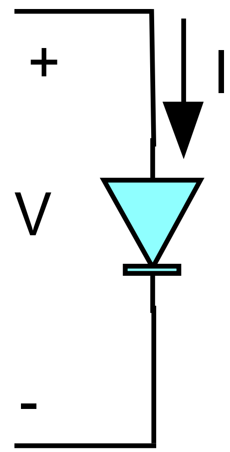
ECE 342
Electronic Circuits

Lecture 4
Diode Models

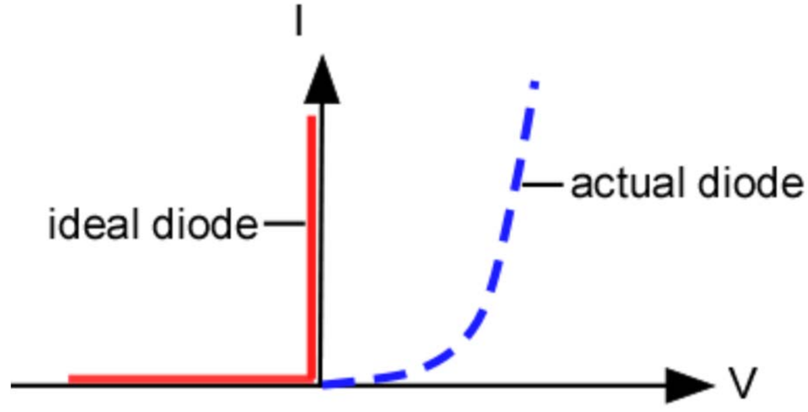
Jose E. Schutt-Aine
Electrical & Computer Engineering
University of Illinois
jesa@illinois.edu

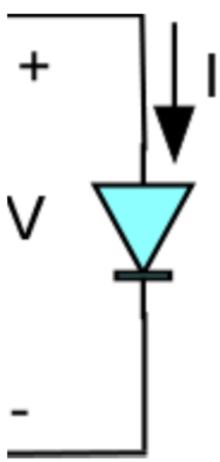
The Diode

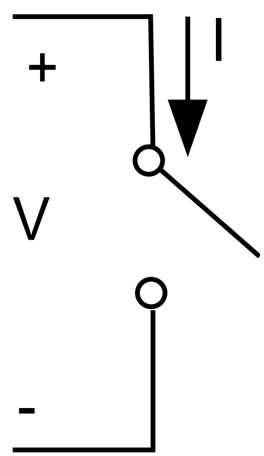


- **Diode Properties**
  - Two-terminal device that conducts current freely in one direction but blocks current flow in the opposite direction.
  - The two electrodes are the anode which must be connected to a positive voltage with respect to the other terminal, the cathode in order for current to flow.

