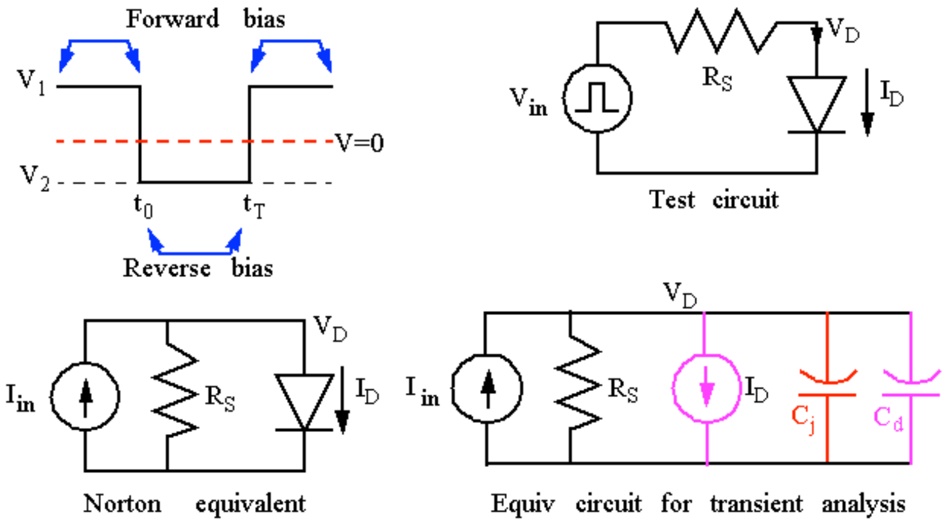
Switching Time of a Diode

- *Switching Time of a diode is the time it takes to switch the diode between two states (ON and OFF states).*



- *Assume R_S is large enough that all current flows through diode in forward bias conditions.*

Switching Time of a Diode

- *For Forward Bias:*
  - *Current source I_D is an ideal diode current source:* $I_D = I_S\left(e^{V_D/\phi_T} - 1\right)$
  - *C_j represents the space-charge (junction capacitance).*
  - *C_d represents the excess minority carrier charge (diffusion capacitance).*
  - *(Note that both of these are small-signal capacitances; to be applicable large-signal analysis, average capacitance values must be used).*

- *For Reverse bias:*
  - *Eliminate the current source I_D and the diffusion capacitance C_d.*

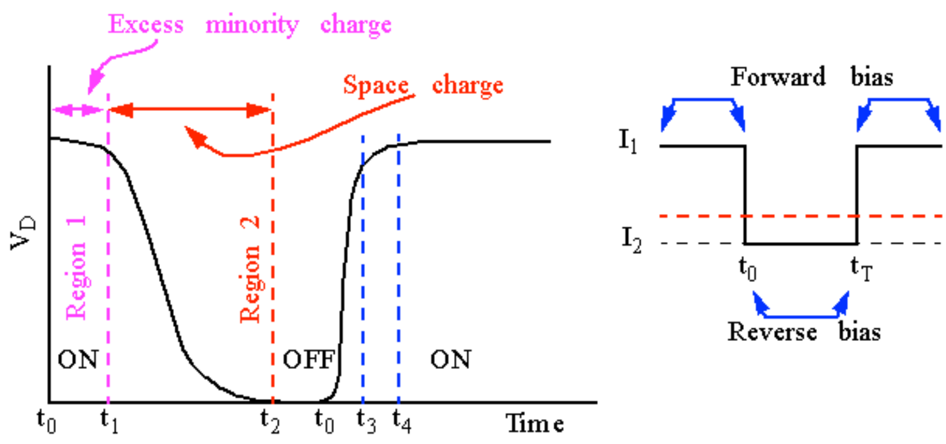
- *Transient response requires finding a solution to:*

$$I_{in} = I_D(t) + (C_d + C_j)\frac{dV_D(t)}{dt}$$

$$I_{in} = I_S(e^{V_D(t)/\phi_T} - 1) + (C_d + C_j)\frac{dV_D(t)}{dt}$$

Switching Time of a Diode

- *Transient response:*
  - *The exponential and the non-linear dependence of C_d and C_j on V_D make this difficult to do by hand.*
  - *Consider the simulated response:*



Switching Time of a Diode

- *Turn-off Transient.*
  - *The turn-off transient, has two operation intervals.*

