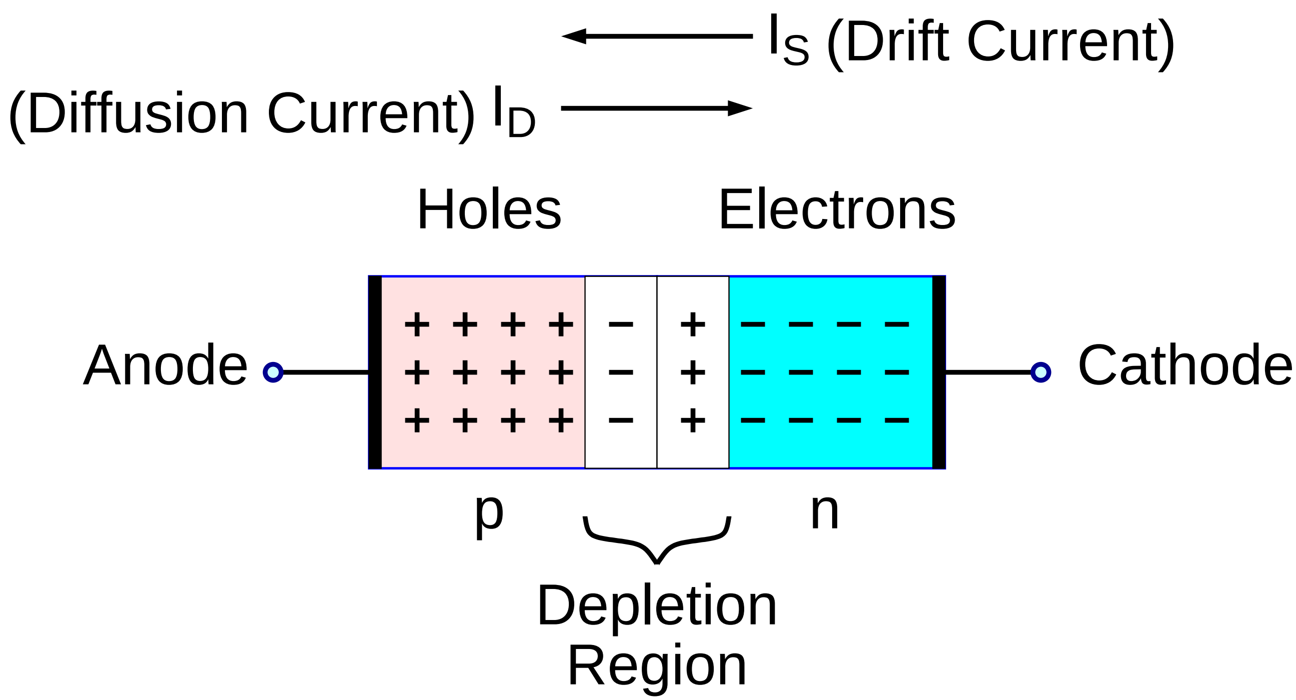
ECEN 325
Electronics

Diodes

Dr. Aydın İlker Karşılayan

Texas A&M University
Department of Electrical and Computer Engineering


I_S (Drift Current)
(Diffusion Current) I_D
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Electrons
Anode
Cathode
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−
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−
+
+
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− − − −
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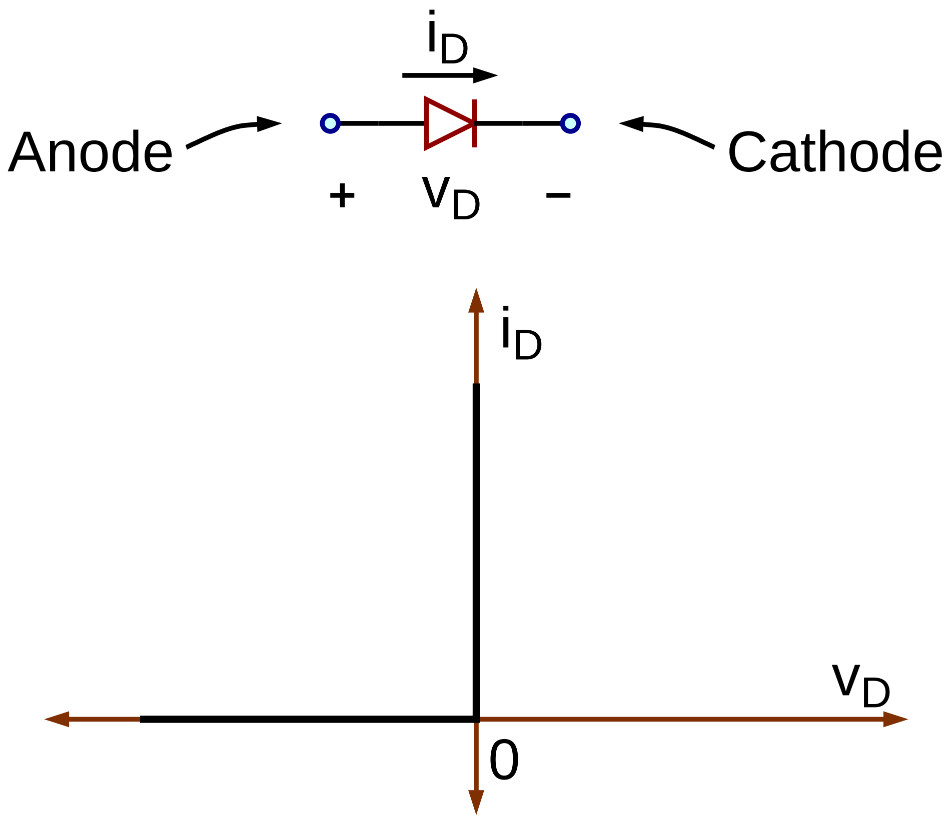
p
n
Depletion
Region

