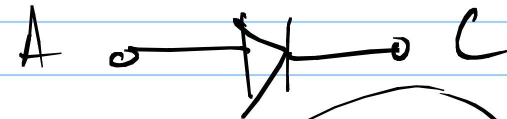
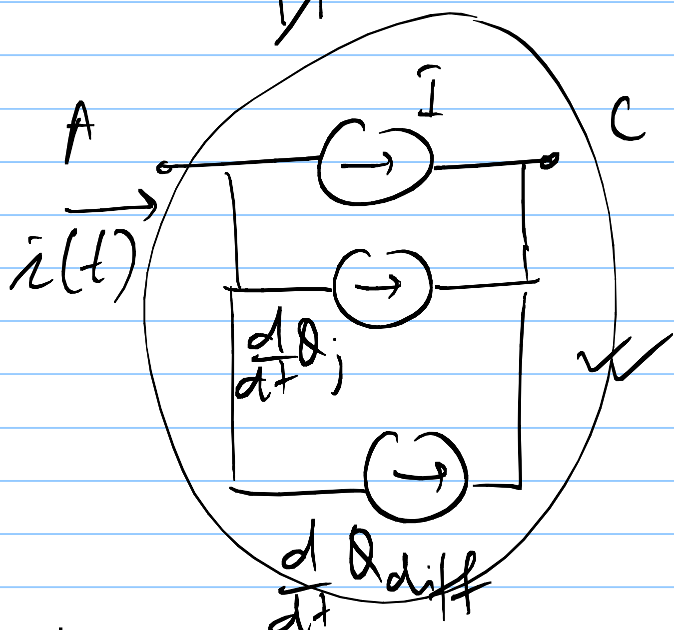
Transients in p-n junction

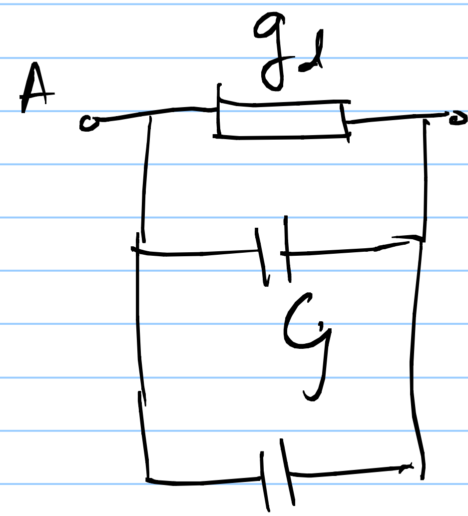
8/10/2014





Large-signal EC
(time domain)

Small-signal EC (freq. domain)

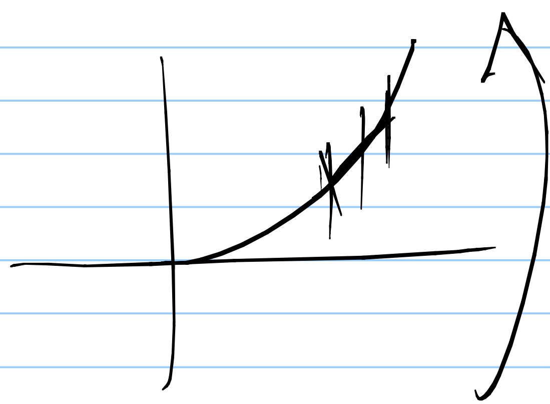


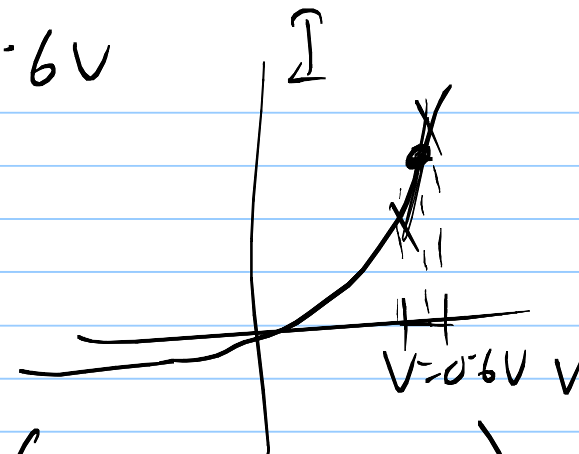
$$C_j = \frac{C_{j0}}{\sqrt{1 - V/V_0}}$$

