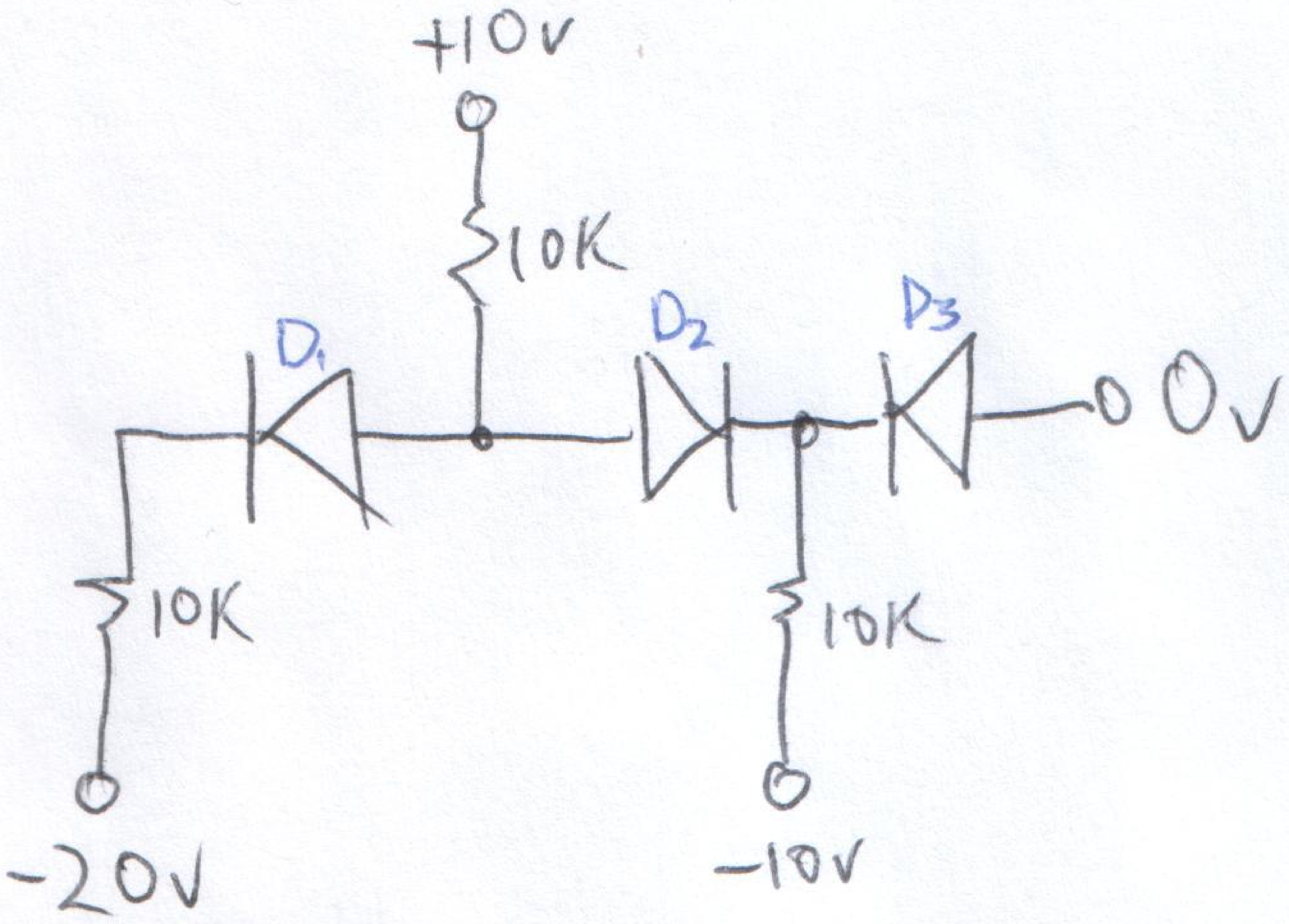
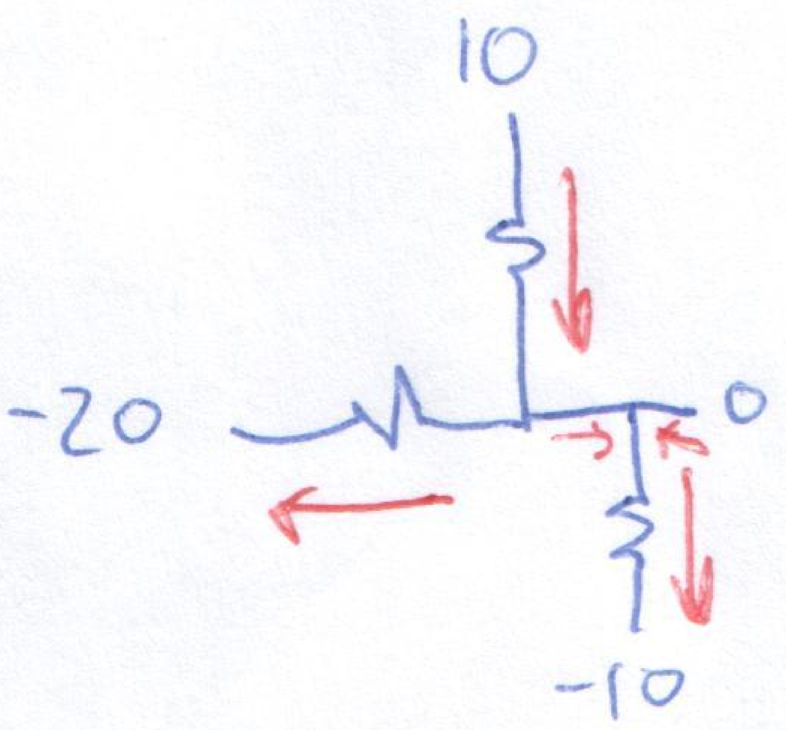
Diodes in Circuits



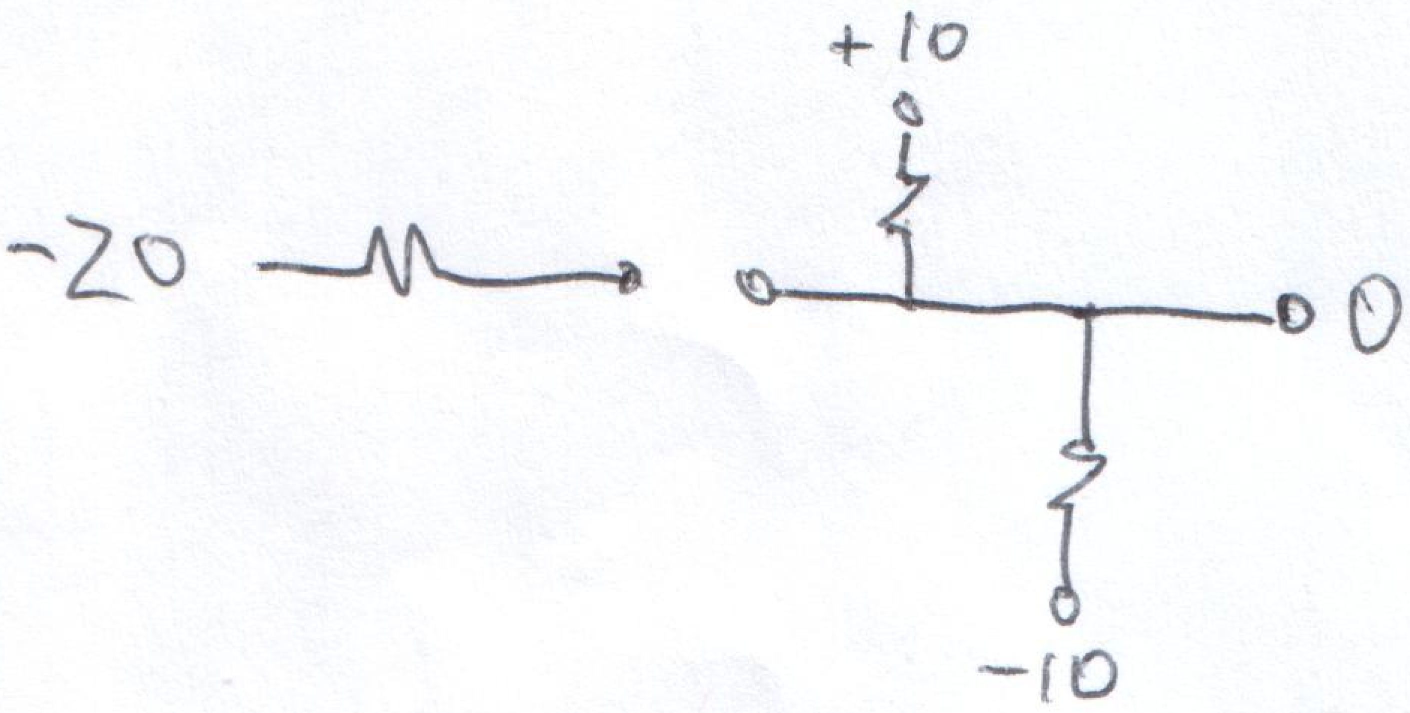
Possible Set of Modes:

D_1	D_2	D_3
off	off	off
off	off	on
off	on	off
off	on	on
on	off	off
on	off	on
on	on	off
on	on	on

However, intuition can help a <u>lot</u> here.

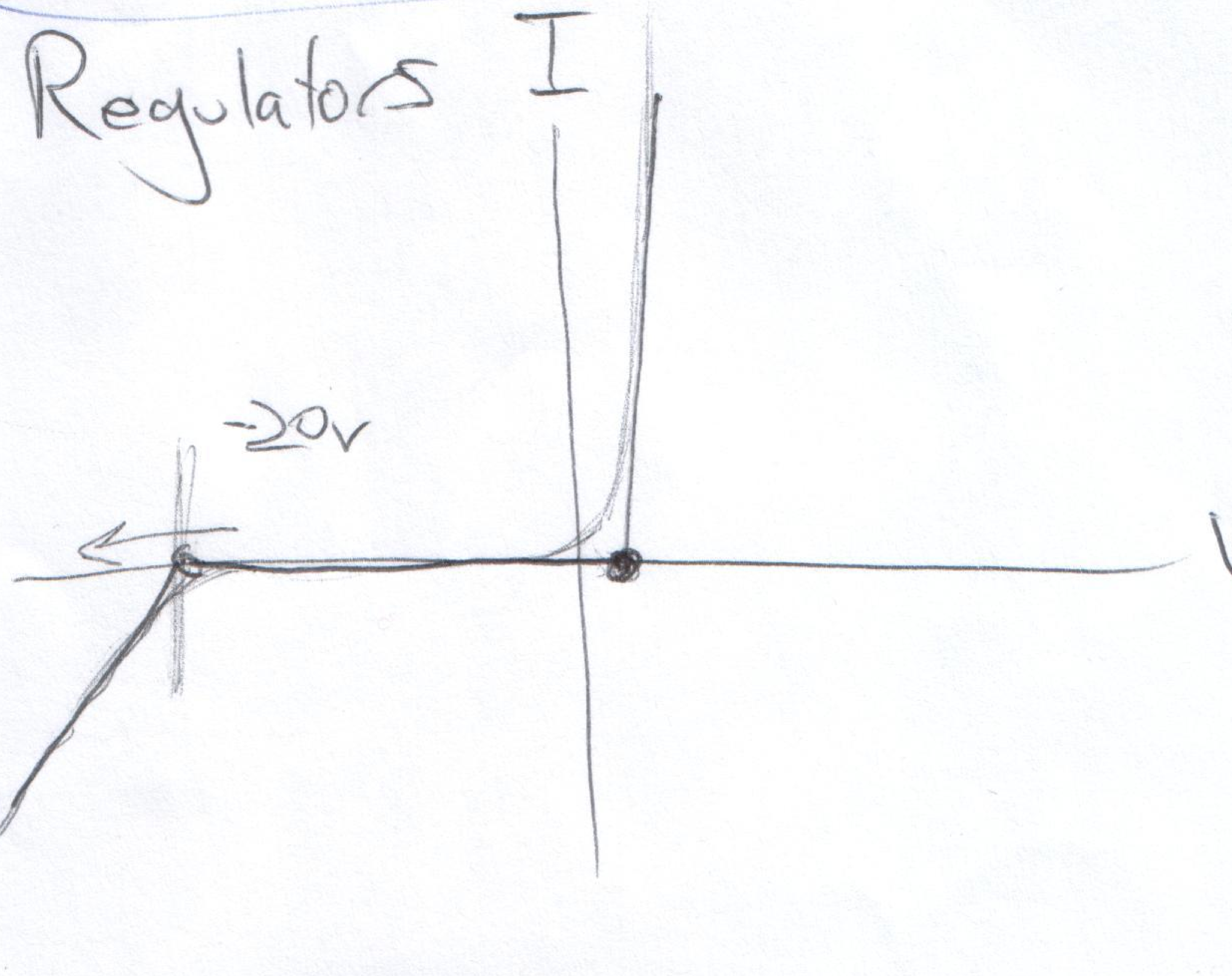


→ <u>Sounds</u> <u>Legit.</u>

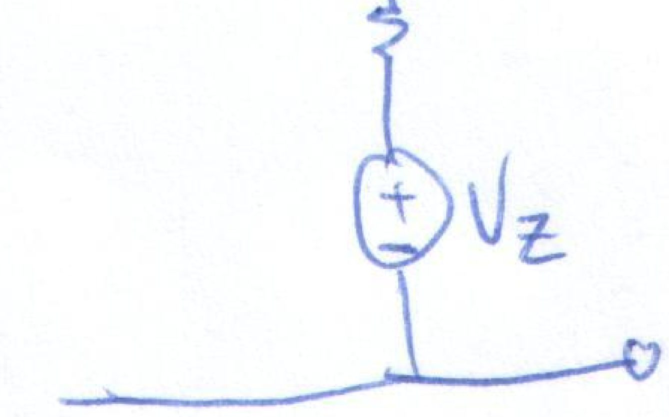


Practice: choosing ~~resistors~~ different diode mode will show <u>+30v</u> across one, obviously <u>F.B.</u>

Regulators

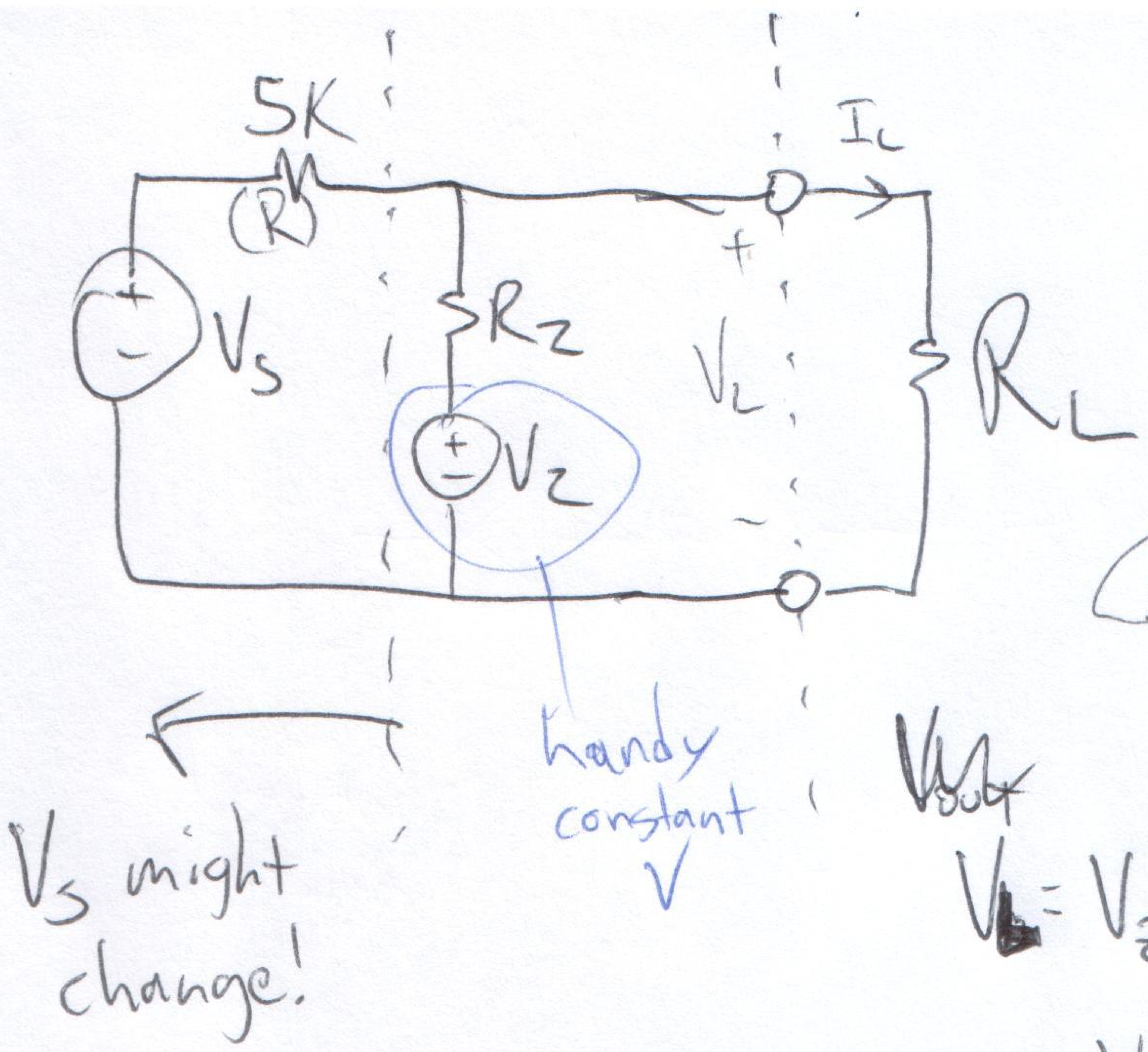


→ Potential use as <u>regulator</u>:



A diode that is Zenering acts at least a little like a voltage source, so maybe we could use it to effectively <u>reduce</u> the output Z of a power supply....

