Lecture # 11 — pn junction transients; large-signal analysis

→ Small-signal admittance: (wrapping up from last lecture)

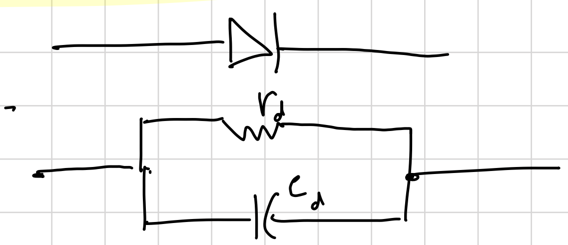
the DC currents

$$Y = g_d + j\omega C_d \qquad g_d = \frac{I_{DQ}}{V_t} = \frac{1}{V_t}\left(I_{po} + I_{no}\right)$$

Where the diffusion cap: $\boxed{C_d = \left(\frac{1}{2V_t}\right)\left(I_{po}\tau_{po} + I_{no}\tau_{no}\right)}$

Equivalent Circuit

- In the ideal case, just consider r_d and C_d:

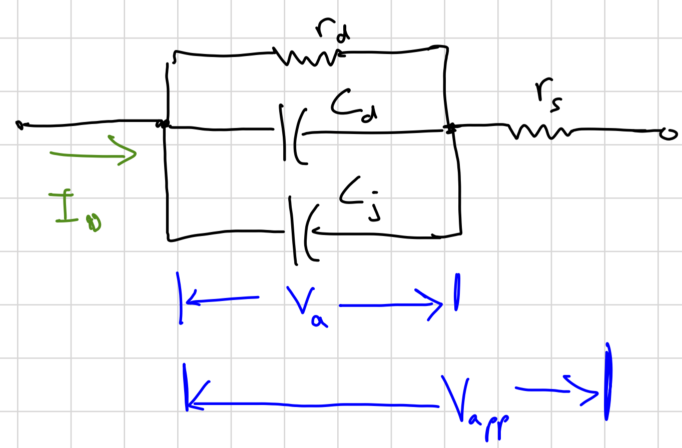


- Complete circuit includes C_j and series resistance, r_s

Voltage across junction: V_a

Total applied voltage: V_{app}

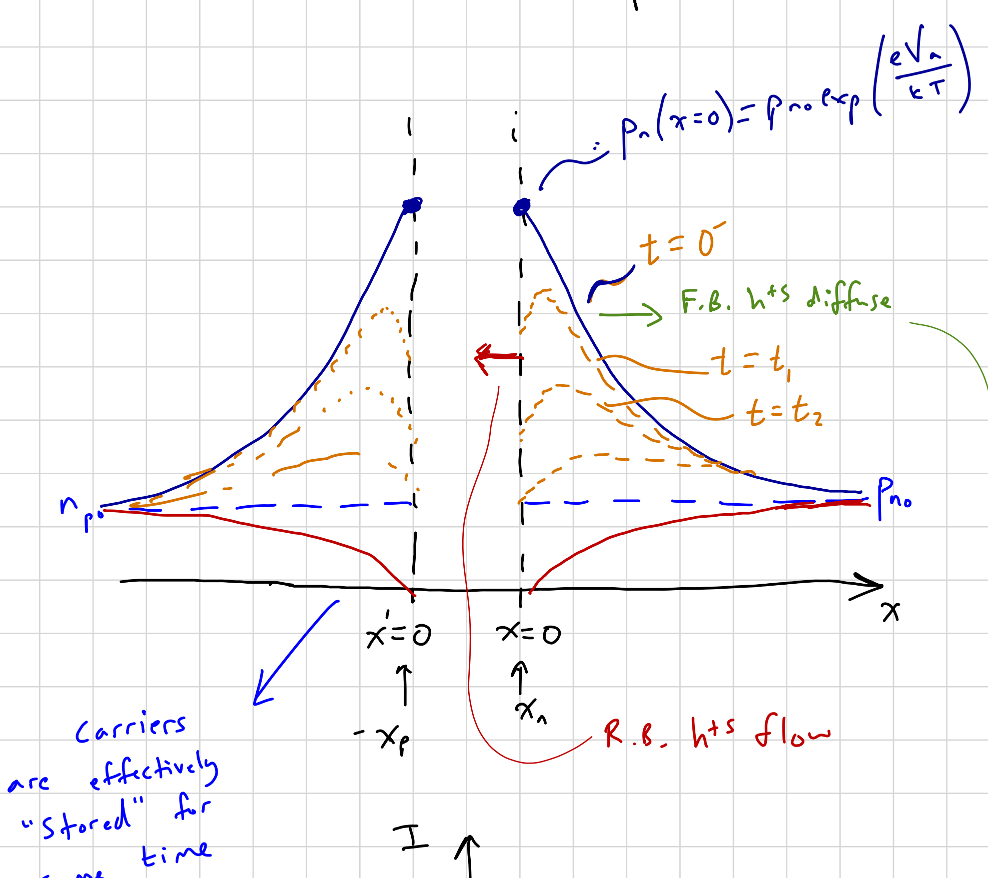
$$V_{app} = V_a + r_s I_D$$

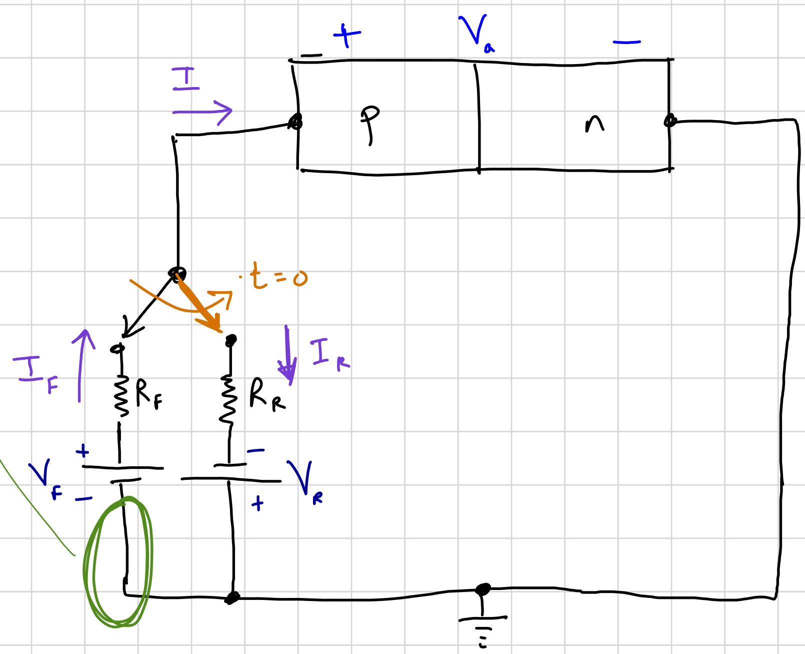


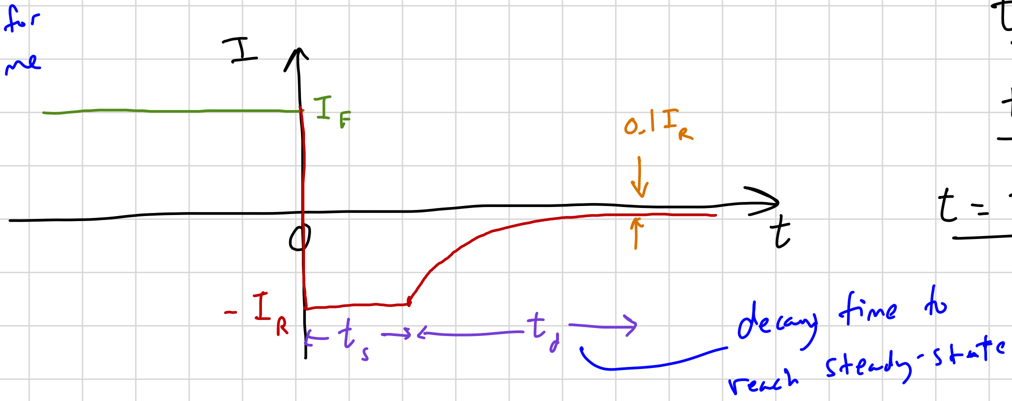
Diode Transients

→ In circuit applications, the "speed" of a pn junction switching is important.

