Course Info

- Course focuses on advanced topics in modeling and control of power electronics
  - Course website: http://web.eecs.utk.edu/~dcostine/ECE692
  - Goal of course is broad understanding of the modeling of switched systems, discrete time modeling and digital control
- Prerequisites: undergraduate Circuits sequence, Microelectronics, ECE 481 – Power Electronics, or equivalent
- Recommended: ECE 581 – High Frequency Power Electronics or equivalent experience

Contact Info

Instructor: Daniel Costinett

- Office: MK504
- E-mail: Daniel.Costinett@utk.edu
- Email questions will be answered within 24 hours (excluding weekends)
- Please use **[ECE 692]** in the subject line

Course Structure

- Course meets MWF 11:30 – 12:20
- Plan to spend ~9 hours per week on course outside of lectures
- Grading:
  - Homework: 40%
    - ~One homework per week
    - Assignments due on Fridays unless otherwise noted on course website
  - Midterm Project: 25%
  - Final Project: 35%

Lectures

- Powerpoint slides for lectures posted to website prior to class
- Annotated slides posted after class
- Lectures recorded and available on website
  - Accessible from UTK network
  - *Not* re-recorded in the event of a technical difficulty

Assignments

- Assignments due *at the start of lecture* on the day indicated on the course schedule
- No late work will be accepted except in cases of documented medical emergences
- 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 optional textbook for the course is

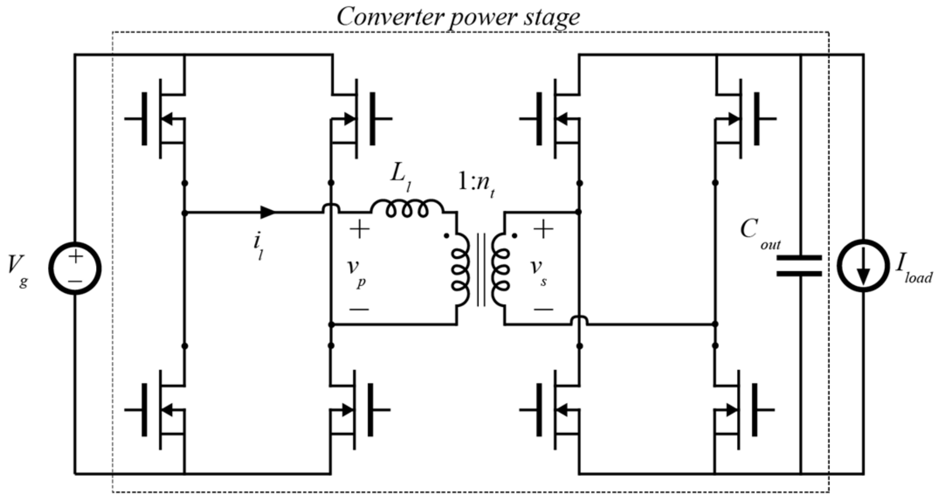
  L Corradini, D Maksimovic, P Mattavelli, and R. Zane *Digital Control of High-Frequency Switched-Mode Power Converters*, Wiley 2015
- MATLAB/Simulink, LTSpice will be used; All installed in the Tesla Lab
- Lecture slides and notes, additional course materials, homework, due dates , etc. posted on the course website
- Additional information on course website