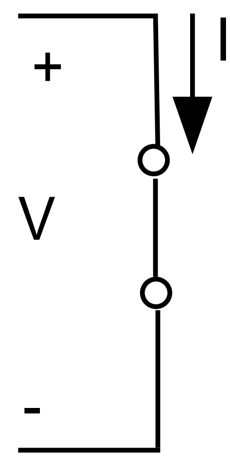
Ideal Diode Characteristics





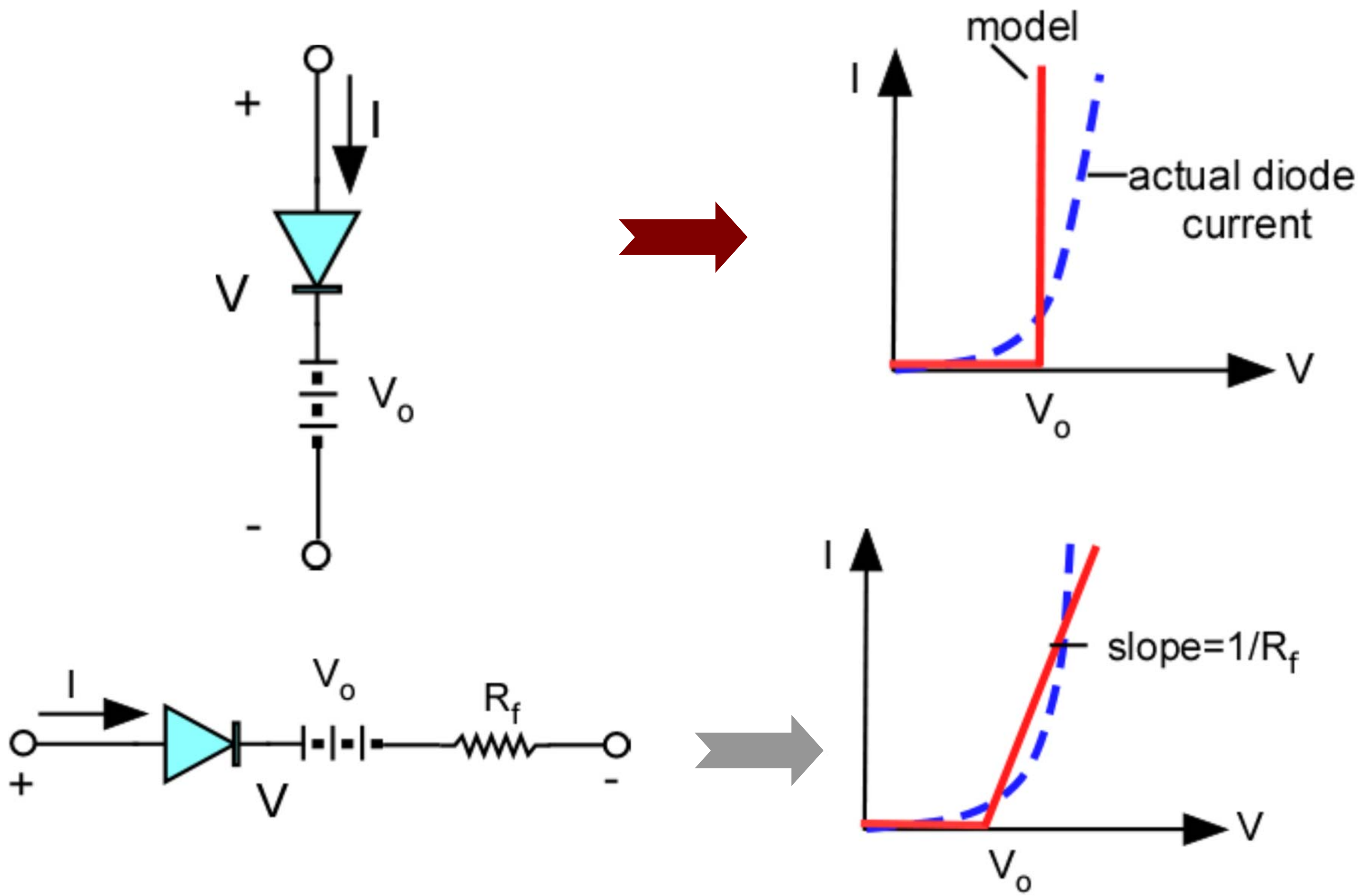


V < 0
OFF



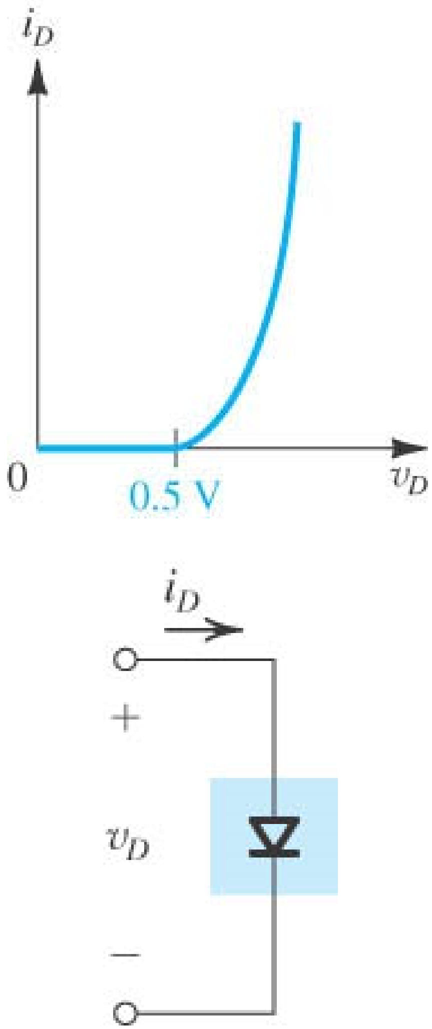
I > 0
ON

Ideal Diode Characteristics

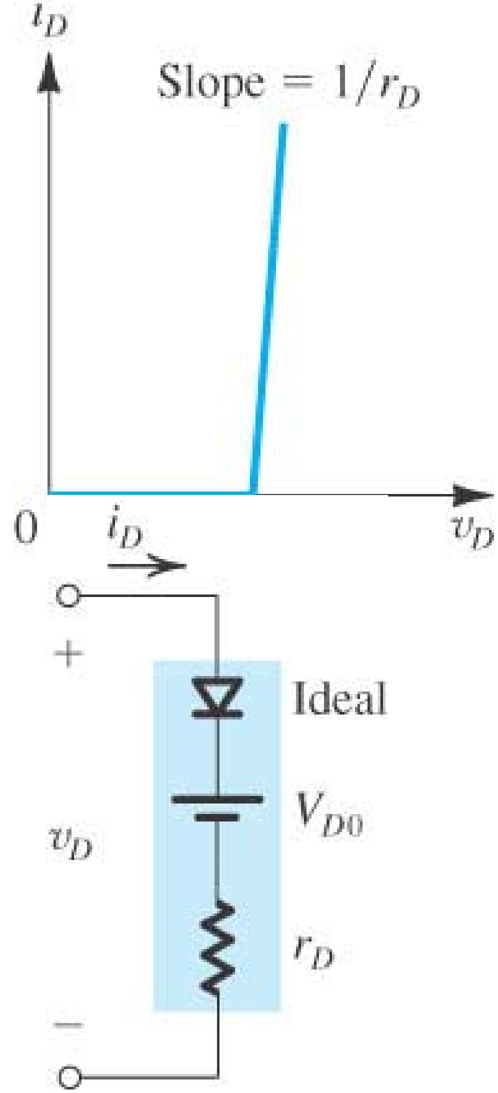


Diode Models

