Lecture #11

Semiconductor Diodes and Basic Circuits

Outline/Learning Objectives:

- Simple circuits using ideal diode model, constant voltage drop model, and mathematical (exponential) model.
- Use of graphical analysis, the load-line concept an iterative numerical methods.
- Study diode rectifier, voltage-limiting, peak-detector, and clamping cir cuits.
- Explain the temperature and breakdown behavior of a diode.
- Analyze and design basic ac/dc converters.

Why Study Diodes and Brief Introduction to Diodes?

pn Junction Diode

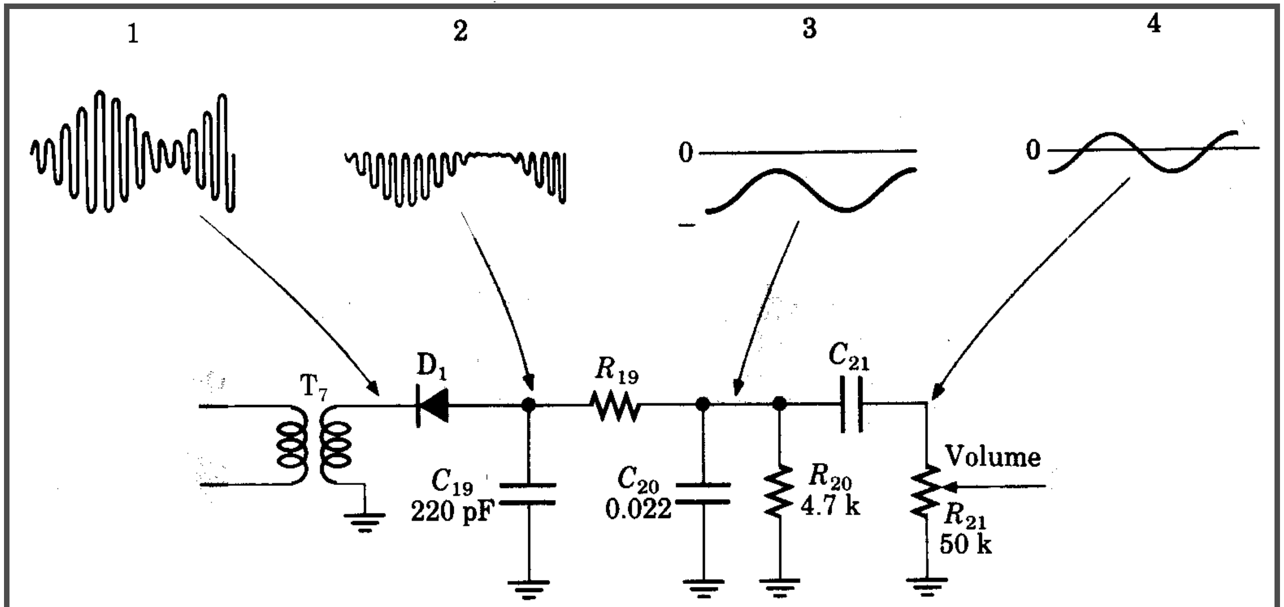
The most common diode is the silicon p-n junction diode. It has non-linear I-V characteristics which is responsible for many of its applications (see page 9 - 4 for 2 circuit examples).

1. Power rectifiers to convert ac to dc;
2. Signal detection in radio receivers;
3. Waveform clamp in digital circuits;
4. Photodetector; Solar cell; Light emitter etc.

