EECS 192: Mechatronics Design Lab

Discussion 4: Power Systems

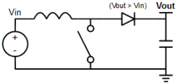
written by: Richard "Ducky" Lin Spring 2015

8 & 9 Feb 2017 (Week 4)

Switching Power Supply Recap

Boost Converter Circuit

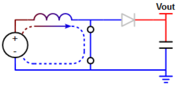
- DC-to-DC switching power supply generating output voltage higher than input
- Uses inductor as storage element
- Efficient, no losses in ideal case
  - Non-idealities: wire resistance, diode and transistor losses
- Capacitive filter to smooth output voltage



Boost Converter

Boost Converter Operation

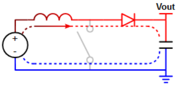
- Inductor charges when switch is closed
  - Energy stored in inductor by magnetic field, current through inductor increases
  - Diode prevents higher output voltage from flowing back to source



Switch Closed

Boost Converter Operation

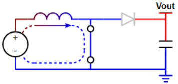
- Inductor charges when switch is closed
  - Energy stored in inductor by magnetic field, current through inductor increases
  - Diode prevents higher output voltage from flowing back to source
- Inductor dischanges when switch is open
  - Magnetic field dissipates, current through inductor decreases
  - Inductor voltage polarity reversed, generating voltage over input
  - Current flows through diode, output capacitor charged



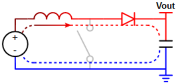
Switch Open

Boost Converter Control

- If switch cycled fast enough, inductor does not fully discharge
- Can do a lot of math, but output voltage is function of duty cycle D
  - $V_{out} = \frac{1}{1-D} V_{in}$



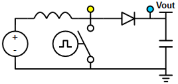
Inductor charging



Inductor discharging

Check your Understanding (Live Demo Edition!)

- So I've got a boost converter set up...
  - One probe on the switch
  - Another probe on the output
- It's running at steady-state



Boost Circuit

Check your Understanding (Live Demo Edition!)

- So I've got a boost converter set up...
  - One probe on the switch
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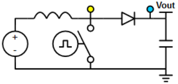
- It's running at steady-state
- Which scope waveform is the switch?



Boost Circuit

Check your Understanding (Live Demo Edition!)

- So I've got a boost converter set up...
  - One probe on the switch
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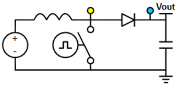
- It's running at steady-state
- Which scope waveform is the switch?
- Is the output waveform what you expect?



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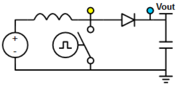
- Which scope waveform is the switch?
- Is the output waveform what you expect?
- On the switch waveform...
  - Which part is the switch closed?



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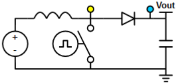
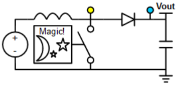


Boost Circuit

Check your Understanding (Live Demo Edition!)

- So I've got a boost converter set up...
  - One probe on the switch
  - Another probe on the output
- A magic chip regulates the output to 12v
  - Duty cycle is adjusted to maintain voltage
  - Remember: $V_{out} = \frac{1}{1-D} V_{in}$
- What happens if I...



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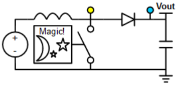
- What happens if I...
  - Increase the input voltage?



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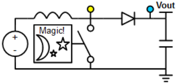
  - Remember: $V_{out} = \frac{1}{1-D} V_{in}$
- What happens if I...
  - Increase the input voltage?
    - Duty cycle decreases, current decreases



Boost Circuit

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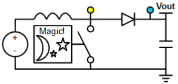
- What happens if I...
  - Increase the input voltage?
    - Duty cycle decreases, current decreases
  - Decrease the input voltage?



Boost Circuit

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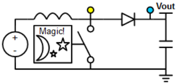
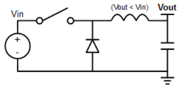
- A magic chip regulates the output to 12v
  - Duty cycle is adjusted to maintain voltage
  - Remember: $V_{out} = \frac{1}{1-D} V_{in}$
- What happens if I...
  - Increase the input voltage?
    - Duty cycle decreases, current decreases
  - Decrease the input voltage?
    - Duty cycle increases, current increases



Boost Circuit

Buck Converter Circuit (for your reference)

- DC-to-DC switching power supply generating output voltage *lower* than input
- Similar principle to boost converter
  - $V_{out} = DV_{in}$
- Also exists buck-boost converters, where output can be greater than, equal to, or less than the input



Buck Converter

Questions?