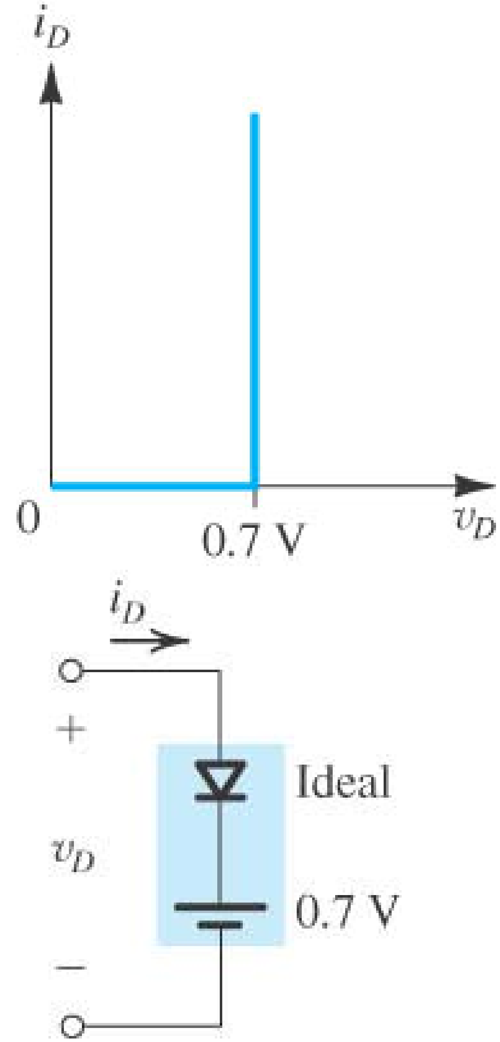
Exponential



Piecewise Linear

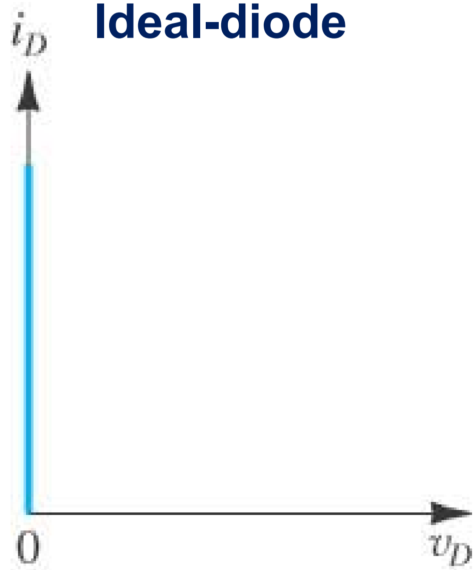


Constant-Voltage-Drop

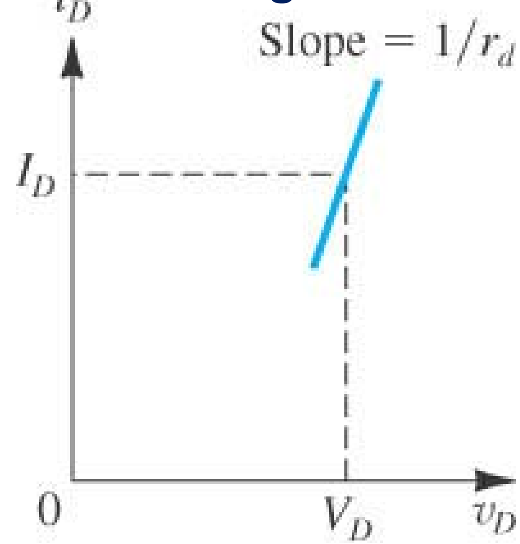


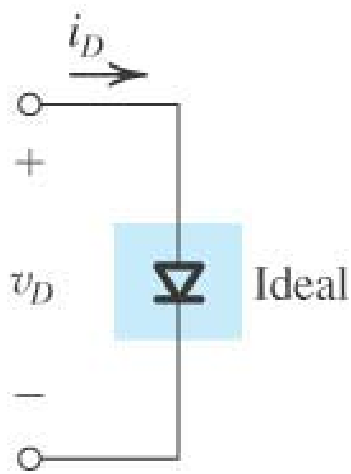
Diode Models

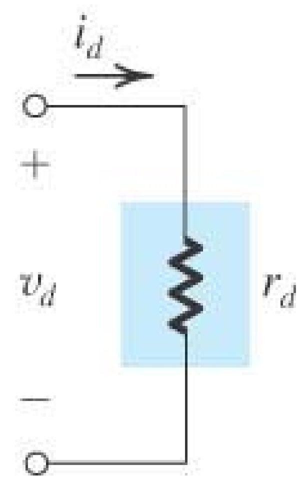
Ideal-diode



Small-signal



