Note to self: Each time you work on the project, you should enter the date, start time and end time. You should document the references you consult, the main points from your reading, important tables or circuits from your reading, the ideas you have, the circuits you design, the software you write, simulation and experimental test results, your successes and failures, etc. You will submit your current notebook each week along with your weekly report, see below.

Illa's 2804 Project Notebook

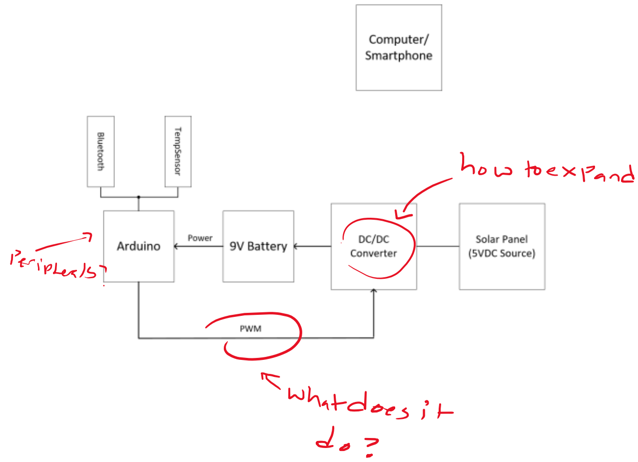
Click on the hyperlink to see the start of the notes taken during the referenced milestone

Table of contents

7/14/21
2:17pm – 3:00pm

To Do's milestone #1

- Intro
  - bkgrnd, proposed sol, significane
- overview
  - explain design + general plan
- Block diagram
  - key functions for hardware (blks)
  - key functions for software + digital
  - analog to digital interface
- Break into milestones
  - list goals for hardware + software
  - specify deliverables
  - specify testing (components + combined)



Software → only can use bluetooth lib

Preliminary Research (sites visited and articles read):

https://en.wikipedia.org/wiki/DC-to-DC_converter (Wikipedia page on DC/DC converter)

Converter_Steady_State_Analysis.pdf (Info for DC/DC converter circuit I think?)

http://ww1.microchip.com/downloads/en/devicedoc/20001942g.pdf (datasheet for temp sensor)

Converter chapter notes

Buck converter → reducing DC voltage using only non-dissipative switches, inducts + caps

↓

rect wave form

$$\langle V_s \rangle = \frac{1}{T_s} \int_0^{T_s} V_s(t)\,dt$$

$$\langle V_s \rangle = \frac{1}{T_s} \left(D T_s V_s \right) = D V_g$$

DC input volt

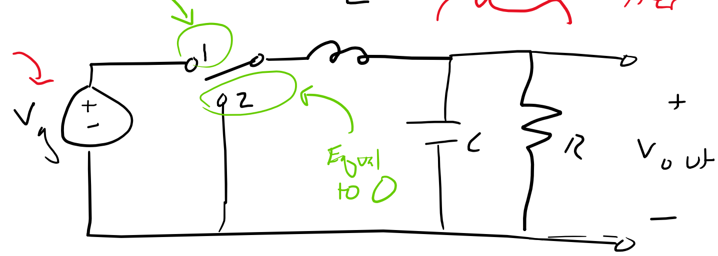
Duty cycle

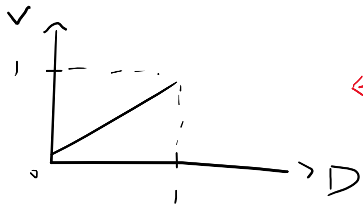
Build for 5 KHz?

Low pass filter

Equal to Vg

Equal to 0





Buck converter DC out V. vs Duty cycle

7/14/21
6:21pm – 7:40pm

Milestone 1 scratch

Wednesday, July 14, 2021 6:18 PM

[redacted]

?

| Temp sensor |

| Analog Pins | Vin |

Pwr

Arduino

| 9V Battery |

if < 9V arduino turns off

| Digital Pins |

| Blue tooth |

| computer / smart Phone |

Display Info

Vin powers in, looks to see if @ full voltage

Interrupt based

full = 30 sec reads + then sleep

else = " " wait sleep

while based (Pwr)

? ?

how much voltage to charge with?

magnetic

DC/DC converter

- regulate output @ const voltage to Pwr Arduino through PWM (Switch freq > 5 kHz) feedback ctrl
- conduct optimal load test
- charges 9V battery
- under diff input volt. output is the same
- output 9V ?
- stores input V temp → charges Inductor
- uses switching conversion

requires few components

storage

Battery charging / discharging test

OP Amp

Where Inductor goes

Wait w/ low/high filter?

Buck circuit

5V

| APZ |

Input V could vary

| Wall |

Met w/ Partner, did more reading, fleshed out some of the blk diagram

7/15/21
1:00am – 1:55 am

Peripherals of Arduino?

