Lecture # 6

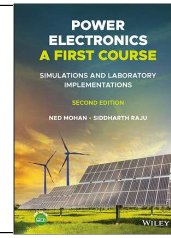
ECEN 438/738 Power Electronics

Spring 2025 Semester

Dr. Prasad Enjeti,
Electrical & Computer Engineering
Texas A&M University
http://enjeti.tamu.edu

1

ECEN 438/738 Power Electronics



Power Electronics
A First Course: 2nd Edition

Free Textbook Online Access Link: https://go.oreilly.com/TAMU/library/view/-/9781119818564/?ar

Chapter 1
Power Electronics: An Enabling Technology

2

ECEN 438/738 Power Electronics

Free Textbook Access Link: https://go.oreilly.com/TAMU/library/view/-/9781119818564/?ar

3

DC - DC Buck Converter Summary

$\boxed{V_o = D V_{in}}$ — **1** Where the duty cycle is 0<D<1

$\boxed{\Delta I_L = \frac{V_o (1-D) T}{L}}$ — **2** Where ΔI_L is inductor current ripple (peak to peak)

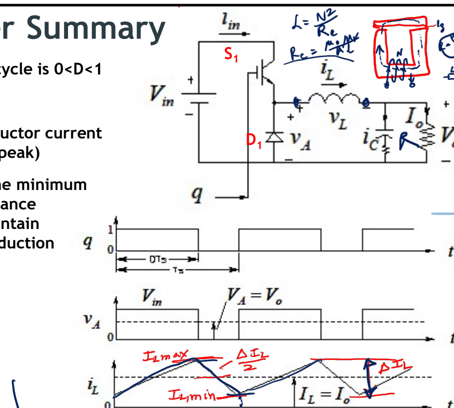
$\boxed{L_{min} = \frac{(1-D)R}{2f}}$ — **3** Where L_{min} is the minimum (critical) inductance required to maintain continuous conduction

4 $I_L = I_o = \frac{V_o}{R}$

$T = \frac{1}{f}$

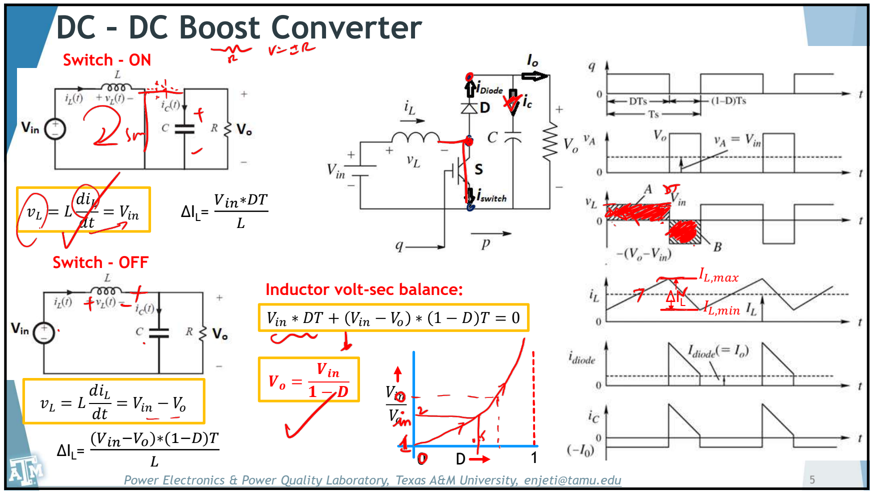
5 (Input Power) $V_{in} I_{in} = V_o \cdot I_o$ (output power)

