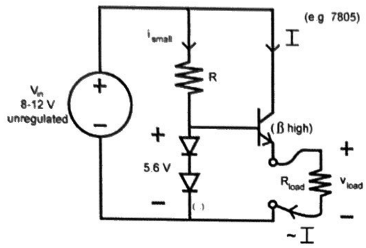
Lecture: Feedback Control and Power Electronics

Regulated Power Supply: given an unregulated DC input, produce a regulated DC output voltage, e.g. 5V. Today consider two possibilities.

<u>Linear Regulator</u>

For sake of comparison
And analysis, let's compute
Efficiency.



(ignore i_{small})

$P_{in} = v_{in} \cdot I$

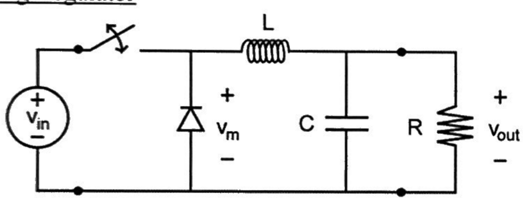
$P_{out} = v_{out} \cdot I$

so, $\eta = efficiency = \dfrac{P_{out}}{P_{in}} = \dfrac{v_{out}}{v_{in}}$

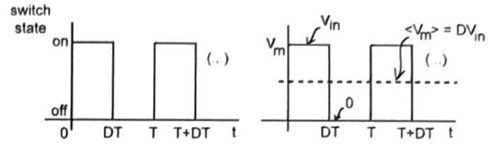
For a typical $v_{in} = 10V$, $\eta = 0.5$ (only 50% of input power goes to load)

Where does the rest of the input power go? Dissipated in the transistor as waste heat.

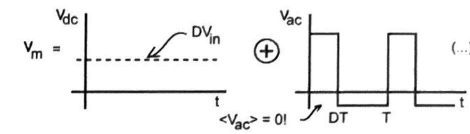
<u>Switching Regulator</u>



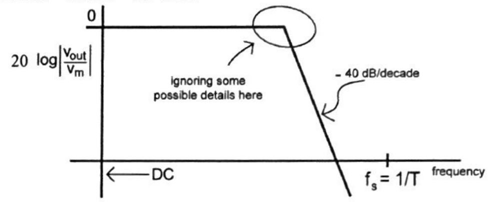
Controllable switch: operated periodically, with period T and "duty cycle" D:



NOTICE:



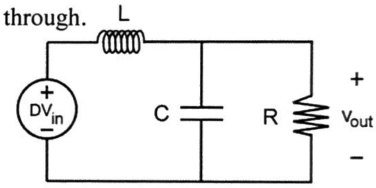
Design LCR "filter" so that



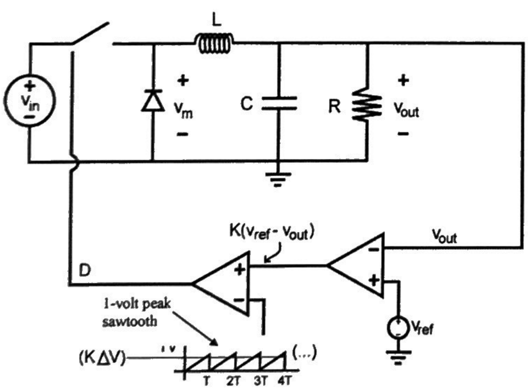
With this arrangement, v_{ac} will be severely attenuated.

$Dv_{in} = v_{dc}$ will pass right through.

Equivalent Circuit:
(ignoring ripple due to v_{ac})



100% efficient! All input power goes to load (for ideal L, C).



Used in many early PC power supplies!