$$C_{diff} = \tau g_d$$

Bias point $V_f = 0.6V$

$\Delta V = 0.001V$ $\Delta V = 0.1V$





$V_f \Rightarrow (0.5V \text{ to } 0.7V)$

large-signal variation

small-signal variation

$$\boxed{i(t) = I(t) + \cancel{\frac{d}{dt} Q_j(t)} + \frac{d}{dt}\left(Q_{diff}\right)}$$

$$I(t) = I_0\left[e^{V(t)/V_T} - 1\right] = \frac{Q_{diff}}{\tau}$$

$$C_j\left(V(t)\right) = \frac{C_{j0}}{\sqrt{1 - V(t)/V_T}}$$

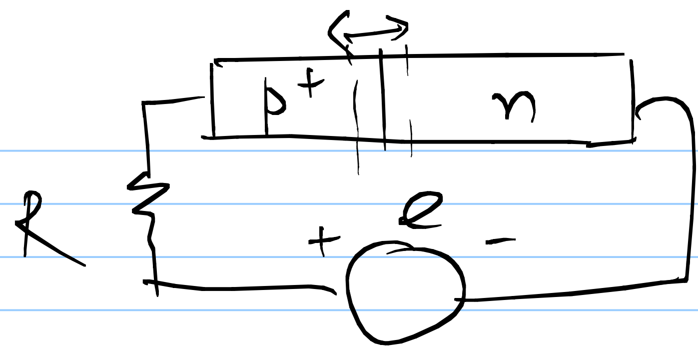
$$\not\Downarrow$$

$$Q_j(t)$$

for p^+n jn.

$$Q_{diff} = Q_p$$

$$\tau = \tau_p$$



$C_j = 1\,fF$

$\Delta V = 1V.$

$I = 1mA$

Charging time for depletion layer capacitance

$$\tau_j = \frac{C_j \Delta V}{I} \approx 10^{-12} \text{ sec.}$$

Dielectric relaxation time $\approx 10^{-12}$ sec.

$i(t)$

$$i(t) = I(t) + \frac{d}{dt} Q_{diff}(t)$$

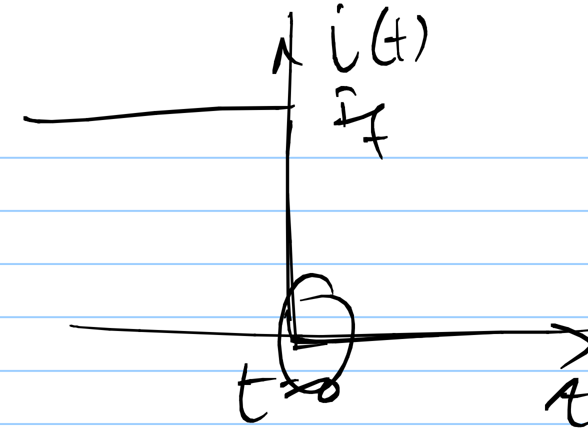
For a p^+n jn:

$$i(t) = \frac{Q_p(t)}{\tau_p} + \frac{d}{dt} Q_p(t)$$

$\Rightarrow$ A diode was in forward bias with $I = I_f$ and suddenly at $t = 0$, current is pulled down to zero.