Or hold it steady over input <u>V_S</u>



Line Regulation

$$\frac{\partial V_L}{\partial V_s}$$

assume $R_L \to \infty$

Load Regulation

$$\frac{\partial V_L}{\partial I_L}$$

~~V_{out}~~

$$V_L = V_Z + R_Z \cdot \frac{V_s - V_Z}{R + R_Z}$$

$$= V_Z\left(1 - \frac{1}{R+R_Z}\right) + V_s \underbrace{\frac{R_Z}{R+R_Z}}_{\text{slope!}}$$

$$\frac{\partial V_L}{\partial V_s} = \frac{R_Z}{R+R_Z}$$

good reg: $R_Z << R$

$\frac{\partial V_L}{\partial I_L}$: R_L, varying -

$$V_L = V_s - R\left(I_L + (V_L - V_Z)/R_Z\right)$$

~~$V_L \to V_Z$~~

$$\cancel{V_L = V_s - RI_L - RR_ZV_L + RR_ZV_Z}$$

$$\cancel{V_L(1+RR_Z) = V_s - RI_L + RR_ZV_Z}$$

$$\cancel{V_L = \frac{1}{1+RR_Z}V_s + \frac{RR_Z}{1+RR_Z}V_Z - \frac{R}{1+RR_Z}I_L}$$

reciprocal err oops

$$V_L = V_s - RI_L + \frac{R}{R_Z}V_Z - \frac{R}{R_Z}V_L$$

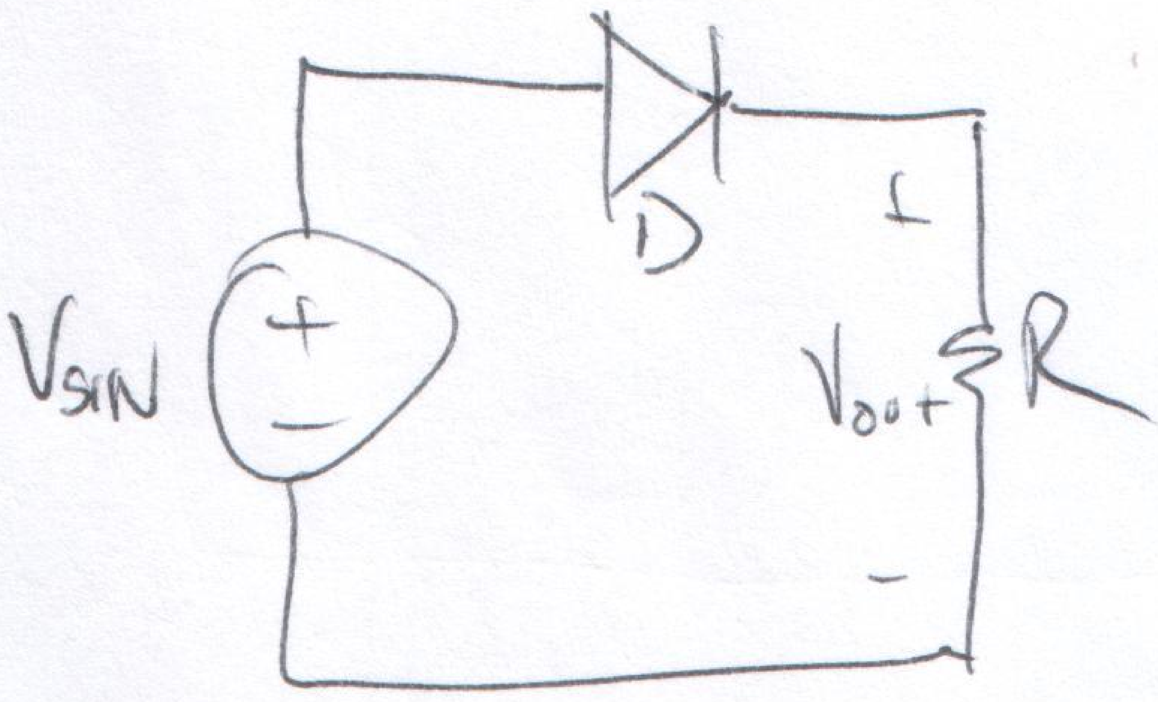
$$V_L\left(1 + \frac{R}{R_Z}\right) = V_s - RI_L + \frac{R}{R_Z}V_Z$$

$$V_L = \frac{1}{1+R/R_Z}V_s - \underbrace{\boxed{\frac{R}{1+R/R_Z}}}_{\text{Slope!}} I_L + \frac{R/R_Z}{1+R/R_Z}V_Z$$

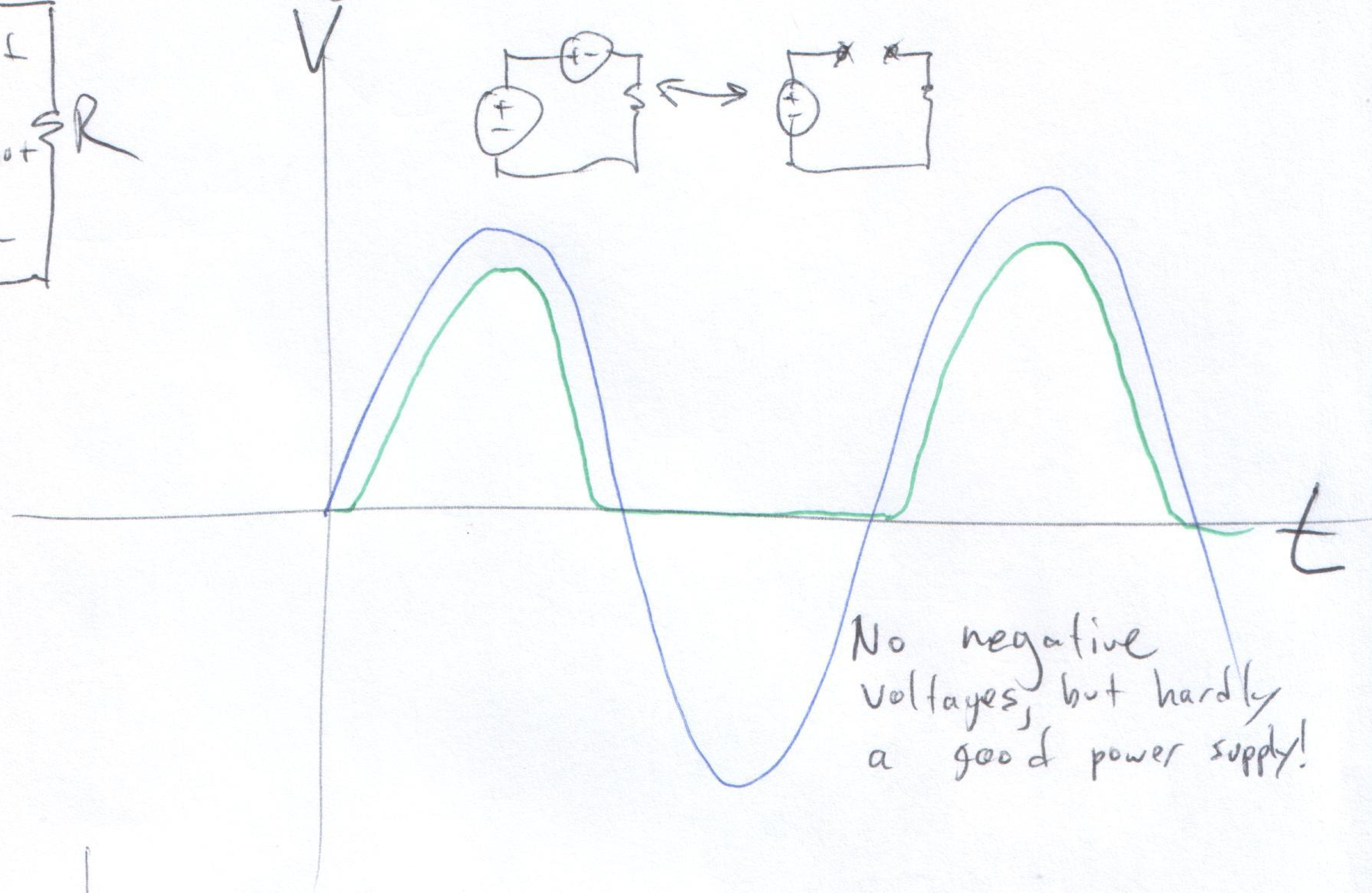
$$-\frac{RR_Z}{R+R_Z} \text{ IE } R // R_Z$$

good reg: <u>both small</u>

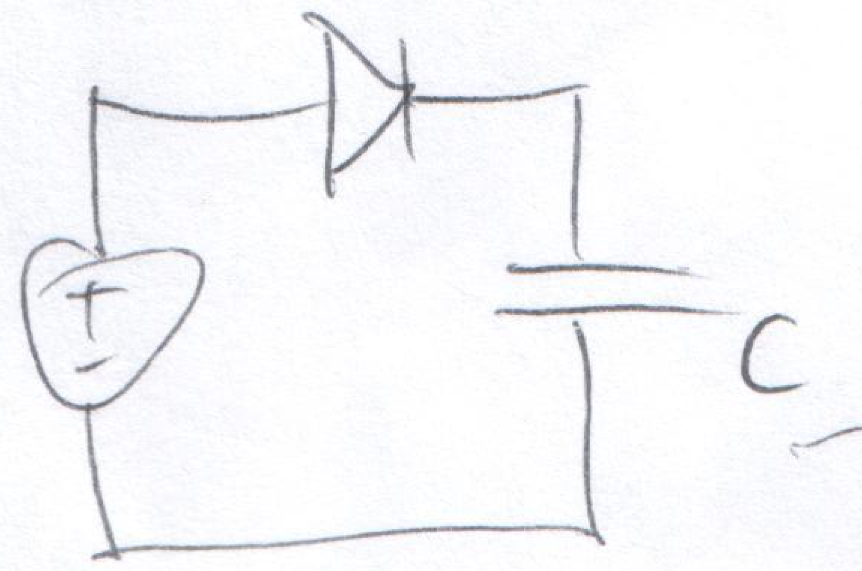
Half-Wave Rectifier

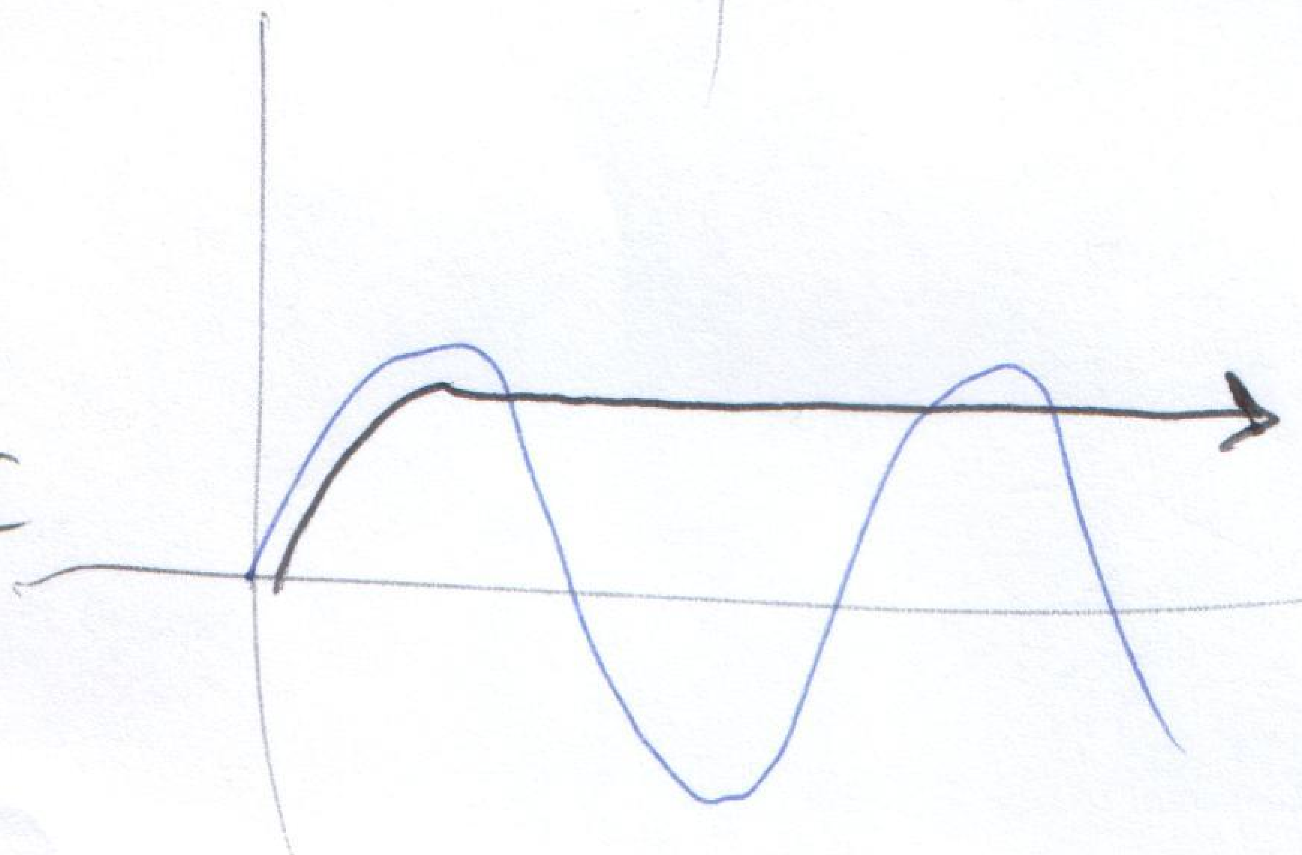


Basic Operation:

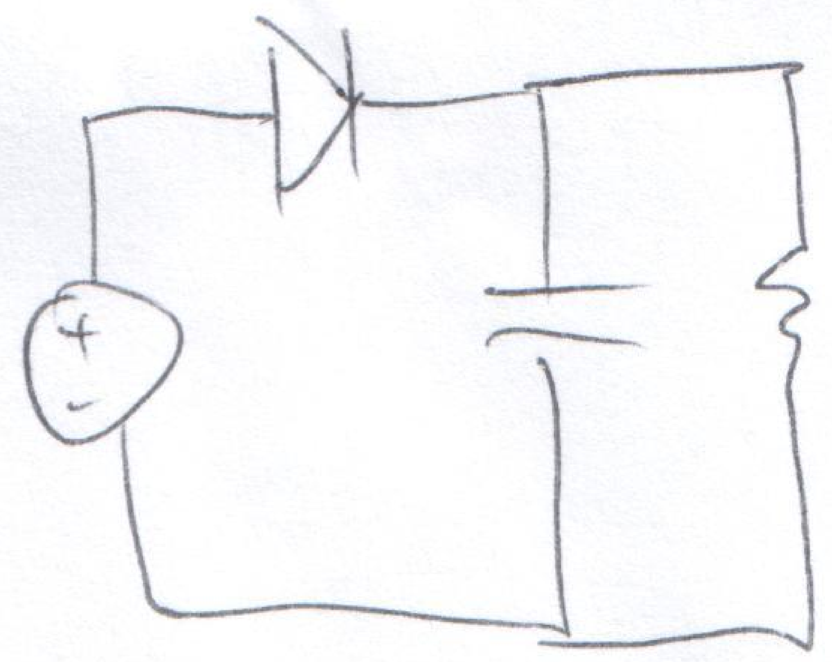


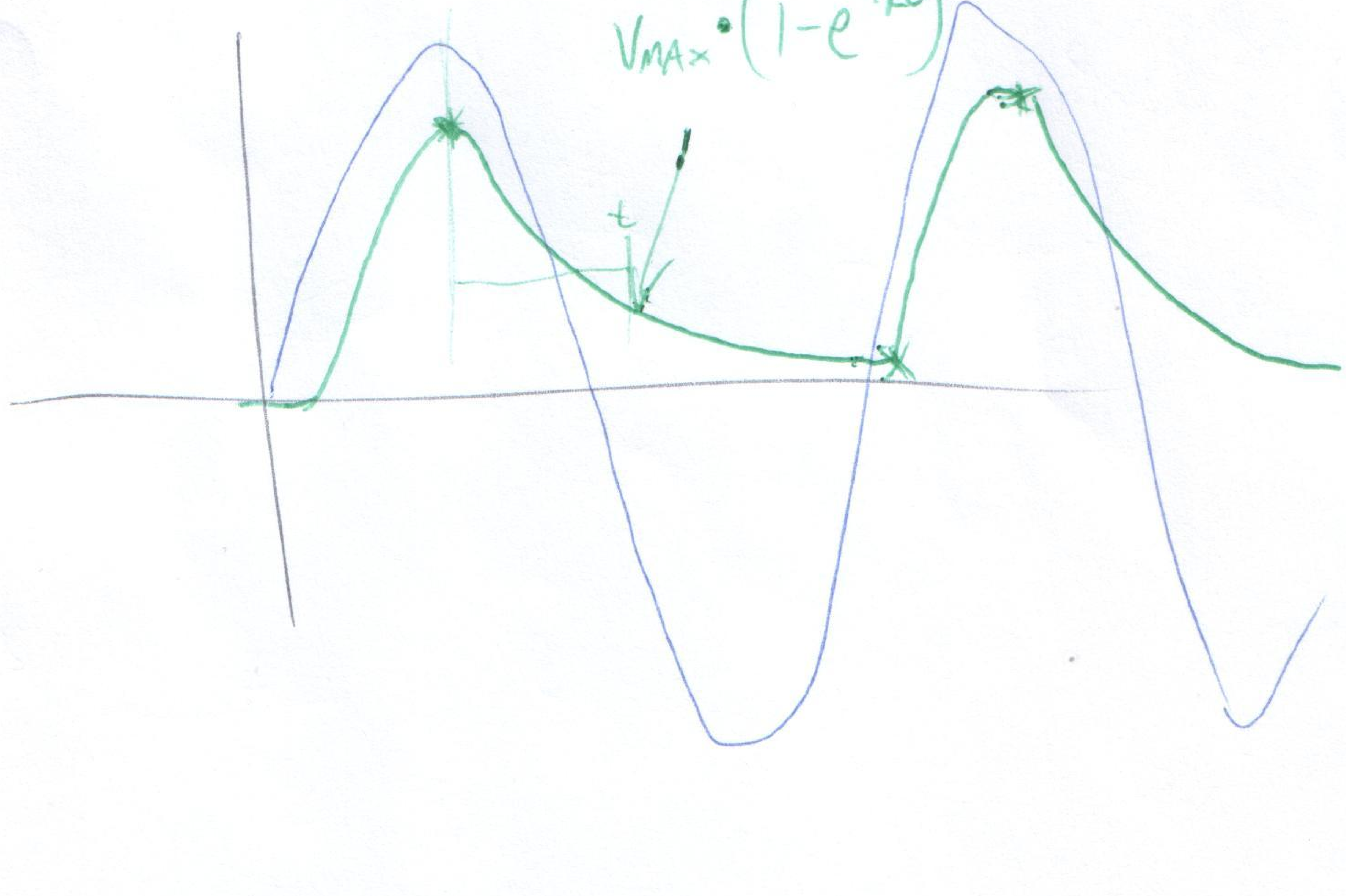
No negative voltages, but hardly a good power supply!



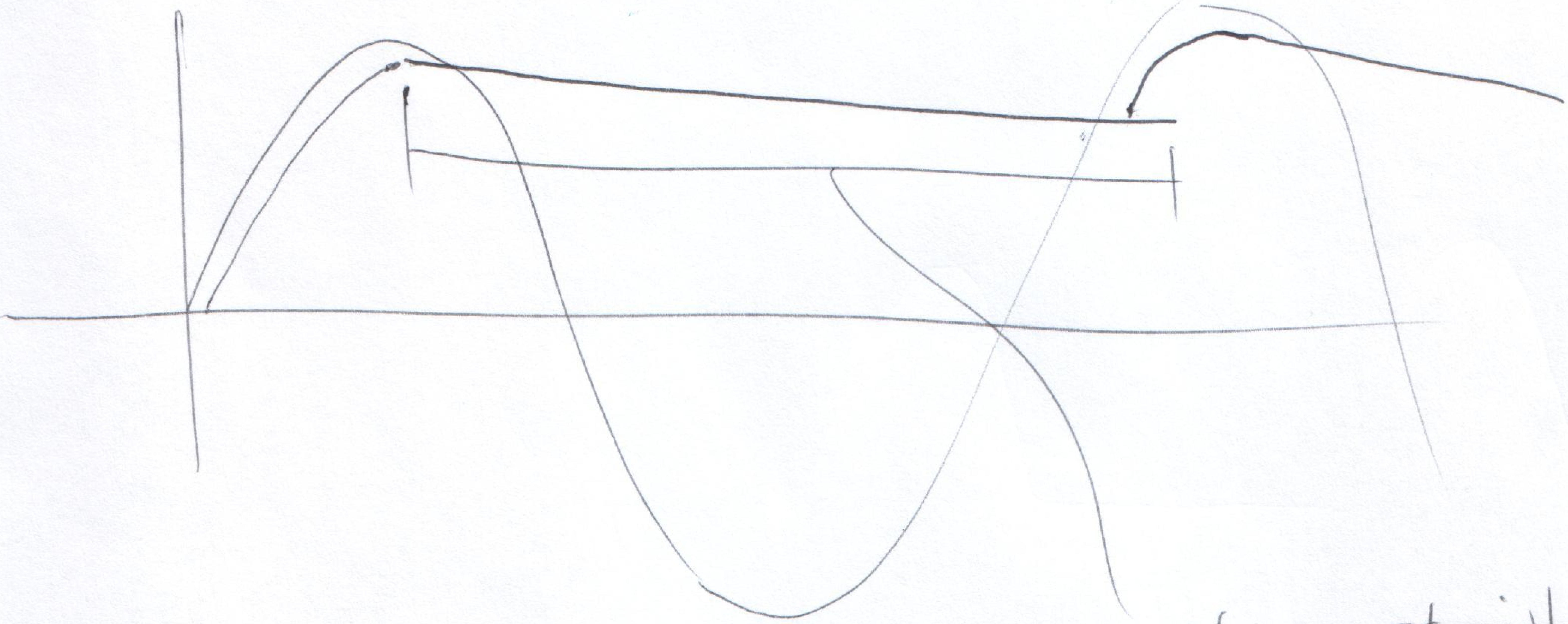


current never leaves C, so flat at max!



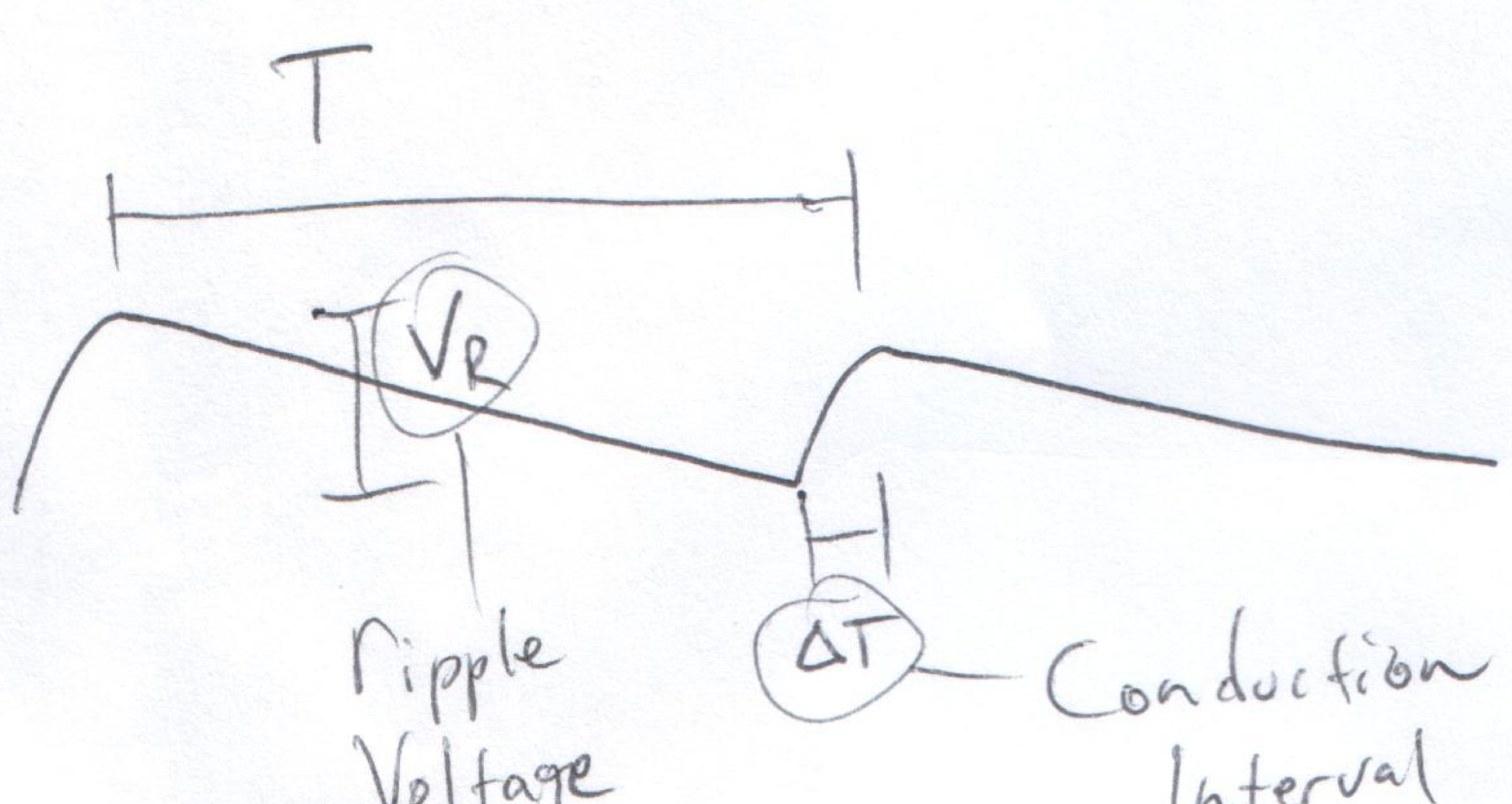


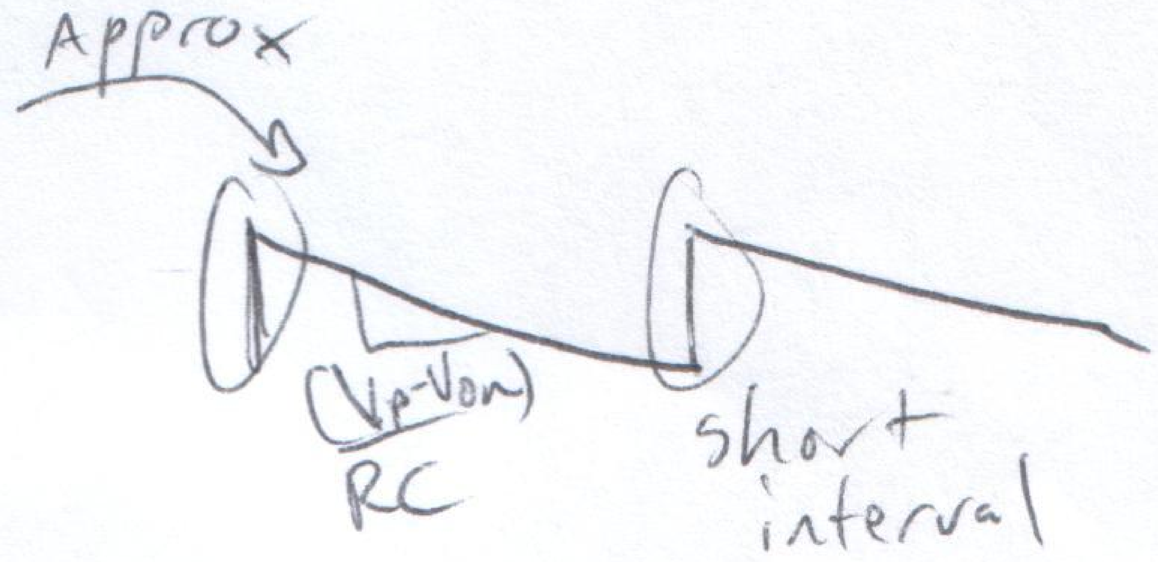
Special Case: $RC \gg \frac{1}{f_{pwr}}$



