Spring 2019 Purdue University

ECE 255: L9

Rectifiers, Clamps, and Special Diodes

(Sedra and Smith, 4.5-4.7)

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Announcements

Spice Project 1 due by 11:59 PM Friday, 2/1 (Submit on Blackboard)

Exam 1: Thursday, Feb. 7, 6:30 PM, LILY 1105.
(Weeks -1- 4 topics, semiconductors, diodes, BJTs. i.e. HW1-HW4)

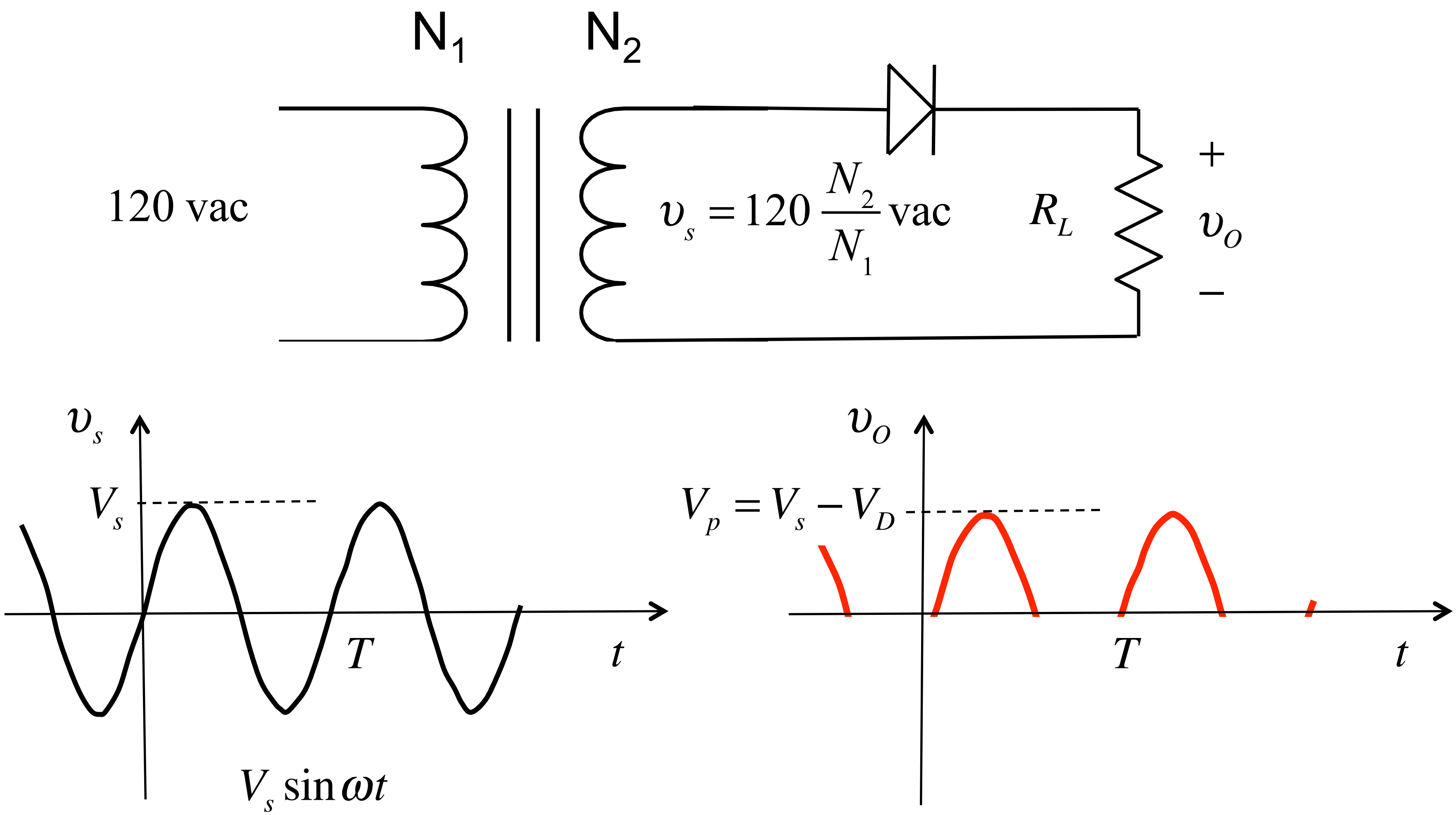
ECE 255 Help Room to change to EE 208 and 209 soon.

Shortened office hours today (until 3:55 PM)