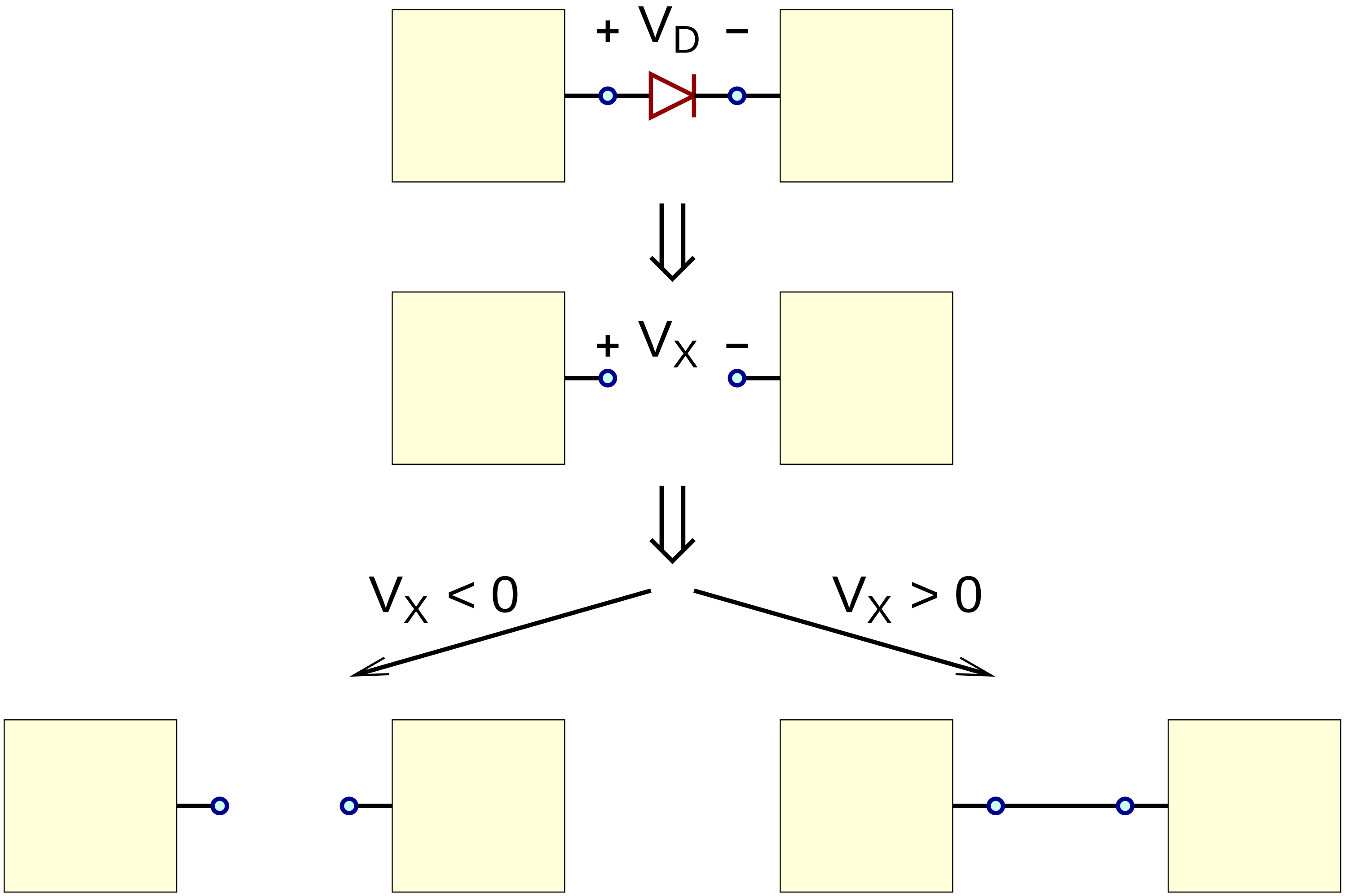
Ideal Diode

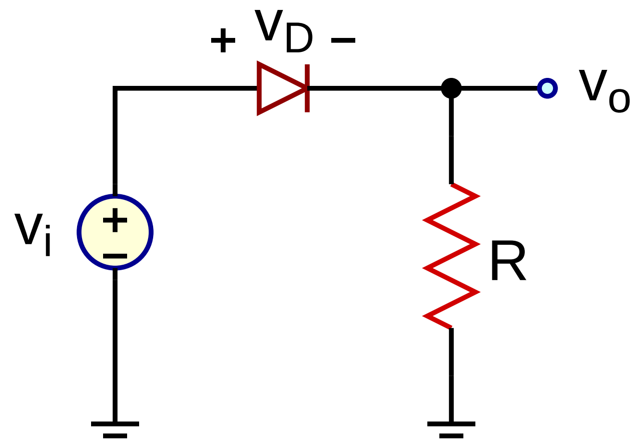


$$v_D < 0 \quad \Rightarrow \quad i_D = 0$$

$$i_D > 0 \quad \Rightarrow \quad v_D = 0$$

Ideal Diode




+ vD –
vo
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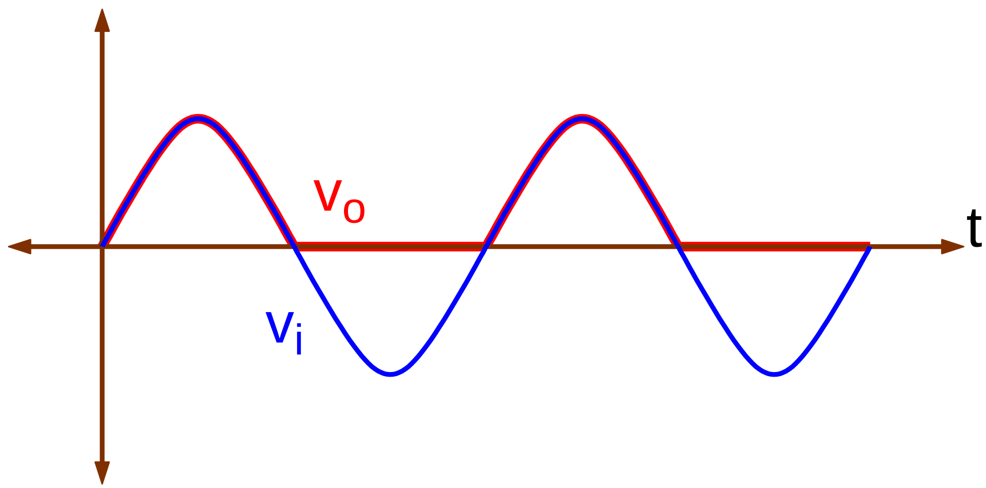
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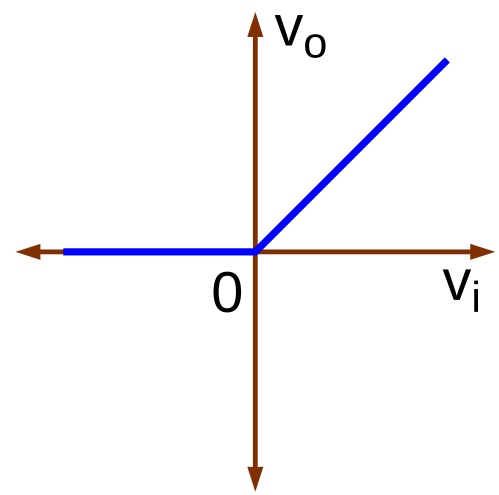
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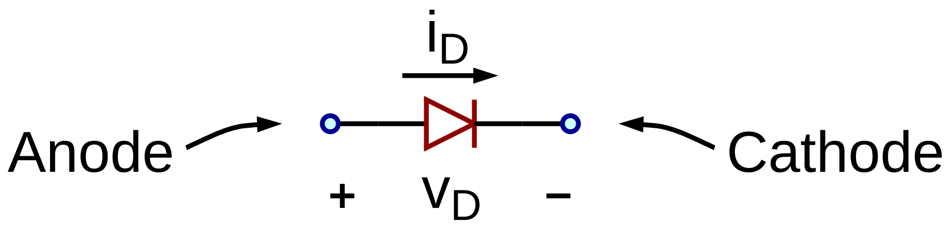
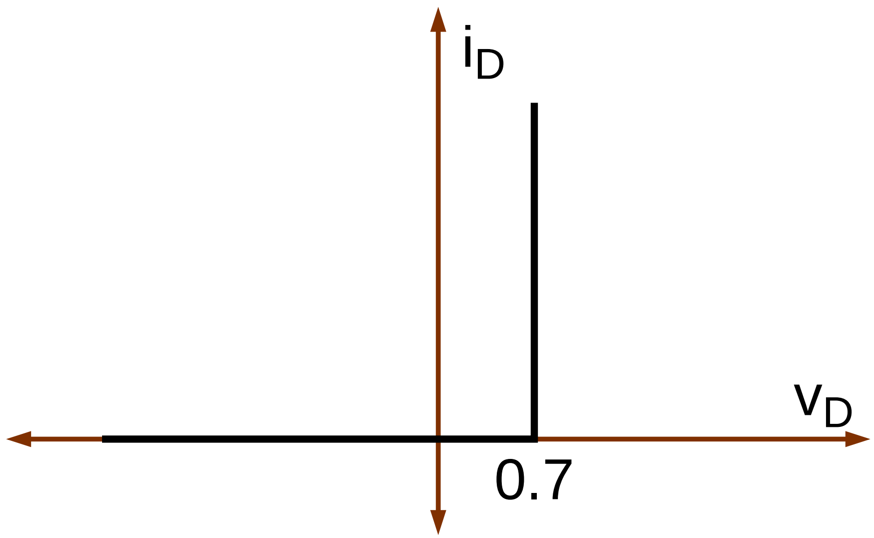
Constant-Voltage-Drop Model

