EECS 192: Mechatronics Design Lab

Discussion 4: Power Systems

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8 & 9 Feb 2017 (Week 4)

- SMPS Recap
- Practical Application
- Summary
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 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 discharges 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
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 $D$
  - $V_{out} = \frac{1}{1-D} V_{in}$
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
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
▶ Which scope waveform is the switch?
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?
So I’ve got a boost converter set up...

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

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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...

Boost Circuit
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...
  ▶ Increase the input voltage?
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- What happens if I...
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What happens if I...
- Increase the input voltage?
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- Decrease the input voltage?
So I’ve got a boost converter set up...
- One probe on the switch
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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
Buck Converter Circuit (for your reference)

- DC-to-DC switching power supply generating output voltage lower than input
- Similar principle to boost converter
  - $V_{out} = D V_{in}$
- Also exists buck-boost converters, where output can be greater than, equal to, or less than the input
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
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
  - ... and 39kΩ For the higher resistor
  - Why these numbers? Preferred numbers!

LT1370 Block Diagram

Application circuit

source: datasheet, Linear Technology
Practical Application

Issues

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:
    \[ \text{Gain} = \frac{1}{\sqrt{1+(\omega RC)^2}}, \ \phi = \tan^{-1}(-\omega RC) \]
    (gain and phase dependent on only RC)
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    (gain and phase dependent on only RC)
  - As frequency increases, behavior diverges
  - Capacitors become inductive - no longer a good filter

RC filter demo circuit
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!
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!