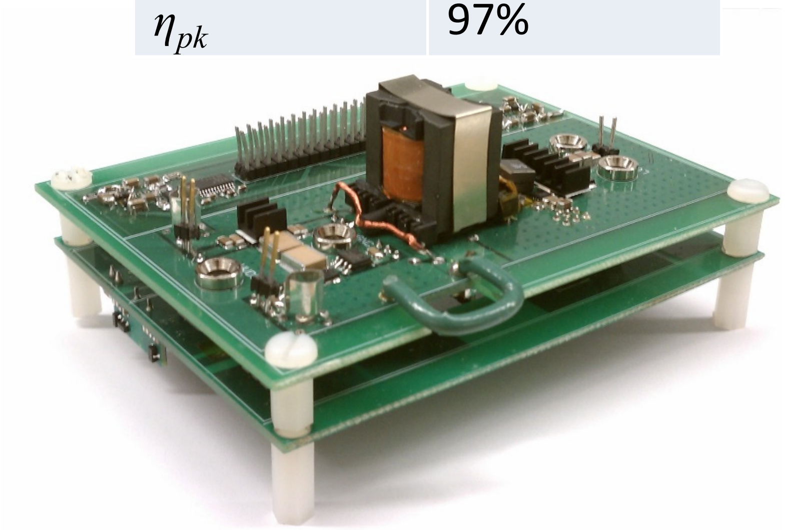
DAB Example

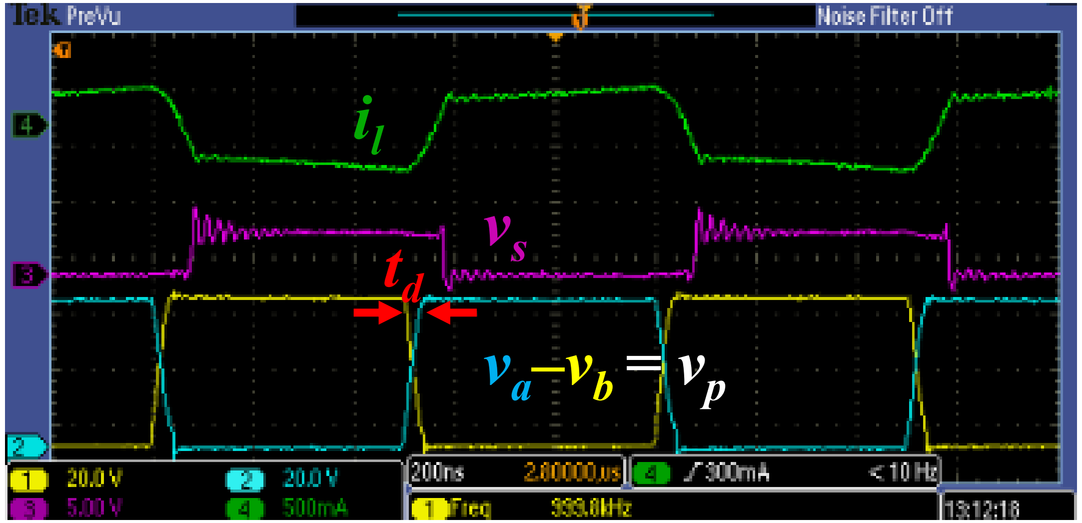
COURSE INTRODUCTION

Motivating Example

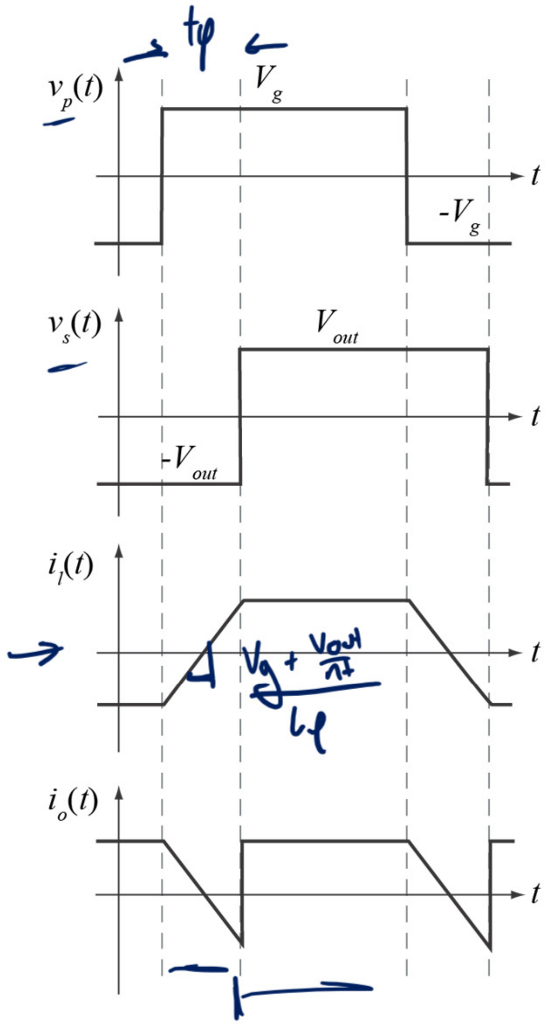
Parameter	Value
V_g	50 V
V_{out}	4 V
I_{load}	2.5-3.5 A
C_{out}	20 µF
L_l	9.5 µH
n_t	25:2
f_s	1 MHz
η_{pk}	97%