- clock: for 30 sec intervals
- monitor/display: to show value
- Bluetooth: to communicate data
- Temp sensor: to read temp
- Input volt val: to pwr + to analyze

Something for PWM?

needed Programming

- clock module
- Interupt based code
- while based code
- Read + interpret temp
- Display module
- Bluetooth module

Pwr Setting

Arduino Research notes

uses simplified c++

major Arduino components

- usb connector —> used to load code (can pwr)?
- Pwr port —> Pwr Port (ops @ 5 v)?
- Analog Pins —> (6 Pins) temp sensor. only measure volt.
- Digital Pins —> In or out (read comp. sig)
- Reset switch —> run from start
- crystal osillator —> tics, math stuff
- TX RX Leds —> Transmit, recive data
- micro controller —> Brain (has flash mem, ram)
  32KB 2KB
- USB Interface chip —> signal translator

might need to reconsider pwr Idea from earlier

can be reconfig as dig

~ (tilde) pins can be used for PWM (simulate analog out)

Arduino References (Read or watched to refresh memory / find info)

https://www.arduino.cc/en/Guide/ArduinoUno

https://www.youtube.com/watch?v=_ItSHuIJAJ8

7/15/21
11:42am –2:00pm

Converter reading notes cont.

converter options

- Buck → dec V; $v \le V_g$
- ☆ boost → Inc V; $v \ge V_g$
- buck-boost → Inc or dec but polarity reverses

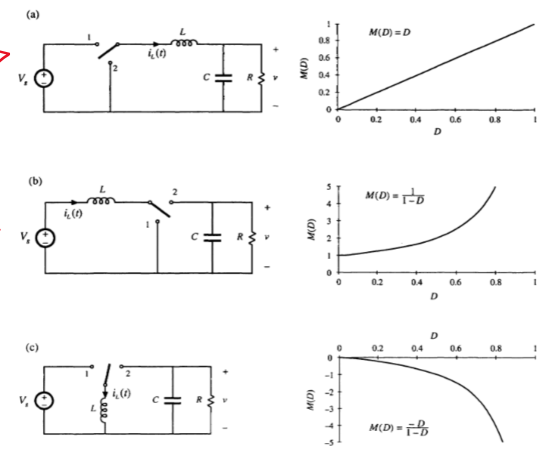


Fig. 2.5 Three basic converters and their dc conversion ratios $M(D) = V/V_g$: (a) buck, (b) boost, (c) buck–boost.

↑ P.5 of pdf

How to make switch?

Is switch related to PWM?

Buck

Impossible for filter to remove all stuff, so there is small V ripple

$|V_{ripple}| << V$; $v(t) \approx V$

$V_L = V_g - v(t)$

$V_L(t) = L \frac{di_L(t)}{dt}$

$\frac{di_L(t)}{dt} \approx \frac{V}{L}$

Knowing peak i(t) is important for specifying ratings

use to select buck L $\Big\{$ $L = \frac{V_g - V}{2\Delta i_L} DT_s$

↑ current ripple
10%-20% full load
Val of DC component I

stored on pg 9

Site used: https://www.analogictips.com/pulse-width-modulation-pwm/

Research on PWM

• Is the switch for converter, releasing + stoping the charge?

how to implement?

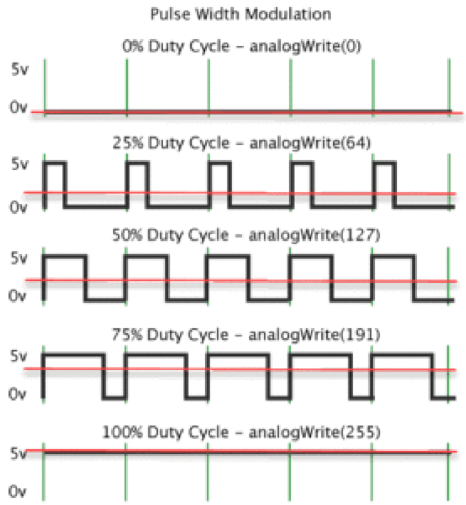


Figure 1: An example of a PWM signal shown at several duty cycles and a high voltage level of 5 volts. The red line is the average voltage that the driven device (e.g., a motor) is experiencing. (Source: Timothy Hirzel,)

Pulse is on 50% of the time

calculating duty cycle could help w/ building converter

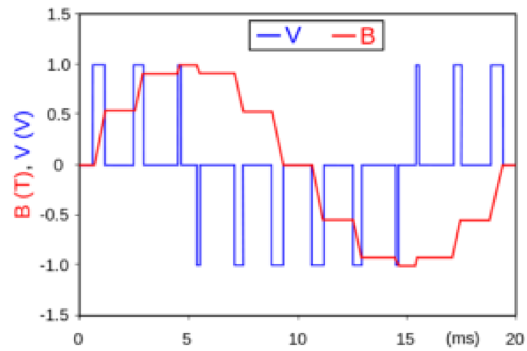


Figure 2: The blue lines are PWM output from an MCU, and the red line is the average voltage. In this case, the pulse width (and corresponding duty cycle) change so that the average voltage looks more like an analog output that is not in a steady state such as shown in Figure 1. (Source: Zureks – Own work, CC BY-SA 3.0,)

$$V_{Avg} = V_{high} \times D$$

Instantaneous D

Instantaneous V

"We use duty cycle + frequency to describe PWM"

ECE Embedded syst notes

$$D = \frac{\text{on Time}}{\text{Period}} \qquad T = \frac{1}{f}$$

need timer for PWM

Prescalar P

Load val N

$$N \times P = \frac{f_s}{f_{PWM}}$$

syst

PWM

PWM for syst counts to when induct is @ value then switches counts till discharge

Interupts

set so when timer exp. triggers?

Proj 3 had pwm I think

Toggle/reset or Toggle set?

