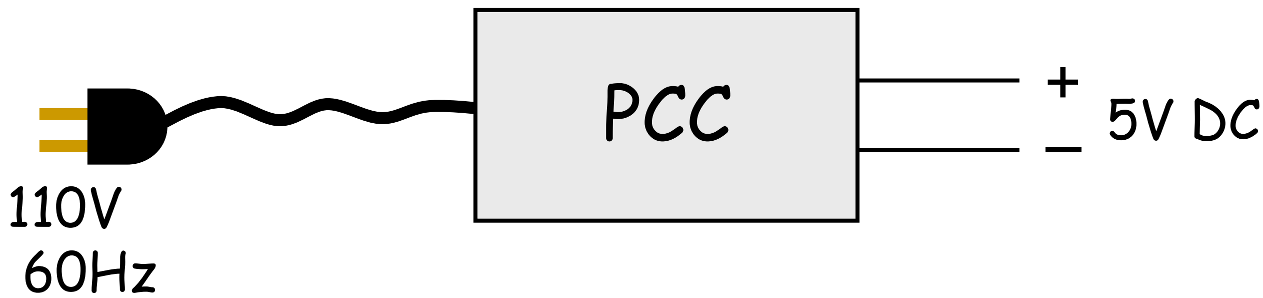
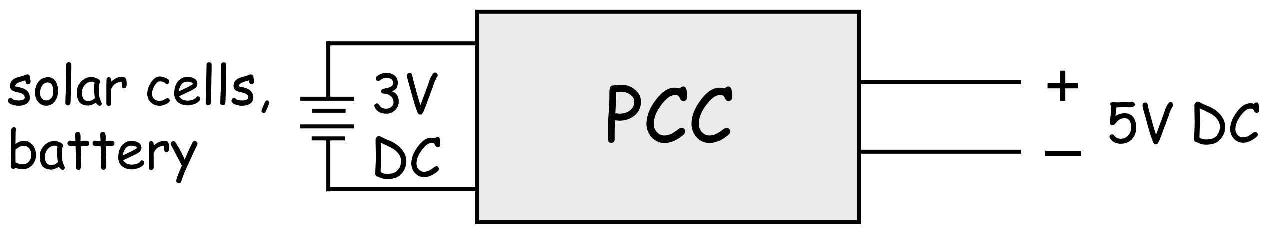
Power Conversion Circuits and Diodes

Power Conversion Circuits (PCC)





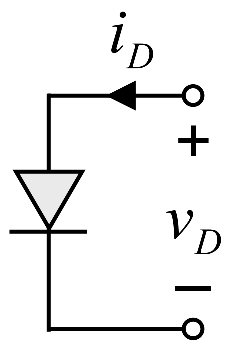
DC-to-DC UP converter

Power efficiency of converter important, so use lots of devices:

MOSFET switches, clock circuits, inductors, capacitors, op amps, diodes

Reading: Chapter 16 and 4.4 of A & L.

First, let's look at the diode



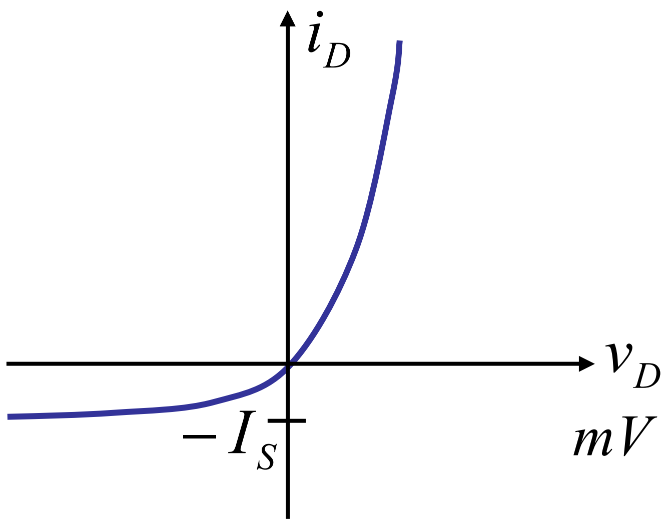
$$i_D = I_S\left(e^{\frac{v_D}{V_T}} - 1\right)$$

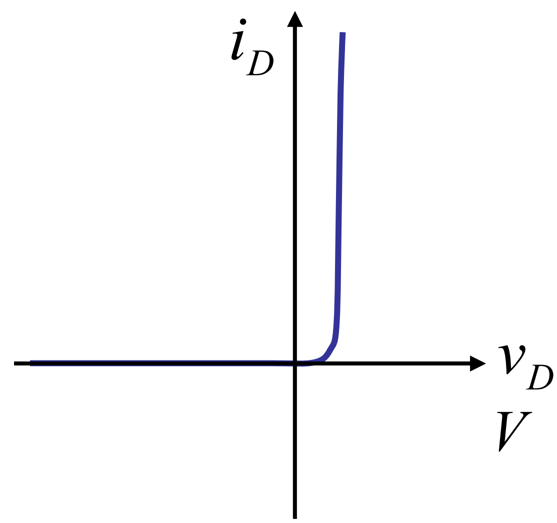
$$I_S = 10^{-12}\,A$$

$$V_T = 0.025V$$

$$V_T = \frac{kT}{q}$$

Boltzmann's constant
temperature in Kelvins
charge of an electron





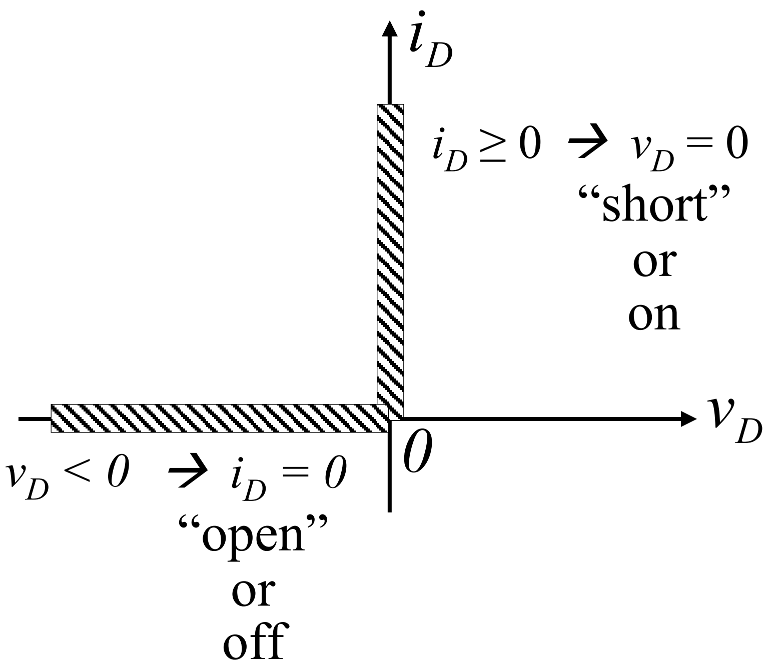
Can use this exponential model with analysis methods learned earlier

- analytical
- graphical
- incremental

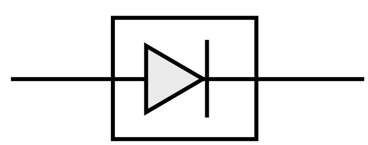
(Our fake expodweeb was modeled after this device!)

