ἀ e SPICE model does not give accurate results for the temperature relationship of the current gain β at high currents. For high current levels the current gain decreases sharply with the temperature, as can be seen from Figure 9.3. Also, the knee current parameters IKF, IKR, IKB are temperature dependent, and this is not implemented in the SPICE program.

9.7.2 Second Order Effects

ἀ e current gain β is sometimes modeled indirectly by using different equations for the collector and base currents [4,5]

$$I_C = \frac{I_s(T)}{Q_b}\left(\exp\frac{V_{BE}}{\eta_F V_T} - \exp\frac{V_{BC}}{\eta_R V_T}\right) - \frac{I_s(T)}{\beta_R(T)}\left(\exp\frac{V_{BC}}{\eta_R V_T} - 1\right) - I_{SC}(T)\left(\exp\frac{V_{BC}}{\eta_C V_T} - 1\right) \tag{9.39}$$

where

$$Q_b = \frac{1+\sqrt{1+4Q_X}}{2\left(1-(V_{BC}/V_{AF})-(V_{BE}/V_{AR})\right)} \tag{9.40}$$

and

$$Q_X = \frac{I_s(T)}{I_{KF}}\left(\exp\frac{V_{BE}}{\eta_F V_T} - 1\right) + \frac{I_s(T)}{I_{KR}}\left(\exp\frac{V_{BC}}{\eta_R V_T} - 1\right) \tag{9.41}$$

$$I_B = \frac{I_s}{\beta_F}\left(\exp\frac{V_{BE}}{\eta_F V_T} - 1\right) + I_{SE}\left(\exp\frac{V_{BE}}{\eta_E V_T} - 1\right) + \frac{I_s}{\beta_R}\left(\exp\frac{V_{BC}}{\eta_R V_T} - 1\right) + I_{SC}\left(\exp\frac{V_{BC}}{\eta_C V_T} - 1\right) \tag{9.42}$$

where
- I_{SE} is the base–emitter junction leakage current
- I_{SC} is the base–collector junction leakage current
- η_E is the base–emitter junction leakage emission coefficient
- η_C is the base–collector junction leakage emission coefficient

ἀ e forward transit time τ_F is a function of biasing conditions. In the SPICE program the τ_F parameter is computed by using

$$\tau_F = \tau_{F0}\left[1 + X_{TF}\left(\frac{I_{CC}}{I_{CC}+I_{TF}}\right)\exp\frac{V_{BC}}{1.44V_{TF}}\right] \quad I_{CC} = I_S\left(\exp\frac{V_{BE}}{\eta_F V_T} - 1\right) \tag{9.43}$$

At high frequencies the phase of the collector current shifts. ἀ is phase shift is computed in the SPICE program in the following way:

$$I_C(\omega) = I_C \exp\left(j\omega P_{TF}\tau_F\right) \tag{9.44}$$

where P_{TF} is a coefficient for excess phase calculation.

Noise is usually modeled as the thermal noise for parasitic series resistances, and as shot and flicker noise for collector and base currents

$$\overline{i_R^2} = \frac{4kT\Delta f}{R} \tag{9.45}$$