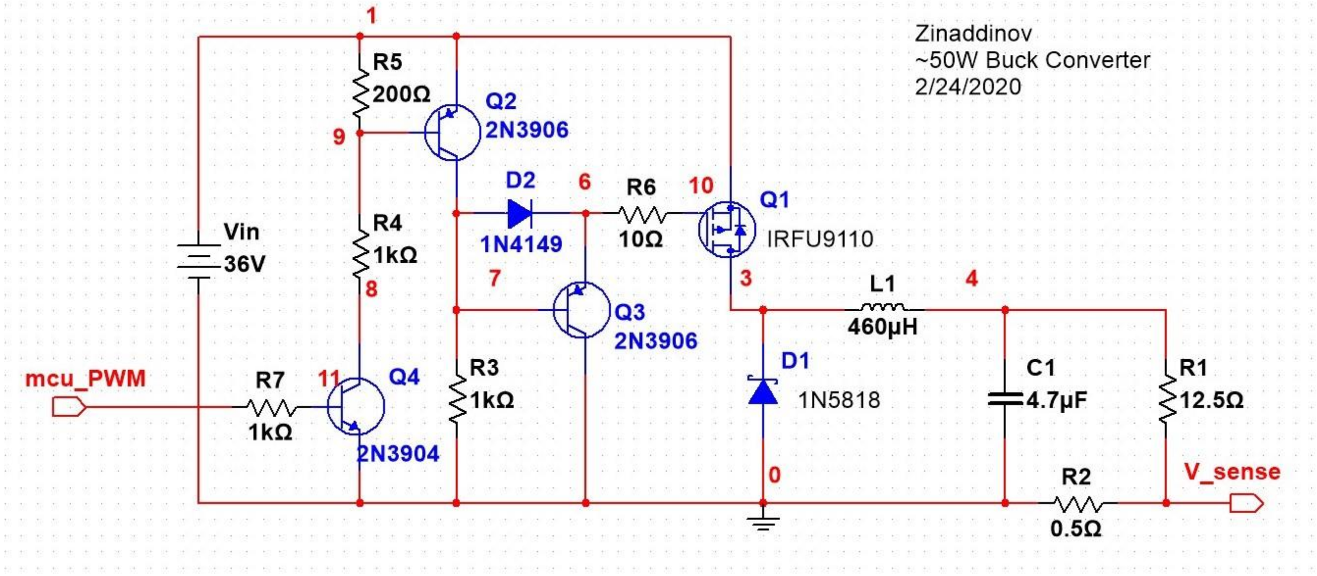
A Simple 50W Buck Converter

Content (~10-15 min read):

- Design & component choice justification
- Brief comments on inductor resistance
- Conduction losses calculation
- Switching losses calculation
- Appendix 1: H-bridge motor driver [old projects]
- Appendix 2: Constant-current LED driver [old projects]



36V-26V (2A) *these values are motivated by component availability

Target:

