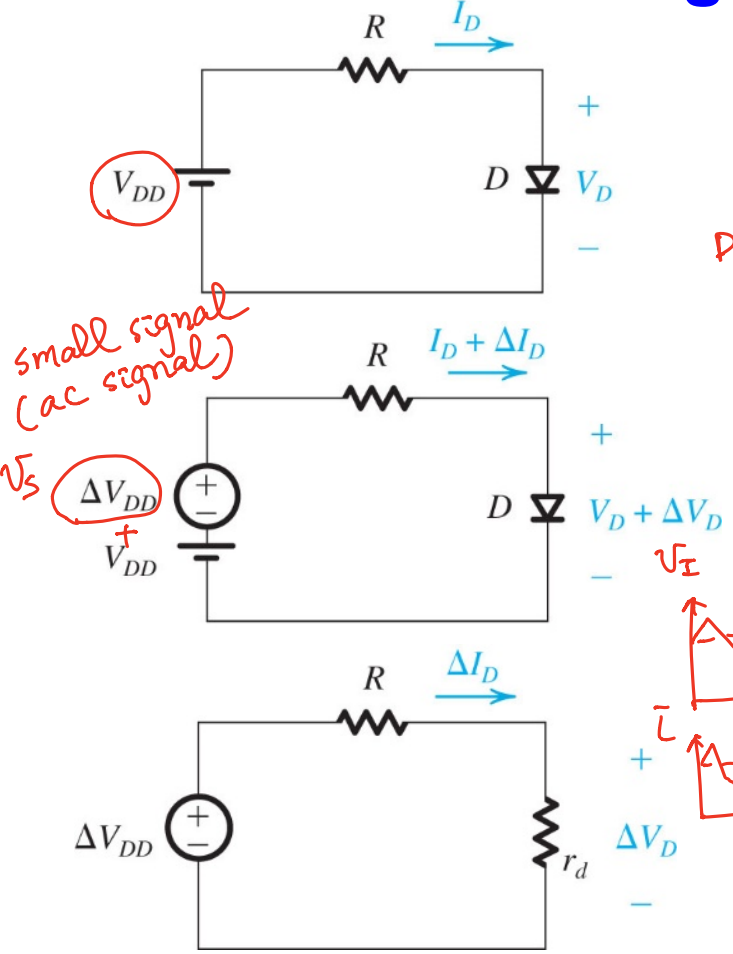
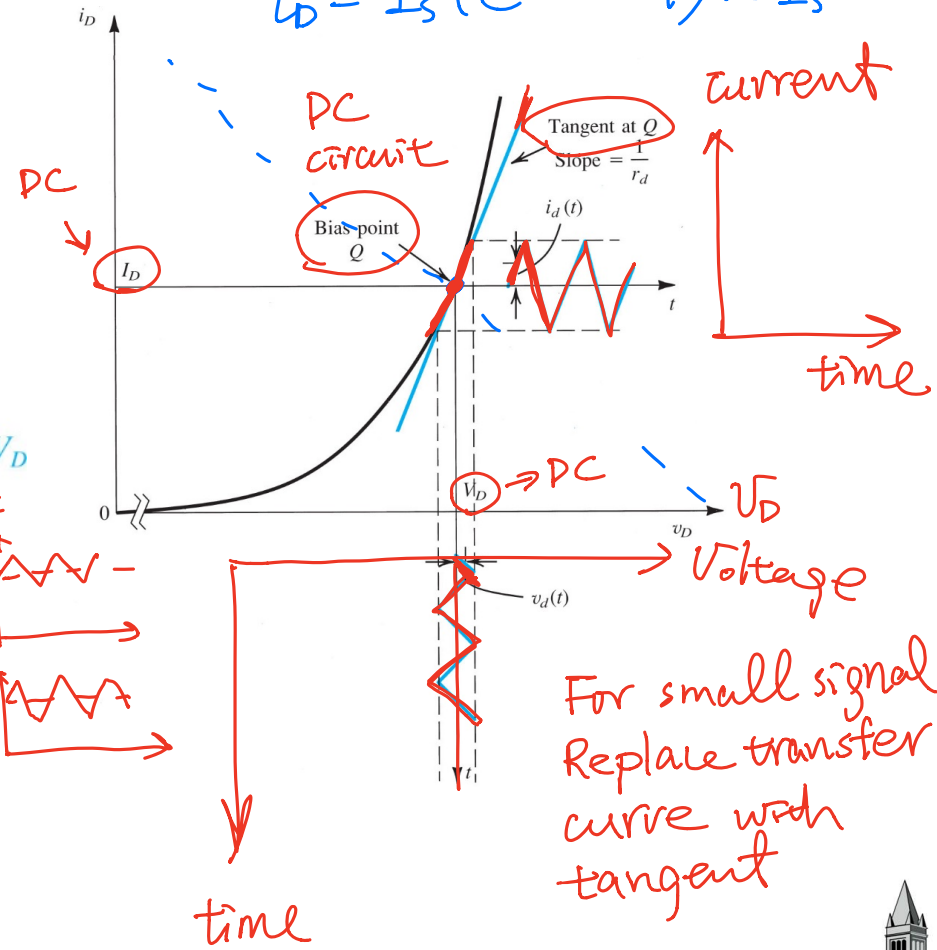
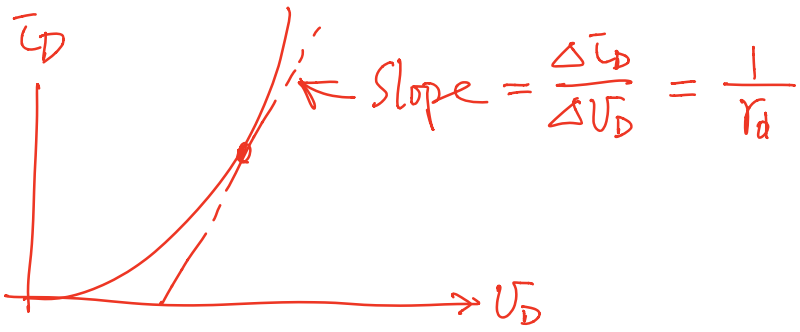
Small Signal Resistance



