Diode Modeling
(Part 2)

Dr. José Ernesto Rayas Sánchez

Some figures of this presentation were taken from the instructional resources of the following textbooks:

A. S. Sedra and K. C. Smith, *Microelectronic Circuits*. New York, NY: Oxford University Press, 2003.

A. R. Hambley, *Electronics: A Top-Down Approach to Computer-Aided Circuit Design*. Englewood Cliffs, NJ: Prentice Hall, 2000.

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Outline

- Temperature effects on I-V characteristics
- Modeling temperature effects on forward characteristics
- Using diodes as temperature sensors
- Modeling temperature effects on reverse characteristics
- Models for small-signal forward region, low/high frequency
- Models for small-signal reverse region, low/high frequency
- Charge storage effects

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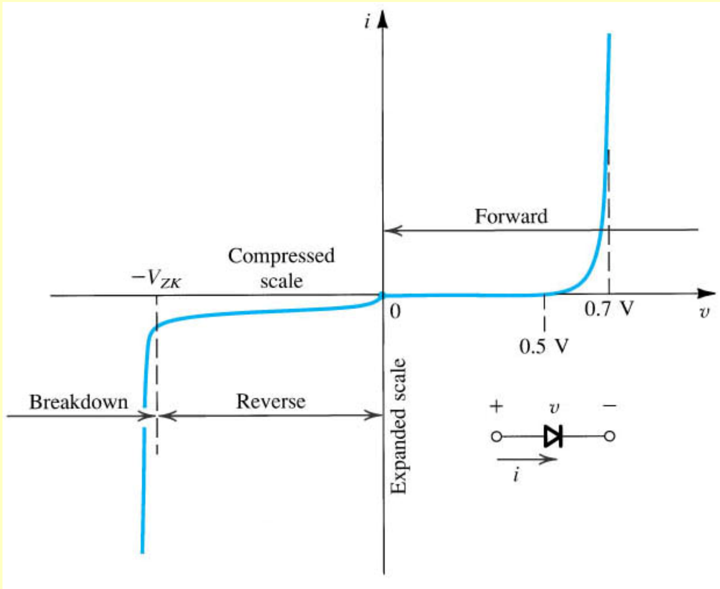
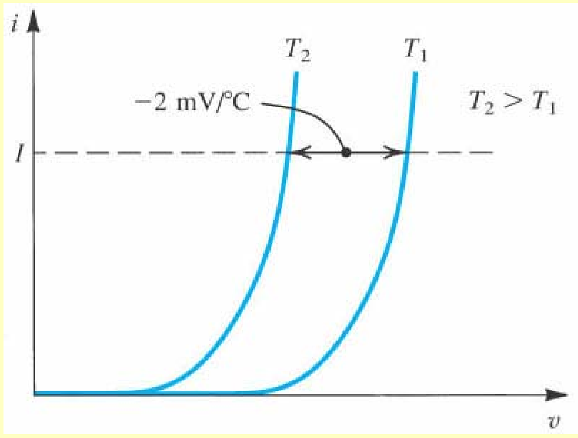
I-V Characteristics



Temperature Effects on Forward Characteristics



- For a constant i_D, v_D decreases linearly with temperature
- For a constant v_D, i_D is very sensitive to temperature; it increases nonlinearly with temperature

Temperature Effects from Shockley Equation

$$i_D = I_S\left(e^{\frac{V_D}{\eta V_T}} - 1\right)$$

In the forward region, $i_D \approx I_S e^{\frac{V_D}{\eta V_T}}$

$$V_T = \frac{kT}{q} \approx \frac{T}{11{,}594}$$

V_T increases linearly with temperature

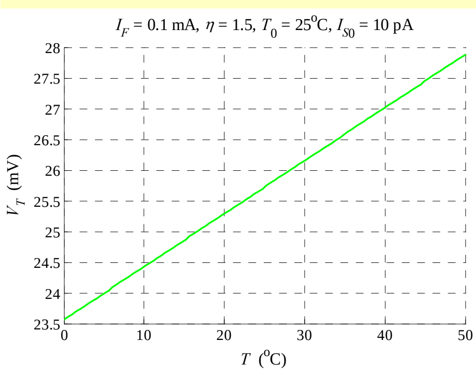
I_S increases nonlinearly with temperature; it increases by 15% per ºC rise in temperature

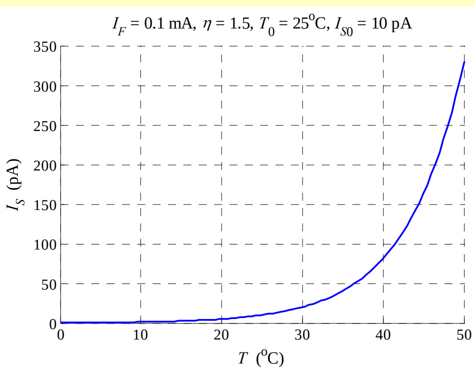
$$I_S(T) = I_S(T_0) \times (1.15)^{(T-T_0)}$$