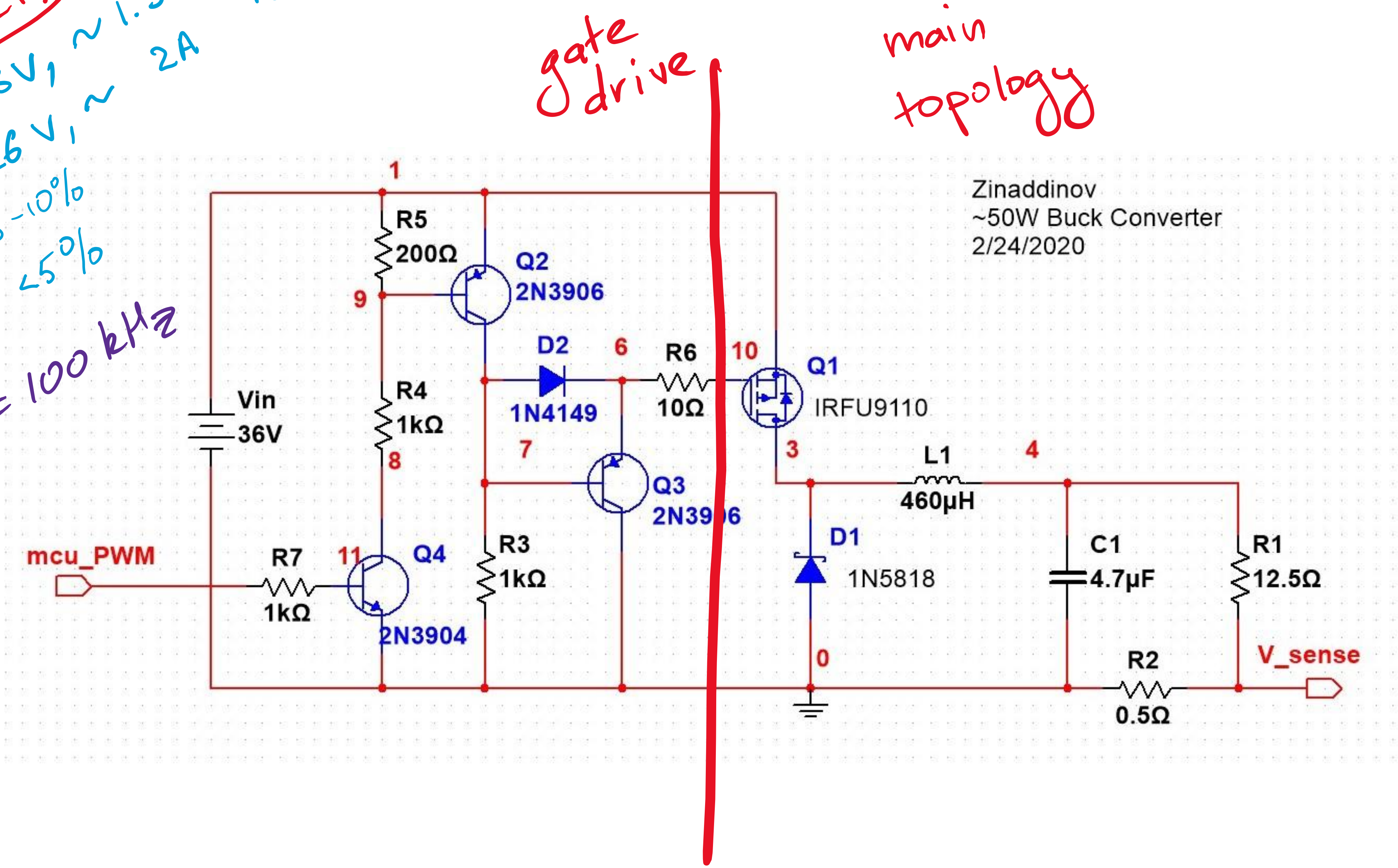
IN: 36V, ~1.5A ~50W

OUT: 26V, ~2A

Irpp 5-10%

Vrpp <5%

f = 100kHz



Zinaddinov
~50W Buck Converter
2/24/2020

Transistor choice

- Normally, p-MOSFET is not the best choice because

$$J = nq\mu E$$

↓

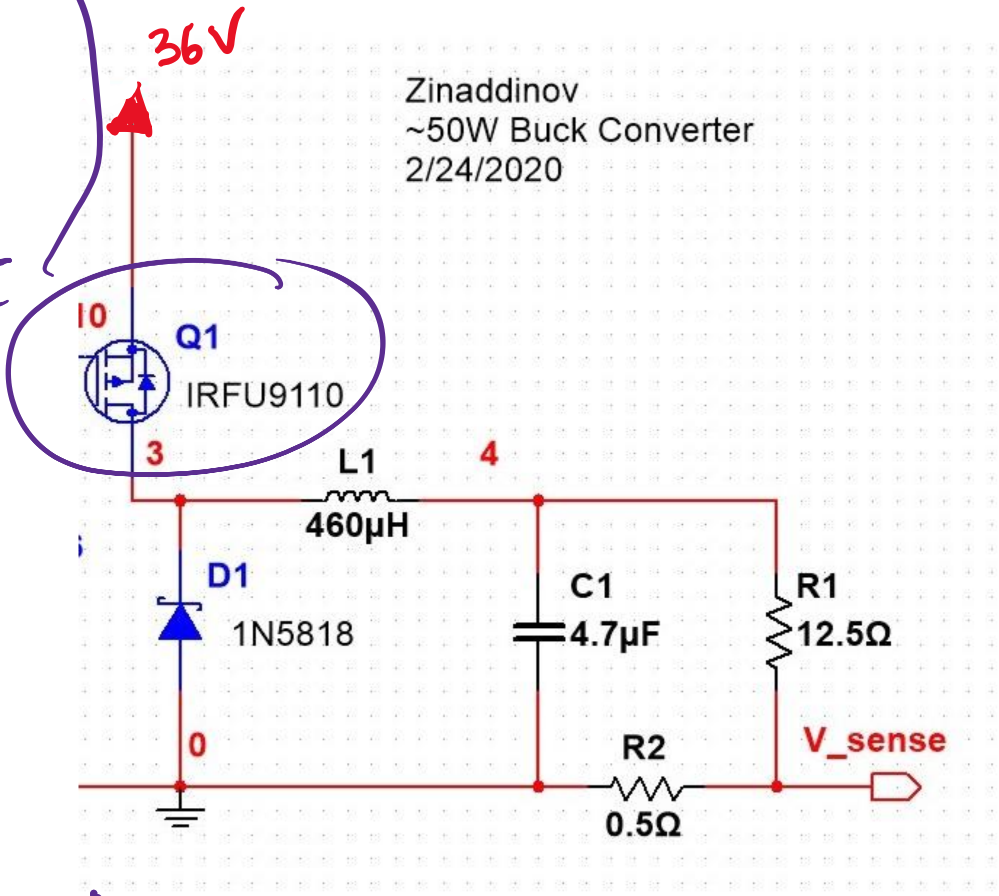
R_{DS_ON} ↑

mobility of holes is smaller than of e^-

- However, p-MOS has a simpler drive circuitry... Otherwise I will need to implement a bootstrap transistor pair

complexity ↑

time & effort ↑



Q1 datasheet:

$V_{DS\,max} = -100V$ ✓

$I_{D\,max} = 2-3A$ ✓

$P_D = 25W$ ✓

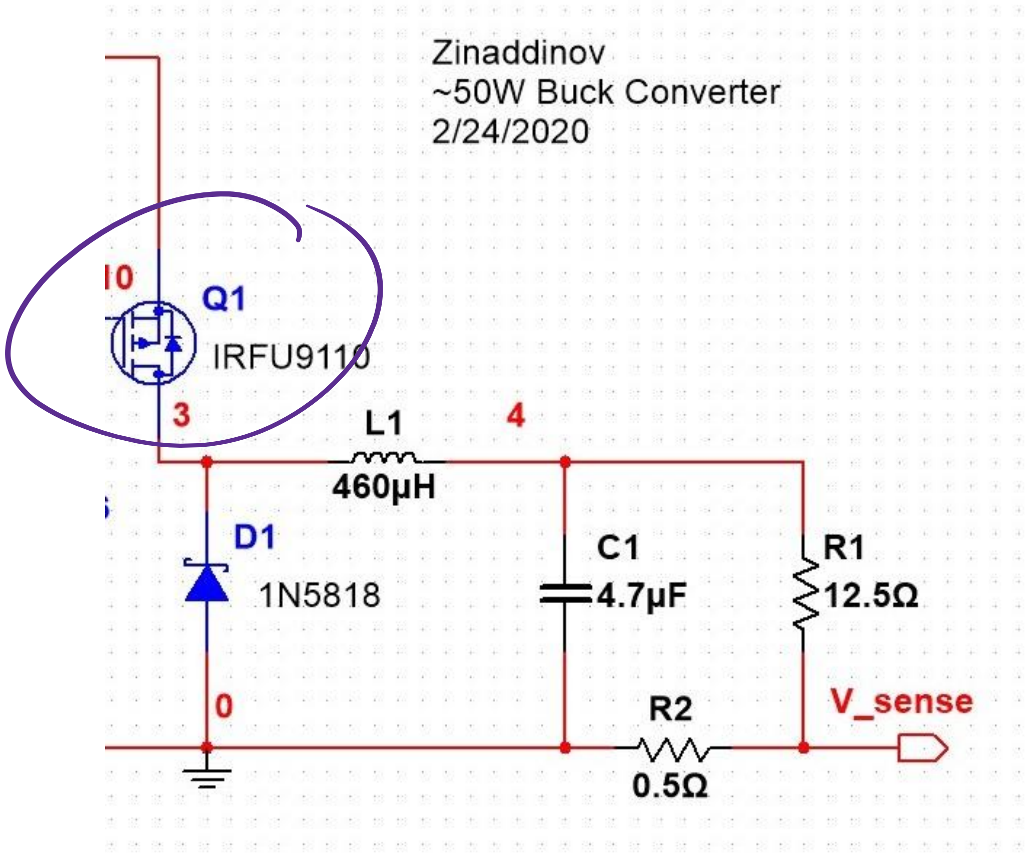
$R_{DS\_ON} = 1.2\Omega$

$I_d = 1.3\,A$

$V_{GS} = -2 — -4\,V$

$C_{iss} = 200pF$

gate capacitance



Diode choice:

- Metal-oxide junction = no reverse recovery
  (schottky) $P_{sw\_Loss} \downarrow$ ✓

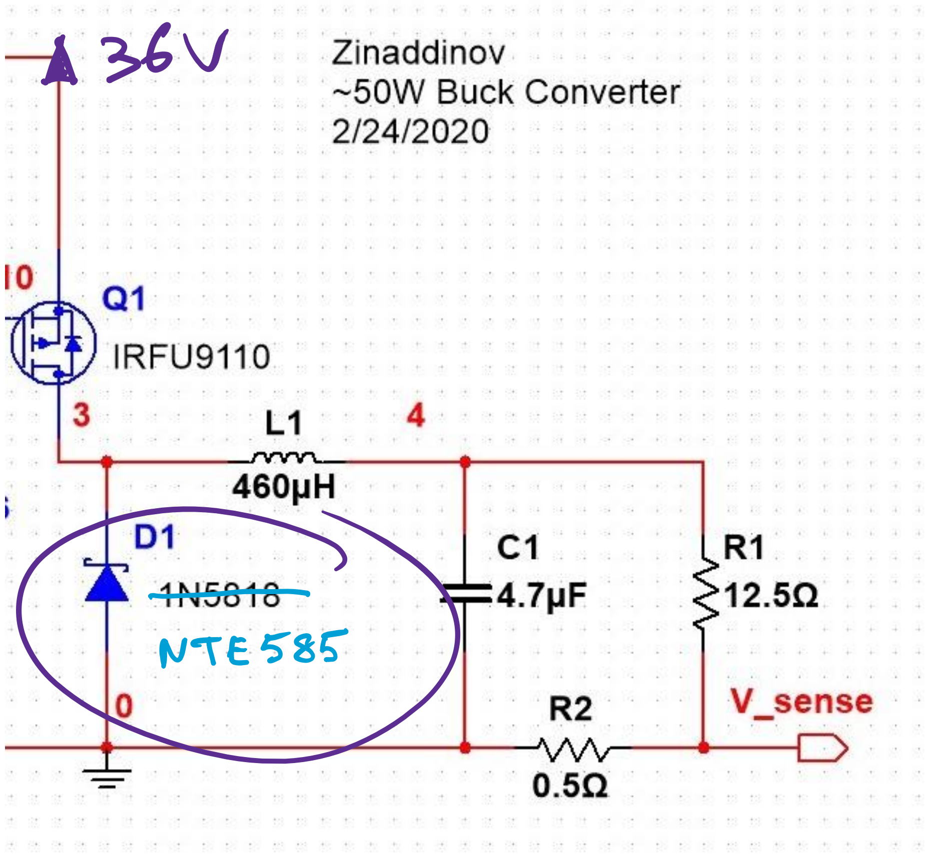
- Datasheet:
  NTE585

  $V_{rev\_max} = 40V$ ✓

  $I_{max\_AVG} = 1A$ ← OK. (Best I got available)

  $I_d = D' I_L \approx 33\% \cdot 2A$

  $V_f = 0.6V$ OK



Inductor choice:

5–10% ripple p.p.