$$i_D = I_S\left(e^{v_D/V_T} - 1\right) \approx I_S e^{\frac{v_D}{V_T}}$$





$$r_d = \frac{\Delta v_D}{\Delta i_D} = \frac{1}{\left(\frac{d i_D}{d v_D}\right)} = \frac{1}{\left(\frac{I_D}{V_T}\right)} = \frac{V_T}{I_D}.$$

$V_T = 26\,mV$ at room temp

$$i_D = I_S e^{\frac{v_D}{V_T}}$$

$$\frac{d i_D}{d v_D} = I_S \cdot \frac{1}{V_T} e^{\frac{v_D}{V_T}} = \frac{1}{V_T}\left(I_S e^{\frac{v_D}{V_T}}\right) = \frac{I_D}{V_T}$$

Symbol convention

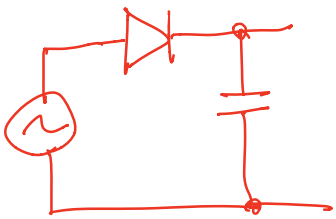
I_D = DC current

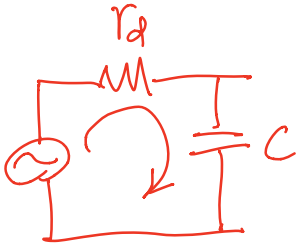
i_D = AC current

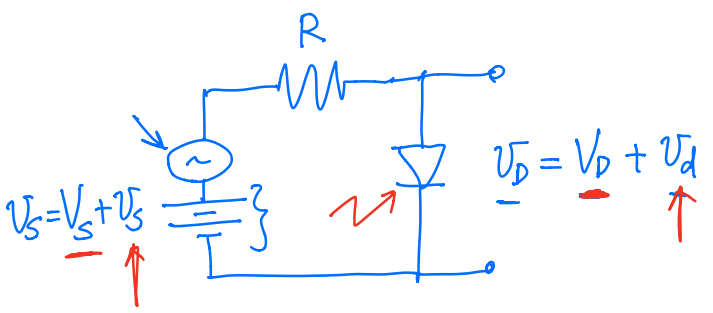
If diode is biased at $I_D = 1\,mA$

$$r_d = \frac{V_T}{I_D} = 26\,\Omega$$

$RC = r_d \cdot C$







Previously solved by iteration → DC solution

$$\begin{cases} I_D = I_S e^{V_D/V_T} \\ V_S = I_D \cdot R + V_D \end{cases}$$

$v_D = V_D + v_d$ ← ac small signal. ∿∿∿

↑ ↑ └ DC : bias $|v_d| \ll |V_D|$

Total signal

[small-case symbole
  Capital subscript

$$i_D = I_S e^{\frac{v_D}{V_T}}$$

$i_D = I_D + i_d$

$v_D = V_D + v_d$

$$I_D + i_d = I_S e^{\frac{V_D + v_d}{V_T}} = f(V_D + v_d) = f(V_D) + \left.\frac{df}{dV}\right|_{V=V_D} \cdot v_d$$

$$= I_S e^{\frac{V_D}{V_T}} + I_S \frac{1}{V_T} e^{\frac{V_D}{V_T}} \cdot v_d$$

($I_S e^{\frac{V_D}{V_T}} = I_D$; $\frac{df}{dV}$; $v_d \sim \Delta V$)

$$i_d = \frac{I_D}{V_T} \cdot v_d$$

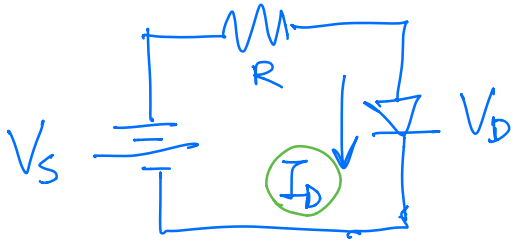
$$\frac{v_d}{i_d} = \frac{V_T}{I_D} = r_d$$: small-signal resistance

2-step Process

① Solve DC.

