A Simple Large Signal Model for Isolated DC-DC Converters

Presented and Authored By:

Wilson Eberle

Co-Authors:

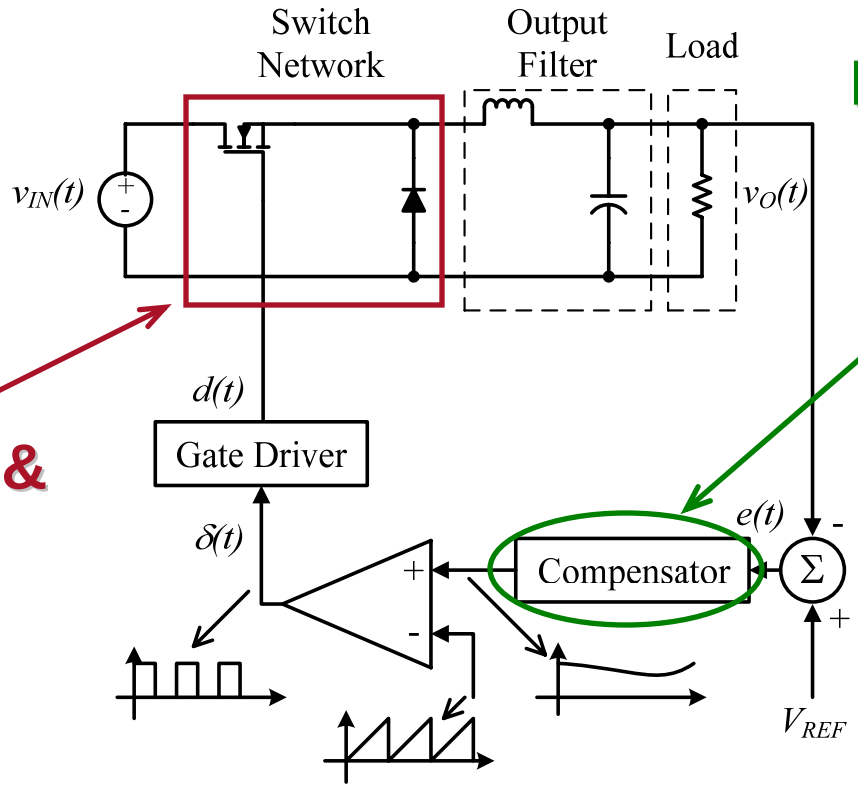
Dr. Yan-Fei Liu and Dr. P.C. Sen

Presentation Overview

1. *Introduction*
   1. *Why we need to model converters*
   2. *Drawbacks of existing techniques*
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions

1. Introduction

- **Application: low power DC-DC power supplies**
- **Why Model?: Switching converters are time variant and non-linear**



Time Variant & Non-Linear Switching

Need Switching Converter Model to Design Compensator

Why Model?

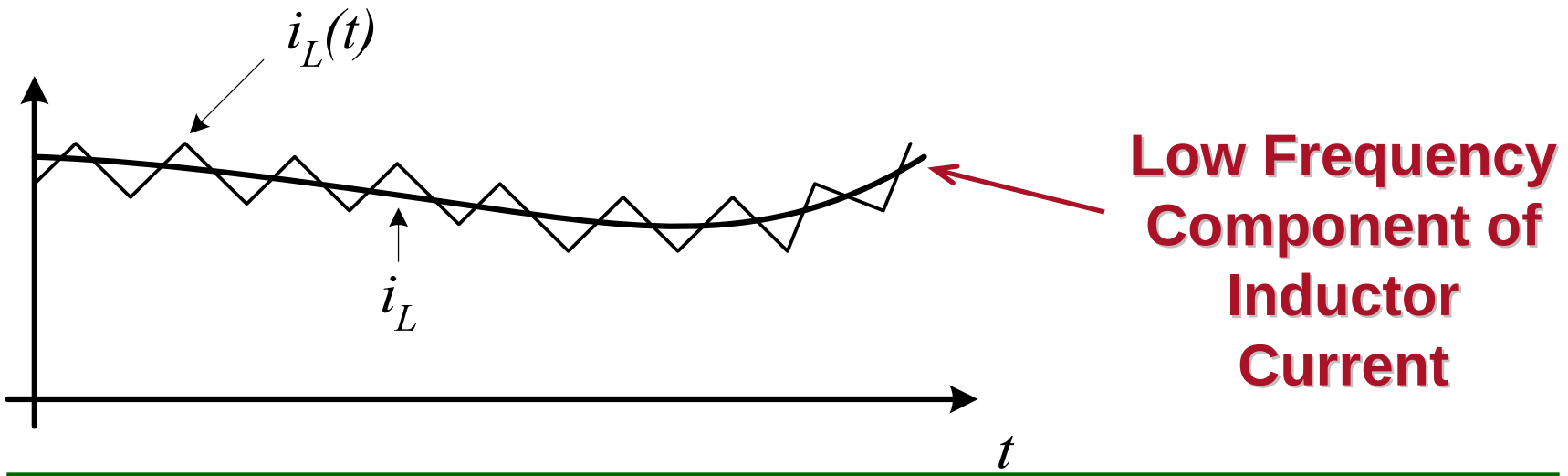
- Design compensator
- Understand and predict small signal dynamic behaviour in frequency domain
- Understand and predict large signal dynamic behaviour in time domain