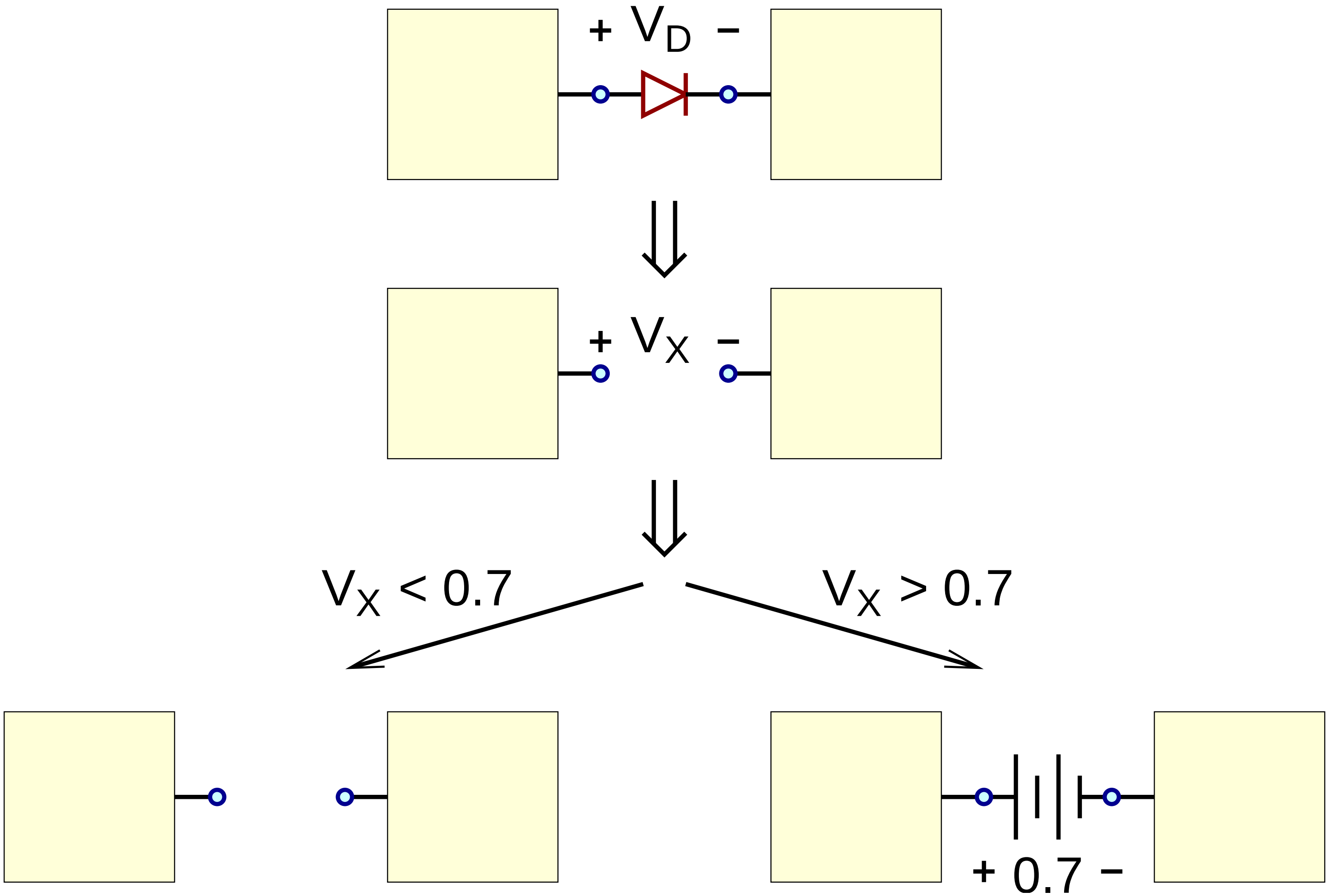




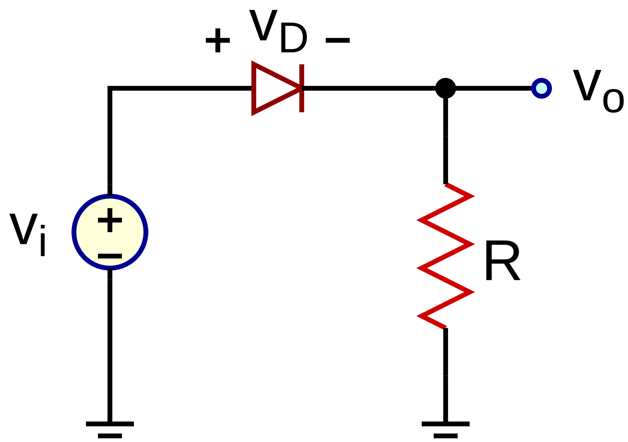
$$v_D < 0.7 \quad \Rightarrow \quad i_D = 0$$

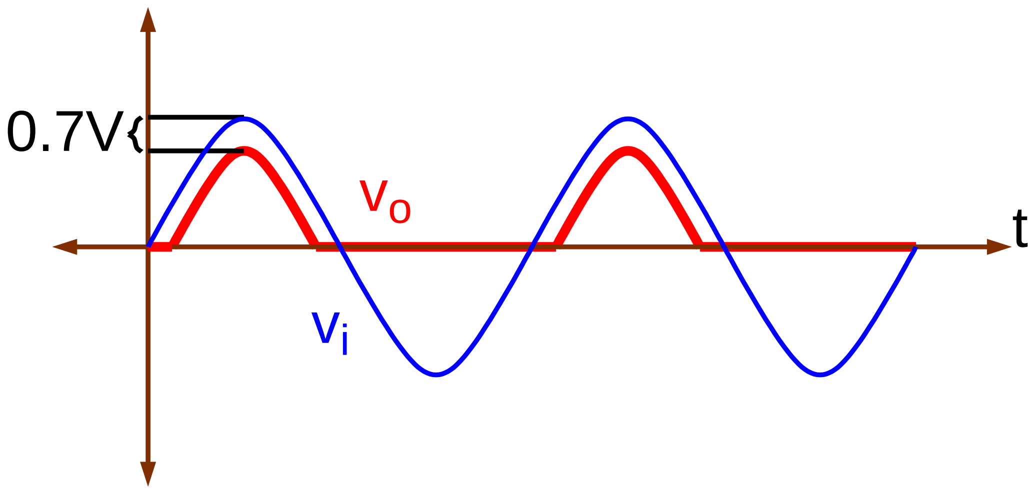
$$i_D > 0 \quad \Rightarrow \quad v_D = 0.7$$