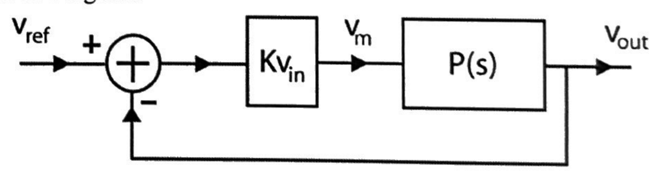
RLC "filter": find transfer fxn $\dfrac{v_{out}}{v_m}(s)$

$$\frac{v_{out}}{v_m}(s) = \frac{R \,||\, \frac{1}{sC}}{sL + R \,||\, \frac{1}{sC}} \;;\; R \,||\, \frac{1}{sC} = \frac{\frac{R}{sC}}{R + \frac{1}{sC}} = \frac{R}{sRC+1}$$

$$\text{so} \quad \frac{v_{out}}{v_m}(s) = \frac{\frac{R}{sRC+1}}{sL + \frac{R}{sRC+1}} = \frac{R}{s^2 RLC + sL + R}$$

$$\text{or} \quad \frac{v_{out}}{v_m}(s) = \frac{\frac{R}{sRC+1}}{sL + \frac{R}{sRC+1}} = \frac{\frac{1}{LC}}{s^2 + s\frac{1}{RC} + \frac{1}{LC}} = P(s)$$

Block Diagram:



Over all transfer function (Black's formula):

$$\frac{v_{out}}{v_m}(s) = \frac{Kv_{in} P(s)}{1 + Kv_{in} P(s)} = \frac{\dfrac{\frac{Kv_{in}}{LC}}{s^2 + s\frac{1}{RC} + \frac{1}{LC}}}{1 + \dfrac{\frac{Kv_{in}}{LC}}{s^2 + s\frac{1}{RC} + \frac{1}{LC}}}$$

$$\text{or} \quad \frac{v_{out}}{v_m}(s) = \frac{\frac{Kv_{in}}{LC}}{s^2 + \frac{s}{RC} + \left(\frac{1}{LC} + \frac{Kv_{in}}{LC}\right)}$$

Is it stable? Depends!

- If R is present, finite, then denominator is quadratic with all positive coefficients. STABLE
- No load, poles on $j\omega$ axis. NOT STABLE

With R present, how does the system perform?

Aside: What are we worried about here? ORIGINAL TTL Spec permitted $5V \pm 300mV$. So, over or undershooting the spec could cause serious problems; possibly even destroy the load!

DC, tracking performance: suppose $v_{ref} = u(t)$ (turn on). After a long time, what is v_{out}?

<u>Final value theorem</u>: $h(t), t \to \infty = \lim_{s \to 0} s \cdot H(s)$

So, $$v_{out}(s) = \frac{\frac{Kv_{in}}{LC}}{s^2 + \frac{s}{RC} + \left(\frac{1}{LC} + \frac{Kv_{in}}{LC}\right)} \cdot \underbrace{\frac{1}{s}}_{input} \cdot s$$

Limit as s → 0:

$$\underset{\lim(s \to 0)}{v_{out}(s)} = \frac{\frac{Kv_{in}}{LC}}{\frac{1}{LC} + \frac{Kv_{in}}{LC}} \approx 1 \quad \text{if K is large}$$

So, for good steady state "tracking" performance, i.e., minimum steady state error, we would seem to want K → large.

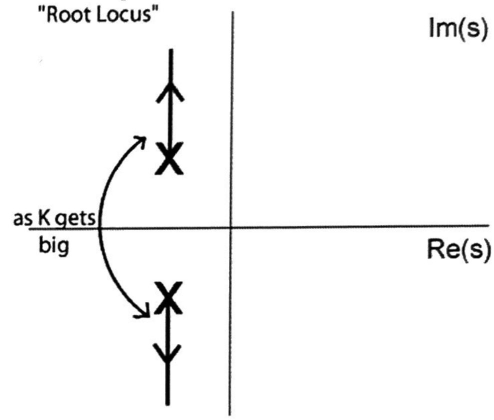
What happens to the closed loop pole (CLP) locations as K gets big?

$$P_{1,2} = -\frac{\frac{1}{RC} \pm \sqrt{\frac{1}{(RC)^2} - \frac{4(1+Kv_{in})}{LC}}}{2}$$

As K gets huge, the term inside the square root gives us complex poles which are increasingly higher in frequency.

Real part stay fixed.

CLP locations in the s-plane:



As K increases, decay rate remains constant, but oscillation frequency increases.