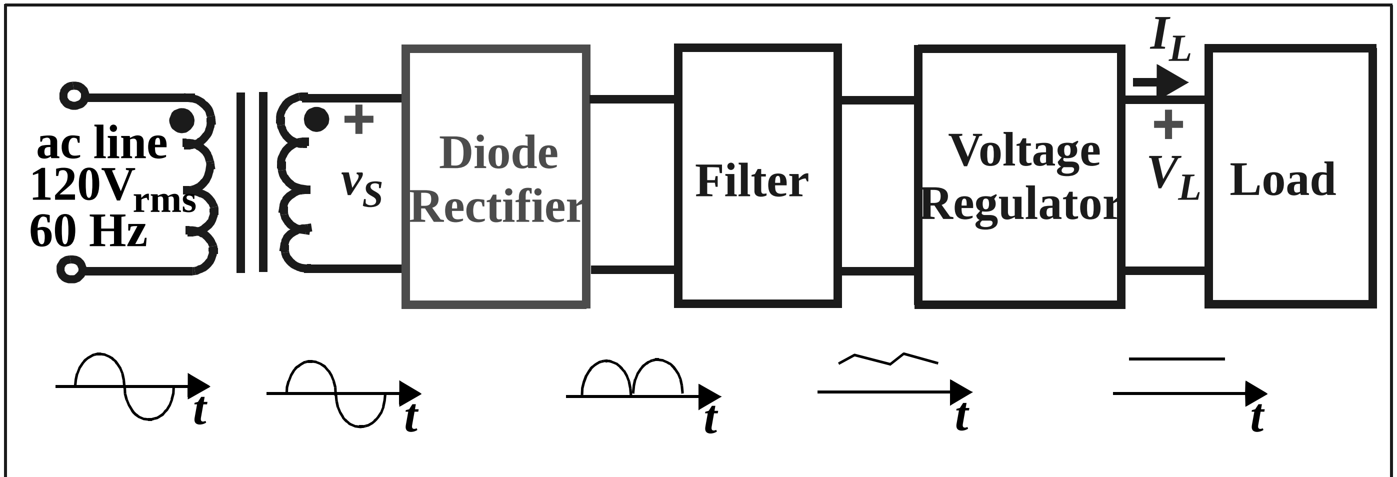
It is also a principal part of other semiconductor devices,

1. in bipolar junction transistors, or
2. as the source/substrate junction of MOSFETs.