Inductors Review

$$L = \frac{\phi_B}{I}$$

ϕ_B ← magnetic flux

I ← current

\# of turns

$$L = \frac{N^2 \mu A}{l}$$

$\mu_r \mu_0$ ← relative Perm

l ← Avg length of coil

A ← Area of coil in m^2 (πr^2)

$$L \approx \frac{\mu N^2 A}{2\pi r}$$

A = cross-sectional area

r = toroid radius to centerline

491 × 94

$$V(t) = L \frac{di_L(t)}{dt}$$

We are making a Toroidal Inductor I think?

$$L = 0.01595 N^2 \left(D - \sqrt{D^2 - d^2}\right)$$

- L = inductance (μH)
- d = diameter of coil winding (in)
- N = number of turns
- D = 2 * radius of revolution (in)

$$L \approx 0.007975 \frac{d^2 N^2}{D}$$

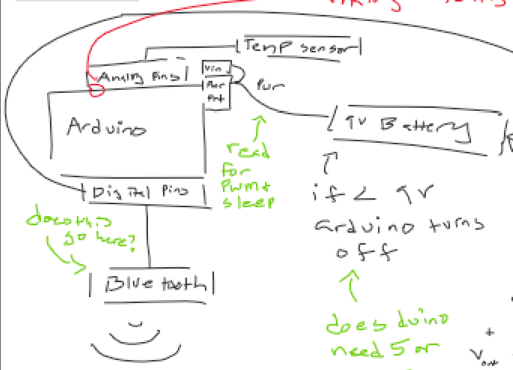
- L = inductance (μH)
- d = diameter of coil winding (in)
- N = number of turns
- D = 2 * radius of revolution (in)

approx when $d < 0.1 D$

Img from wikipedia

Milestone 1 scratch

Analog to dig Interface



read for PWM + sleep

does this go here?

if < 9V arduino turns off

does duino need 5 or 9V?

charging

~Pin for PWM

fed into transistor

Vin powers it, looks to see if @ full voltage

Interupt based

full = 30 sec reads + then sleep

else = " " wait sleep

while based (pwr)

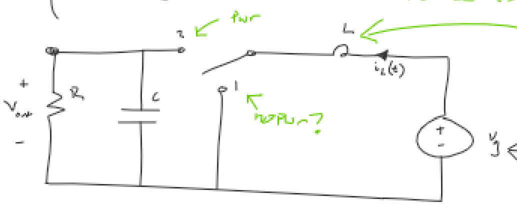
? how much voltage to charge with?

send PWM to charge

how to use as a switch?

pwr

no pwr?



how to calculate L? + # of turns

5V

APZ

Wall

Input V could vary

magnetic

DC/DC converter

- regulate output @ const voltage to pwr Arduino through PWM (switch freq > 5 kHz) feedback ctrl
- conduct optimal load test
- charges 9V battery
- under diff input volt. output is the same
- output 9V?
- stores input V temp → charges Inductor
- uses switching conversion

requires few components

storage

Where Inductor goes

Wait w/ low/high filter?

