University of Central Florida

EEL 5245 POWER ELECTRONICS I
Lecture #13: Chapter 4
Non-Isolated DC-DC Converters
PWM Converters
Boost and Buck Boost Analysis (CCM)

Objectives

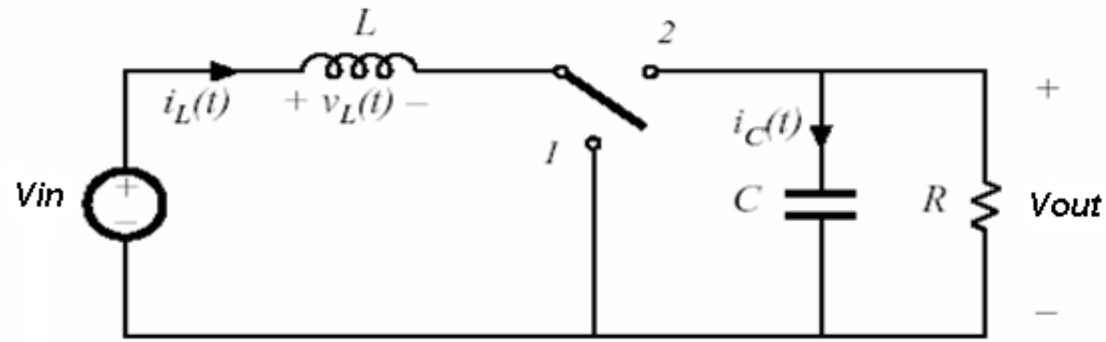
- Boost and Buck-Boost Converter Analysis (CCM)
  - Voltage Conversion Ratio (M=Gain)
  - Average Input and Output Currents
  - Output Voltage Ripple via Charge approximation
  - Boundary Between CCM and DCM
- iPES Examples for Boost CCM
- Calculation Example
- Analysis Verification by Simulation

Figures of Merit for the PWM DC-DC Converter "Plan of Attack"

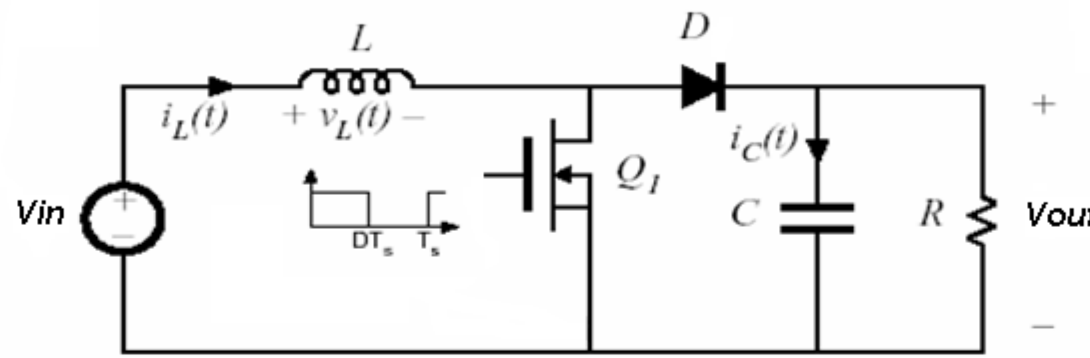
- Classic Converter Analysis (CCM)
  - Voltage Conversion Ratio (M=Gain)
    - Use Inductor Volt-second balance
  - Average Input and Output Currents
    - Use waveform analysis and
    - Capacitor charge balance and small ripple approximation (I_{cavg}=0)
  - Output Voltage Ripple via Charge approximation
    - Small ripple approximation means all ac component of output current seen by capacitor, DC to load R
  - Inductor current Ripple
    - Derived from inductor current waveform
  - Boundary Between CCM and DCM
    - Concept of Critical Inductance derived from i_L expressions

Boost Converter Analysis (Step Up)