Examples of 2 practical circuits using diodes



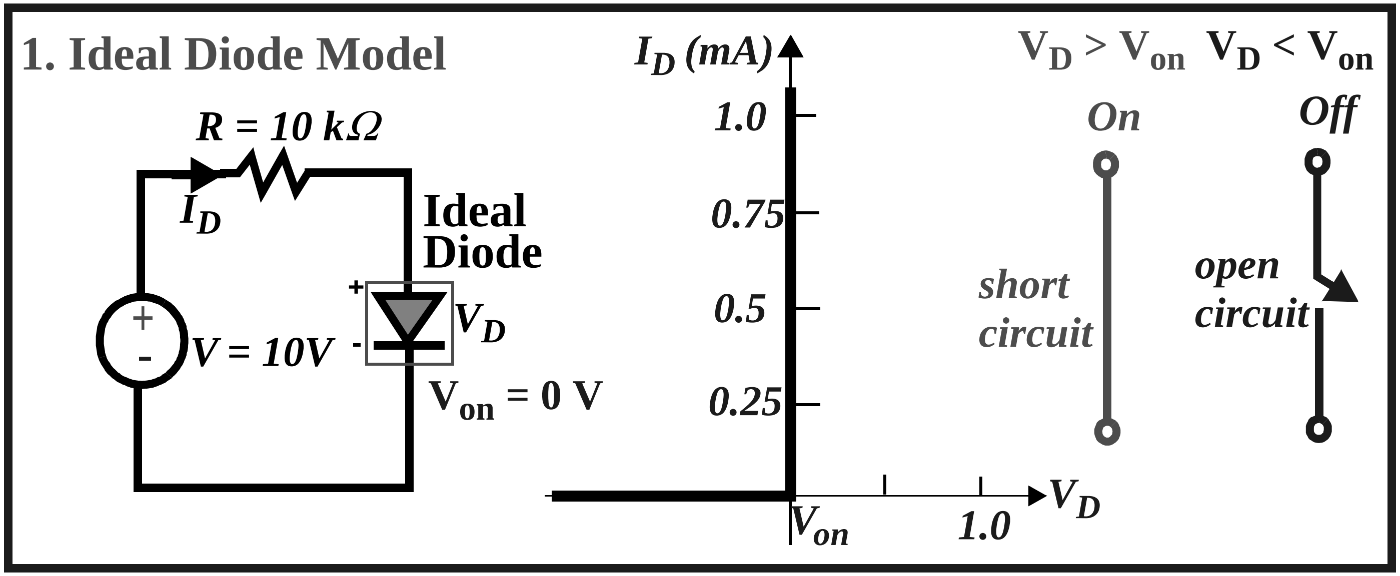
AM Diode Detection Circuit



Block diagram of a dc power supply

DC Electrical Characteristics

The ideal diode model



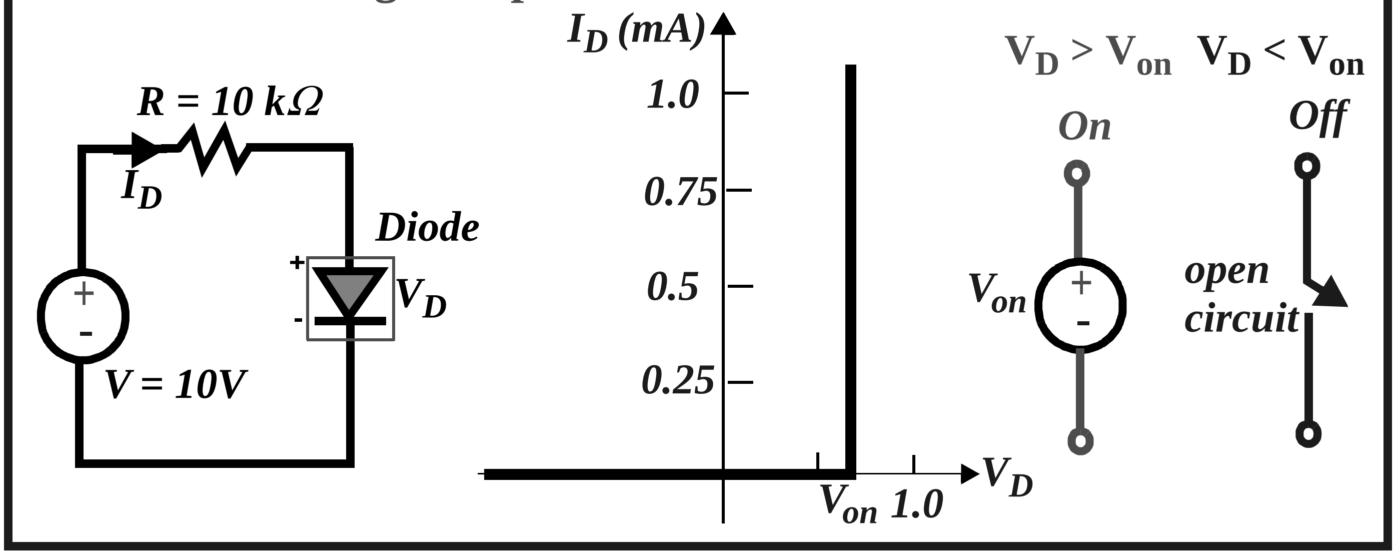
$$\boxed{V_D = 0 \text{ for } I_D > 0 \text{ and } I_D = 0 \text{ for } V_D < 0.}$$

$$I_D = \frac{10 - 0}{10k\Omega} = 1mA.$$

For V = -10 V, $\boxed{-10V = V_D - 10^4 I_D = 0 \text{ since } I_D = 0 \text{ for } V_D < 0.}$