Battery charging/ discharging test

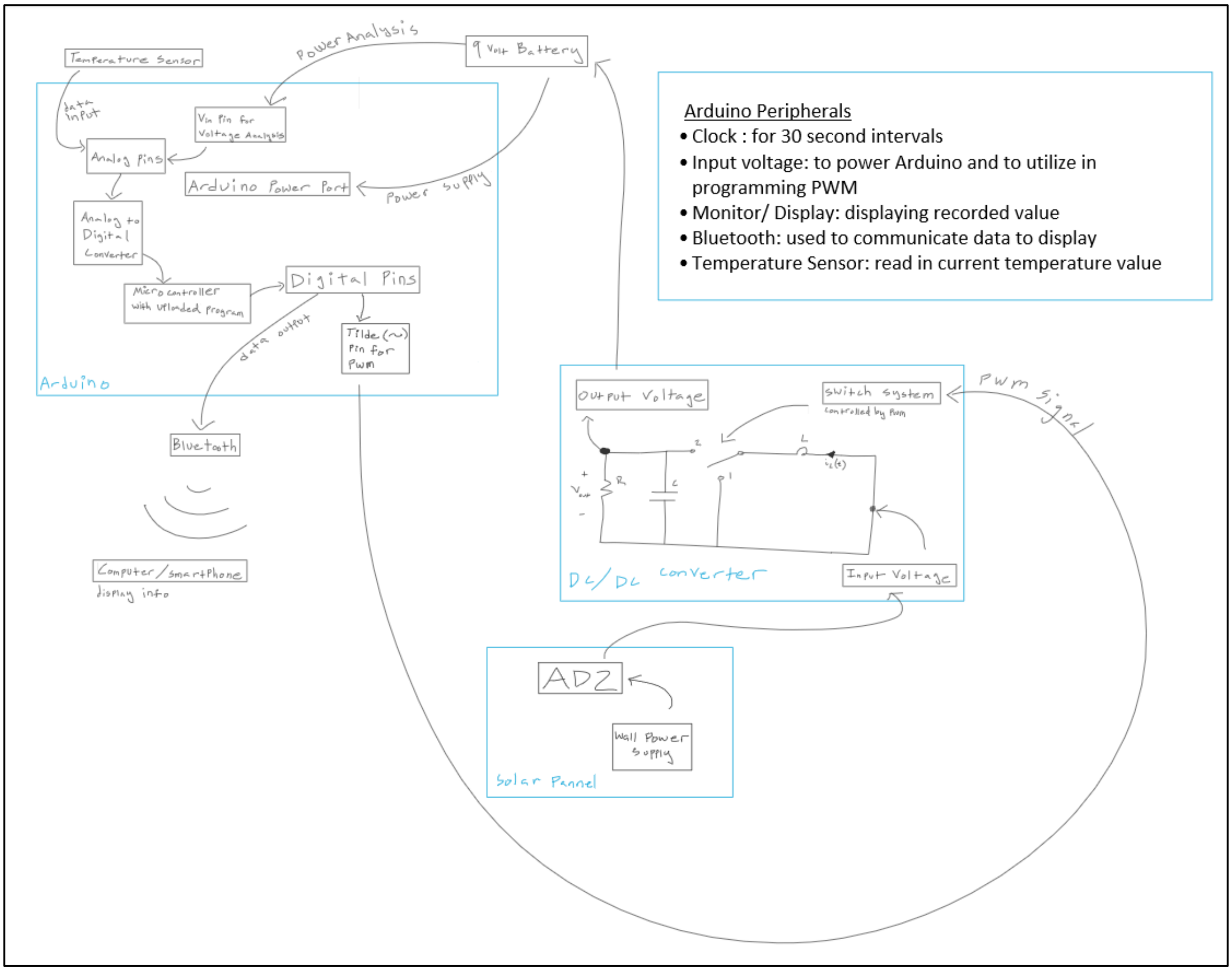
OP Amp

~~Buck~~ circuit

boost

Useful for programming Bluetooth: https://www.geeksforgeeks.org/all-about-hc-05-bluetooth-module-connection-with-android/

Talked with partner and finalized report. Made clean version of block diagram and wrote part of the outline



Today's Goals

- Calculate Values for DC/DC converter
  - Inductor specifics
  - Resistor + cap values
  - Figure out switch
- Simulate in LT spice
  - Test behavior
  - optimal Load test

$v_L = V_g - v$

$v_L = 5 - 9 = -4$

shouldn't be −?

duty cycle

$$L_{min} = \frac{D(1-D)^2 R}{2f}$$

mH

freq

$v = \frac{V_g}{D}$

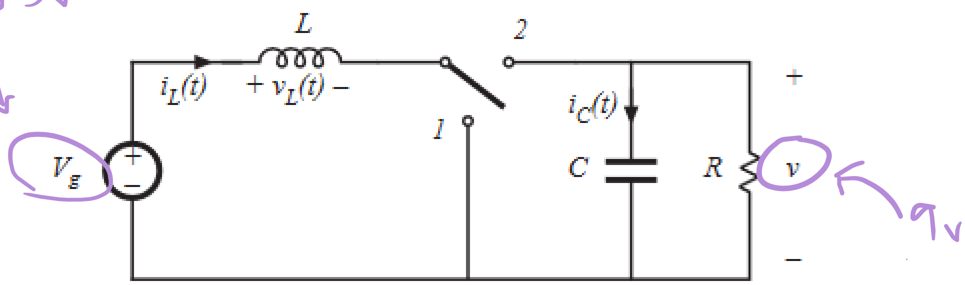
duty cycle?

do we need a filter?

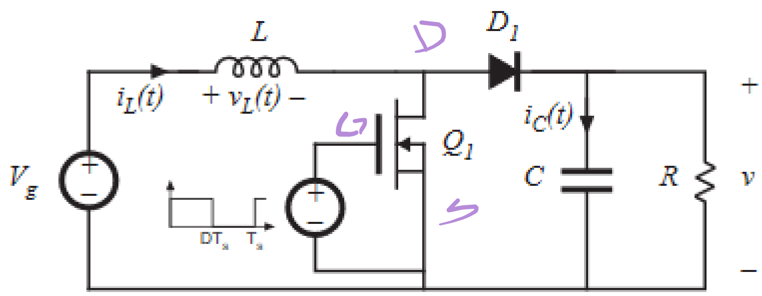
switching 5 kH

4 to 5v

Boost converter
with ideal switch



Realization using
power MOSFET
and diode



Average Current in the Boost Inductor

$$L \approx \frac{\mu N^2 A}{2\pi r}$$

491 × 94

A = cross-sectional area

r = toroid radius to centerline

- Average input current and average inductor current are equal
- Two basic ways to calculate I_{IN} and I_L:

$$\Phi = BA\cos\theta$$

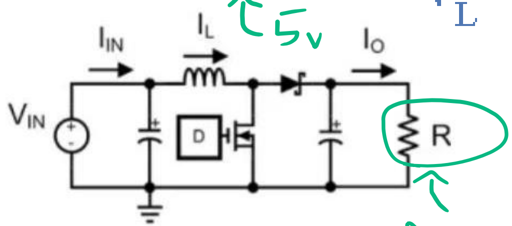
$$I_L = I_{IN} = \frac{I_O}{(1-D)\times\eta_{EST}} \qquad I_L = I_{IN} = \frac{I_O \times V_O}{V_{IN}\times\eta_{EST}}$$

9v

5v

$$V_L = N\frac{d\Phi}{dt} = \frac{\mu N^2 A}{\ell}\frac{di}{dt}$$

- Use 85-90% for η_{EST}
    - Non-sync
- Use 85-95% for η_{EST}
    - Synchronous



Any size?

$$v(t) = L\frac{di(t)_L}{dt}$$

$$-\frac{d\Phi_B}{dt} = v_L = L\frac{di_L}{dt}$$

ask later

$$L = \frac{\phi_B}{I}$$

magnetic flux

current

V_{max} L?

assume $V_L = -4$

How do we calculate L, C, + R?

$$I_L = \frac{V_L}{X_L} = \frac{V}{2\pi f L} = \frac{V}{2\pi\left(\frac{\mu N^2 A}{2\pi r}\right)} = \frac{I_o \times V_o}{V_{in}\times\eta_{est}}$$

?