Plotting v_D VS Temperature (i_D = constant)

$$v_D = \eta V_T \ln\left(\frac{i_D}{I_S}\right) \qquad V_T = \frac{kT}{q} \qquad I_S(T) = I_S(T_0) \times (1.15)^{(T-T_0)}$$

Example:

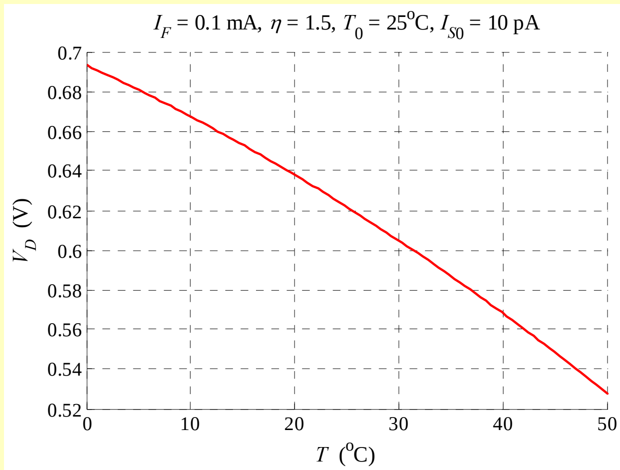




Plotting v_D VS Temperature (i_D = constant)

$$v_D = \eta V_T \ln\left(\frac{i_D}{I_S}\right) \qquad V_T = \frac{kT}{q} \qquad I_S(T) = I_S(T_0)\times(1.15)^{(T-T_0)}$$

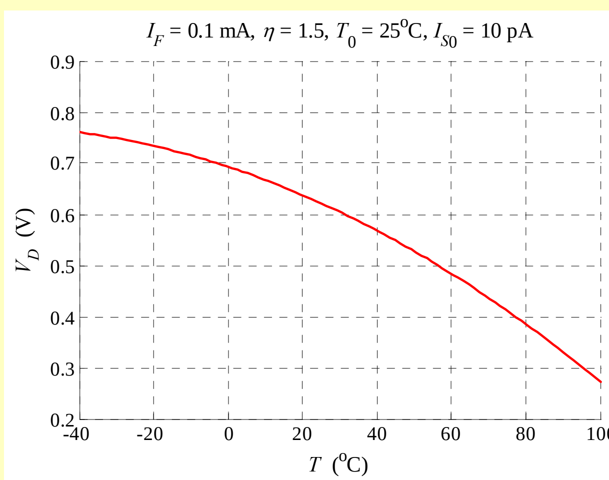
Example:



Plotting v_D VS Temperature (i_D = constant)

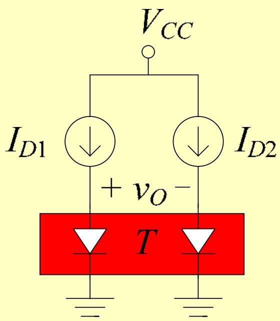
$$v_D = \eta V_T \ln\left(\frac{i_D}{I_S}\right) \qquad V_T = \frac{kT}{q} \qquad I_S(T) = I_S(T_0)\times(1.15)^{(T-T_0)}$$

Example:



Using Diodes as Temperature Sensors

- If temperature variation is large, the forward v_D (keeping I_D constant) is no longer a linear function of temperature
- To measure temperature more effectively (linear sensor):



Assuming identical diodes:

$$v_O = \left[\frac{\eta k}{q} \ln\left(\frac{I_{D1}}{I_{D2}} \right) \right] T$$

Temperature Effects on Reverse Characteristics

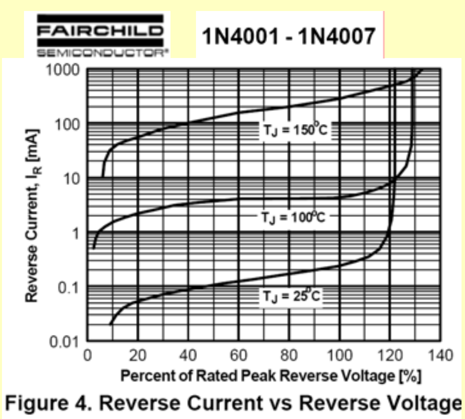
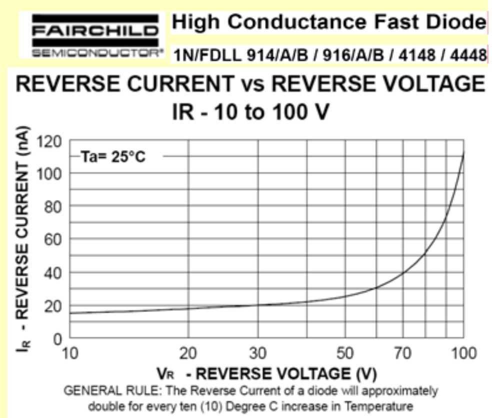