Control Techniques

- **Voltage Mode Control:** output voltage controlled by duty ratio of high side switch
- **Current Mode Control:** output voltage controlled by peak switch current
- Non-linear and digital techniques gaining popularity, but current mode still most widely used

Modeling Approach

- Average out the switching ripple
- Interested in low frequency behaviour

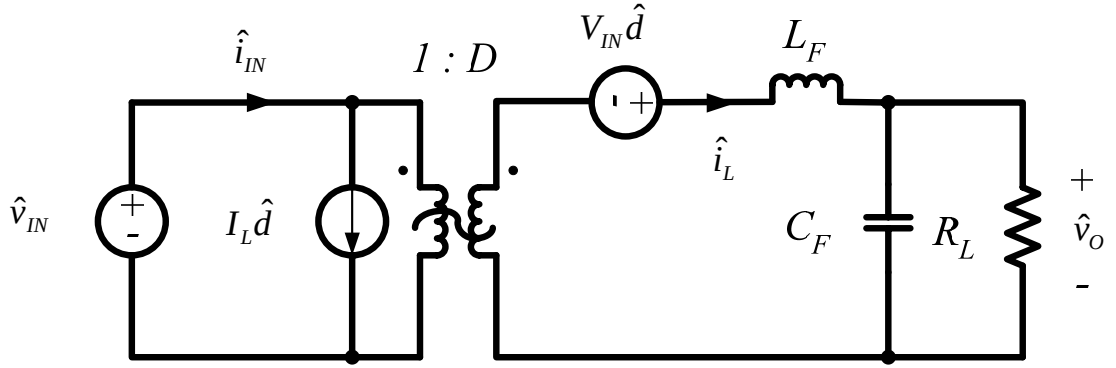


Average Over One Switching Period

Existing Techniques for Voltage Mode Control

Small-Signal AC Equivalent Circuit Method

e.g. Voltage Mode Buck



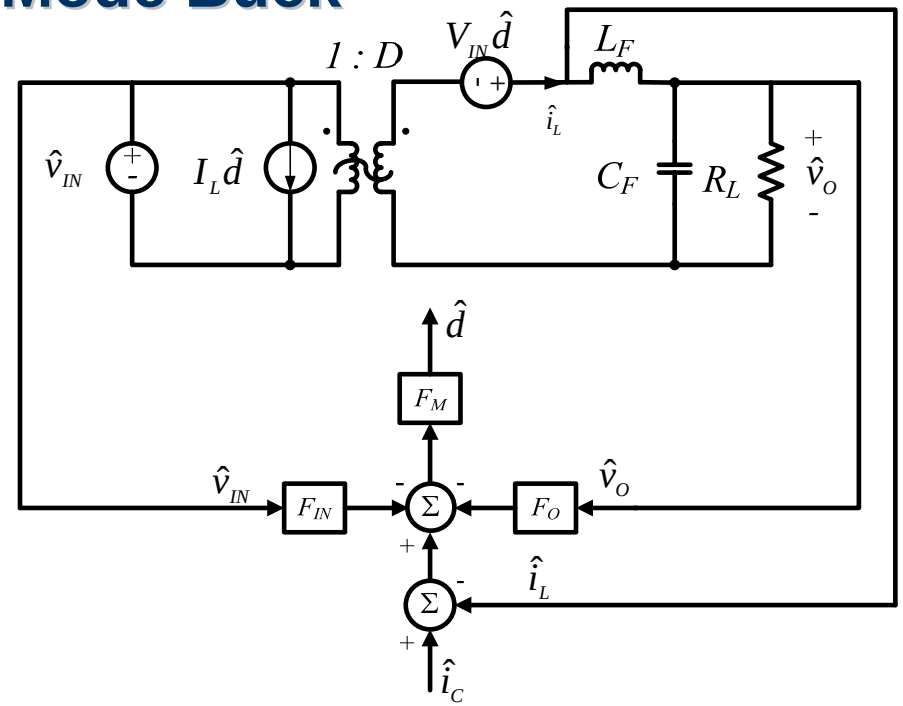
- Derived from perturbed and linearized state equations

Complicated, Small-Signal ONLY & Doesn't Resemble Circuit!