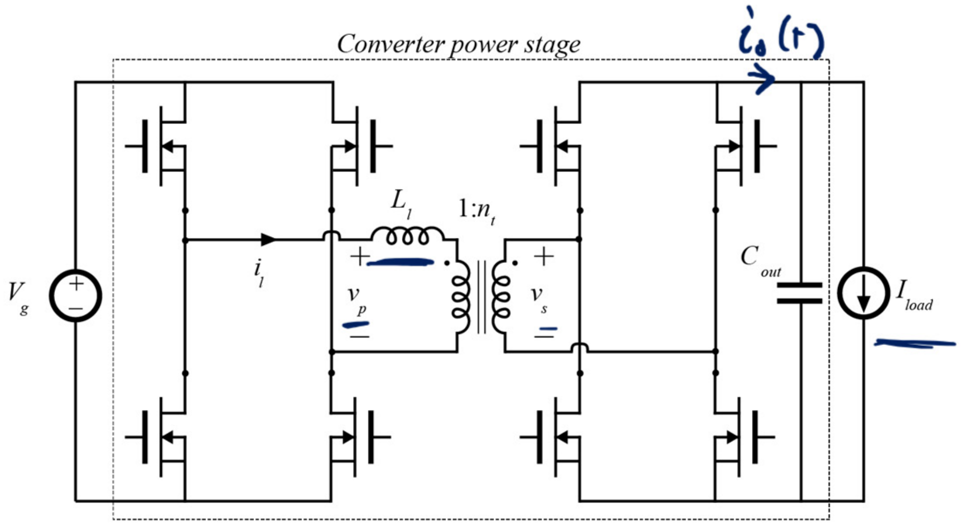






DAB Topology





- Dual Active Bridge (DAB) with phase shift modulation
- Transformer isolation with incorporated leakage inductance
- Soft switching of all devices across a wide range of loads

Section 1

STEADY-STATE MODELING

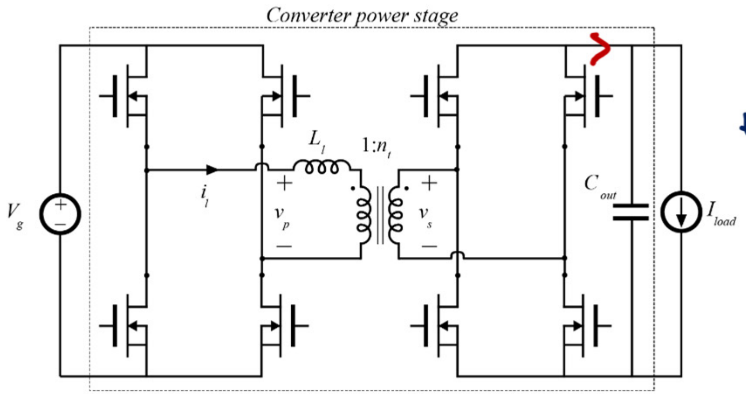
Averaged Modeling

ECE 481: Intro Power Electronics

1) Small Ripple Approximation

$i_L(t) \approx I_L$ ← Problem

$v_c(t) \approx V$



\+ $v_c(t)$ −

2) Apply Volt-sec balance & cap-Q balance

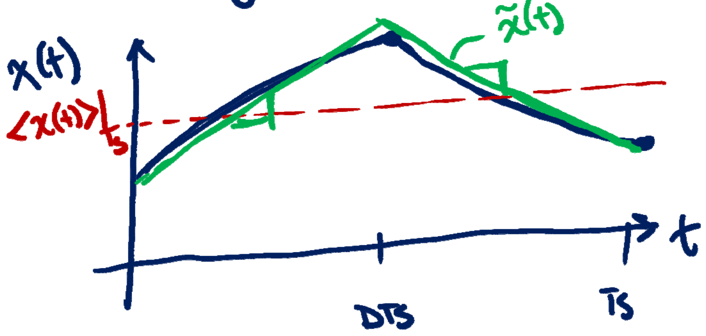
$$\langle v_L \rangle \big|_{T_s} = 0 = \frac{1}{T_s}\left[V_g \frac{T_s}{2} + (-V_g)\frac{T_s}{2} - \left(\frac{V_{out}}{n_t}\right)\frac{T_s}{2} + \left(\frac{V_{out}}{n_t}\right)\frac{T_s}{2} \right] = 0$$