$I_{in} = \frac{V_o}{V_{in}} \cdot I_o = D \cdot I_o = D I_L$

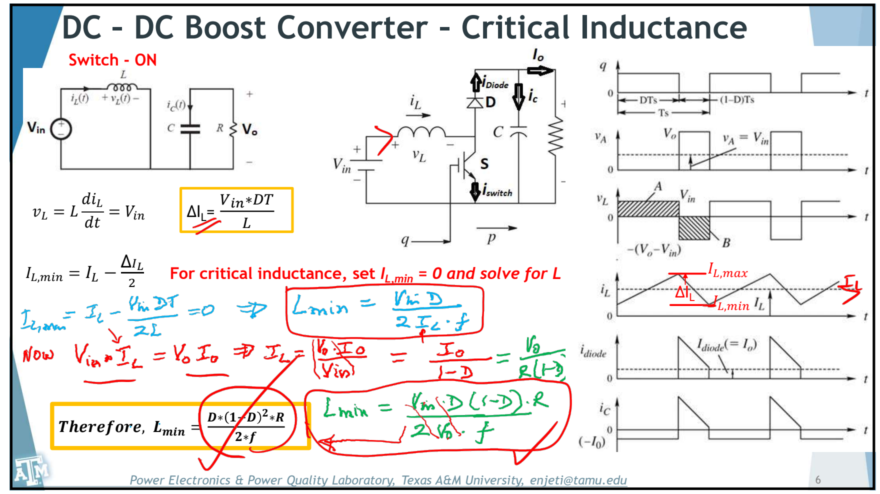


solve for: $C = \frac{(1-D)}{\left(\frac{\Delta V_o}{V_o}\right) * 8 * L * f^2}$ — **6** Capacitor value is inversely proportional to L

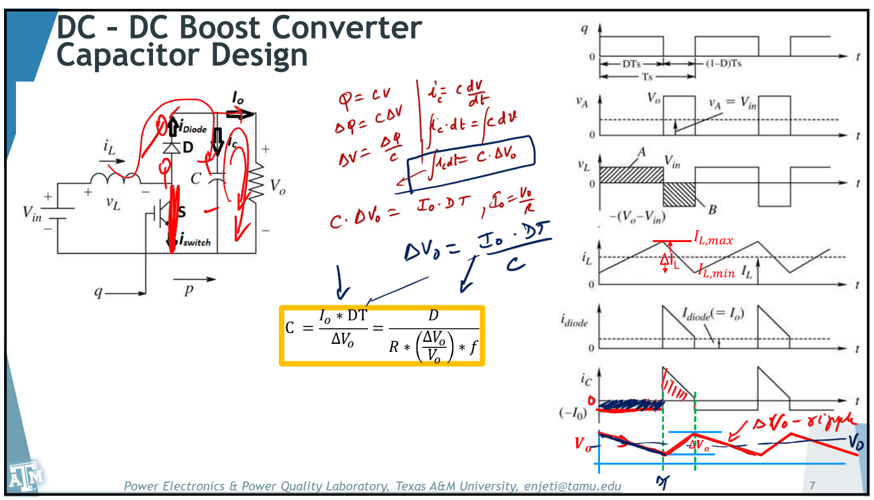
4


DC - DC Boost Converter
Switch - ON
$v_L = L\frac{di_L}{dt} = V_{in}$
$\Delta I_L = \frac{V_{in}*DT}{L}$
Switch - OFF
$v_L = L\frac{di_L}{dt} = V_{in} - V_o$
$\Delta I_L = \frac{(V_{in}-V_o)*(1-D)T}{L}$
Inductor volt-sec balance:
$V_{in} * DT + (V_{in} - V_o) * (1-D)T = 0$
$V_o = \frac{V_{in}}{1-D}$
Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu

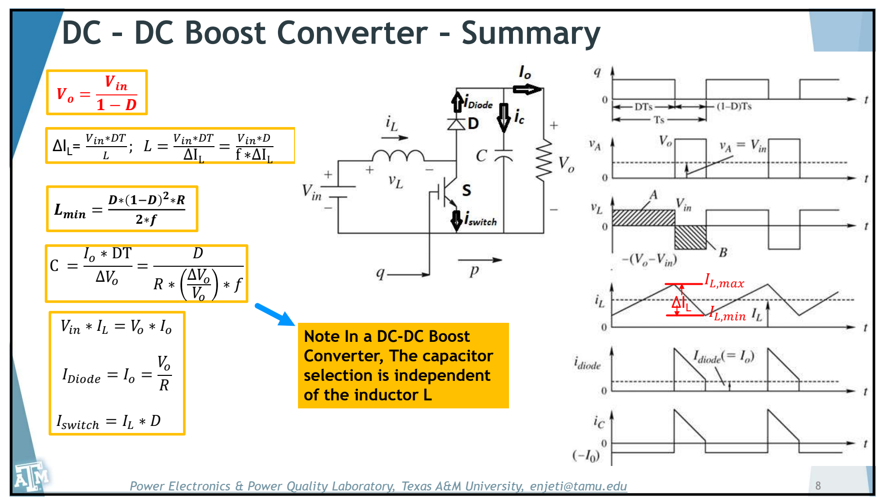
5


DC - DC Boost Converter - Critical Inductance
Switch - ON
$v_L = L\frac{di_L}{dt} = V_{in}$
$\Delta I_L = \frac{V_{in}*DT}{L}$
$I_{L,min} = I_L - \frac{\Delta I_L}{2}$
For critical inductance, set $I_{L,min} = 0$ and solve for L
Therefore, $L_{min} = \frac{D*(1-D)^2*R}{2*f}$
Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu

6


DC - DC Boost Converter
Capacitor Design
$Q = CV$
$\Delta Q = C\Delta V$
$i_c = C\frac{dv}{dt}$
$C \cdot \Delta V_o = I_o \cdot DT$
$\Delta V_o = \frac{I_o \cdot DT}{C}$
$C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f}$
Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu

7


DC - DC Boost Converter - Summary
$V_o = \frac{V_{in}}{1-D}$
$\Delta I_L = \frac{V_{in}*DT}{L}$; $L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$
$L_{min} = \frac{D*(1-D)^2*R}{2*f}$
$C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f}$
$V_{in} * I_L = V_o * I_o$
$I_{Diode} = I_o = \frac{V_o}{R}$
$I_{switch} = I_L * D$
Note In a DC-DC Boost Converter, The capacitor selection is independent of the inductor L
Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu

8

DC - DC Boost Converter - Design Example

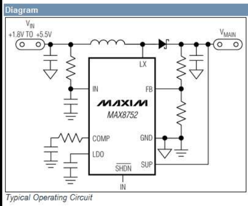
Key Specifications: Step-Up Switching Regulators

Part Number	V_{IN} (V) min	V_{IN} (V) max	V_{OUT} (V) min	V_{OUT} (V) max	Max. I_{OUT} (A) ≥	Max. I_{OUT} (A) ≤	Output Adjust. Method	DC-DC Outputs	Oper. Freq. (kHz)	Package/Pins	Smallest Available Pckg. (mm^2) max w/pins	Price See Notes
MAX8752	1.8	5.5	1.8	13	1.8	1.8	PWM	1	1200	TDFN-EP/8	9.6	$0.97 @1k

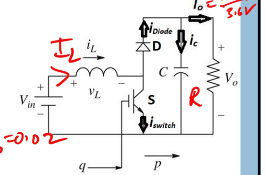
See All Step-Up Switching Regulators (87)

Pricing Notes: This pricing is BUDGETARY, for comparing similar parts. Prices are in U.S. dollars and subject to change. Quantity pricing may vary substantially and international prices may differ due to local duties, taxes, fees, and exchange rates. For volume-specific prices and delivery, please see the price and availability page or contact an authorized distributor.

Diagram



Typical Operating Circuit



D=0.5

$\Delta V_o/V_o = 0.02$

Example # 1: Design a DC-DC Boost Converter for: V_{in}=1.8V, V_o=3.6V a max of 2% voltage ripple, Output Power P=3.6W, f = 1MHz. Inductor current ripple not to exceed 10% of its average current. Assume ideal components for this design.

Solution:

I_o =1A, R=3.6 ohms, D = 0.5

Now $V_{in} * I_L = V_o * I_o$ i.e. 1,8*I_L = 3.6 ; Therefore I_L = 2A

ΔI_L= 0.1*2 = 0.2A

Since $\Delta I_L = \frac{V_{in}*DT}{L}$ --- Calculate L = 4.5uH and C = 7uF

Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu 9

9

DC - DC Boost Converter - Design Example

Input voltage V_{in} = 2.7V to 4.2V

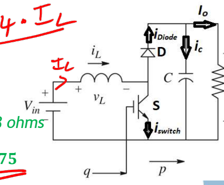
Output voltage V_o = 8V ; voltage ripple not to exceed 2%

Output current I_o = 1A

Switching frequency f = 200kHz

Specify the inductor value such that the peak-to-peak variation in inductor current does not exceed 40% of its average current. Also calculate the capacitor value C that meets the above specifications.