Constant voltage drop diode model

2. Constant Voltage Drop Model



$$\boxed{V_D = V_{on} \text{ for } I_D > 0 \text{ and } I_D = 0 \text{ for } V_D < V_{on}.}$$

$$I_D = \frac{10 - V_{on}}{10k\Omega}.$$

Diode Current - Mathematical Model

$$\boxed{i_D = I_i + I_s = I_s \cdot \left(e^{qv_D/nkT} - 1\right)} .$$

Reverse saturation component (I_s) is independent of the junction potential. I_s doubles for every 10^o increase in temperature, near room temperature.

n - ideality factor (1 to 2) q - electron charge $(1.6x10^{-19}C)$

v_D - diode voltage k - Boltzmann constant $\left(1.38x10^{-23}\frac{J}{K}\right)$

T - absolute temperature

Reverse biases: $\boxed{i_D \approx -I_s \quad \text{for} \quad v_D \ll \frac{nkT}{q} = nV_T}$. Zero V: $\boxed{i_D = 0}$.

Forward biases: $\boxed{i_D = I_s \cdot e^{qv_D/nkT} \quad \text{for} \quad v_D \gg nV_T}$. (usually $4V_T \approx 0.1V$)

Diode Temperature Coefficient

$$\boxed{i_D = I_s \cdot \left(e^{qv_D/nkT} - 1\right) \Rightarrow v_D = V_T \cdot \ln\left(\frac{i_D}{I_s} + 1\right) \approx \frac{kT}{q} \cdot \ln\left(\frac{i_D}{I_s}\right).}$$

$$\boxed{\frac{dv_D}{dT} = \frac{k}{q} \cdot \ln\left(\frac{i_D}{I_s}\right) - \frac{kT}{q}\frac{1}{I_s} \cdot \frac{dI_s}{dT} = \frac{v_D}{T} - \frac{V_T}{I_s} \cdot \frac{dI_s}{dT} = \frac{v_D - V_{G0} - 3V_T}{T} \text{ in } \frac{V}{K}.}$$

$i_D \gg I_s$; $I_s \approx n_i^2$ and $I_s \approx BT^3 \cdot e^{-E_G/kT}$.

For example, v_D = 0.65 V, E_G = 1.12 eV and V_T = 0.025V.

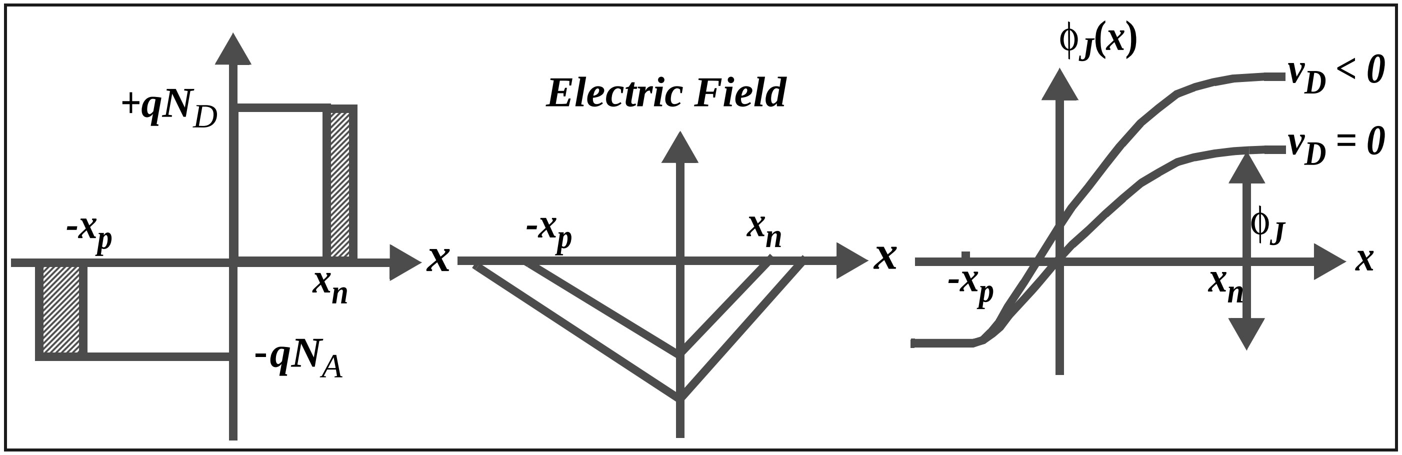
$$\boxed{\frac{dv_D}{dT} = \frac{v_D - V_{G0} - 3V_T}{T} = \frac{0.65 - 1.12 - 3(0.025)}{300} = -1.82 \ \frac{mV}{K}}. \qquad V_{G0} = \frac{E_G}{q}$$