- switching from forward to reverse-bias
- Voltage is abruptly changed from Forward to reverse-bias at $t=0$
- Junction capacitances do not allow junction voltage to change instantly (gradual discharge)







$t<0$: $I = I_F = \dfrac{V_F - V_a}{R_F}$

$t>0$: $I = -I_R \simeq -\dfrac{V_R}{R_R}$

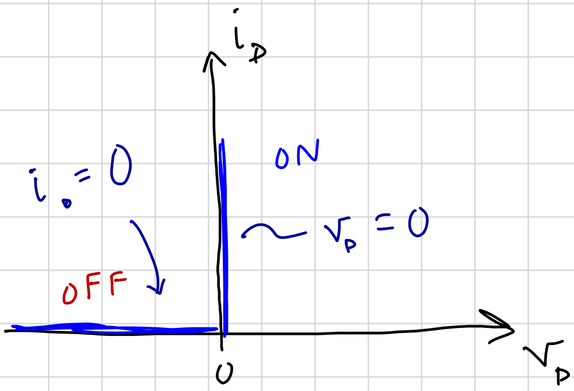
$t = t_s$: $t_s \simeq \tau_{po}\ln\left(1 + \dfrac{I_F}{I_R}\right)$ for one-sided junction (p^+n)

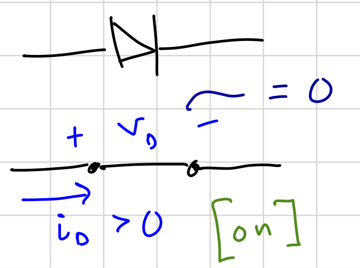
pn diode circuits large-signal (DC) analysis

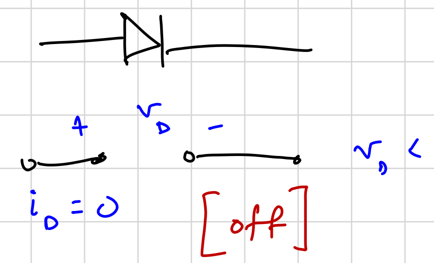
★ look in textbook for difference between large-signal and small-signal

must consider non-linearity (large-signal); can assume linearity (small-signal)

An "Ideal diode" (different than the ideal diode eqn.) as a circuit element would do the following:

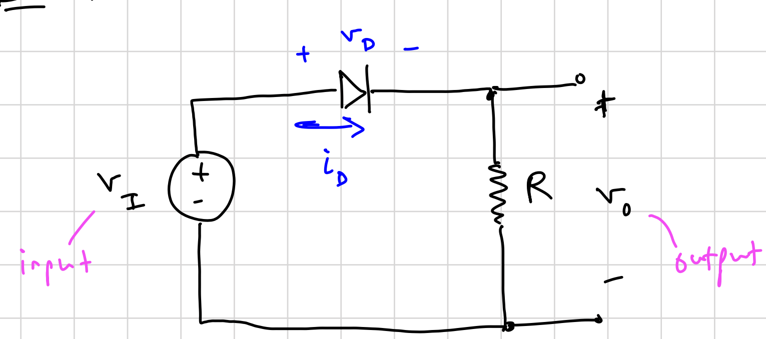


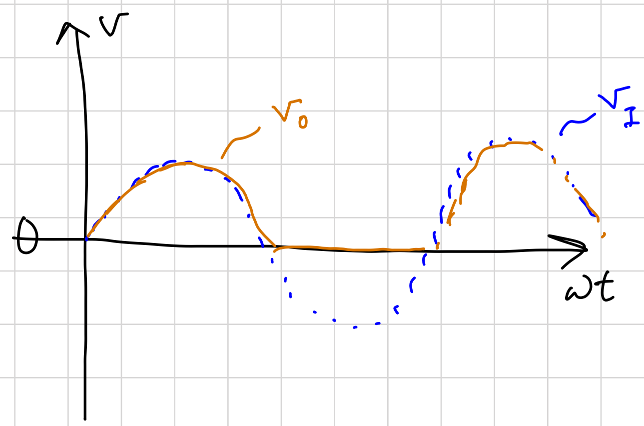




★ This allows conceptualization of how a diode circuit functions but need more work for actual analysis:

