CHARGE CONTROL MODEL : TIME VARIABLES ARE CONTROLLED CHARGES INSTEAD OF V AND I

ACTIVE BIAS

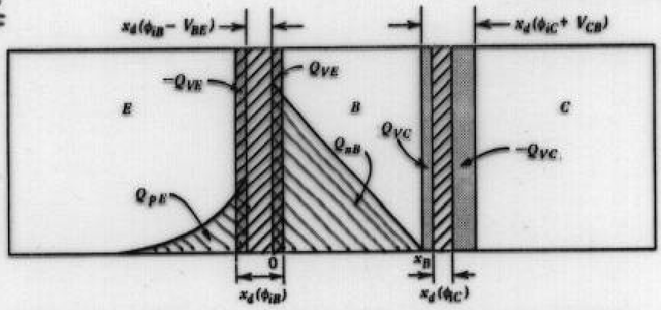


Figure 7.14 Cross section of a prototype transistor showing the locations of the charge components used in charge-control modeling. The charges Q_V represent storage at the edges of the space-charge regions. The cross-hatching indicates the two junction space-charge regions at thermal equilibrium.

EX : STEADY STATE

$$I_C = \frac{Q_F}{\tau_F}$$

$$I_B = \frac{Q_F}{\tau_{BF}}$$

$Q_F > 0$ MAJORITY CH. (IN THE BASE)

$Q_F = Q_{nB} + Q_{pE}$

τ_F : $\bar{e}$ TRANSIT TIME

τ_{BF} : $\bar{e}$ LIFE TIME

SET OF LINEAR EQUATIONS

$$i_C = \frac{Q_F}{\tau_F} - \frac{d}{dt}Q_{VC}$$

← TRANSIENT TERMS ASSOCIATED TO THE VARIATION OF THE SPACE CHARGE

$$i_B = \frac{Q_F}{\tau_{BF}} + \frac{d}{dt}Q_F + \frac{d}{dt}Q_{VE} + \frac{d}{dt}Q_{VC}$$

$$i_E = -Q_F\left(\frac{1}{\tau_F} + \frac{1}{\tau_{BF}}\right) - \frac{d}{dt}Q_F - \frac{d}{dt}Q_{VE}$$

$$\beta_F = \frac{\tau_{BF}}{\tau_F} = \frac{I_C}{I_B}$$

τ_F AND τ_{BF} : OBTAINED FROM MEASUREMENT

$$Q_F = Q_{FO}\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$$

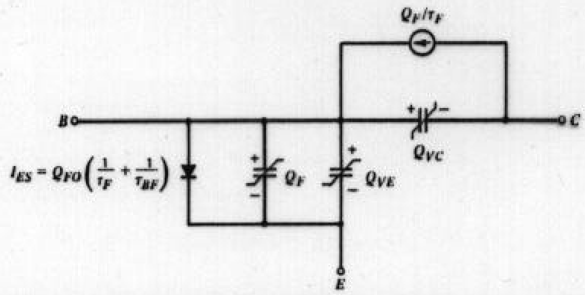
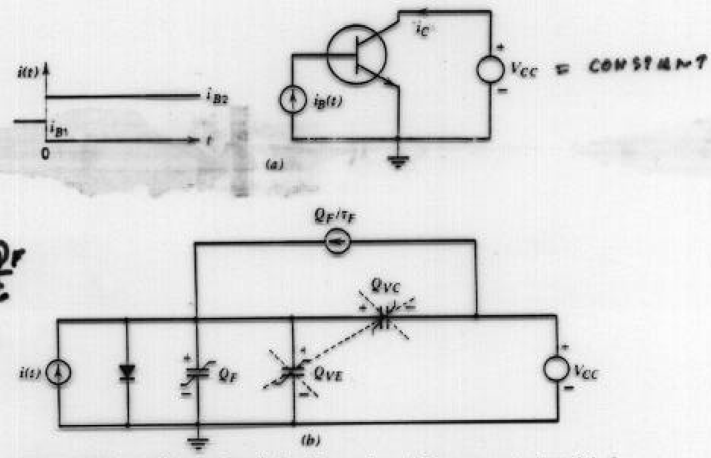


Figure 7.15 Charge-control representation of an *npn* transistor under active bias with junction-charge storage and injected-base charge taken into account.

BASIC PREMISES FOR CHARGE-CONTROL ANALYSIS : τ_F AND τ_{BF} INDEPENDENT OF CHARGE AND VOLTAGE.

BUT NOT EXACTLY TRUE FOR SHORT TIME AFTER SWITCHING.

APPLICATIONS : BJT IN F.A.M.



$$i_B = \frac{Q_F}{\tau_{BF}} + \frac{dQ_F}{dt}$$

what is $i_c(t)$?