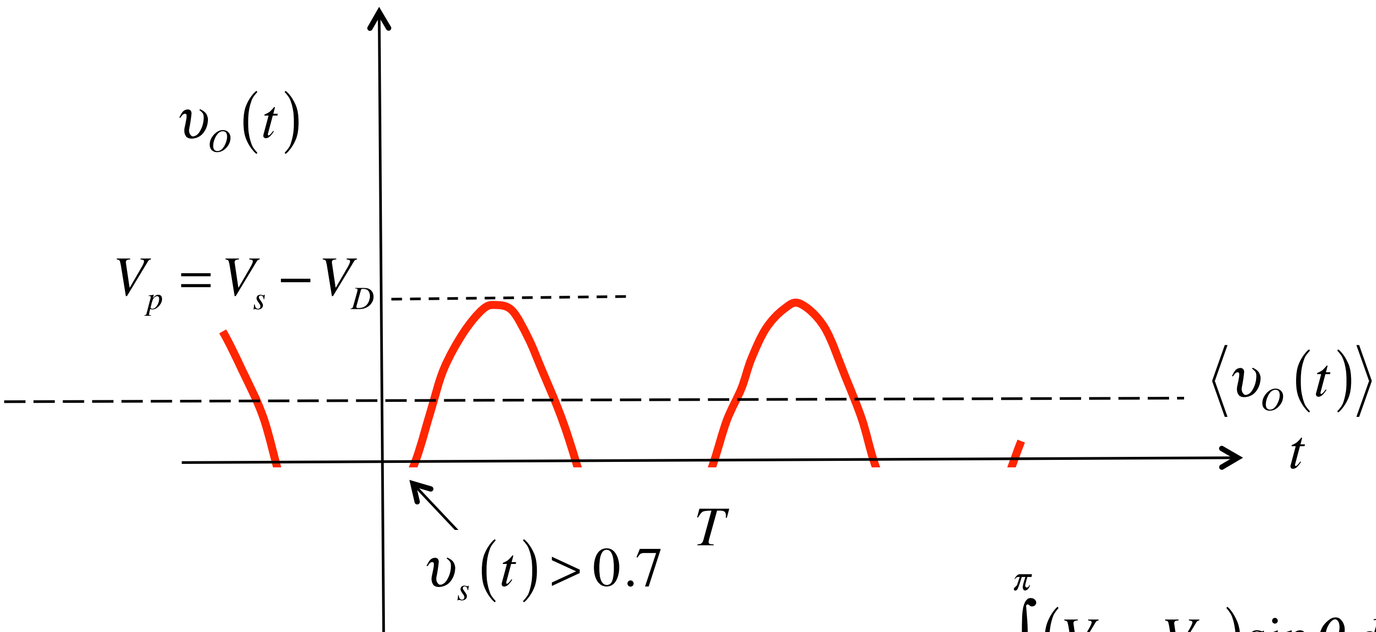
Rectifiers, Clamps, and Special Diodes

1) Rectifiers
2) Diode limiters and clamps
3) Special diodes

Half wave rectifier



Half wave rectifier

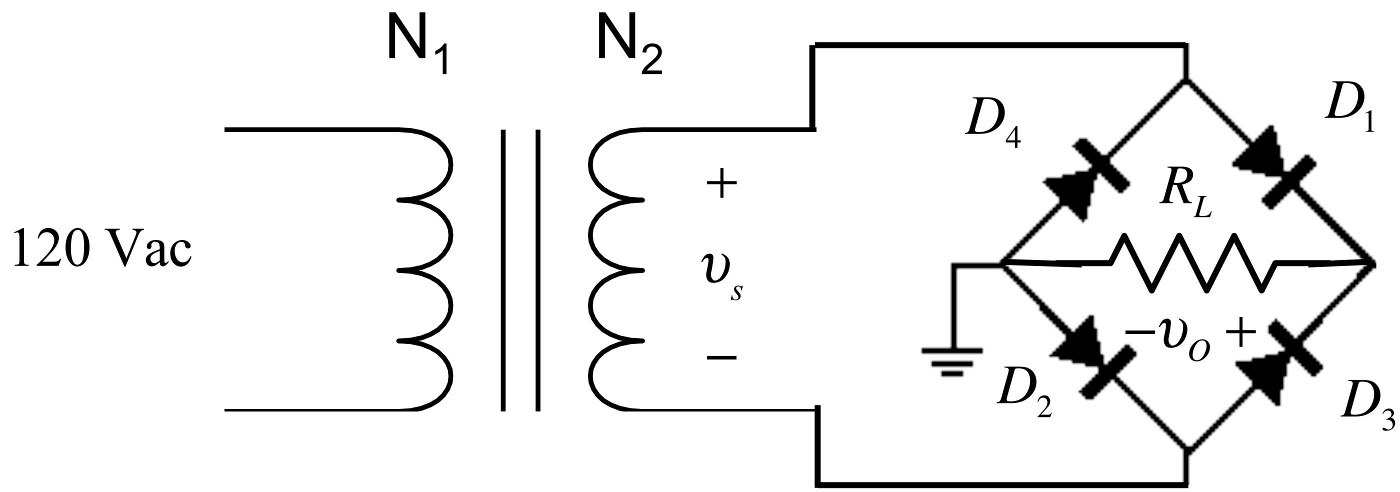


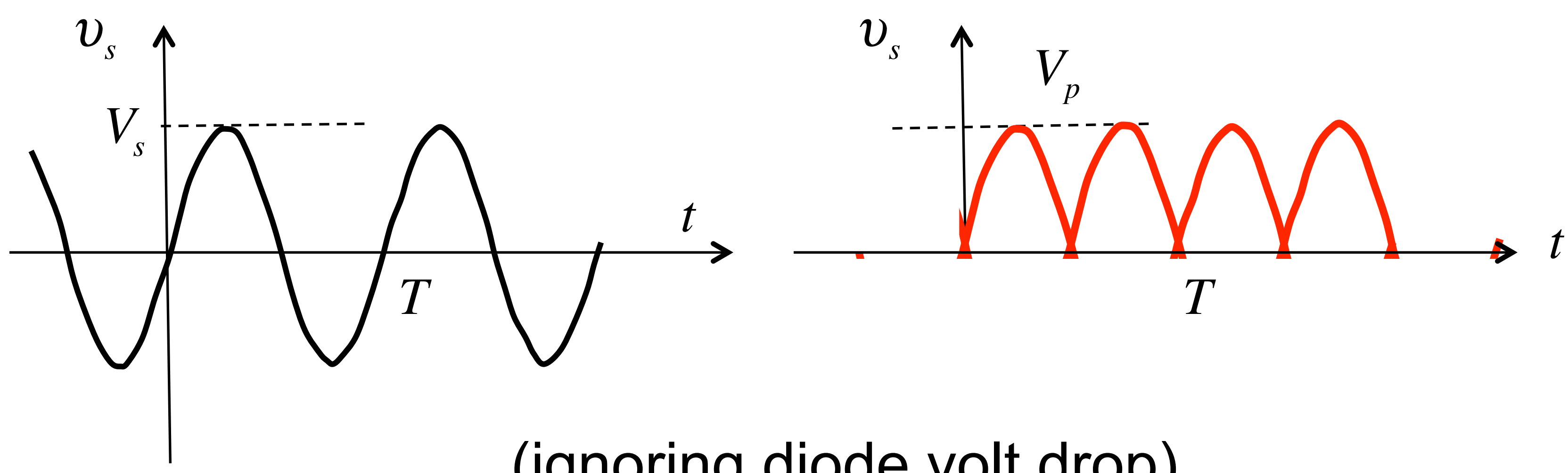
Average output V: $V_O = \langle v_O(t) \rangle \approx \dfrac{\int_0^{\pi} (V_S - V_D)\sin\theta \, d\theta}{2\pi} = \dfrac{(V_S - V_D)}{\pi}$

Ripple voltage: $V_r = v_o\big|_{\max} - v_o\big|_{\min} = (V_S - V_D)$

Peak Inverse Voltage: $PIV = V_s$

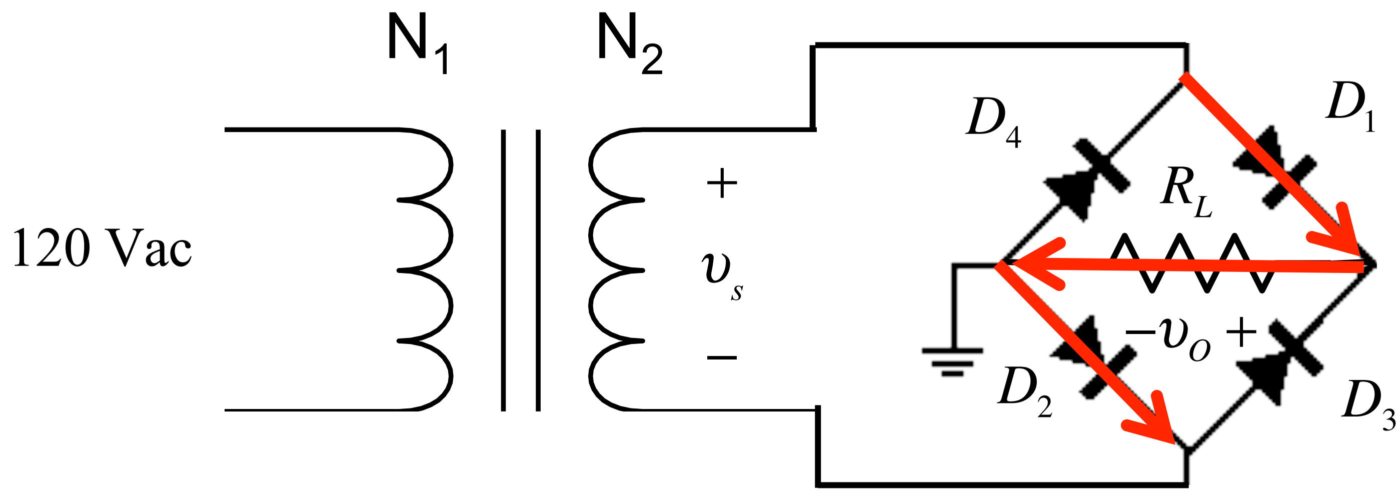
Full wave (bridge) rectifier





(ignoring diode volt drop)

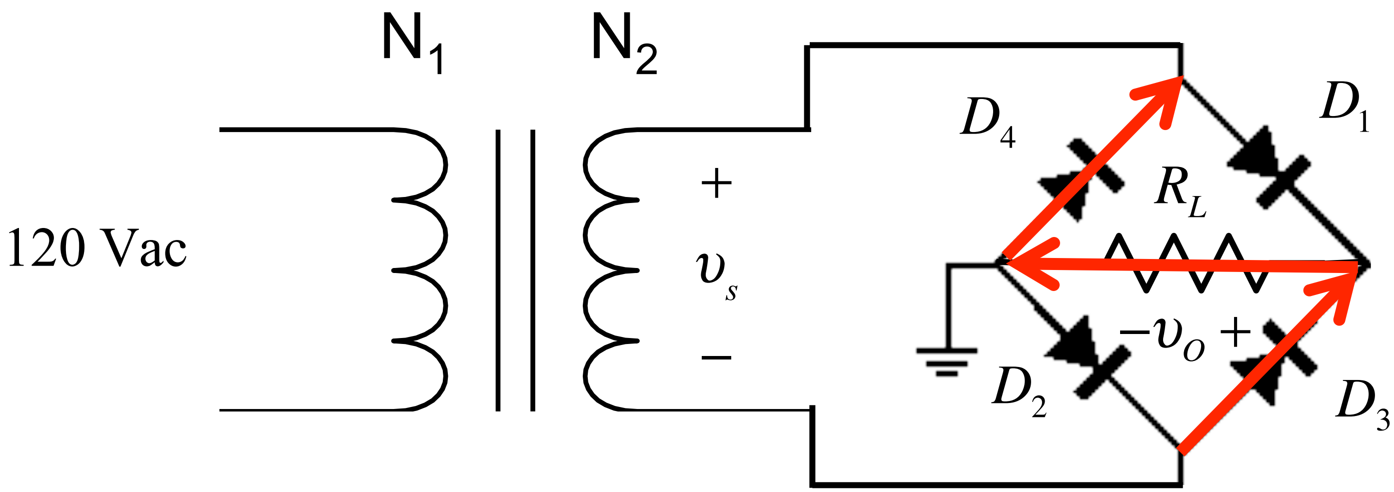
+ half of cycle



D1 and D2 on (FB)