$i(t) = I_f$ at $t < 0$

$i(t) = 0$ at $t \geq 0$



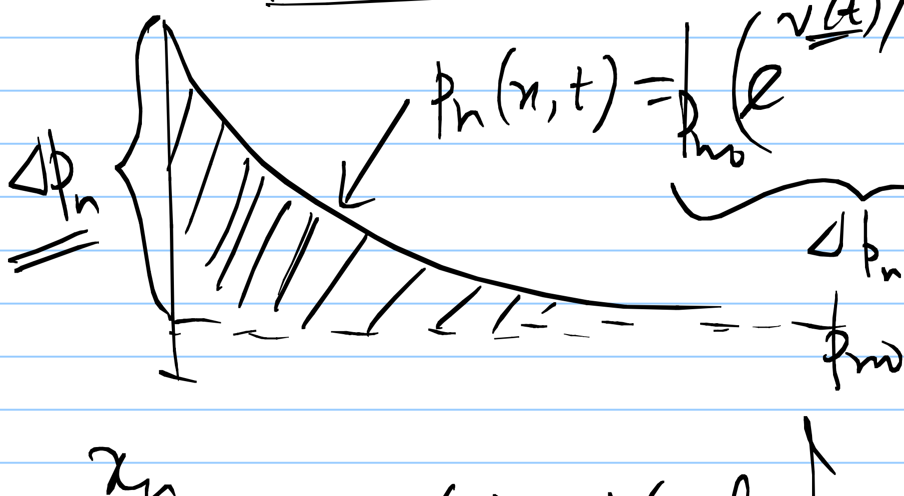
$$i(t) = \frac{Q_p(t)}{\tau_p} + \frac{d}{dt} Q_p(t)$$

$$0 = \frac{Q_p(s)}{\tau_p} + s\,Q_p(s) - \underbrace{Q_p(0)}_{= I_f \tau_p}$$

$$= \frac{Q_p(s)}{\tau_p} + s\,Q_p(s) - I_f \tau_p$$

$$Q_p(s) = \frac{I_f \tau_p}{s + \frac{1}{\tau_p}}$$

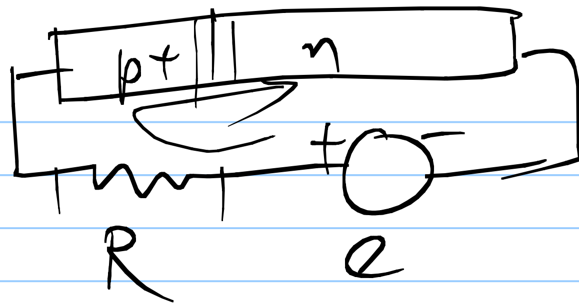
$$\boxed{Q_p(t) = I_f \tau_p e^{-t/\tau_p}} = qA \int_{x_n}^{\infty} p_n(x,t)\,dx$$

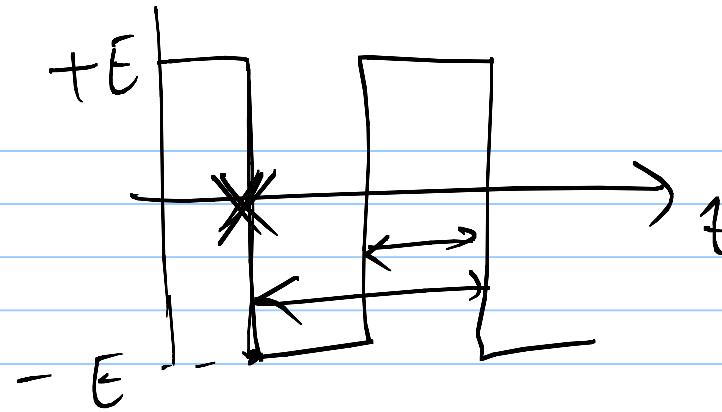


$$p_n(x,t) = \underbrace{p_{no}\left(e^{v(t)/V_T} - 1\right)}_{\Delta p_n(t)} e^{-\frac{(x-x_n)}{L_p}}$$

$$\boxed{Q_p(t) = qA L_p p_{no}\left(e^{v(t)/V_T} - 1\right)}$$

$$v(t) = V_T \ln\left[1 + \frac{I_f \tau_p e^{-t/\tau_p}}{qA L_p p_{no}}\right]$$