roughly a straight line

$$\frac{dV}{dt} = \frac{d}{dt}(V_p)e^{-t/RC} = -\frac{(V_p-V_{on})}{RC}$$

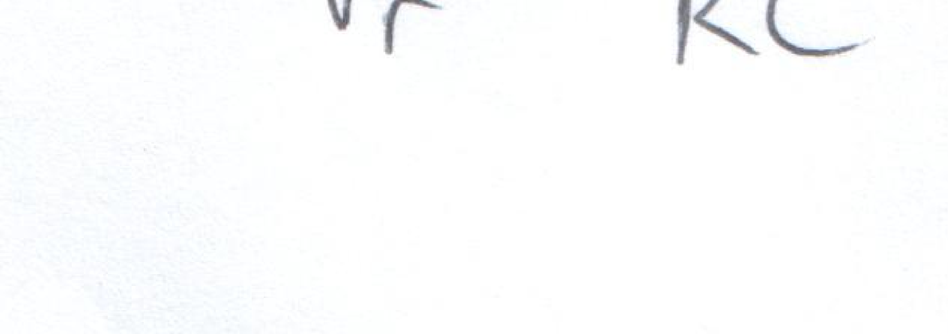




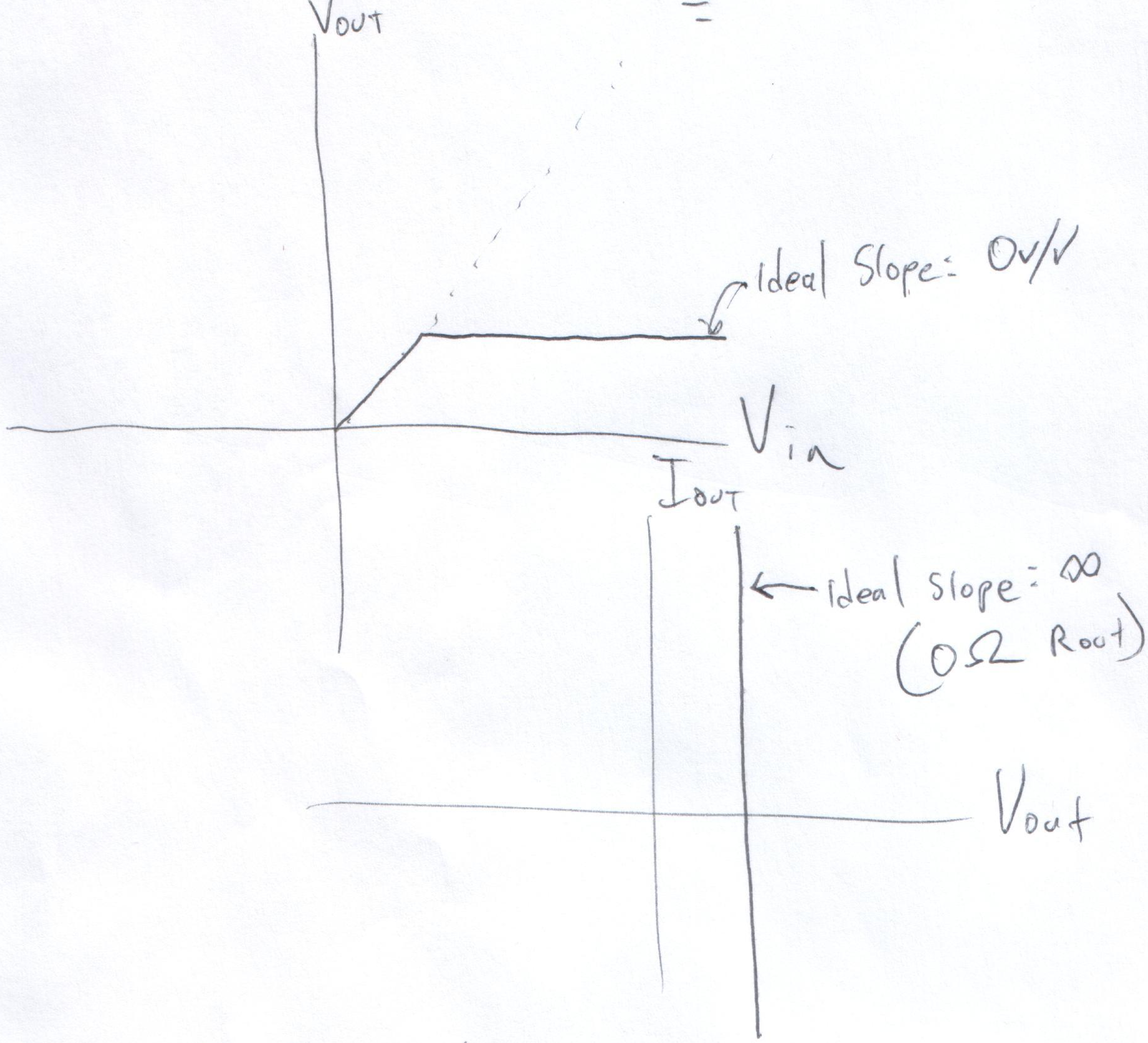
$$V_r = \frac{V_p - V_{on}}{RC} \cdot T$$

— Note: half the power doesn't go anywhere, the AC only pushes a little bit, and C should be very big for heavy loads.

Power brick LED: goes out after you unplug — faster for laptop plugged in.

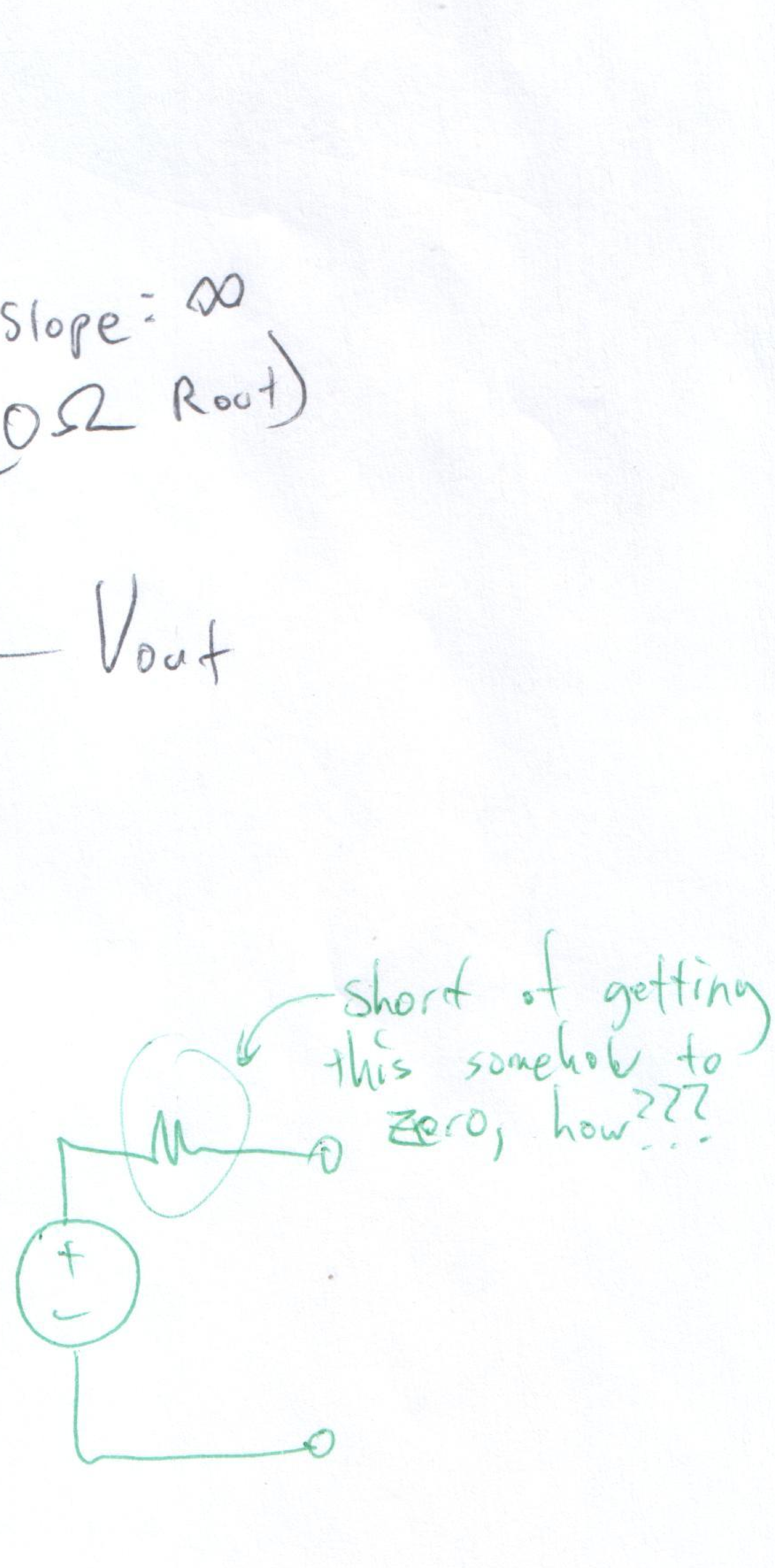


Regulators: In Depth



Important Reason to use nonlinear Circuits:

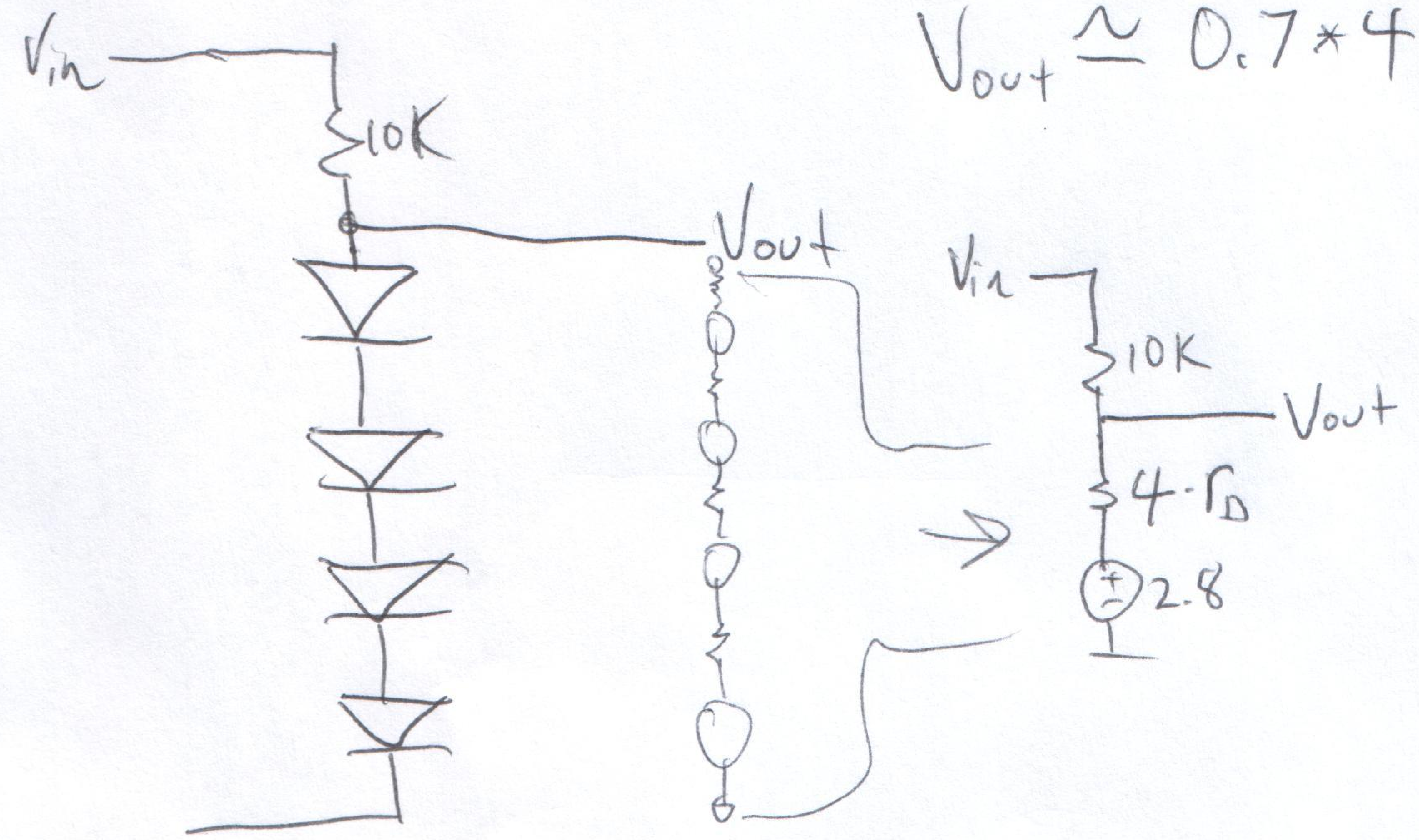
Resistors are terrible at meeting either goal without using tons of power and/or failing at least one goal.



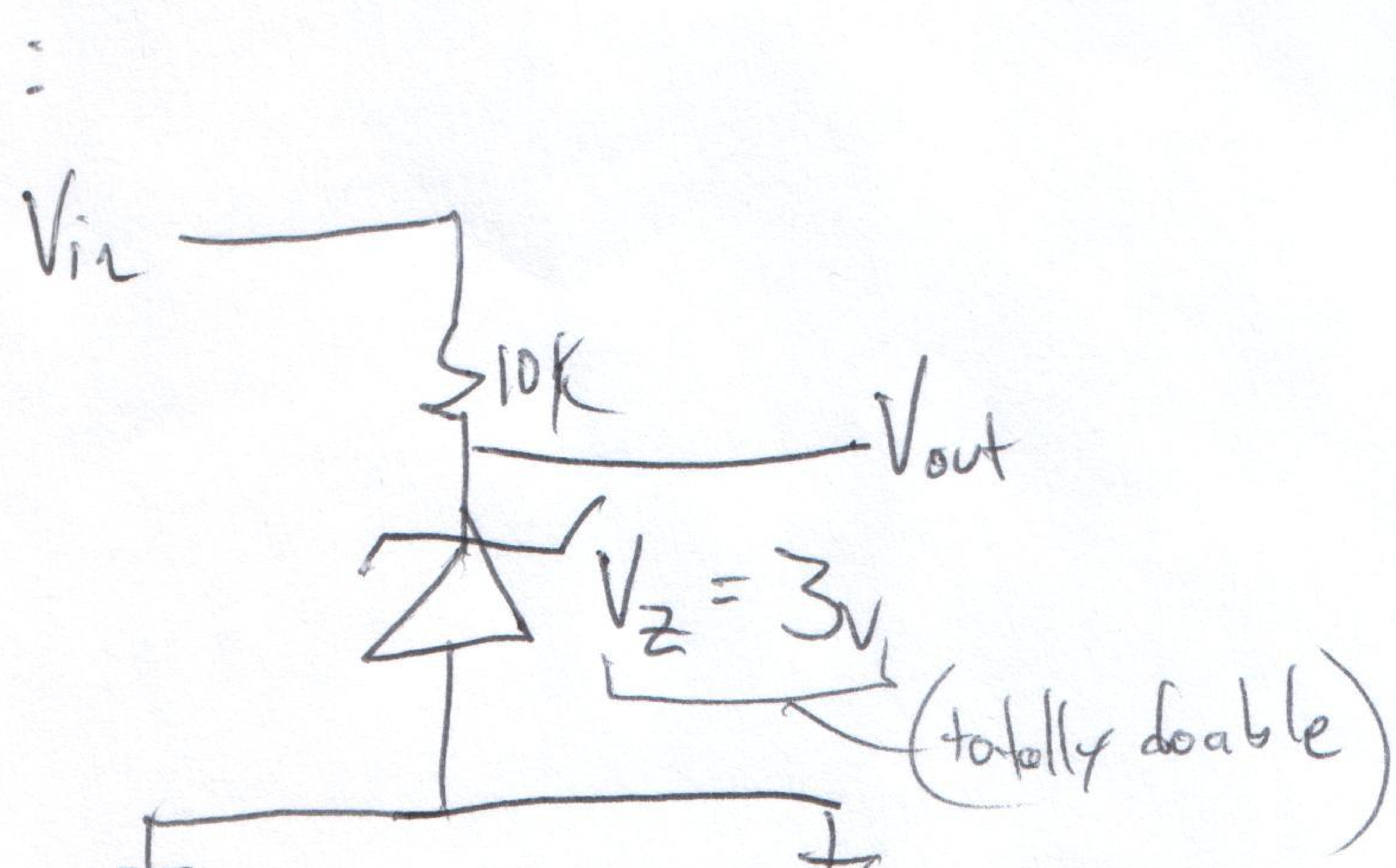
Complex circuits can not only achieve very good regulation numbers but also reference the band gap energy -directly- which is amazing and also beyond the scope of this course.