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

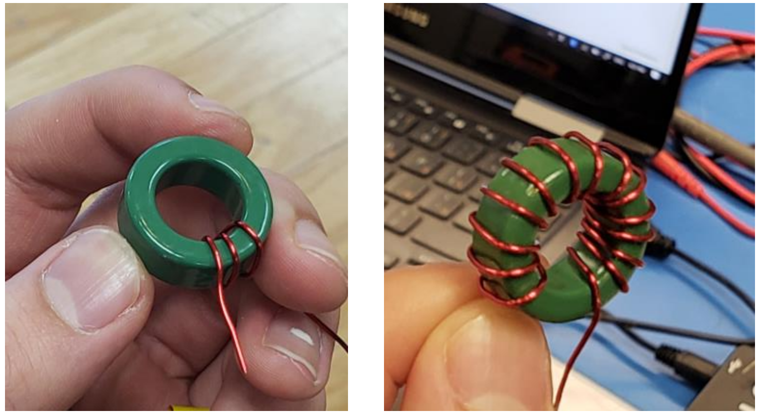
(36−26) V

~70% duty @ 100 kHz

$$L = \frac{10\,V \cdot 7\,\mu sec}{100\ mA} = 700\,\mu H$$

or $200\,mA$

or $350\,\mu H$

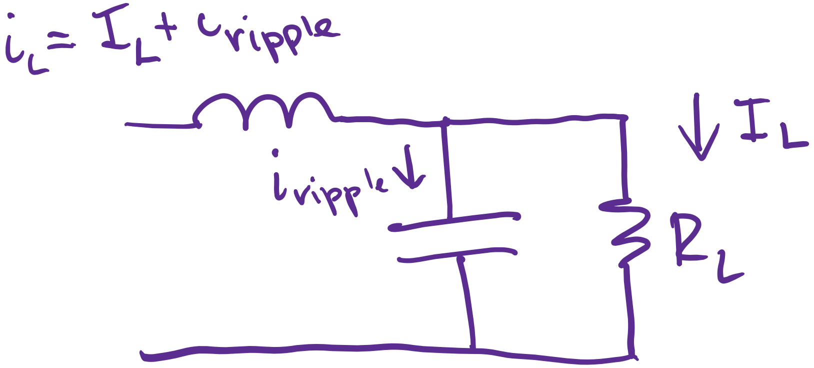


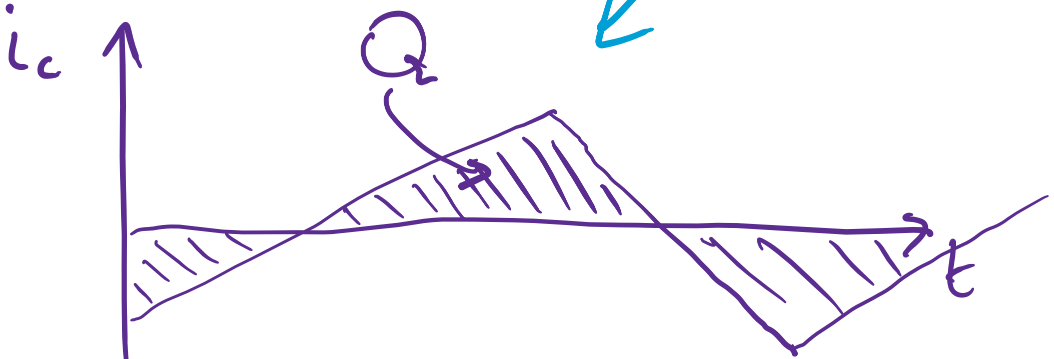
measured inductance $460\,\mu H$ ✓

Capacitor choice

approximation: assume entire average current is going to the load

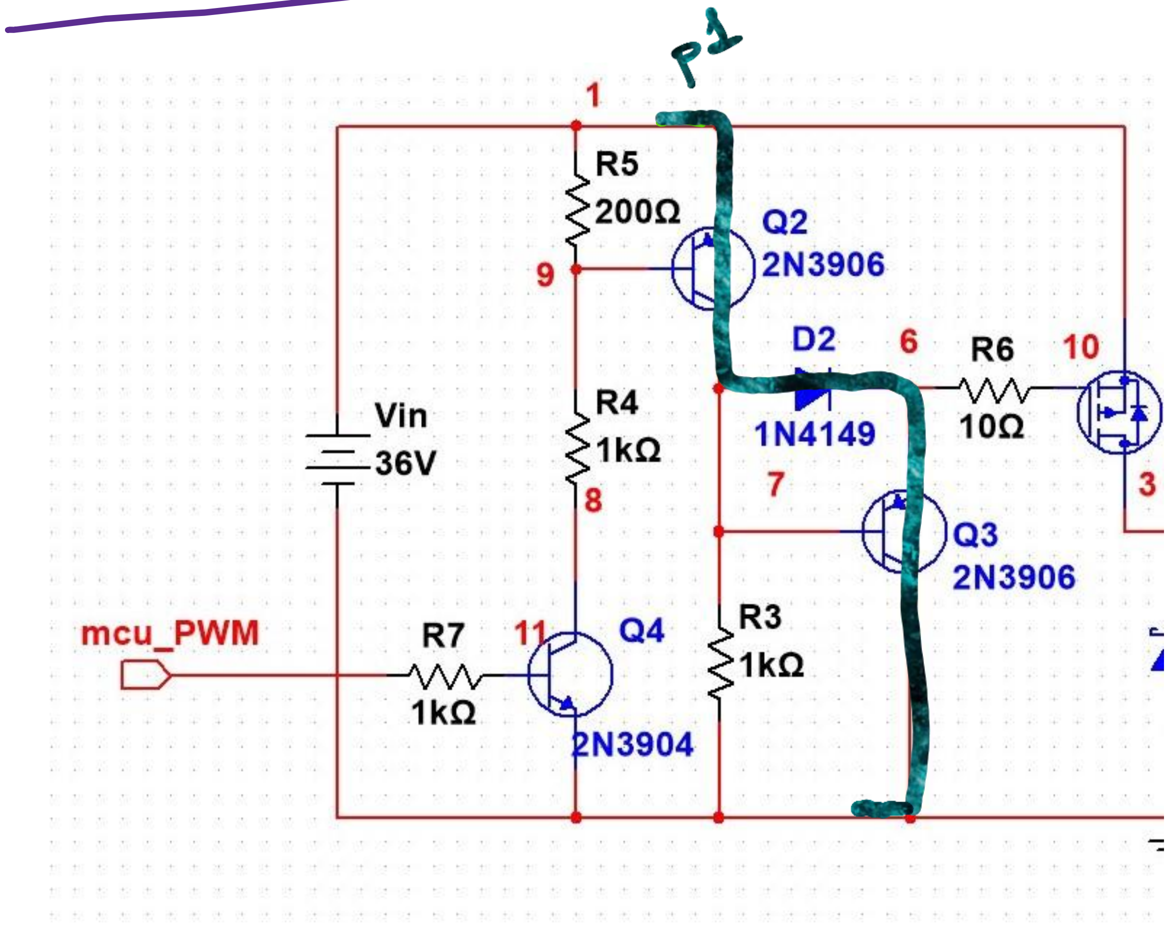
assume $Z_c(f) \ll Z_L(f)$, so entire ripple is going to the capacitor