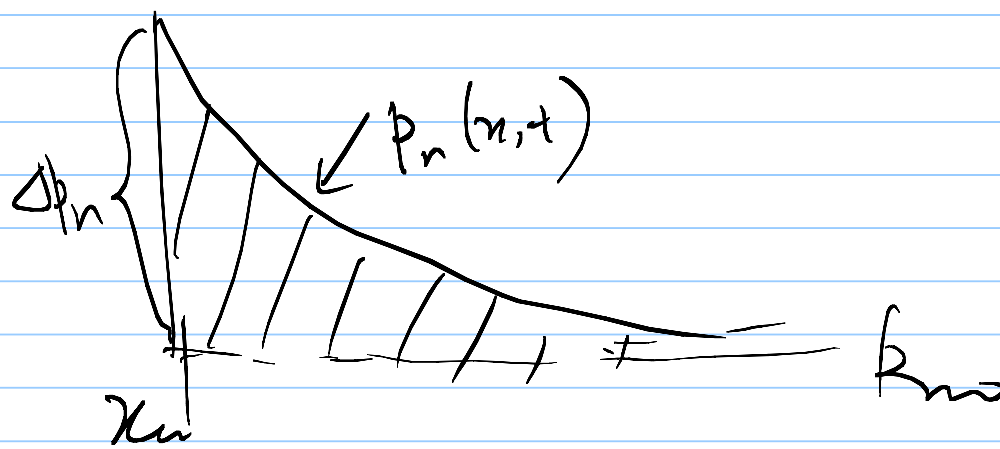


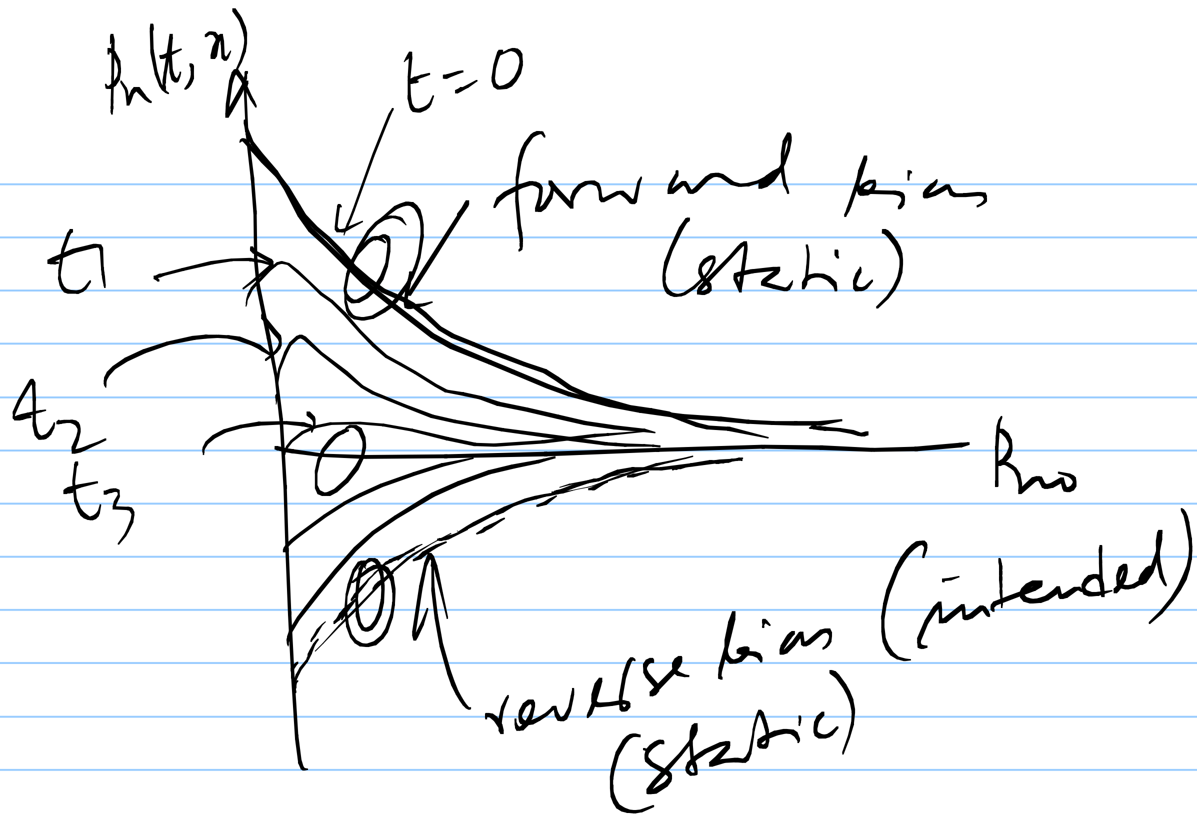


$$i(t) = \frac{Q_p(t)}{\tau_p} + \frac{d}{dt} Q_p(t)$$

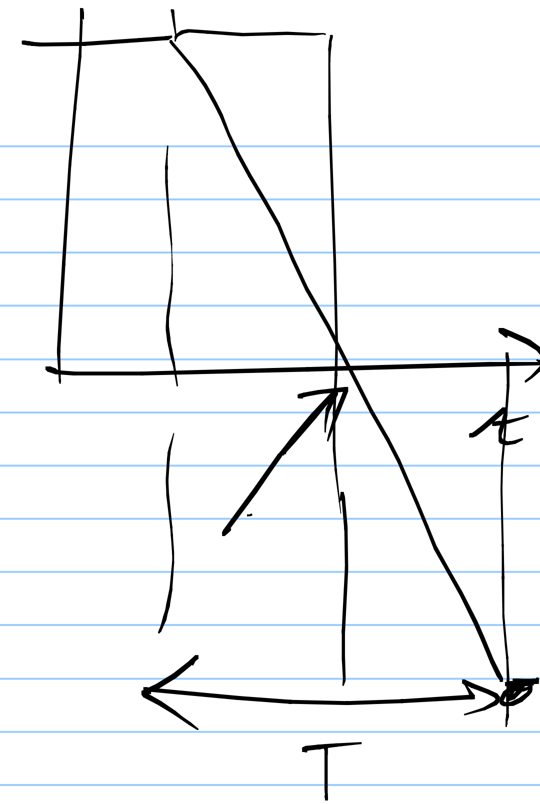
$$I_f \cong E/R$$

$$-I_r \approx -E/R.$$





$p_n(t,x)$
$t=0$
forward bias
(static)
t1
t_2
t_3
p_{n0}
reverse bias (intended)
(static)



t
T

$$i(t) = \frac{Q_p(t)}{\tau_p} + \frac{d}{dt} Q_p(t)$$

$$-\frac{I_r}{s} = \frac{Q_p(s)}{\tau_p} + s\,Q_p(s) - I_f \tau_p$$

$$Q_p(s) = \frac{I_f \tau_p}{s + \frac{1}{\tau_p}} - \frac{I_r}{s\left(s + \frac{1}{\tau_p}\right)}$$

$$Q_p(t) = I_f \tau_p e^{-t/\tau_p} + I_r \tau_p \left(e^{-t/\tau_p} - 1\right)$$

$$= \tau_p \left[-I_r + (I_f + I_r) e^{-t/\tau_p} \right] = qAL_p \Delta p_n(t)$$

