High Frequency Power Electronics

Prof. Daniel Costinett

ECE 581 Lecture 1
August 19, 2020
Course Info

• Course focuses on design an modeling of “high frequency” power electronics
  • Course website: http://web.eecs.utk.edu/~dcostine/ECE581
  • Goal of course is understanding of motivations and issues with high frequency power electronics; analysis and design techniques; applications
• Prerequisites: undergraduate Circuits sequence, Microelectronics, ECE 481 – Power Electronics, or equivalent
Contact Info

• **Instructor:** Daniel Costinett
  
  • Office: MK504

  • Office Hours: TBD

  • E-mail: Daniel.Costinett@utk.edu

  • Email questions will be answered within 24 hours (excluding weekends)

  • Please use **[ECE 581]** in the subject line
Course Structure

• Course meets MWF 10:20-11:10 am
• Plan to spend ~9 hours per week on course outside of lectures
• Grading:
  - Homework/Lab: 40%
    ▪ One homework per week
    ▪ Assignments due on Fridays unless otherwise noted on course website
  - Midterm: 25%
    ▪ Tentatively scheduled for October 29th
  - Final: 35%
Assignments

• Assignments due *at the start of lecture* on the day indicated on the course schedule

• All assignments submitted through canvas
  - [https://utk.instructure.com/courses/104569](https://utk.instructure.com/courses/104569)

• No late work will be accepted except in cases of documented medical emergencies

• Collaboration is encouraged on all assignments except exams; Turn in your own work

• All work to be turned in through canvas
Textbook and Materials

• The textbook
  will cover some of chapters 19-20 and reference materials from prior chapters. The textbook is available on-line from campus network. Purchase is not required for this course.

• MATLAB/Simulink, LTSpice will be used; All installed in on-campus labs, free, available through apps@UT, or on EECS servers

• Lecture slides and notes, additional course materials, homework, due dates, etc. posted on the course website

• Additional information on course website
Office Hours

• In-person office hours not permitted
• Scheduled office hours are times of maximum availability
• Contact me by e-mail, slack to start a telecon
• Outside of office hours, I will respond within 24 hours to e-mail or slack messages
• Design competition to build and test an optimized dc-dc converter
  - Fall ’16 – 60-to-12V, 60W
  - Fall ’18 – 48-to-1.2V, 12W
  - Fall ‘20 – 48-to-12V, 36W

• Specs and details TBD
  - Usually ~October-November
  - Usually in groups of 2
COURSE INTRODUCTION
Introduction

• Why high frequency?
  – Power Density
  – Control Bandwidth

• Techniques
  – Devices
  – Control
  – Topologies
  – Passives
Motivating Example

12V/48V Electrical Architecture

- eBooster
- EPS / EHPS
- Roll Stabilization

- 48V Starter/Generator
- 48V Boardnet
- 48V High-Power Consumer

- 48V Battery System

- Classic 12V Boardnet
- DC/DC

AVL UK Expo 2014 / Ulf Stenzel

Audi, “Electric biturbo and hybridization”, 2014
AVL, “48V Mild Hybrid Systems”
Baseline Design

- Use TI WebBench (webench.ti.com) to get a baseline design

<table>
<thead>
<tr>
<th>Param</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_g$</td>
<td>12 V</td>
</tr>
<tr>
<td>$V_{out}$</td>
<td>48 V</td>
</tr>
<tr>
<td>$R_{out}$</td>
<td>48 Ω</td>
</tr>
<tr>
<td>$\Delta V_{out}$</td>
<td>0.1 V</td>
</tr>
</tbody>
</table>
LTSpice Simulation

<table>
<thead>
<tr>
<th>$L$</th>
<th>$C_{out}$</th>
<th>$f_s$</th>
<th>Diode</th>
<th>$\eta$ (Sim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22uH</td>
<td>22uF</td>
<td>202k</td>
<td>Si (FR)</td>
<td>93.9%</td>
</tr>
</tbody>
</table>
LTSpice Simulation

- **I(D1)**
- **V(out)**
- **V(sw)**
- **I(L1)**
- **V(out)*I(R1)**
- **V(g)*I(L1)**
Switching Transition

\[ \text{Id(M2)+Id(M1)} \quad \text{I(D1)} \]

-50A
-600A

50V
40V
30V
20V
10V
0V

V(sw)
V(g1)

V(sw, out)*I(D1)
V(sw)*(Id(M2)+Id(M1))

14kW
10kW
6kW
2kW
-2kW

9.9088\mu s
9.9096\mu s
9.9104\mu s
9.9112\mu s
9.9120\mu s
9.9128\mu s

5.8 \mu J
1.3 \mu J
Diode Reverse Recovery
Datasheet RR Characteristics

Fig. 9 - Typical Reverse Recovery Time vs. $dl_F/dt$

Fig. 10 - Typical Stored Charge vs. $dl_F/dt$
Charge Storage
IGBT Current Tailing

Example: buck converter with IGBT

transistor turn-off transition

\[ P_{sw} = \frac{1}{T_s} \int_{t_{sw}} p_A(t) \, dt = (W_{on} + W_{off}) \, f_s \]

Fundamentals of Power Electronics

Chapter 4: Switch realization