The junction capacitance dominates the reactance of a p-n junction under reverse bias; for forward bias, however, the charge storage capacitance \( C_s \) becomes dominant. To calculate the capacitance due to charge storage effects, let us assume that a p-n junction is forward biased with a steady current \( I \).

The stored charge in the injected hole distribution is

\[
Q_s = I_s = q \Delta P_L p_s = qAL_p p_e e^{\eta/\tau} \quad \text{for } V \gg 0.0259 \text{ V} \tag{5-64}
\]

The capacitance due to small changes in this stored charge is

\[
C_s = \frac{dQ_s}{dV} = \frac{q^2}{kT} \Delta P_L p_s e^{\eta/\tau} = \frac{q}{kT} I_s \tag{5-65}
\]

Similarly, we can determine the a-c conductance by allowing small changes in the current:

\[
G_i = \frac{dI}{dV} = \frac{2AL_p p_e}{\tau_s} \frac{d}{dV} (e^{\eta/\tau}) = \frac{q}{kT} I \tag{5-66}
\]

Thus the a-c component of current is

\[
i(a-c) = G_i(a-c) + C_s \frac{d(a-c)}{dt} \tag{5-67}
\]

where

\[
G_i = \frac{q}{kT} I(d-c) \quad \text{and} \quad C_s = G_i \tau_s
\]

The charge storage capacitance can be a serious limitation for forward-biased p-n junctions in high-frequency circuits. As in the case of the switching performance discussed in the two preceding sections, the high-frequency a-c response of a junction can be improved by reducing the carrier lifetime. Since \( C_s \) is proportional to \( \tau_s \), a short hole lifetime can make the forward-biased capacitance of a p-n junction acceptably small for many applications.

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\[
\frac{e}{2kBT} \tau_p J_p(x_n0) + \tau_n J_n(-x_p0) \tag{189}
\]

where the additional factor of 1/2 is explicitly commented and the claim is made that Eq. (188) is in error. This factor can be justified in hand-waving fashion by noting that the charges \( Q_{diff,p} \) and \( Q_{diff,n} \) are like the charges in the two opposite plates of a capacitor, so that the capacitance should be given by the change w.r.t. the applied bias of the average of the electron and hole charges. A more sophisticated and rigorous explanation is given by S. E. Laux and K. Hess, IEEE Trans. Electron. Device vol. 46, no. 2 (February 1999), p. 396. Their argument is based on the observation that — rigorously speaking — the diffusion charge extends also inside the depletion region, so that the integration in Eq. (186) should extend from 0 to \( \infty \), not from \( x_n0 \) (and similarly for the expression for \( Q_{diff,n} \)). Since as \( V_a \) changes charges will leave the depletion region, we will obtain a lower estimate for the charge, and so for the capacitance. In a way, this argument is equivalent to our ‘hand-waving’ argument since both reduce to accounting for the charges throughout the entire junction, not just in the quasi-neutral regions.