Existing Techniques for Current Mode Control

Small-Signal AC Equivalent Circuit Method

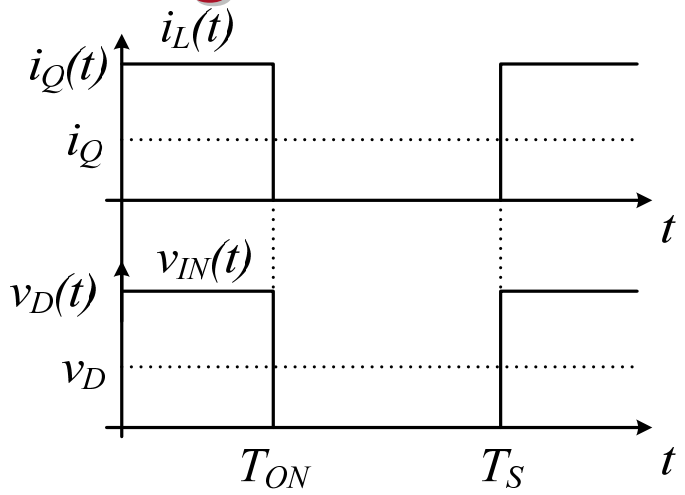
e.g. Current Mode Buck

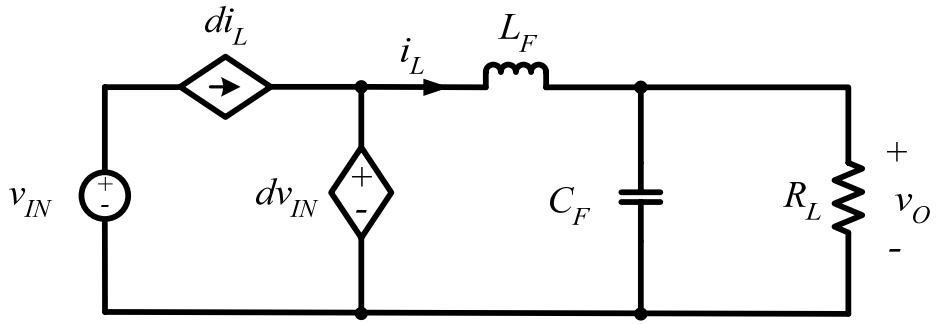


Complicated, Small-Signal ONLY & Doesn't Resemble Circuit!

Existing Techniques for Voltage Mode Control

Averaged Circuit Modeling e.g. Voltage Mode Buck





Same Circuit as Buck

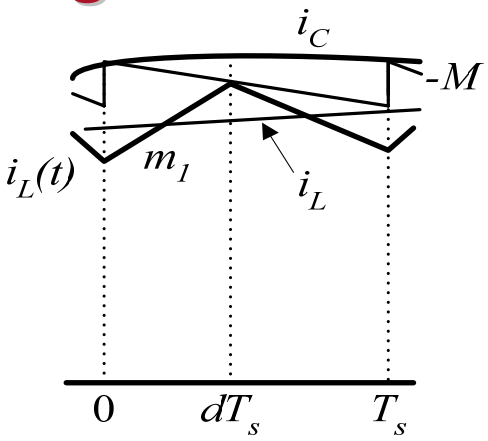
- Low ripple assumption for i_L and Vo
- Active switch replaced by dependent average current source
- Rectifier replaced by dependent average voltage source