Inductance

$$T_{on} = \alpha T$$

$$v_o = \frac{V_{in}(1-\alpha)}{\frac{r}{R} + (1-\alpha)^2}$$

$$\alpha_{max} = 1 - \sqrt{\frac{r}{R}}$$

$$1-\alpha = \sqrt{\frac{r}{R}}$$

$$\frac{V_o}{V_{in}} = \frac{1}{1-\alpha}$$

$$\frac{1}{5} \Rightarrow \alpha \cong 0.41$$

Self Inductance – the Maths

- When self inductance occurs the flux is proportional to the current in the inductor

$$\Phi = L \times I$$

Where:

Φ = magnetic flux (Wb)
L = self-inductance (H)
I = Current (a)

- Substituted into Faraday's law;

$$V = \frac{-L\Delta I}{\Delta t}$$

- Units for self-inductance is the Henry (symbol H)

$$I = \frac{V}{X_L}$$

where V is the rms voltage ac

$$X_L = 2\pi f L$$

https://www.powerelectronicsnews.com/the-dc-dc-boost-converter-power-supply-design-tutorial-section-5-1/

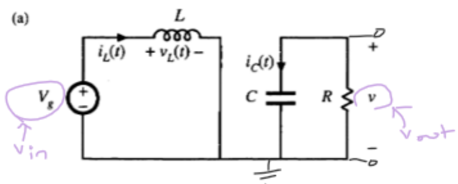
7/21/21
2:00pm – 3:06pm

Reading PDF so I can try a bit more to figure out converter.

QP 1:

switch in Pos 1:

charges Inductor, cap discharges



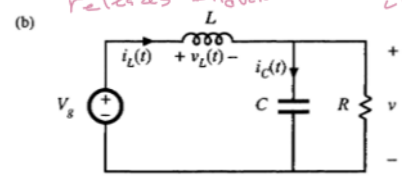
$V_L = V_g$ $i_C = -\frac{V}{R}$

ripple approx

$v \approx V$

switch in pos 2:

releases Inductor charge, cap charges



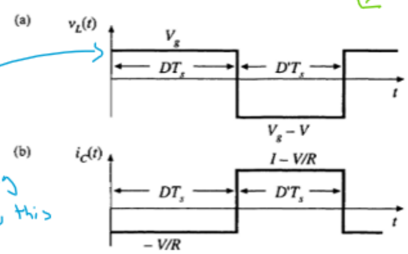
cap volt = $V_g + V_L$?

$V_L = V_g - V$

$i_C = i_L - \frac{V}{R}$

$v \approx V$ + $i_L \approx I$ } $V_L = V_g - V$, $i_C = I - \frac{V}{R}$

Equ used to sketch Inductor + cap waveforms



according to text, this implies $V_{out} > V_g$

output / input ie duty cycle

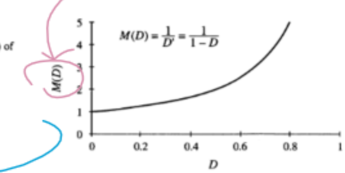


Fig. 2.16 Dc conversion ratio M(D) of the boost converter.

How to use? are important?

The total volt-seconds applied to the inductor over one switching period are:

$$\int_0^{T_s} v_L(t)dt = (V_g)DT_s + (V_g - V)D'T_s$$

T_s is the Period, ie $\frac{1}{f}$

Instructor Yu Conversation

(0.1)(700mA)

similar equ for cap

$$\Delta i_L = \frac{V_g}{2L} D T_s$$

Vin

switching freq

$T_s = \frac{1}{sf}$

Proj description: $f_s > 5KHz$

Inductor

Duty cycle

Inductor current ripple

$\frac{T_{on}}{T_s} = D$

See text for details but basically Pick a value smaller than that

duty cycle Varies bc

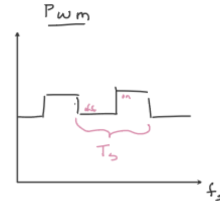
$$V = \frac{V_g}{D'} = \frac{V_g}{1-D}$$

$D' = 1 - D$

Proj description: $4_v \leq V_g \leq 5_v$

If input voltage Varies → D varies s.t. output Voltage is constant

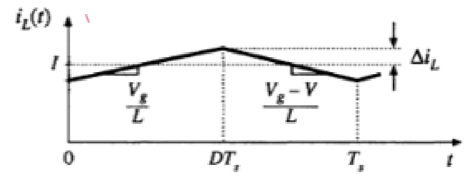
PWM



If we assume V_g is constant then D doesn't vary

7/21/21
5:00pm – 7:00pm

Fig. 2.18 Boost converter inductor current waveform $i_L(t)$.