Another analysis method: piecewise-linear analysis

P-L diode models:



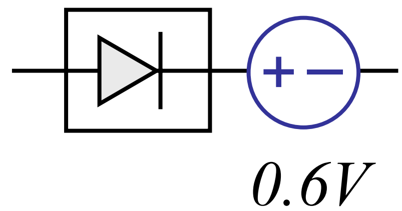
Ideal diode model

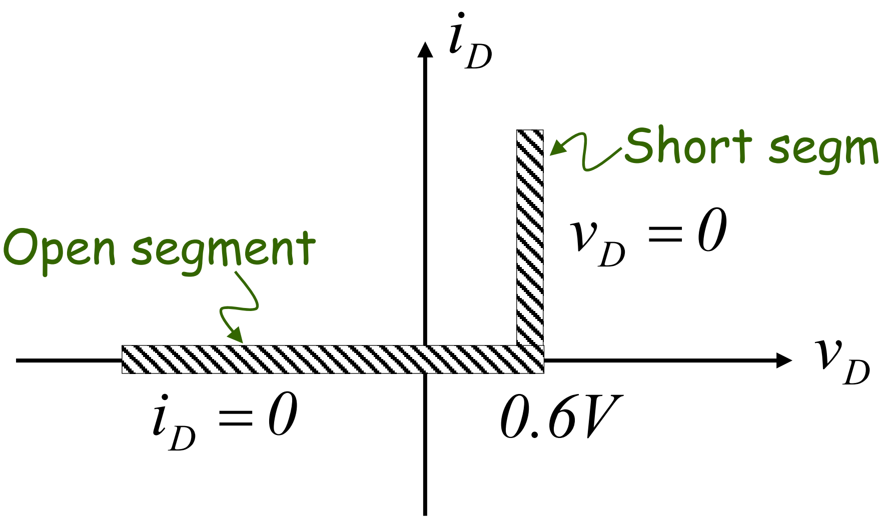


Another analysis method: piecewise-linear analysis

"Practical" diode model

ideal with offset





Another analysis method: piecewise-linear analysis

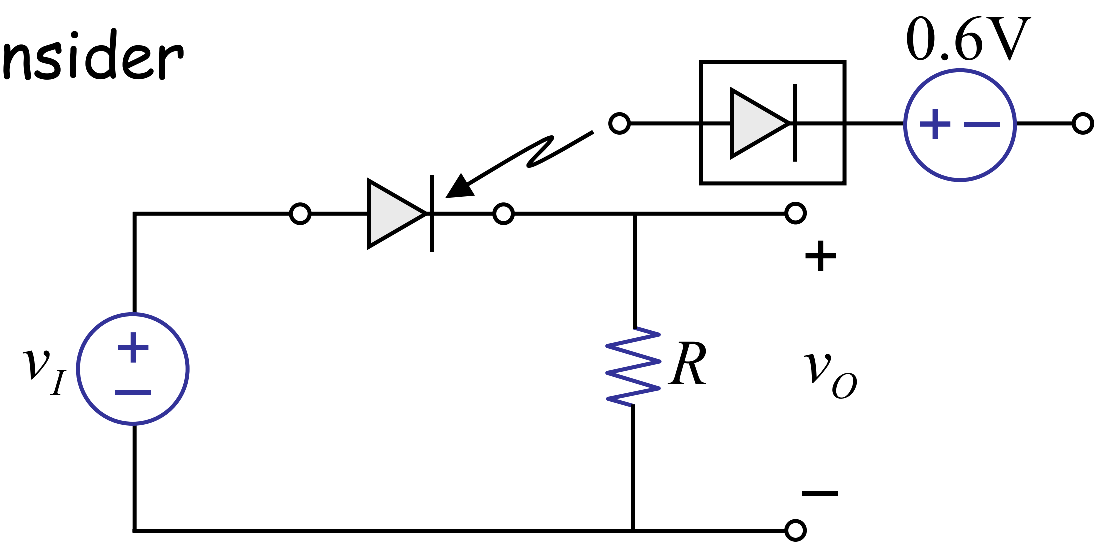
Piecewise-linear analysis method

- Replace nonlinear characteristic with linear segments.
- Perform linear analysis within each segment.

Example

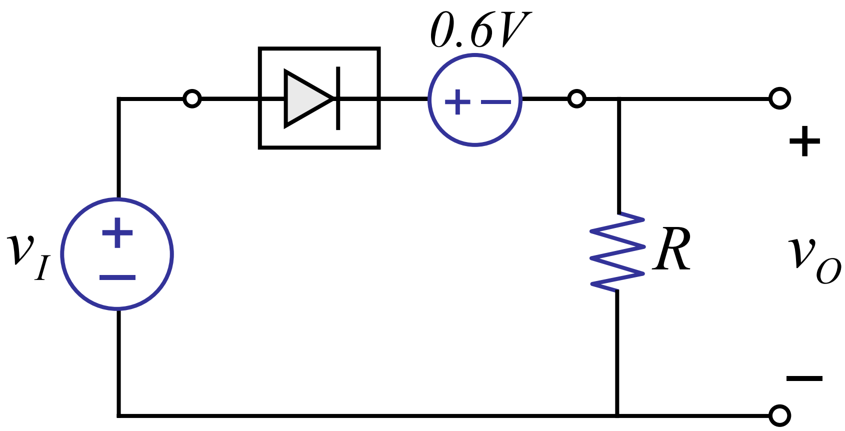
(We will build up towards an AC-to-DC converter)