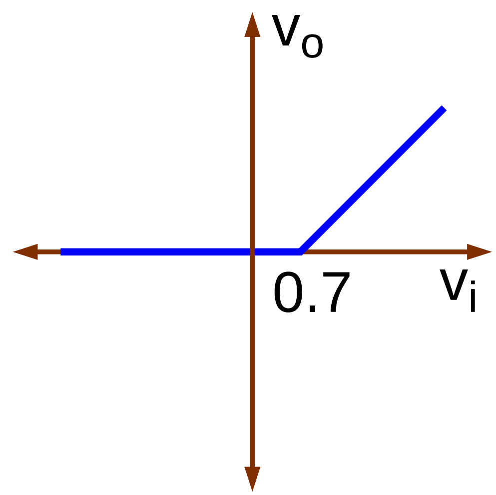
Constant-Voltage-Drop Model



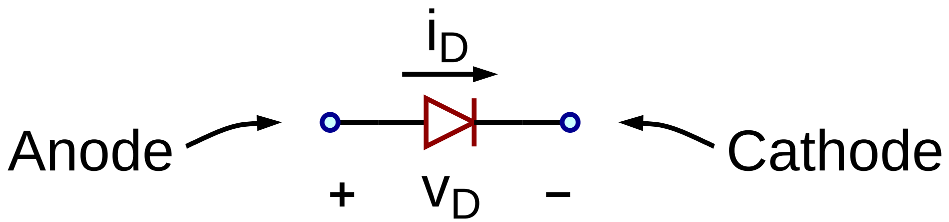
Constant-Voltage-Drop Model

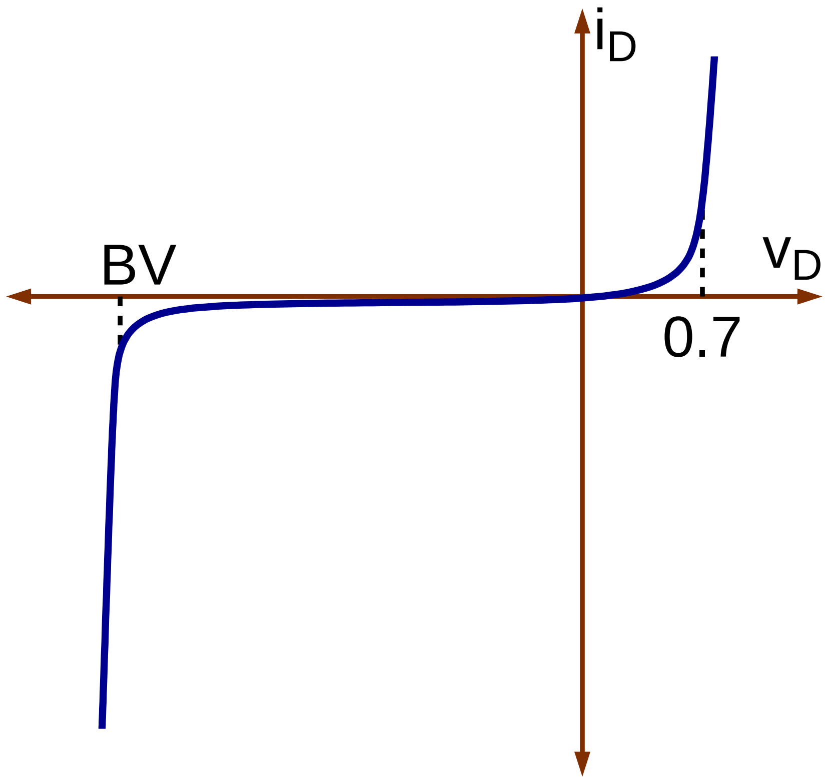






Exponential I-V Model





Exponential I-V Model

$$\mathbf{I_D = I_S \left(e^{\frac{V_D}{nV_T}} - 1 \right)}$$

$$\mathbf{V_D = nV_T \ln \left(\frac{I_D}{I_S} + 1 \right)}$$

$$\mathbf{V_T = \frac{kT}{q} \approx 25} \text{ mV @ room temp.}$$

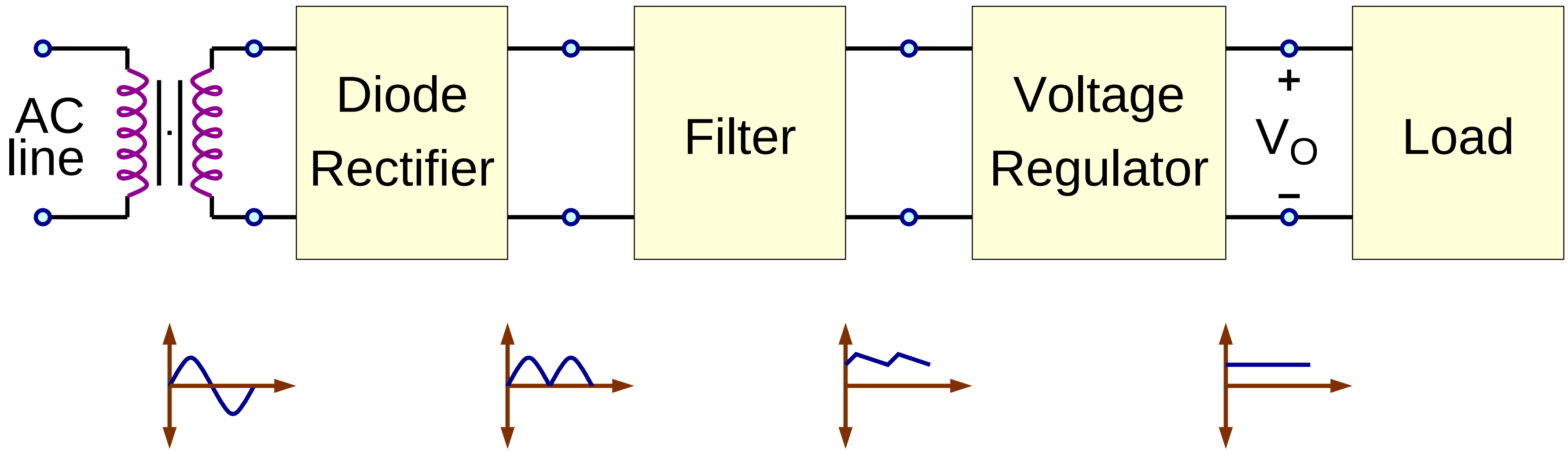
If $\mathbf{V_D}$ > (a few $\mathbf{V_T}$) or $\mathbf{I_D \gg I_S}$,

$$\mathbf{I_D = I_S \, e^{\frac{V_D}{nV_T}}}$$

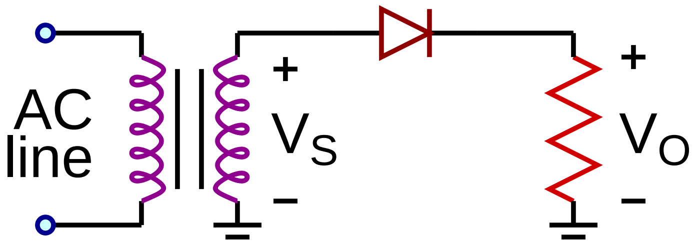
$$\mathbf{V_D = nV_T \ln \frac{I_D}{I_S}}$$