$$\Delta V = \frac{V}{2RC} D T_s$$

Voltage ripple peak magnitude

R_{bias}

capacitor

References for finding Δi_L

https://ridleyengineering.com/design-center-ridley-engineering/39-magnetics/66-031-choosing-the-inductor-for-a-buck-converter.html

https://www.instructables.com/Using-the-Power-Supplies-With-the-Analog-Discovery/

Δi_L % range from 2.5% to 50% → 10% Pretty commonly used

ADZ has:

no more than 3%

Current max of 700mA

Voltage max of 5v

found in waveforms

Pick a decent duty cycle

Calculations

Inductor

$$\Delta i_L = \frac{V_{in}}{2L} DT_s$$

$$L = \frac{V_{in}}{2\Delta i_L} DT_s$$

$$L = \frac{(5v)}{2(0.03)(700mA)} (0.5)\left(\frac{1}{5.5kHz}\right)$$

$$L = \boxed{0.0108\ H}$$

make sure ADZ can handle

capacitor

close to 0.

$$\Delta V = \frac{V_{out}}{2RC} DT_s$$

$$C = \frac{V_{out}}{2R\Delta V} DT_s$$

$$C = \frac{(9v)}{2(1.5k\Omega)(0.03)(5)} (0.5)\left(\frac{1}{5.5kHz}\right)$$

$$C = 1.8 \times 10^{-6} = \boxed{1.8\mu F}$$

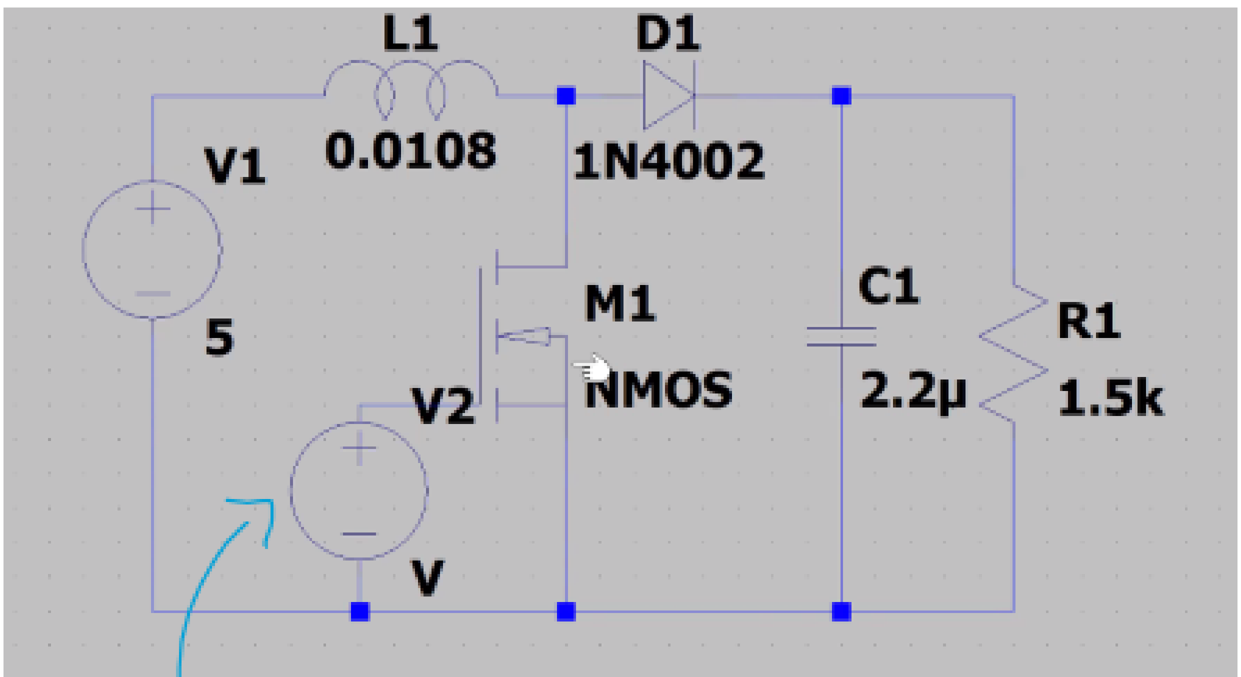
choosing 2.2µF from kit
choosing R = 1.5kΩ

LT spice

1N4001 ← diode

2N7000A ← N-mosfet

How to make work



is PWM

7/23/21

3:30pm – 11:00pm (some breaks taken)

Worked by self to make changes to LT Spice recommended. Also worked on refining block diagram for report and creating the Optimal Load Test graph. Uncertain if calculations are correct. Will check later.

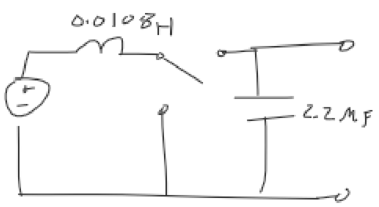
Efficency curve based on load (R_{load})