Consider



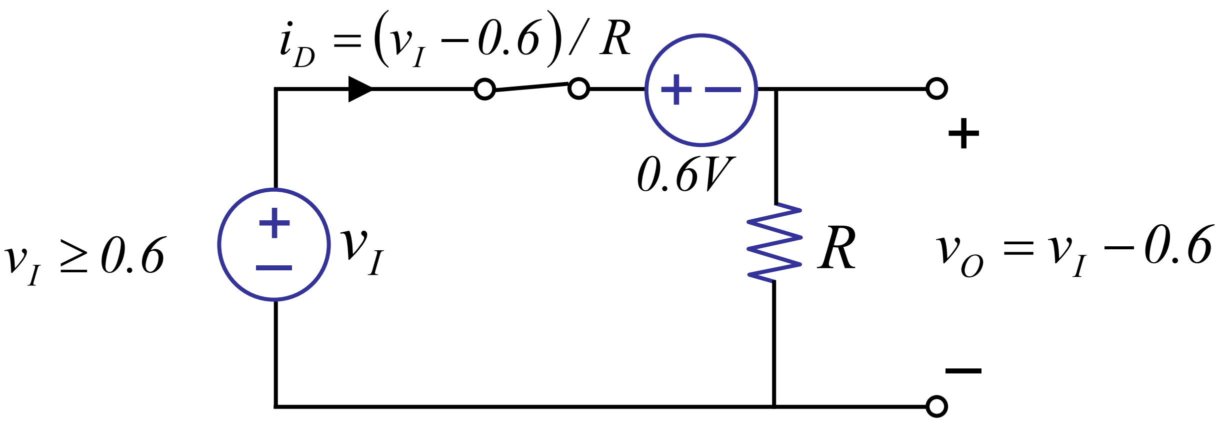
v_I is a sine wave

Example

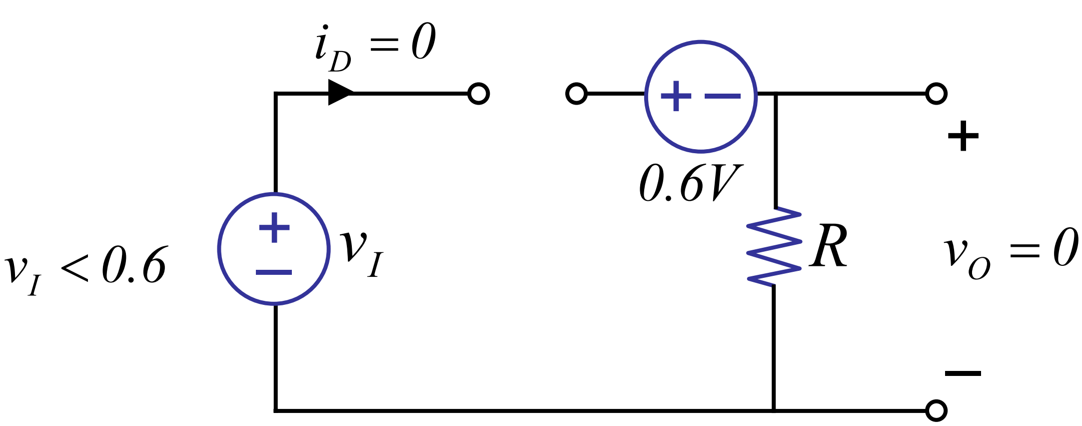


Equivalent circuit

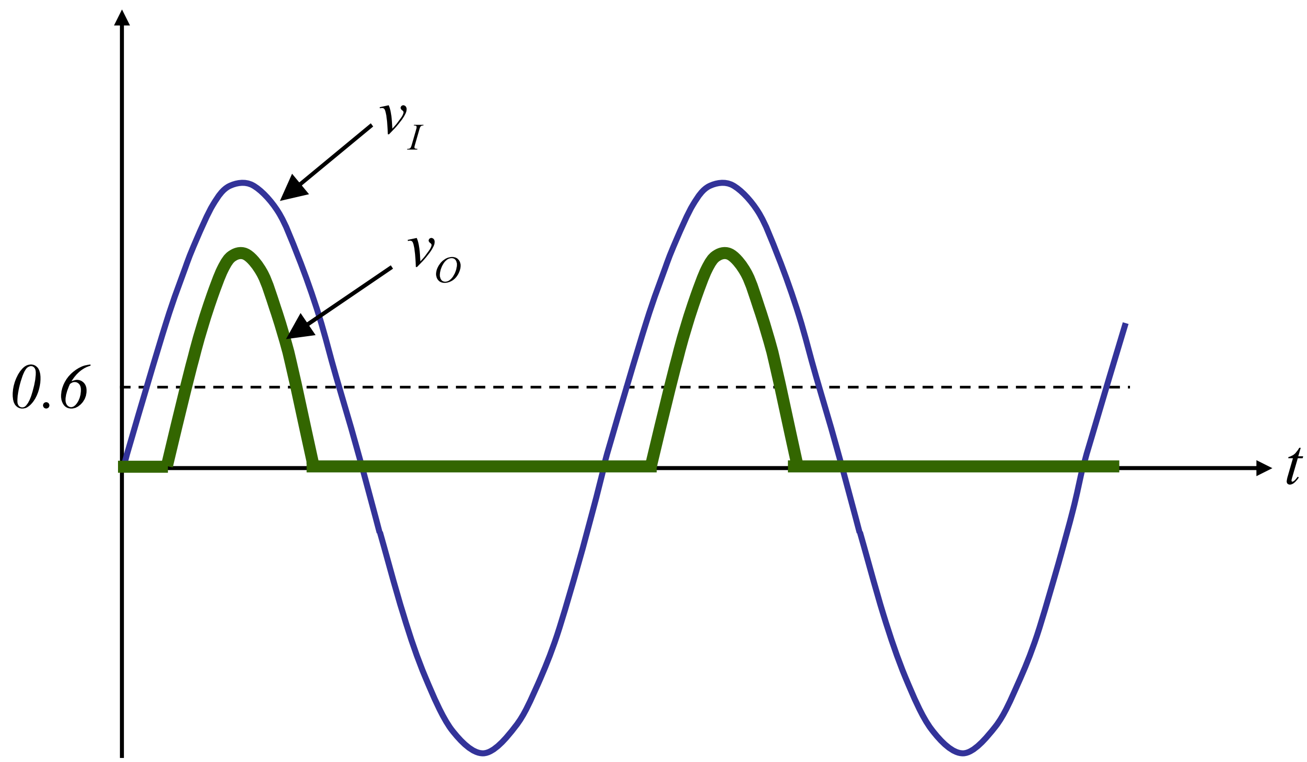
“Short segment”:



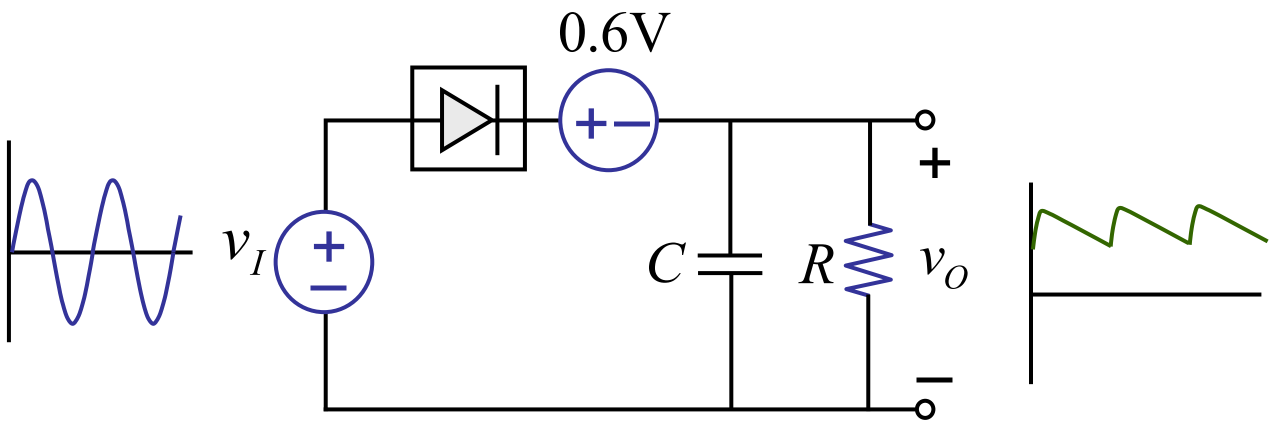
“Open segment”:



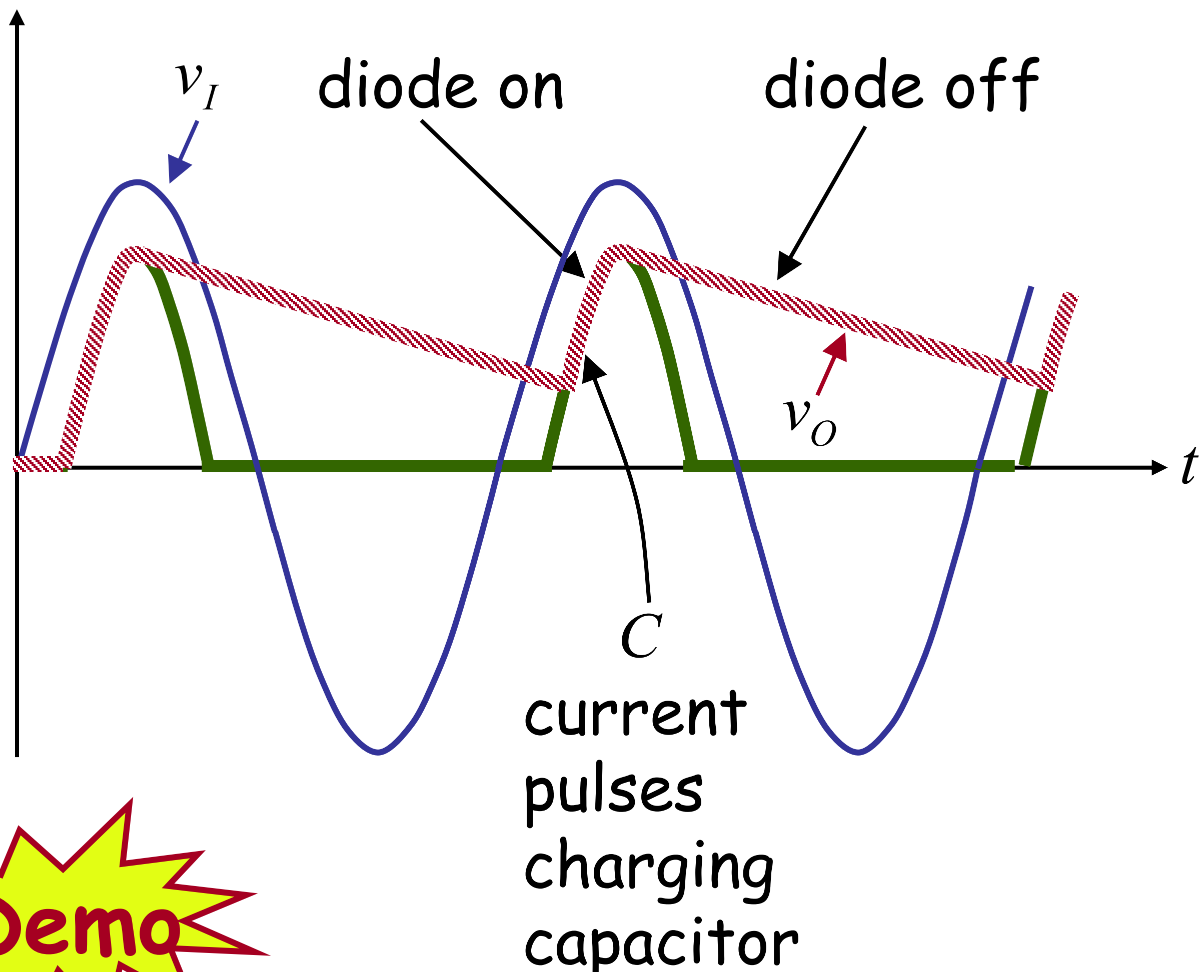
Example



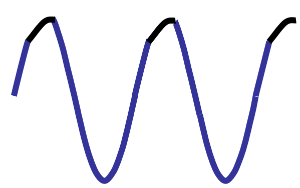
Now consider — a half-wave rectifier



A half-wave rectifier

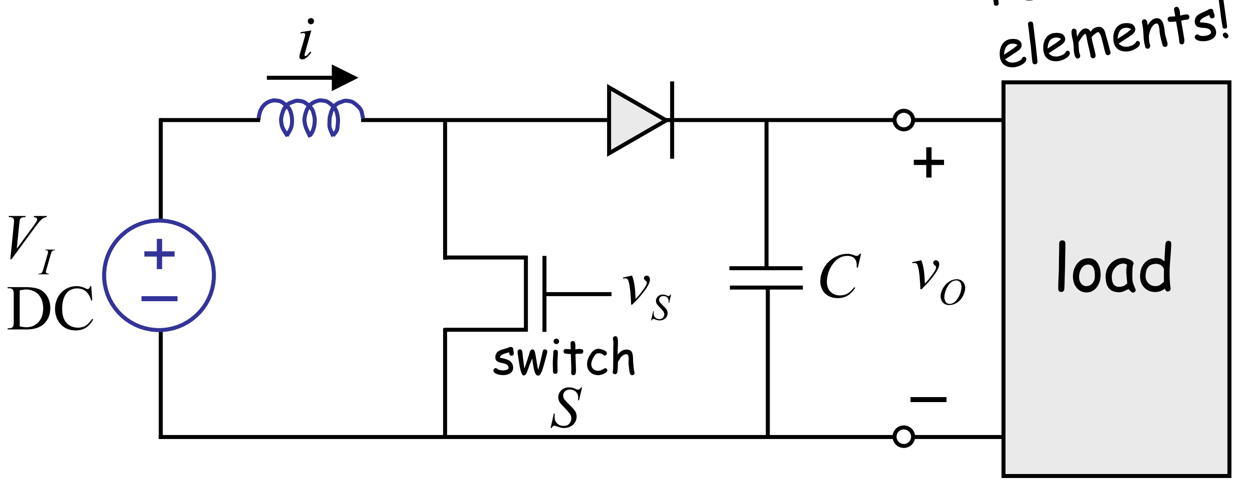


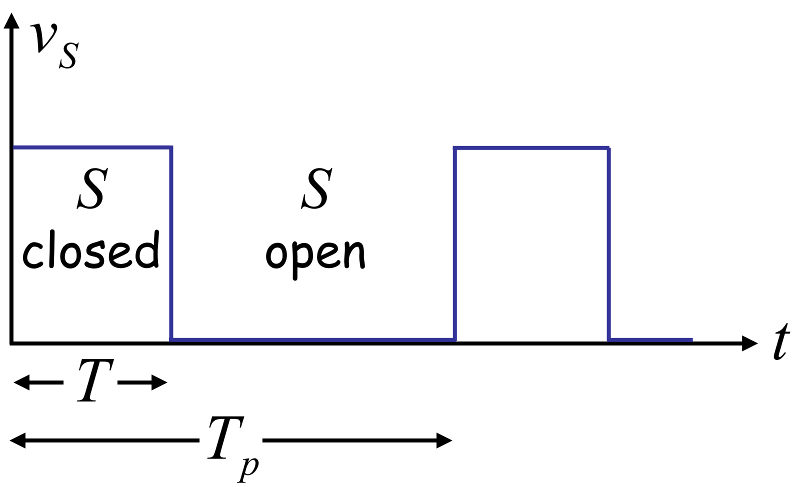
MIT's supply shows "snipping" at the peaks (because current drawn at the peaks)



DC-to-DC UP Converter

Do not use resistive elements!





The circuit has 3 states:

I. S is on, diode is off
i increases linearly

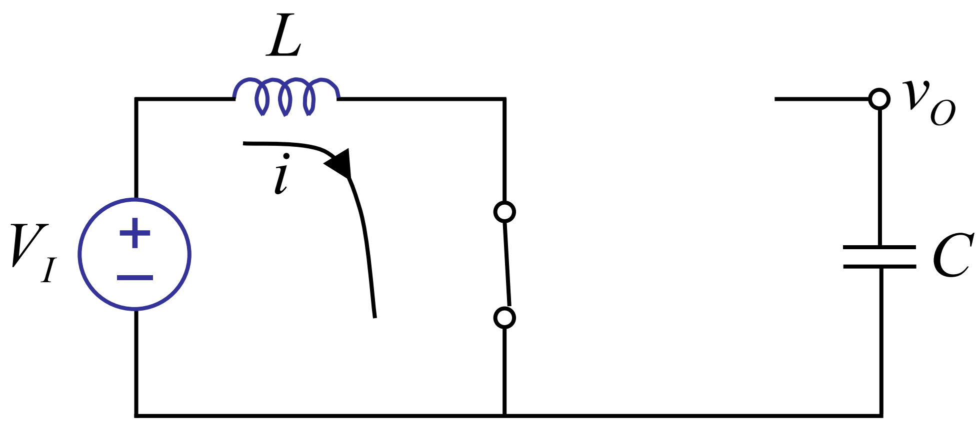
II. S turns off, diode turns on
C charges up, v_O increases