Ex: Half-wave rectifier



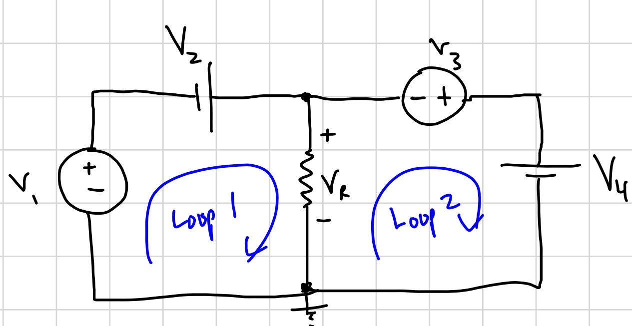


For analyzing diode circuits with large signals (or DC), there are options:

First, recall Kirchoff's voltage & current laws (KVL, KCL):

KVL

sum of all voltages around a loop is zero

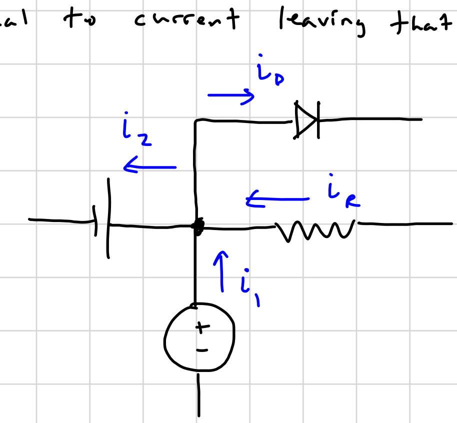


Loop 1: $-v_1 - V_2 + V_R = 0$

Loop 2: $-V_R - v_3 + V_4 = 0$

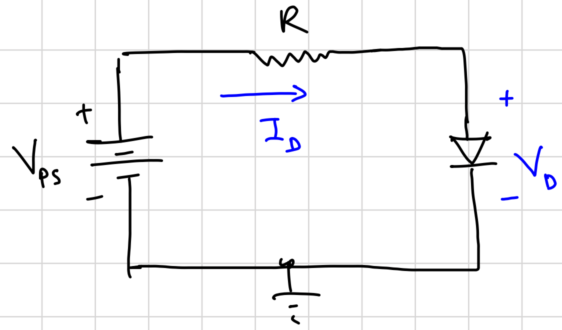
KCL

current entering a junction/node is equal to current leaving that junction

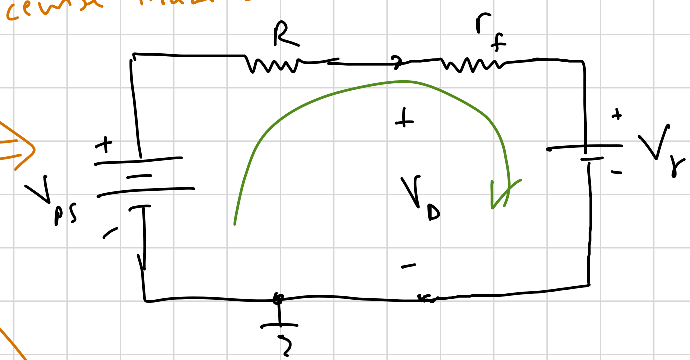


$i_1 + i_R = i_2 + i_D$

Techniques for analyzing large-signal diode circuits:



piecewise linear:



Iteration

KVL:

$V_{PS} = I_D R + V_D$

$I_D = \frac{V_{PS}}{R} - \frac{V_D}{R}$

Recall ideal diode eqn.:

$I_D = I_S\left[\exp\left(\frac{V_D}{V_t}\right) - 1\right]$

$$\boxed{V_{PS} = I_S R\left[\exp\left(\frac{V_D}{V_t}\right) - 1\right] + V_D}$$

→ Typically given: V_{PS}, I_S, R

→ Find V_D and then I_D by trial and error (iteration)