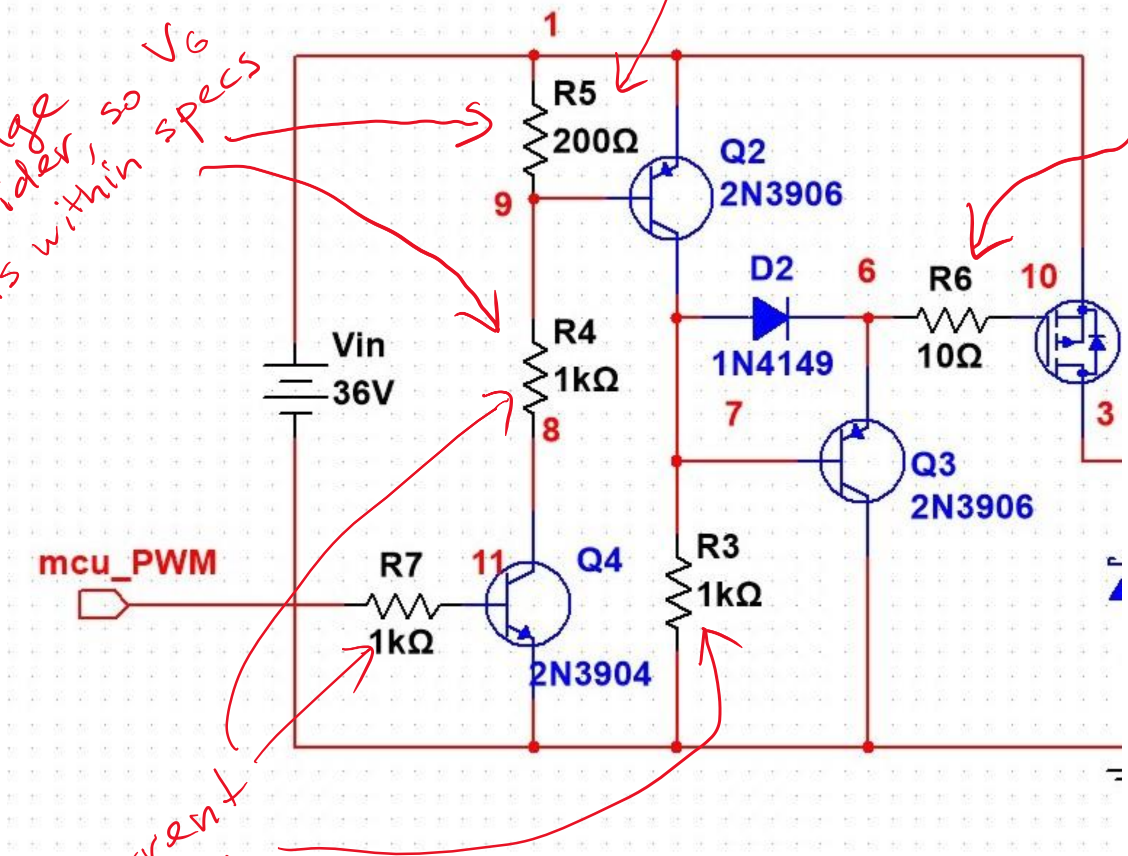
- we can find ripple capacitor charge
- using $Q = CV \Rightarrow \Delta Q = C \Delta V$ we can select C for a specific ΔV.
- my calculations showed that even 1.5μF works.
- ESR has negligible effect.

Gate drive:



- power fets have high gate capacitance
- need to have short rise/fall times (within EMC)
- when on, path p1 carries high current ⇒ charges up gate cap quickly

* I forgot a "bleeder" resistor to discharge the gate capacitor (!)



pull-up

for EMC purposes (rising edge) forms RC with gate

voltage divider, so V_G is within specs

current limit

The effect of inductor copper losses:

The converter efficiency hinders if inductor copper resistance is large relative to load resistance.

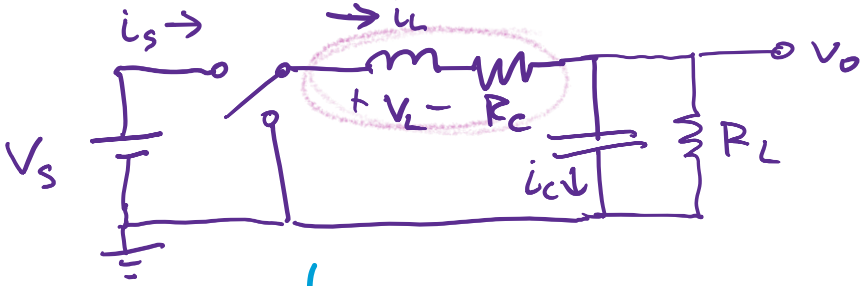
Larger inductor, higher cost, higher efficiency
(Thicker wire gauge, lower frequency, less hysteresis)

Trade-off

Lower cost, lower efficiency
(**Thinner** wire gauge, **higher** frequency)

Derivation (can skip):

① Base circuit



② Steady state eqns:

* can be derived using:

1) small ripple approx.
2) inductor volt-sec balance
3) capacitor amp-sec balance

$$\langle V_L \rangle = DV_s - I_L R_c - V_o = 0$$

$$\langle i_c \rangle = I_L - \frac{V_o}{R_L} = 0$$

$$I_s = DI_L$$

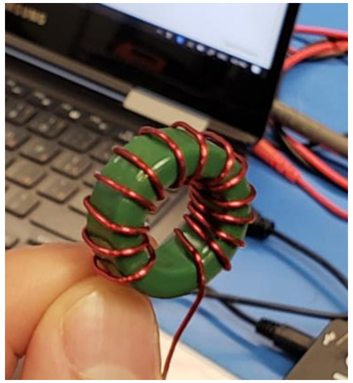
③ S.S. EQ. MODEL

④ TRANSF. F VS. $\frac{R_c}{R_L}$

$$\frac{V_o}{V_s} = D \frac{1}{1+\frac{R_c}{R_L}}$$

← copper loss

← load



I made a 460 uH inductor (measured). Measured copper resistance is 0.16R.