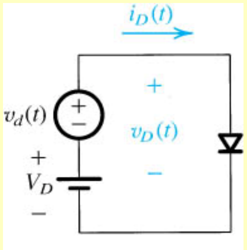
Figure 4. Reverse Current vs Reverse Voltage



I_R increases nonlinearly with temperature; it increases by 100% per 10 ºC rise in temperature

$$I_S(T) = I_S(T_0) \times 2^{\left(\frac{T - T_0}{10}\right)}$$

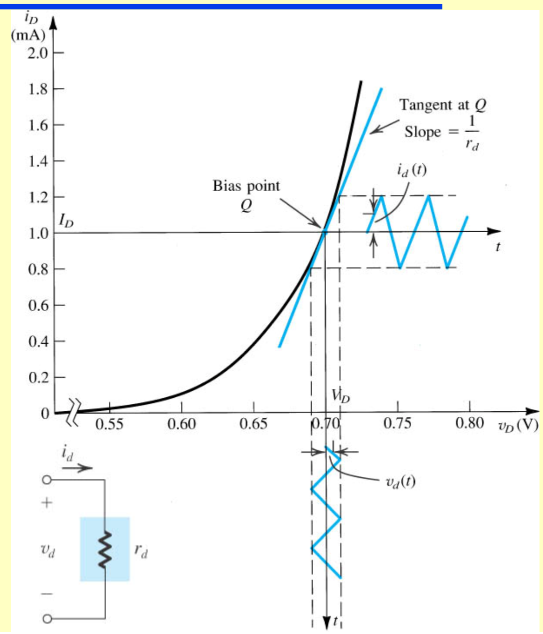
Diode Small-Signal Model – Forward Region



$$i_D \approx I_S e^{\frac{V_D}{\eta V_T}}$$

$$r_d = \left.\frac{\partial v_D}{\partial i_D}\right|_{v_D = V_{DQ}}$$

$$r_d = \frac{\eta V_T}{I_{DQ}}$$



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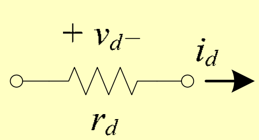
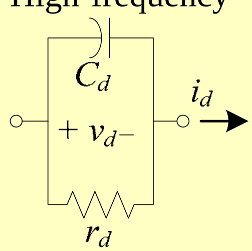
Diode Small-Signal Model – Forward Region

- Low-frequency



$$r_d = \frac{\eta V_T}{I_{DQ}}$$

- High-frequency



$$C_d = K_d I_{DQ}$$

K_d is a constant that depends on the junction cross-section area and diode materials

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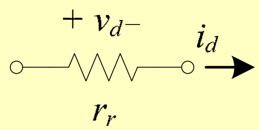
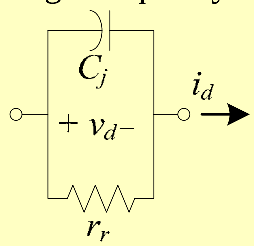
Diode Small-Signal Model – Reverse Region

- Low-frequency



$$r_r = R_R$$

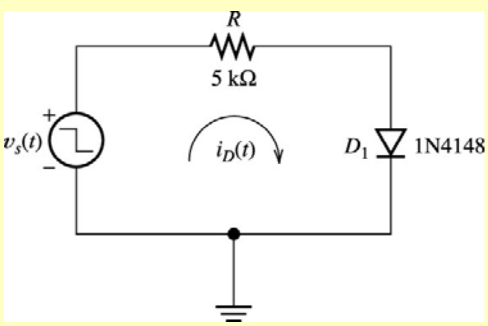
- High-frequency



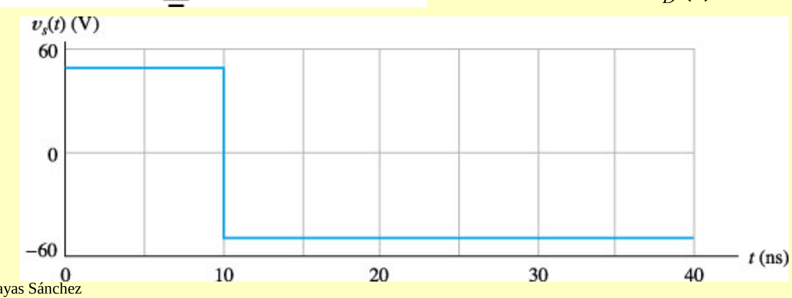
$$C_j = \frac{C_{j0}}{\sqrt{\psi_0 - V_{DQ}}} \qquad (V_{DQ} < 0)$$