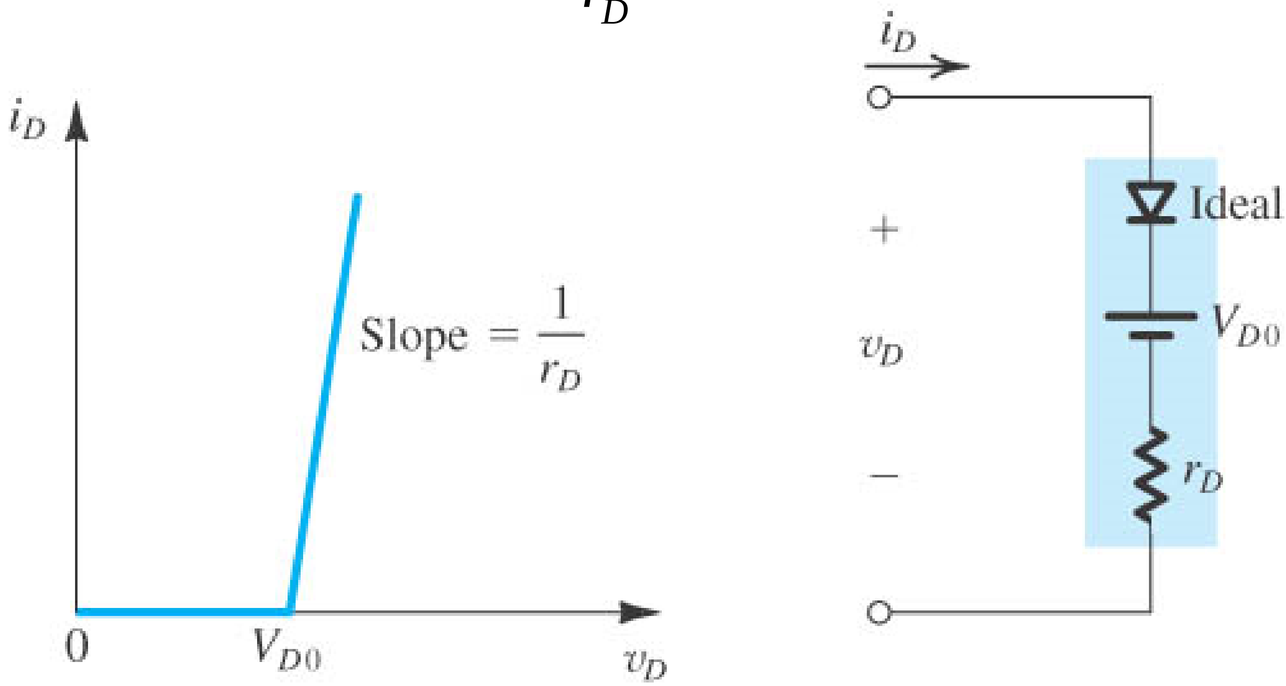




Piecewise-Linear Model

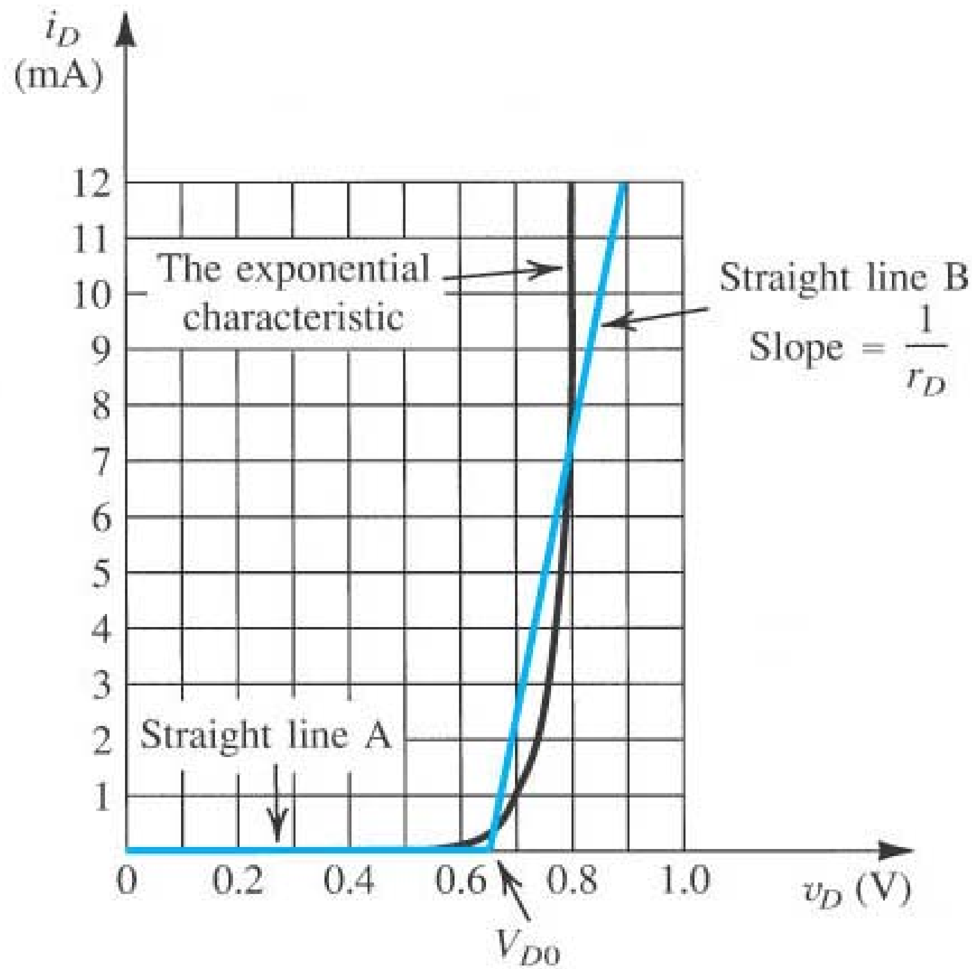
$$\text{for } v_D \le V_{D0}:\ i_D = 0$$

$$\text{for } v_D \ge V_{D0}:\ i_D = \frac{1}{r_D}\left(v_D - V_{D0}\right)$$



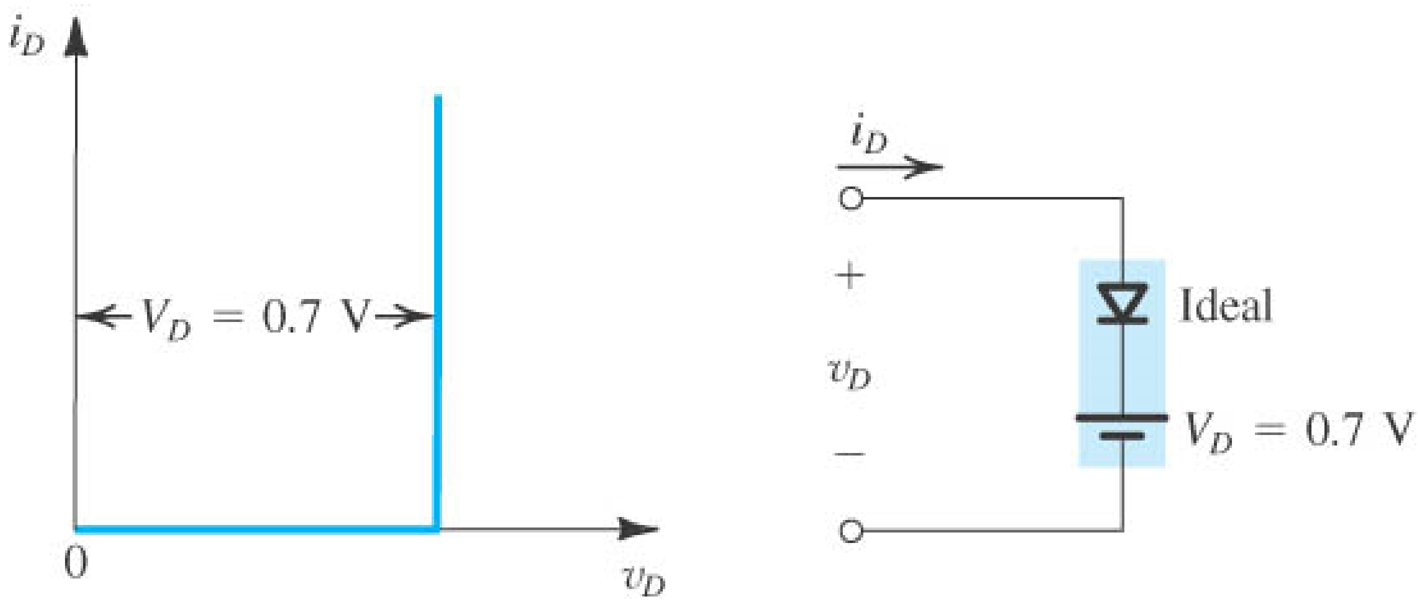
(a) (b)

