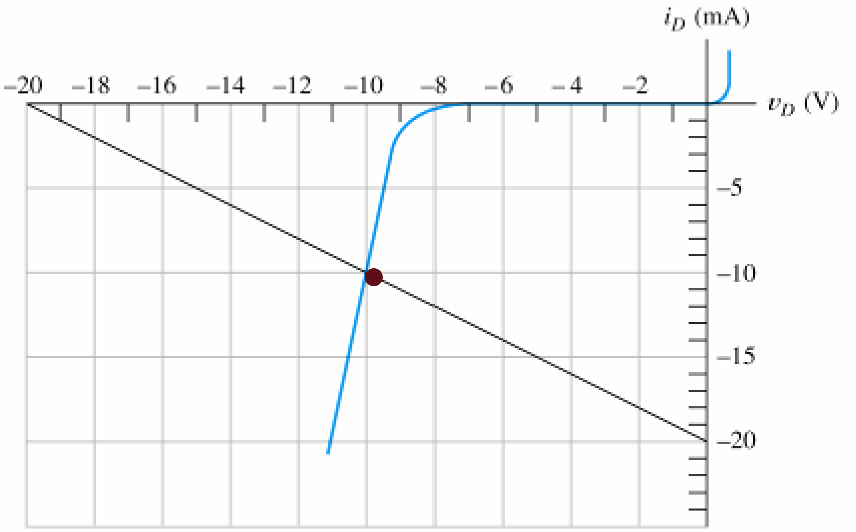


Figure 10.13 Zener-diode characteristic for Example 10.4 and Exercise 10.4.

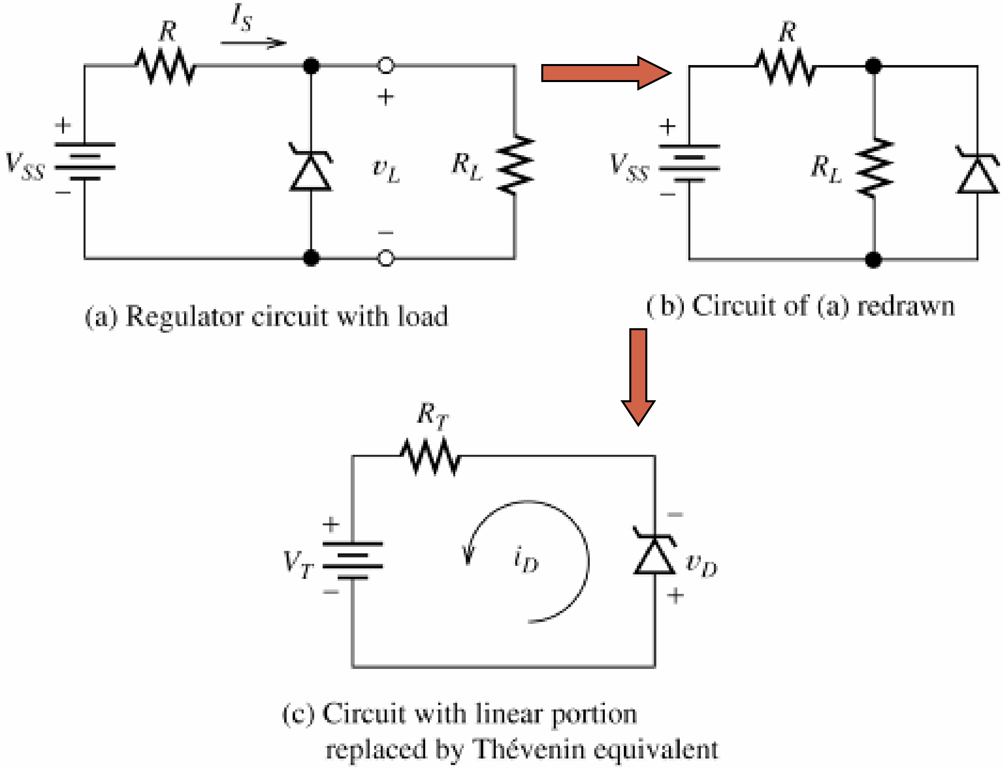


Figure 10.12 See Example 10.4.