- C_{j0} is a constant that depends on the junction cross-section area and diode materials
- ψ_0 is the built-in potential, that depends on the doping characteristics

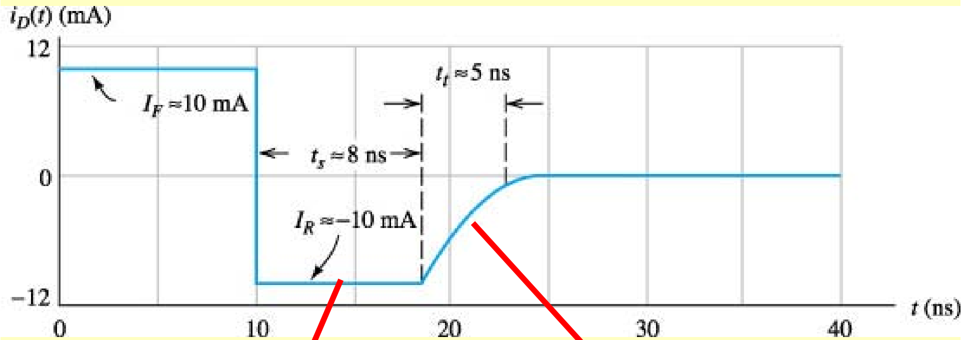
Effects of C_j, C_d, and Charge Storage – Example



$$i_D(t) = ?$$
$$v_D(t) = ?$$



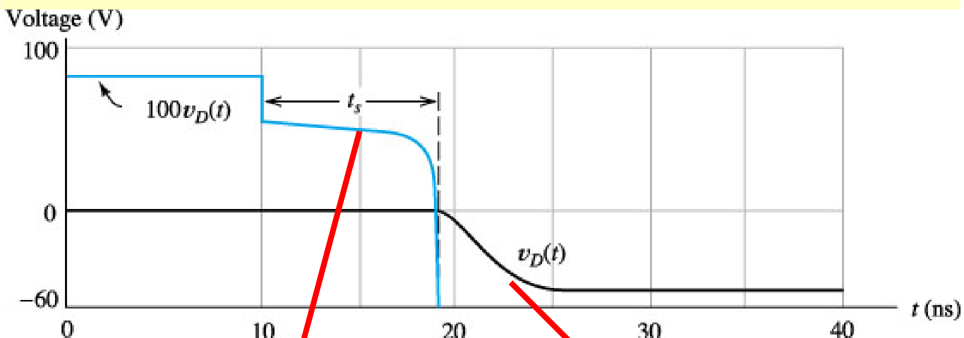
Effects of C_j, C_d, and Charge Storage – Example



Effects of charge storage

Effects of C_j

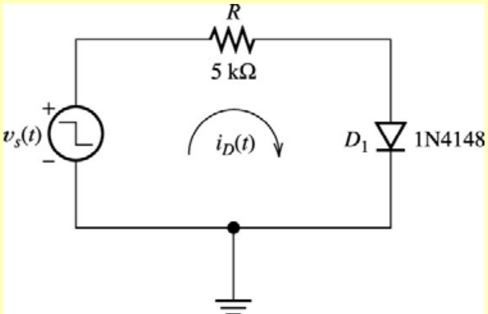
Effects of C_j, C_d, and Charge Storage – Example



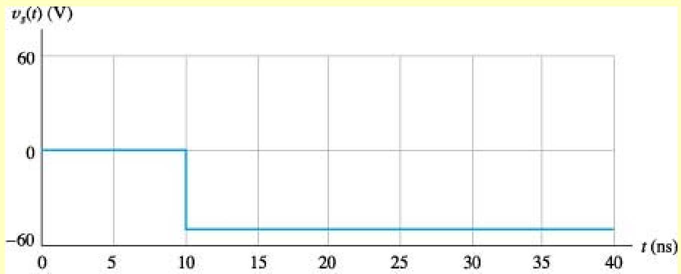
Effects of charge storage

Effects of C_j

Effects of C_j, C_d, and Charge Storage – Ex. 2



$$i_D(t) = ?$$
$$v_D(t) = ?$$



Effects of C_j, C_d, and Charge Storage – Ex. 2

Effects of C_j

(No effects of charge storage)