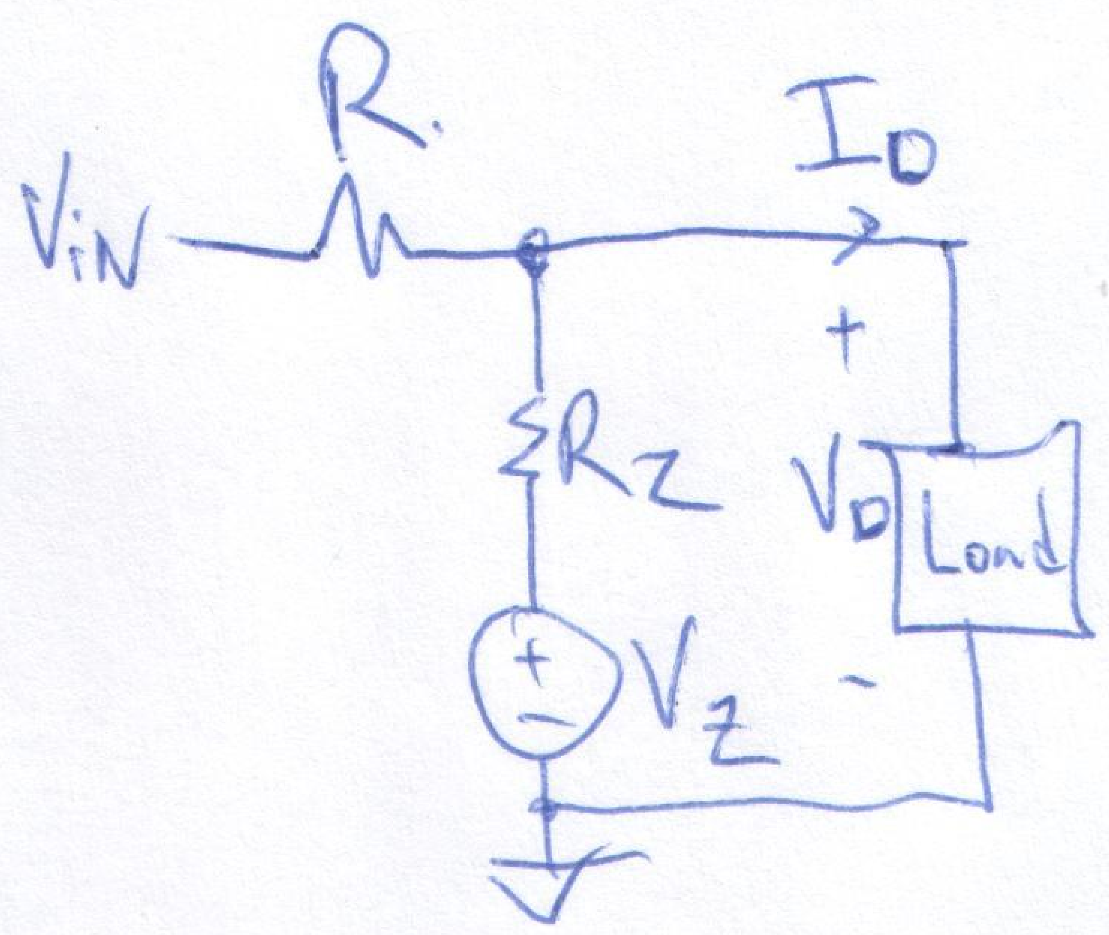
So lets make a <u>simple</u> one:

$V_{out} \simeq 0.7 * 4 = \underline{2.8v}$ adequate for logic

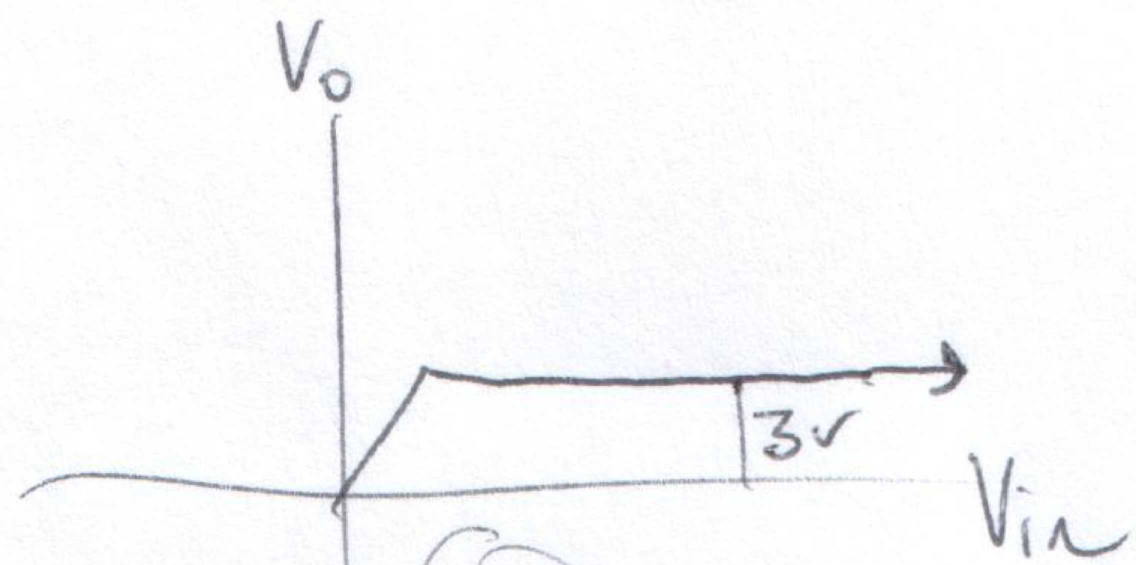


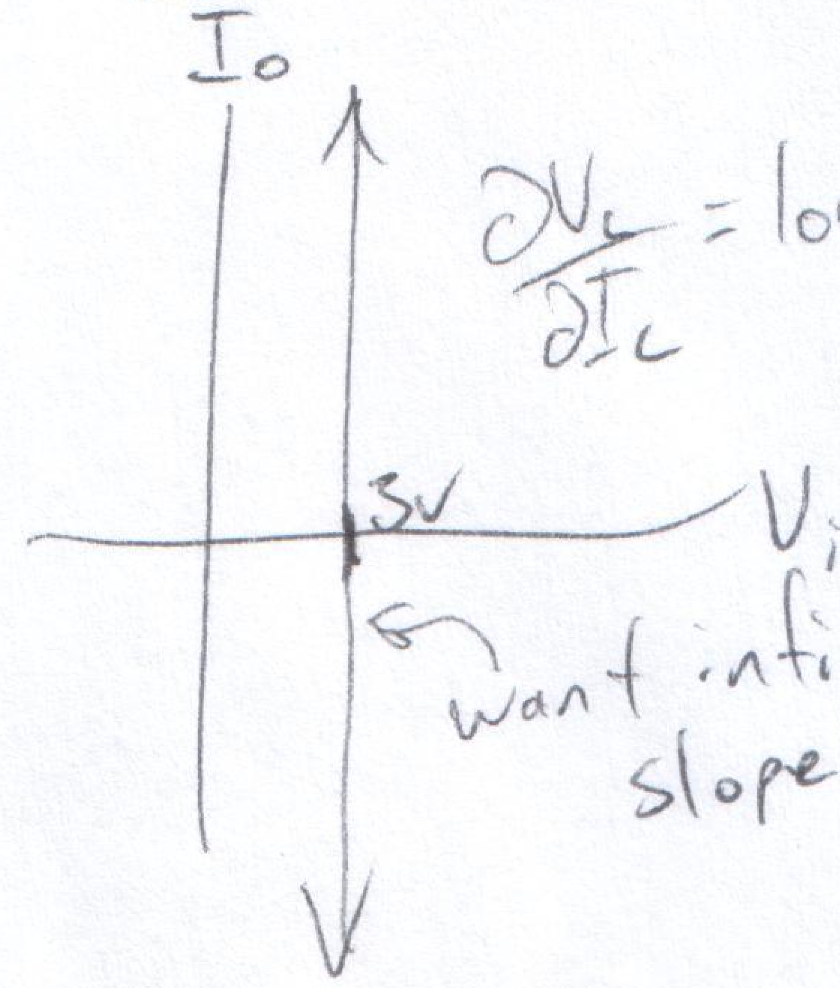
If r_D is very small, and the attached load doesn't pull a huge amout of current, this will work, but being made of 4 diodes is kind of a mess, so:





Ideal behavior: $V_0 \equiv V_Z$





$\frac{\partial V_L}{\partial I_L}$ = load reg

$\frac{dV_{in}}{dV_0}$ = Line Regulation

$\left(\frac{dV_0}{dV_{in}}\right)^{-1}$, flat $\Rightarrow 0$, $\frac{dV_{in}}{dV_0} = \infty$

Line Regulation assume $I_0 = 0$

$$V_0 = V_Z + R_Z \cdot I$$

$$I = \frac{V_{IN} - V_Z}{R + R_Z}$$

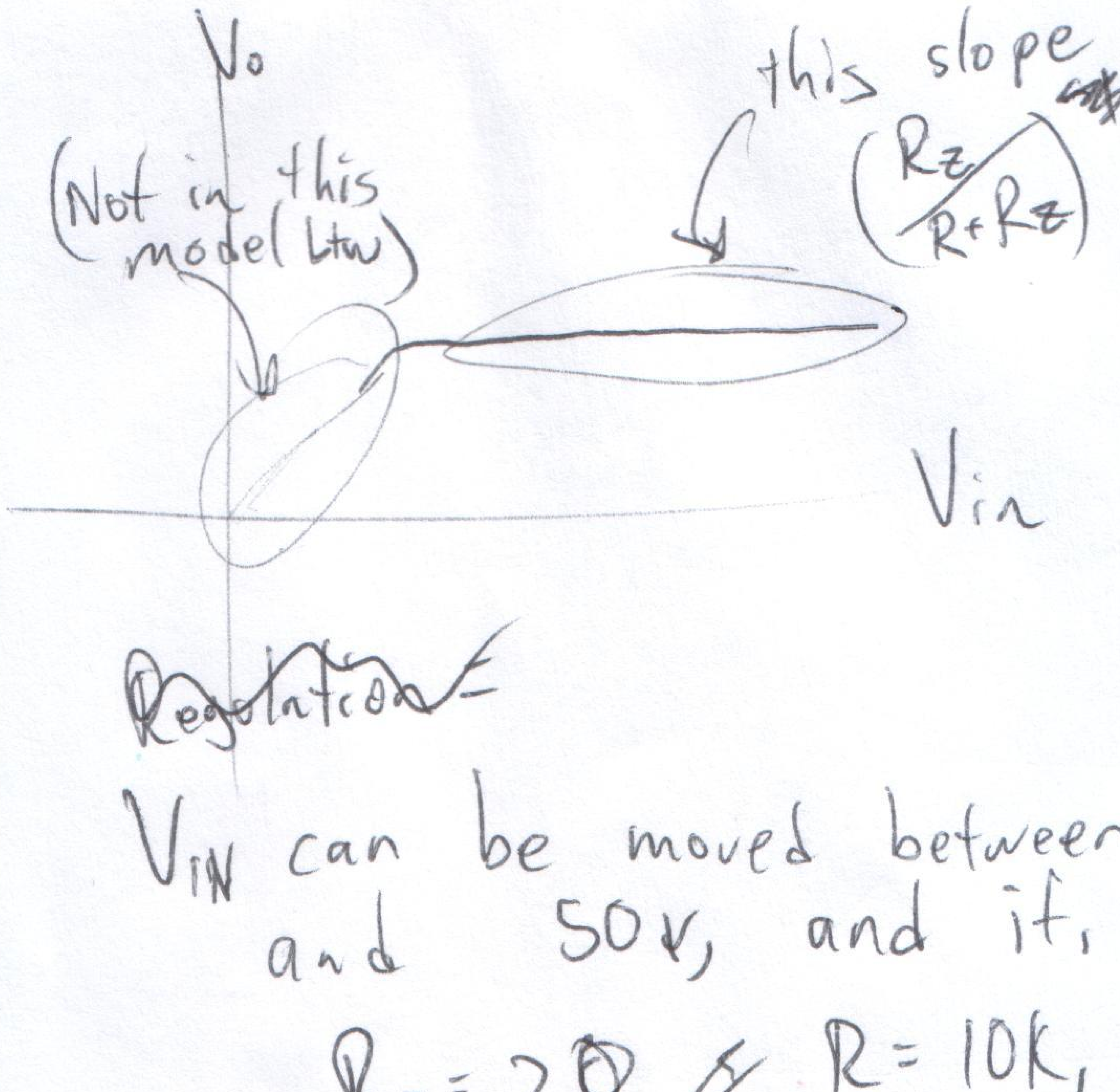
$$V_0 = V_Z + R_Z \frac{V_{IN} - V_Z}{R + R_Z}$$

$$V_0 = V_Z + \frac{R_Z}{R+R_Z} \cdot V_{in} - \frac{R_Z}{R+R_Z} V_Z$$

derivative!

$$\frac{dV_0}{dV_{in}} = \frac{R_Z}{R+R_Z}$$

$$\boxed{reg = \frac{dV_{in}}{dV_0} = \frac{R+R_Z}{R_Z}}$$



Regulation:

V_{IN} can be moved between 20 and 50v, and if, say, $R_Z = 20$ & $R = 10k$, V_0 will only move by 0.06V!

(Regulation = 501%)

Load Regulation:

Circuit trick: try not to use variables you don't want in your final answer.

V_0, I_0 ~~V_{in}~~ ~~R_{load}~~

$$V_0 = V_s - R(I_0 + I_{DIODE})$$

$$I_{DIODE} = \frac{V_0 - V_Z}{R_Z}$$

$$V_0 = V_s - RI_0 - R\frac{V_0 - V_Z}{R_Z}$$

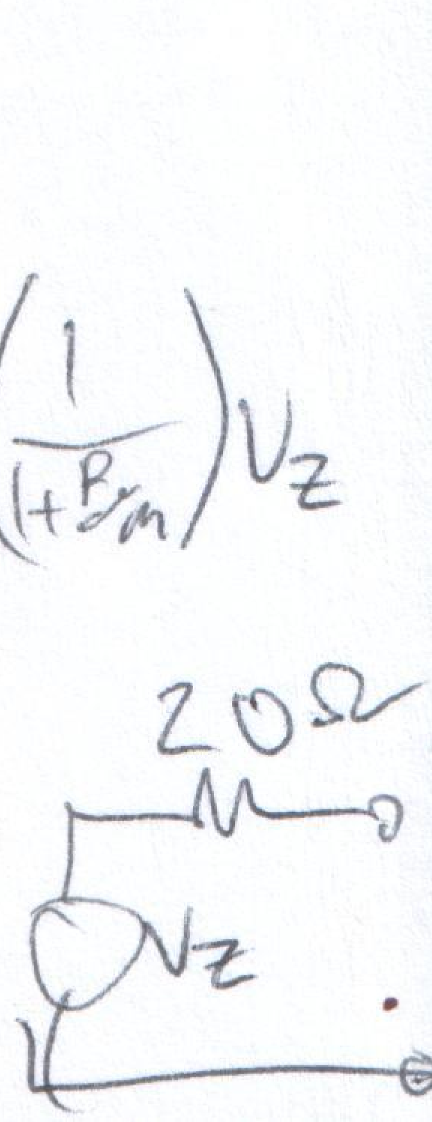
$$V_0 = V_s - RI_0 - \frac{R}{R_Z}V_0 + \frac{R}{R_Z}V_Z$$

$$V_0\left(1 + \frac{R}{R_Z}\right) = V_s - RI_0 + \frac{R}{R_Z}V_Z$$

$$V_0 = V_s\frac{1}{1+R/R_Z} - \frac{R}{1+R/R_Z}I_0 + \frac{R}{R_Z}\left(\frac{1}{1+R/R_Z}\right)V_Z$$

Slope!

$$\frac{\partial V_0}{\partial I_0} = \frac{RR_Z}{R+R_Z} \rightarrow \sim 20V/A$$



This regulator: looks like ~10KΩ loading the supply

if current does not deactivate the diode, looks like 20Ω R!