Simple, Small & Large Signal & Resembles Circuit

Existing Techniques for Current Mode Control

Averaged Circuit Modeling

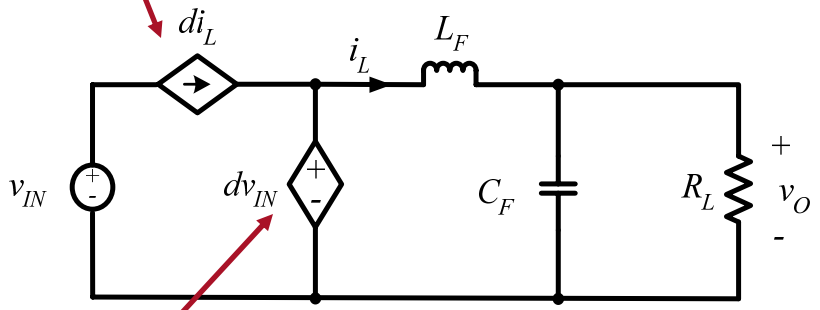
e.g. Current Mode Buck



$$i_L = i_C - \frac{1}{2} m_1 d T_S - d M T_S$$

$$d = \frac{i_C - i_L}{\frac{T_S}{2L_F}(v_S - v_O) + M T_S}$$

$$i_Q = d i_L = i_L \frac{i_C - i_L}{\frac{1}{2} m_1 T_S + M T_S}$$



$$v_D = d v_S = v_S \frac{i_C - i_L}{\frac{1}{2} m_1 T_S + M T_S}$$

Same Circuit as Buck

Simple, Small & Large Signal & Resembles Circuit

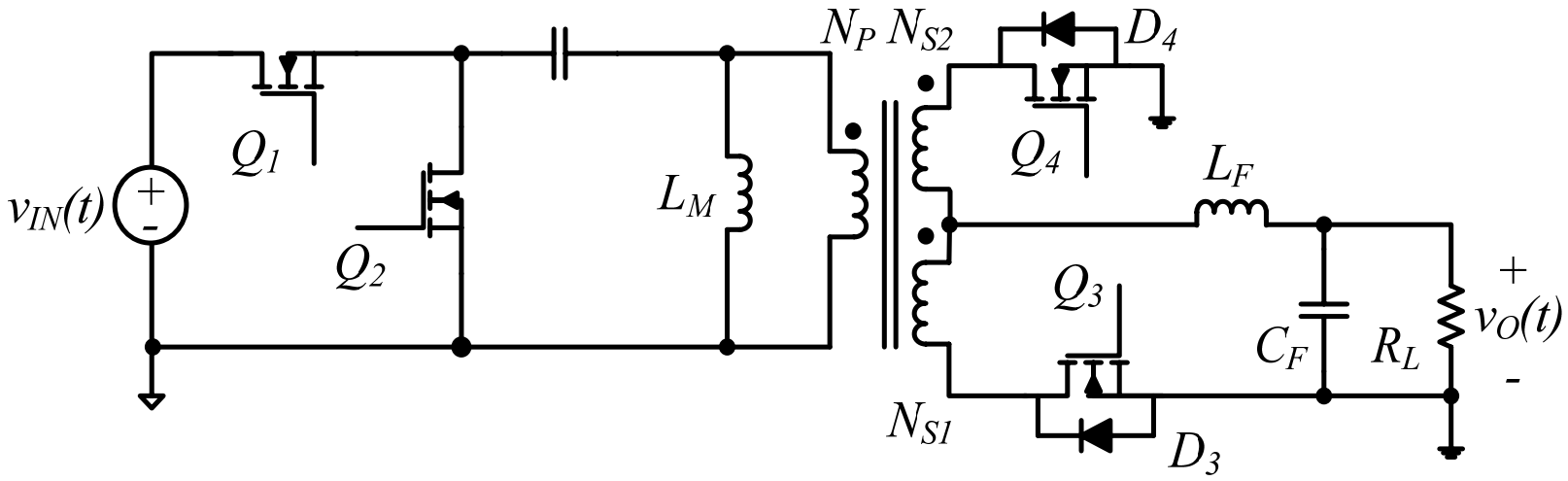
Motivation

- **Existing Averaged Circuit Modeling:** only for simple single switch non-isolated converters!
- **Idea:** extend model to more complex multi-switch isolated converters

Presentation Overview

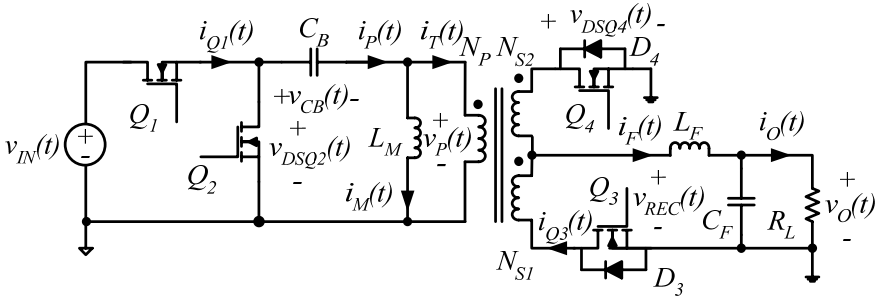
1. Introduction
2. *Deriving the Averaged Model for Isolated DC-DC Converters*
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions

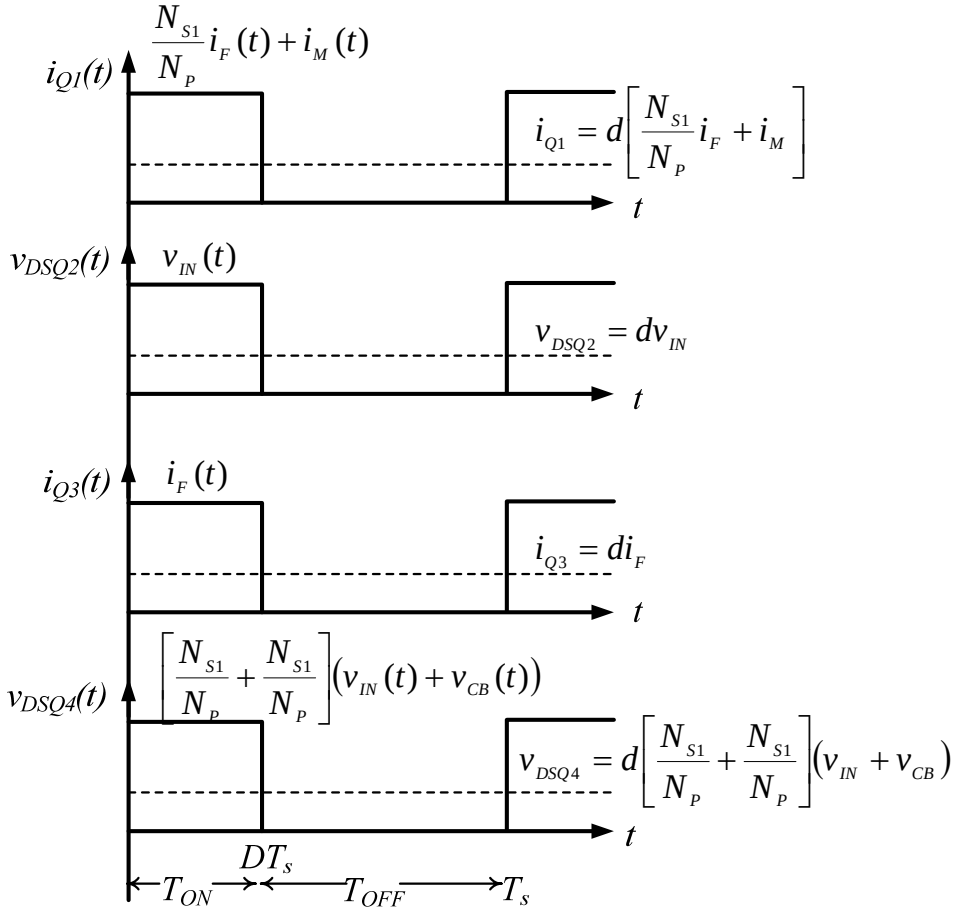
Proposed Model
Asymmetrical Half-Bridge



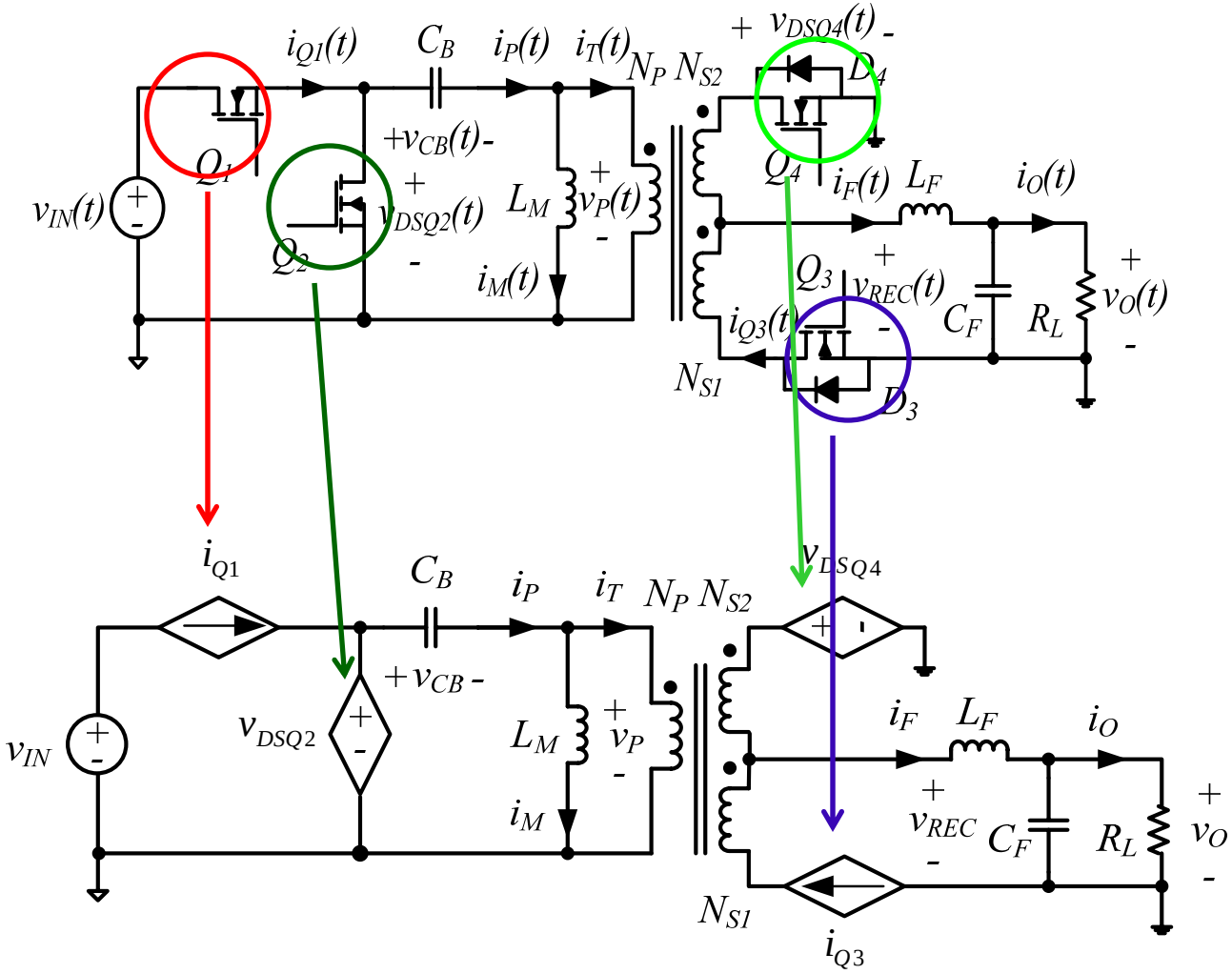
- 2 primary switches and 2 synchronous rectifiers
- Isolation step down transformer
- Q1 and Q3 operate during DTs
- Q2 and Q4 operate during (1-D)Ts