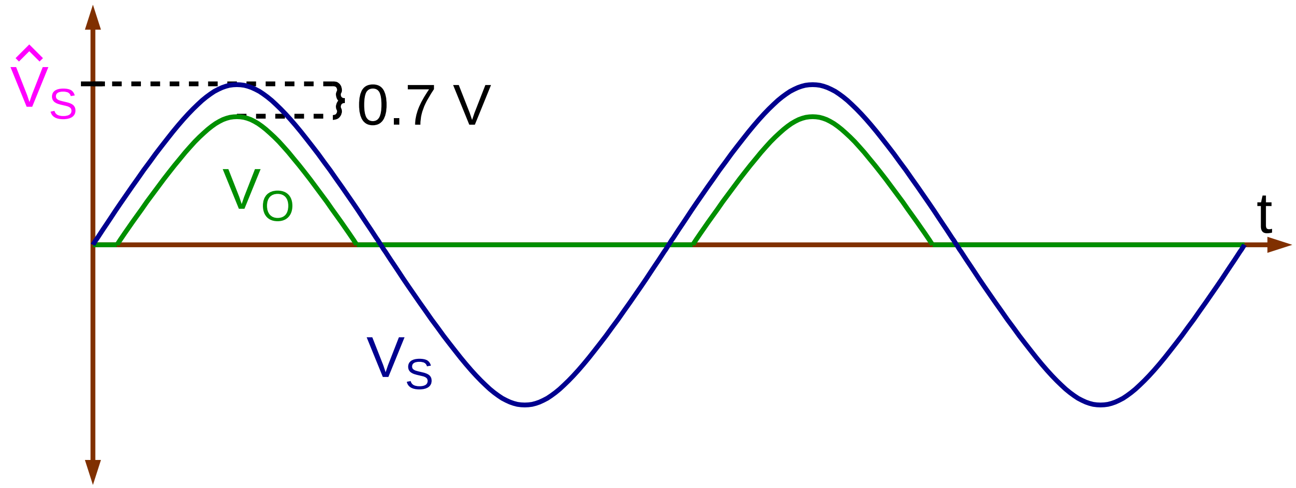
$$\mathbf{V_{D2} - V_{D1} = nV_T \ln \frac{I_{D2}}{I_{D1}}}$$