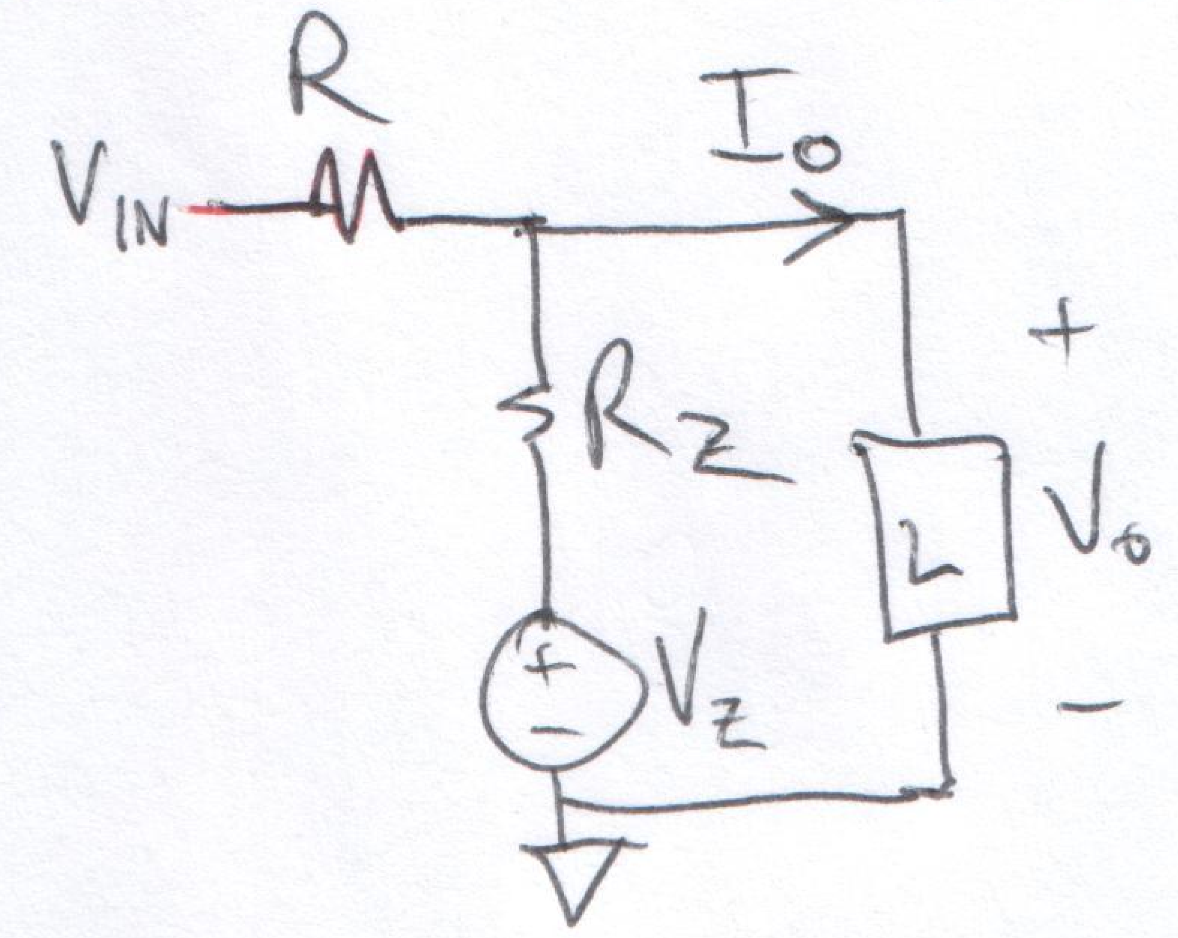
Takes a change of 50V to move V_{OUT} by 100mV!

Lab Prep aside:

- Lab will ask for lots of data on $I = f(V)$.
- Read questions ahead of time!
- Remember that curve tracing can have weird limits

Regulators Redox

Line Regulation: if $I_o = 0$:

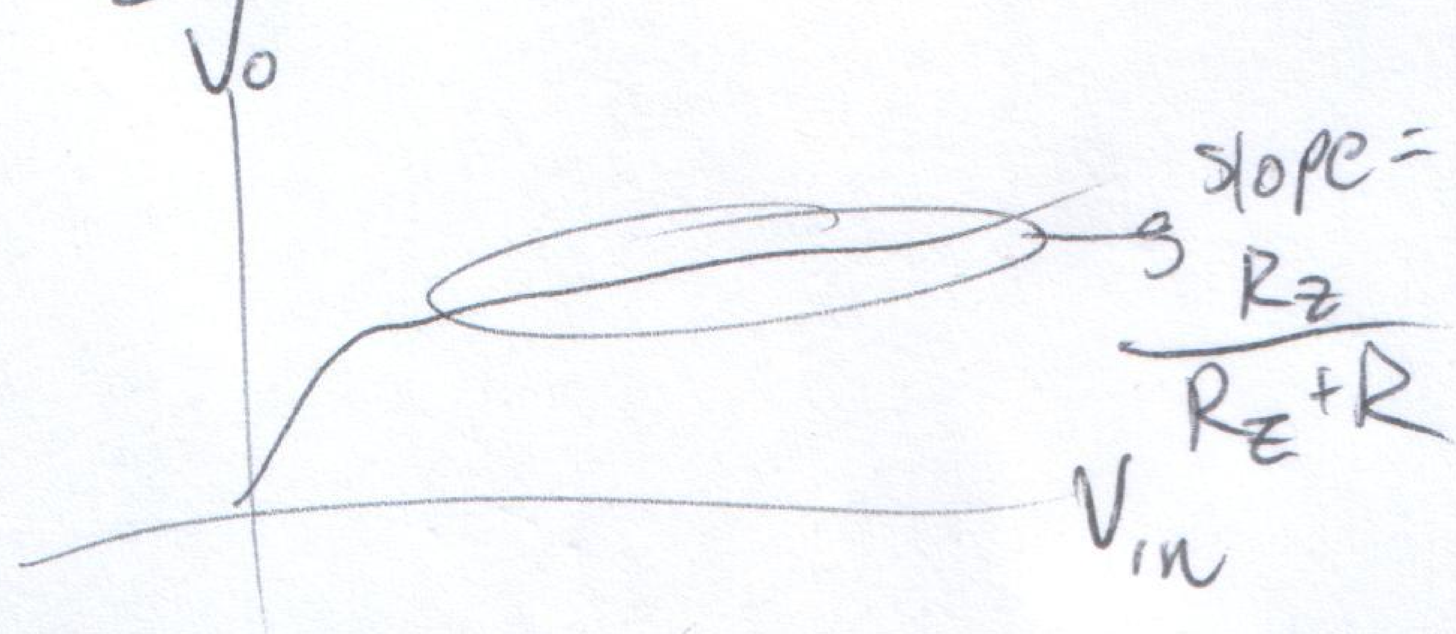


$$V_o = V_Z + R_Z \cdot I_x \quad \left(I_x = \frac{V_{IN} - V_Z}{R + R_Z} \right)$$

$$V_o = V_Z + R_Z \frac{V_{IN} - V_Z}{R + R_Z}$$

$$V_o = V_Z + V_{IN} \cdot \frac{R_Z}{R + R_Z} + -V_Z \frac{R_Z}{R + R_Z}$$

$$\frac{\partial V_{IN}}{\partial V_o} = \frac{R + R_Z}{R_Z}$$



$R_Z = 20$, $R = 10K\Omega$

$$\text{Line Regulation} = \frac{10.02K}{.02K} = 501 \, V/V$$

$$\Delta V_{in} = \underline{10v} \longrightarrow \Delta V_o = \frac{10}{501} \approx \underline{20mV}$$ ✓ Decent!

Load Regulation: $\frac{\partial V_o}{\partial I_o}$ KCL Route

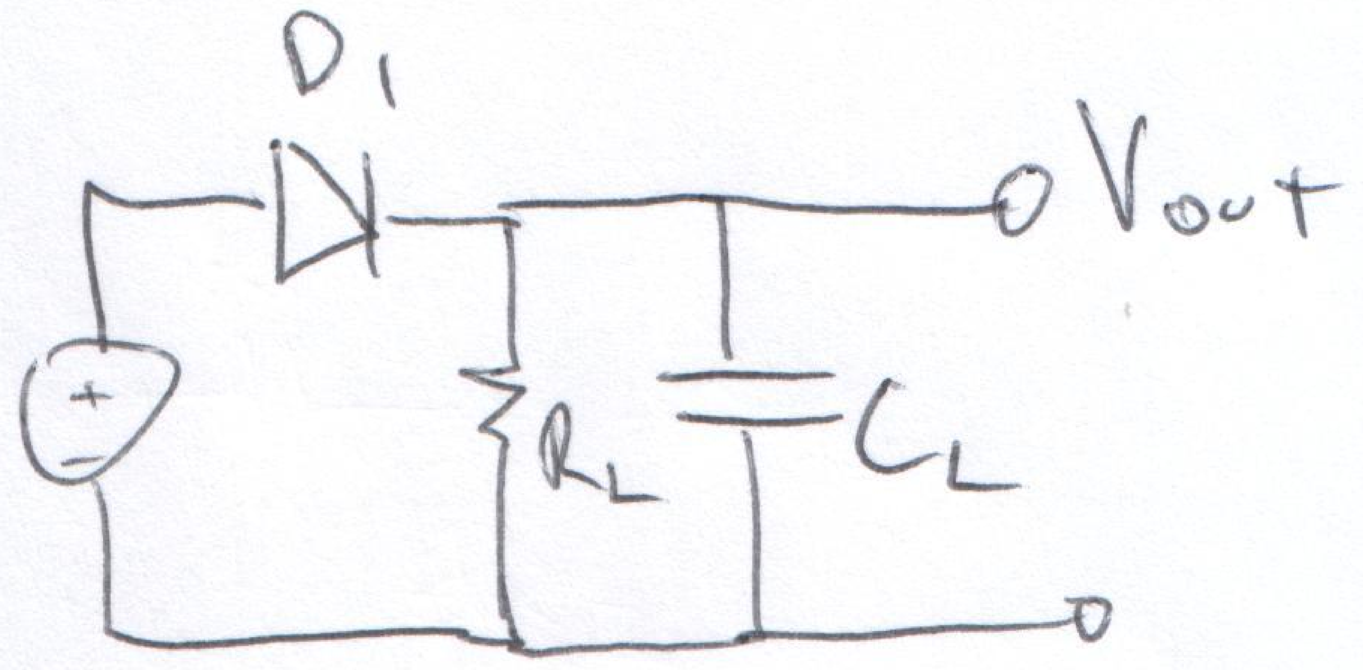
$$\cancel{V_o = V_{IN} - R \cdot (I_o + I_x) \quad I_x =}$$

$$\frac{V_o - V_{IN}}{R} + \frac{V_o - V_Z}{R_Z} + I_o = 0$$

$$V_o \left(\frac{1}{R} + \frac{1}{R_Z} \right) - V_{IN} \frac{1}{R} + -V_Z \frac{1}{R_Z} + I_o = 0$$

$$\frac{\partial V_o}{\partial I_o} = - \frac{1}{\frac{1}{R} + \frac{1}{R_Z}}$$

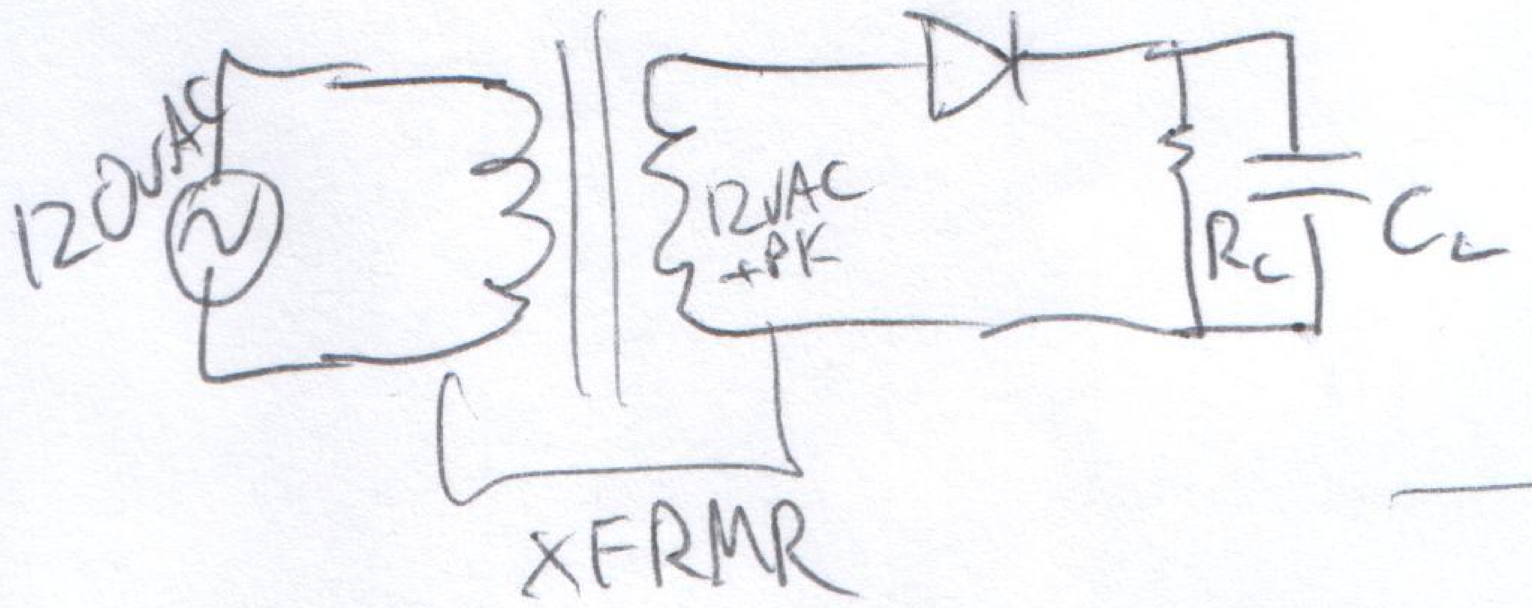
it <u>is</u> negative.
<u>ok</u>.