Explain how it is used to make a thermometer.

Diode Breakdown Under Reverse Bias

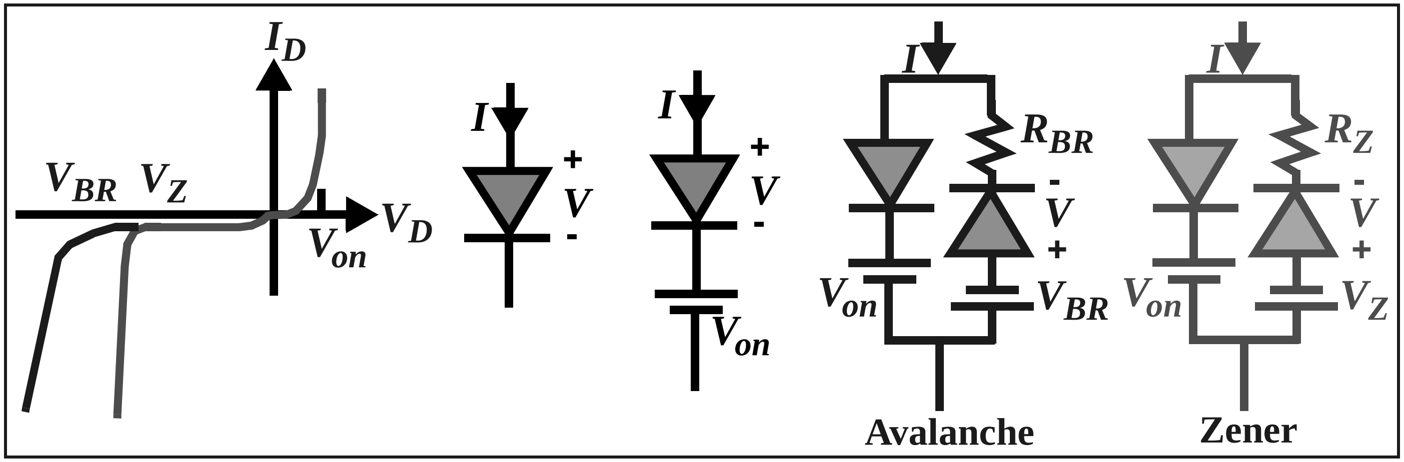
$$_J = \phi_J + v_R \quad for \quad (v_R > 0).$$

$$w_d = x_n + x_p = \sqrt{\frac{2\varepsilon_{Si}}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\phi_J + v_R)}$$



Zener Breakdown - occurs only in heavily doped diods. The heavy doping results in narrow depletion regions. Reverse bias causes tunneling between ***CB*** and ***VB*** with ***I*** increasing rapidly. The breakdown voltage (V_Z) can vary from a few volts to 100's of V. Zener diodes are used to maintain a constant ***V*** for varying ***I'*s**. Used in voltage regulators. Also V_Z increases as ***T*** decreases.

