EE-464 STATIC POWER CONVERSION-II

DC/DC Converters Continued

Ozan Keysan

keysan.me

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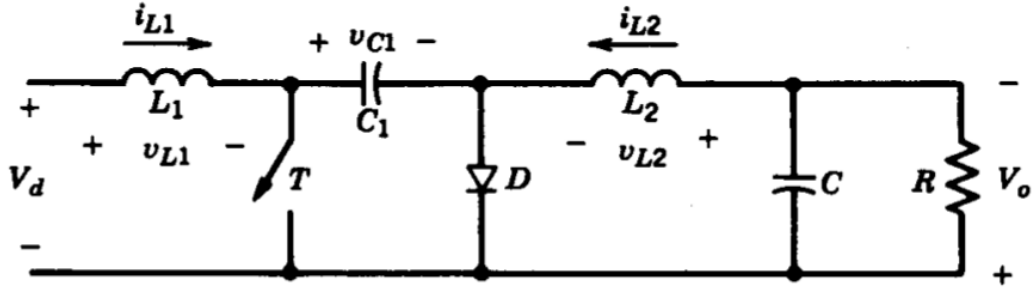
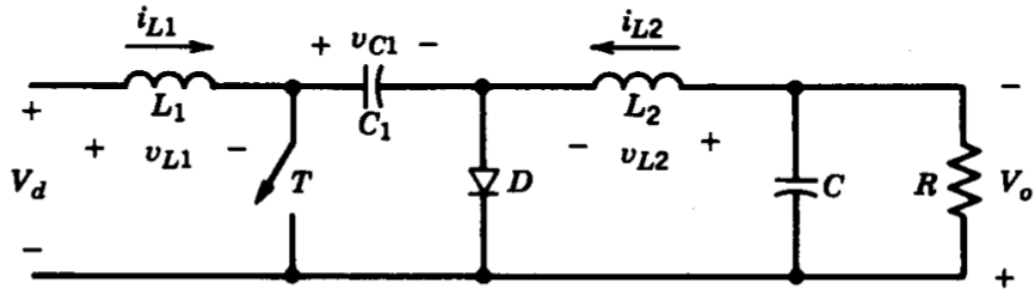
Slobodan Ćuk

Linked-in profile

Ćuk converter

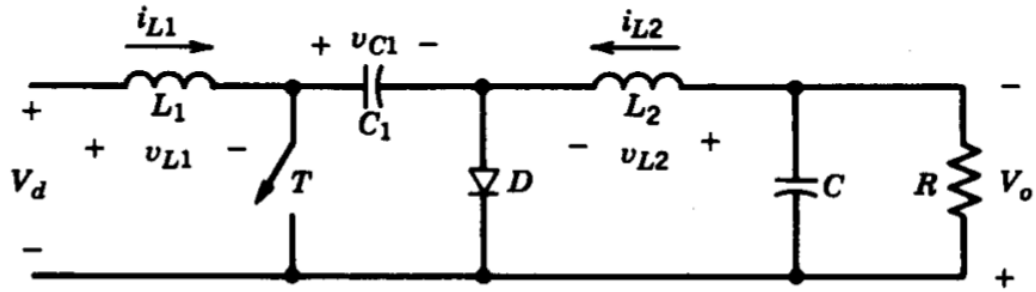


Ćuk converter



Supplies a negative voltage

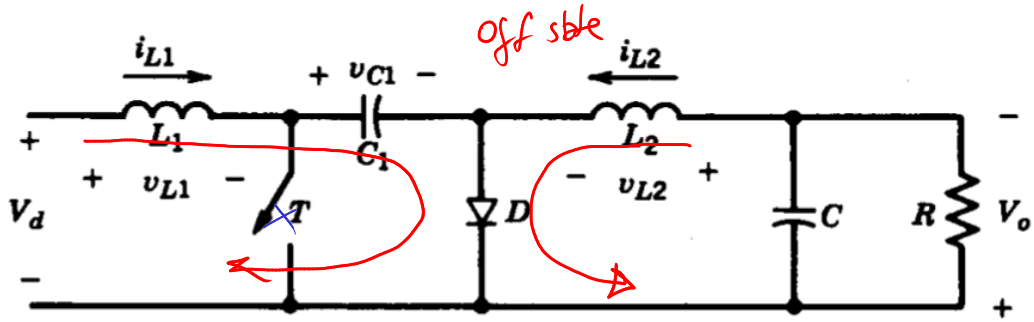
Ćuk converter



Supplies a negative voltage

Reduced EMI and bi-directional power flow

Ćuk converter

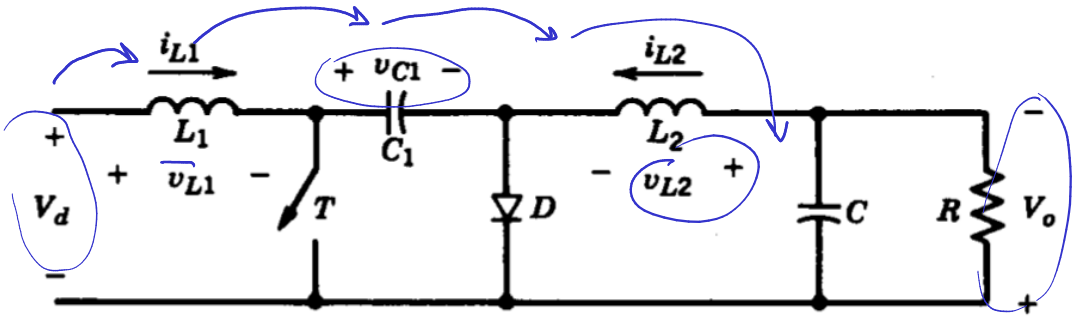


Supplies a negative voltage

Reduced EMI and bi-directional power flow

C1 is the primary energy storage element (should be large)

Ćuk converter



Can you plot the on & off states?

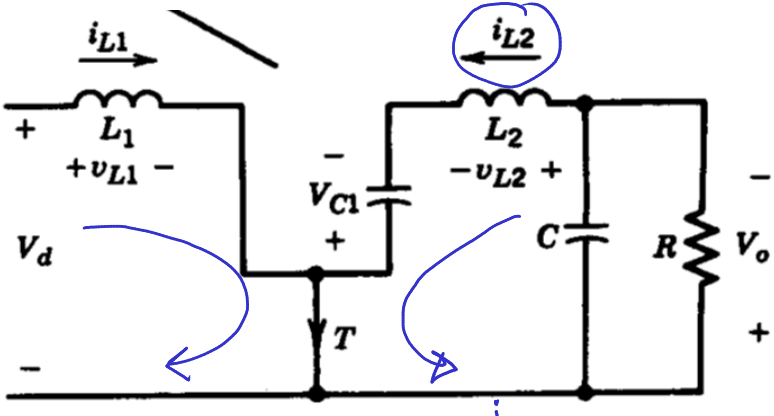
on average $\Rightarrow V_{L1}=0$, $V_{L2}=0$

$V_{C1} = V_d - (-V_o) \Rightarrow \boxed{V_{C1} = V_d + V_o}$

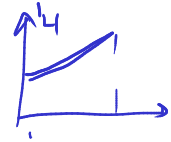
$V_{C1} > V_d$

$V_{C1} > V_o$

ON State

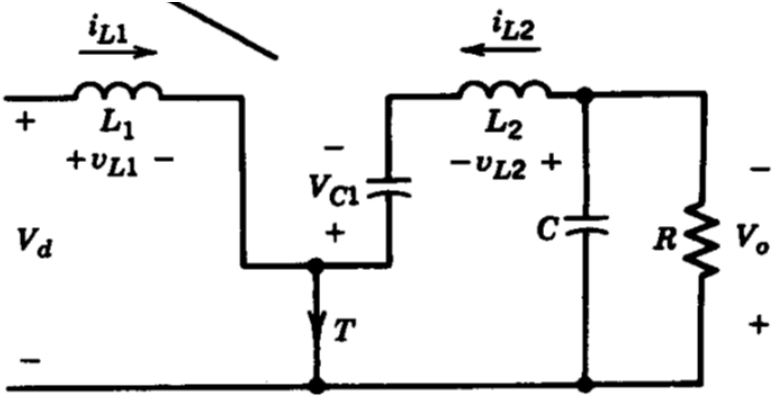


L_1 is charging with V_d



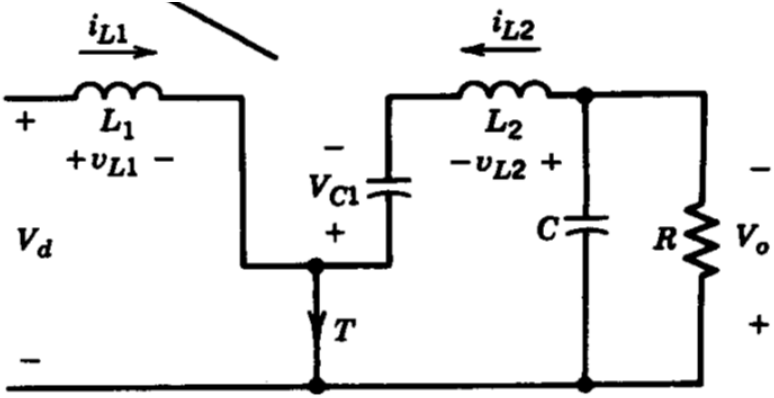
$L_2 \Rightarrow V_{C1}+V_o$

ON State



Diode off (reverse biased by C1)

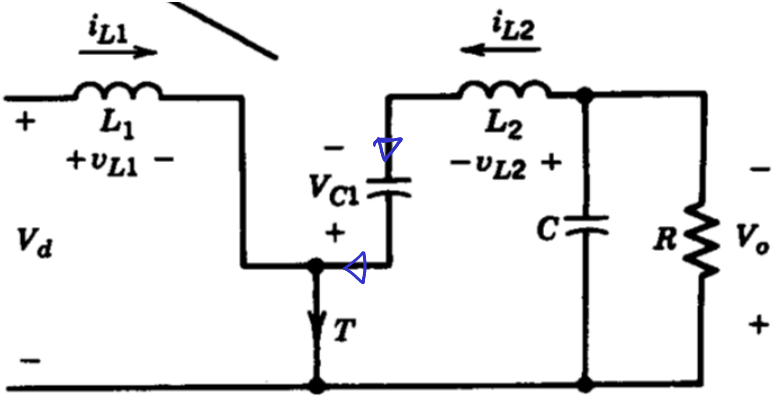
ON State



Diode off (reverse biased by C1)

i_{L1} and i_{L2} passes through T1

ON State

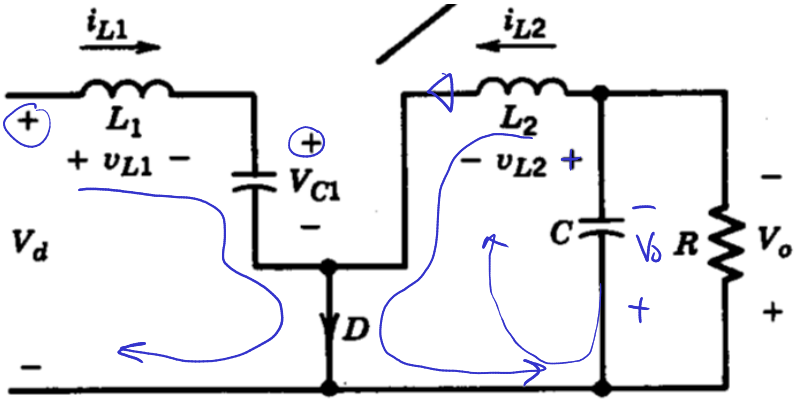


Diode off (reverse biased by C1)

i_{L1} and i_{L2} passes through T1

C1 discharges through T1 ($V_{C1} > V_o$)

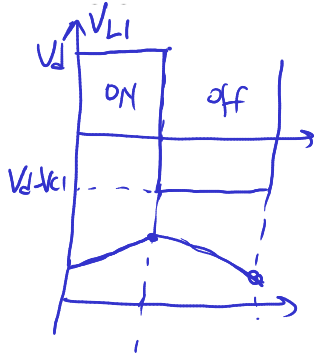
OFF State



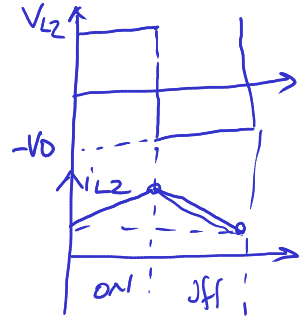
$V_{C1} > V_d$

$V_{L1} = V_d - V_{C1}$ (negative)

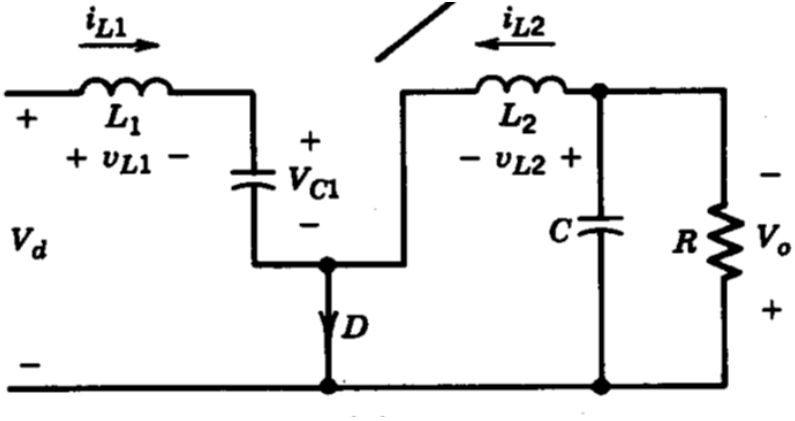
i_{L1} decreases



$V_{L2} = -V_0 \Rightarrow i_{L2}$ is decreasing

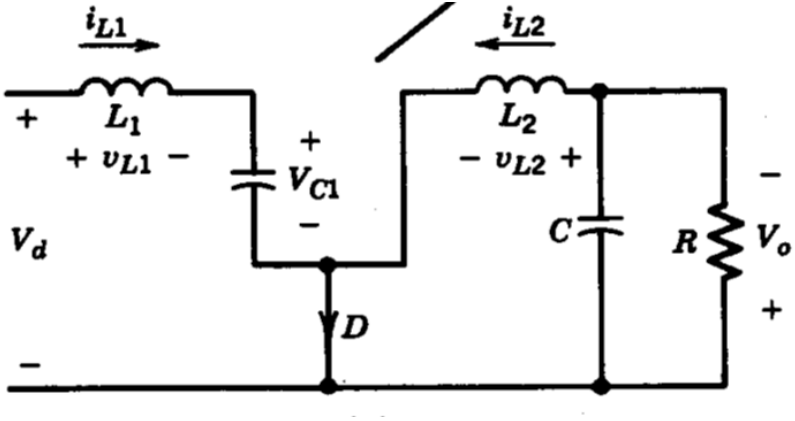


OFF State



Diode on

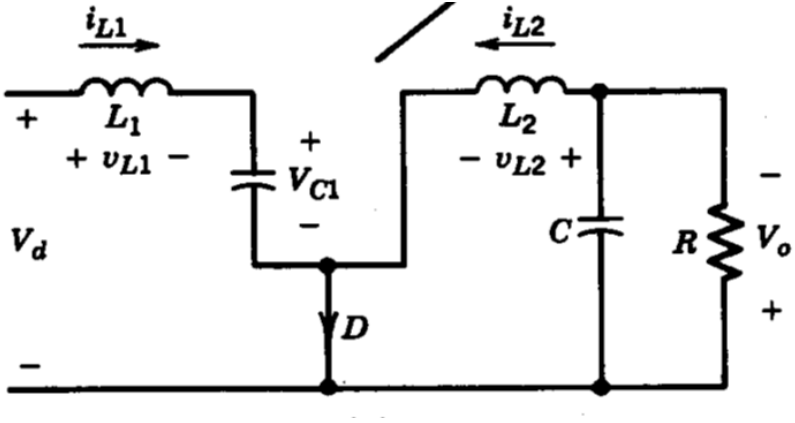
OFF State



Diode on

i_{L1} decreases $(V_{C1} > V_d)$

OFF State

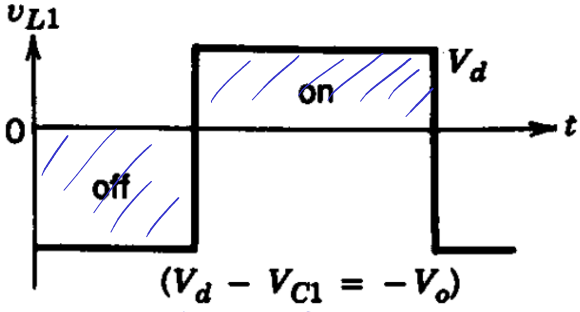


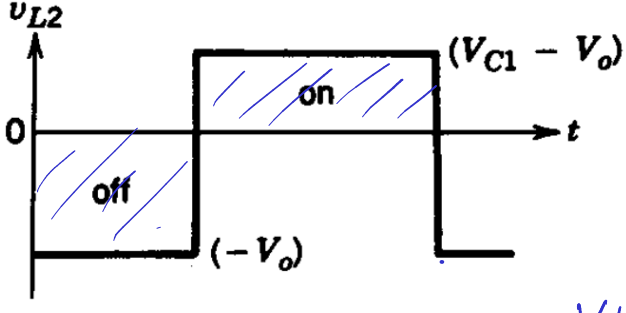
Diode on

i_{L1} decreases ($V_{C1} > V_d$)

C1 charges through D1 (from input and L1)

Operating States





$V_{C1} > V_o$

L_1

$V_d \cdot D \cdot T_s + (V_d - V_{C1}) \cdot (1-D) T_s = 0$

$V_d D T_s + V_d - V_{C1} - D V_d + D V_{C1} = 0$

$$V_{C1} = \frac{V_d}{1-D}$$

L_2 :

$(V_{C1} - V_o) \cdot D T_s + (-V_o) \cdot (1-D) T_s = 0$

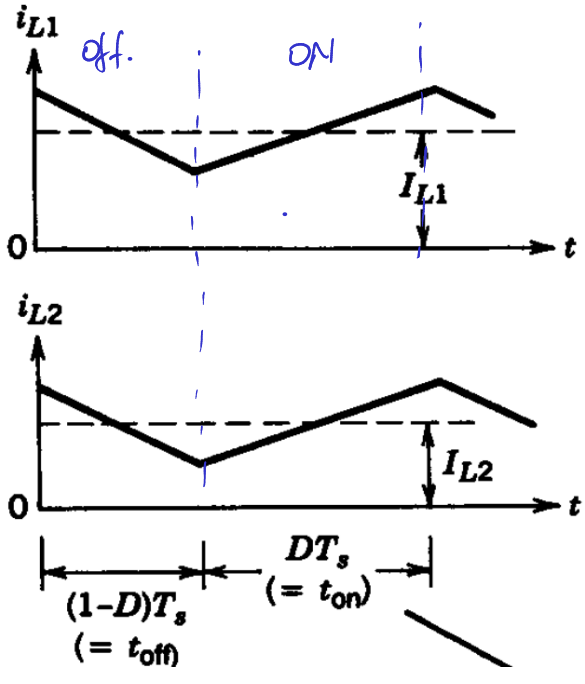
$V_{C1} \cdot D - V_o D - V_o + V_o D = 0$

$$V_{C1} = \frac{V_o}{D}$$

$$\frac{V_d}{1-D} = \frac{V_o}{D} \Rightarrow V_o = \left(\frac{D}{1-D}\right) \cdot V_d$$

Buck-boost converter

Operating States

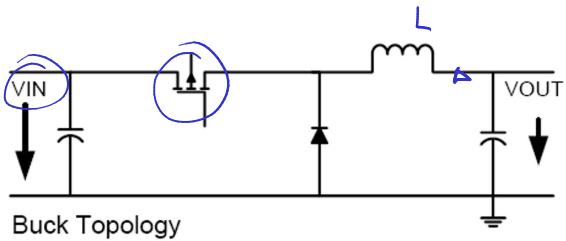


Ćuk converter

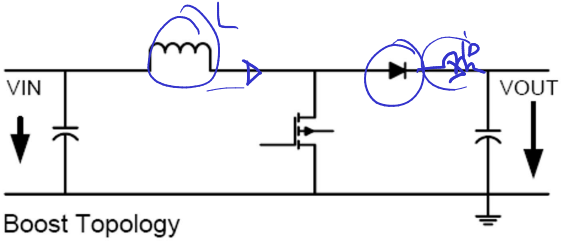
$$V_o = \frac{D}{(1-D)} V_d$$

It is a buck-boost converter!

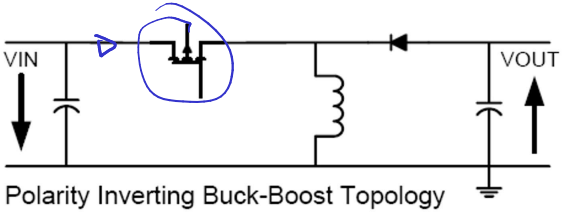
Input/Output Ripple?



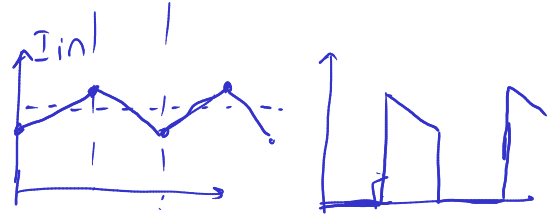
Buck Topology



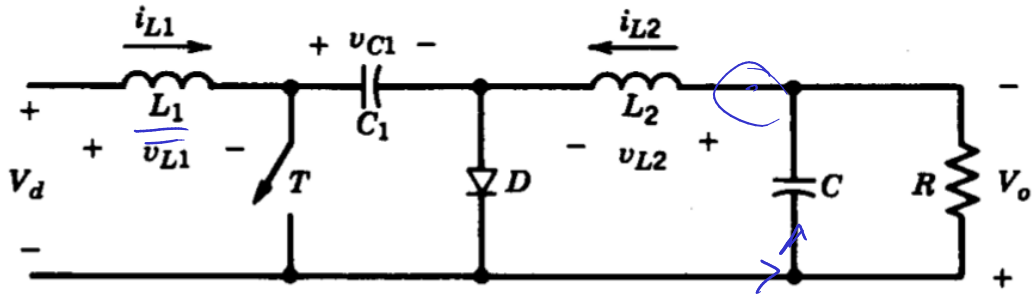
Boost Topology



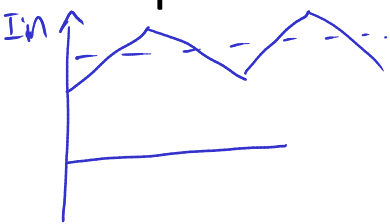
Polarity Inverting Buck-Boost Topology

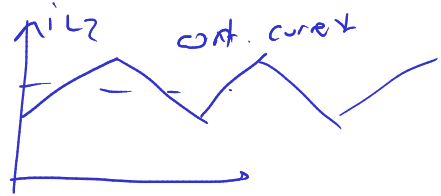


Ćuk converter



Double ended: Inductors placed at both the input and the output





Ćuk converter

Advantages:

- Both input and output currents are ripple free (fed through inductors)

Ćuk converter

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- Both input and output currents are ripple free (fed through inductors)
- Lower filtering requirements

Ćuk converter

Advantages:

- Both input and output currents are ripple free (fed through inductors)
- Lower filtering requirements
- Constant source current

Ćuk converter

Disadvantages:

Ćuk converter

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- Capacitor(C1) is quite bulky

Ćuk converter

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- Capacitor(C1) is quite bulky
- Capacitor (C1) should have a large ripple current rating

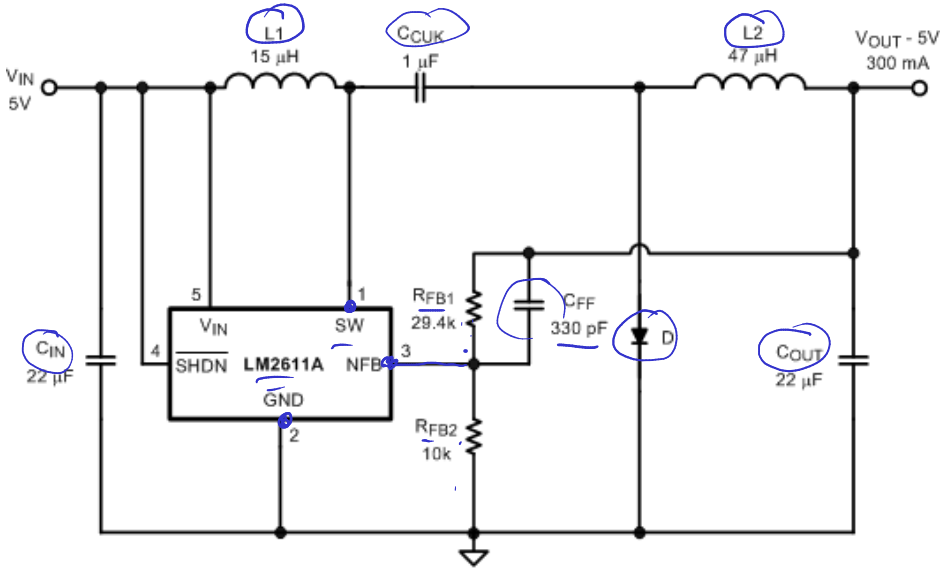
Ćuk converter

Disadvantages:

- Capacitor(C1) is quite bulky
- Capacitor (C1) should have a large ripple current rating
- Complex circuit

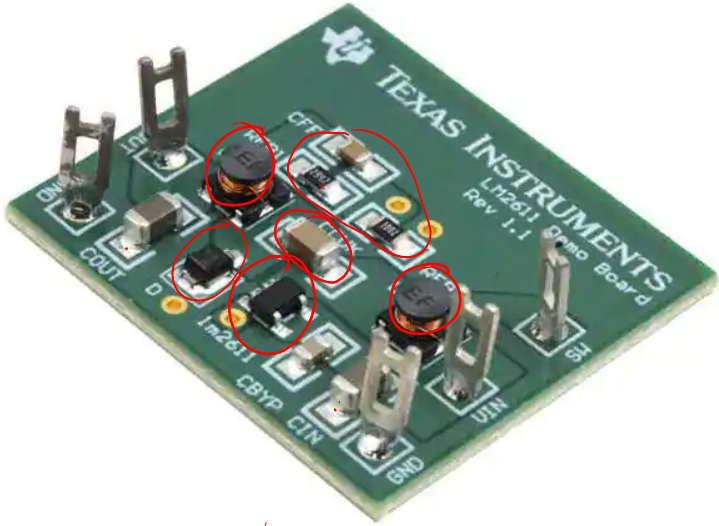
For curious students: Power Electronics Manifesto by Slobodan Ćuk

Practical Product: LM2611



CIN: TAIYO YUDEN X5R JMK325BJ226MM
CCUK: TAIYO YUDEN X5R EMK316BJ105MF
COUT: TAIYO YUDEN X5R JMK325BJ226MM
D: ON SEMICONDUCTOR MBR0520
L1: SUMIDA CR32-150
L2: SUMIDA CR32-470

Practical Product: LM2611



Example

Mohan Exercise 7-3

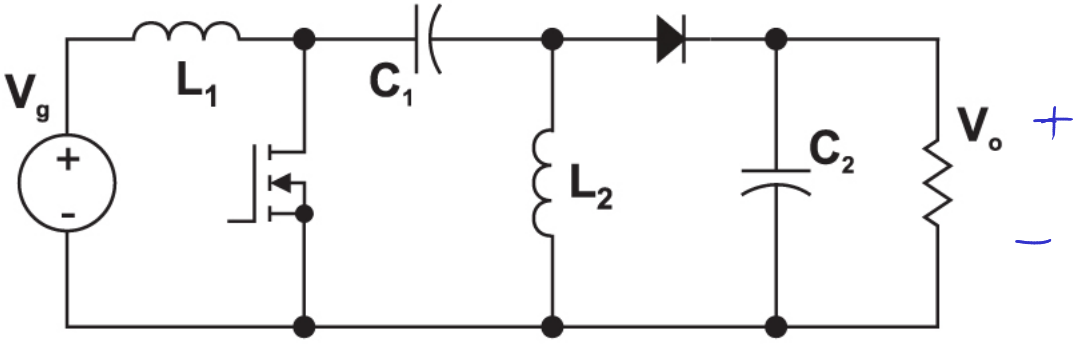
SEPIC Converter

SEPIC Converter

Single Ended Primary Inductor Converter

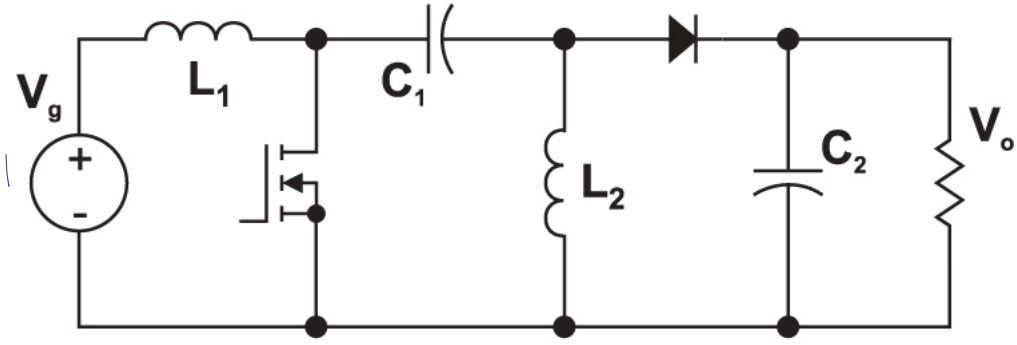
SEPIC Converter

Single Ended Primary Inductor Converter



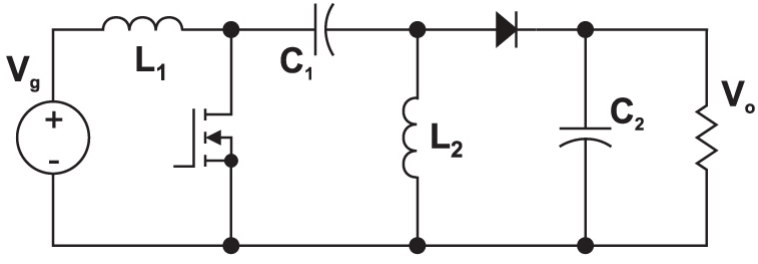
SEPIC Converter

Single Ended Primary Inductor Converter



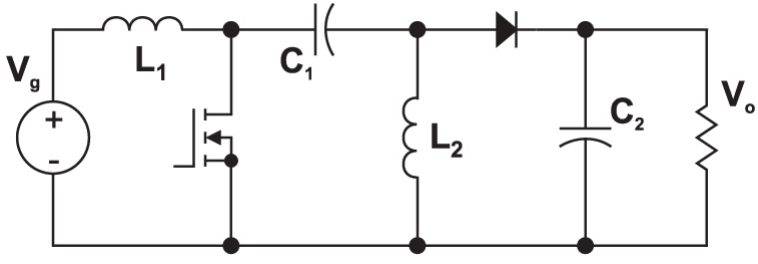
Essentially a boost converter cascaded with a buck-boost converter

SEPIC Converter



Popular in battery powered systems (voltage level can be adjusted according to charge level)

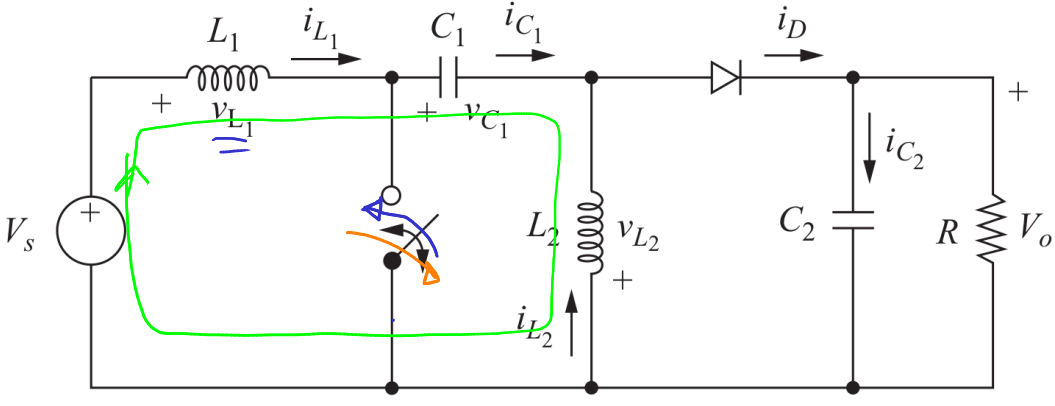
SEPIC Converter



Popular in battery powered systems (voltage level can be adjusted according to charge level)

Possible to shutdown completely (when the switch is off)

Operating Modes:



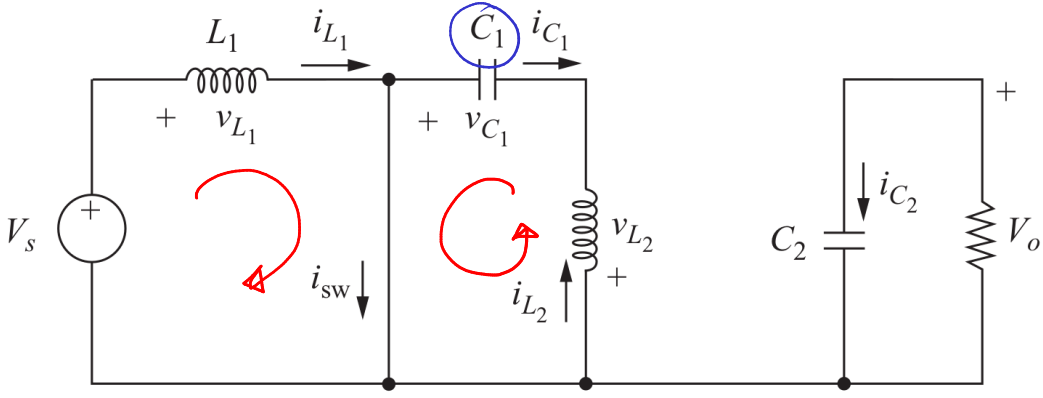
$-V_s + V_{L1} + V_{C1} - V_{L2} = 0$ } for inst. and average voltages

in the steady state $\Rightarrow V_{L1} = 0$, $V_{L2} = 0$ (average values)

C_1 is large enough $\Rightarrow V_{C1}$ is constant

$$V_{C1} = V_s$$

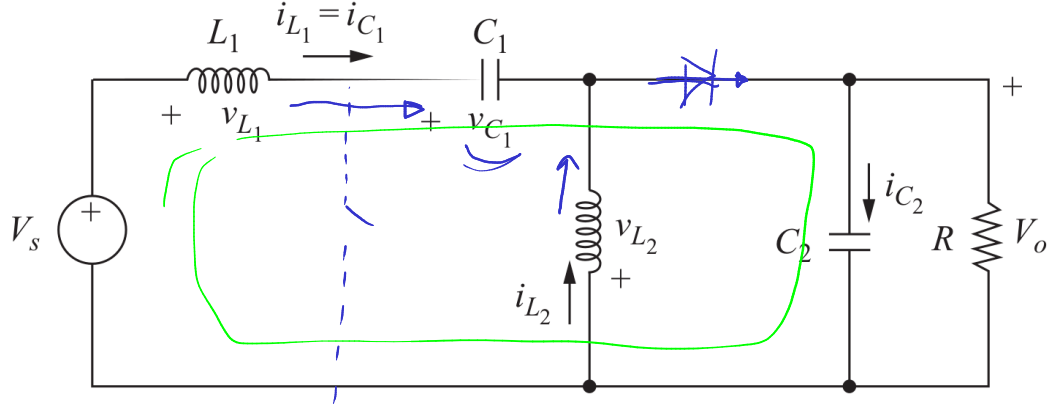
Operating Modes: ON State



$$v_{L1} = Vs$$

$V_{L2} = V_{C1} = V_s$

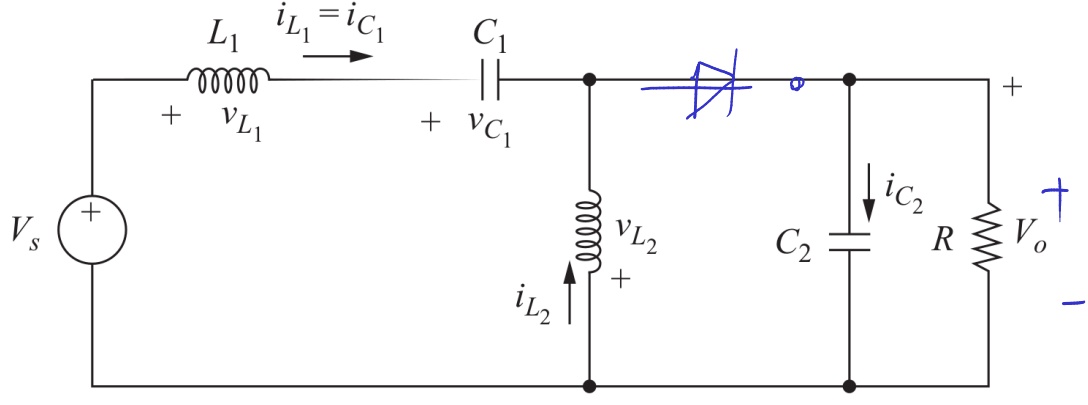
Operating Modes: OFF State



$$-V_s + v_{L1} + v_{C1} + V_o = 0$$

$V_{L1} = -V_o$

Operating Modes: OFF State



$$-V_s + v_{L1} + v_{C1} + V_o = 0$$

If $v_{C1} = V_s$ then $v_{L1} = -V_o$

Use voltage second balance

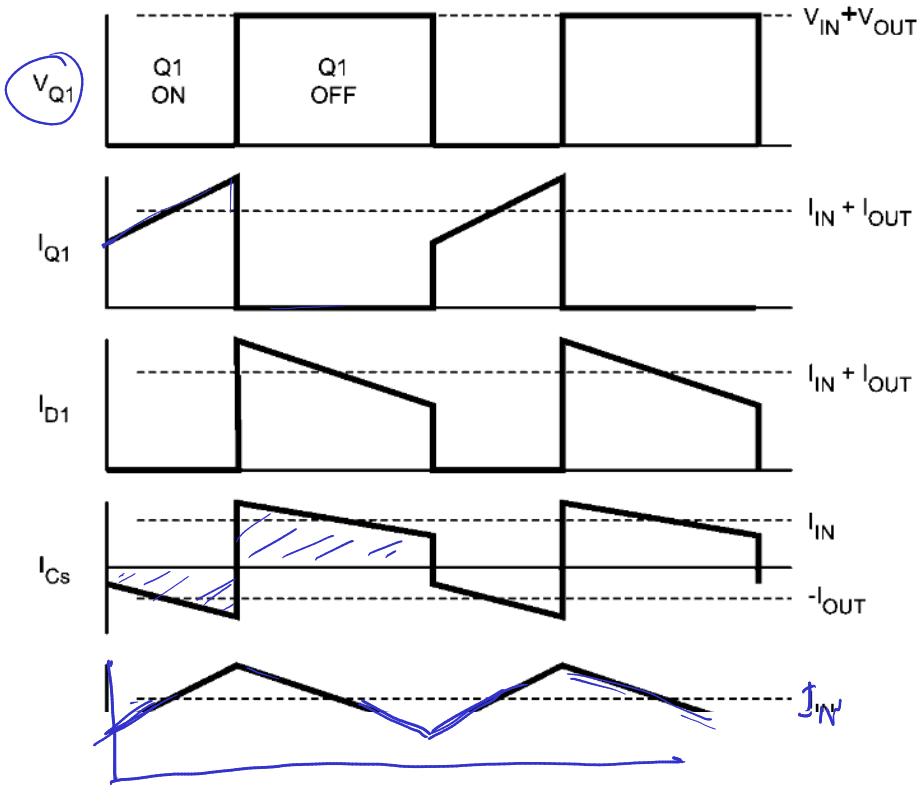
$V_s \cdot D T_s +$

$-V_o(1-D)T_s = 0$

$V_o = V_s \cdot (D/1-D)$

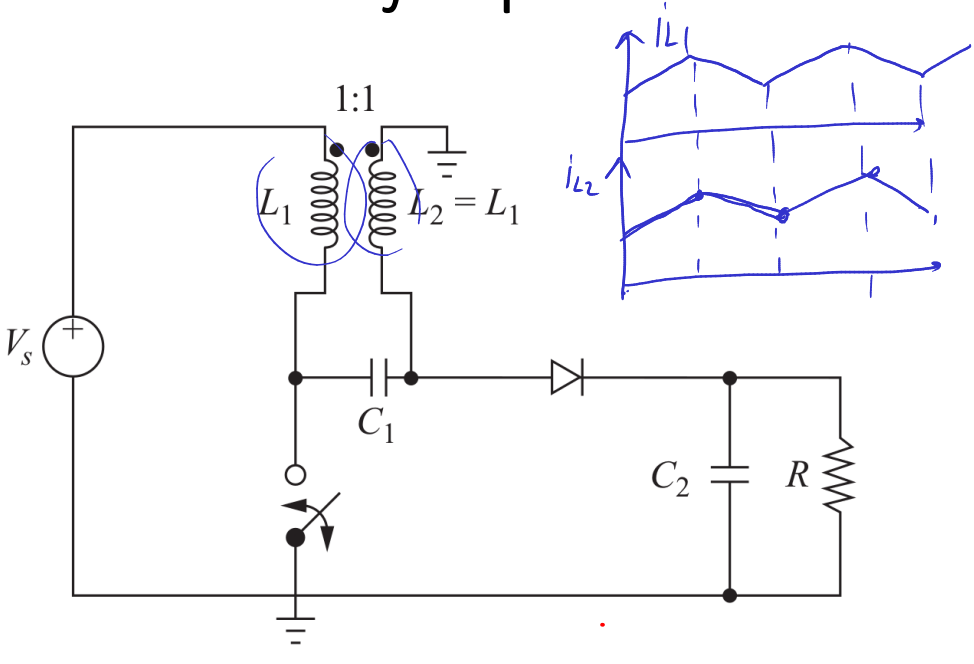
↳ buck-boost converter

Operating Modes: Currents



Example (Handout)

SEPIC With Mutually Coupled Inductors



SEPIC Converter

SEPIC Converter

Advantages:

- Non-inverting buck-boost converter

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Disadvantages:

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- Large capacitance (and large ripple current rating)

SEPIC Converter

Advantages:

- Non-inverting buck-boost converter
- Energy Efficient (can be completely turned-off)

Disadvantages:

- Pulsating output current
- Large capacitance (and large ripple current rating)
- Fourth order transfer function, difficult to control

SEPIC Converter

SEPIC Converter

Inductors can be combined is a single core (coupled inductors)

Lower required inductance, and size

Minimize oscillation in the circuit (more on that later)

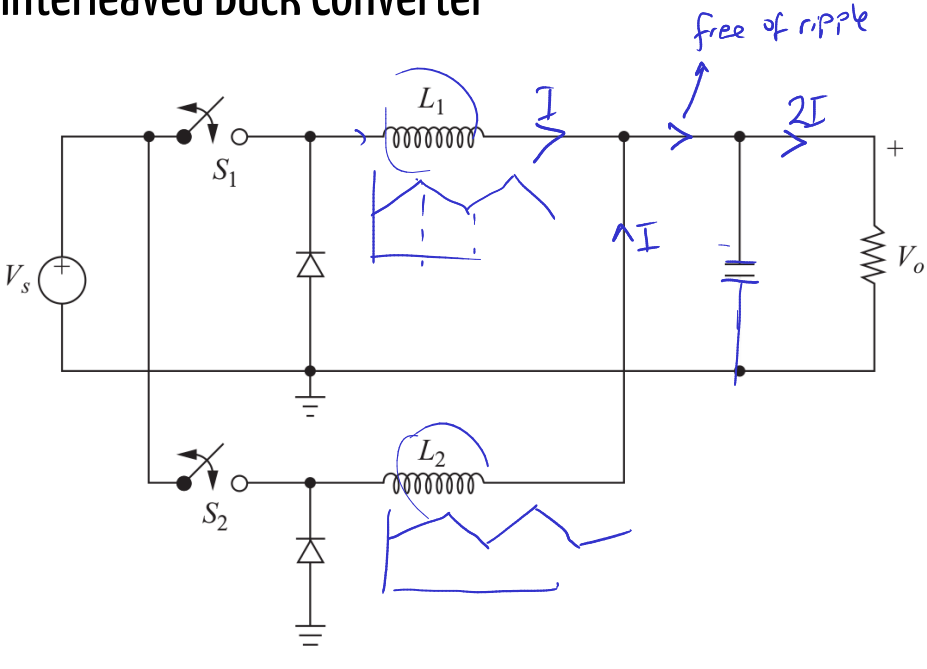
Interleaved Converters

Interleaved Converters

Interleaved Buck Converter

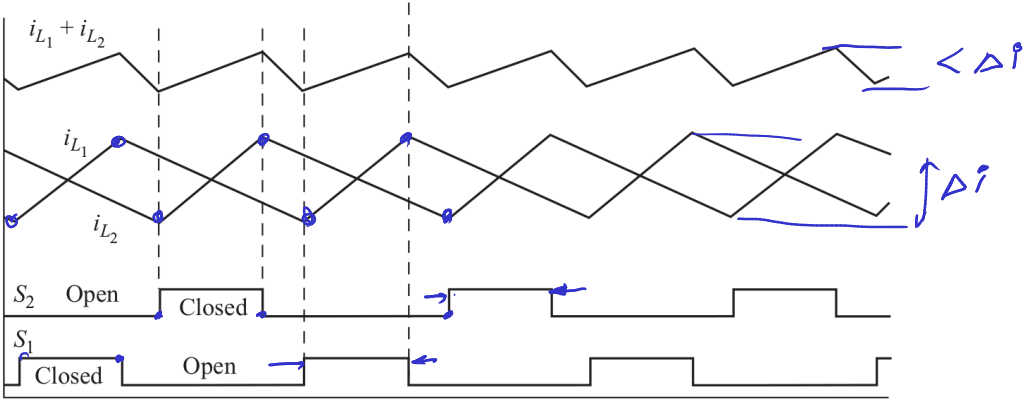
Interleaved Converters

Interleaved Buck Converter



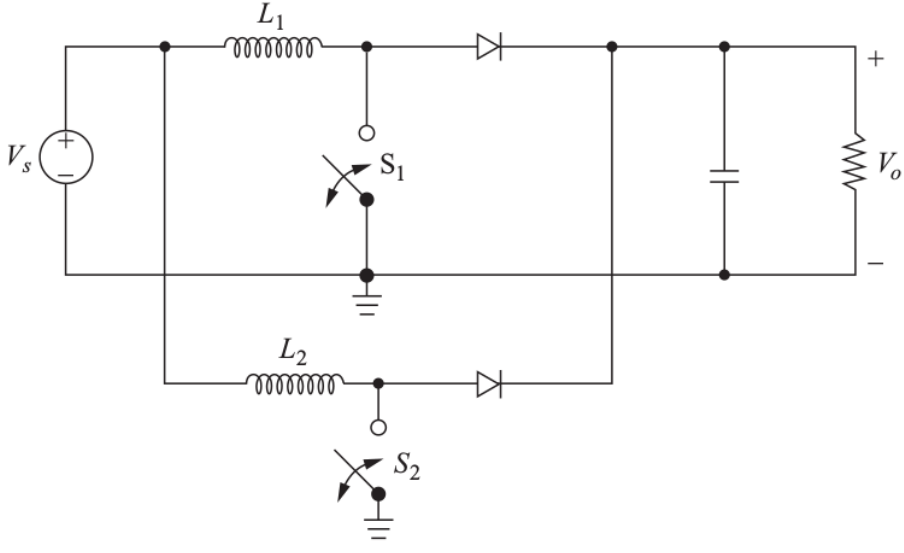
Interleaved Converters

Interleaved Buck Converter



Interleaved Converters

Interleaved Boost Converter



Reading Assignments

- TI Training Videos
- MATLAB Topology Comparison
- Application Note: Designing A SEPIC Converter
- Sepic and Ćuk Converters
- Sepic Converter Basics
- Power supply topology: SEPIC vs Flyback

You can download this presentation from:
keysan.me/ee464