~~$R_L C_L$~~

$$R_L C_L >> \frac{1}{f_{sin}} \rightarrow \text{constant } V_{out} \text{ DC}$$

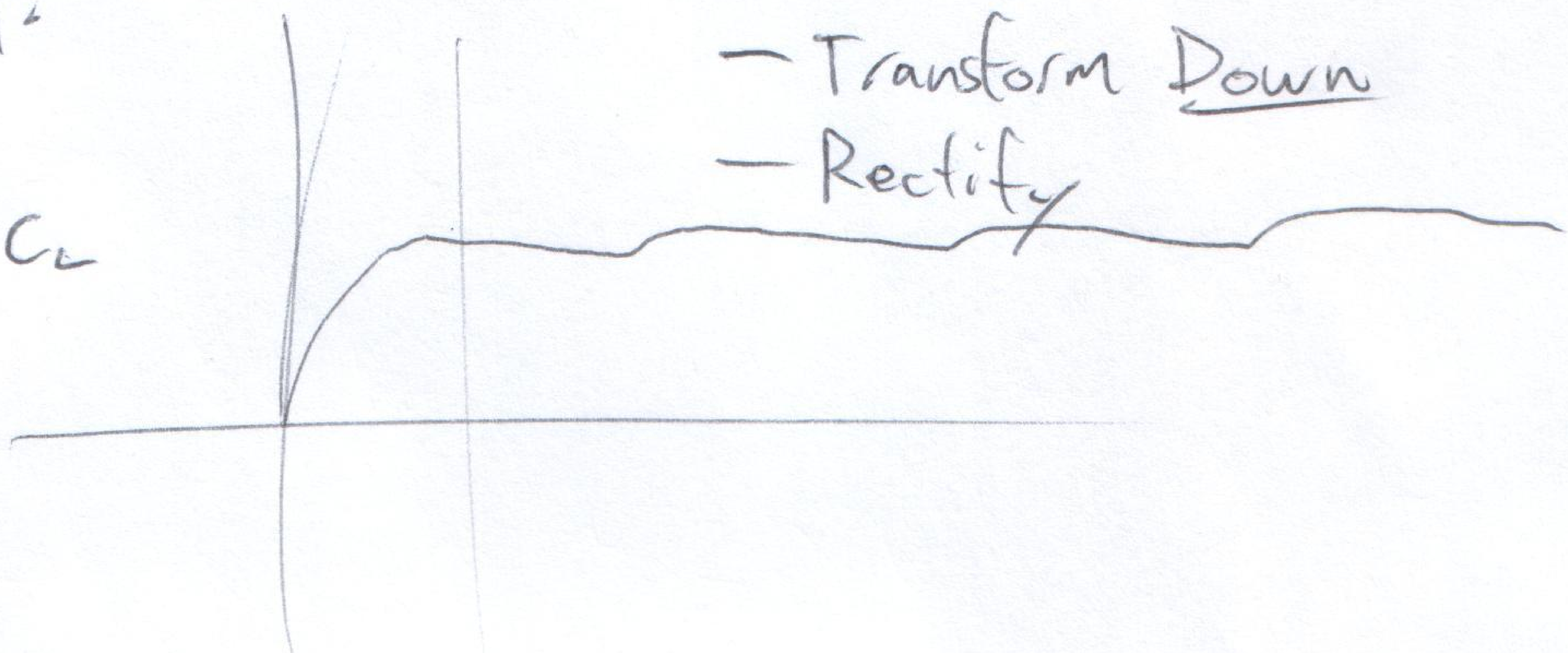
Construction Detail:



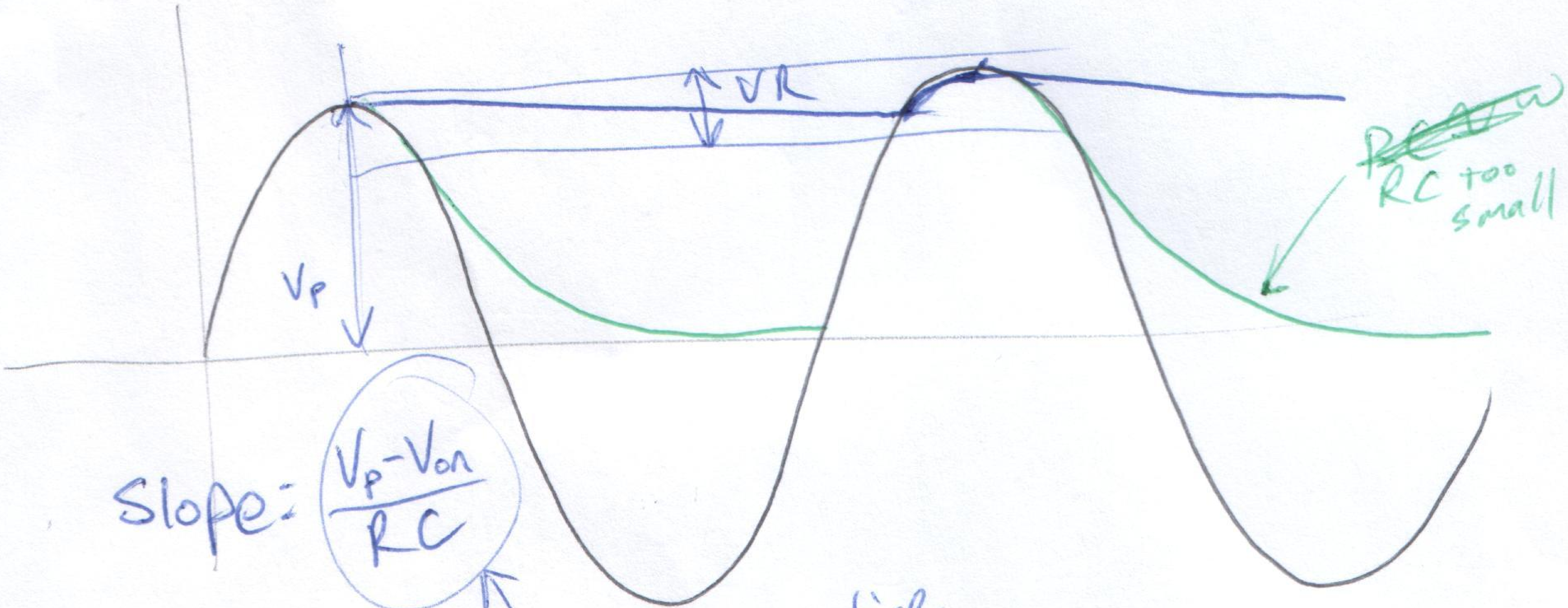
Want +12VDC

— Transform Down

— Rectify



Ripple Voltage:



Slope: $\frac{V_p - V_{on}}{RC}$

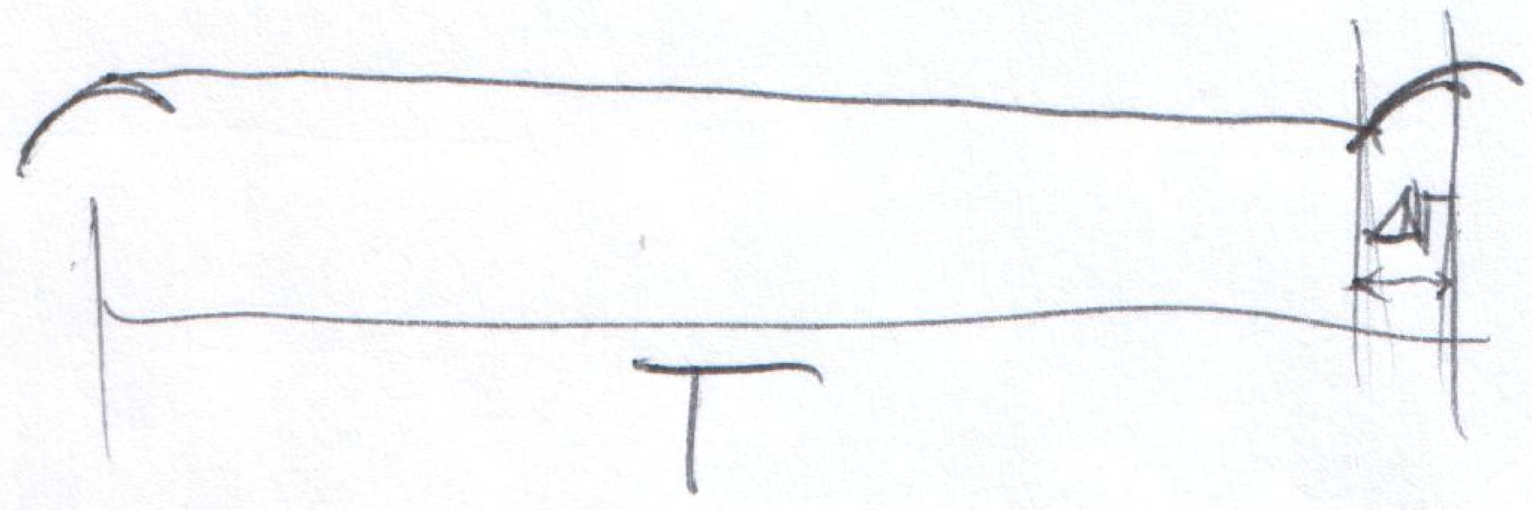
RC time constant derivative

$$V_R = \frac{(V_p - V_{on})}{RC} \cdot T \quad @ \; V \cong 0$$

period

Δ_t ignored for this

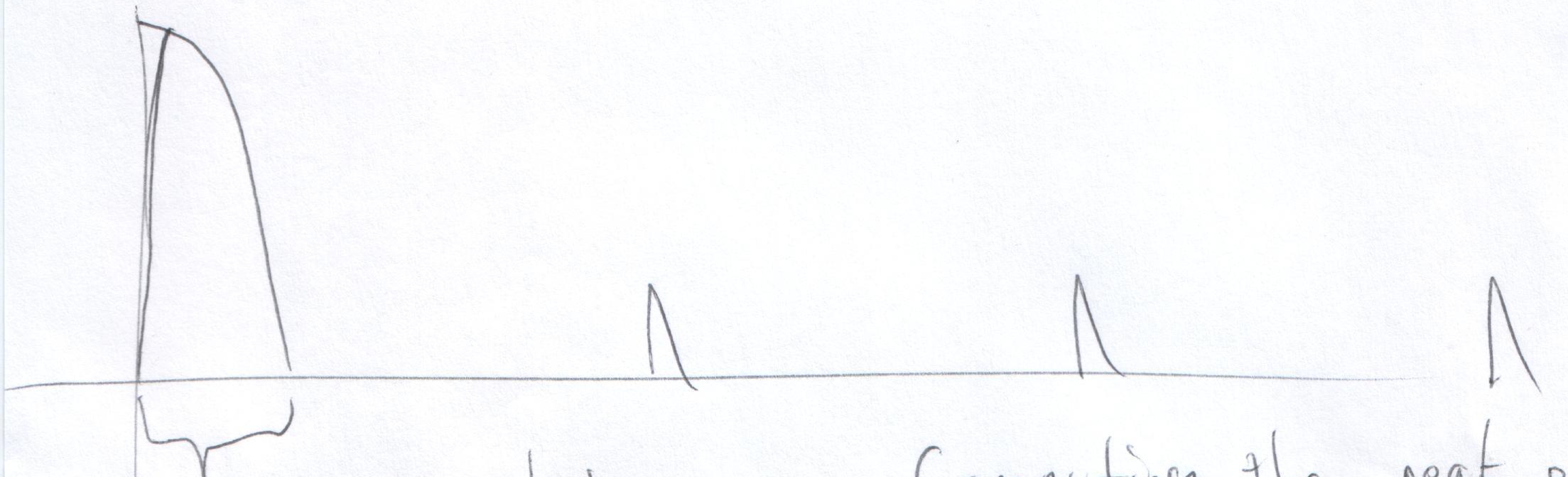
ΔT:



$$\theta_c \approx \sqrt{\frac{2V_r}{V_p}}$$

$$\Delta T \approx \frac{\theta_c}{\omega}$$

Major Points: Current is only flowing during ΔT!



Capacitor neds to change voltage nearly instantly

Computing the peak of the surge current is ugly, but we can do good work with charge:

$$Q_{SURGE} = C_L \cdot V_{OUT}$$

$$I_{\substack{Average\\(SURGE)}} = \cancel{\frac{Q_{SURGE}}{\frac{T}{4}}}$$

how long it takes to charge

$$\boxed{I_{AVE} = \frac{4Q}{T}}$$

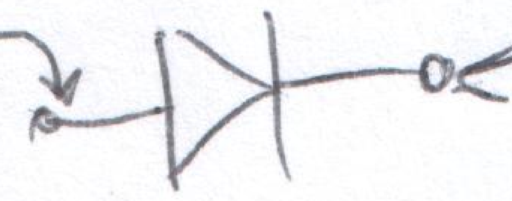
$$\boxed{\begin{aligned} I &= C\frac{d}{dt}V_p \sin\omega t \\ I &= \omega C V_p \cos\omega t \\ PK &= \omega C V_p \end{aligned}}$$

$$Q_{repeating} \approx \underbrace{I_{OUT} \cdot T}_{\text{total drain over one period}}$$

$$\boxed{I_{AVE\,Rep} = \frac{Q_{rep}}{\Delta T}}$$

These equations are less important than the idea: a big load of current at startup followed by slow drain with little bursts of refill current.

Peak Inverse Voltage

$-V_p$ →  ← $V_p - V_{ON}$

$2V_p - V_{ON}$ ← make sure your diode is tougher than that!

In real designs:

Assuming the H.W.R. makes sense, you have some practical concerns:

- How much capacitance do you need? RC
- How much diode current must you support? I_{SURGE}
- How much reverse bias will you face?
- How much power must the diode dissipate? ($I \cdot V$)

Homework: Design a 5v power supply.

specify:

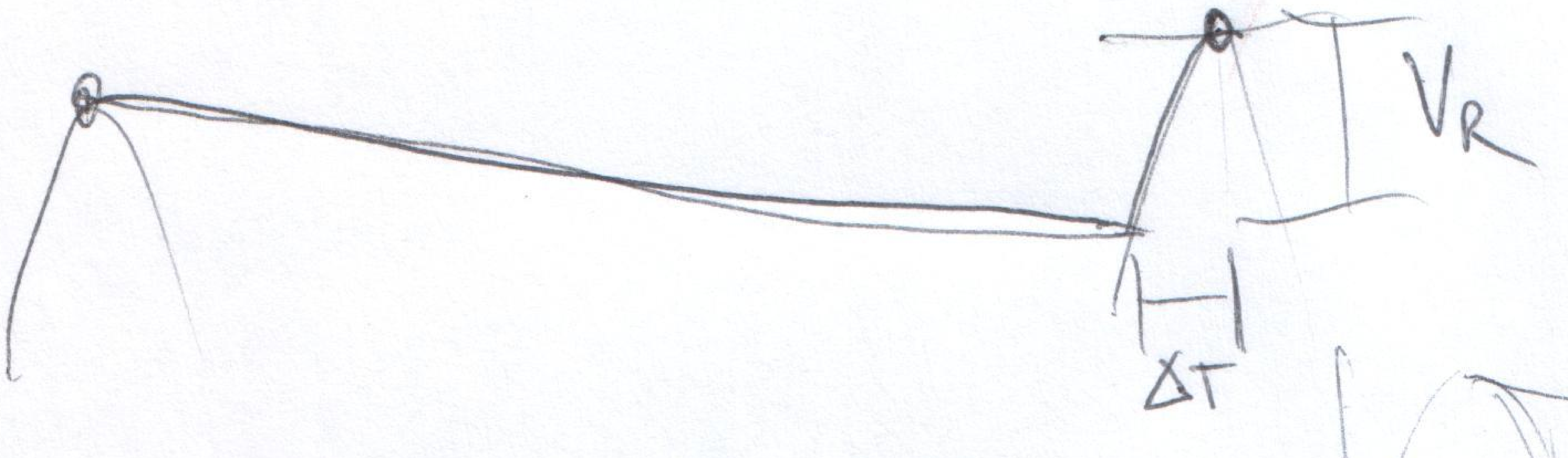
- XFORMR in ratio from 120VAC to ??VAC
- A Rectifier (~~full wave or ha~~ Half wave) with C
- A zener diode regulator to drop the voltage to 5V.