Piecewise-Linear Model

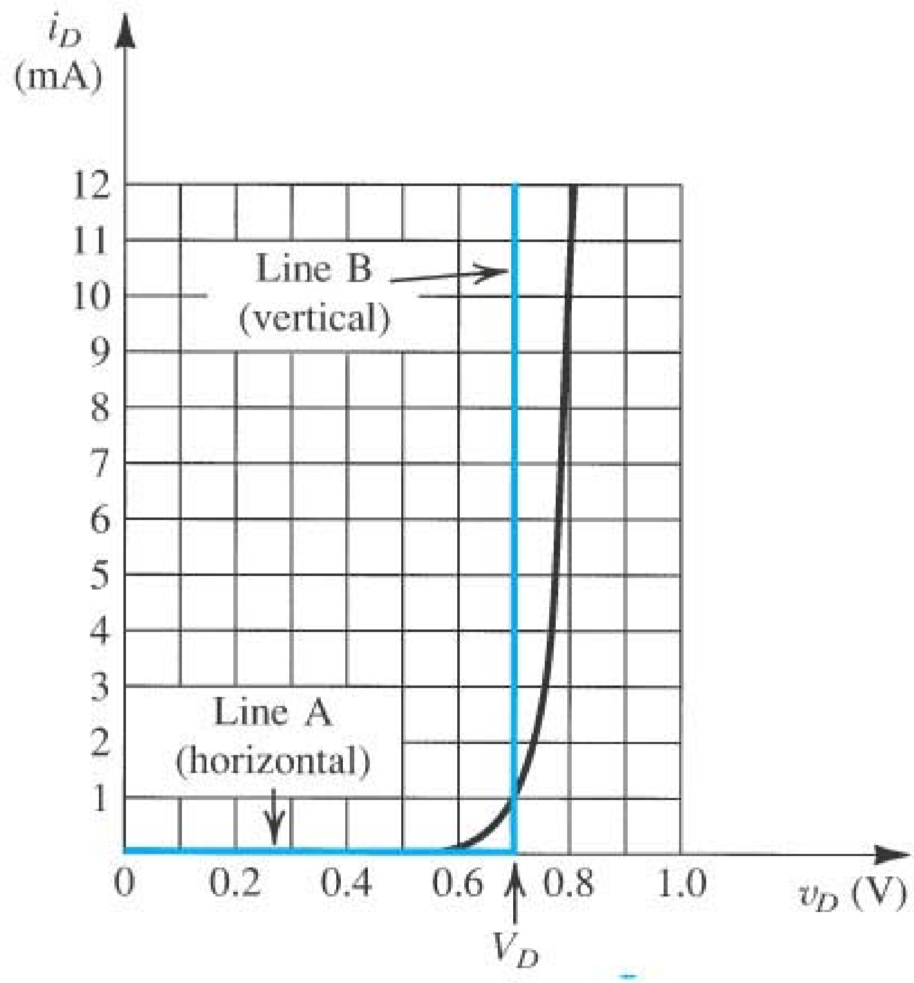


Constant-Voltage-Drop Model

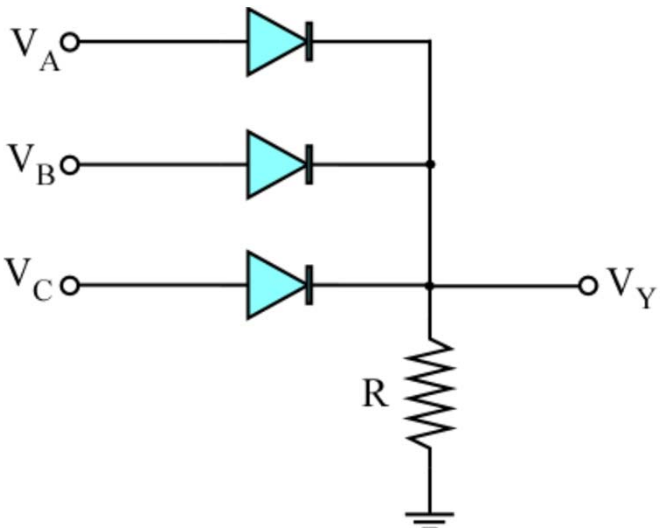
$$for\ i_D > 0:\ v_D = 0.7\,V$$

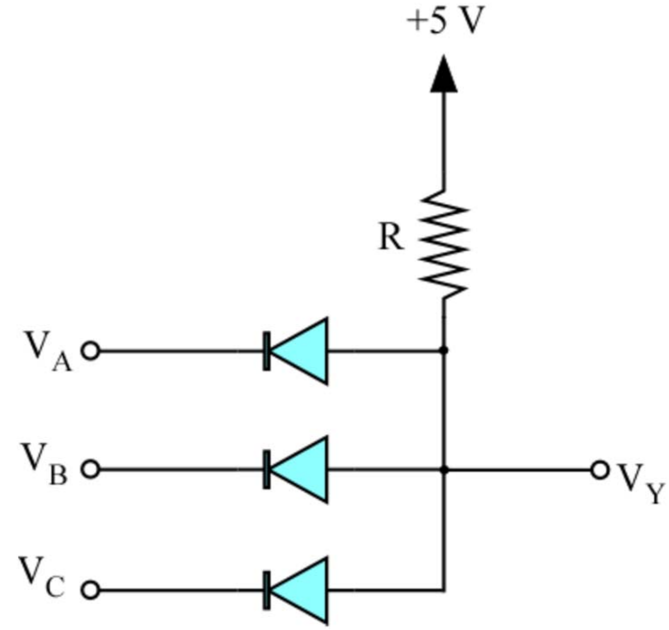


Constant-Voltage-Drop Model



Diodes Logic Gates





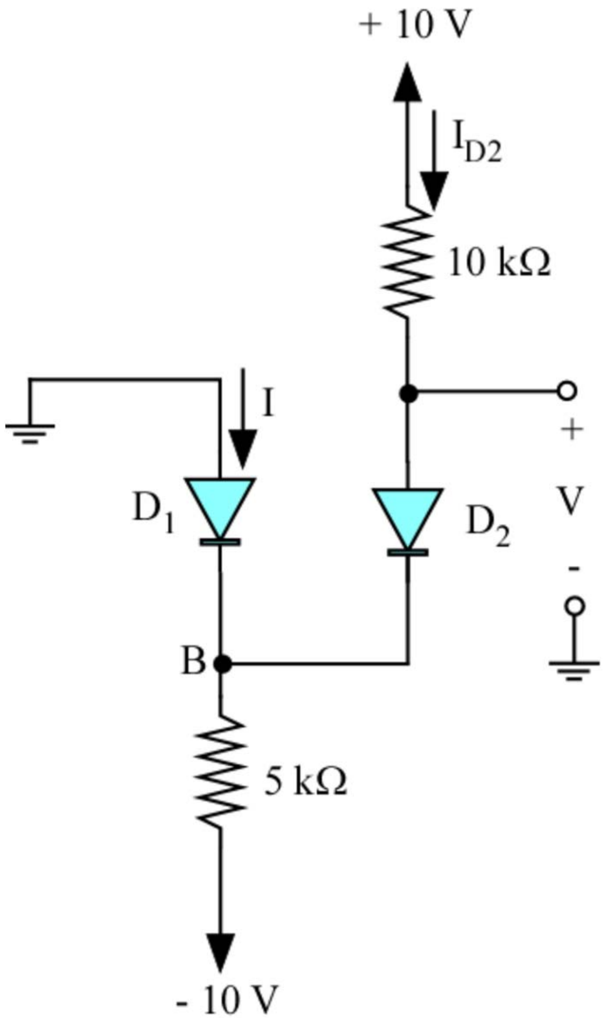
OR Function

$$Y = A + B + C$$

AND Function

$$Y = A \cdot B \cdot C$$

Diode Circuit Example 1



IDEAL Diodes

Assume both diodes are on; then

$$V_B = 0 \quad and \quad V = 0$$

$$I_{D2} = \frac{10-0}{10} = 1\, mA$$

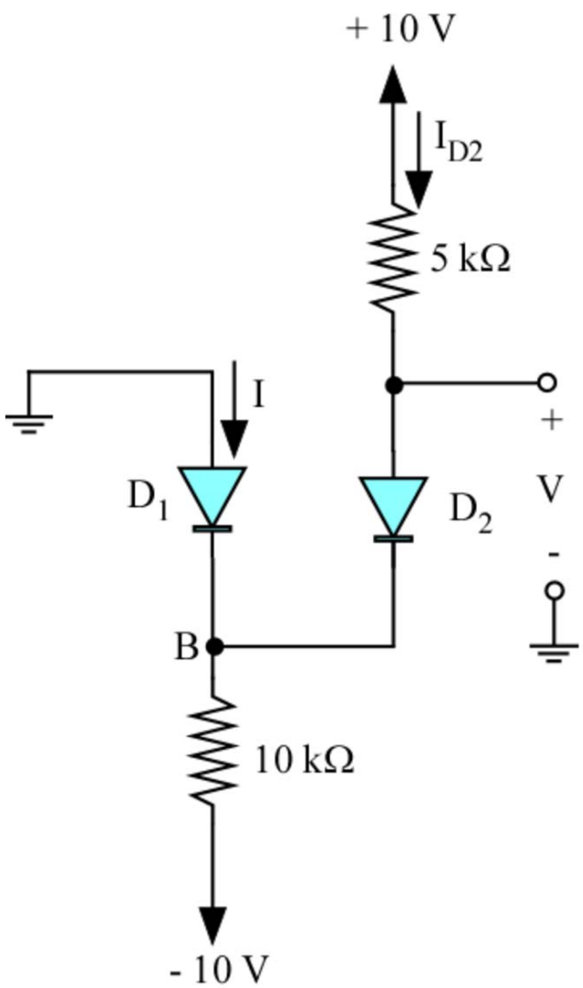
At node B

$$I + 1 = \frac{0-(-10)}{5} \Rightarrow I = 1\, mA, V = 0\, V$$