"Sweep" across different R_L

Plot Ω vs. Pwr

$R_L = R_S$ is where max Power transfer is usually

need to find R_S for our circuit



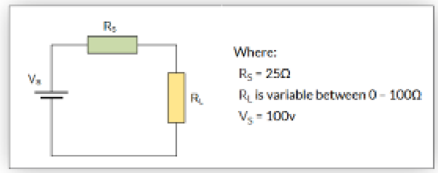
$X_c = \frac{1}{j\omega C}$

$X_L = j\omega L$

$\omega = 2\pi f$

$f = 5.5\ kHz$

Maximum Power Transfer Example No1



$$I = \frac{V_S}{R_S + R_L} \quad \text{and} \quad P = I^2 R_L$$

https://www.electronics-tutorials.ws/dccircuits/dcp_9.html

For better understanding

AP2 has max bandwidth of 12 MHz so 5.5 kHz is fine

$w = 2\pi(5.5 \times 10^3) = 34557.5$

$X_c = \frac{1}{j(34557.5)(2.2\,MF)} = -13.153j$ note $\frac{1}{i} = -i$

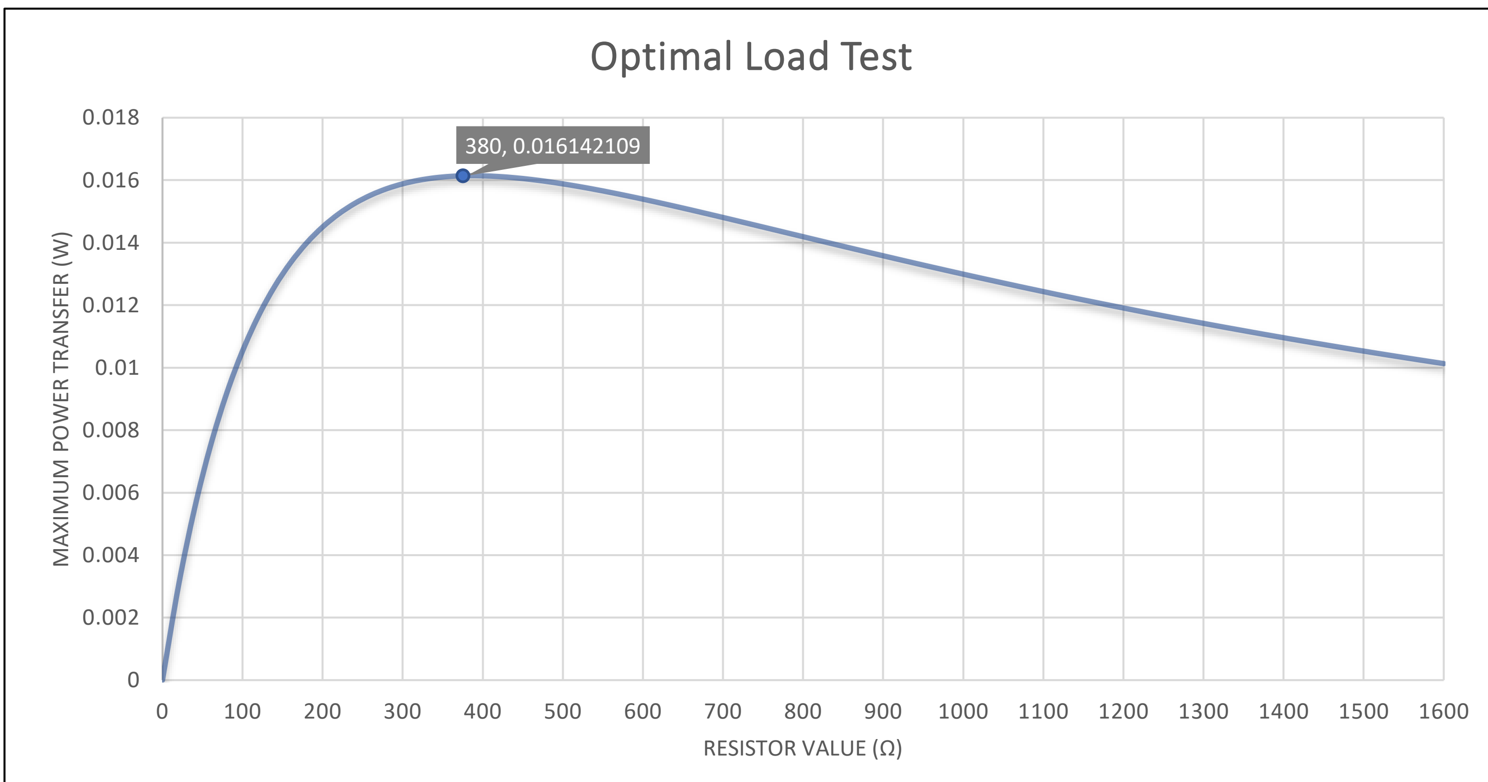
$X_L = j(34557.5)(0.0108_H) = 374.00j$

$R_s = 374.00j + 13.153j = 387.15j$

$|Z_e|^2 = R^2 + X^2$ real Imag

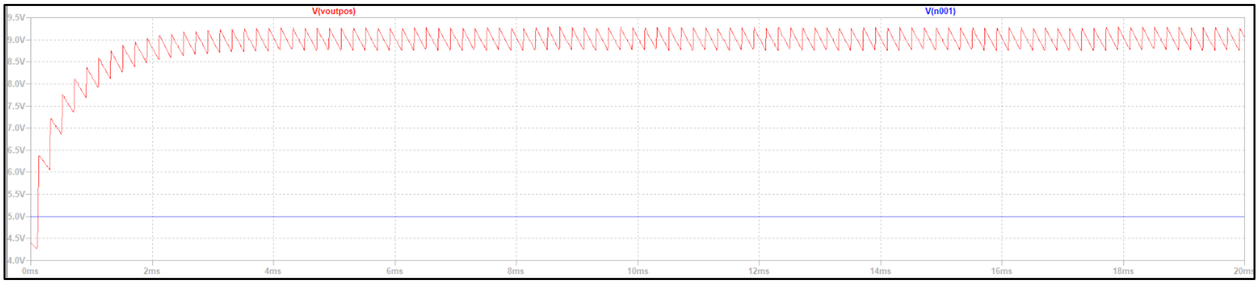
imi. magnitude

$|R_s| = \sqrt{(0)^2 + (387.15)^2} = \boxed{387.15}$



7/24/21
3:00pm – 7:00pm

Just refined math, redid calculations and wrote final report



Calculations

Inductor

$$\Delta i_L = \frac{V_{in}}{2L} DT_s$$

