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

Course Information

- Lectures
- HW assignments
- Laboratory – Mandatory

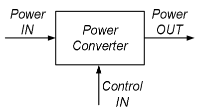
- Grading: Final Exam – 75%, Lab – 25%

- Office Hours:

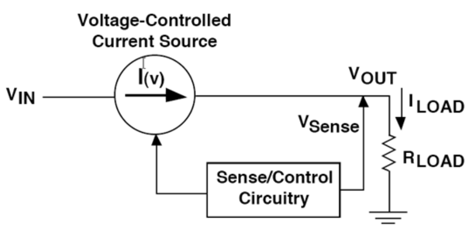
- Website: **http://www.ee.bgu.ac.il/~dcdc**

Power Conversion

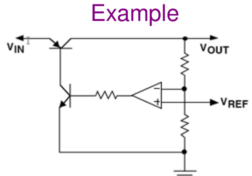
- AC-DC (Rectifier)
- DC-DC (Converter)
- DC-AC (Inverter)
- AC-AC (Cyclo-converter)



Linear regulators



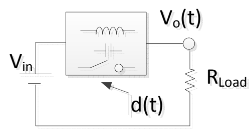
The problem of linear regulation
Example



- Vin = 10v
- Vout = 5V
- Iout = 5A
- Efficiency: 50%
- Power loss: 25W (Heat dissipation)

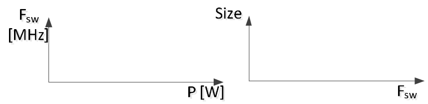
Switch-mode converters

- Reactive elements
- on/off switches



Advantages:
- High efficiency
- Small size

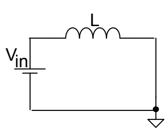
Disadvantages:
- Reliability
- Cost
- Noise



PWM converters

Inductor

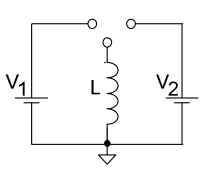
$$\frac{V}{L} = \frac{dI}{dt}$$



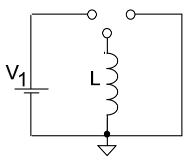
PWM converters

Inductor

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



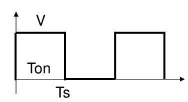
PWM converters
Inductor



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

PWM converters
Inductor average voltage

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

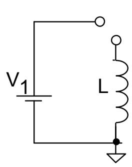


The average voltage across the inductor must be zero

$$\overline{V_L} = 0$$

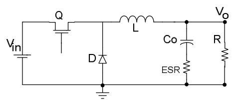
Why???

PWM converters
Inductor Current Interruption



Polarity at the interruption instance: Imaginary resistor method

Operation of Buck converter



On

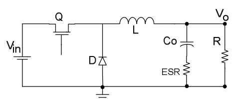
Waveforms

Off

Operation of Buck converter

Voltage transfer function – CCM

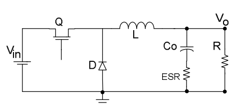
ΔI method



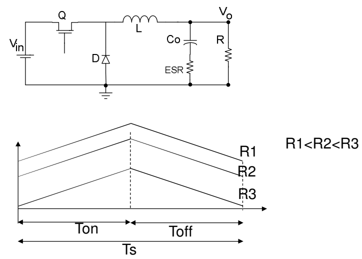
Operation of Buck converter

Voltage transfer function – CCM

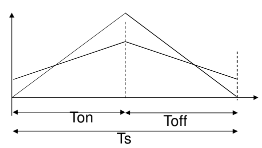
average voltage method



Operation of Buck converter
DCM



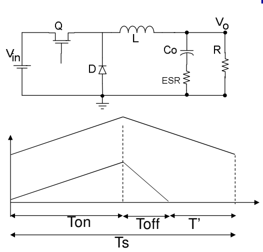
Operation of Buck converter
Boundary mode - Lmin



$$Ipk = \frac{Vo}{Lmim} Toff = 2Iav$$

$$Lmin = \frac{VoDoff}{2Iav\,fs}$$

Operation of Buck converter
DCM



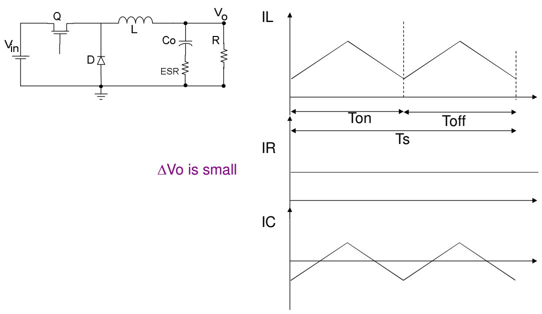
$$Ipk = \frac{Vin - Vo}{L} Ton = \frac{Vo}{L} Toff'$$

$$Doff' = \frac{Vin - Vo}{Vo} Don$$

$$Iav = \frac{1}{Ts}\left(\frac{Ipk(Ton + Toff')}{2}\right) = \frac{Vo}{R}$$

$$\frac{Vo}{Vin} = \frac{RDon^2 Ts}{4L}\left(\sqrt{1 + \frac{8L}{RDon^2 Ts}} - 1\right)$$

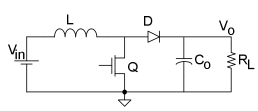
Operation of Buck converter
Output capacitor



Buck converter
Design Example

- Vin = 10v ; Vout = 5V ; Iout = 5A ; fs=100kHz
- Calculate <u>Lmin</u>

Operation of Boost converter



On

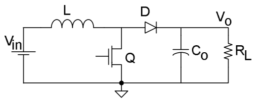
Waveforms

Off

Operation of Boost converter

Voltage transfer function – CCM

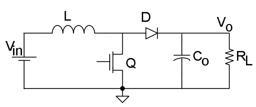
ΔI method



Operation of Boost converter

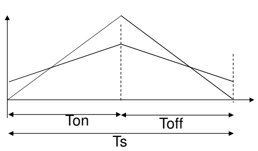
Voltage transfer function – CCM

average voltage method



Operation of Boost converter

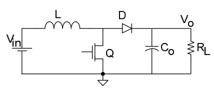
Boundary mode - Lmin

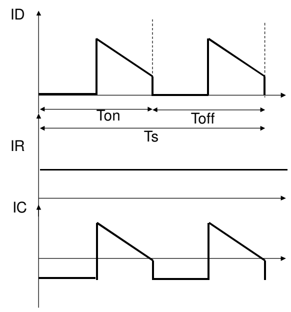


$$Ipk = \frac{Vin}{Lmim} Ton = 2Iav$$

$$\boxed{Lmin = \frac{VinDon}{2Iav\,fs}}$$

Operation of Boost converter
Output capacitor



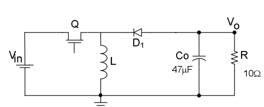


ΔVo is small

Boost converter
Design Example

- Vin = 12V ; Vout = 48V ; Iout = 1A ; fs=50kHz
- Calculate L for ΔI=0.1ILavg

Operation of Buck-Boost converter



On

Waveforms

Off

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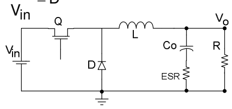
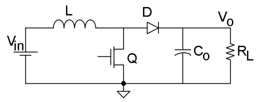
Types of PWM converters
Basic

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

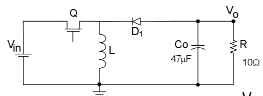


Buck



Boost

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



Buck-Boost

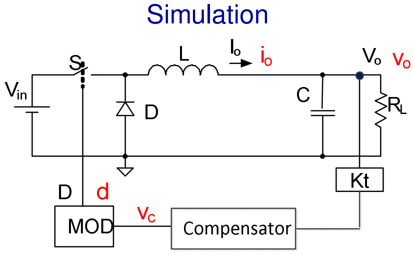
$$\frac{V_o}{V_{in}} = -\frac{D}{1-D}$$

Mor M. Peretz, DC-DC Converters [1-29]

Input and Output Currents

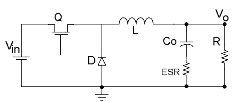
Mor M. Peretz, DC-DC Converters [1-30]

Simulation

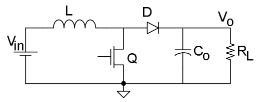


- Cycle-by-cycle Vs. Average simulation
- Objective: Create a continuous model

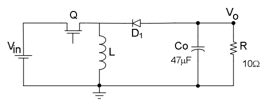
Average Simulation
Common Switched-Inductor Cell



Buck

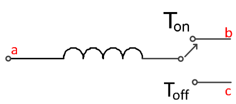


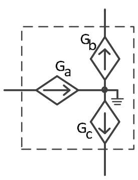
Boost



Buck-Boost

Switched Inductor Model (SIM)
Continuous model



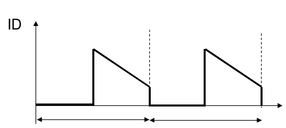


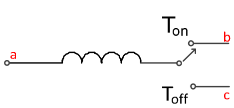
$I_a = I_L$

$I_b = I_L D_{on}$

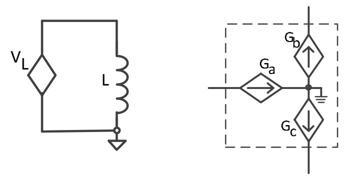
$I_c = I_L D_{off}$

The SIM with Average Current



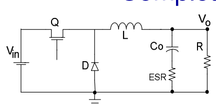


Auxiliary Circuit to Create IL

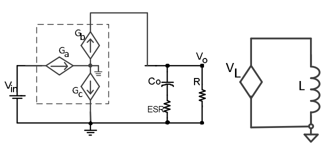


$$\overline{V_L} = \frac{V(a,b)T_{on} + V(a,c)T_{off}}{T_S}$$

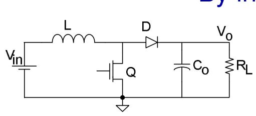
Complete Average Model



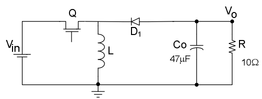
Formal method



Complete Average Model
By inspection



Complete Average Model
By inspection



In the Simulator Environment
Coding variables into voltages