D_1 is conducting as originally assumed

Diode Circuit Example 2

IDEAL Diodes



Assume both diodes are on; then

$$V_B = 0 \quad and \quad V = 0$$

$$I_{D2} = \frac{10-0}{5} = 2\, mA$$

At node B

$$I + 2 = \frac{0-(-10)}{10} \Rightarrow I = -1\, mA \Rightarrow wrong$$

original assumption is not correct …

assume D_1 is off and D_2 is on

$$I_{D2} = \frac{10-(-10)}{15} = 1.33\, mA$$

$$V_B = -10 + 10 \times 1.33 = +3.3\, V$$

D_1 is reverse biased as assumed

Example

The diode has a value of I_S = 10^{-12} mA at room temperature (300° K)

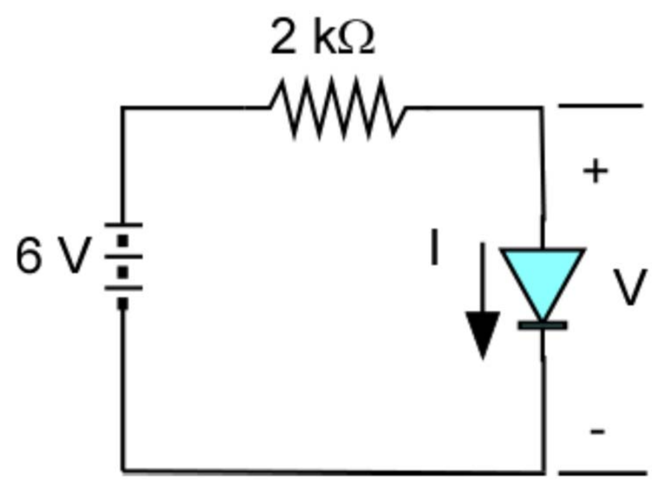
(a) Approximate the current I assuming the voltage drop across the diode is 0.7V