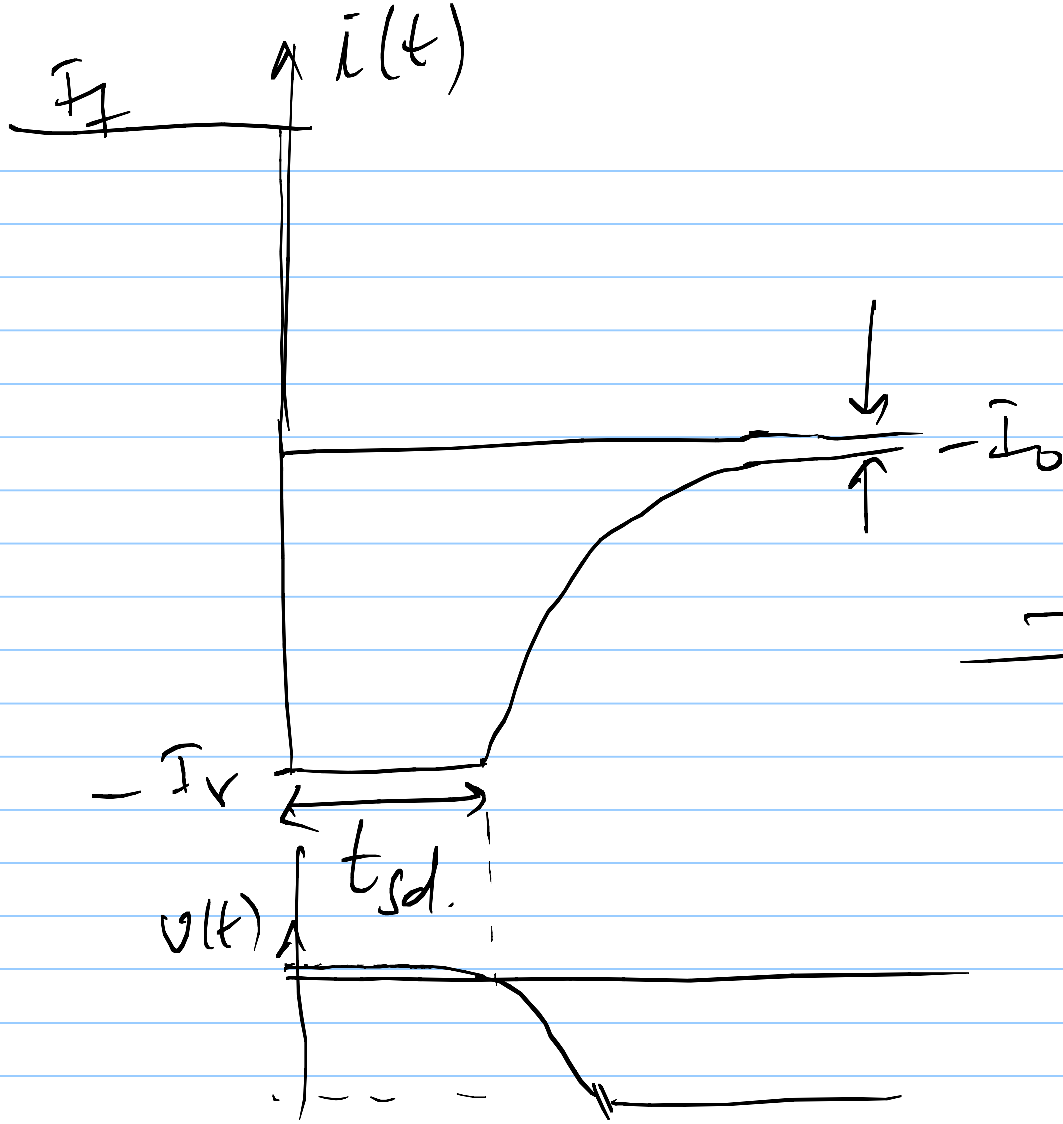
$$\Delta p_n(t) = \frac{\tau_p}{qAL_p}\left[-I_r + (I_f + I_r)e^{-t/\tau_p}\right] = 0$$