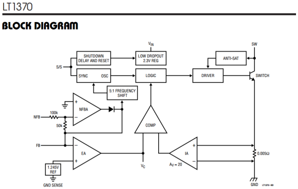
got it?

power supply pros, right?

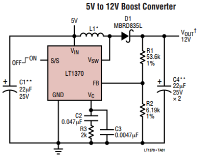
Practical Application

Automatic Feedback Control

- So, what is the switch-controlling magic?
- Feedback control: chip has logic to regulate the voltage on the feedback pin to an internal 1.245v reference
- Pop quiz: what resistor divider do I use to regulate the output to 7.2v?
  - Use 8.2kΩ for the lower resistor



LT1370 Block Diagram



Application circuit

source: datasheet, Linear Technology

Automatic Feedback Control

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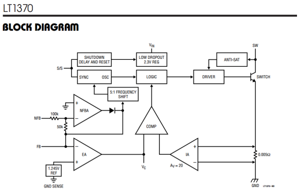
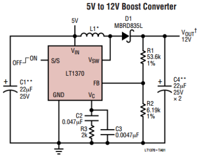
- Feedback control: chip has logic to regulate the voltage on the feedback pin to an internal 1.245v reference
- Pop quiz: what resistor divider do I use to regulate the output to 7.2v?
  - Use 8.2kΩ for the lower resistor
  - ... and 39kΩ For the higher resistor
  - Why these numbers? Preferred numbers!



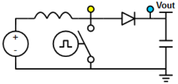
LT1370 Block Diagram



Application circuit
source: datasheet, Linear Technology

Noise (Live Demo Edition!)

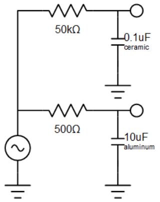
- Let's take a closer look at the output
  - Specifically, note the ripple near the switch toggling
- What issues might this cause?
- What do you think are some ways to reduce noise?



Boost Circuit

Capacitors at High Frequencies (Live Demo Edition!)

- Output smoothing is critical for proper operation, depends on output capacitors
- Not all capacitors are created equal
  - Ceramic, tantalum, aluminum, ...
- Live demo
  - Expect both filters to behave the same: $Gain = \frac{1}{\sqrt{1+(\omega RC)^2}}$, $\phi = atan(-\omega RC)$ (gain and phase dependent on only RC)



RC filter demo circuit

Capacitors at High Frequencies (Live Demo Edition!)

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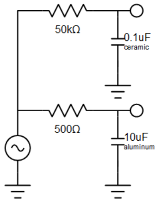
  - Expect both filters to behave the same: $Gain = \frac{1}{\sqrt{1+(\omega RC)^2}}$, $\phi = atan(-\omega RC)$ (gain and phase dependent on only RC)
  - As frequency increases, behavior diverges
  - Capacitors become inductive - no longer a good filter



RC filter demo circuit

Layout Guidelines

- Switching power supplies are layout sensitive
  - Part placement and routing matters!
- Tips from the datasheet:
  - Keep output diode, switch pin, output capacitor as short as possible
  - Minimize length and area of switch pin
  - Minimize high frequency current path (switch, diode, capacitor)
- Read the datasheet!

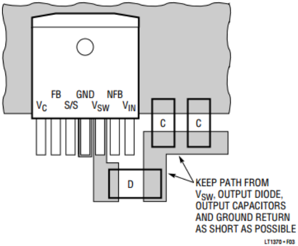


Figure 3. Layout Considerations—R Package

Recommended layout
(uses surface-mount components)
source: datasheet, Linear Technology

Summary

Summary

- Boost converters step up a DC voltage to a higher DC voltage
- LT1370 uses feedback control to do voltage regulation
- Follow recommended layout guidelines during PCB design

Parts Handout

- Get a battery and charger!
  - Please, keep explosions and flames to a minimum

Office hours for the rest of the section

- PCB deadline coming up in a week! Need help? Get it now!
- Need tips on mechanical fabrication? Get some here!