Proposed Model
Asymmetrical Half-Bridge





Proposed Model
Asymmetrical Half-Bridge



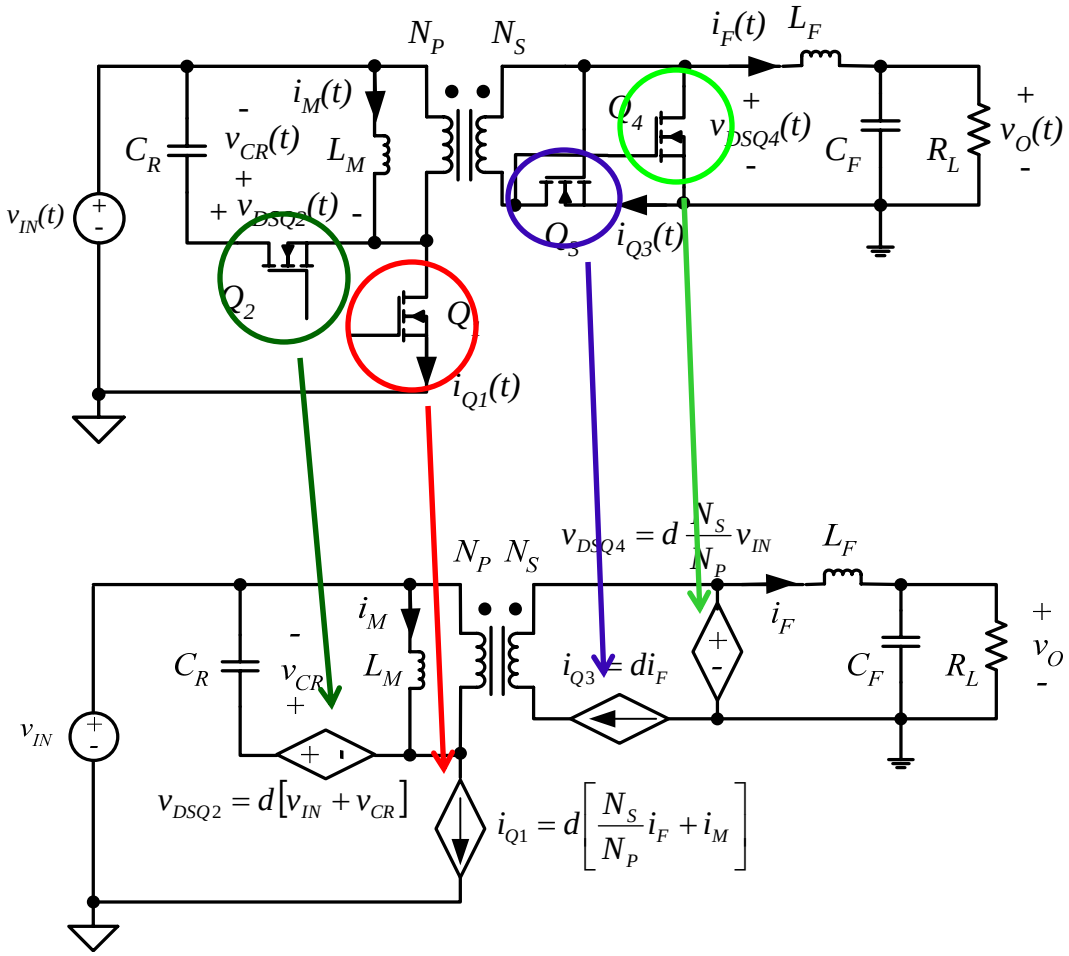
Proposed Model
Asymmetrical Half-Bridge

- Active switch & corresponding rectifier replaced by dependent average current source
- Second switch & corresponding rectifier replaced by dependent average voltage source
- Extend to current mode control with duty cycle as a function of control current