$t = t_{sd} \Rightarrow$ storage delay time

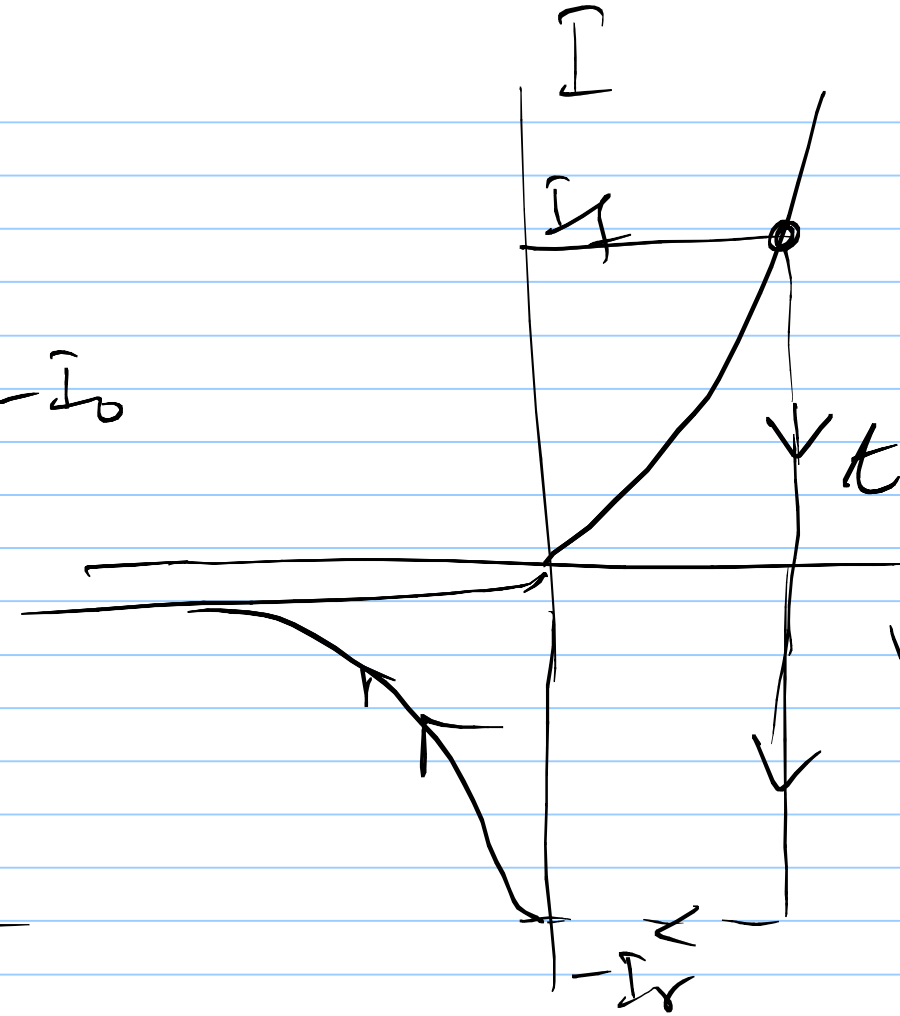
$$t_{sd} = \tau_p \ln\left[\frac{I_f + I_r}{I_r}\right]$$

$$\boxed{p_{n0}\left(e^{v(t)/V_T} - 1\right) = \frac{\tau_p}{qAL_p}\left[-I_r + (I_f + I_r)e^{-t/\tau_p}\right]}$$

$v(t_{sd}) = 0$



i(t)
I_f
$-I_0$
$-I_r$
t_{sd}
v(t)



I
I_f
t
V
$-I_r$