Rectifier Circuits



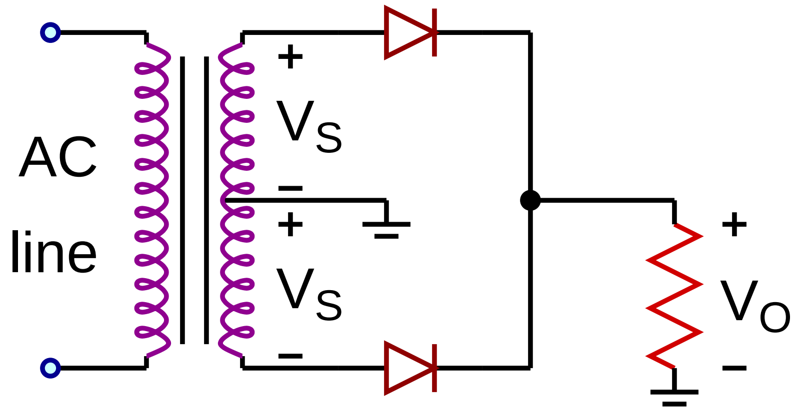
Half-Wave Rectifier

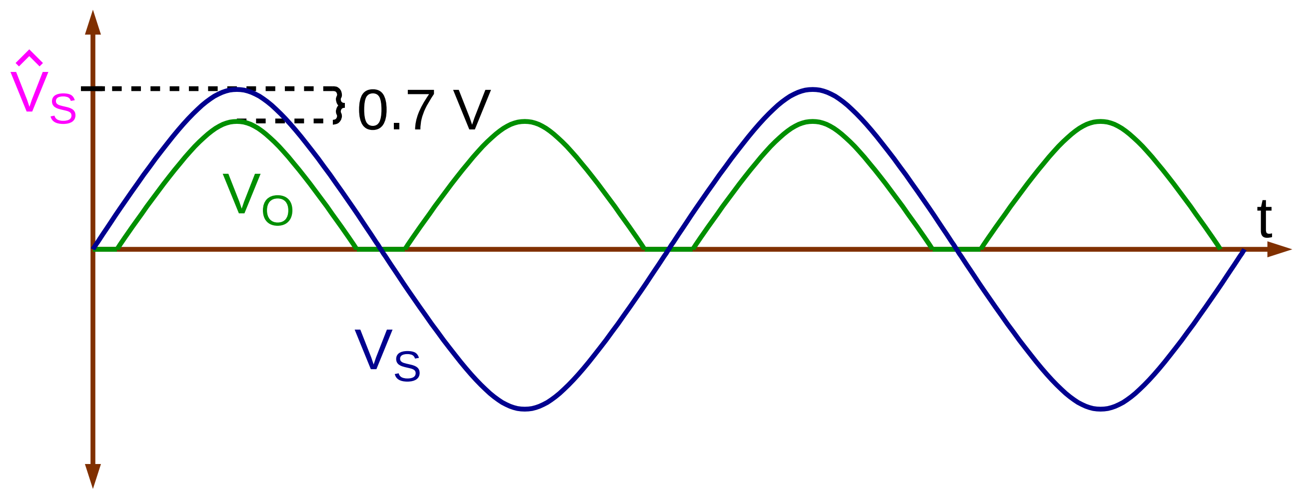




$$\mathbf{PIV = \hat{V}_S}$$

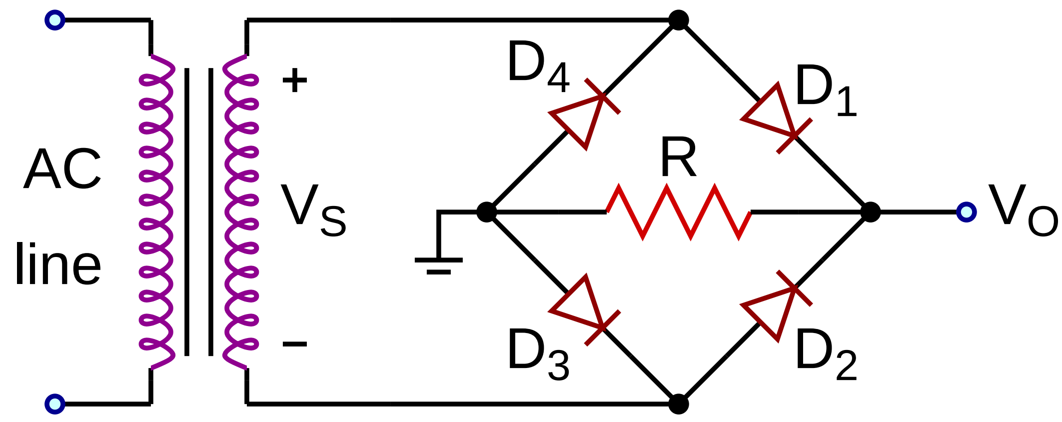
Full-Wave Rectifier

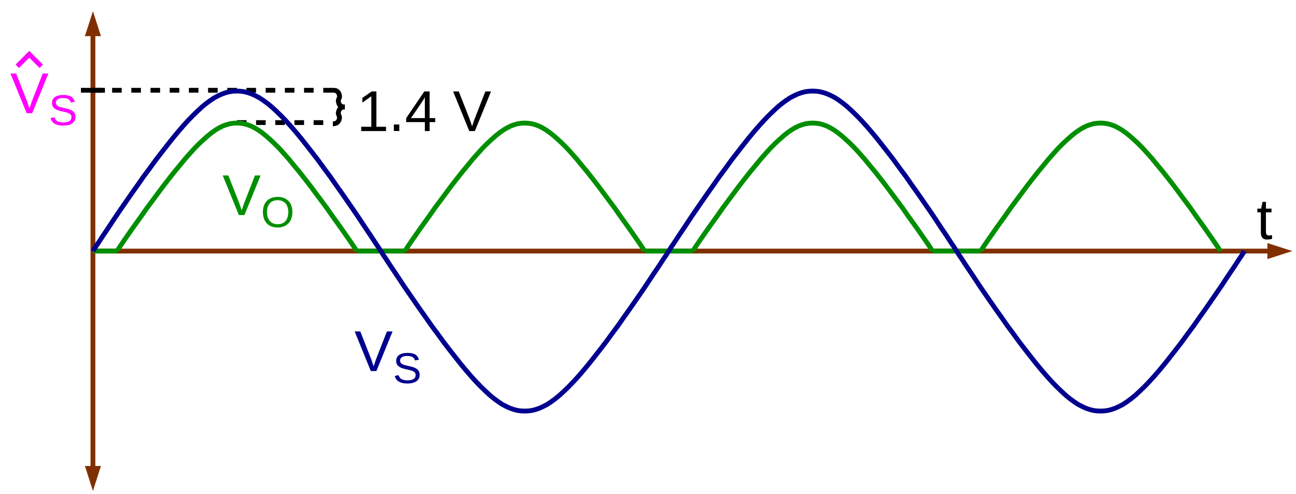




$$\mathbf{PIV} = 2\hat{V}_S - 0.7$$

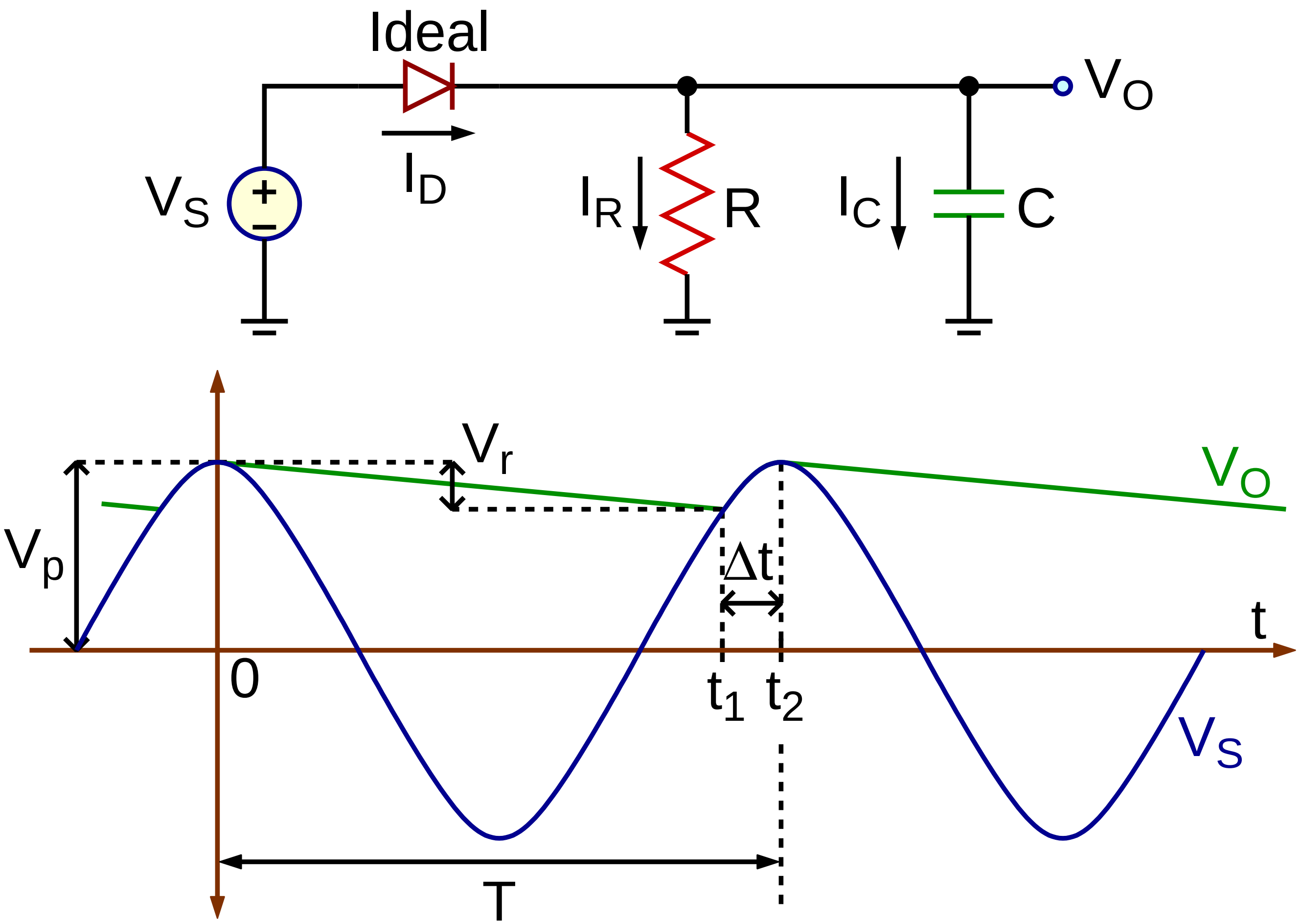
Bridge Rectifier





$$\mathbf{PIV = \hat{V}_S - 0.7}$$

Half-Wave Rectifier with a Filter Capacitor

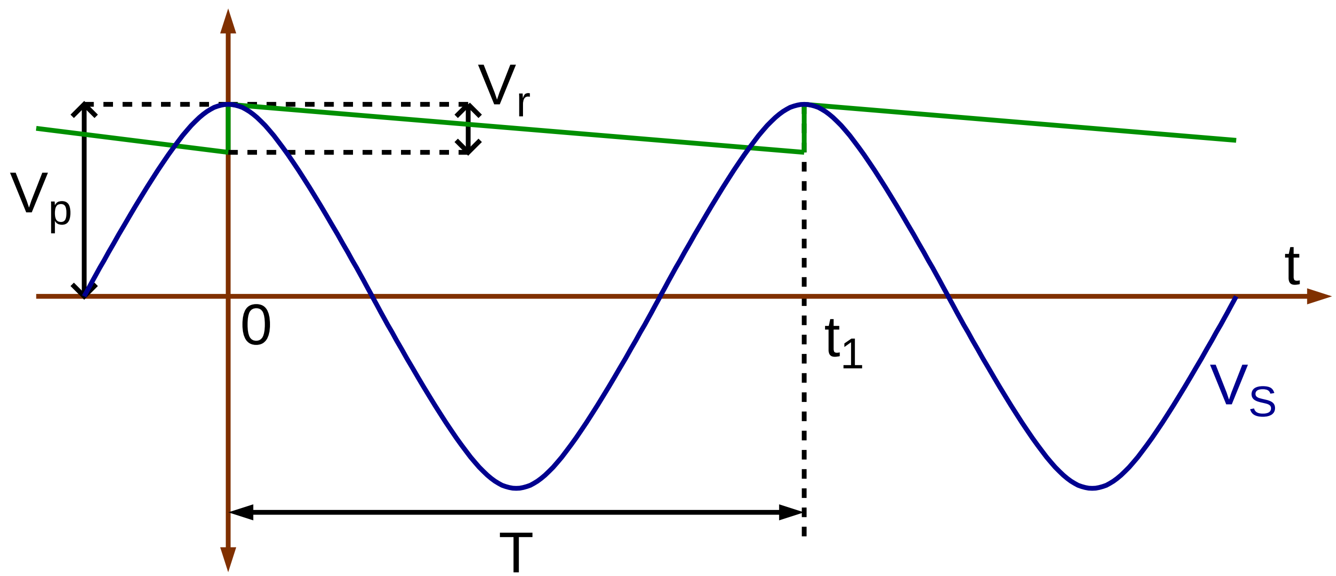


$$v_O(t) = \begin{cases} v_S(t) & , \; t_1 < t < t_2 \\ V_p \, e^{-\frac{t}{RC}} & , \; 0 < t < t_1 \end{cases} \quad \Rightarrow \quad v_O(t_1) = V_p \, e^{-\frac{t_1}{RC}}$$