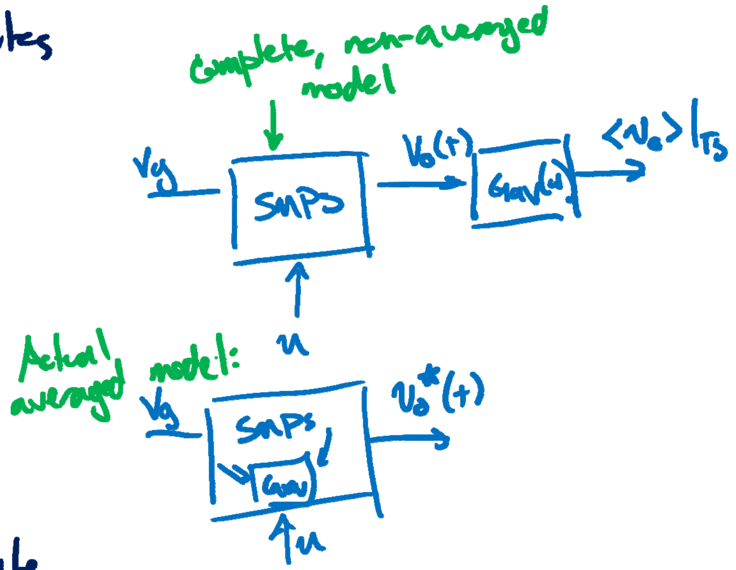
$$\langle i_c \rangle \big|_{T_s} = 0 = \frac{1}{T_s}\left[\frac{T_s}{2}\frac{I_L}{n_t} - \frac{T_s}{2}\frac{I_L}{n_t} - T_s I_{load} \right] = -I_{load} \rightarrow \boxed{I_{load} = 0}$$

Limitations of Average Modeling

1) Small-Ripple Approx

- when looking at any one state, assume all others are approx. DC
- Assumes no significant interaction between states





2) Volt-sec & cap-charge balance

$$\langle v_L \rangle\big|_{T_s} = \langle i_C \rangle\big|_{T_s} = \varnothing \quad \text{in steady-state}$$

- Always true
- Not always a good approximation to replace $i_L(t) \rightarrow \langle i_L(t) \rangle\big|_{T_s}$

Averaging always destroys information about the converter

The Averaging Filter

$$\langle x(t)\rangle\big|_{T_s} = \frac{1}{T_s}\int_{t-T_s/2}^{t+T_s/2} x(\tau)\,d\tau \;\rightarrow\; \mathcal{F}[\,\cdot\,] \;\rightarrow$$

$$X(j\omega) \rightarrow \boxed{G_{av}(j\omega)} \rightarrow \langle X(j\omega)\rangle\big|_{T_s}$$