III. S is off, diode turns off
C holds v_O (discharges into load)

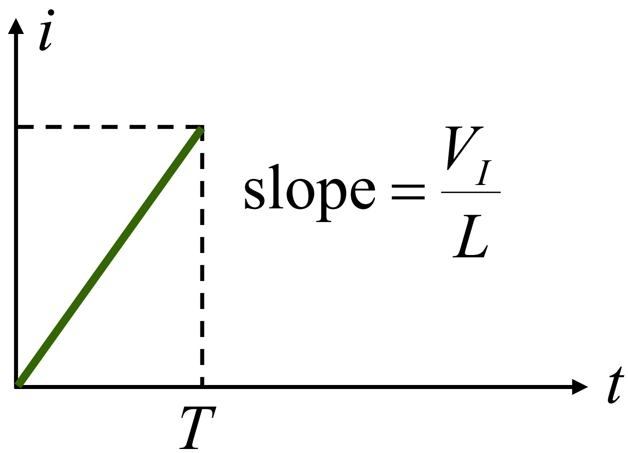
More detailed analysis

I. Assume $i(0) = 0,\ v_O(0) > 0$

S on at $t = 0$, diode off



$$i(T) = \frac{V_I T}{L}$$



$$\text{slope} = \frac{V_I}{L}$$

$$V_I = L\frac{di}{dt}$$

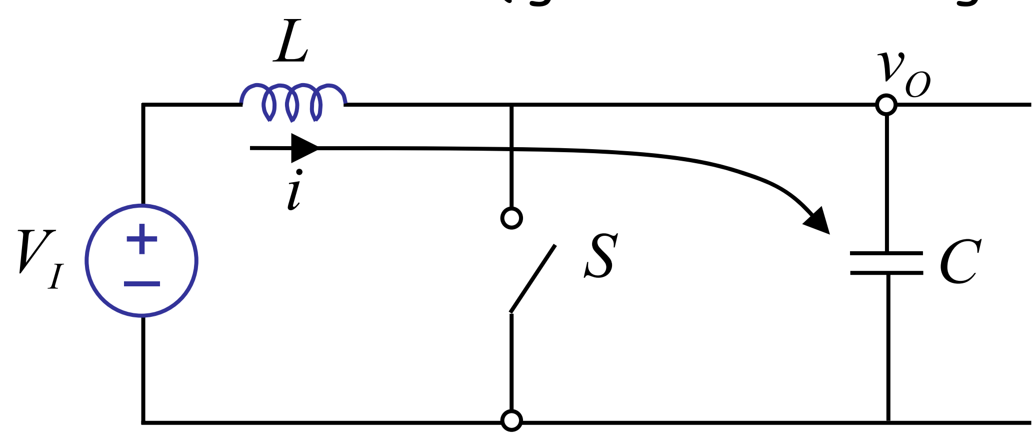
i is a ramp

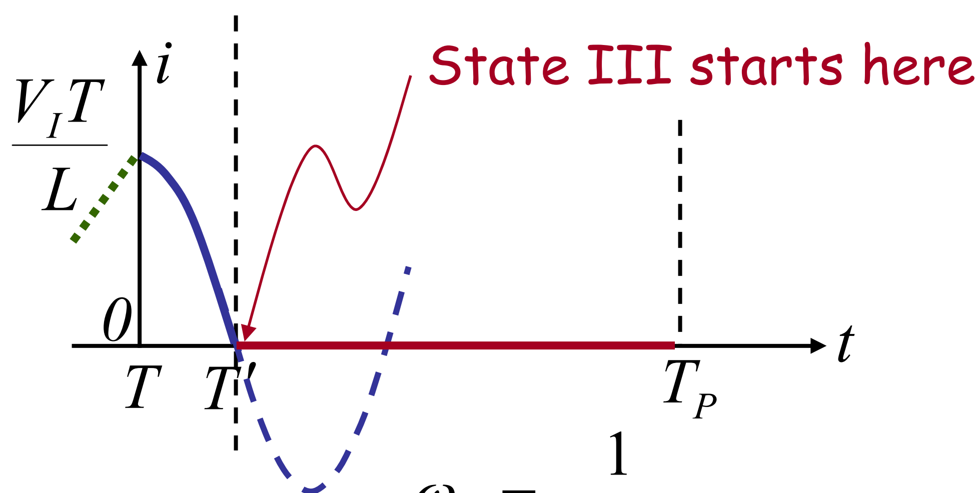
$$\Delta E = energy\ stored\ at\ \ t = T : \frac{1}{2} Li(T)^2$$

$$\Delta E = \frac{V_I^{\,2} T^2}{2L}$$

II. S turns off at $t = T$

diode turns on (ignore diode voltage drop)