Ideal-Diode Model

* Graphical load-line analysis is too cumbersome for complex circuits,
* We may apply "*Ideal-Diode Model*" to simplify the analysis:

(1) in forward direction: *short-circuit assumption*, zero voltage drop;

(2) in reverse direction: *open-circuit assumption*.

* The ideal-diode model can be used when the forward voltage drop and reverse currents are negligible.

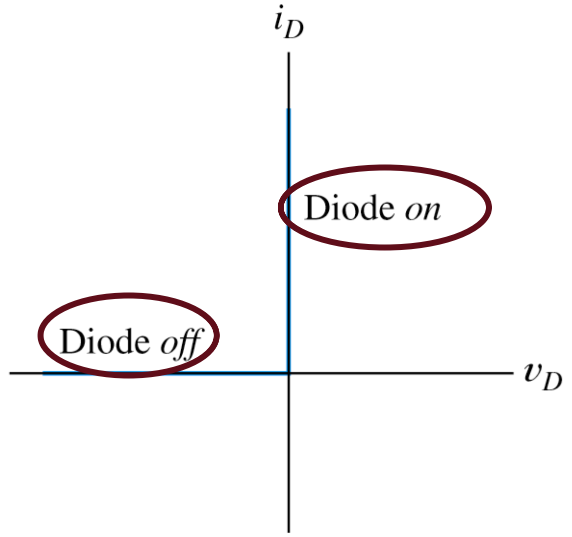
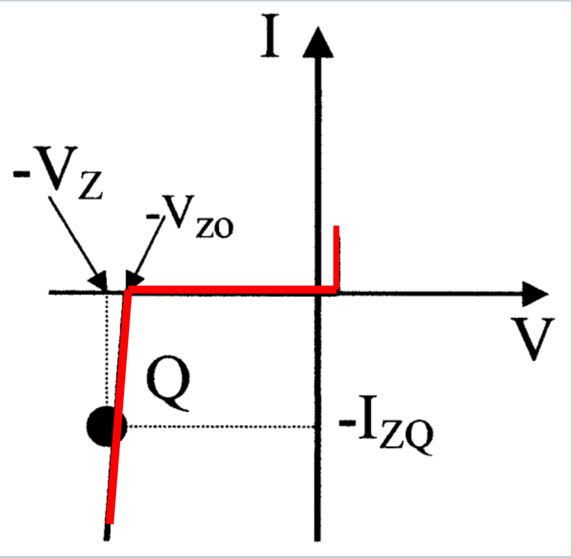


Figure 10.15 Ideal-diode volt–ampere characteristic.

Zener Diode

- The linear approximation to the I-V characteristic of a zener diode in the reverse bias and breakdown regions is as follows.



Zener Diode

- The slope of the line at Q is $1/r_Z$
- r_Z is called the incremental resistance of the zener diode
- This is exaggerated for clarity in the figure. In practice r_Z is small (a few ohms) and the breakdown voltage is approximately constant irrespective of the reverse current.

Zener Diode

- Zener breakdown occurs when the electric field in the depletion layer increases to the point where it can break covalent bonds and generate electron-hole pairs.
- Electrons generated in this way are swept by the electric field into the n side.
- Holes generated in this way are swept by the electric field into the p side.

Zener Current

- These electrons and holes constitute a reverse current through the junction.
- Once the zener effect starts a large number of carriers can be generated with negligible increase in the junction voltage.
- In the breakdown region the reverse current is thus determined by the external circuit,the reverse voltage across the diode remains close to the rated breakdown voltage.

Zener Diode

- The other breakdown mechanism is avalanche breakdown.
- This occurs when minority carrier in the depletion layer gain sufficient kinetic energy to break covalent bonds in atoms when they collide.

Zener Diode

- Avalanche breakdown.
- Carriers liberated may have or gain sufficient energy to cause other carriers to be generated.
- This process continues in the fashion of an ‘avalanche’
- Many carriers can be created to support any reverse current determined by the external current.

Zener Diode

- The device is operated in reverse bias.
- Thus we reverse the sign notation that we normally use for diode voltages and currents, as shown on the next slide

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