(b) Calculate the accurate value of I

(c) If I_S doubles for every 6° C increase in temperature, repeat part (b) if the temperature increases by 40° C

(a) The resistor will have an approximate voltage of 6-0.7 = 5.3 V. Ohm's law then gives a current of

$$I = \frac{5.3}{2} = 2.65\ mA$$



(b) The current through the resistor must equal the diode current; so we have

$$I = \frac{6-V}{2}(resistor\ current) \qquad I = I_S e^{V/V_T}\ (diode\ current)$$

Example (cont'd)

$$\frac{6-V}{2}=10^{-12}e^{V/0.026}$$

Nonlinear equation ➔ must be solved iteratively
Solution: V = 0.744 V

Using this value of the voltage, we can calculate the current

$$I=\frac{6-V}{2}=\frac{6-0.744}{2}=2.63\ mA$$

When the temperature changes, both I_s and V_T will change. Since $V_T=kT/q$ varies directly with T, the new value is:

$$V_T(340)=V_T(300)\times\frac{340}{300}=0.0295$$

Example (cont'd)

The value of I_s doubles for each 6° C increase, thus the new value of I_s is

$$I_S(340) = I_S(300) \times 2^{40/6} = 1.016 \times 10^{-10}\ mA$$

The equation for I is then

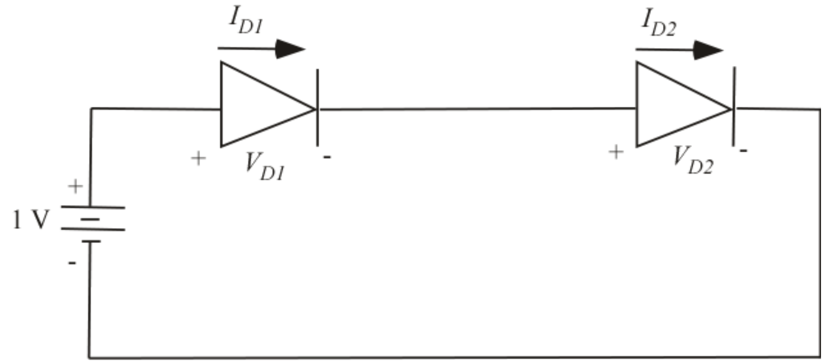
$$I = \frac{6 - V}{2} = 1.016 \times 10^{-10} \times e^{V/0.0295}$$

Solving iteratively, we get

$$V = 0.640\,V \quad and \quad I = 2.68\,mA$$

Example

Two diodes are connected in series as shown in the figure with I_{s1} $=10^{-16}$ A and $I_{s2}=10^{-14}$ A. If the applied voltage is 1 V, calculate the currents I_{D1} and I_{D2} and the voltage across each diode V_{D1} and V_{D2}.



The diode equations can be written as:

$$I_{D1} = I_{S1} e^{V_{D1}/V_T} \qquad I_{D2} = I_{S2} e^{V_{D2}/V_T} \qquad \frac{I_{S1}}{I_{S2}} e^{\frac{V_{D1}-V_{D2}}{V_T}} = \frac{I_{D1}}{I_{D2}} = 1$$

from which $V_{D1} - V_{D2} = -V_T \ln\left(\frac{I_{S1}}{I_{S2}}\right) = -0.12$

Using KVL, we get $V_{D1} + V_{D2} = 1$ from which $V_{D2} = 0.44\text{ V}$ and $V_{D1} = 0.56\text{ V}$