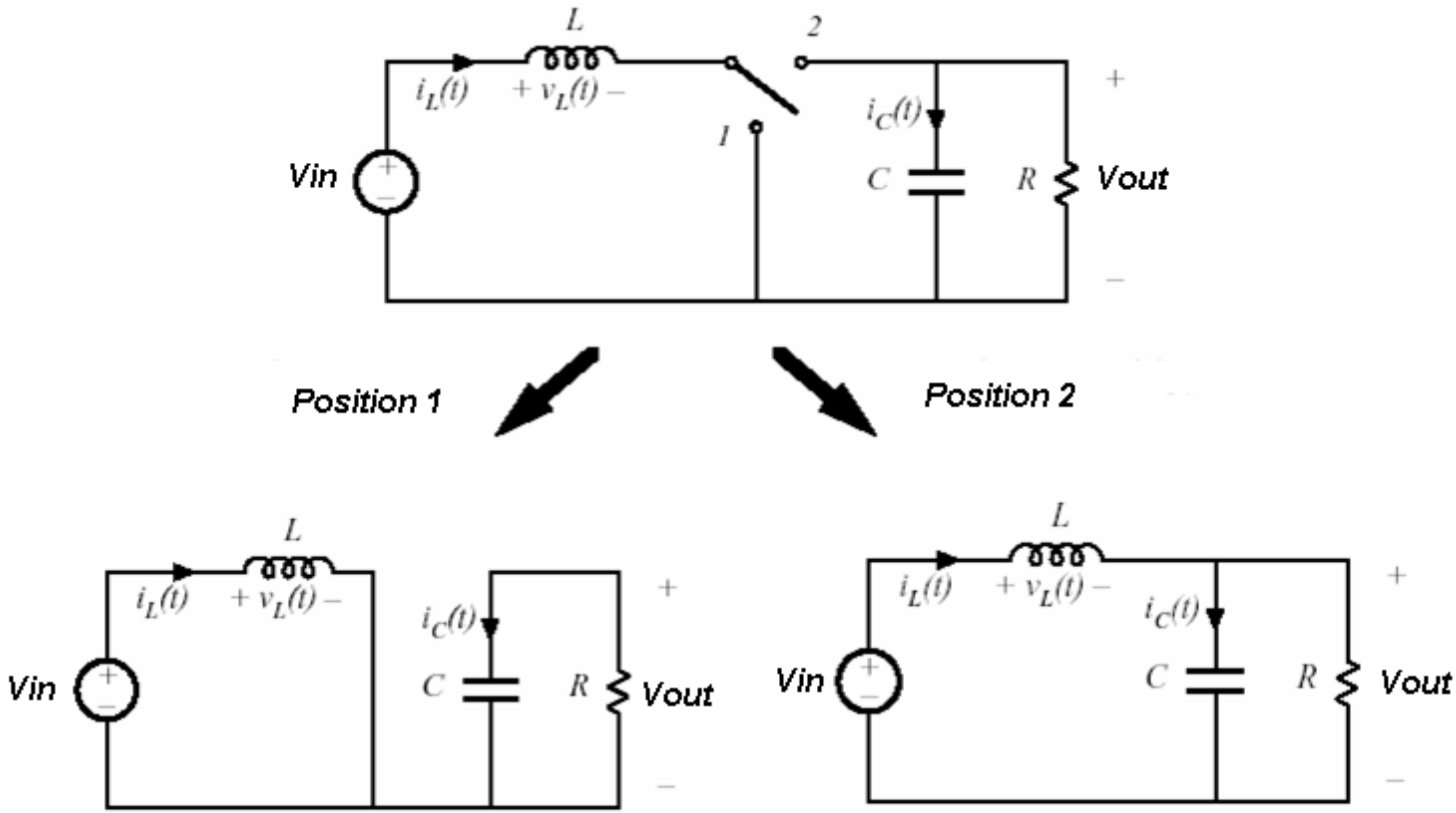
Boost Converter w/ Ideal Switch



Boost Converter realized w/ MOSFET



Boost Converter Analysis
Circuit Modes

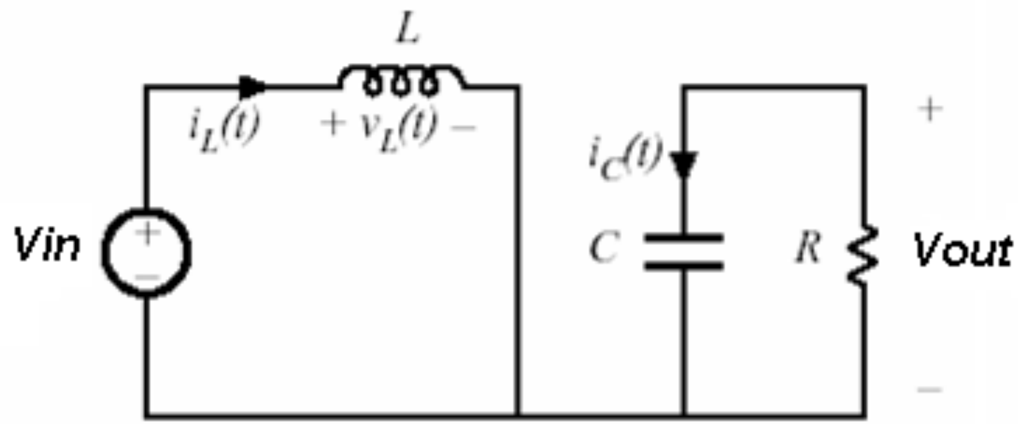


Boost Converter Analysis
Circuit Mode I

Inductor Voltage and Capacitor Current

$$v_L = V_{in}$$

$$i_c = -\frac{V_{out}}{R}$$

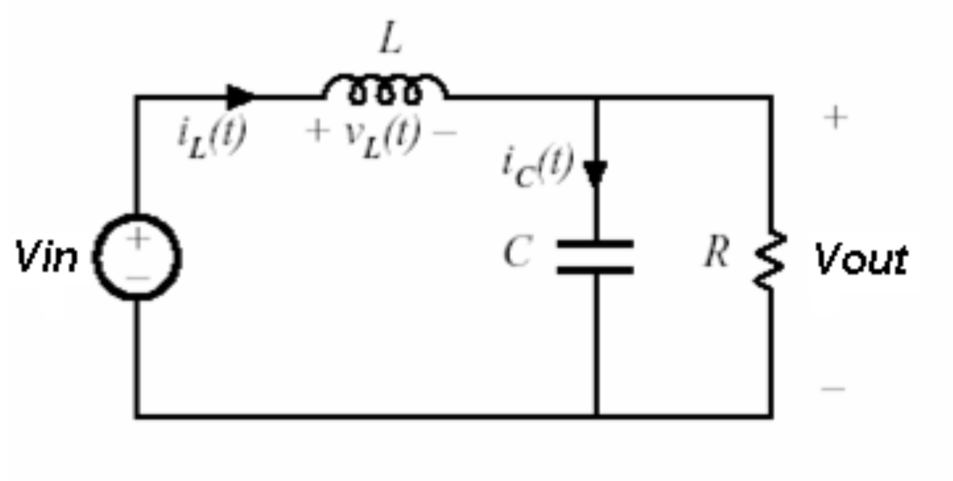