Diode Breakdown Under Reverse Bias

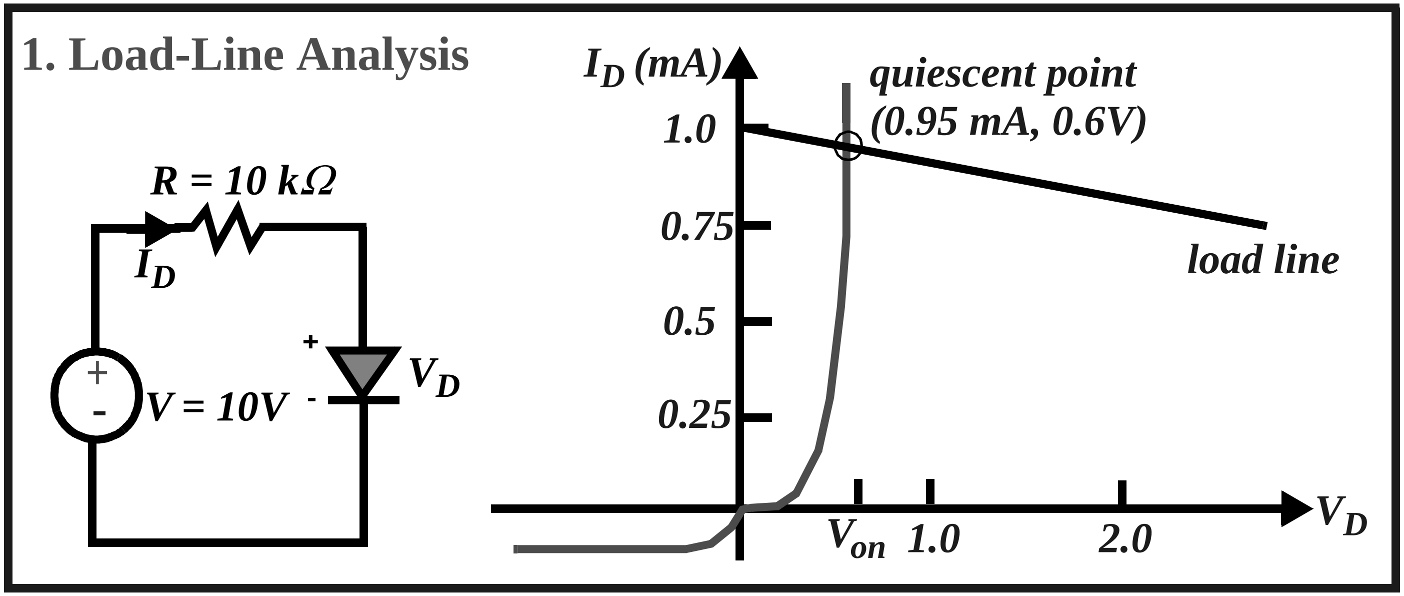


Avalanche Breakdown - occurs at high voltages $V > V_Z$. Here, carriers gain sufficient energy from E-field to knock electron-hole pairs from covalent bonds. Also V_Z increases as T increases.

Diode Circuit Analysis

1. Graphical analysis using load line.
2. Analysis with mathematical model of diode.
3. Simplified analysis using ideal diode model.
4. Simplified analysis using constant voltage drop model.