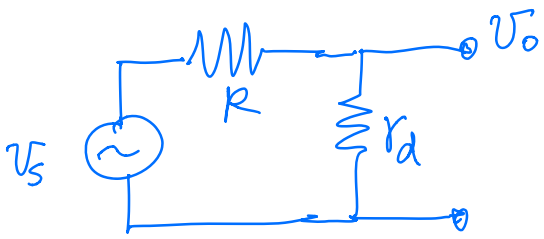
e.g. $V_D = 0.72\ V$

$I_D = 1\ mA$



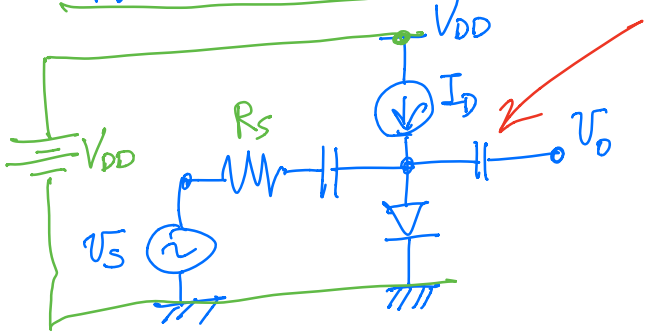
② Replace circuit with small-signal equivalent circuit

* All DC voltage source → short ckt
* All DC current source → open ckt
* Replace diode with $r_d = \frac{V_T}{I_D}$