$$V_p = V_s - 2V_D$$

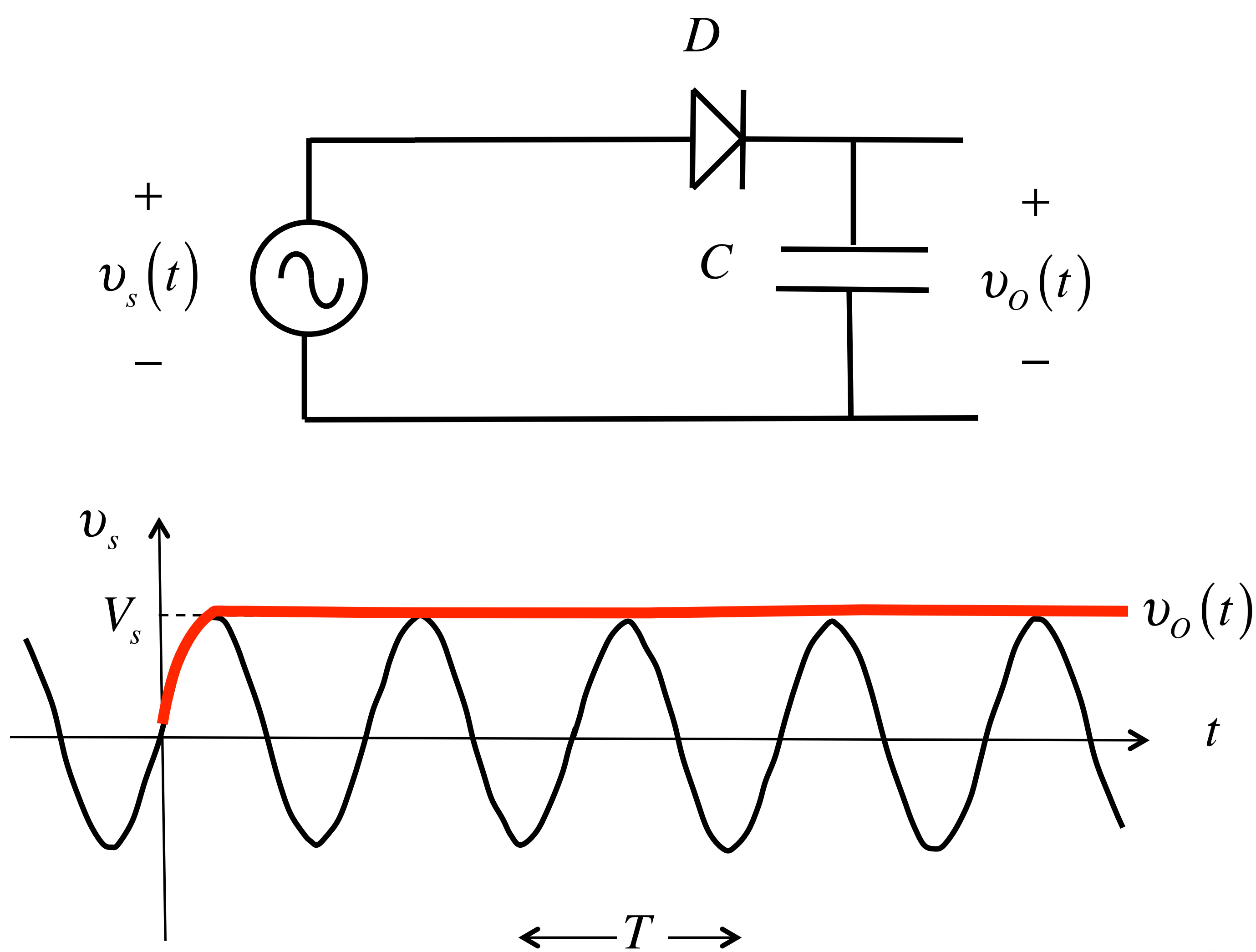
- half of cycle



D3 and D4 on (FB)

$$V_p = V_s - 2V_D$$

Peak rectifier (peak detector)



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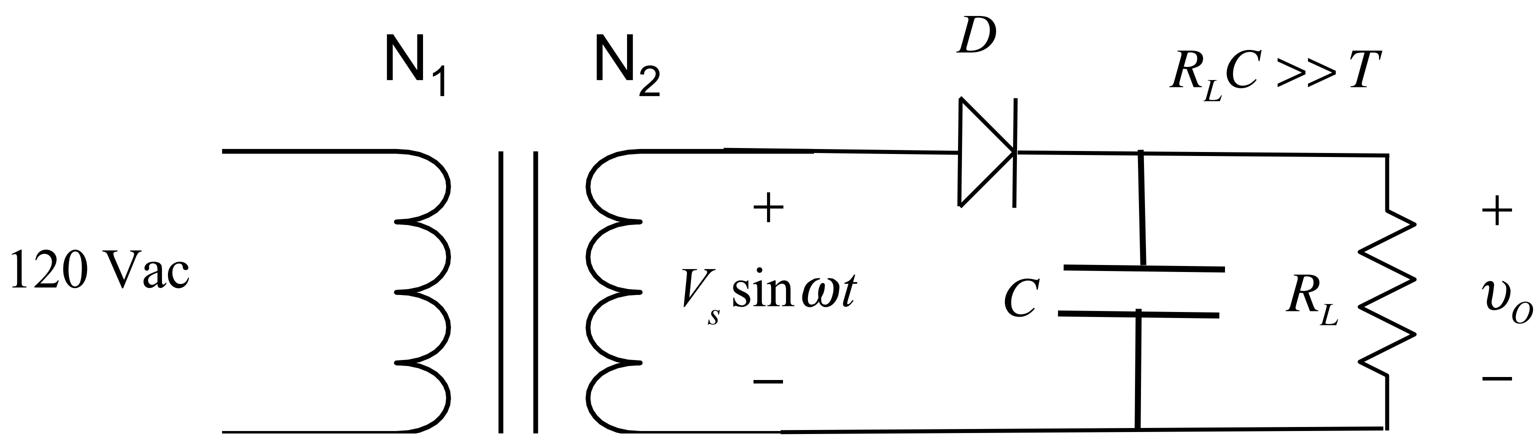
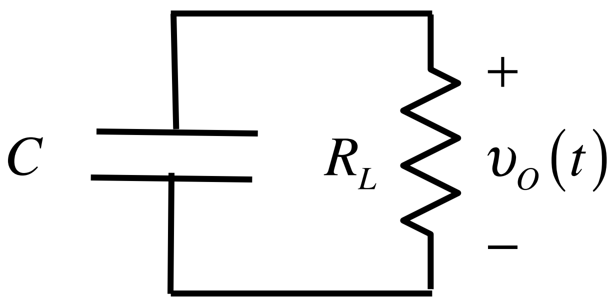
RC filter for half wave rectifier

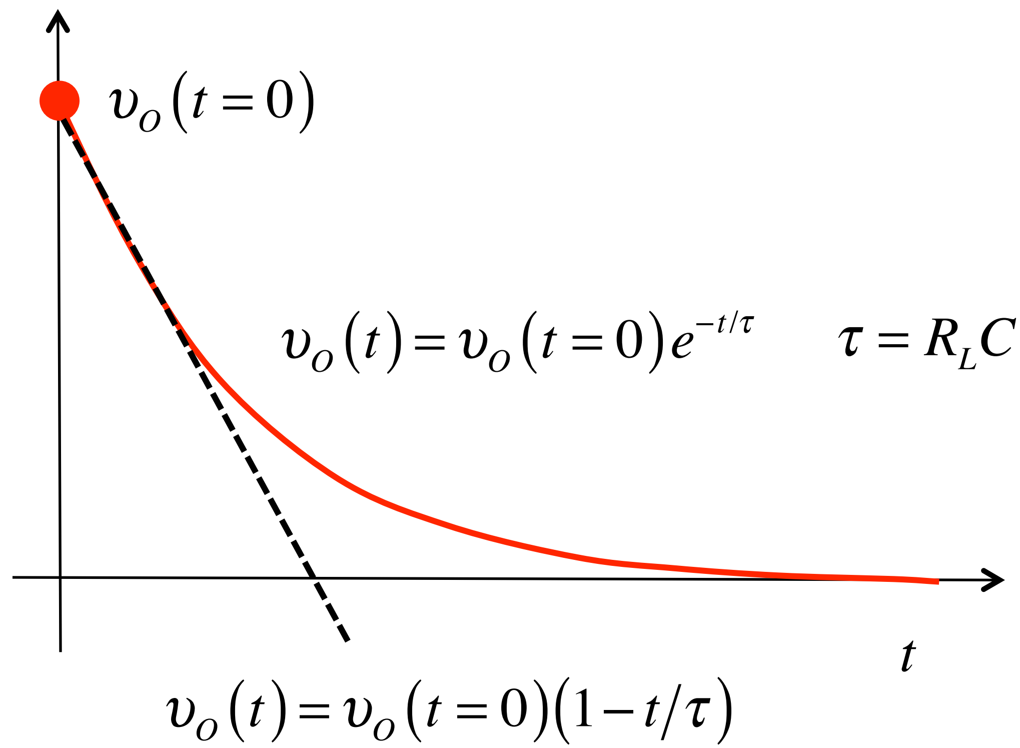


We **expect** that to make the output voltage nearly constant, we should have:

$$\tau = R_L C >> T$$

RC decay

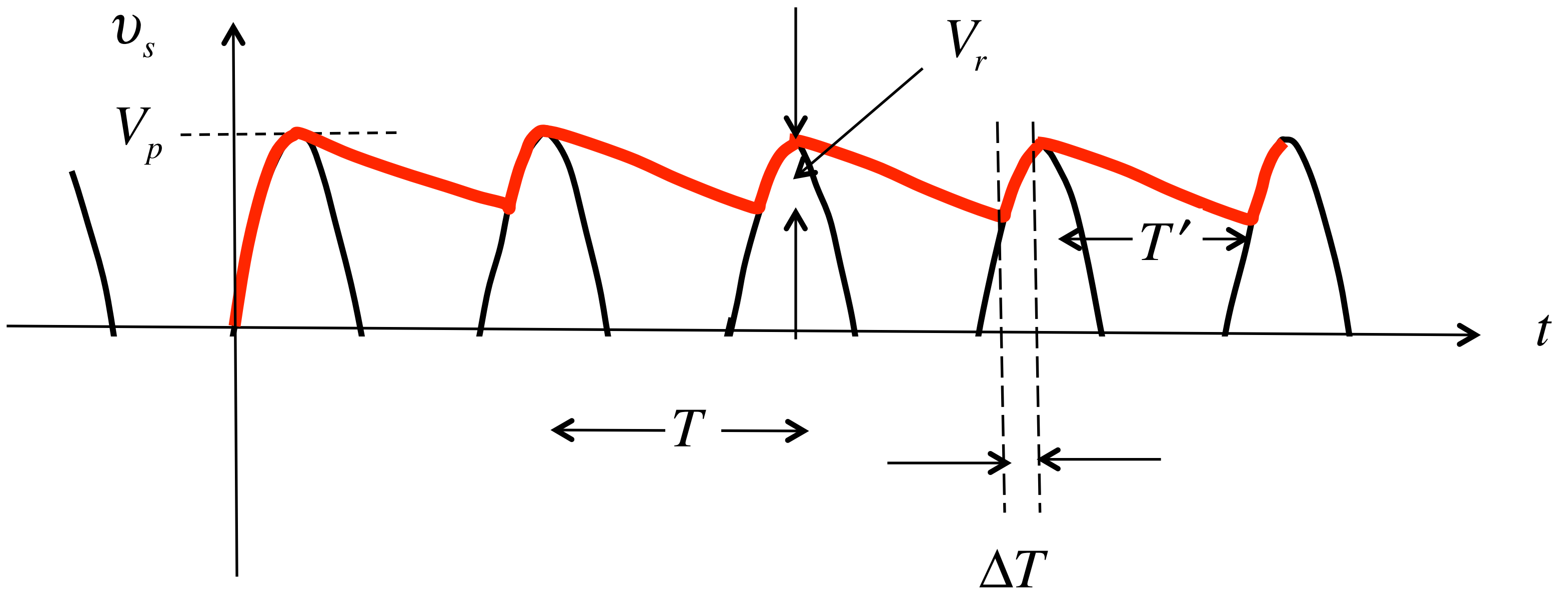




Taylor series expansion for small x

$$e^{-x} = 1 - x$$

RC filter



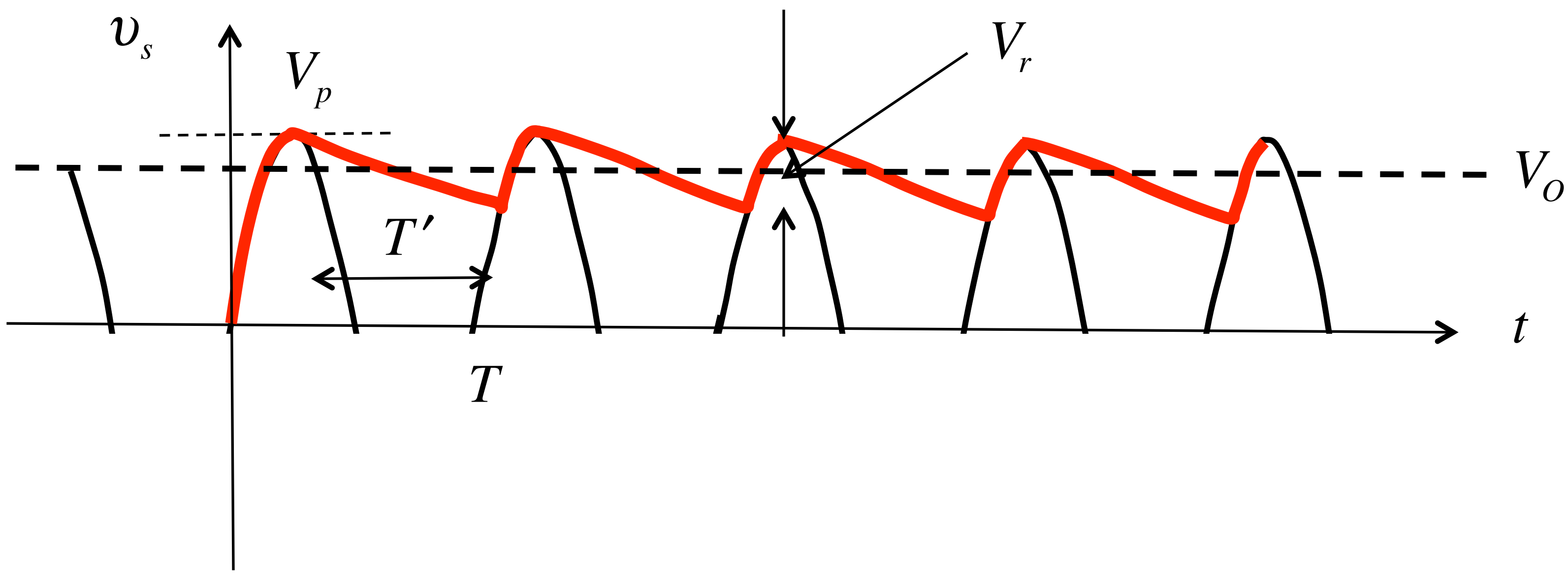
$T' = T - \Delta T$ Good filter: $\Delta T << T$ $\tau = R_L C >> T$

Ripple V:

$$V_r = V_p - V_p e^{-T/\tau} = V_p\left(1 - e^{-T/\tau}\right) = V_p\left(1 - \left(1 - T/\tau\right)\right) = V_p \frac{T}{R_L C}$$

$$\boxed{V_r = V_p \frac{T}{R_L C}}$$

Average output voltage



$$V_r = V_p \frac{T}{R_L C}$$

ripple voltage

$$V_O = V_p - \frac{1}{2} V_r = V_p \left(1 - \frac{T}{2 R_L C} \right)$$

average output voltage

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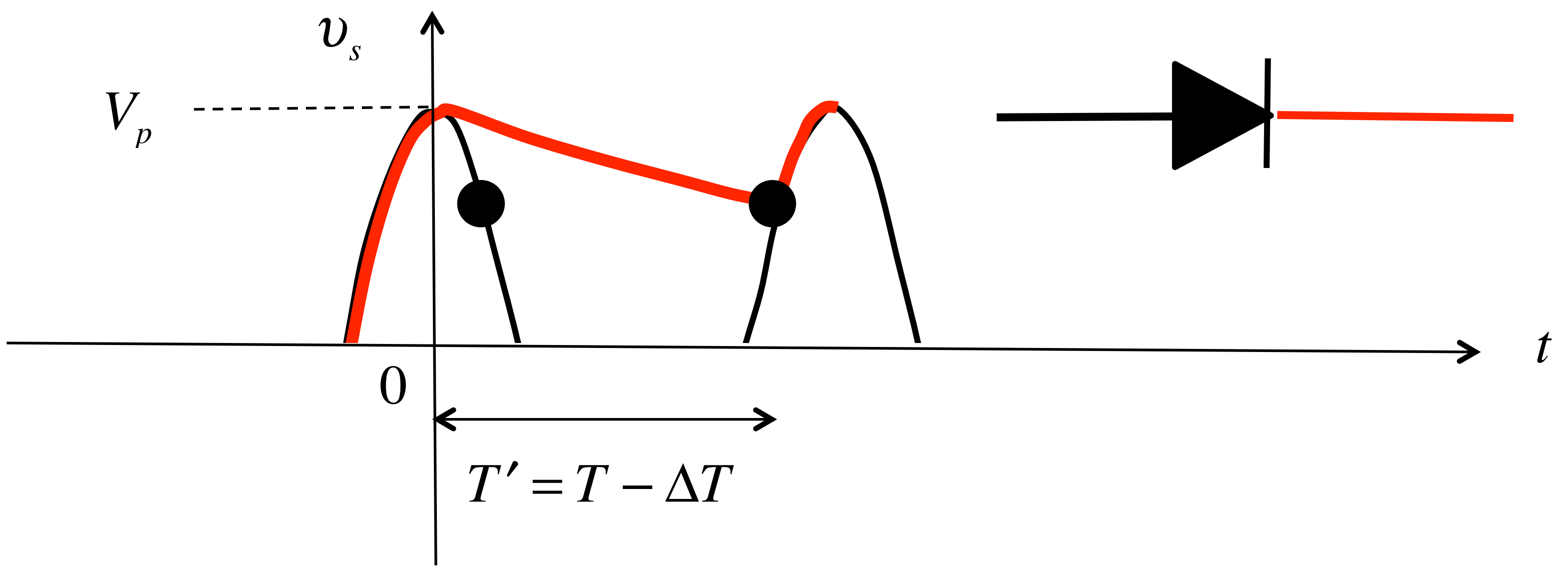
ΔT



$$V_p \cos\omega\left(T - \Delta T\right) = V_p \cos\omega\left(\Delta T\right) = V_p - V_r$$

$$\cos\omega\,\Delta T = 1 - \frac{V_r}{V_p}$$

$$\cos x \approx 1 - \frac{x^2}{2}$$

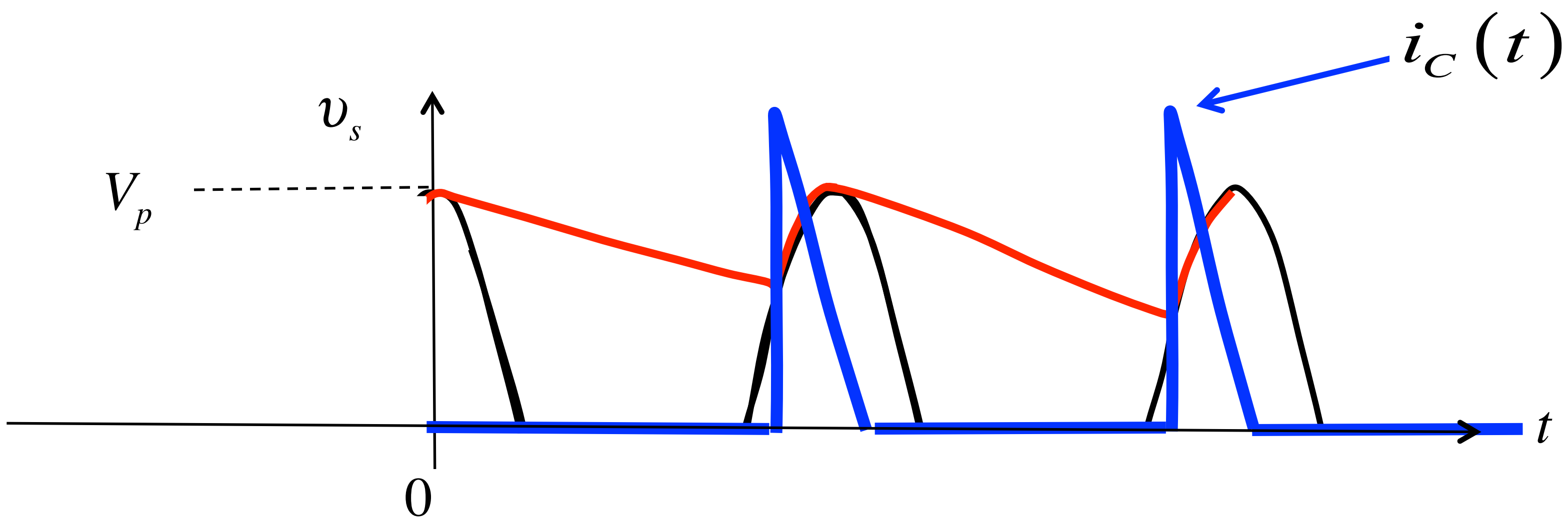
$$1 - \frac{\left(\omega\,\Delta T\right)^2}{2} = 1 - \frac{V_r}{V_p}$$

$$\omega\,\Delta T = \sqrt{\frac{2V_r}{V_p}}$$

$$\frac{\Delta T}{T} = \frac{1}{2\pi}\sqrt{\frac{2V_r}{V_p}}$$

$$\Delta T << T$$

Capacitor current



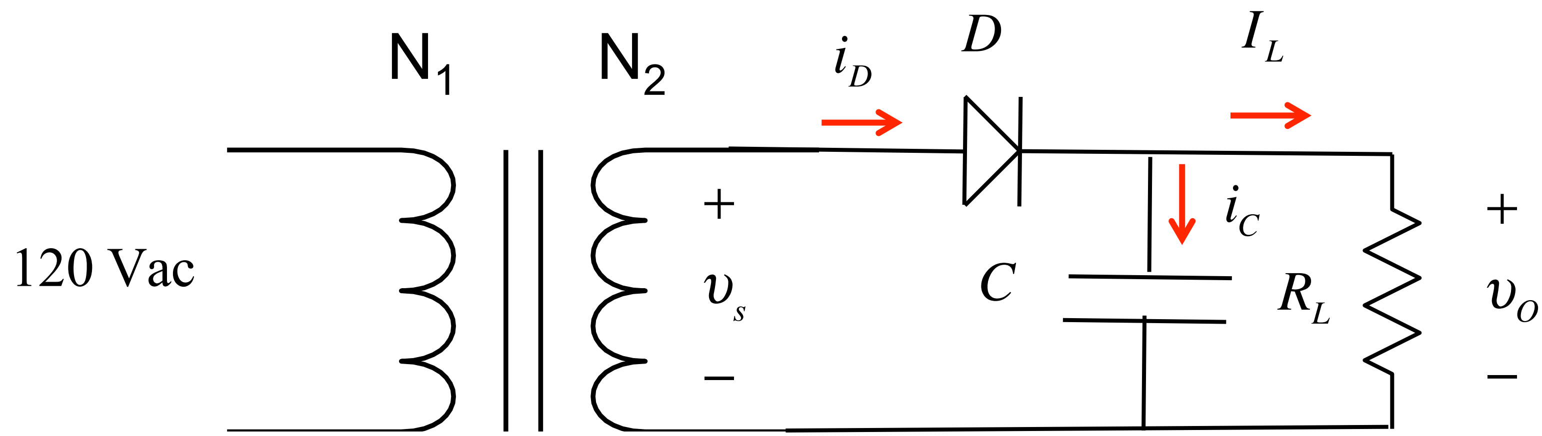
$$Q_{out} = CV_r \qquad \frac{1}{2} i_C(\max)\Delta T = CV_r \qquad i_C(\max) = 2\frac{T}{\Delta T}\left(\frac{V_p}{R_L}\right)$$

Large!

$$Q_{in} = \frac{1}{2} i_C(\max)\Delta T \qquad i_C(\max) = 2\frac{CV_r}{\Delta T} \qquad \left(\frac{V_p}{R_L}\right) \approx R_L$$

$$Q_{in} = Q_{out} \qquad V_r = V_p \frac{T}{R_L C} \qquad i_C(\max) = 2\frac{T}{\Delta T} I_L$$

Maximum diode current



$$i_C(\max) = 2\frac{T}{\Delta T} I_L$$

$$i_D(\max) = I_L + i_C(\max)$$

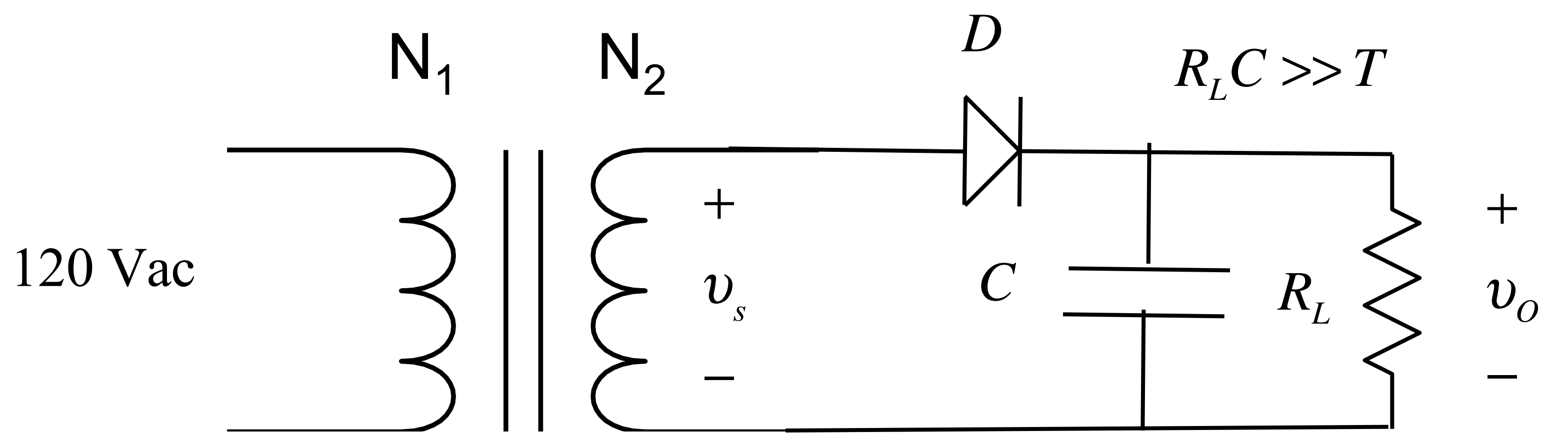
$$\frac{\Delta T}{T} = \frac{1}{2\pi}\sqrt{\frac{2V_r}{V_p}}$$

$$i_D(\max) = I_L\left(1 + 2\pi\sqrt{\frac{2V_p}{V_r}}\right)$$

$$i_C(\max) = 4\pi\sqrt{\frac{V_p}{2V_r}} I_L$$

Sedra and Smith, eqn. 4.32)

Summary



Ripple voltage: $V_r = V_p \frac{T}{RC}$

dc output voltage: $V_O = V_p - \frac{1}{2} V_r = V_p \left(1 - \frac{T}{2 R_L C} \right)$

Max diode current: $i_D(\max) = I_L \left(1 + 2\pi \sqrt{\frac{2V_p}{V_r}} \right) >> I_L$

Peak inverse voltage: $PIV = 2V_s$

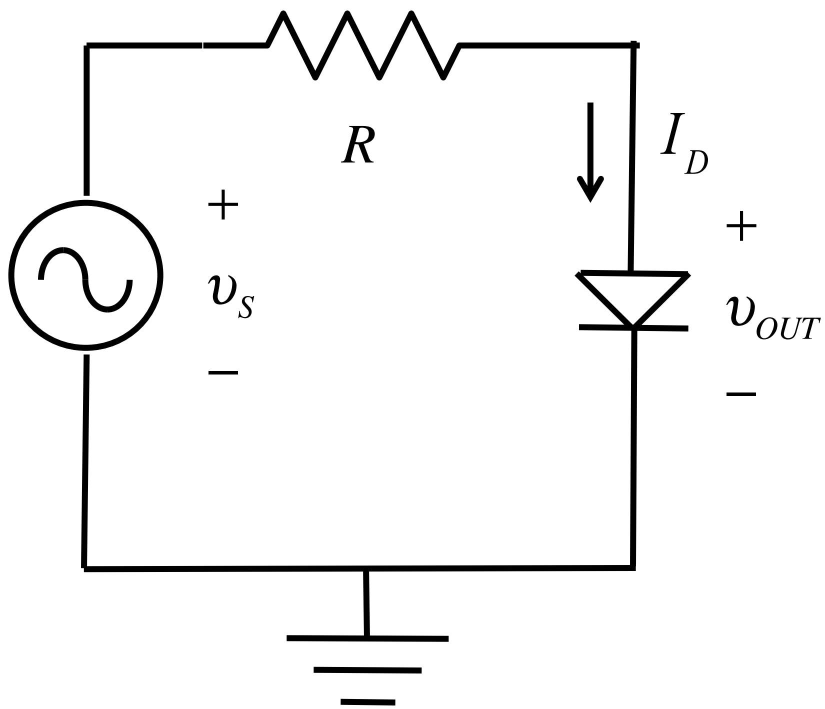
Outline

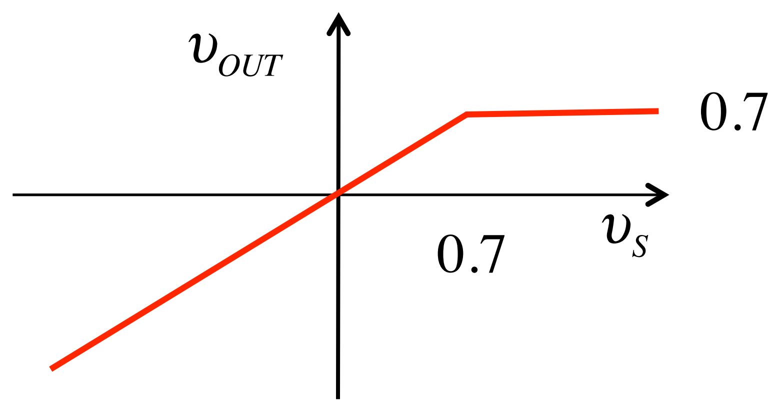
1) Rectifiers

2) Diode limiters and clamps (Sec. 4.6.2)

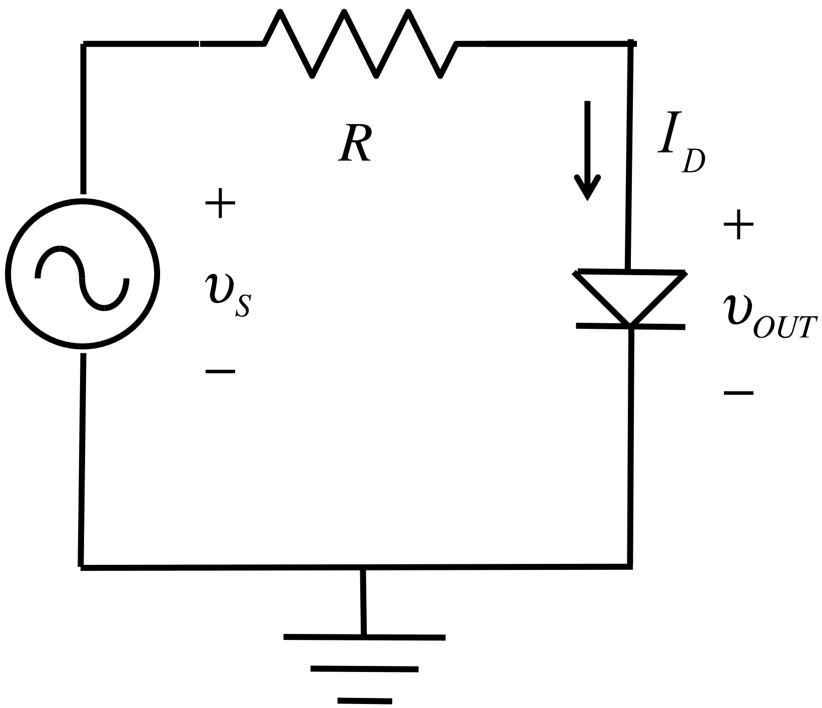
3) Other diodes

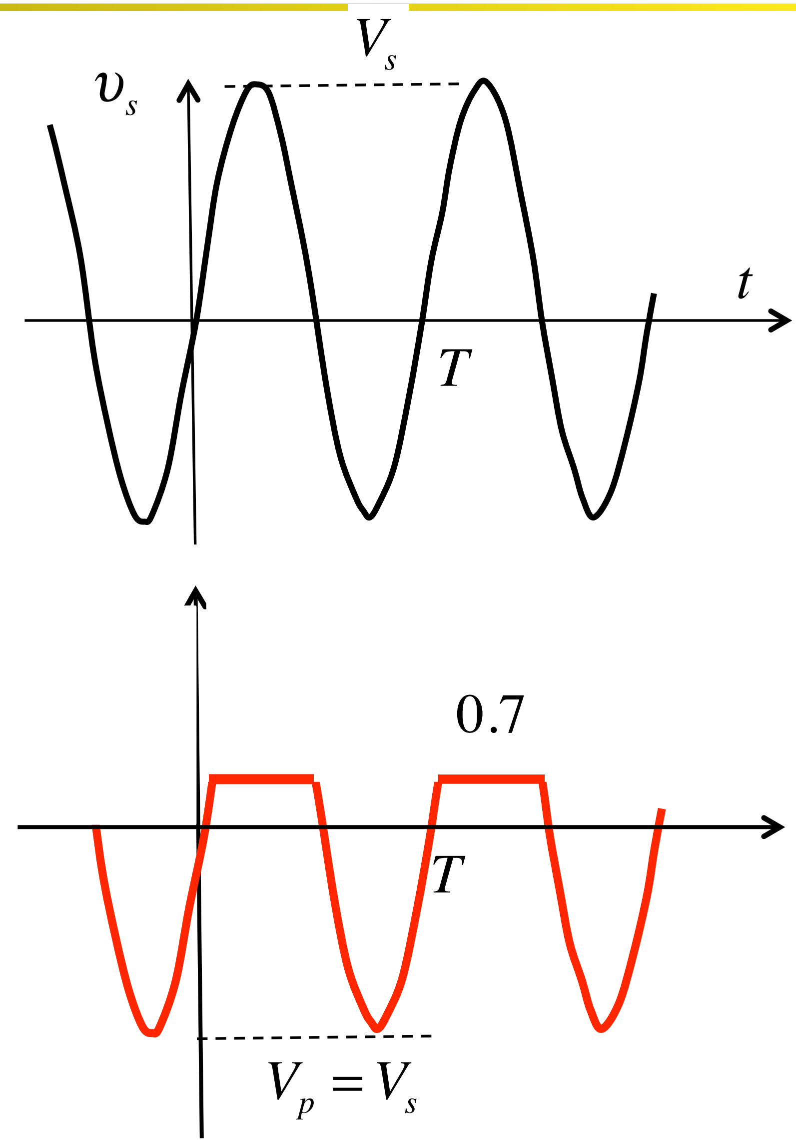
Limiter Circuit with Diode



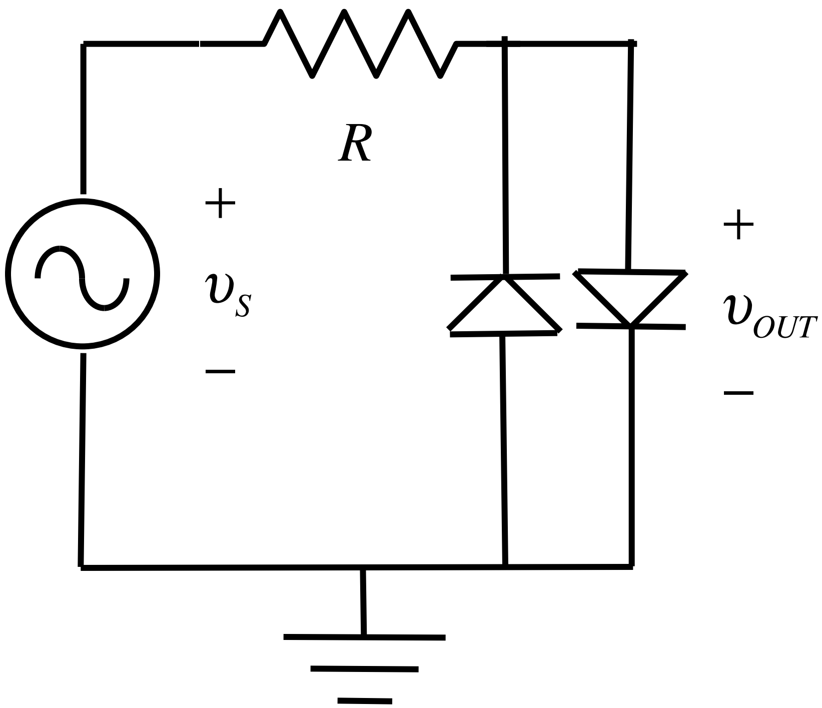


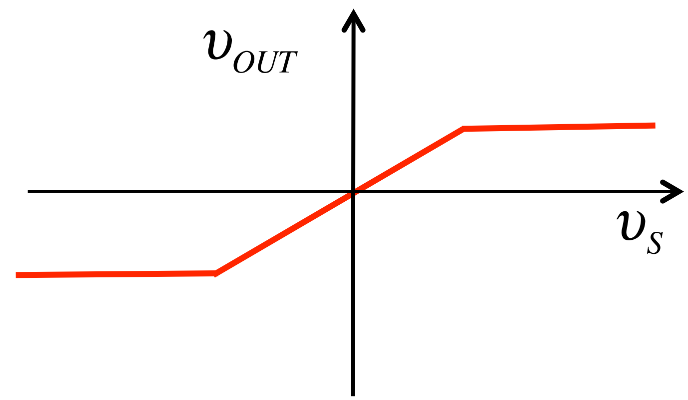
Limiter Circuit with Diode



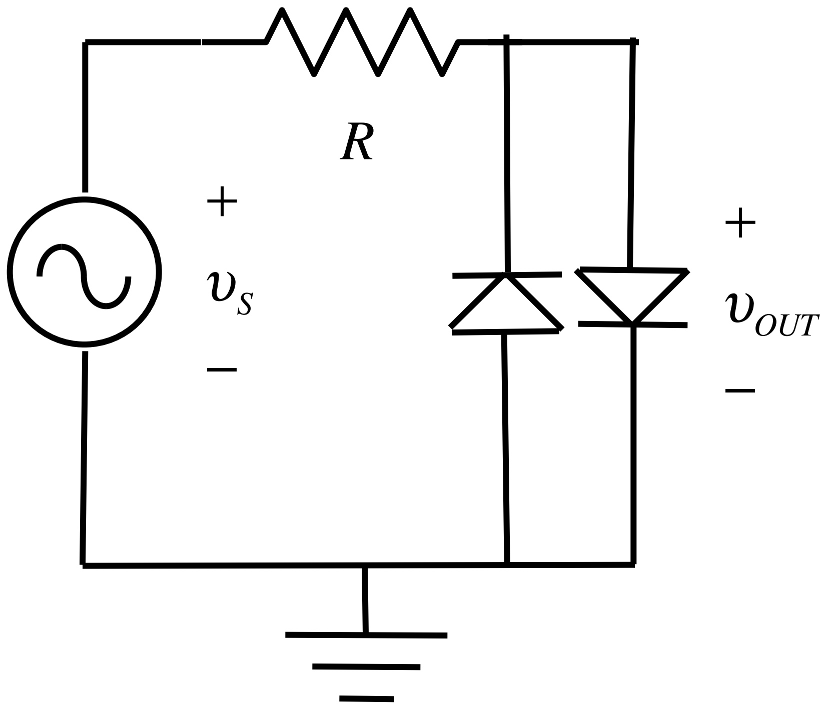


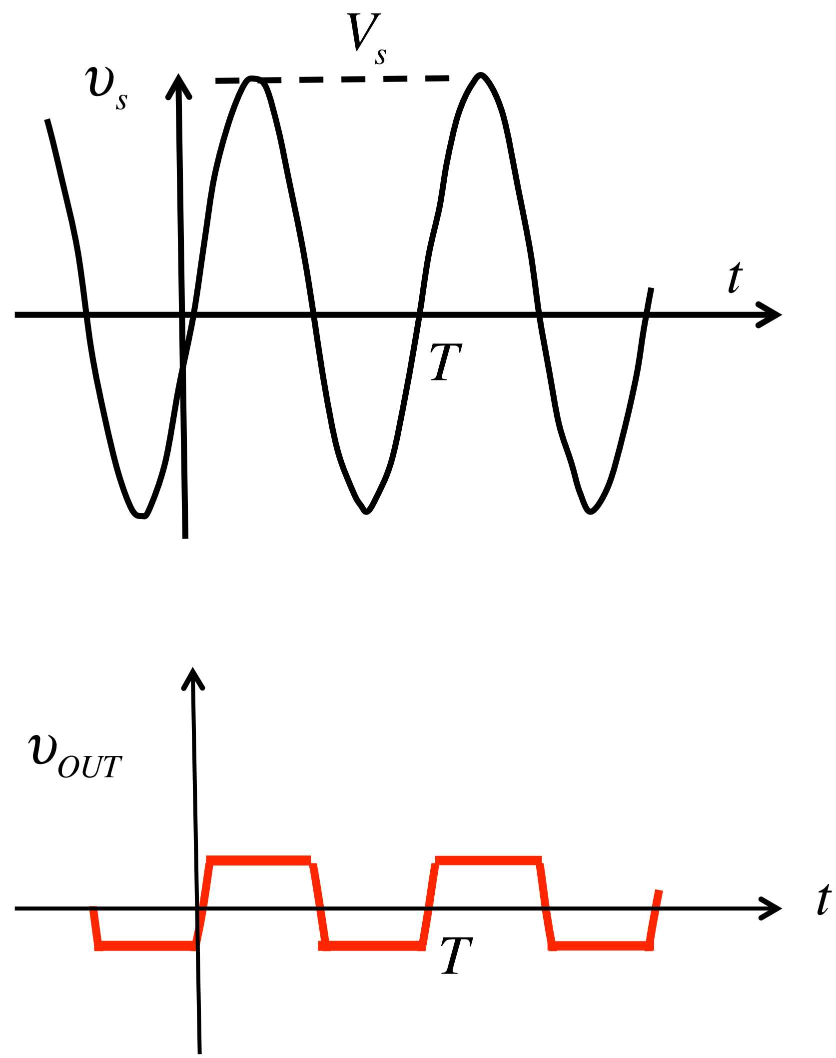
Limiter/Clamping Circuit with Diodes



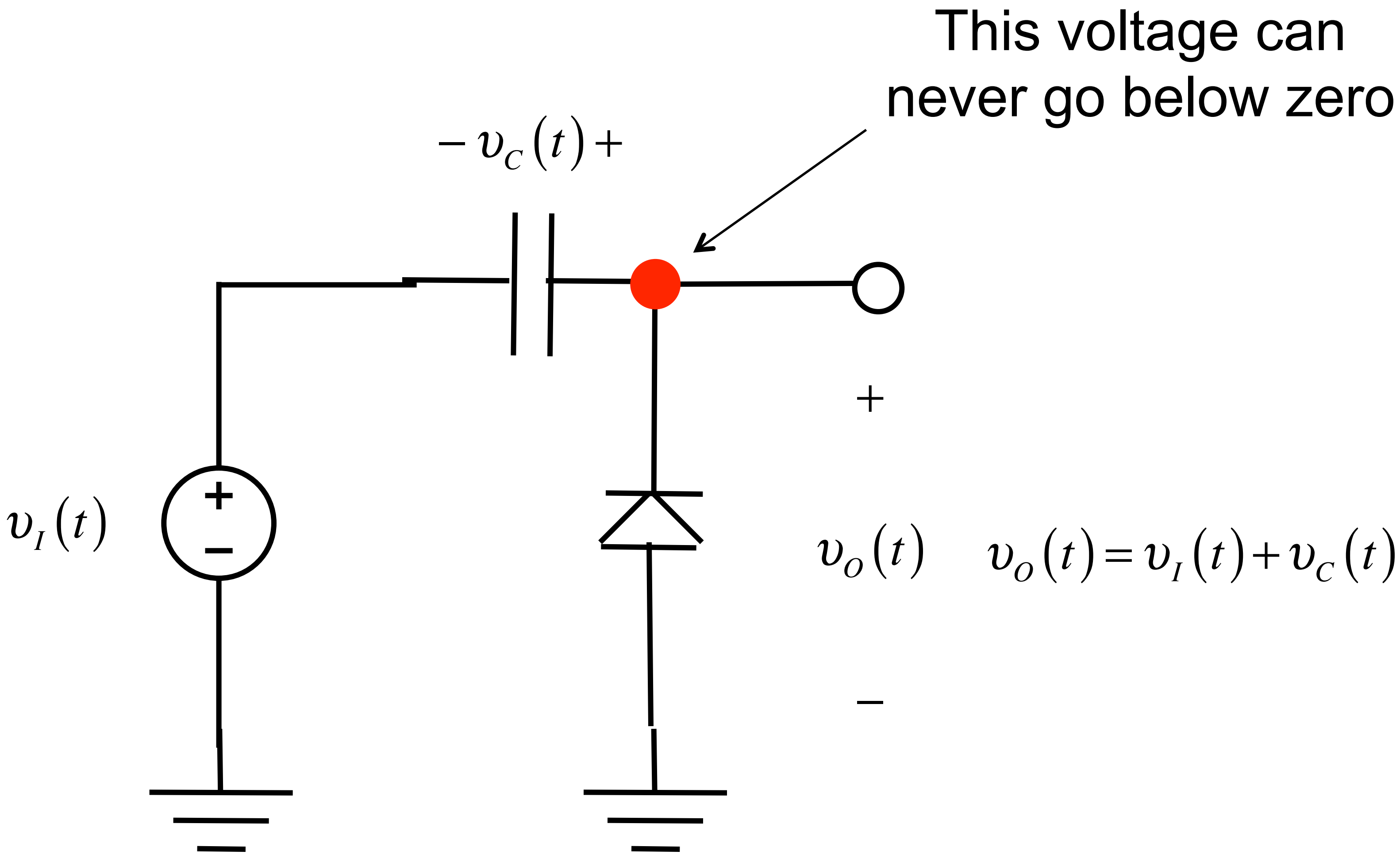


Limiter/Clamping Circuit with Diodes



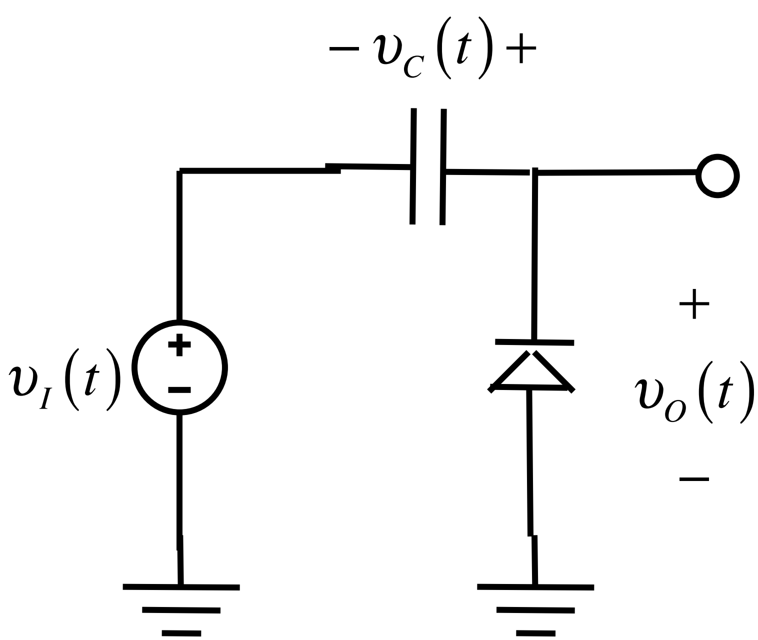


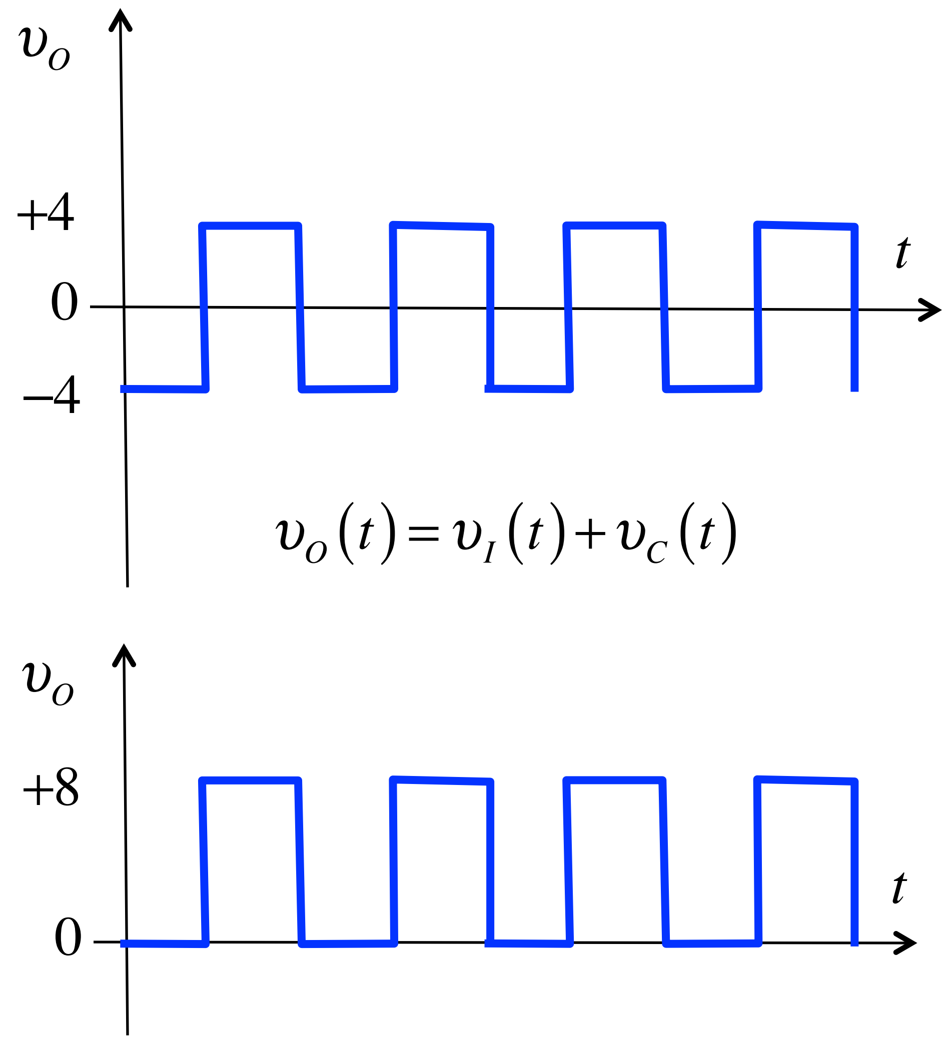
The circuit



This voltage can never go below zero!
$-\upsilon_C(t)+$
$\upsilon_I(t)$
+
$\upsilon_O(t)$
−
$\upsilon_O(t) = \upsilon_I(t) + \upsilon_C(t)$

clamped capacitor





The voltage doubler

See if you can understand the voltage doubler circuit described in Sec. 4.6.3 of Sedra and Smith.

Outline

1) Rectifiers

2) Diode limiters and clamps

3) Other diodes

Diodes

1) Schottky Barrier Diodes (MS diodes)

2) Varactors

3) Photodiodes

4) Light-emitting diodes

Summary

Diodes have several useful applications

There are several different kinds of diodes

Diodes are a simple example of how we model nonlinear electronics devices.

DC model

AC small signal models (model parameter values depend on DC bias).

Modeling diodes

1) Rectifiers

2) Diode limiters and clamps

3) Other diodes