Presentation Overview

1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. *Other Isolated DC-DC Converter Topologies*
4. Experimental Results
5. Conclusions

Proposed Model
Active Clamp Forward



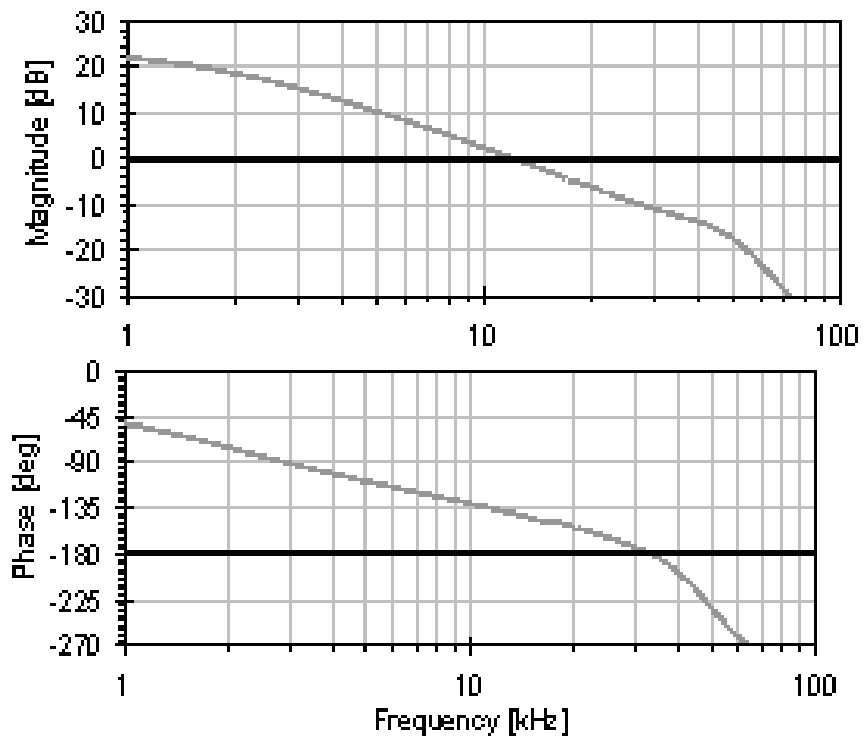
Presentation Overview

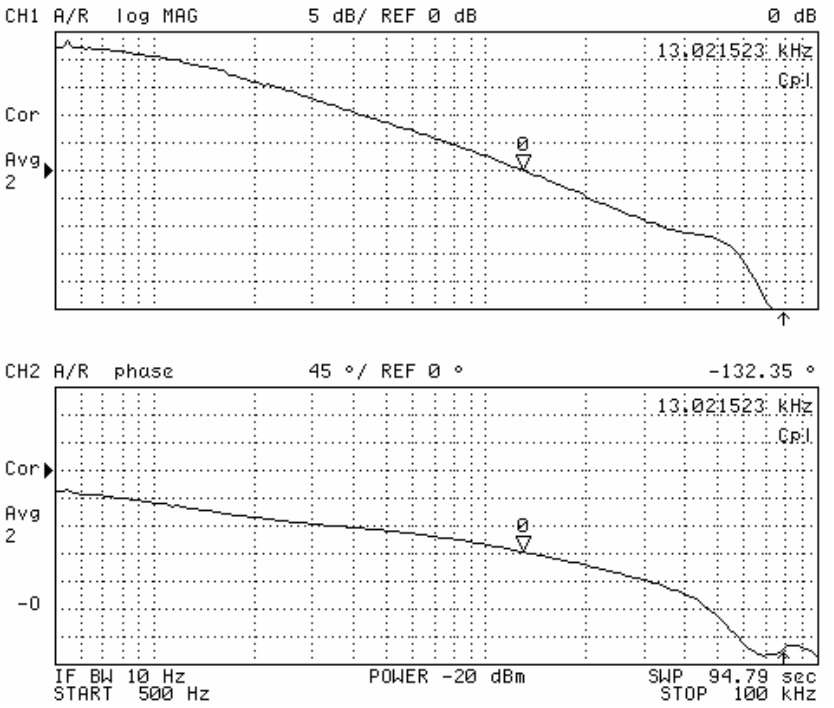
1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. *Experimental Results*
5. Conclusions