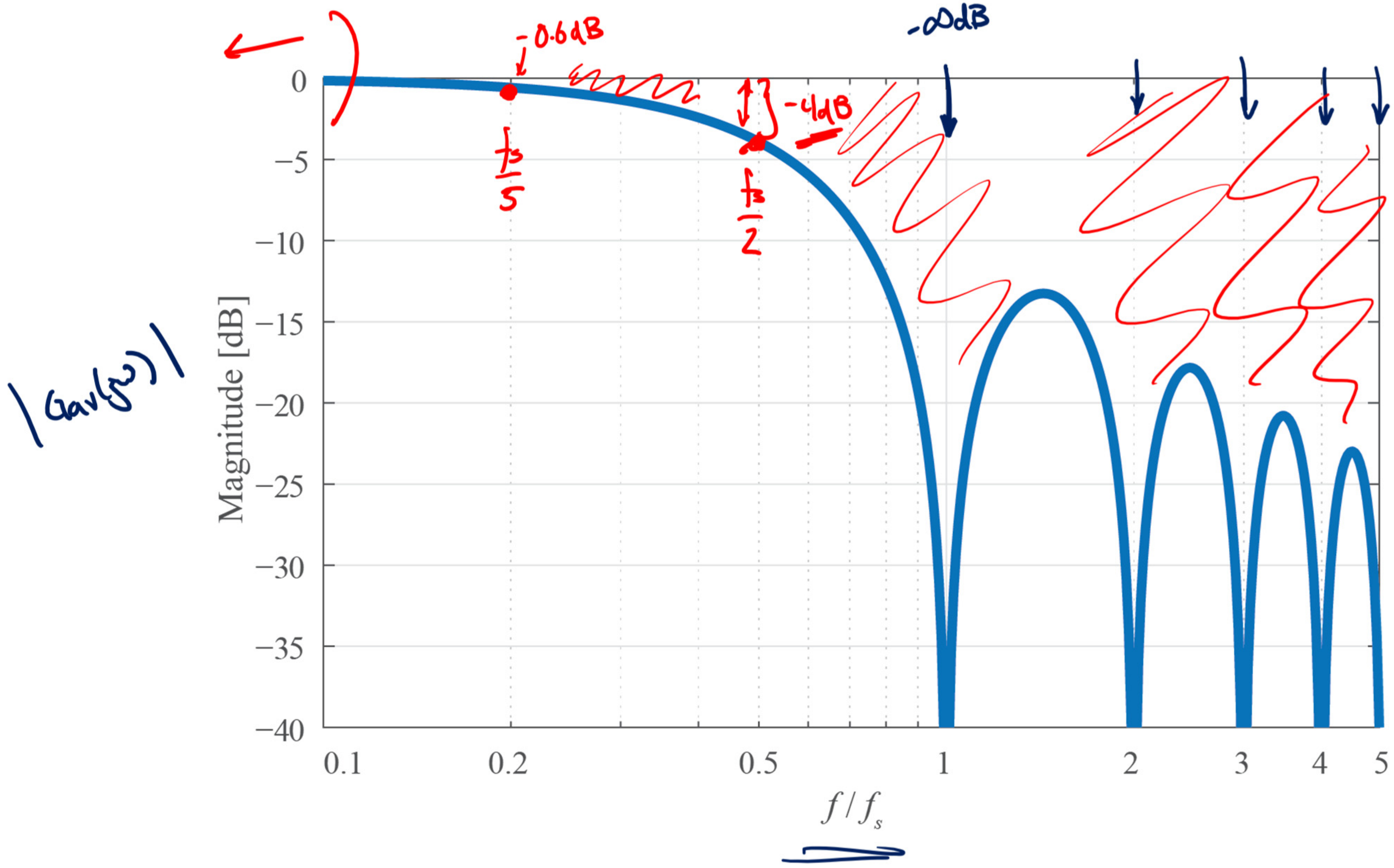
$$\mathcal{F}\left[\frac{1}{T_s}\left[\int_0^{t+\frac{T_s}{2}} x(\tau)\,d\tau - \int_0^{t-\frac{T_s}{2}} x(\tau)\,d\tau\right]\right] = \frac{1}{T_s}\frac{1}{j\omega}e^{j\omega\frac{T_s}{2}}X(j\omega) - \frac{1}{T_s}\frac{1}{j\omega}e^{-j\omega\frac{T_s}{2}}X(j\omega) = G_{av}(j\omega)$$

$$= \frac{1}{T_s}\frac{1}{j\omega}\left(e^{j\omega\frac{T_s}{2}} - e^{-j\omega\frac{T_s}{2}}\right)X(j\omega)$$

$$= \frac{1}{T_s}\frac{1}{j\omega}\left(2j\sin\left(j\omega\frac{T_s}{2}\right)\right)X(j\omega)$$

$$\boxed{G_{av}(j\omega) = \mathrm{sinc}\left(j\omega\frac{T_s}{2}\right)X(j\omega)}$$

Averaging: Discussion



Applicability of Averaging