Boost Converter Analysis
Circuit Mode II

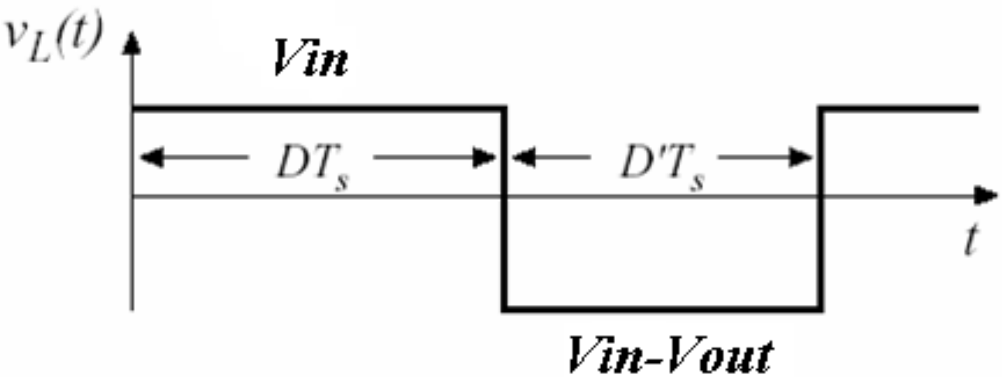
Inductor Voltage and Capacitor Current

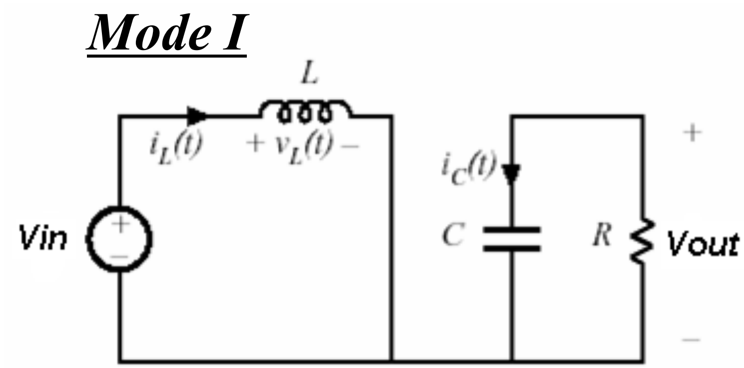
$$v_L = V_{in} - V_{out}$$

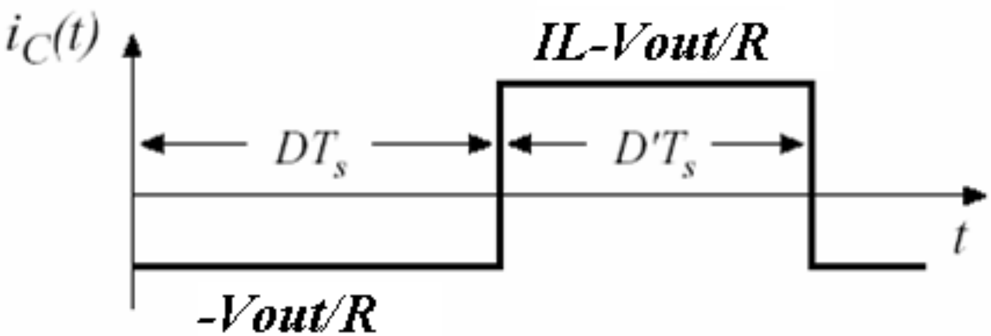
$$i_c = I_L - \frac{V_{out}}{R}$$

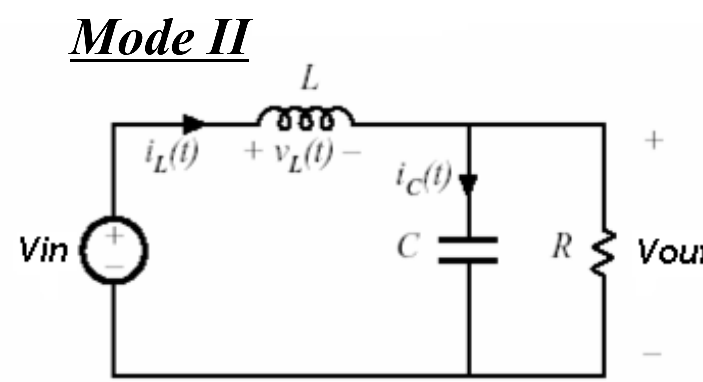


Boost Converter Analysis
Inductor Voltage and Capacitor Current