$$L = \frac{V_{in}}{2\Delta i_L} DT_s$$

$$= \frac{(5v)}{(2)(100\,mA)} (0.5)\left(\frac{1}{20\,kHz}\right)$$

$$L = 1.79 \times 10^{-4}\,Hz = \boxed{179\,\mu H}$$

choosing 162 uH based on LT spice

Capacitor

$$\Delta V = \frac{V_{out}}{2RC} DT_s$$

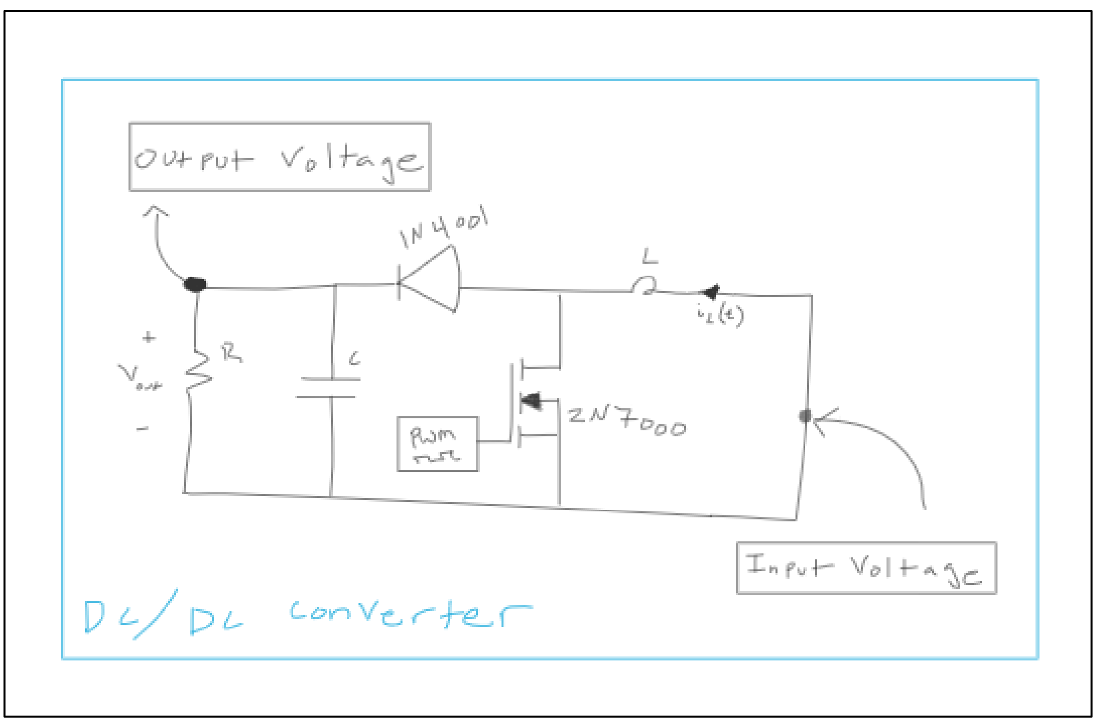
$$C = \frac{V_{out}}{2R\,\Delta V} DT_s$$

$$C = \frac{(9v)}{2(1.5k\Omega)(0.03)(5)} (0.5)\left(\frac{1}{5.5\,kHz}\right)$$

$$C = 1.8 \times 10^{-6} = \boxed{1.8\,\mu F}$$

choosing 2.2 uF from kit

choosing R = 1.5 kΩ



Efficency curve based on load (R_{load})

"Sweep" across different R_L

Plot Ω vs. Pwr

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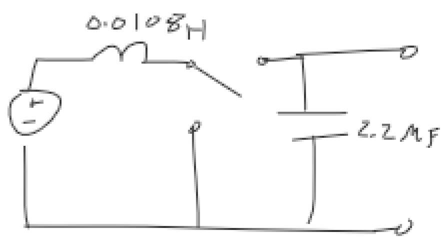
need to find R_S for our circuit



$$X_c = \frac{1}{j\omega C}$$

$$X_L = j\omega L$$

$$\omega = 2\pi f$$

$$f = 5.5\,kHz$$

$$w = 2\pi(5.5\times10^3) = 34557.5$$

$$X_c = \frac{1}{j(34557.5)(2.2\mu F)} = -13.153j$$ note $\frac{1}{i} = -i$

$$X_L = j(34557.5)(162\mu H) = 5.5\,j$$

$$R_s = 5.5\,j + 13.153j = 18.75j$$

$$|R_s| = \sqrt{(0)^2 + (18.75)^2} = \boxed{18.75j}$$