R_c

$$\eta = \frac{P_o}{P_{in}} = \frac{V_o I_L}{V_s \cdot D I_L} = \frac{V_o}{V_s} \cdot \frac{1}{D} = \frac{1}{1 + \frac{R_c}{R_L}} = 98.7\%$$

12.5Ω

Conduction losses:

$$\eta = \frac{V_o I_L}{V_s D I_L} = \frac{1 - \frac{D' V_f}{D V_s}}{1 + \frac{R_c}{R_L} + D\frac{R_{on}}{R_L} + D'\frac{R_d}{R_L}}$$

Best if:

$V_f \downarrow$ — diode forward voltage

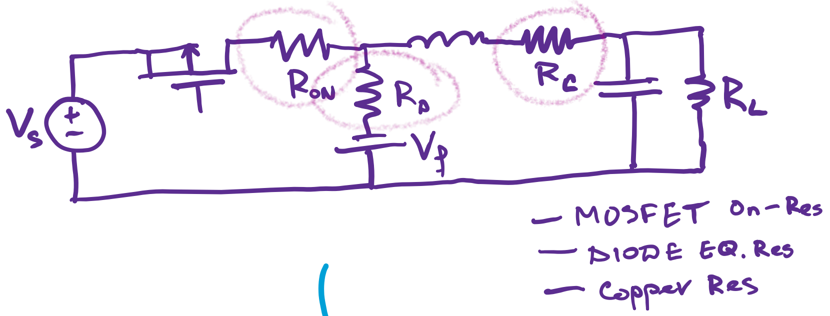
$R_c \downarrow$ — inductor copper loss

$R_{ON} \downarrow$ — transistor on-resistance

$R_d \downarrow$ — diode on-resistance

Derivation (can skip):

① Base circuit



② Steady state eqns:

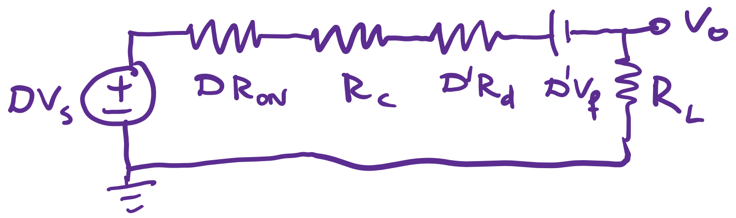
can be derived using:

1) small ripple approx.
2) inductor volt-sec balance
3) capacitor amp-sec balance

$$0 = \langle V_L \rangle = DV_s - DR_{on} I_L - I_L R_c - V_o - D'R_d I_L - D'V_f$$

$$0 = \langle i_c \rangle = I_L - \frac{V_o}{R}$$

③ S.S. EQ. MODEL



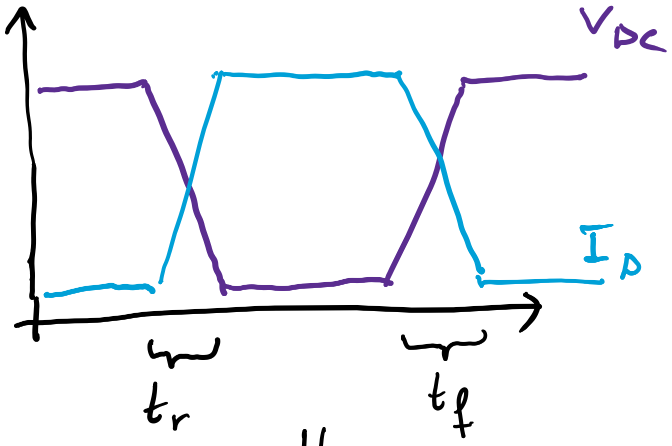
④ Efficiency:

$$\eta = \frac{V_o I_L}{V_s D I_L} = \frac{1 - \frac{D'V_f}{DV_s}}{1 + \frac{R_c}{R_L} + D\frac{R_{on}}{R_L} + D'\frac{R_d}{R_L}}$$

Switching losses:

MOSFET

Simplified model



$$\Downarrow$$

$$P_{Loss} \simeq \frac{1}{2}(V_{in} - V_{out}) \cdot I_L \cdot f_{sw}(t_r + t_f)$$

DIODE

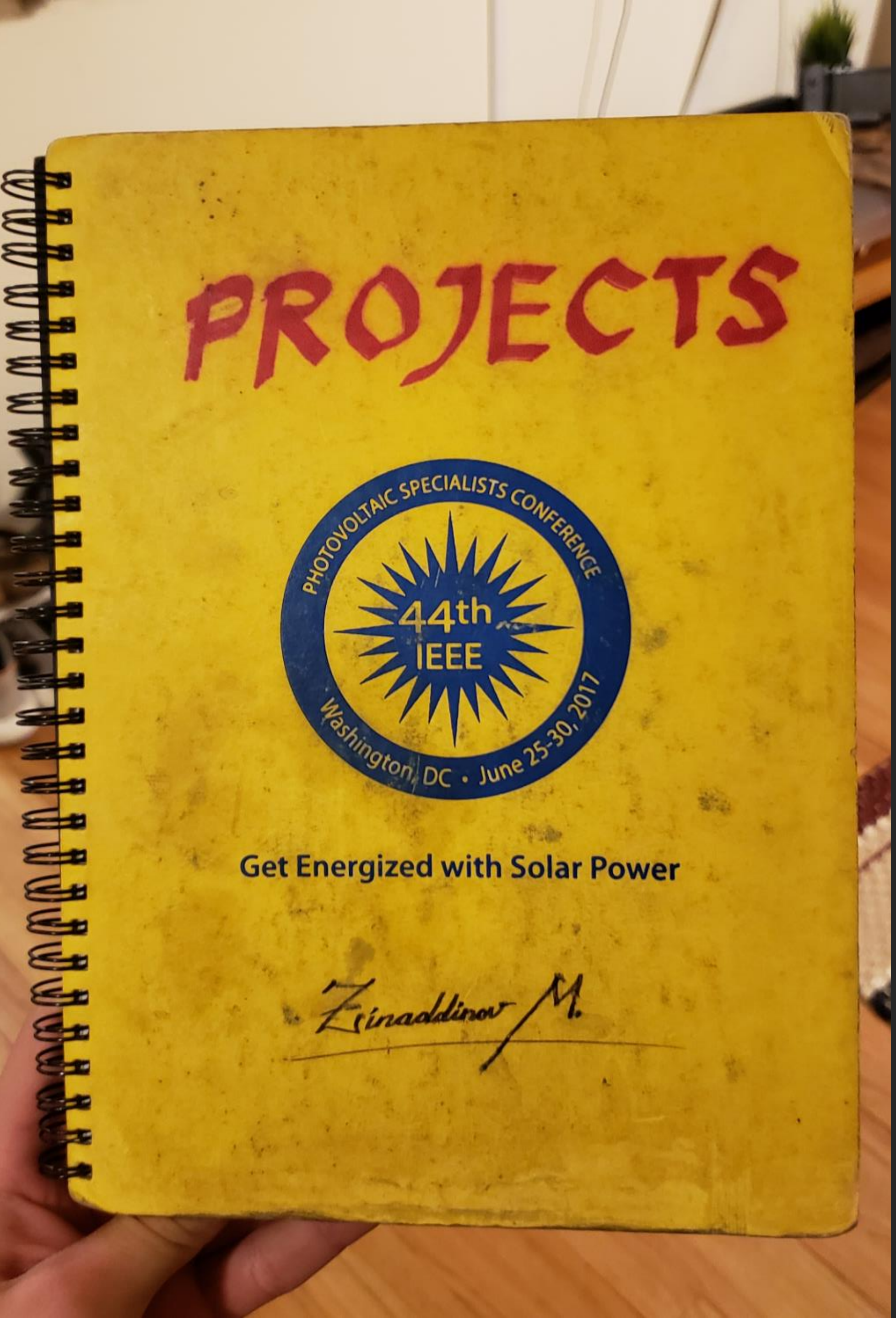
Losses are due to reverse recovery time & charge.