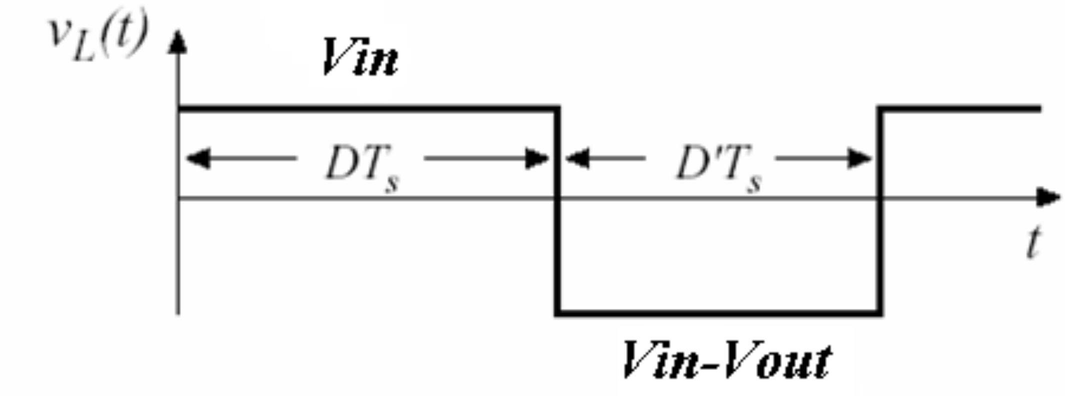






Boost Converter Analysis
Inductor Voltage Second Balance

Net volt-seconds applied to inductor over one switching period:

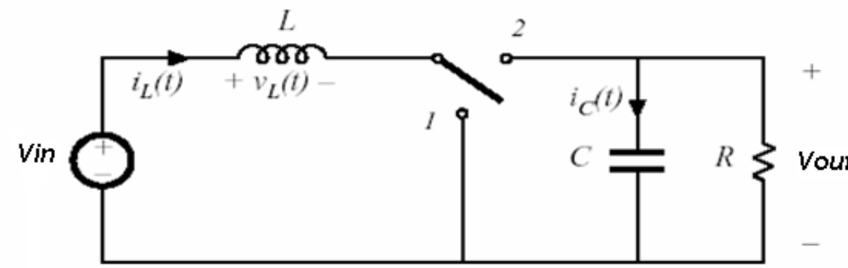


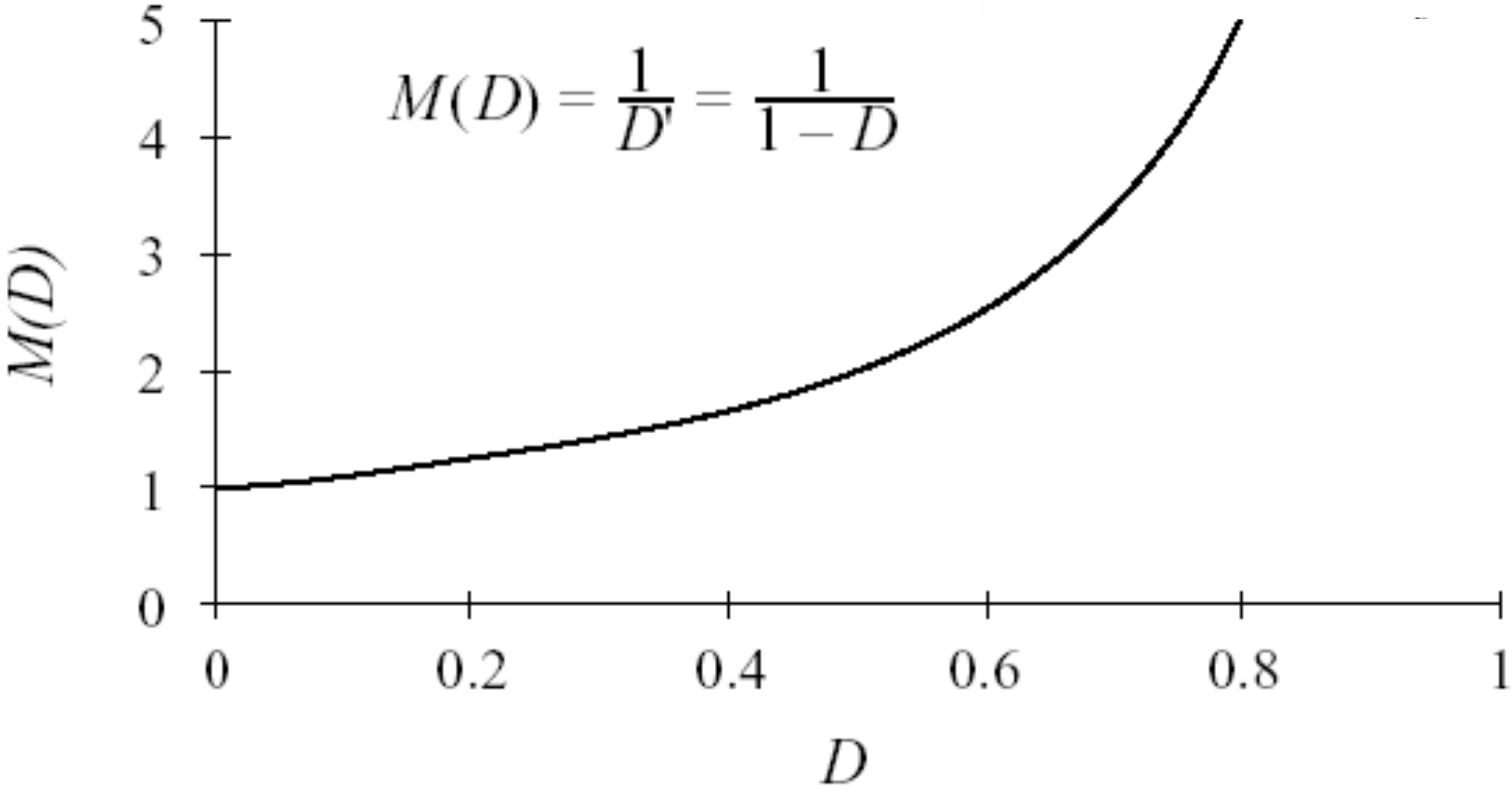
$$\int_0^{T_s} v_L(t)\cdot dt = V_{in}\cdot D\cdot T_s + (V_{in} - V_{out})\cdot(1-D)\cdot T_s$$