Half-Wave Rectifier with a Filter Capacitor

For a properly designed filter:

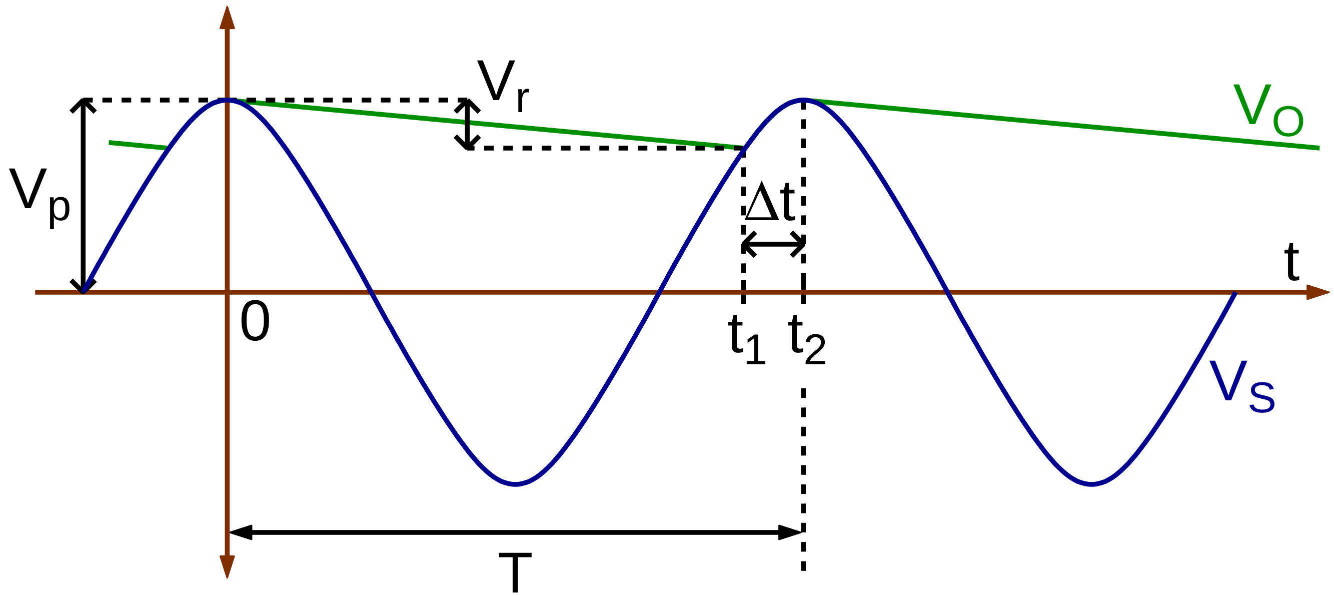
$$\left.\begin{array}{ll} t_1 \approx T & \Rightarrow \; V_O(t_1) \approx V_p \, e^{-\frac{T}{RC}} \\ RC \gg T & \Rightarrow \; e^{-\frac{T}{RC}} \approx 1 - \frac{T}{RC} \end{array}\right\} \Rightarrow V_O(t_1) = V_p\left(1 - \frac{T}{RC}\right)$$



Peak-to-peak ripple voltage:

$$V_r = V_p - V_O(t_1) = V_p - V_p\left(1 - \frac{T}{RC}\right) \Rightarrow V_r = V_p \frac{T}{RC}$$