AHB Experimental Results:

400kHz, Vin=48V, Vo=5V, Io=6A

Small Signal Frequency Response of the Loop





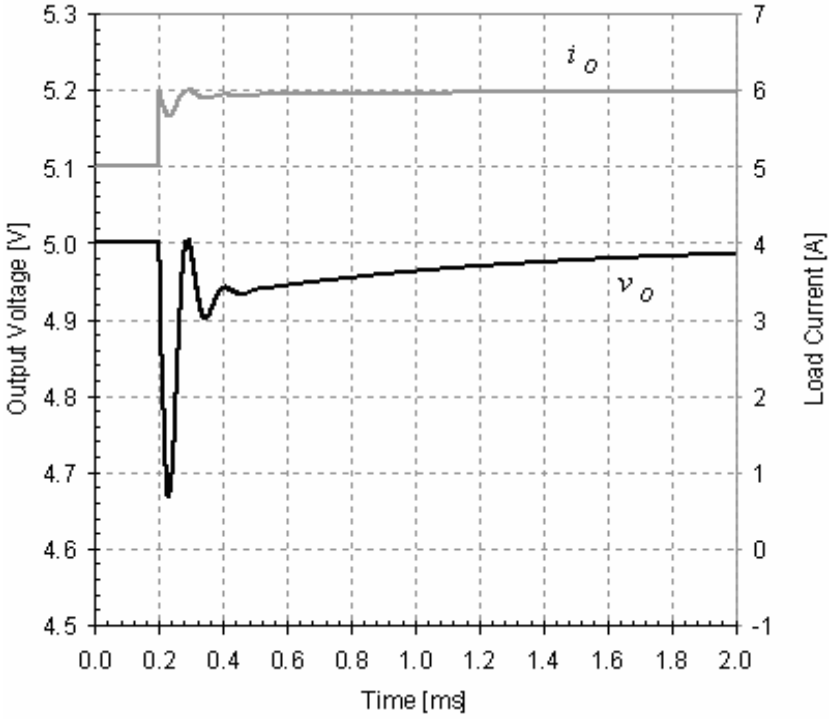
13kHz bandwidth
45deg phase margin

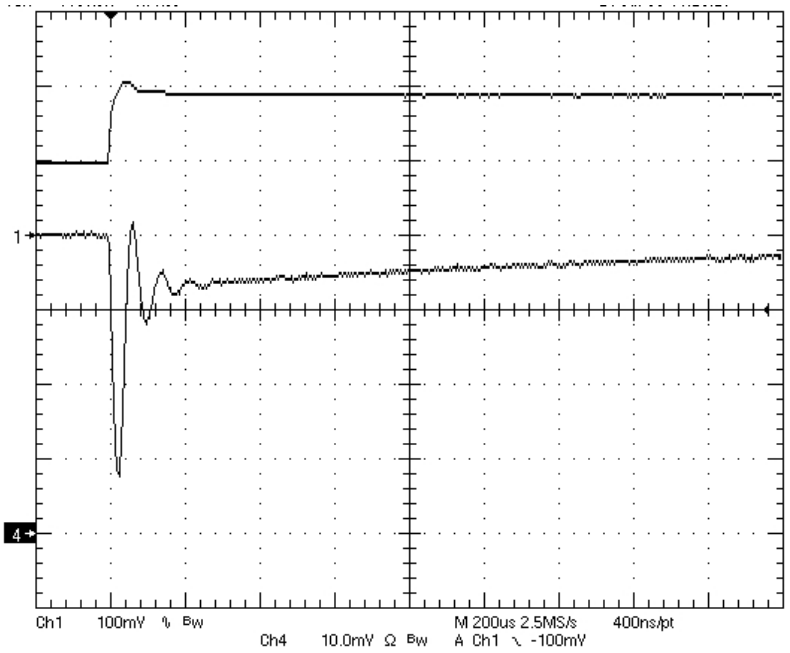
13kHz bandwidth
47deg phase margin

AHB Experimental Results:

400kHz, Vin=48V, Vo=5V, Io=6A

Large Signal (Time Domain) Step Load Change





330mV undershoot

320mV undershoot

Presentation Overview

1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. *Conclusions*

Conclusions

Model Proposed for Isolated DC-DC Converters:

- **Specific Advantages:**
  - Simple to derive
  - Circuit similar to switching converter
  - Large Signal
  - Easily adapted to peak current mode control
- **Applicable to other isolated topologies**
- **Good agreement between model and experimental results for small and large signal cases**

Thank You For Your Time

Modeling and other material at:

www.queenspowergroup.com