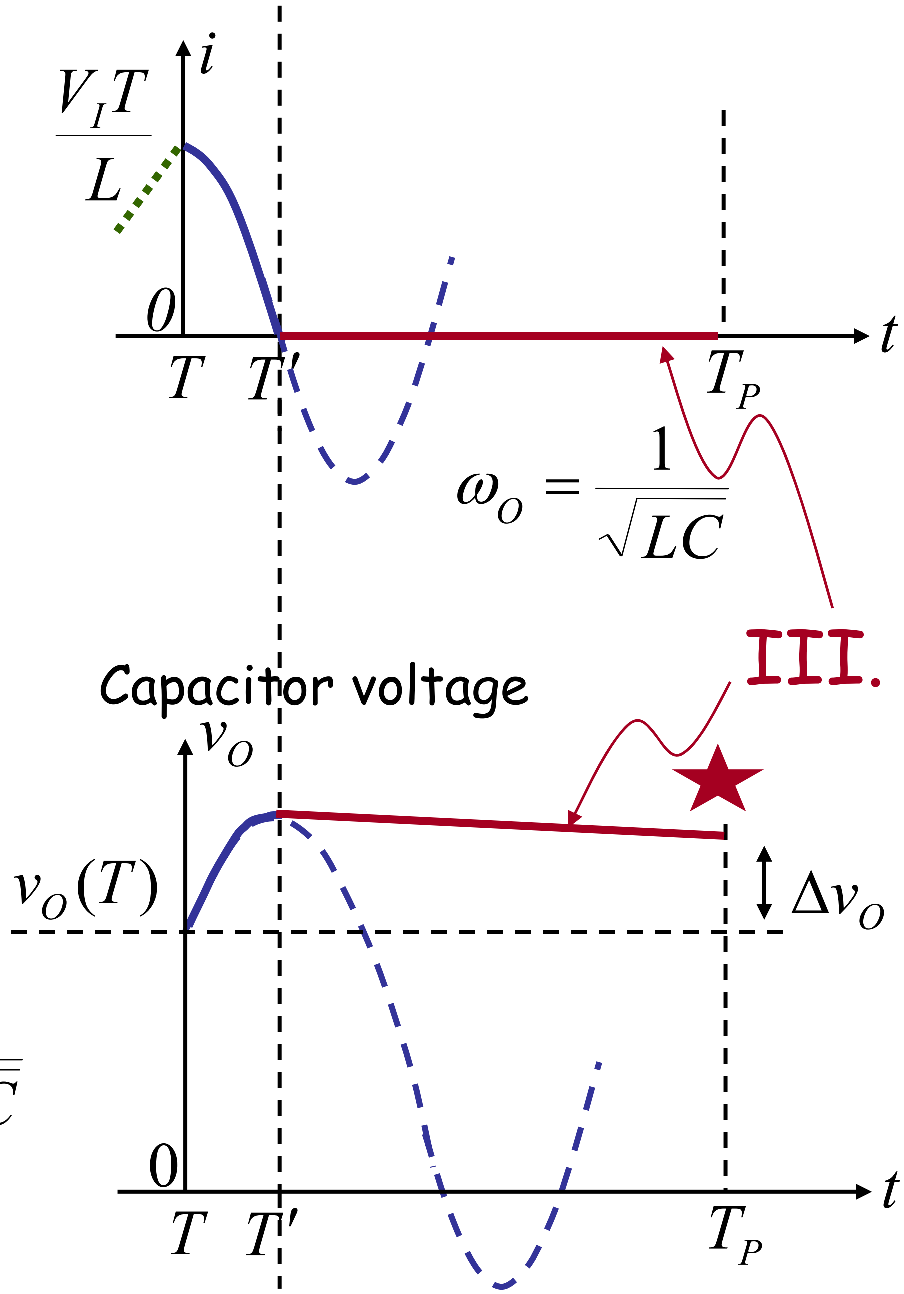


$$\omega_O = \frac{1}{\sqrt{LC}}$$

Diode turns off at T' when i tries to go negative.

II. S turns off at $t = T$, diode turns on

Let's look at the voltage profile



ignore diode drop

$$\omega_O = \frac{1}{\sqrt{LC}}$$

Diode turns off at T' when I tries to go negative.

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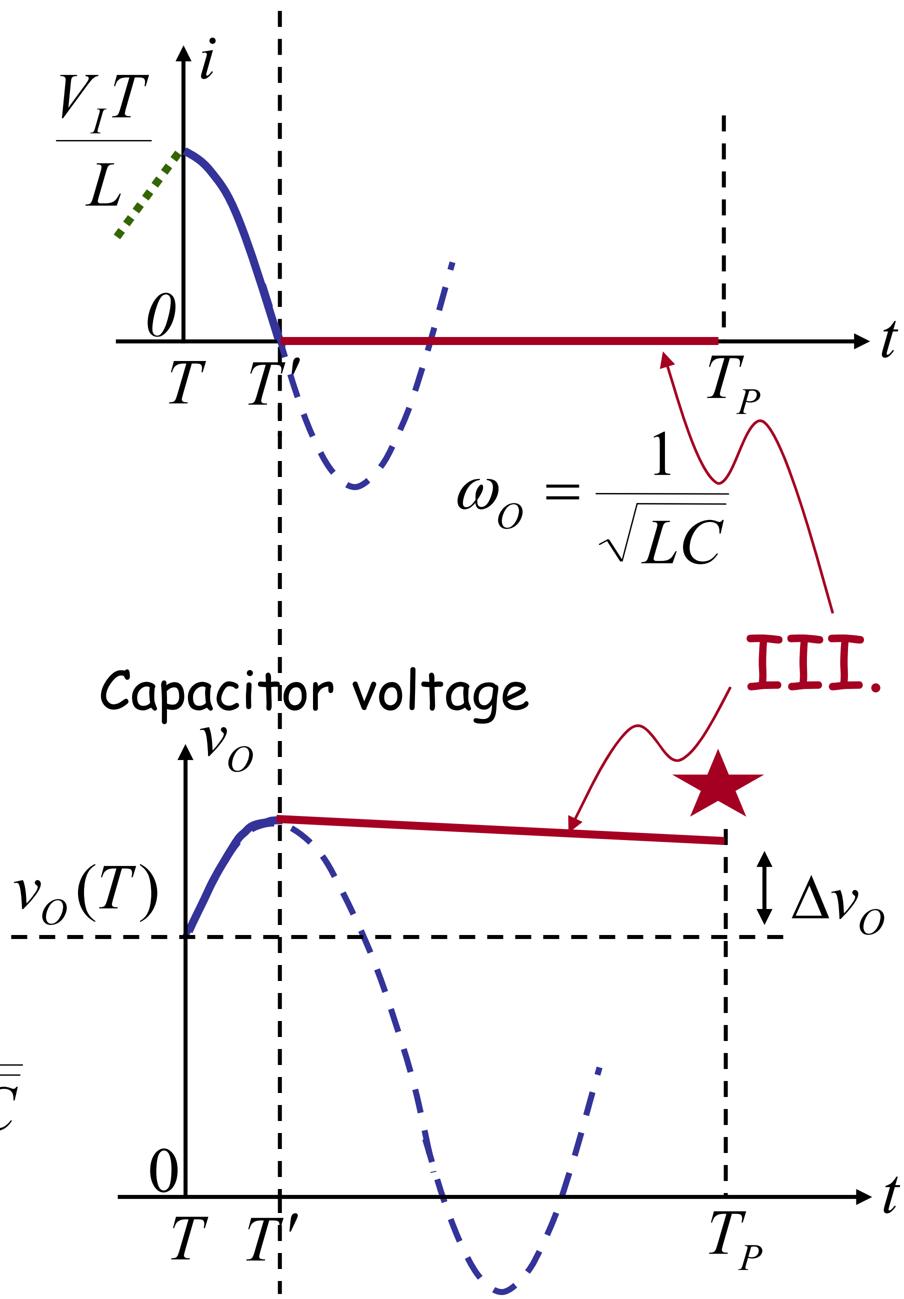
Let's look at the voltage profile