However Schottky diode is a majority carrier device (low to no reverse recovery)

HYSTERESIS

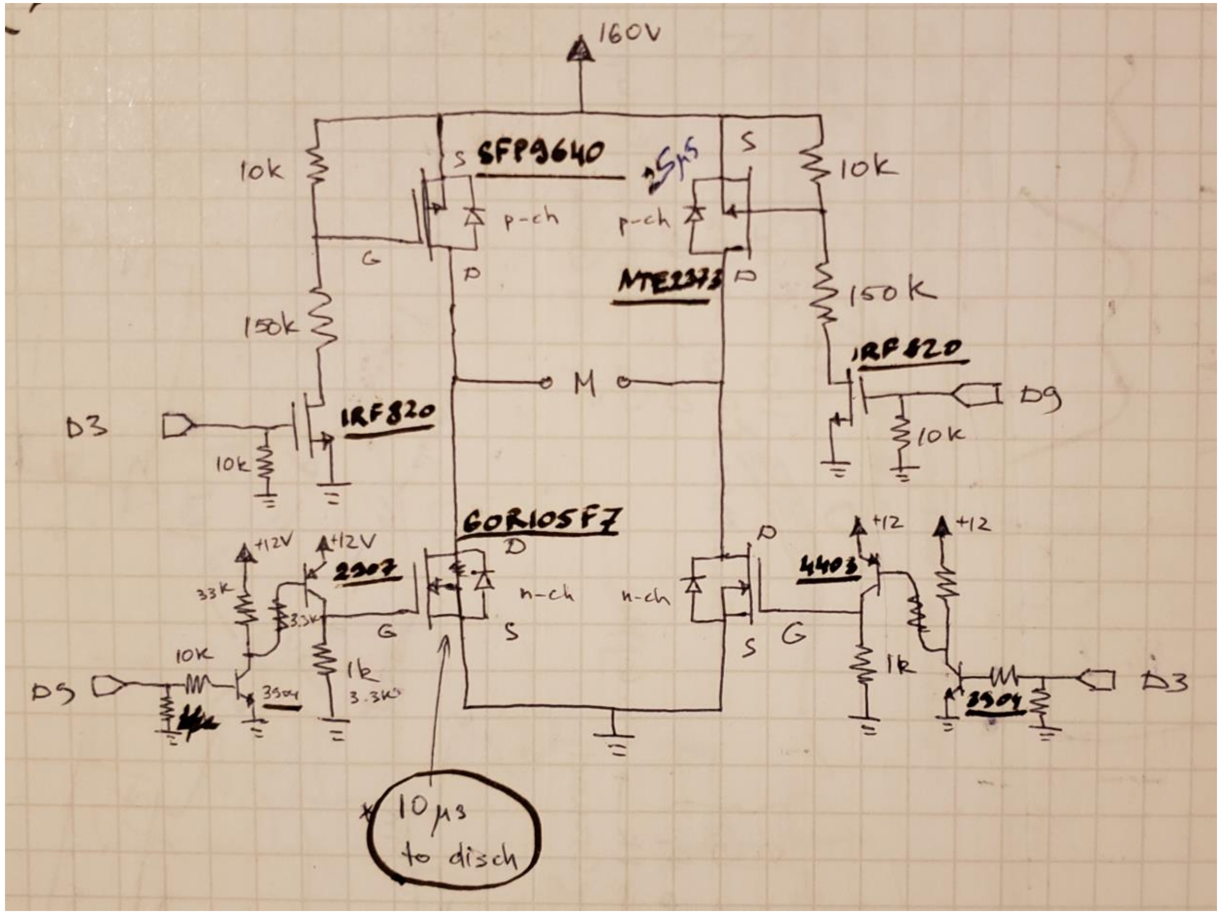
$P_{Loss} \propto f_{sw}$ & core material

I plan to assemble the circuit within a couple days to test its operation.