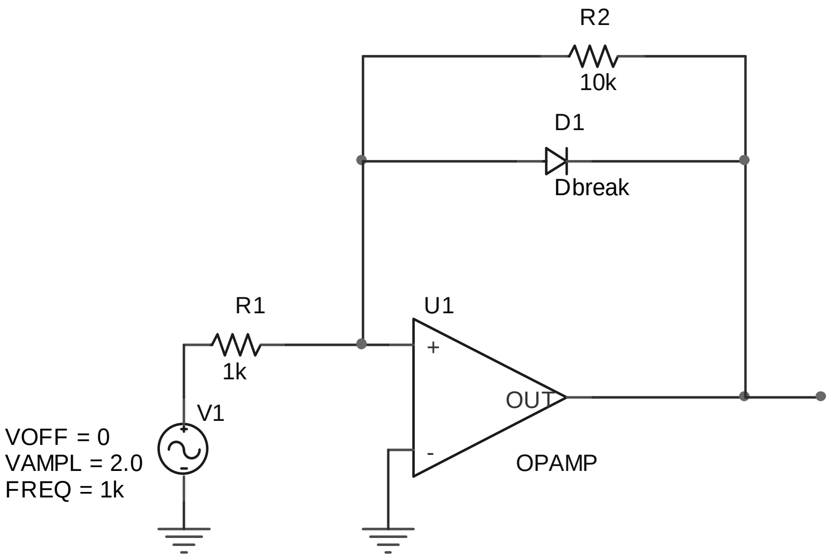
1. Graphical analysis using load line

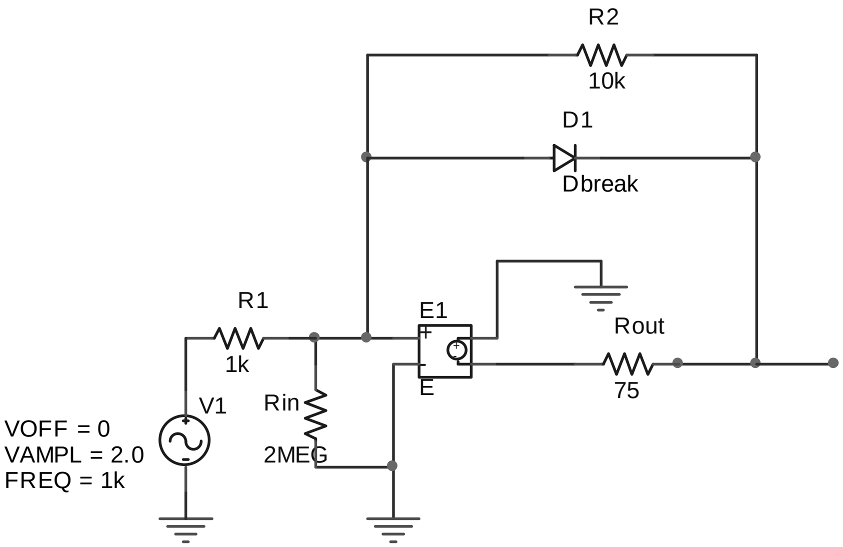


$$V = I_D R + V_D \qquad .V_D = 0 \Rightarrow I_D = \frac{V}{R}; I_D = 0 \Rightarrow V_D = V$$

Quiescent point is the intersection of the diode's I-V and the load line. This gives the operating point of the circuit.

PSPICE EXAMPLE





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*Libraries:
* Local Libraries :
* From [PSPICE NETLIST] section of C:\Program Files\OrcadLite\PSpice\PSpice.ini file:
.lib "nom.lib"
*Analysis directives:
.TRAN  0 10m 0 0.1u
.PROBE V(*) I(*) W(*) D(*) NOISE(*)
.INC ".\example4-SCHEMATIC1.net"
**** INCLUDING example4-SCHEMATIC1.net ****
* source EXAMPLE4
```

PSPICE EXAMPLE (Cont'd)

```
D_D1         N00162 N00115 Dbreak
E_E1        0 N01347 N00162 0 200000
R_Rout        N01347 N00115  75
R_Rin        0 N00162  2MEG
V_V1         N00351 0
+SIN 0 2.0 1k 0 0 0
R_R2         N00162 N00115  10k
R_R1         N00351 N00162  1k

**** RESUMING example4-SCHEMATIC1-Example4Profile.sim.cir ****
.END
****     Diode MODEL PARAMETERS
****************************************************************************
        Dbreak
         IS   10.000000E-15
        RS      .1
       CJO  100.000000E-15
```

PSPICE EXAMPLE (Cont’d)