Set equal to zero and solve:

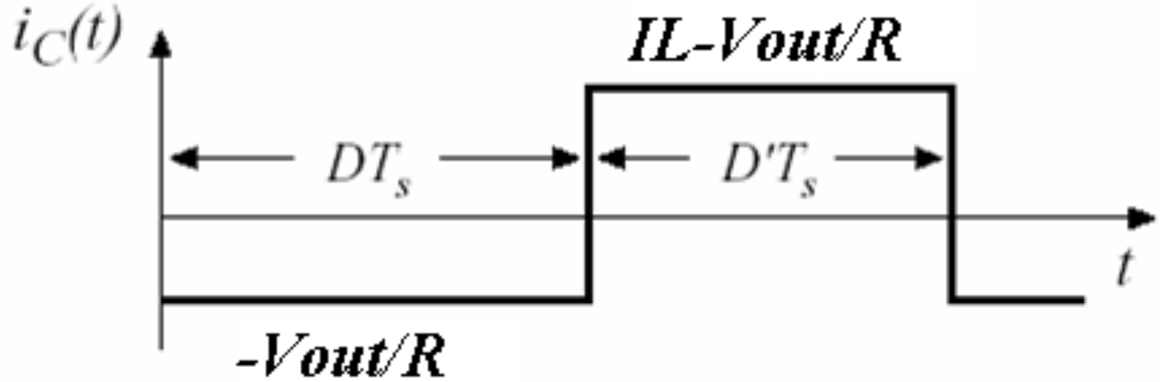
$$V_{in}\cdot(D+1-D) - V_{out}\cdot(1-D) = 0 \quad \Longrightarrow \quad M(D) = \frac{V_{out}}{V_{in}} = \frac{1}{1-D}$$

Boost Converter Analysis
Voltage Conversion Ratio





Boost Converter Analysis
Capacitor Current Average Value



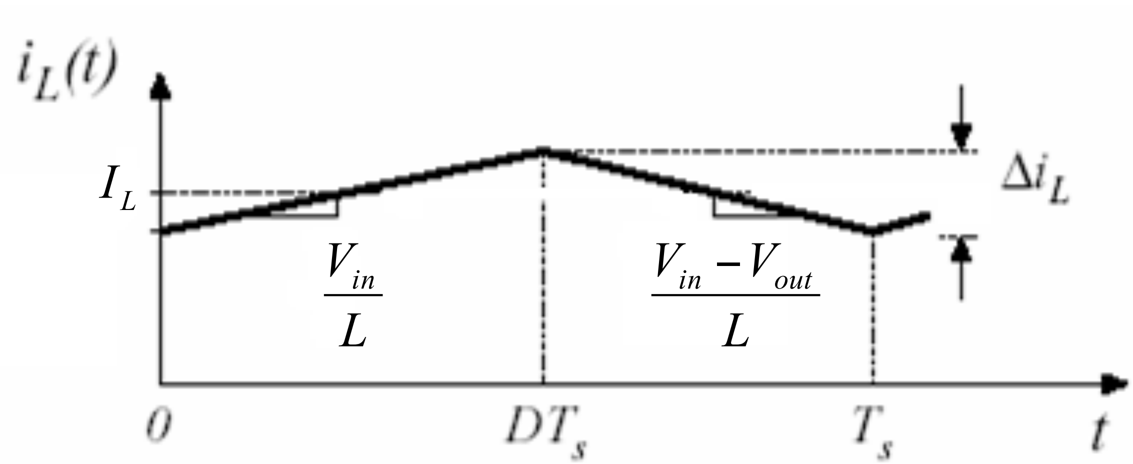
<u>Capacitor charge balance:</u>

$$\int_0^{T_s} i_c(t)\cdot dt = (-\frac{V_{out}}{R})\cdot D\cdot T_s + (I_L - \frac{V_{out}}{R})\cdot(1-D)\cdot T_s = 0$$

Set equal to zero and solve:

$$-\frac{V_{out}}{R}\cdot(D+1-D) + I_L\cdot(1-D)\cdot T = 0_s \quad \Rightarrow \quad I_L = I_{in} = \frac{V_{in}}{(1-D)^2\cdot R}$$

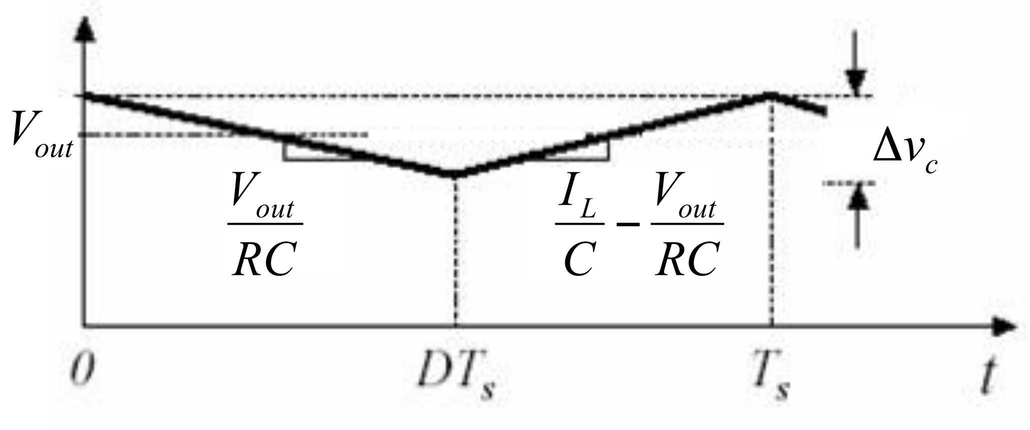
Boost Converter Analysis
Inductor Current Ripple



<u>Change in inductor current during Mode I =Change in inductor current during Mode II (assuming steady-state)</u>

$$\Delta i_L = \frac{V_{in}}{L}\cdot D\cdot T_s = \frac{V_{in}-V_o}{L}\cdot(1-D)\cdot T_s$$

Boost Converter Analysis
Capacitor Voltage Ripple



<u>Change in capacitor voltage during Mode I = Change in capacitor voltage during Mode II (assuming steady-state)</u>

$$\Delta v_c = \frac{V_{out}}{RC} \cdot D \cdot T_s$$

Boost Converter Analysis:
iPES Examples for Boost CCM

DC/DC-Converter Basic Topologies

Boost-Converter

Boost-Converter: Start-Up with Constant Duty Cycle

Boost Converter Analysis

Hand Calculation Example 4.4

Example 4.4:

Sketch the current waveforms for $i_L, i_{in}, i_D, i_o, i_c$ for the boost converter with the following parameters: L=1.8mH, V_{in}=50V, V_o=120V, R=20Ω, C=147μF, and f=15kHz.

Also sketch the voltage waveform v_L, v_{switch}, v_c and v_D.

Boost Converter Analysis:

Hand Calculation Example 4.4

Example 4.4

Sketch all waveforms for a boost converter with the following circuit parameters: V_{in} = 50V, V_o= 120V and R= 20, f_s = 15kHz

L=1.8mH, C=147μF

Solution:

In order to sketch the waveforms, we need to find D, the maximum and minimum. inductor currents, and the average output current.

The duty cycle is given by,

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} = \frac{120}{50}$$

Yields, D=0.58

Boost Converter Analysis:
Hand Calculation Example 4.4

Using R=20Ω and T=66.67μs, the maximum and minimum inductor currents are given by,

$$I_{L\max} = V_{in}\left(\frac{1}{(1-D)^2 R} + \frac{DT}{2L}\right) = 14.71A$$

Ilmax=14.937

and,

$$I_{L\min} = V_{in}\left(\frac{1}{(1-D)^2 R} - \frac{DT}{2L}\right) = 13.635A$$

Ilmin=13.863

The average input and output currents are given by,

$$I_{in} = \frac{I_{L\max} + I_{L\min}}{2} = 14.17\text{A}$$

Iinavg=14.4

$$I_o = I_{in}(1-D) = 5.95A$$

Ioavg=6

Boost Converter Analysis:
Hand Calculation Example 4.4

$$I_{c\max} = I_{L\max} - I_o = 8.76A$$
$$I_{c\min} = I_{L\min} - I_o = 7.685A$$

Hence,

$$\Delta I_c = I_{c\max} - I_{c\min} = 1.01A$$

Notice this value must be equal to ΔI_L.

The capacitor voltage is given by,

$$v_c(t)\big|_{t=0} = 120V$$

$$v_c(t)\big|_{t=DT} = \frac{-I_o}{C} DT + 120V$$

$$= \frac{-5.95\text{A}}{147\mu F}(0.58)(66.67\mu s) + 120V = 118.43V$$

Hence, the ripple is 1.57 volts

Icmax=14.937-6=8.937

Icmin=13.863-6=7.863

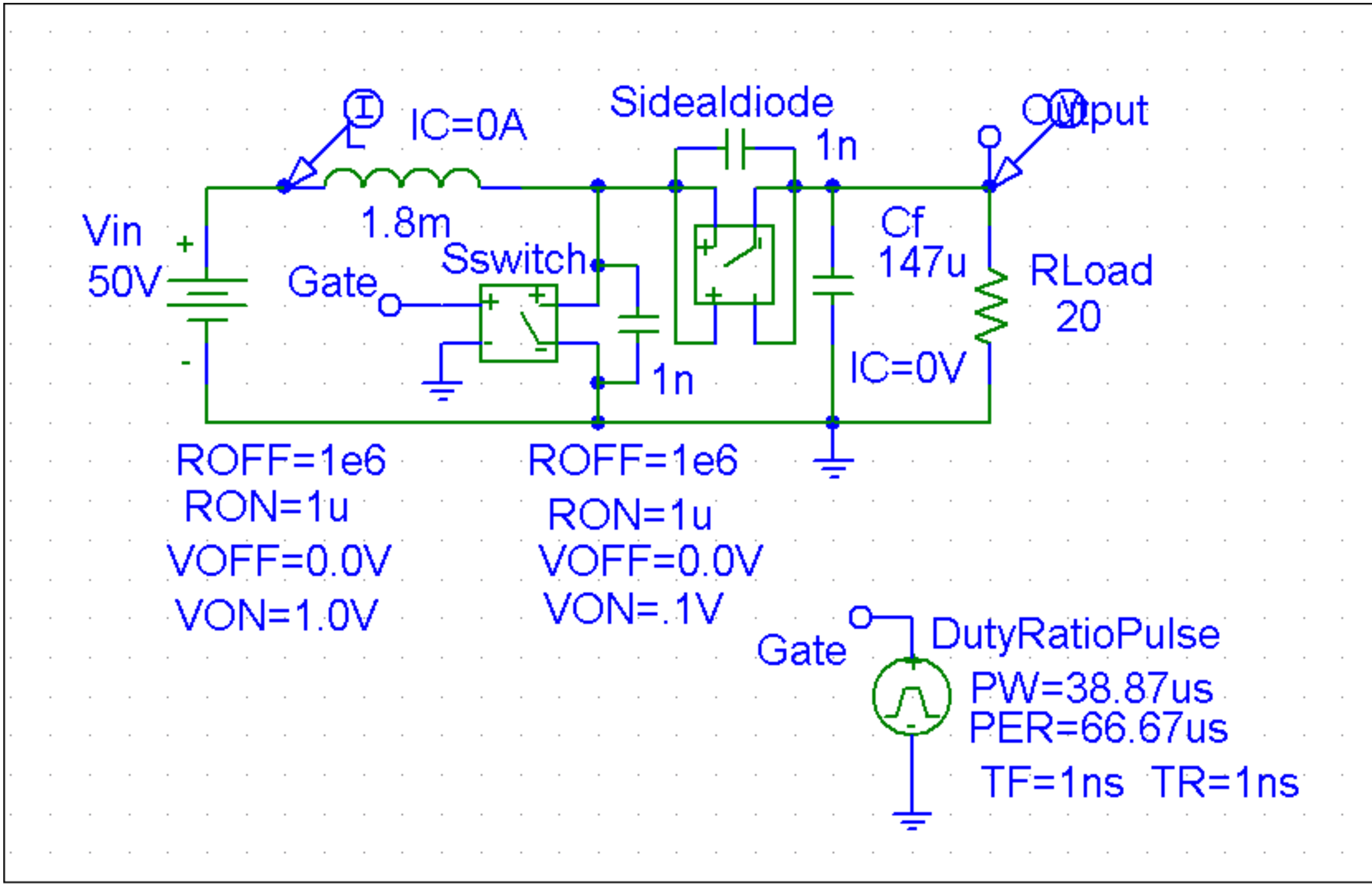
Delta Ic=1.074

Ripple=D/(R*C*f)=1.32%

=1.58V

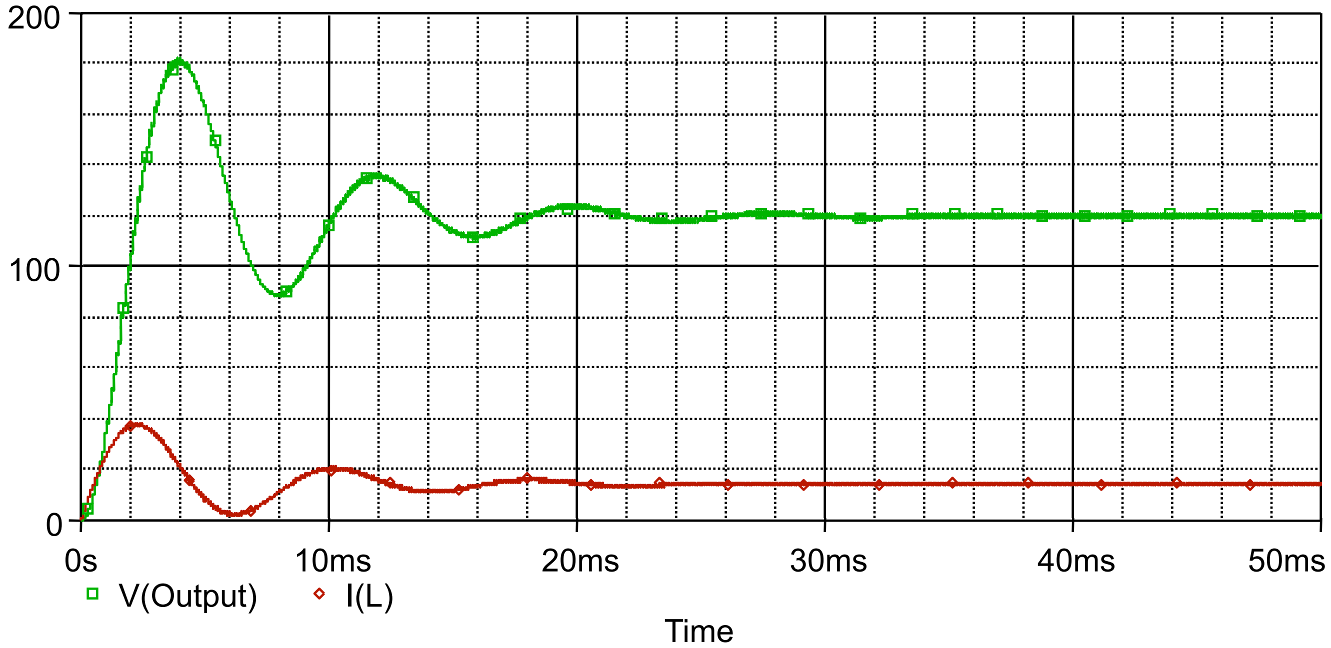
Boost Converter Analysis: Simulation Verification

Example 4.4



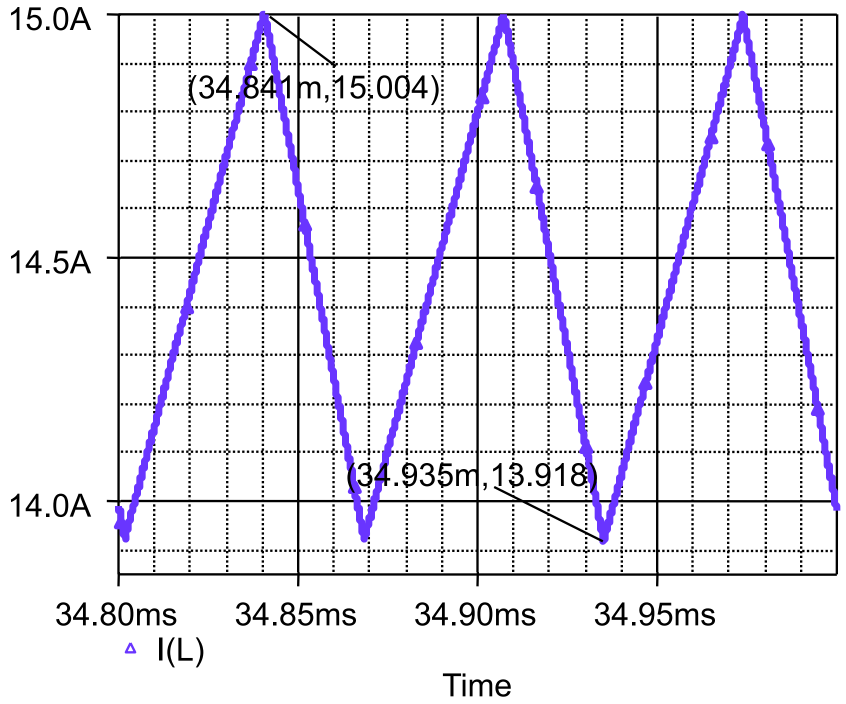
Boost Converter Analysis: Simulation Verification

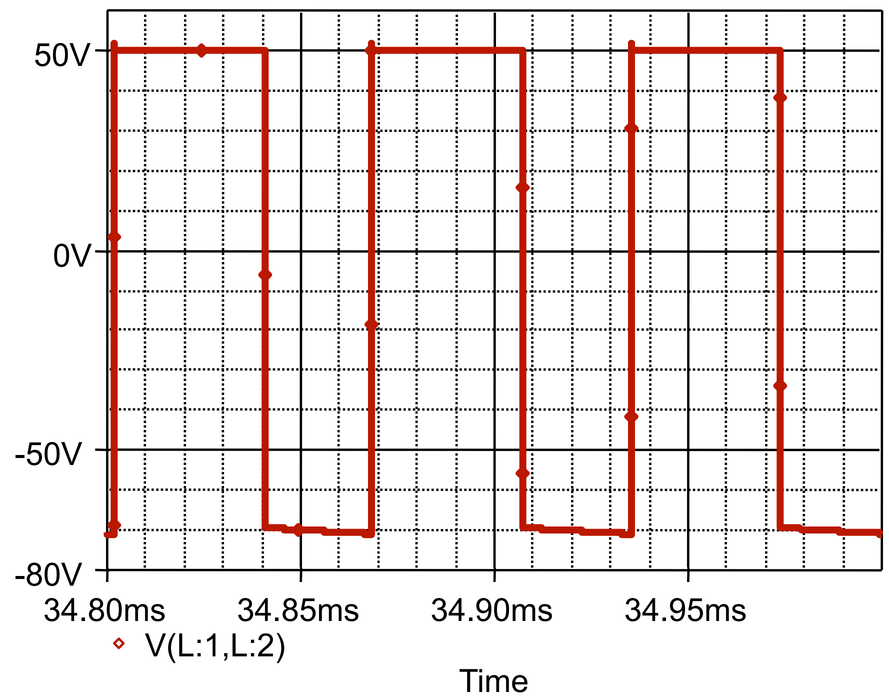
Example 4.4-Startup



Boost Converter Analysis: Simulation Verification

Example 4.4-Inductor Current/Voltage





Boost Converter Analysis: Simulation Verification

Example 4.4-Capacitor Current/Voltage