\[ J_D = J_{np}^{\text{diff}} + J_{pn}^{\text{diff}} \]

\[ I_D = A \left[ J_{np}^{\text{diff}} + J_{pn}^{\text{diff}} \right] \]

\[ X_n \ll W_n \quad X_p \ll W_p \]

\[ I_D = qm_H^2 A \left[ \frac{D_p}{N_d W_n} + \frac{D_n}{N_n W_p} \right] \left( \frac{V_D}{V_{th}} - 1 \right) \]

\[ I_D = I_c \cdot \left( e \right)^{V_D/V_{th} - 1} \]

\[ I_D \approx I_0 \cdot \frac{V_D}{V_{th}} \]
pn Junctions in ICs

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Large-Signal Model

$I_D = I_0 (e^{V_D/V_A} - 1)$
\[ i_D = i_D + I_D \]

**Small-Signal Model:** \( r_d \)

Forward-bias assumed \( \rightarrow V_D = 0.7 \text{ V (approx)} \)

\[ i_D(t) = I_O(e^{v_D(t)/V_{th}} - 1) \approx I_O e^{v_D(t)/V_{th}} \]

Substitute \( v_D(t) = V_D + v_d(t) \):

\[ i_D(t) = I_O e^{(V_D + v_d)/V_{th}} \]

Power Series Expansion

\[ e^x = 1 + x + \frac{1}{2!} x^2 + \frac{1}{3!} x^3 + \ldots \]

Can quantify the limit of the linear approximation

\[ e^{v_d/V_{th}} \approx 1 + \frac{v_d}{V_{th}} + \frac{1}{2!} \left( \frac{v_d}{V_{th}} \right)^2 + \frac{1}{3!} \left( \frac{v_d}{V_{th}} \right)^3 + \ldots \]
Graphical Interpretation

Diffusion Capacitance

Depletion region narrows under forward bias, increasing capacitance to \( C_j = 1.4 \cdot C_{jo} \)

Dominant capacitance is from storage of minority carriers in the diode’s p and n regions: the diffusion capacitance
Physics of Diffusion Capacitance

Diffusion Capacitance

Minority carrier charge storage is proportional to the DC diode current:

\[ C_d = \left( \frac{I_D}{V_{th}} \right) \tau_T = g_d \tau_T \]

where \( \tau_T \) is the diode's \textit{transit time}