Half-Wave Rectifier with a Filter Capacitor

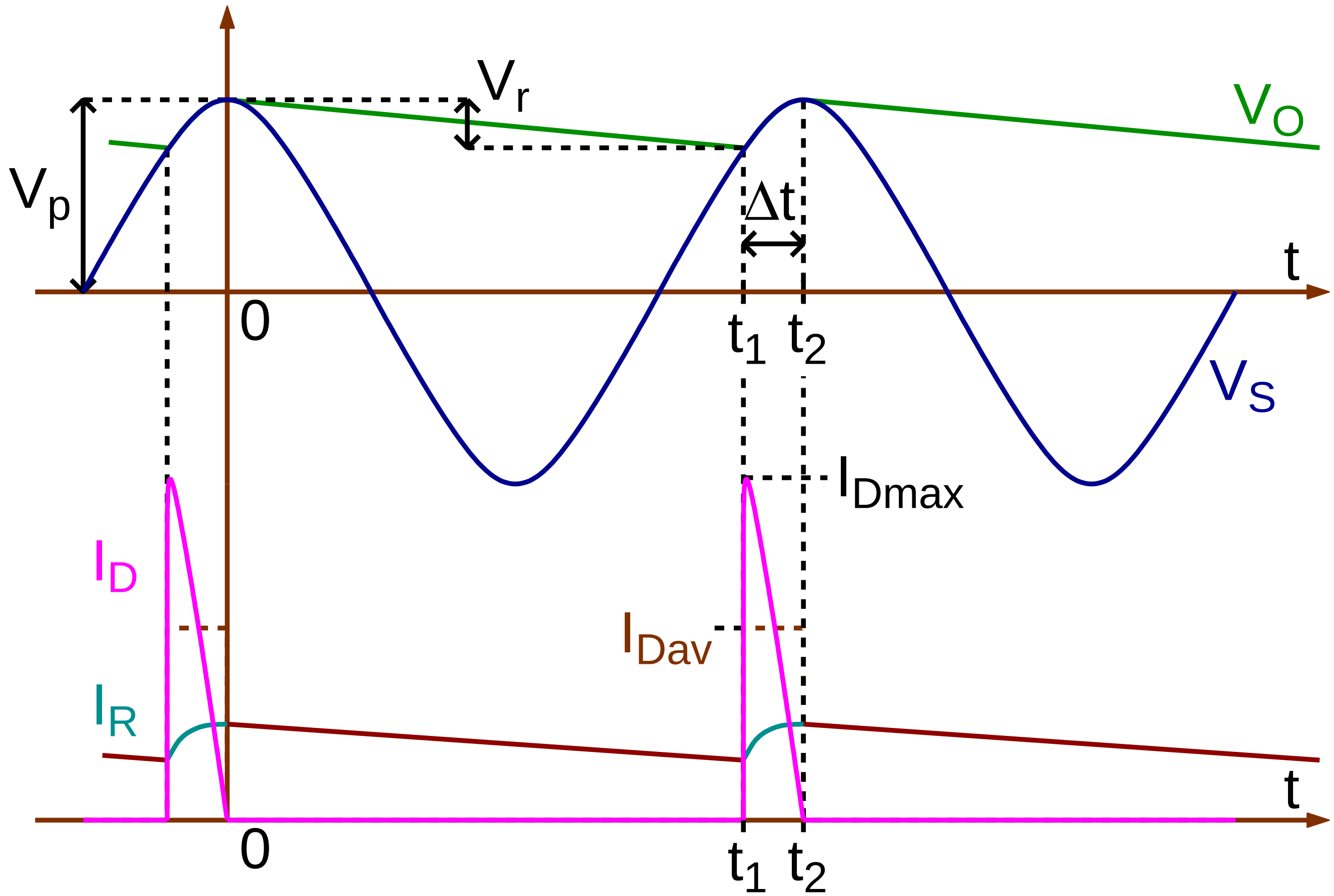


$$\mathbf{V_p \cos(\omega \Delta t) = V_p - V_r}$$

$$\omega \Delta t \text{ is small } \Rightarrow \quad \cos(\omega \Delta t) \approx 1 - \frac{1}{2}(\omega \Delta t)^2$$

$$\Rightarrow \quad \omega \Delta t \approx \sqrt{\frac{2V_r}{V_p}} \quad \Rightarrow \quad \Delta t \approx \frac{T}{2\pi}\sqrt{\frac{2V_r}{V_p}}$$

Half-Wave Rectifier with a Filter Capacitor



During conduction ($\mathbf{t_1}$-$\mathbf{t_2}$): $\mathbf{Q_{supplied} = Q_{lost}}$

$$\mathbf{I_{Cav}\Delta t = CV_r}$$

Half-Wave Rectifier with a Filter Capacitor

Substitute Δt in $I_{Cav}\Delta t = CV_r$

$$I_{Cav}\,\frac{T}{2\pi}\sqrt{\frac{2V_r}{V_p}} = CV_r \;\;\Rightarrow\;\; I_{Cav} = \frac{2\pi CV_r}{T}\sqrt{\frac{V_p}{2V_r}}$$

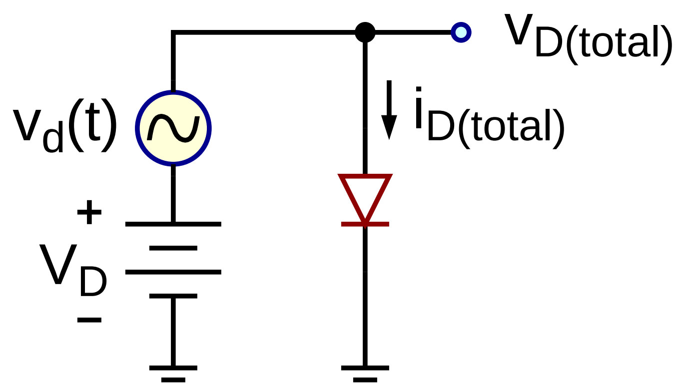
$$I_{Dav} = I_R + I_{Cav} = I_R + \frac{2\pi CV_r}{T}\sqrt{\frac{V_p}{2V_r}}$$

$$V_r = V_p\,\frac{T}{RC}\;\;,\;\;\; V_p \approx I_R R \;\;\Rightarrow\;\; V_r = I_R\frac{T}{C}$$

$$I_{Dav} = I_R + 2\pi I_R\sqrt{\frac{V_p}{2V_r}} = I_R\left(1 + \pi\sqrt{\frac{2V_p}{V_r}}\right)$$

$$I_{Dmax} = I_R\left(1 + 2\pi\sqrt{\frac{2V_p}{V_r}}\right)$$

Small Signal Model



$$v_{D(total)} = V_D + v_d(t)$$
$$i_{D(total)} = I_D + i_d(t)$$

$$i_{D(total)} = I_S\, e^{\frac{V_D + v_d(t)}{nV_T}} = I_S\, e^{\frac{V_D}{nV_T}}\, e^{\frac{v_d(t)}{nV_T}} = I_D\, e^{\frac{v_d(t)}{nV_T}}$$

$$\approx I_D\left(1 + \frac{v_d(t)}{nV_T}\right), \quad v_d(t) \ll nV_T$$

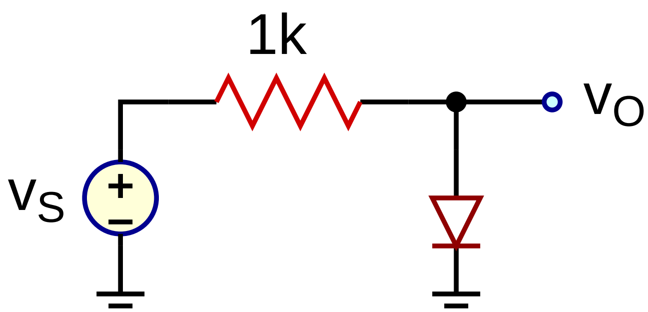
$$\approx I_D + \frac{I_D}{nV_T} v_d(t)$$

$$\frac{di_D}{dv_d} = \frac{1}{r_d} = \frac{I_D}{nV_T} \quad \Rightarrow \quad r_d = \frac{nV_T}{I_D}$$

Small Signal Analysis

- **Step 1:** Eliminate AC sources, find the DC solution ($\mathbf{I_D}$, $\mathbf{V_D}$) of the circuit (use constant-voltage-drop model, unless specified otherwise).
- **Step 2:** Calculate small signal parameters ($\mathbf{r_d}$).
- **Step 3:** Eliminate DC sources, replace the diode with its small-signal equivalent model and find the small-signal solution. Verify the assumptions ($\mathbf{v_d} \ll \mathbf{nV_T}$).
- **Step 4:** The total solution is (DC solution + AC solution).

Small Signal Analysis



$$v_S = 5 + 0.2\sin(\omega t), \quad n = 2$$

Find $v_O(t)$.

DC Solution:

$$V_O = 0.7 \text{ V} \qquad I_D = \frac{5 - 0.7}{1k} = 4.3 \text{ mA}$$

$$r_d = \frac{nV_T}{I_D} = \frac{50 \text{ mV}}{4.3 \text{ mA}} = 11.6\ \Omega$$

AC Solution:

$$v_o(t) = \frac{11.6}{10^3 + 11.6}\, 0.2\sin(\omega t) = 2.3 \times 10^{-3}\sin(\omega t)$$

Total: $v_O(t) = V_O + v_o(t) = 0.7 + 2.3 \times 10^{-3}\sin(\omega t)$