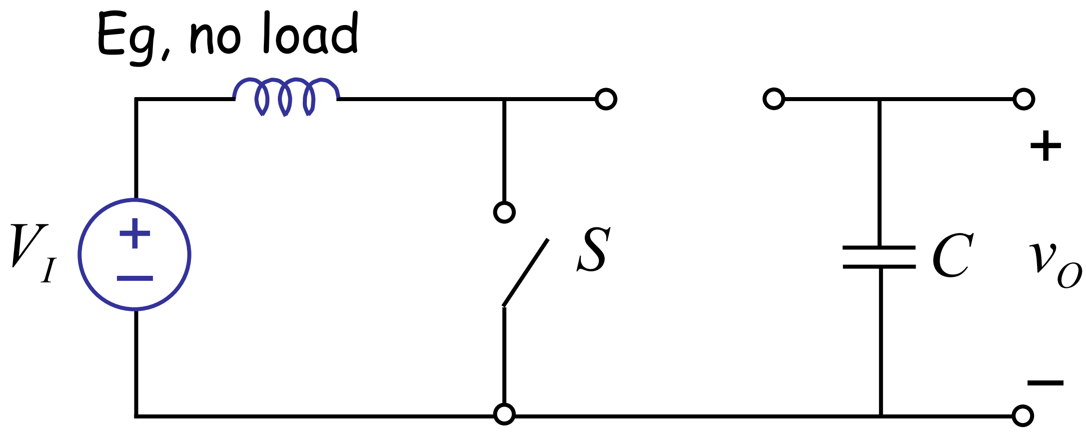


ignore diode drop

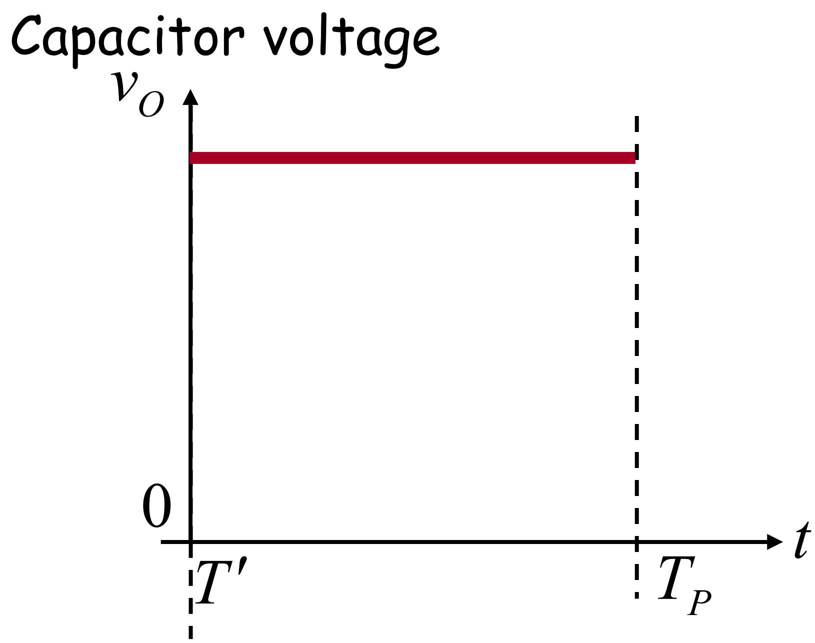
$$\omega_O = \frac{1}{\sqrt{LC}}$$

Diode turns off at T' when I tries to go negative.

