

Mor M. Peretz, DC-DC Converters [1-1]

DC-DC Converters

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Background and Scope

- Analog Electronics
- Power Electronics
- Provides knowledge and tools for analysis and design of Switch-Mode Power Systems (SMPS)

- PWM Converters
- Magnetics
- Passive and active elements
- Control

Introductory Course

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Course Information

- Lectures
- HW assignments
- Laboratory – Mandatory

- Grading: Final Exam – 75%, Lab – 25%

- Office Hours:

- Website: <http://www.ee.bgu.ac.il/~dcdc>

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Power Conversion

- AC-DC (Rectifier)
- DC-DC (Converter)
- DC-AC (Inverter)
- AC-AC (Cyclo-converter)

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Linear regulators

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The problem of linear regulation Example

- $V_{in} = 10v$
- $V_{out} = 5V$
- $I_{out} = 5A$
- Efficiency: 50%
- Power loss: 25W (Heat dissipation)

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Switch-mode converters

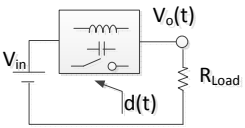
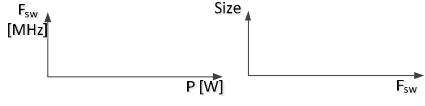
- Reactive elements
- on/off switches

Advantages:

- High efficiency
- Small size

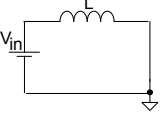

Disadvantages:

- Reliability
- Cost
- Noise

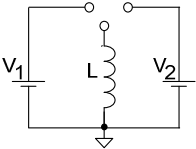
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PWM converters Inductor

$$\frac{V}{L} = \frac{di}{dt}$$



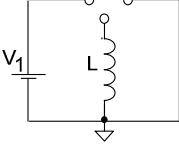
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PWM converters Inductor

$$\frac{V}{L} = \frac{di}{dt}$$


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PWM converters
Inductor

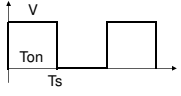


$$\frac{V}{L} = \frac{dI}{dt}$$

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PWM converters
Inductor average voltage

Still valid: $\frac{\bar{V}}{L} = \frac{d\bar{I}}{dt}$



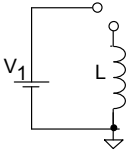
The average voltage across the inductor must be zero

$$\bar{V}_L = 0$$

Why???

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PWM converters
Inductor Current Interruption



Polarity at the interruption instance: Imaginary resistor method

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Operation of Buck converter

The diagram shows a buck converter circuit with input voltage V_{in} , a MOSFET switch, a diode D , an inductor L , a capacitor C_o with equivalent series resistance ESR , and a load resistor R . The output voltage is V_o .

On

Off

Waveforms

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Operation of Buck converter

Voltage transfer function – CCM

ΔI method

The diagram shows a buck converter circuit with input voltage V_{in} , a MOSFET switch, a diode D , an inductor L , a capacitor C_o with equivalent series resistance ESR , and a load resistor R . The output voltage is V_o .

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Operation of Buck converter

Voltage transfer function – CCM

average voltage method

The diagram shows a buck converter circuit with input voltage V_{in} , a MOSFET switch, a diode D , an inductor L , a capacitor C_o with equivalent series resistance ESR , and a load resistor R . The output voltage is V_o .

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Operation of Buck converter DCM

$R1 < R2 < R3$

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Operation of Buck converter Boundary mode - Lmin

$$I_{pk} = \frac{V_o}{L_{min}} T_{off} = 2I_{av}$$

$$L_{min} = \frac{V_o D_{off}}{2 I_{av} f_s}$$

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Operation of Buck converter DCM

$$I_{pk} = \frac{V_{in} - V_o}{L} T_{on} = \frac{V_o}{L} T_{off}'$$

$$D_{off}' = \frac{V_{in} - V_o}{V_o} D_{on}$$

$$I_{av} = \frac{1}{T_s} \left(\frac{I_{pk}(T_{on} + T_{off}')}{2} \right) = \frac{V_o}{R}$$

$$\frac{V_o}{V_{in}} = \frac{R D_{on}^2 T_s}{4L} \left(\sqrt{1 + \frac{8L}{R D_{on}^2 T_s}} - 1 \right)$$

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Operation of Buck converter Output capacitor

ΔV_o is small

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Buck converter Design Example

- $V_{in} = 10\text{V}$; $V_{out} = 5\text{V}$; $I_{out} = 5\text{A}$; $f_s = 100\text{kHz}$
- Calculate L_{min}

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Operation of Boost converter

On

Off

Waveforms

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Operation of Boost converter
Voltage transfer function – CCM
 ΔI method

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Operation of Boost converter
Voltage transfer function – CCM
average voltage method

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Operation of Boost converter
Boundary mode - Lmin

$$I_{pk} = \frac{V_{in}}{L_{min}} \cdot T_{on} = 2I_{av}$$

$$L_{min} = \frac{V_{in} D_{on}}{2 I_{av} f_s}$$

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Operation of Boost converter Output capacitor

ΔV_o is small

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Boost converter Design Example

- $V_{in} = 12V$; $V_{out} = 48V$; $I_{out} = 1A$; $f_s = 50kHz$
- Calculate L for $\Delta I = 0.1 I_{Lavg}$

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Operation of Buck-Boost converter

On

Off

Waveforms

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Types of PWM converters Basic

$\frac{V_o}{V_{in}} = D$

Buck

$\frac{V_o}{V_{in}} = \frac{1}{1-D}$

Boost

Buck-Boost

$\frac{V_o}{V_{in}} = -\frac{D}{1-D}$

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Input and Output Currents

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Simulation

- Cycle-by-cycle Vs. Average simulation
- Objective: Create a continuous model

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Average Simulation Common Switched-Inductor Cell

Buck Boost Buck-Boost

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Switched Inductor Model (SIM) Continuous model

$$I_a = I_L$$

$$I_b = I_L D_{on}$$

$$I_c = I_L D_{off}$$

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The SIM with Average Current

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Auxiliary Circuit to Create IL

$$\overline{V_L} = \frac{V(a,b)T_{on} + V(a,c)T_{off}}{T_s}$$

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Complete Average Model

Formal method

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Complete Average Model By inspection

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Complete Average Model
By inspection

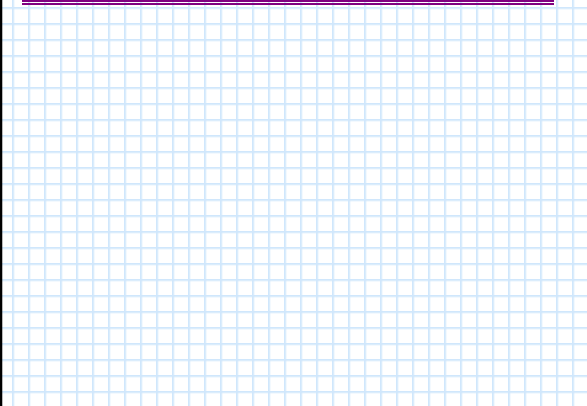
The diagram shows a buck converter circuit. On the left, there is an input voltage source V_{in} . This is connected to a MOSFET Q in series with an inductor L . The other end of the inductor is connected to a diode D_1 in series with a capacitor C_o (labeled $47\mu F$). The output of the capacitor is connected to a load resistor R (labeled 10Ω). The output voltage is labeled V_o .


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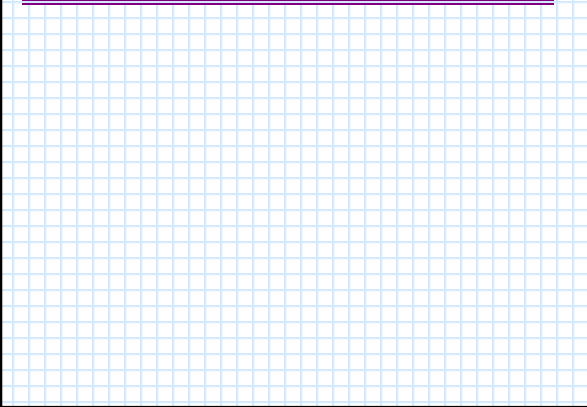
In the Simulator Environment
Coding variables into voltages


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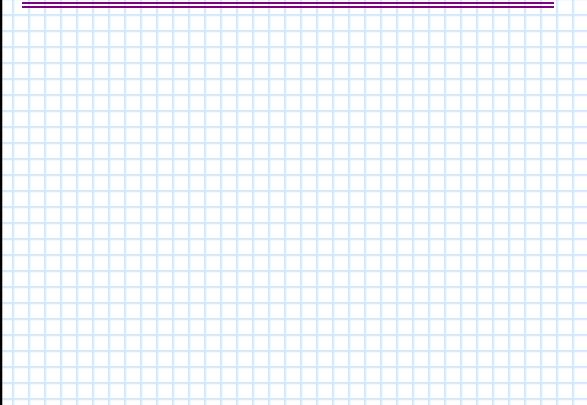
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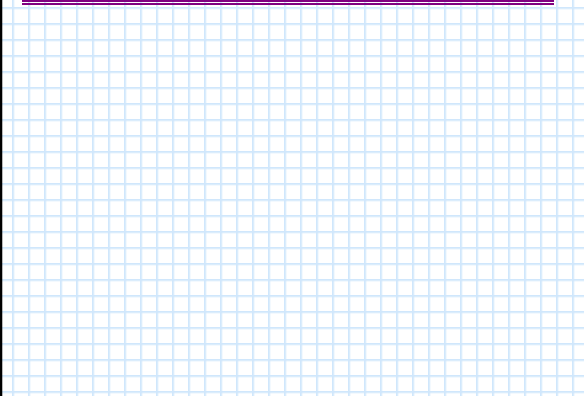
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