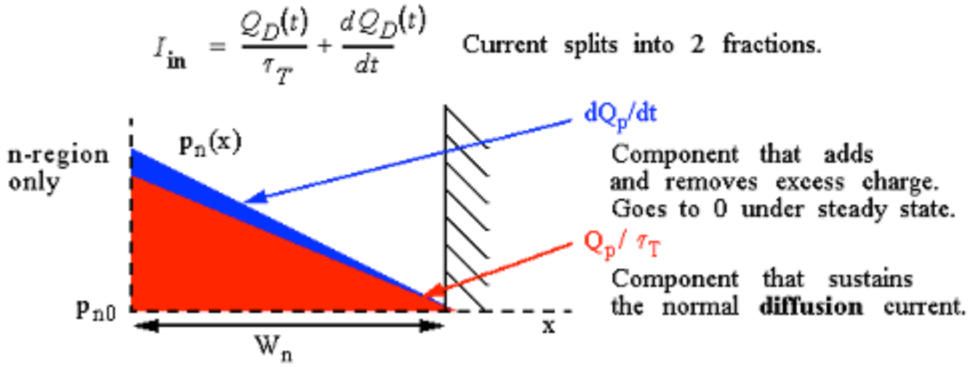
- ***Region 1** :*
  - *Diode is on.*
  - *I_2 removes excess minority charge .*
  - *Voltage drop is small allowing C_j to be ignored since space-charge remains ~constant.*

- ***Region 2** :*
  - *I_D ~= 0 (diode off).*
  - *Space-charge changes while building a reverse-bias over the diode.*
  - *Therefore, C_j dominates performance.*

Derivation of Turn-off Transient.

○ ***Region 1*** *: Removal of excess minority charge .*

▪ *Charge-control expression:*



The term $\frac{dQ_D(t)}{dt}$ represents the current due to the removal of injected carriers from the base region and the term $\frac{Q_D(t)}{\tau_T}$ represents the normal Diffusion current where τ_T is the Base transit time.

○ *Solving this differential equation assuming that:*

$Q_D = I_1 \tau_T$ at time t = 0 or the initial value of Q_D and $I_{in} = I_2$

Where $I_1 \approx \frac{(V_1 - V_D)}{R_S}$ is the current under forward bias and $I_2 = \frac{V_2}{R_S}$

○ *Yields:* $$Q_D(t) = \tau_T \left[I_2 + (I_1 - I_2) e^{-t/\tau_T} \right]$$

○ *The turn-off time is derived by solving for the time t = t_1 (Q_D evaluates to 0):*

$$t_1 = \tau_T \ln\left[\frac{(I_1 - I_2)}{-I_2}\right]$$

○ ***Region 2*** *: Changing the Space Charge.*

▪ *Diode is off, circuit evolves toward steady state.*

$V_D\ (t = \infty) = V_2 = I_2 R_S$

▪ *During this time, a reverse voltage is built over the diode.*
▪ *Therefore, space charge has to be provided.*

- *The change in excess minority charge can be ignored as well as the reverse bias diode current I_d.*
- *This leaves us with a simple RC circuit (red capacitor model shown earlier).*

$I_2 = \frac{V_D(t)}{R_S} + C_j \frac{dV_D}{dt}$ C_j is the average junction capacitance over the voltage range of interest.

- *Assuming the value of V_D at time $t = t_1$ is 0, the solution is the well-known exponential:*

$$V_D(t) = I_2 R_S \left[1 - e^{\frac{-(t-t_1)}{R_S C_j}} \right]$$

- *The 90% point is reached after* ***2.2*** *time-constants of $R_S C_j$.*

$$t_2 - t_1 = 2.2 R_S C_j$$

- ***Derivation of Turn-on Transient.***
  - *Similar considerations hold for the turn-on transient.*
  - *Space Charge :*
    - *The transient waveform for the diode voltage (assume $t = 0$):*

$$V_D(t) = R_S \left[I_1 - (I_2 - I_1) e^{-\frac{1}{R_S C_j}} \right]$$

$$t_3 = R_S C_j \ln\left[\frac{I_1 - I_2}{I_1}\right] \qquad \text{Assuming } V_D = 0$$

  - *Excess charge :*

$$Q_D(t) = I_1 \tau_T \left[1 - e^{\frac{-(t-t_3)}{\tau_T}} \right]$$

  - *It takes* ***2.2*** *time constants for Q_D to reach 90% of its final value.*

$$t_4 - t_3 = 2.2 \tau_T$$