I_S must be given

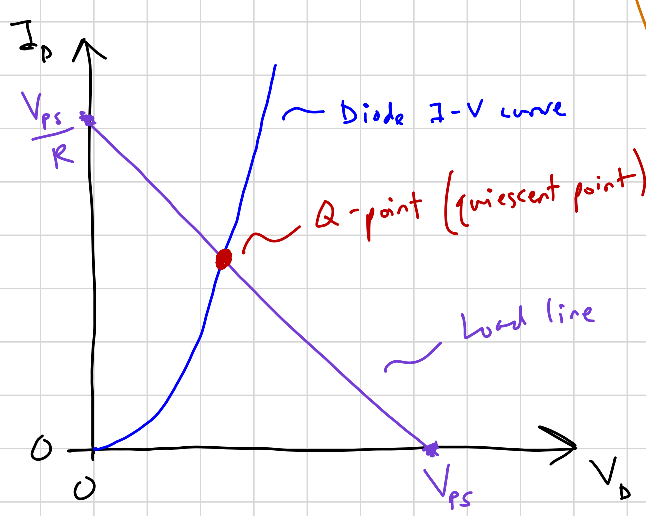
Graphical Analysis

$$\boxed{I_D = \frac{V_{PS} - V_D}{R}}$$

→ linear relationship between V_D and I_D for a given power supply voltage

LOAD LINE ☆

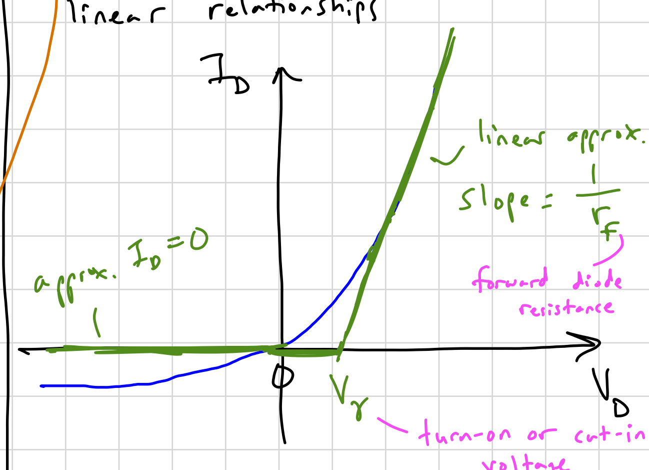
↳ relationship between I_D & V_D for a given circuit



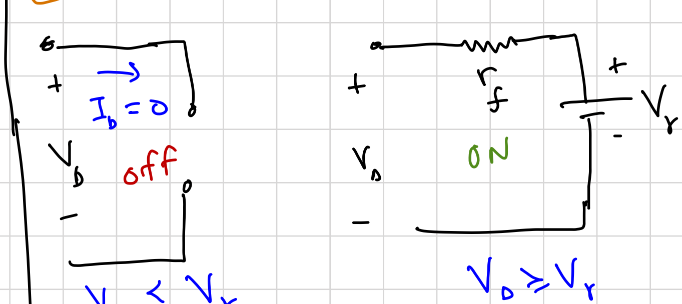
→ extract I_D, V_D from the Q-point

Piecewise Linear Model

→ approx. diode's nonlinear I-V using linear relationships



Diode looks like:



☆ must be given V_γ and r_f

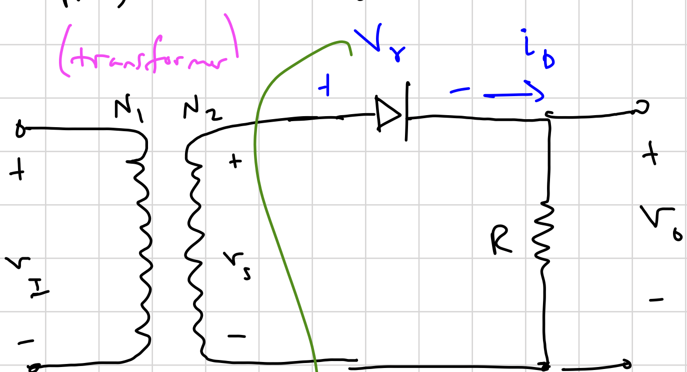
OR

Common standard assumptions: assume: $V_\gamma = 0.7V$ and $r_f = 0$

KVL: $I_D = \frac{V_{PS} - V_\gamma}{R + r_f}$

$V_D = V_\gamma + I_D r_f$

Apply this analysis to the half-wave rectifier:



use piecewise linear model assuming $V_\gamma = 0.7V$ and $r_f = 0$ ($r_f << R$)

KVL:

$v_S = V_\gamma + i_D R$

→ $\boxed{i_D = \frac{v_S - V_\gamma}{R}}$

AND

$$\boxed{v_O = i_D R = v_S - V_\gamma}$$

☆ NOTE: None of these are "universal" equations, but came from analyzing the given circuit!