$$I_{D1} = 10^{-16} e^{0.56/0.026} = 0.22\ \mu\text{A} = I_{D2}$$

Small Signal Model

Approximation - valid for small fluctuations about bias point

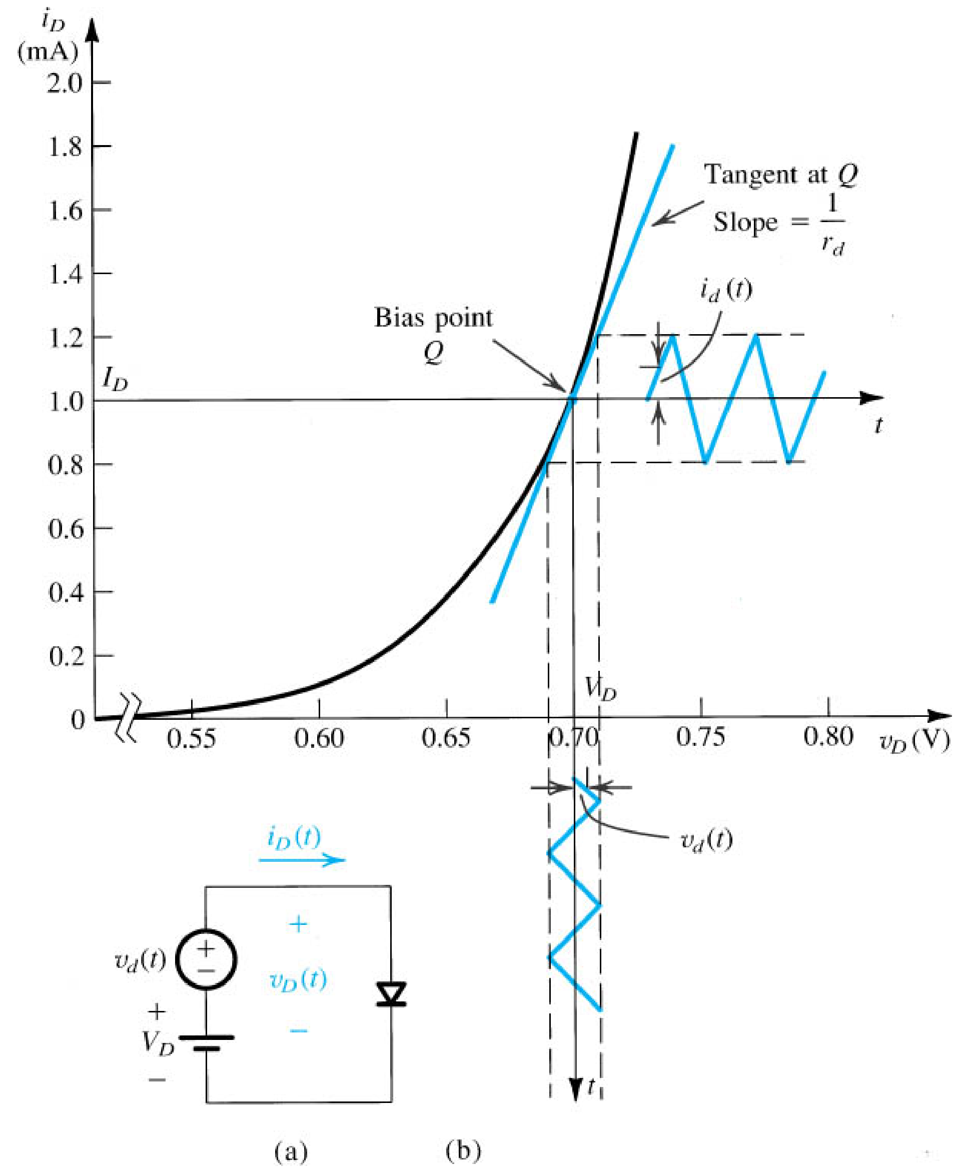
$$i_D = I_D e^{v_d / nV_T}$$

$$r_d = \frac{1}{\left[\frac{\partial i_D}{\partial v_D}\right]_{i_D = I_D}} = \frac{nV_T}{I_D}$$

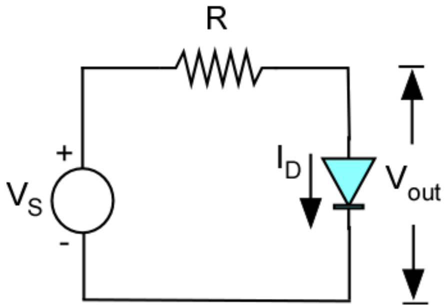
$$i_D = I_D + i_d$$

Total — DC — applied (small)

$$v_D = V_D + v_d$$



Diode Circuits

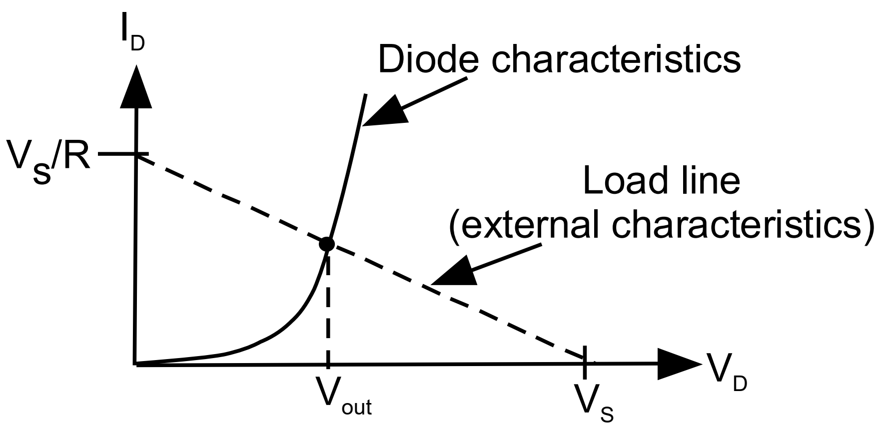


$$V_{out} = V_D$$

$$I_D = I_S\left(e^{V_D/V_T} - 1\right)$$

$$V_S = RI_D + V_D = RI_D(V_D) + V_D$$

Nonlinear transcendental system ➔ Use graphical method

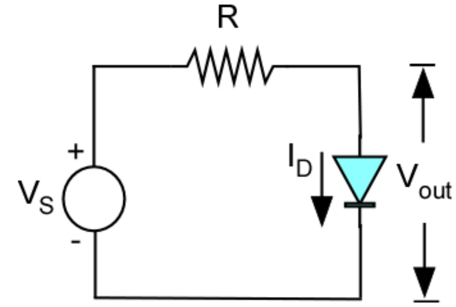


Solution is found at itersection of load line characteristics and diode characteristics

Diode Circuits – Iterative Methods

Newton-Raphson Method

$V_{out} = V_D$



Wish to solve *f(x)=0* for *x*

Use: $x_{k+1} = x_k - \left[f'(x_k) \right]^{-1} f(x_k)$

$$x^{(k+1)} = x^{(k)} - \left[f'(x^{(k)}) \right]^{-1} f(x^{(k)})$$

$$f(V_D) = \frac{V_D - V_S}{R} + I_S \left(e^{V_D/V_T} - 1 \right) = 0$$

$$f'(V_D) = \frac{1}{R} + \frac{I_S}{V_T} e^{V_D/V_T}$$

$$V_D^{(k+1)} = V_D^{(k)} - \frac{\dfrac{V_D^{(k)} - V_S}{R} + I_S \left(e^{V_D^{(k)}/V_T} - 1 \right)}{\dfrac{1}{R} + \dfrac{I_S}{V_T} e^{V_D^{(k)}/V_T}}$$

Where $V_D^{(k)}$ is the value of V_D at the *k*th iteration

Procedure is repeated until convergence to final (true) value of V_D which is the solution. Rate of convergence is quadratic.