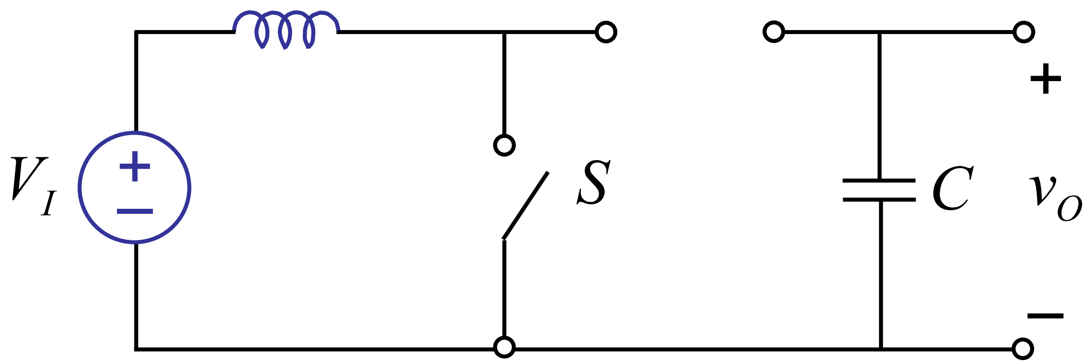
III. S is off, diode turns off



C holds v_O after T'
i is zero

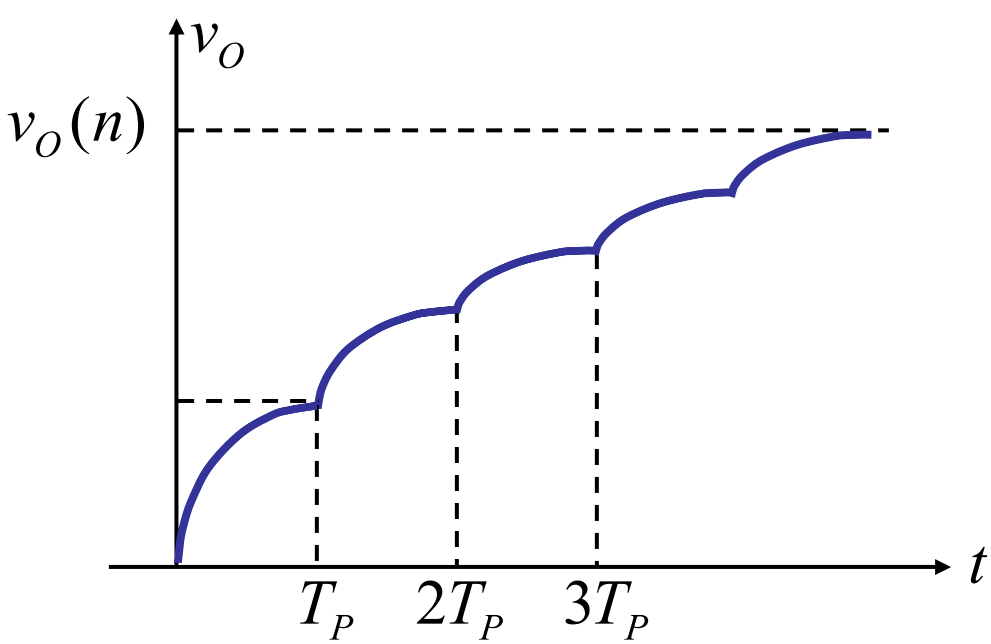


III. S is off, diode turns off



C holds v_O after T'
i is zero
until S turns ON at T_P, and cycle repeats
I II III I II III …

Thus, v_O increases each cycle, if there is no load.



What is v_O after n cycles → $v_O(n)$?

Use energy argument … (KVL tedious!)

Each cycle deposits ΔE in capacitor.

$$\Delta E = \frac{1}{2}\frac{V_I{}^2 T^2}{L} \qquad \begin{cases} \Delta E = \frac{1}{2} L\, i(t=T)^2 \\ \quad = \frac{1}{2} L \left(\frac{V_I T}{L}\right)^2 \end{cases}$$

After n cycles, energy on capacitor

$$n\Delta E = \frac{nV_I{}^2 T^2}{2L}$$

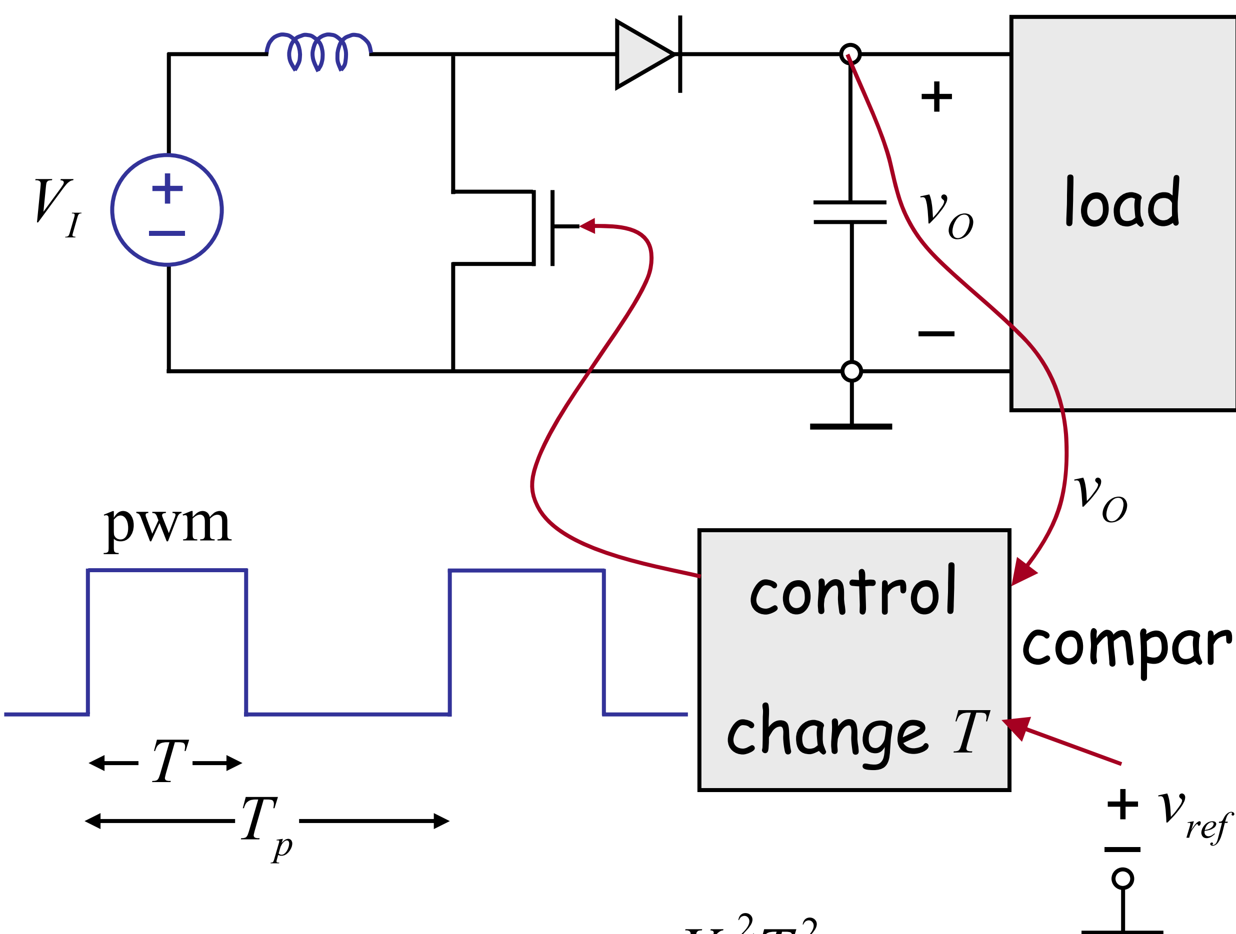
This energy must equal $\frac{1}{2} C v_O(n)^2$

so, $$\frac{1}{\cancel{2}} C v_O{}^2(n) = \frac{nV_I{}^2 T^2}{\cancel{2}L}$$

or $$v_O(n) = \sqrt{\frac{nV_I{}^2 T^2}{LC}} \qquad \left\{ \omega_O = \frac{1}{\sqrt{LC}} \right.$$

$$\boxed{v_O(n) = V_I\, T\, \omega_O \sqrt{n}}$$

How to maintain v_O at a given value?



recall $\quad \Delta E = \dfrac{V_I^{\,2} T^2}{2L}$

Another example of negative feedback:

$$\text{if} \quad (v_O - v_{ref})\uparrow \qquad \text{then} \quad T\downarrow$$

$$\text{if} \quad (v_O - v_{ref})\downarrow \qquad \text{then} \quad T\uparrow$$