$$v_o = \frac{r_d}{R + r_d} v_s$$

HW Problem

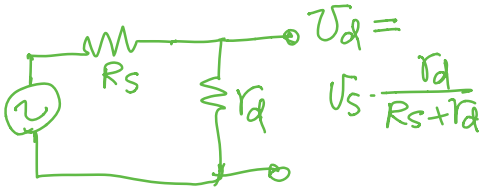


Coupling capacitor, C large

$Z_C = \frac{1}{j\omega C}$ ≪ all resistance

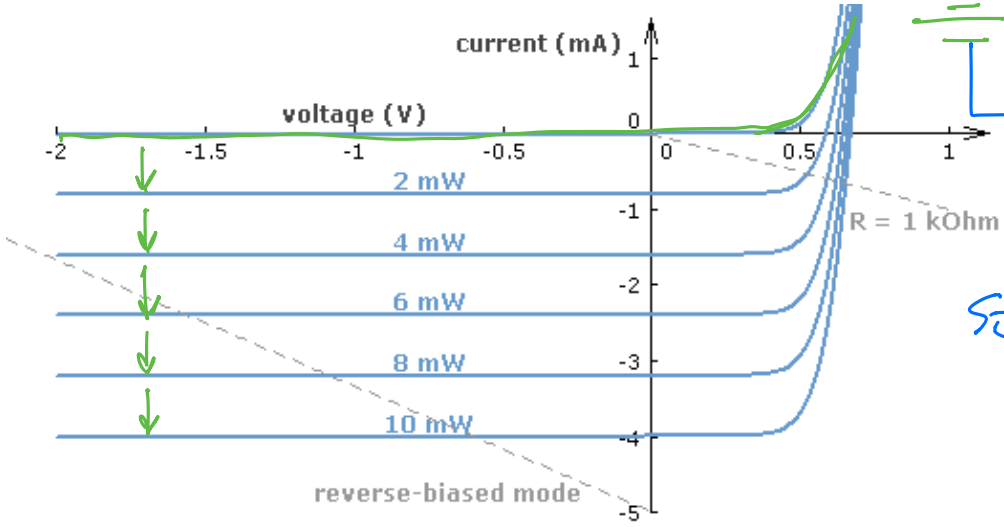
↳ Short ckt

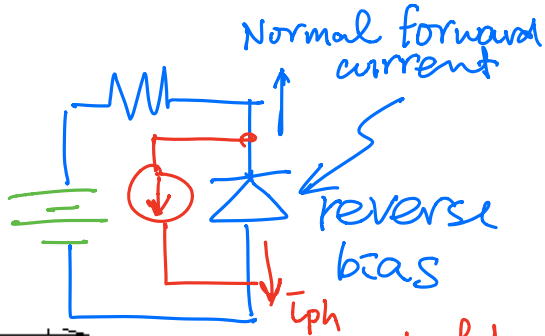
⇒

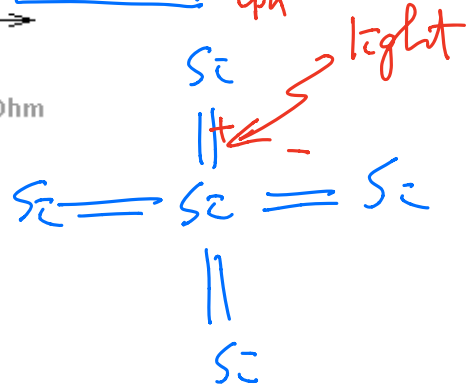


Photodiodes

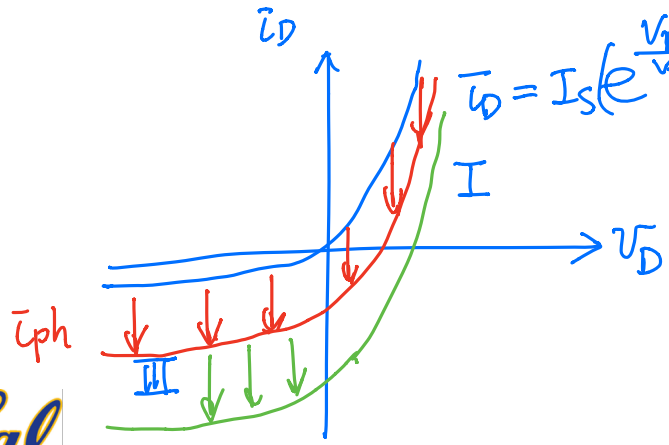
"3rd Quadrant" ←







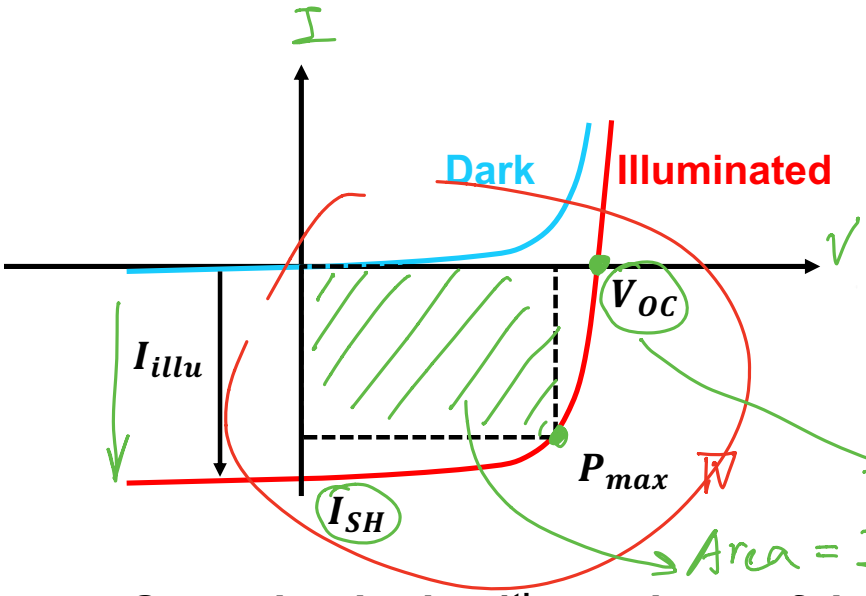
light create electron-hole pair, → Photocurrent

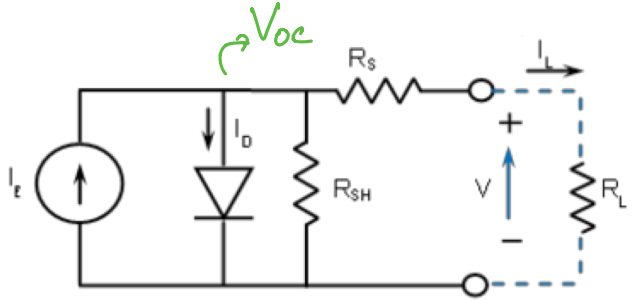


$$i_D = I_S\left(e^{\frac{v_D}{V_T}} - 1\right) + i_{ph}$$

$i_{ph} \propto$ light intensity

Solar (Photovoltaic, or PV) Cells





I=0 ⇒ Voc = open-circuit voltage

Area = I·V = generated energy

- **Operating in the 4th quadrant of the I-V curve**
  → It generates power !

- **Key parameters:**
  - **Open circuit voltage, V_{OC}**
  - **Short-circuit current, I_{sh}**
  - **Fill factor**

PV ~ 20%

≤ 31% for Si PV

⇒ EE134