OLD PROJECTS

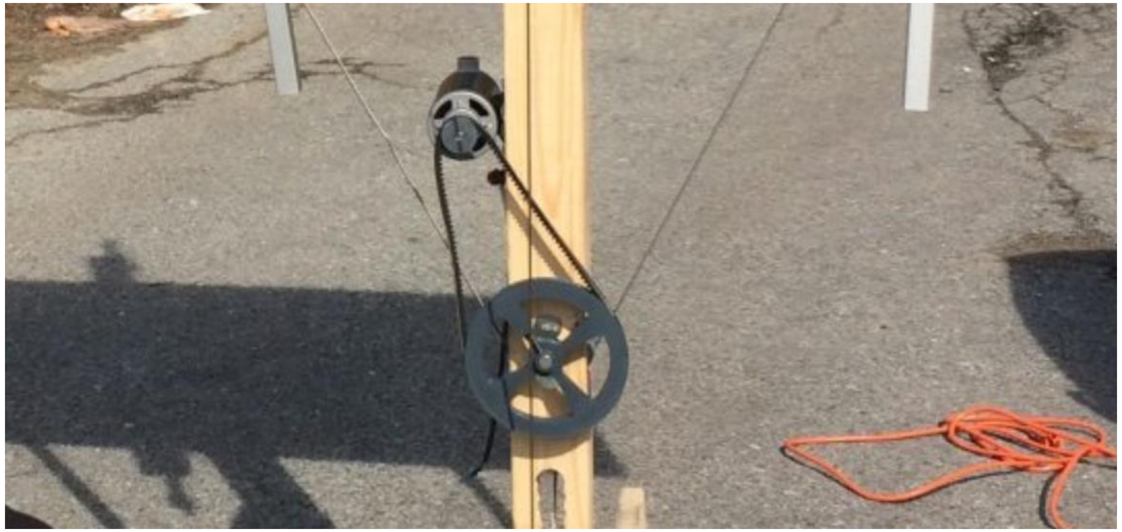
Solar Tracker Motor Drive

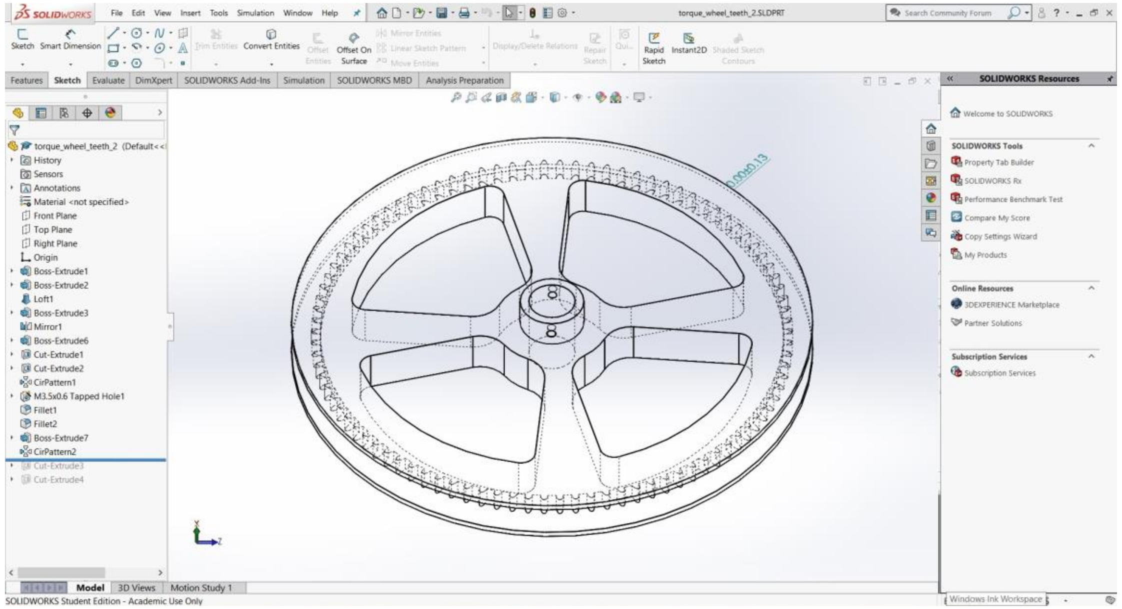


This was my attempt to make an h-bridge motor driver for my custom design solar tracker. For some reason it had shoot-through problems. I was in a time crunch, so instead of figuring out what the problem was, I used relays to perform the same function (I just wanted to be able to change the direction of rotation).

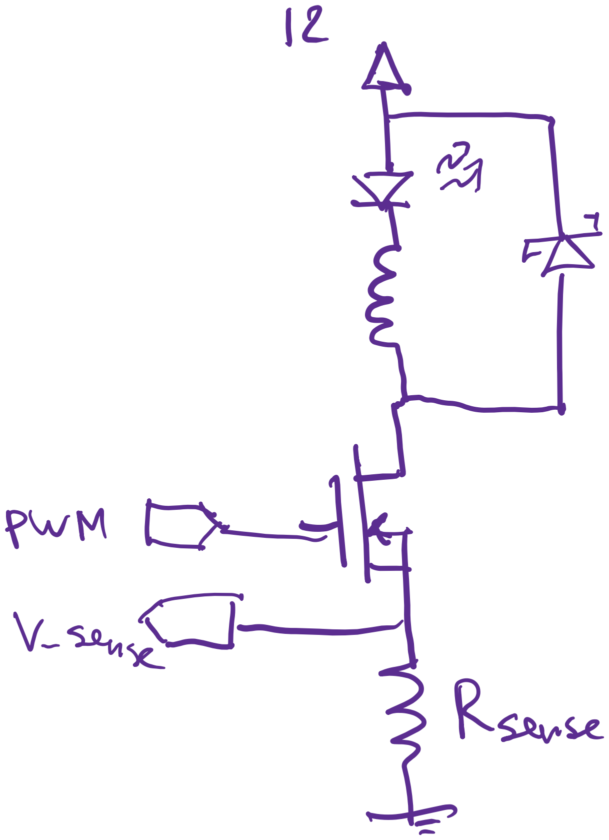
More details, pictures, and videos are on my website:
https://masa8q.com/solar-tracker-design-failed/

By the way, when I was working on my solar tracker,
I picked up some SolidWorks skills through online courses on Udemy during my free time.
That was in order to be able to make custom parts
for my design (like this torque wheel for an automotive belt that I bought in a local AutoZone)





Constant Current LED driver



A month ago I wanted to practice my Embedded C programming, So I made this simple constant current LED driver with digital feedback and control.

More details, videos, and sample code are on my website: https://masa8q.com/a-simple-constant-current-led-driver-with-digital-feedback-and-control-msp430/

gate drive: