EE-463 STATIC POWER CONVERSION-I

An Introduction to DC/DC Converters

Ozan Keysan

keysan.me

Office: C-113 • Tel: 210 7586

DC/DC Converters

DC/DC Converters

Can be used to:

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Can be used to:

Step down the input voltage

DC/DC Converters

Can be used to:

Step down the input voltage

Step up the input voltage

DC/DC Converters

Can be used to:

Step down the input voltage

Step up the input voltage

or Both

DC/DC Converter Applications

DC/DC Converter Applications

All Types of Power Supplies

DC/DC Converter Applications

DC/DC Converter Applications

Renewables: PV

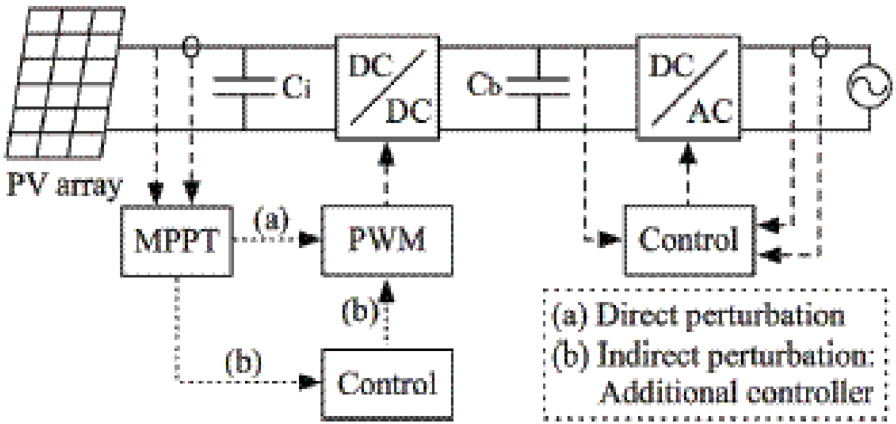
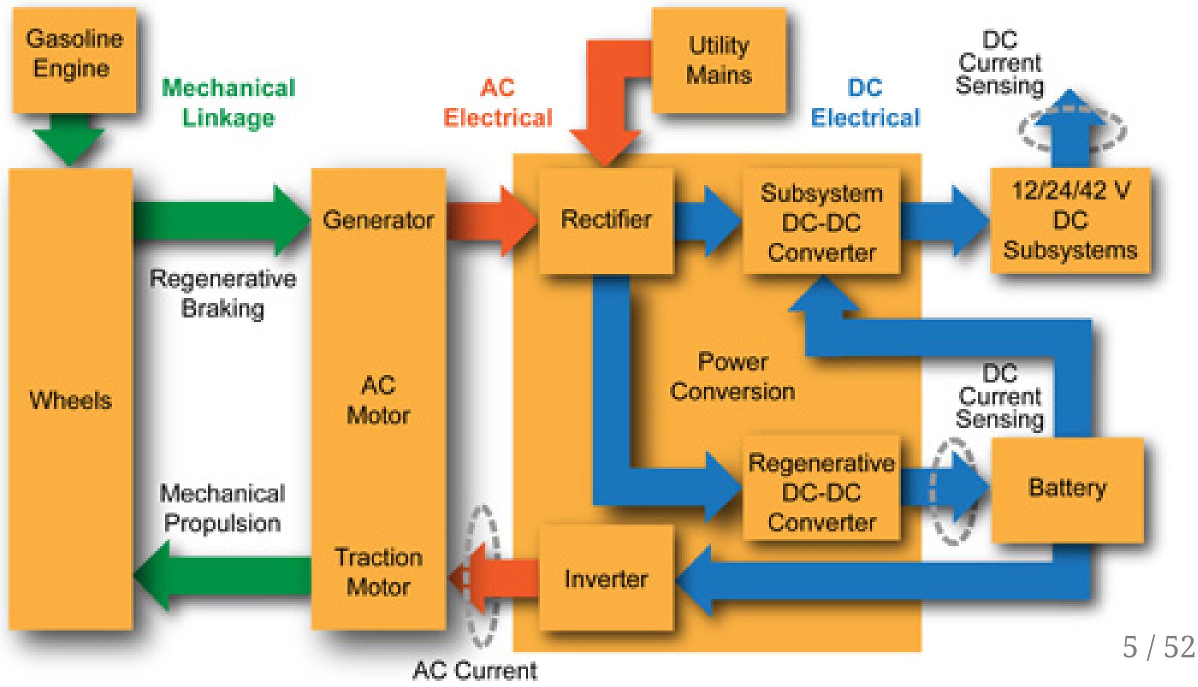


Figure 1 Double stage PV grid-connected system

DC/DC Converter Applications

Electric Cars/Traction

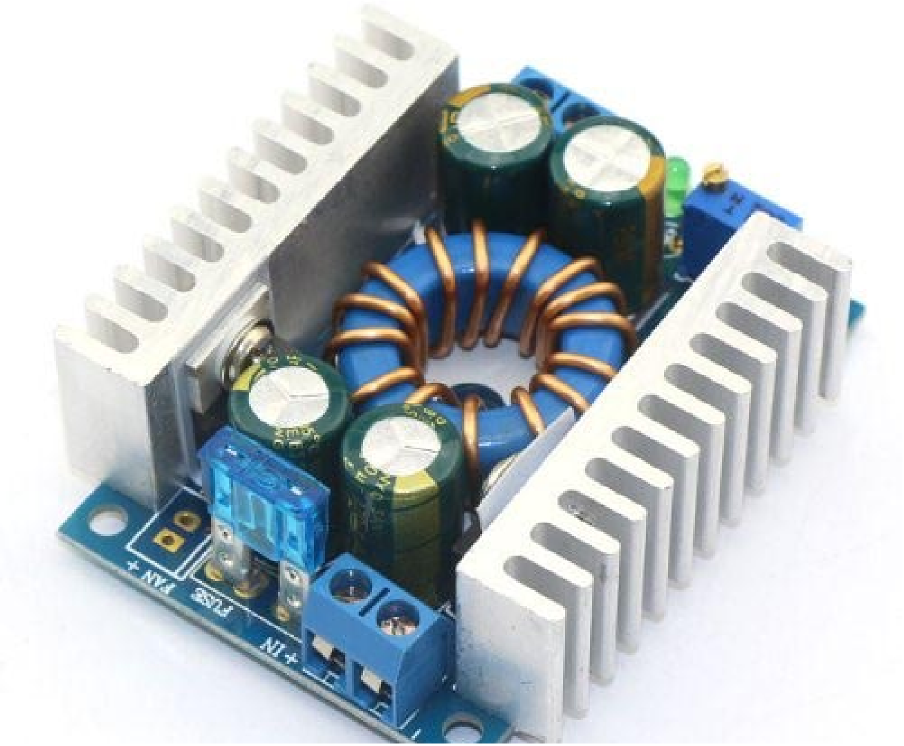


DC/DC Converter Applications

Electric Cars/Traction

[200 kW SiC DC/DC Converter]

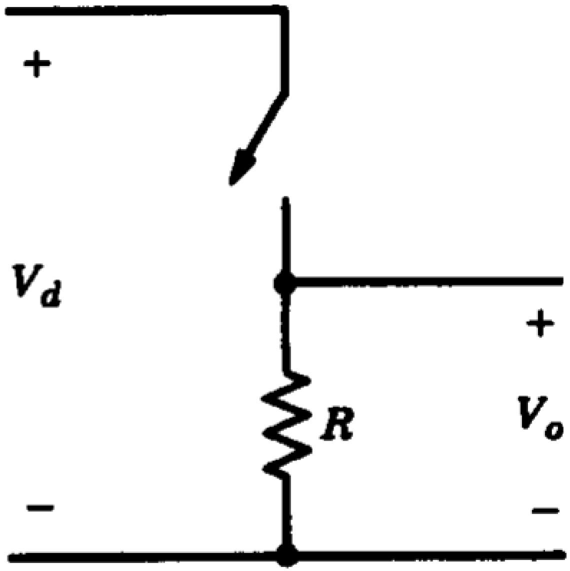
Which components do you see?



Which components do you see?

Step-Down (Buck) Converter:

Simplest Case



Step-Down (Buck) Converter:

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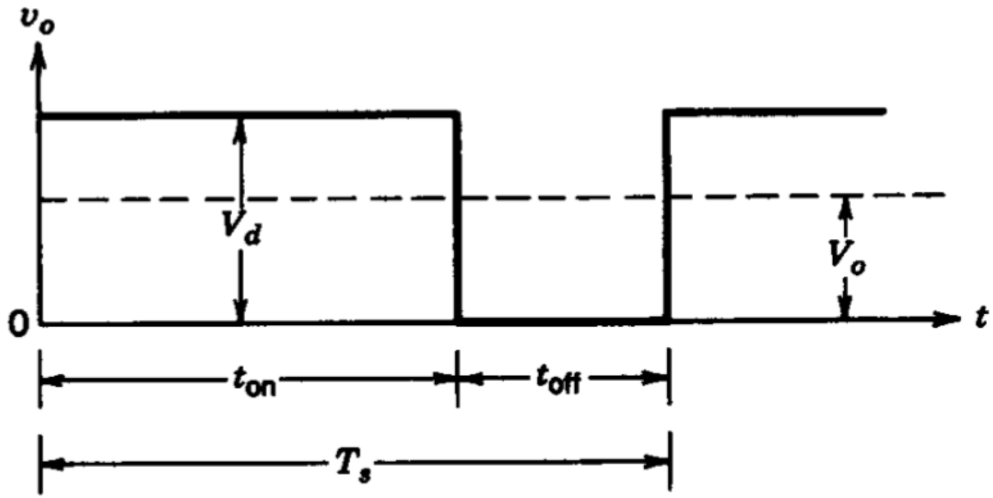
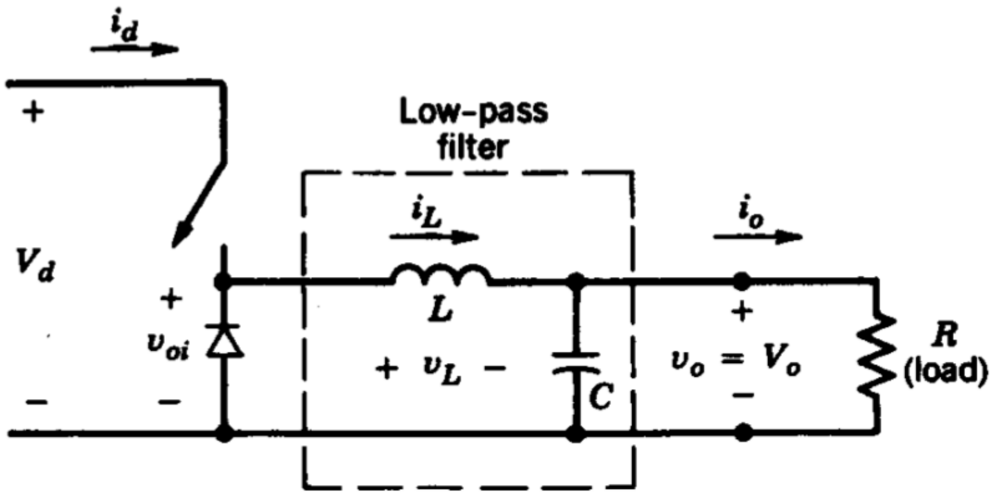


Let's make the output voltage smoother

Let's make the output voltage smoother

Add a Low Pass Filter (eg LC Filter)

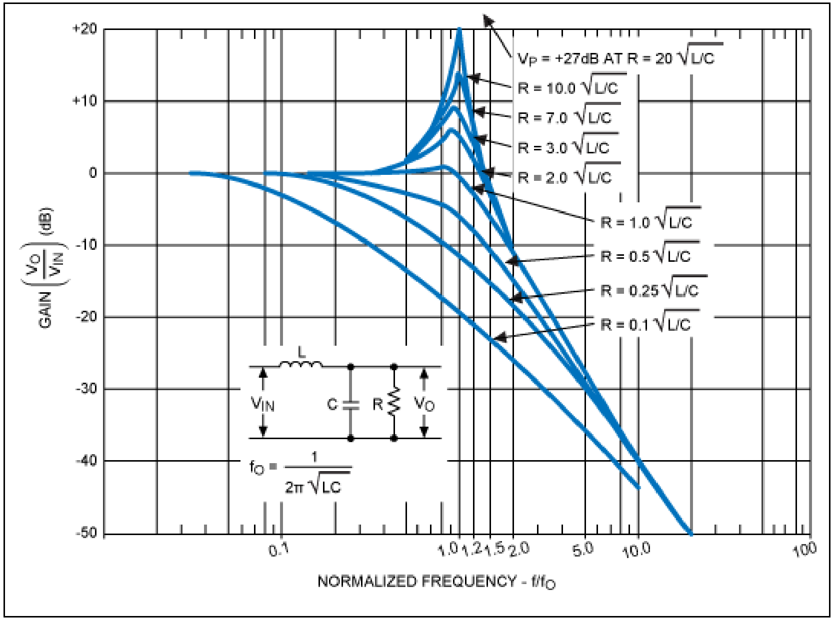


[Buck Converter Simulation]

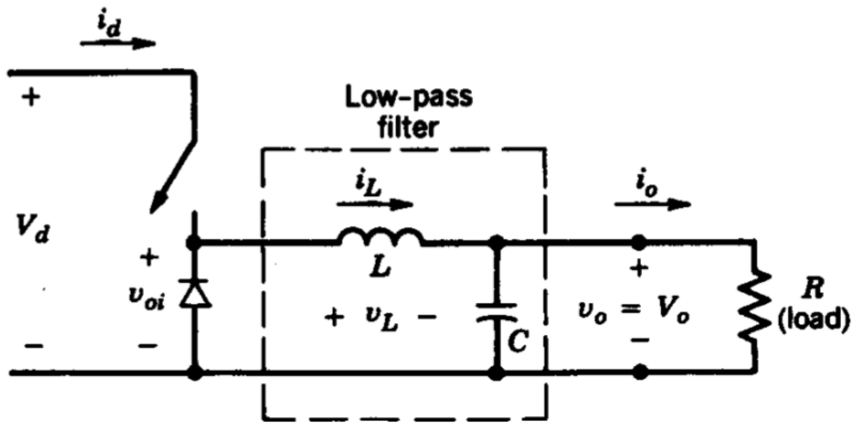
Let's make the output voltage smoother

Let's make the output voltage smoother

LC Filter Characteristics (More in the following weeks)



Why do we have the diode for?



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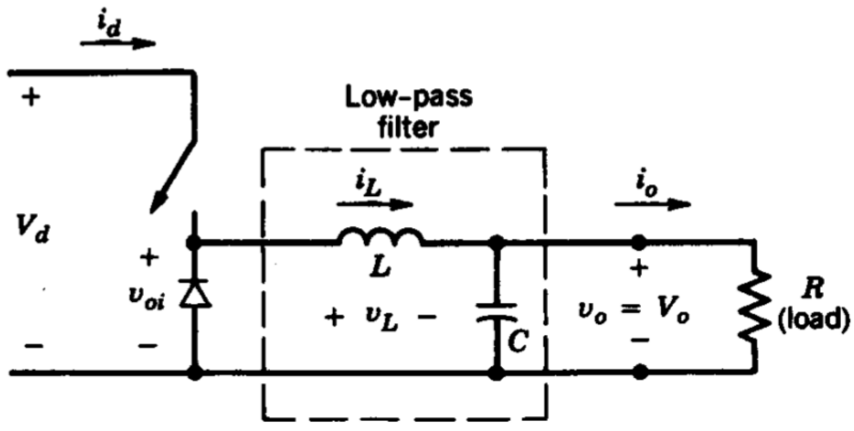
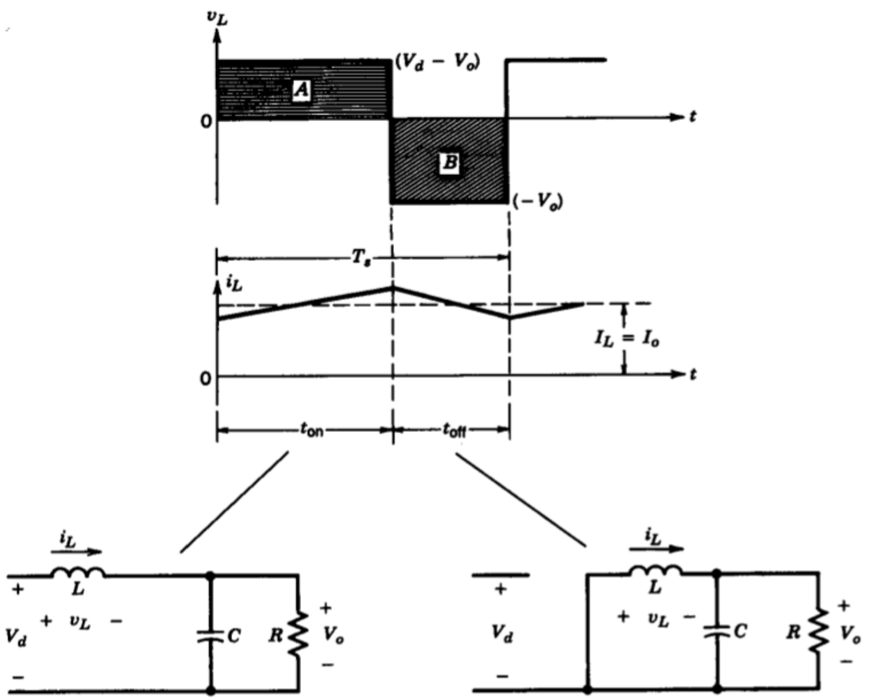


Freewheeling Diode: Conducts when switch is off

Operating Modes (in CCM)



CCM: Continuous Conduction Mode

Step-Down (Buck) Converter:

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$$V_o = DV_d$$

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$$V_o = DV_d$$

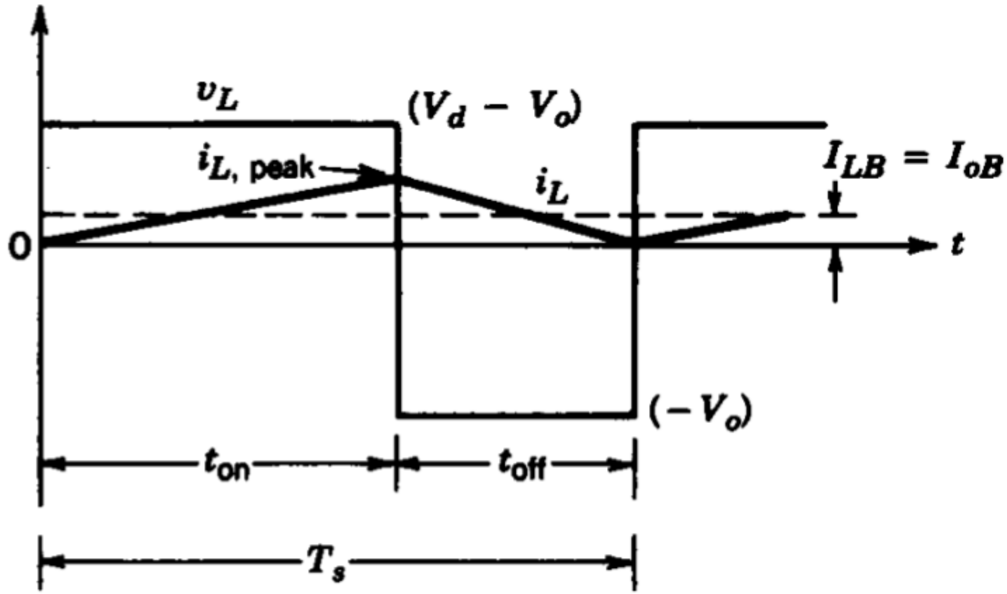
Neglecting losses

$$I_o = I_d / D$$

Like a DC transformer with a turns ratio of $D : 1$!

Transition to DCM

Transition to DCM



Transition to DCM

Boundary Current between CCM and DCM

Transition to DCM

Boundary Current between CCM and DCM

$$I_{LB} = \frac{DT_s}{2L}(V_d - V_o)$$

Transition to DCM

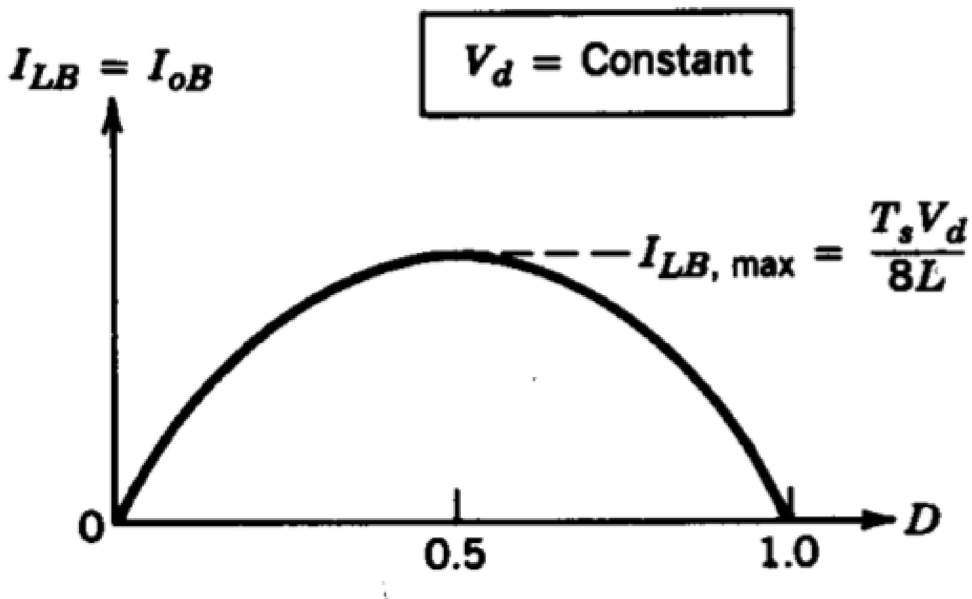
Boundary Current between CCM and DCM

$$I_{LB} = \frac{DT_s}{2L}(V_d - V_o)$$

when D=0.5

$$I_{LB_{max}} = \frac{T_s V_d}{8L}$$

Transition to DCM



Transition to DCM

Minimum Inductance for Continuous Current

$$L_{min} = \frac{(1-D)}{2f_s}R$$

Transition to DCM

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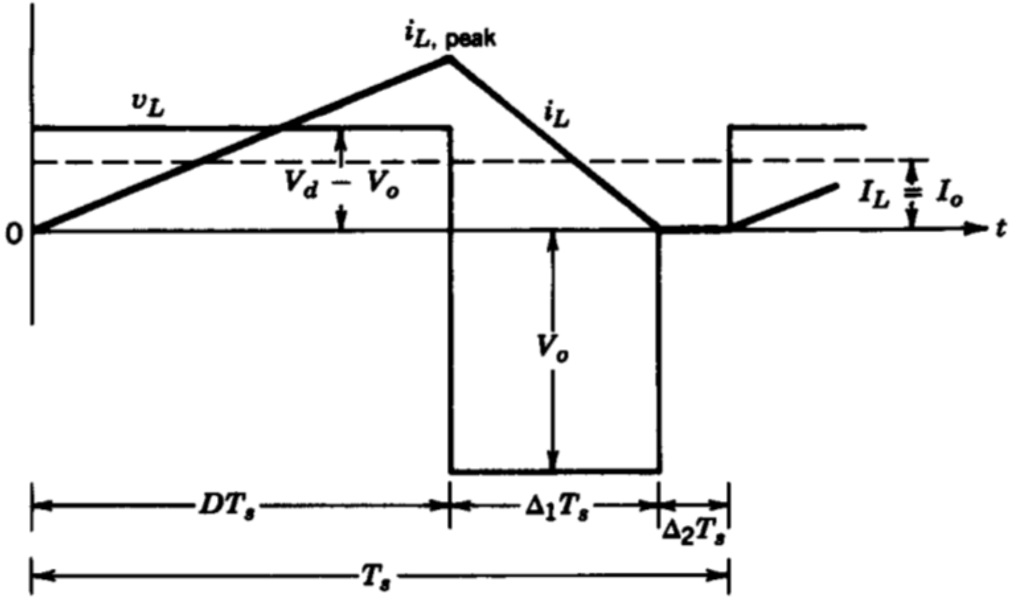
Current Ripple for a given inductance

$$\Delta i_L = (\frac{V_s - V_o}{L})DT = \frac{V_o(1-D)}{Lf_s}$$

Discontinuous Conduction Mode

Discontinuous Conduction Mode



Details and derivations are in the textbook.

Discontinuous Conduction Mode

Output voltage is increases in DCM if Vd and D is kept constant

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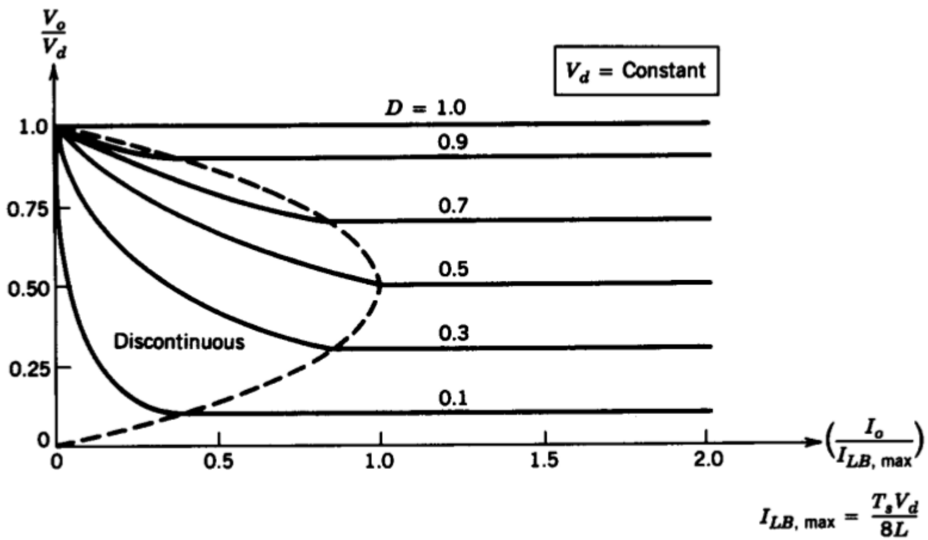

Critical current is max, when D=0.5

Discontinuous Conduction Mode

or duty cycle needs to be reduced to keep Vo constant

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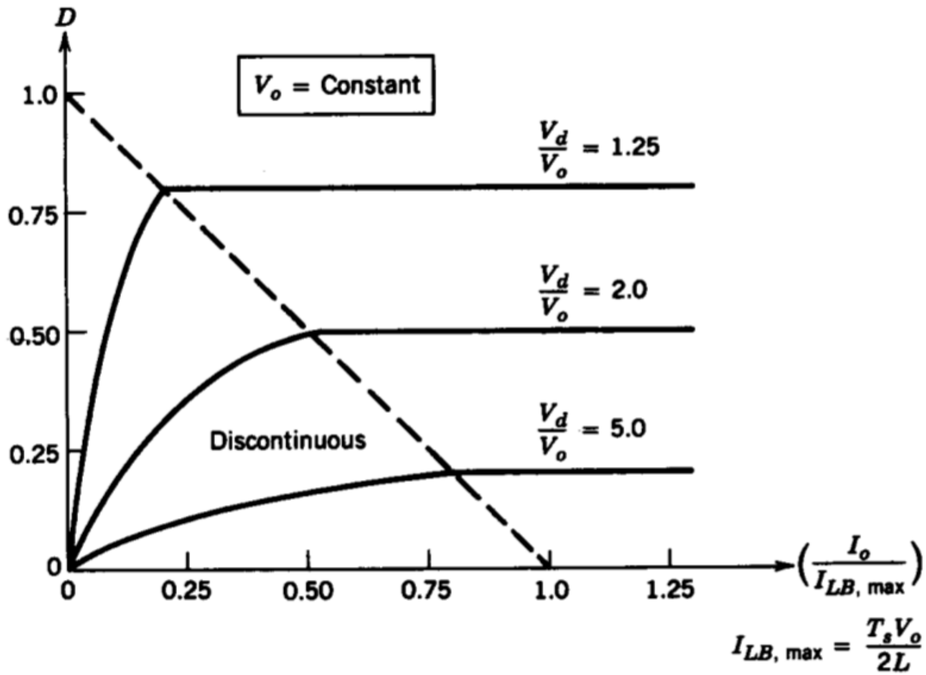
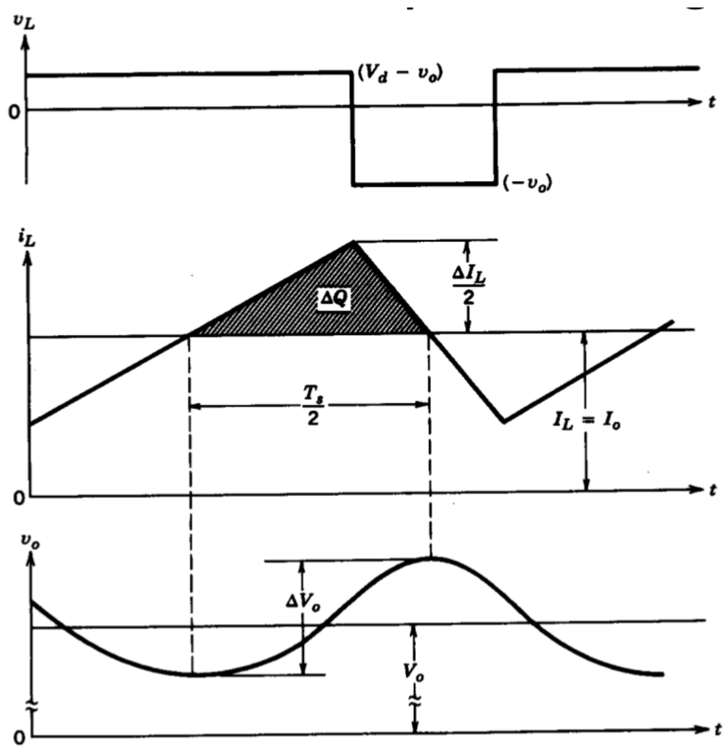


Voltage Ripple

Voltage Ripple



Voltage Ripple

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$$\Delta V_o = \frac{\Delta i_L T_s}{8C}$$

$$\frac{\Delta V_o}{V_0} = \frac{(1-D)T_s^2}{8LC}$$

Can you put it in a much nicer form?

Voltage Ripple

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Voltage Ripple

$$\frac{\Delta V_o}{V_0} = \frac{(1-D)T_s^2}{8LC}$$

$$\frac{\Delta V_o}{V_0} = \frac{\pi^2(1-D)}{2}\left(\frac{f_c}{f_s}\right)^2$$

Effect of Capacitor ESR

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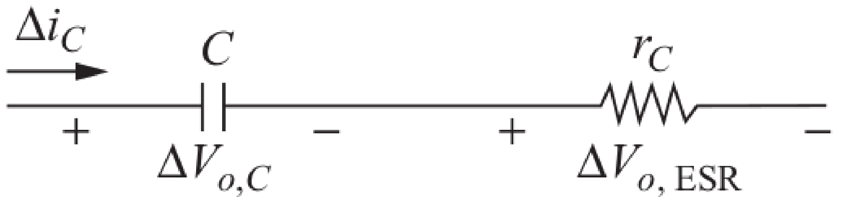
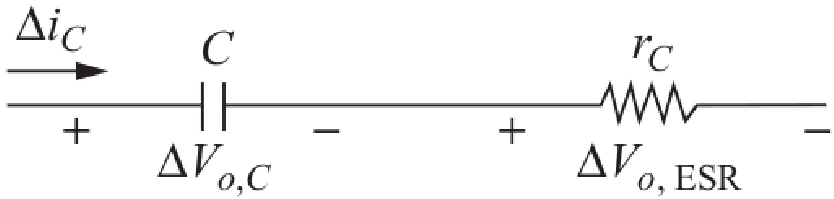


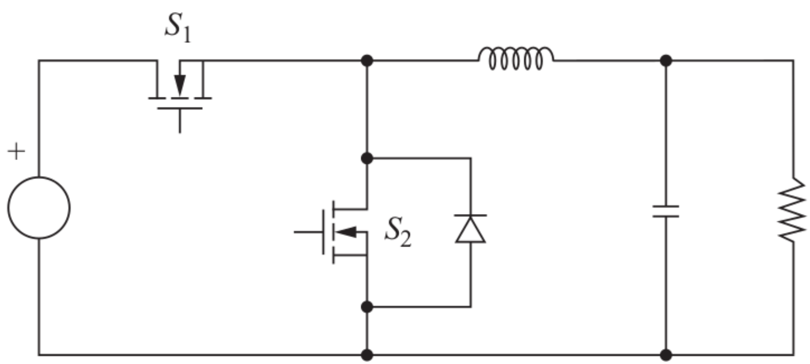
Effect of Capacitor ESR



$$\Delta V_{o,ESR} = \Delta i_c r_c = \Delta i_L r_c$$

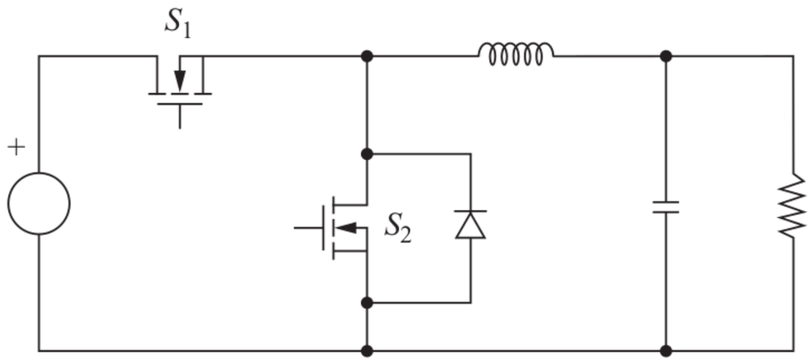
Synchronous Buck Converter

Synchronous Buck Converter



What is the purpose of the extra MOSFET?

Synchronous Buck Converter



What is the purpose of the extra MOSFET?

Increased efficiency due to reduced diode loss.

(R_{ds-on} instead of $V_{forward}$)

Design Decisions

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Small Volume is desired:

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- Increase f_s, LC filter gets smaller.
- Switching loss is increased (also increases heatsink volume)

Design Decisions

High Efficiency is desired:

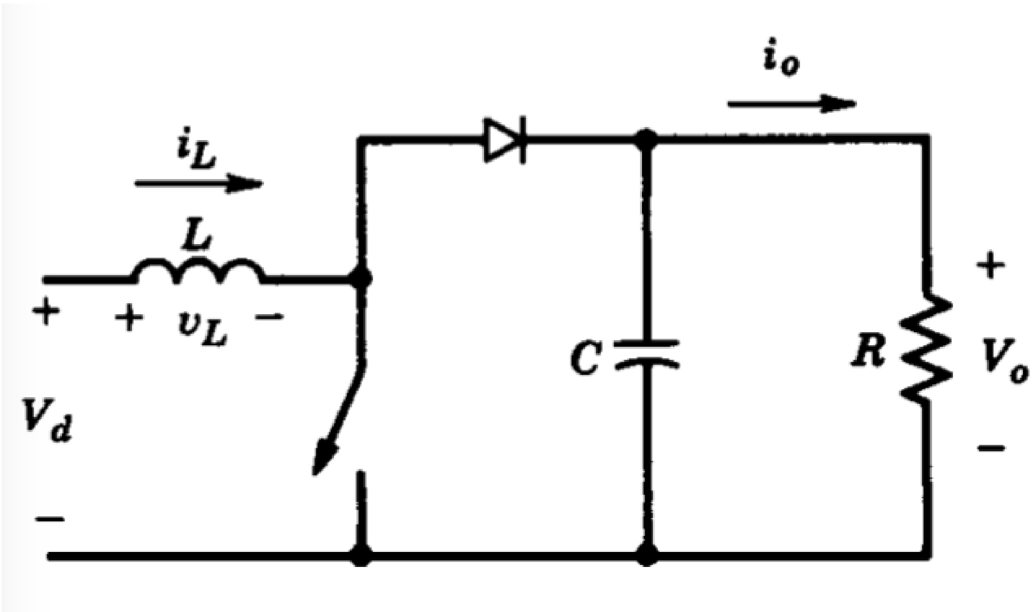
Design Decisions

High Efficiency is desired:

- Limit f_s, switching loss is reduced.
- LC filter gets bigger
- Use Synchronous Buck (Can achieve higher f_s for same efficiency)
- Cost of the converter is increased

Step-Up (Boost) Converter

Step-Up (Boost) Converter



Step-Up (Boost) Converter

Can you plot the on & off states?

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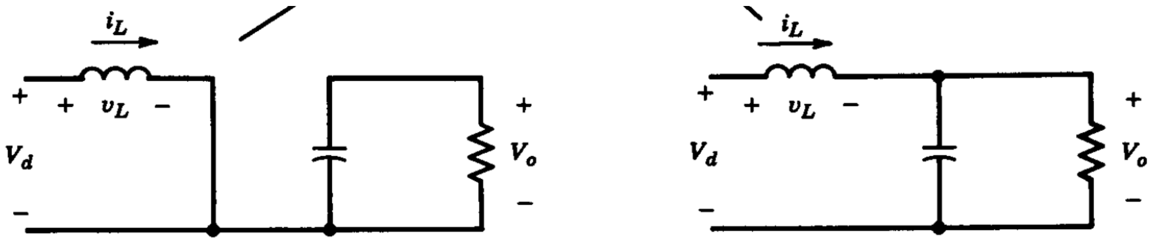
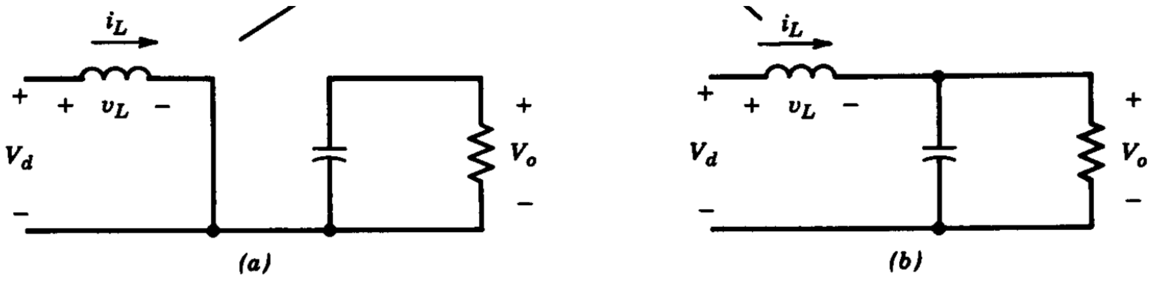


(a) (b)

Step-Up (Boost) Converter

Can you plot the on & off states?



Mechanical Analogy: Ram Pump

[How the ram pump works?](), [How to make a ram pump](), [Largest ram pump]()

Step-Up (Boost) Converter

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Can you plot the voltage & current waveforms?

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Can you find the relation between V_o and V_d?

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Plexim Simulation

Step-Up (Boost) Converter

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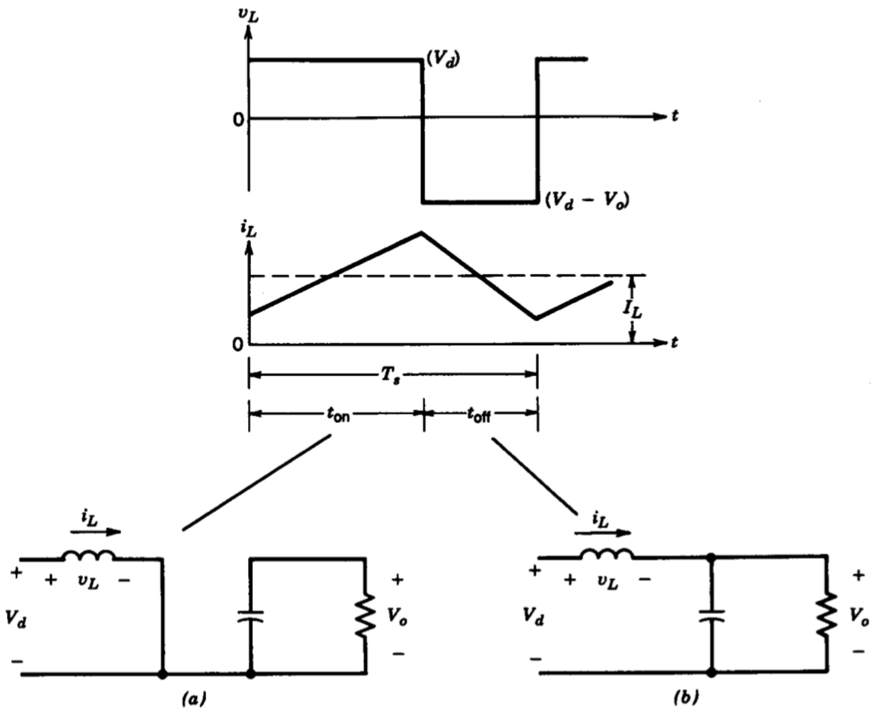

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$$V_d t_{on} + (V_d - V_o) t_{off} = 0$$

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$$\frac{V_o}{V_d} = \frac{T_s}{t_{off}} = \frac{1}{1-D}$$

Step-Up (Boost) Converter

$$V_d t_{on} + (V_d - V_o) t_{off} = 0$$

$$\frac{V_o}{V_d} = \frac{T_s}{t_{off}} = \frac{1}{1-D}$$

$$\frac{I_o}{I_d} = (1-D)$$

Transition to DCM

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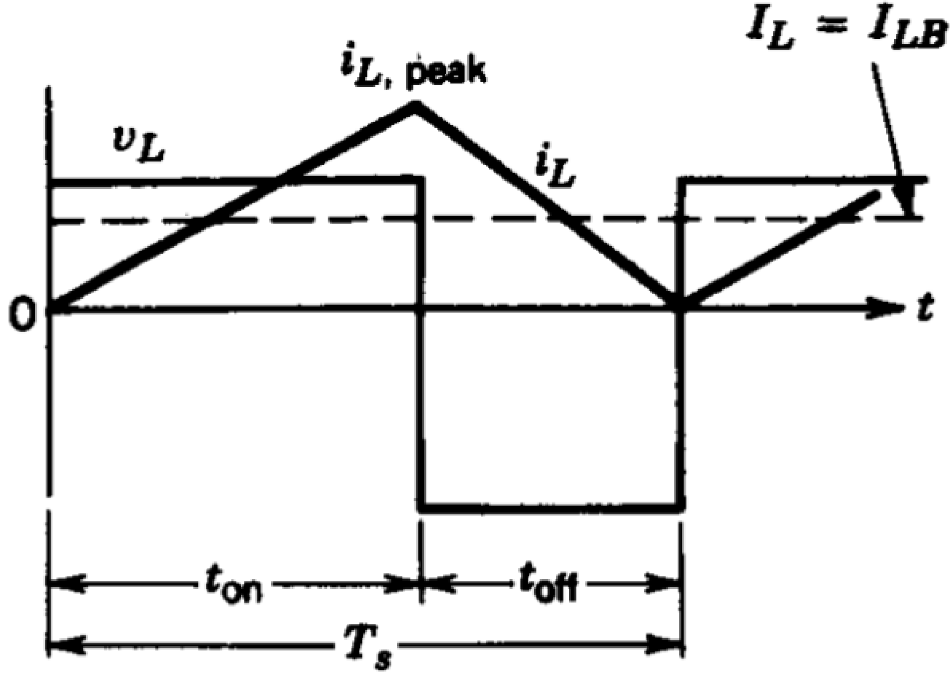

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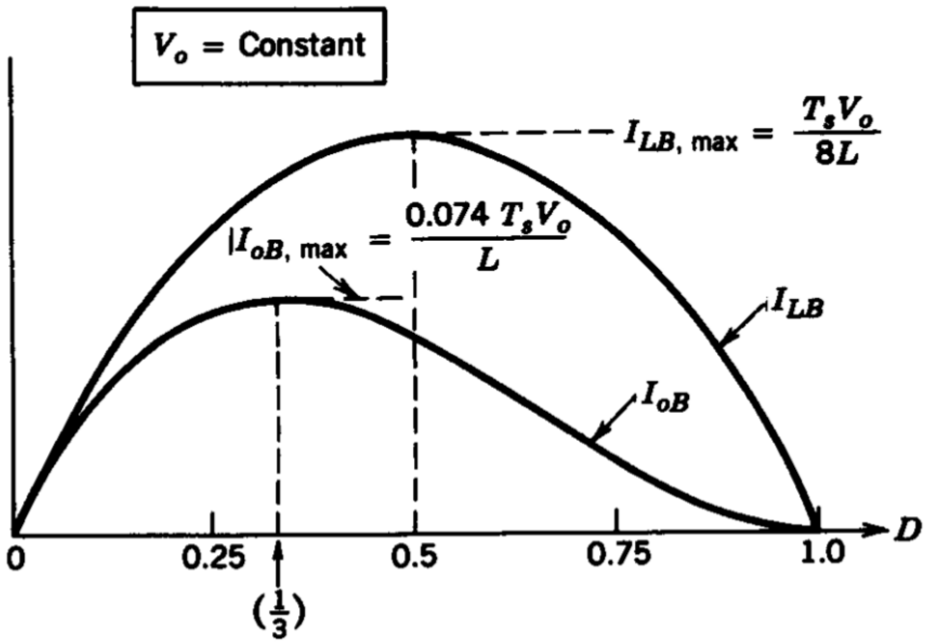
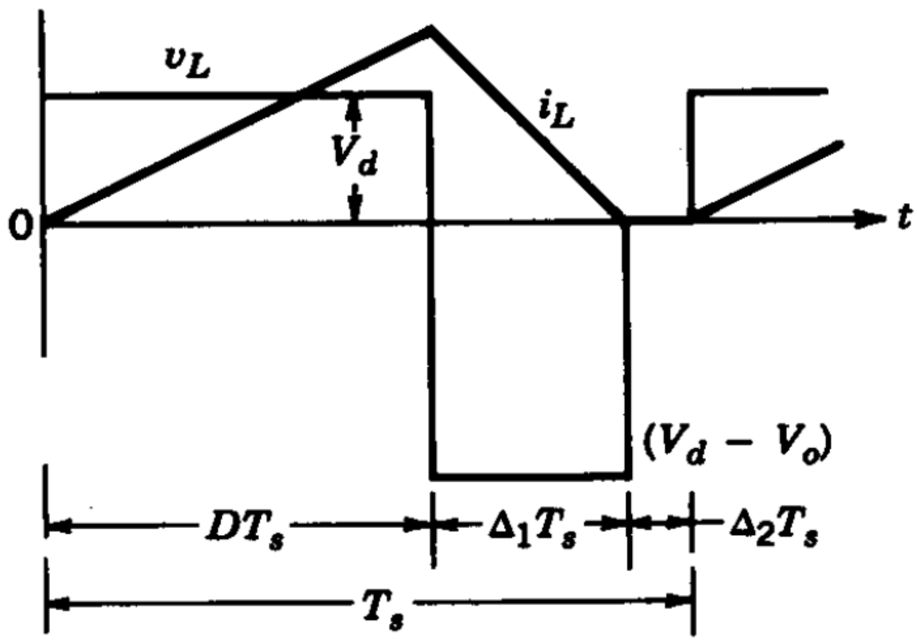


DCM

DCM

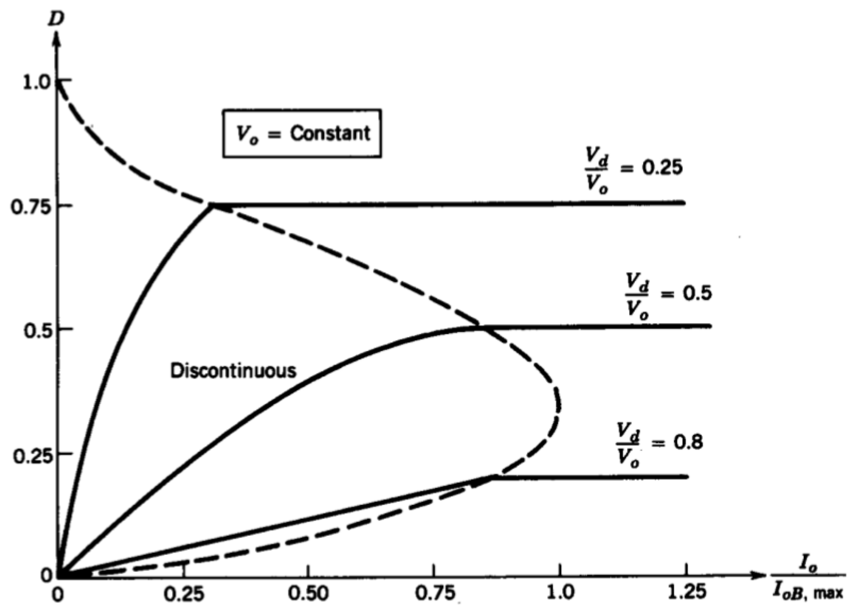
Occurs at light loads



DCM

DCM

In order to keep Vo constant



$I_{oB,\,max} = 0.074\,\frac{T_s V_o}{L}$

Ideal vs. Reality

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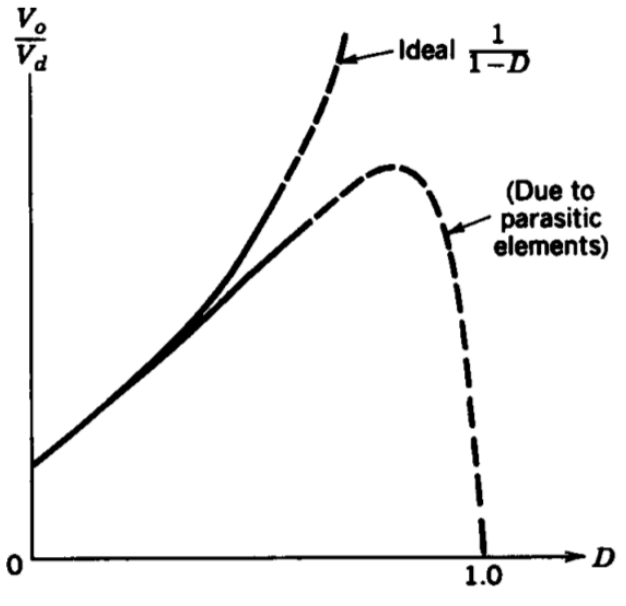
What is Vo as D goes to 1?

Ideal vs. Reality

What is Vo as D goes to 1?



Output Ripple

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Can you derive the operating modes?

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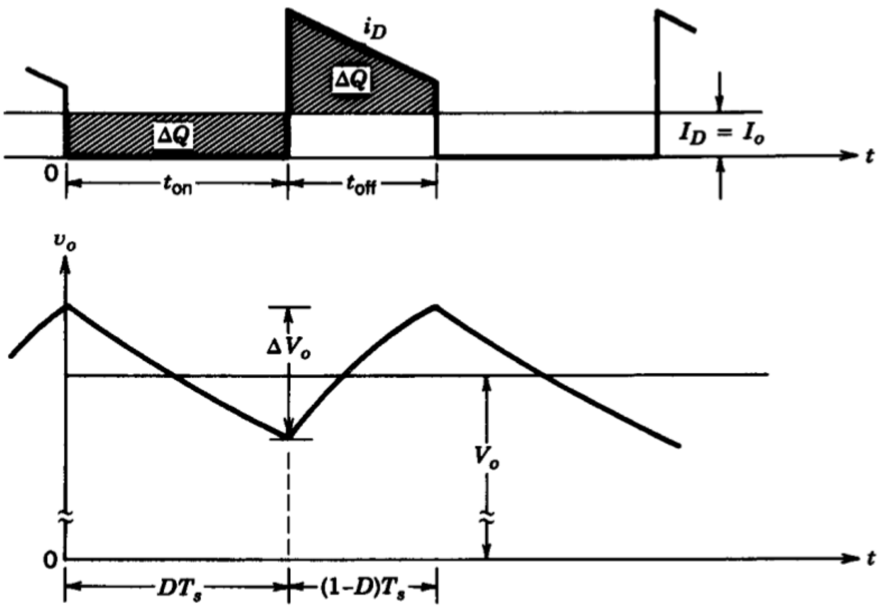

Can you obtain the operating modes of this converter?

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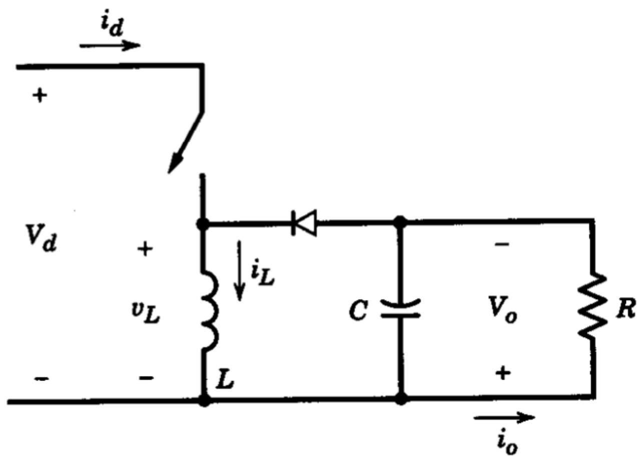

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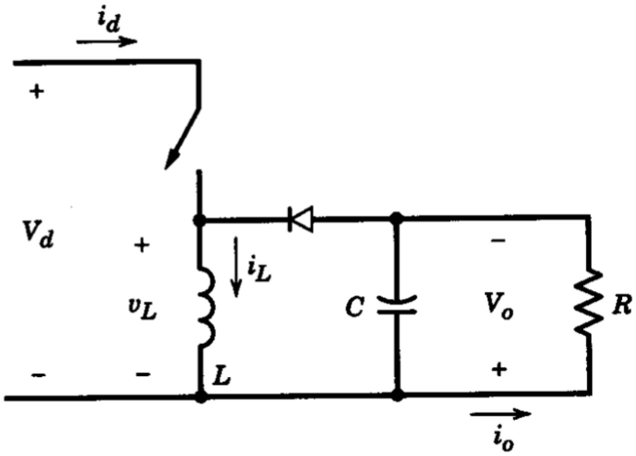


Buck-Boost Converter

[Plexim Simulation]

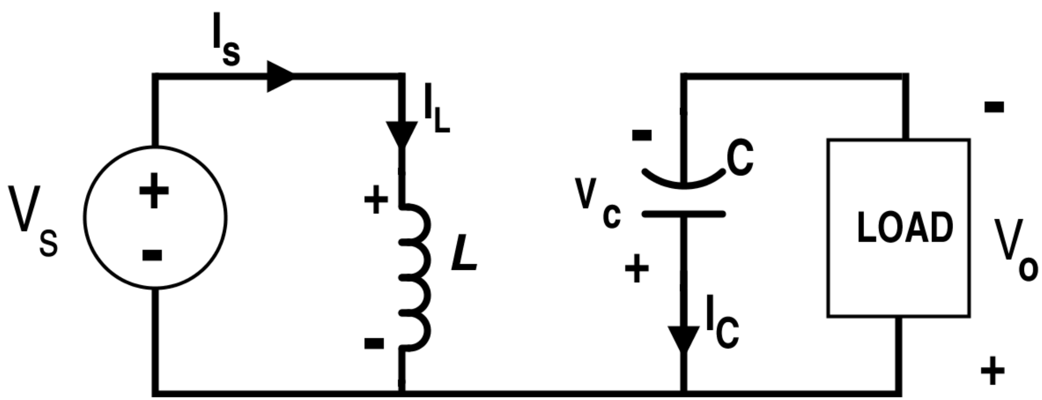
Buck-Boost Converter

Operating Modes

Buck-Boost Converter

Operating Modes

Switch is ON (Inductor Charges)



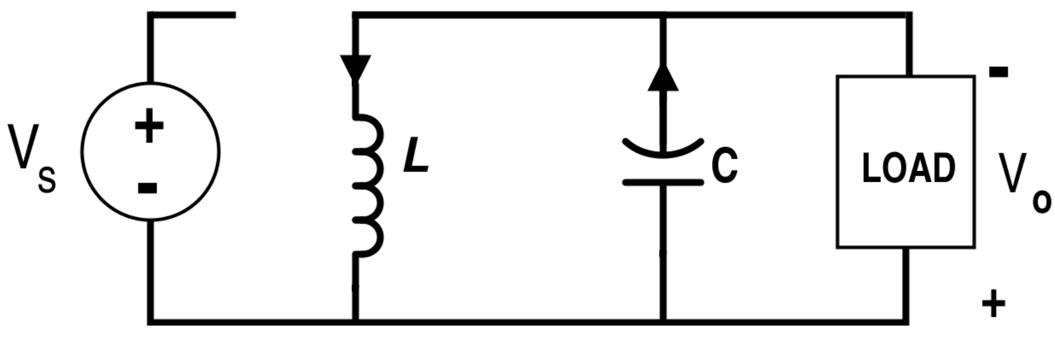
Buck-Boost Converter

Operating Modes

Buck-Boost Converter

Operating Modes

Switch is OFF (Inductor Discharges)



Buck-Boost Converter

Output Voltage

Buck-Boost Converter

Output Voltage

$$V_o = \frac{D}{(1-D)} V_d$$

Notice the reverse polarity of Vo in the circuit

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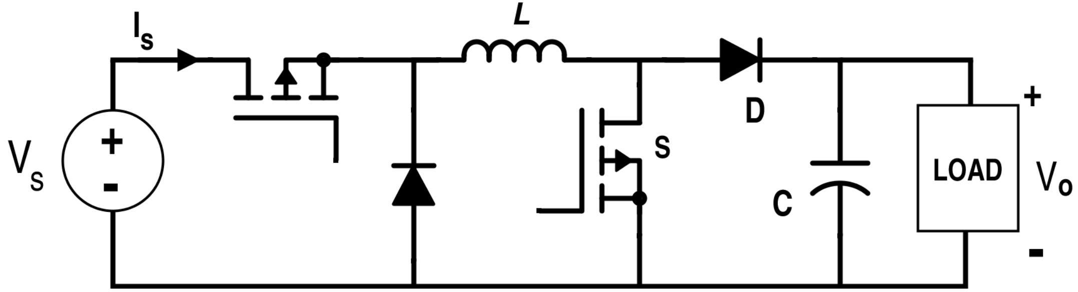
Notice the reverse polarity of Vo in the circuit

Practical Design Exercise

Non-Inverting Buck-Boost Converter

Non-Inverting Buck-Boost Converter

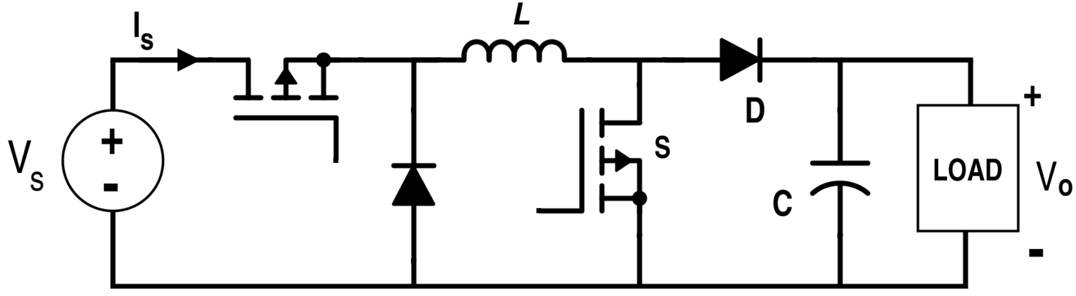


Uses two synchronized switches

Both switches turn on and off simultaneously

[Design tips for an efficient non-inverting buck-boost convertee]

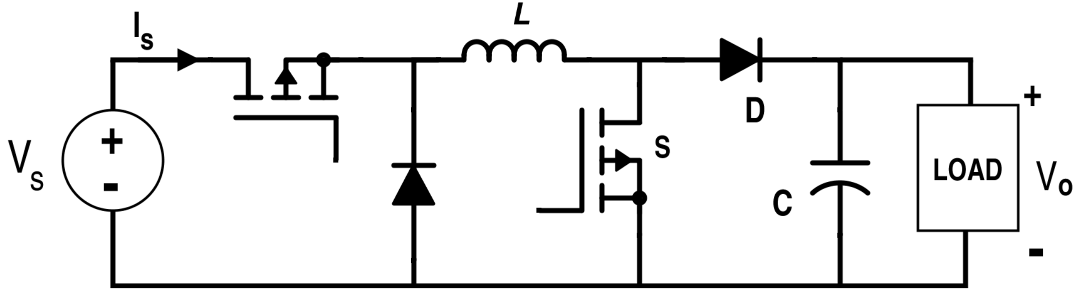
Non-Inverting Buck-Boost Converter



It is also possible to use as a buck converter

Q2 always off, Q1 is controlled

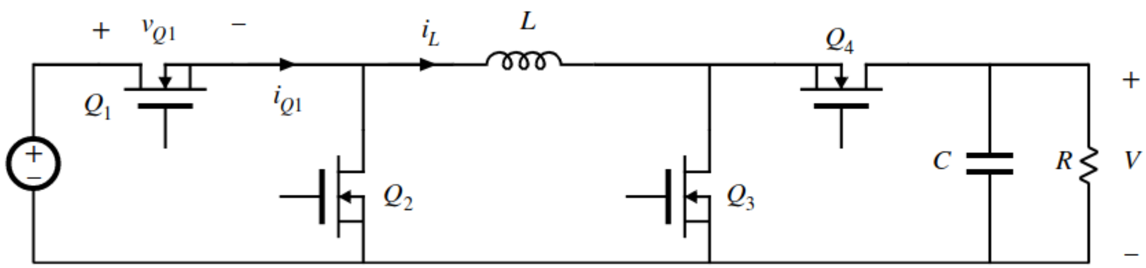
Non-Inverting Buck-Boost Converter



It is also possible to use as a boost converter

Q1 always on, Q2 is controlled

Generalized Version: 4-switch buck-boost



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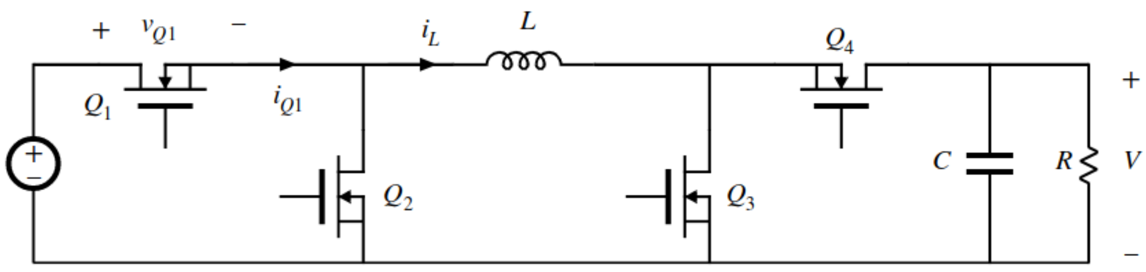
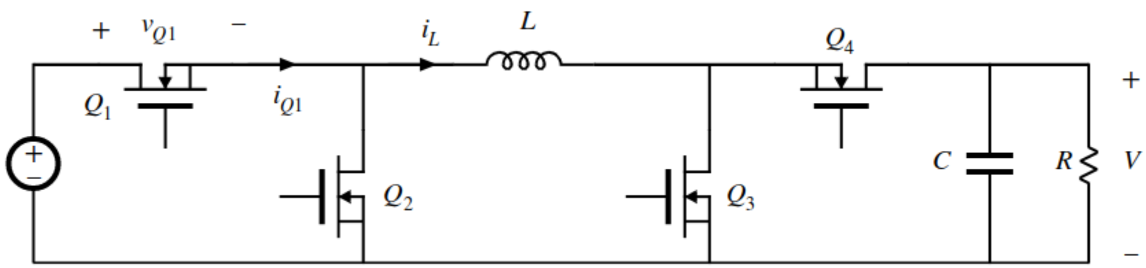


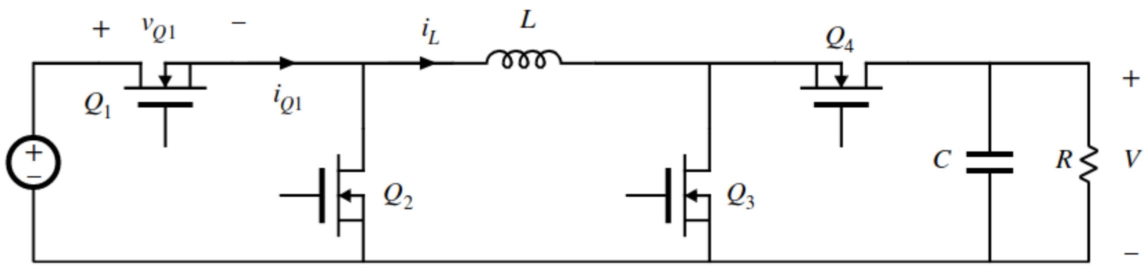
- Buck Mode: Q1, Q2 are controlled, Q3 is OFF, Q4 is ON

Generalized Version: 4-switch buck-boost



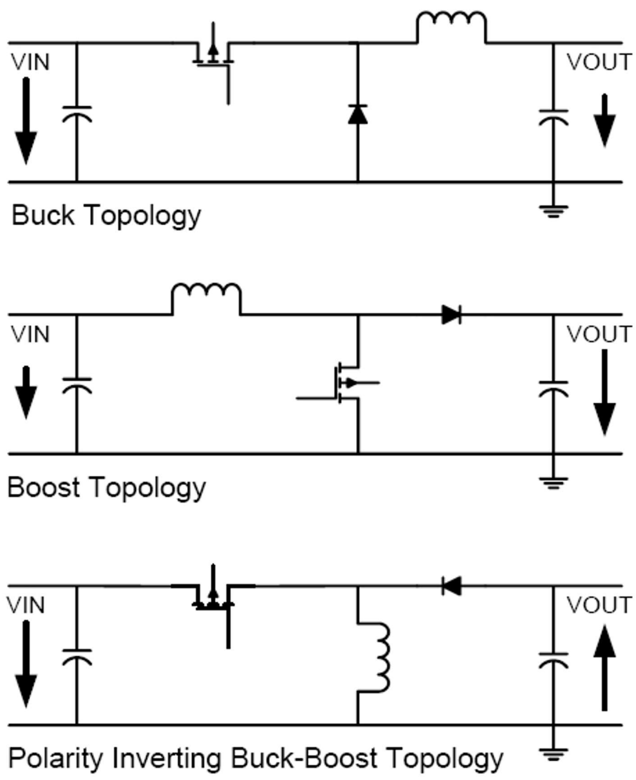
- Buck Mode: Q1, Q2 are controlled, Q3 is OFF, Q4 is ON
- Boost Mode: Q3,Q4 are controlled, Q1 is ON, Q2 is OFF

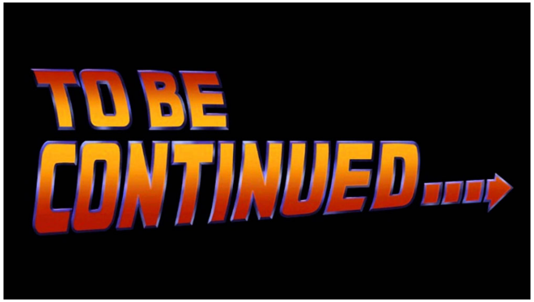
Generalized Version: 4-switch buck-boost



- Buck Mode: Q1, Q2 are controlled, Q3 is OFF, Q4 is ON
- Boost Mode: Q3,Q4 are controlled, Q1 is ON, Q2 is OFF
- Buck-Boost Mode: Q1 & Q3 are simultaneously ON, when Q2 & Q4 are simultaneously OFF, and vice versa.

Can you compare the input/output noise level?

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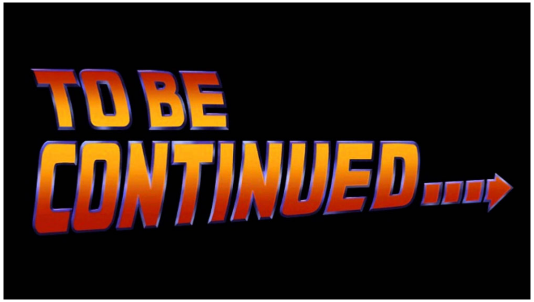
CONTINUED....



EE464

- Flyback Converter
- Ćuk Converter
- SEPIC Converter
- Resonant Converters

Exercises

You can download this presentation from:
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