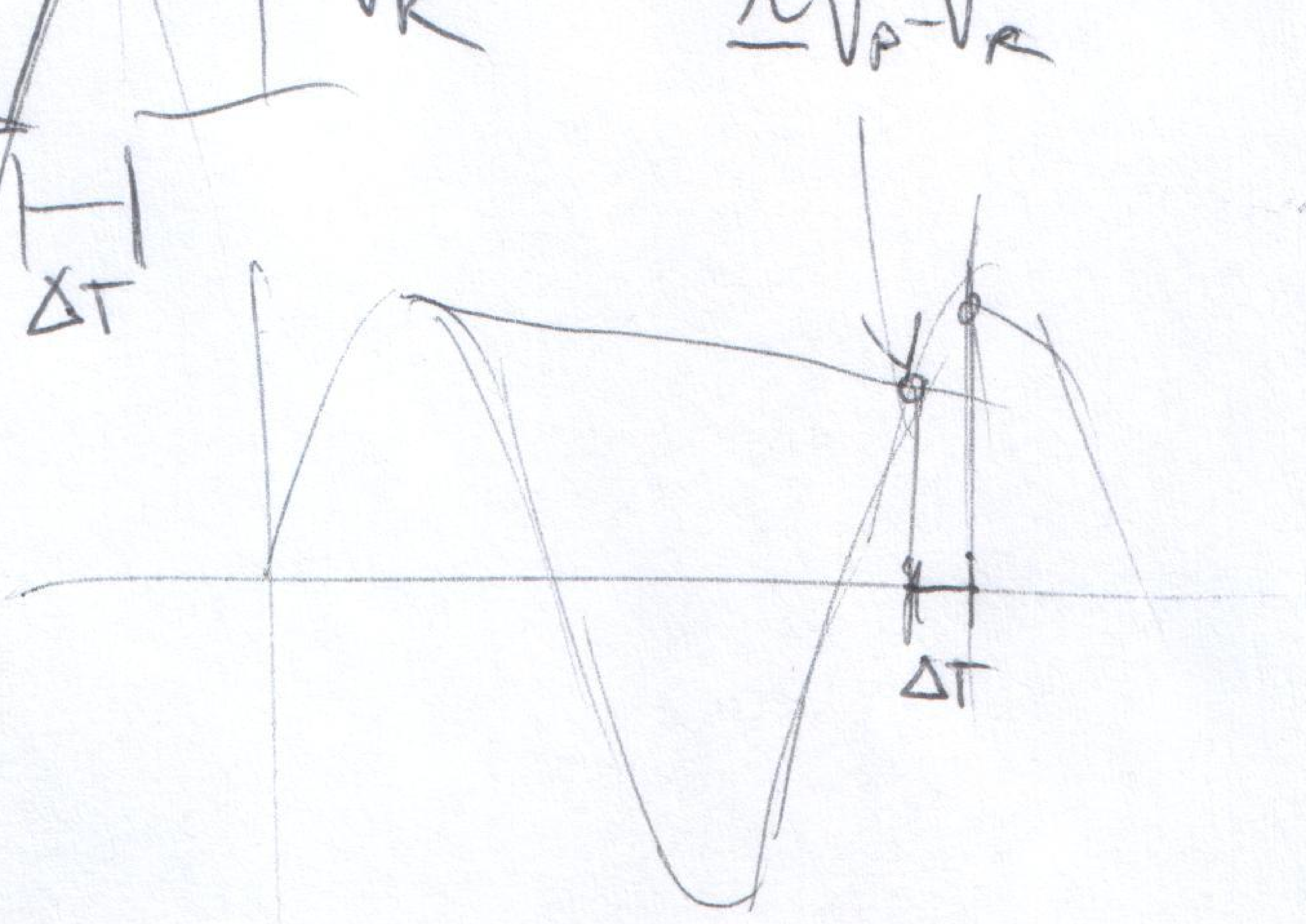
Report:

- Parts list
- Schematic
- V_{RIPPLE} at output.
- Max diode current, reverse bias

Due 1.27.
(study problems to follow)

Analyzing ΔT





$\cancel{\Delta T \simeq \operatorname{acos}\left(1 - \frac{V_R}{V_{PK}}\right)}$

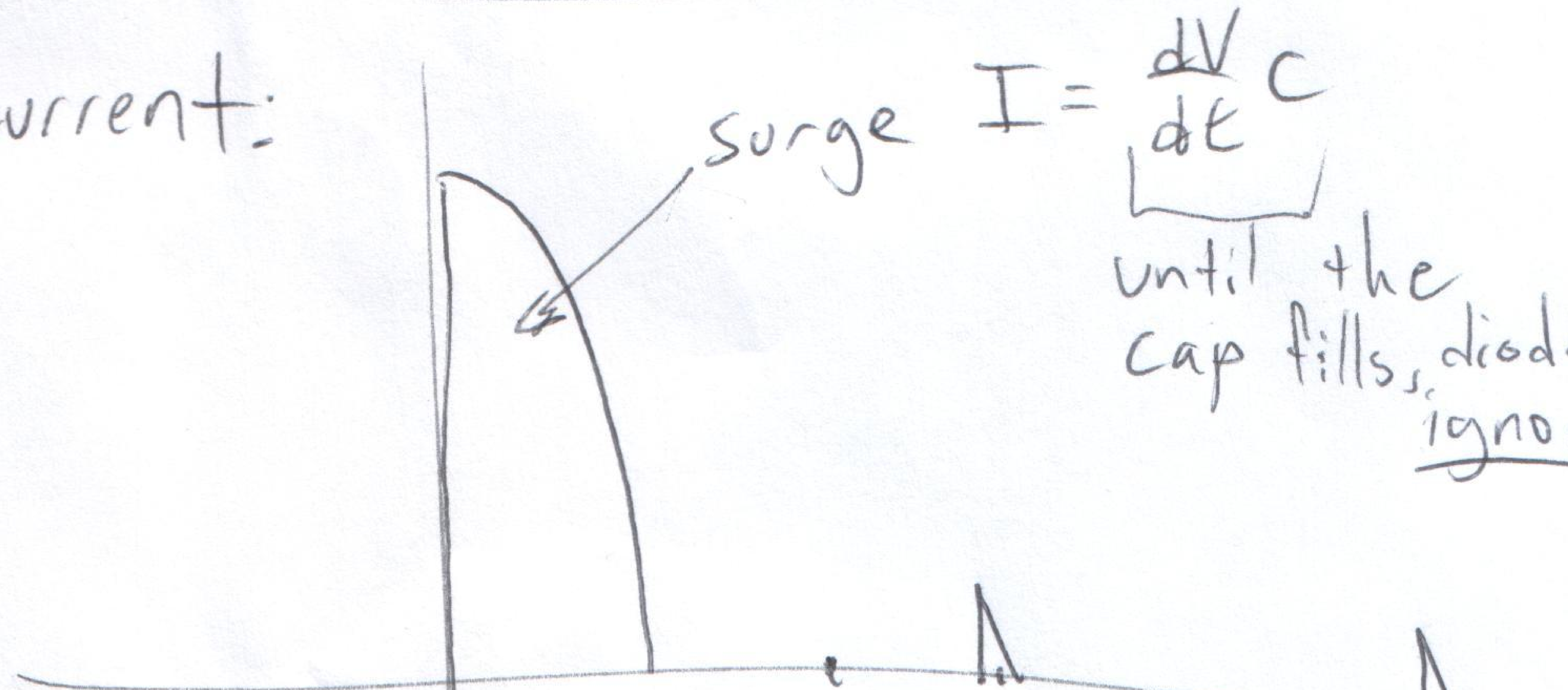
Angle of this time, θ_c:

$$\cos\theta_c = 1 - \frac{V_R}{V_p} = \frac{V_p - V_R}{V_p} \qquad \cos\theta_c \simeq 1 - \frac{\theta_c^2}{2}$$

$$1 - \frac{\theta_c^2}{2} \simeq 1 - \frac{V_R}{V_p} \implies \underline{\theta_c \simeq \sqrt{\frac{2V_R}{V_p}}}$$

$$\Delta T = \frac{\theta_c}{\omega} = \underline{\frac{1}{\omega}\sqrt{\frac{2V_R}{V_p}}}$$

Current:



surge $I = \underbrace{\frac{dV}{dt}C}_{}$

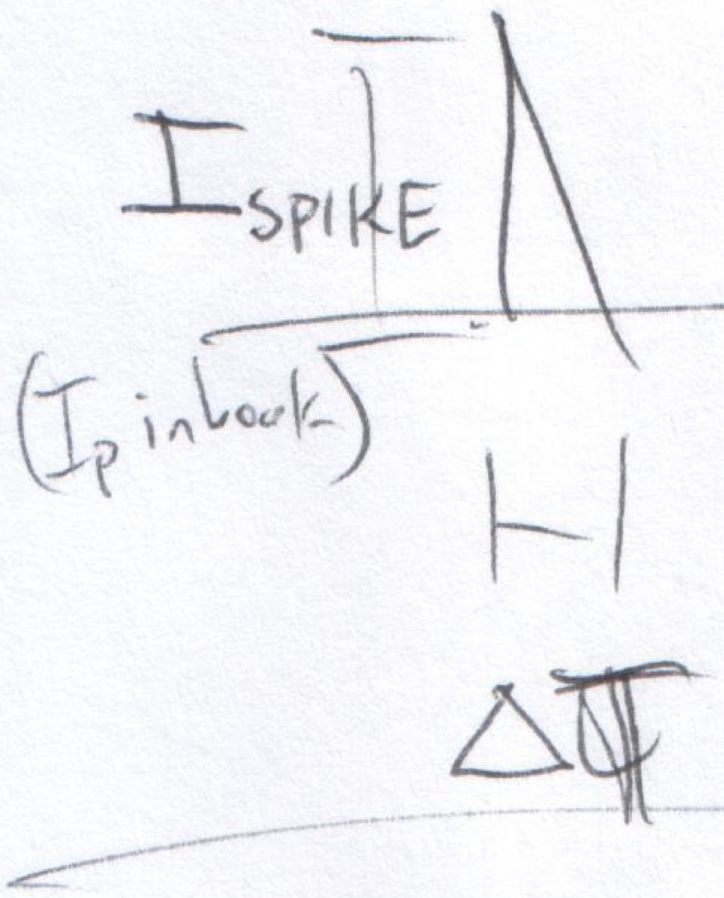
until the cap fills, diode ignore it.

$I = C \cdot V_p \omega \cos(\omega t)$

Initial surge $= \boxed{\omega C V_p}$

Note: bigger for higher f, C, and V_p.

Spikes:

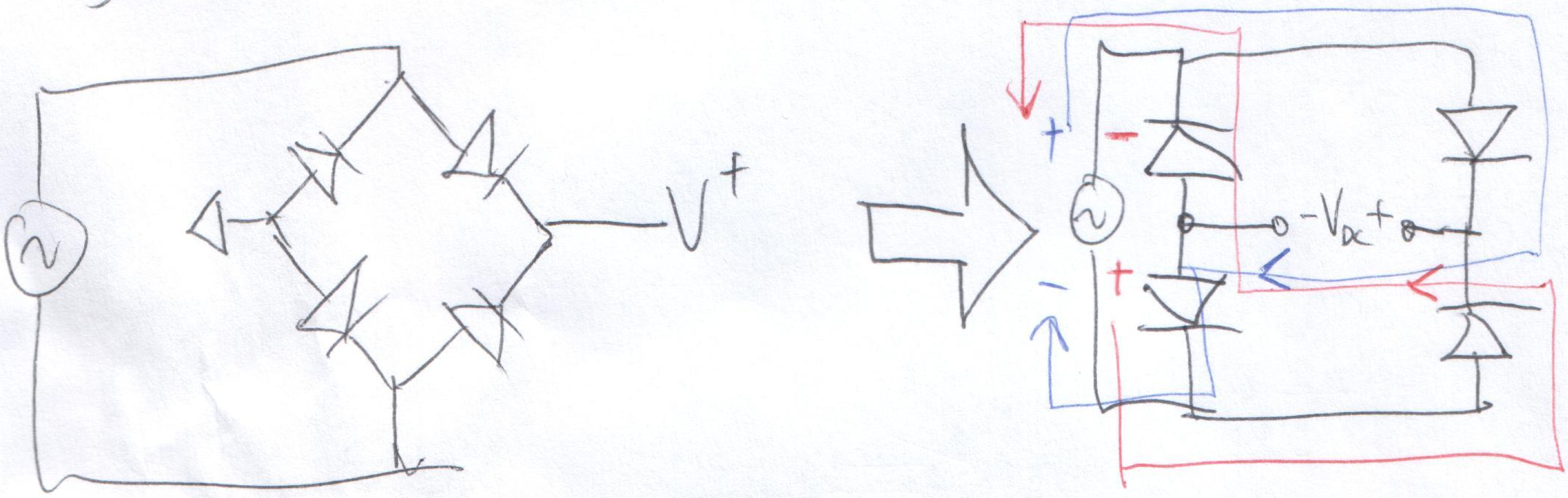


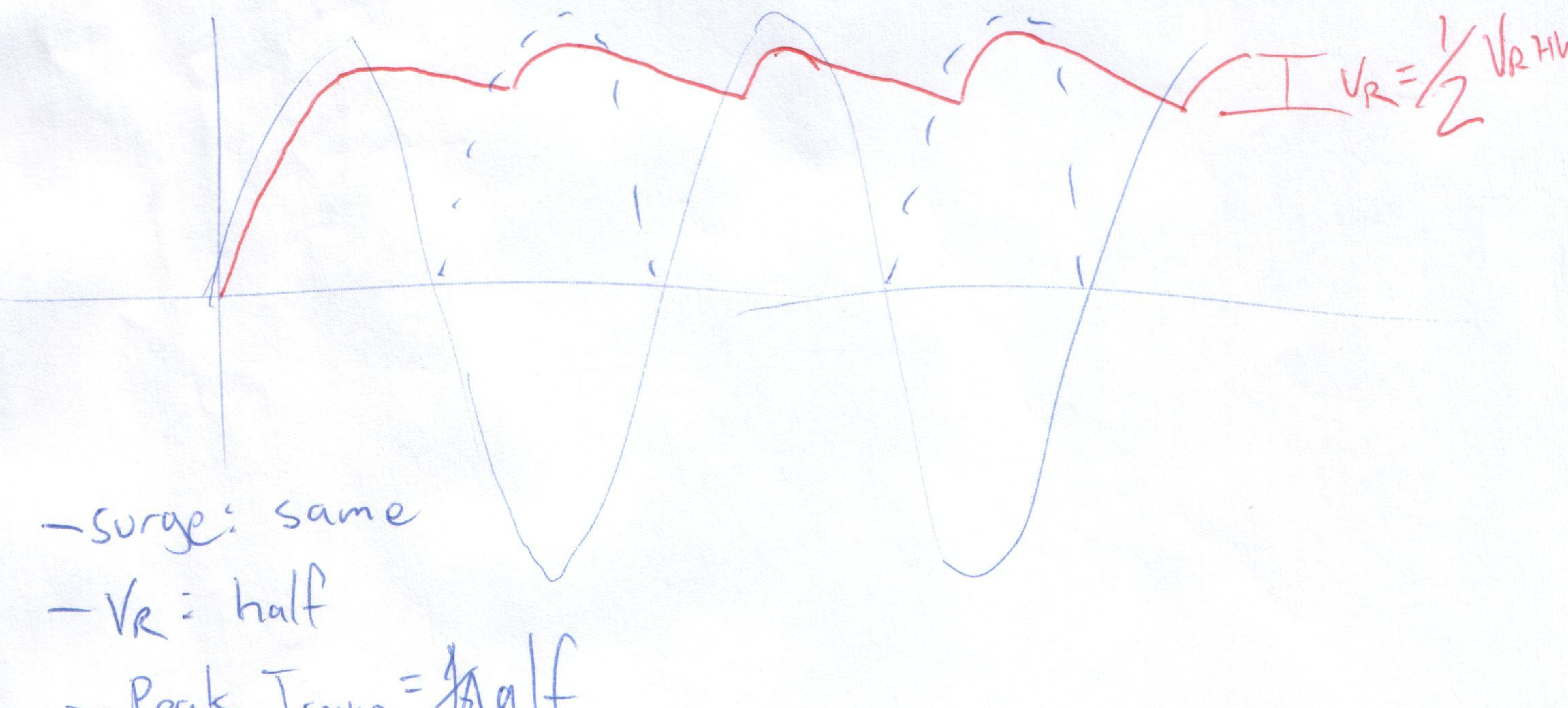
$$Q = I_{DC} \cdot T = I_{SPIKE} \frac{\Delta T}{2}$$

$$I_{SPIKE} = I_{DC} \frac{2T}{\Delta T}$$

$\cancel{= I_{DC}}$

Going Full WAVE





- surge: same
- V_R: half
- Peak I_{SPIKE} = half