Figure 7.16 (*a*) Simple circuit for illustration of charge-control model. (*b*) Equivalent-circuit model. The cancelled elements carry negligible currents.

$$i_C = \beta_F \left[i_{B_2} + (i_{B_1} - i_{B_2}) e^{-t/\tau_{BF}} \right]$$

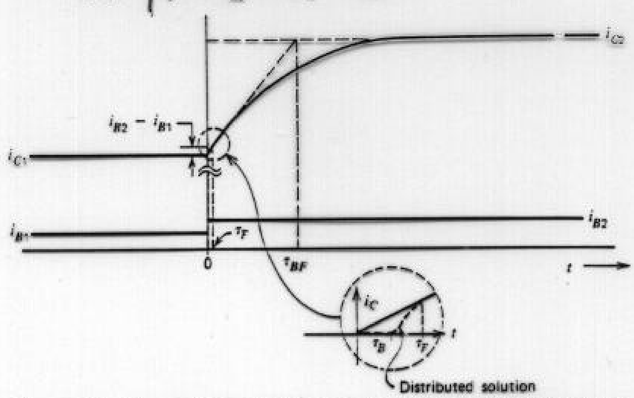
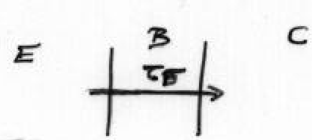


Figure 7.17 Time variation of collector current in the circuit of Figure 7.16 as calculated from the charge-control model.



LARGE SIGNAL MODEL : SWITCHING: CUT-OFF ⟺ SATURATION

Q_F, Q_R : SUPERPOSITION

$$\begin{cases} i_E = -\dfrac{dQ_F}{dt} - Q_F\left(\dfrac{1}{\tau_F} + \dfrac{1}{\tau_{BF}}\right) + \dfrac{Q_R}{\tau_R} - \dfrac{dQ_{VE}}{dt} \\[2ex] i_C = \dfrac{Q_F}{\tau_F} - \dfrac{dQ_R}{dt} - Q_R\left(\dfrac{1}{\tau_R} + \dfrac{1}{\tau_{BR}}\right) - \dfrac{dQ_{VC}}{dt} \\[2ex] i_B = \dfrac{d}{dt}(Q_F + Q_R) + \dfrac{Q_F}{\tau_{BF}} + \dfrac{Q_R}{\tau_{BR}} + \dfrac{d}{dt}(Q_{VE} + Q_{VC}) \end{cases}$$

WITH $Q_F = Q_{F0}\left(e^{\frac{qV_{BE}}{kT}} - 1\right)$

$Q_R = Q_{R0}\left(e^{\frac{qV_{BC}}{kT}} - 1\right)$

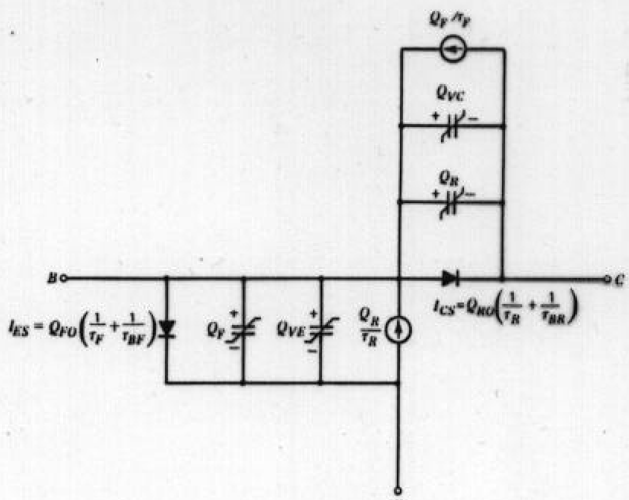
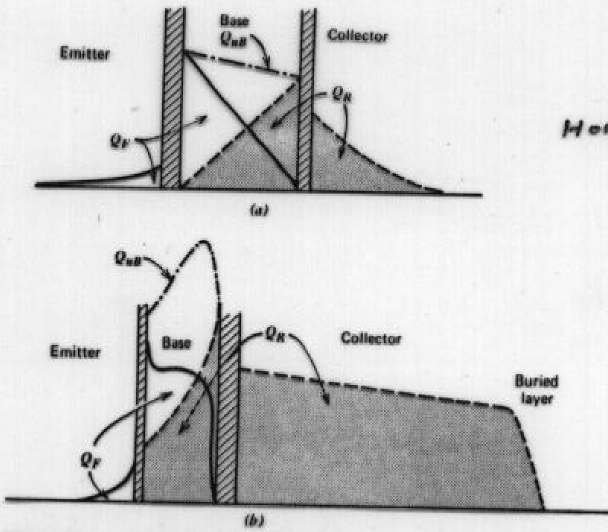


Figure 7.18 Complete bipolar charge-control model for large-signal applications.

$$Q_R = Q_{R0}\left(\exp\left(q\frac{V_{BC}}{kT}\right) - 1\right)$$

SATURATION



HOMOGENEOUS BJT

EPITAXIAL DIFFUSED IC TRANSISTOR.

Figure 7.19 The locations of Q_F and Q_R (dashed lines) for saturated conditions: (*a*) in a homogeneously doped transistor with a lightly doped collector region and (*b*) in an epitaxial diffused *IC* transistor. The dot-dash lines represent the total base charge Q_{nB}

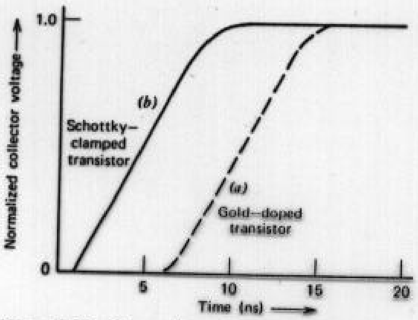


Figure 7.20 Comparison of turn-off times of (*a*) gold-doped and (*b*) Schottky-clamped transistors. The gold-doped device is delayed 7 *ns* for recombination to take place before it begins to change state.[11]