$\Delta I_L = 0.4 \cdot I_L$



Case # 1: V_{in} = 2.7V, V_o = 8V, R = 8 ohms

$V_o = \frac{V_{in}}{1-D}$; $D = 1 - \frac{V_{in}}{V_o} = 0.663$

$V_{in} * I_L = V_o * I_o$; $I_L = \frac{8*1}{2.7} = 2.96A$;

ΔI_L=(40%)*2.96 = 1.19A

$L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$ =7.5uH

$C = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f} = 20.7uF$

Case # 2: V_{in} = 4.2V, V_o = 8V, R = 8 ohms

$V_o = \frac{V_{in}}{1-D}$; $D = 1 - \frac{V_{in}}{V_o} = 0.475$

$V_{in} * I_L = V_o * I_o$; $I_L = \frac{8*1}{4.2} = 1.19A$;

ΔI_L=(40%)*1.19 = 0.762A

$L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$ =13.1uH

$C = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f} = 14.8uF$

L =

C =

Note In a DC-DC Boost Converter, The capacitor selection is independent of the inductor L

Choose the largest L = 13.1uH and C = 20.7uF → 22 μF

15 μH

Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu 10

10

DC - DC Boost Converter - Summary

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

$\Delta I_L = \frac{V_{in}*DT}{L}$; $L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$

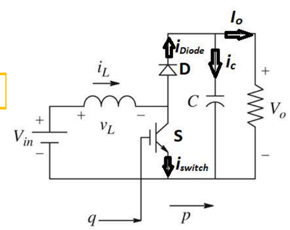
$$L_{min} = \frac{D*(1-D)^2*R}{2*f}$$

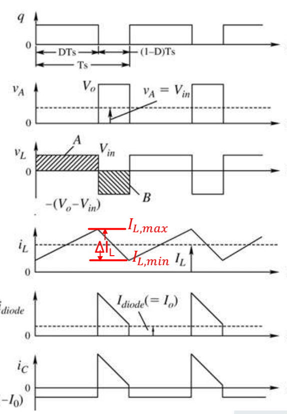
$$C = \frac{I_o*DT}{\Delta V_o} = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f}$$

$$V_{in} * I_L = V_o * I_o$$

$$I_{Diode} = I_o = \frac{V_o}{R}$$

$$I_{switch} = I_L * D$$



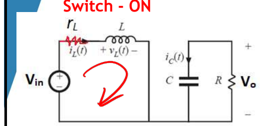


Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu 11

11

DC - DC Boost Converter - Inductor Resistance

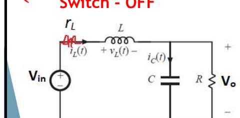
Switch - ON



$$L\frac{di_L}{dt} + i_L * r_L = V_{in}$$

$$v_L = L\frac{di_L}{dt} = V_{in} - i_L * r_L$$

Switch - OFF



$$v_L = L\frac{di_L}{dt} = V_{in} - i_L * r_L - V_o$$

Inductor Volt-second-balance

$(V_{in} - I_L * r_L) * D + (V_{in} - I_L * r_L - V_o)$*(1-D) = 0

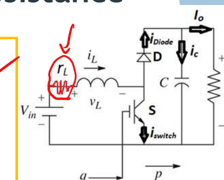
Solve the above equation to obtain V_o

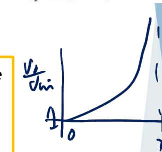
$$\frac{V_o}{V_{in}} = \left(\frac{1}{1-D}\right)\left(\frac{1}{1+\frac{r_L}{R(1-D)^2}}\right) \quad \text{6}$$

Efficiency $\eta = \frac{V_o*I_o}{V_o*I_o + I_L^2*r_L}$ since $I_L = \frac{I_o}{1-D}$ we have

Simplify the above equation to obtain η

$$\eta = \frac{1}{1+\frac{r_L}{R(1-D)^2}} \quad \text{7}$$





Power Electronics & Power Quality Laboratory, Texas A&M University, enjeti@tamu.edu 12

12

DC - DC Boost Converter - Inductor Resistance

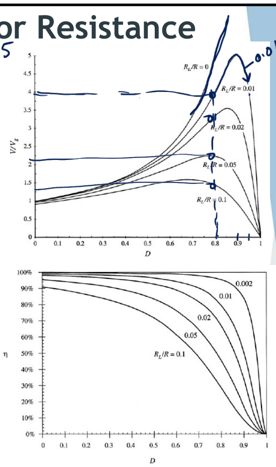
$D = 0.8;\ \frac{V_0}{V_{in}} = \frac{1}{1-D} = 5$

$$\frac{V_o}{V_{in}} = \left(\frac{1}{1-D}\right)\left(\frac{1}{1+\frac{r_L}{R(1-D)^2}}\right)$$

$$\eta = \frac{1}{1+\frac{r_L}{R(1-D)^2}}$$

$\frac{r_L}{R}$	D	$\frac{V_o}{V_{in}}$	η
0.01	0.8	4	80%
0.02	0.8	3.33	67%

$Q = \frac{\omega L}{r_L}$

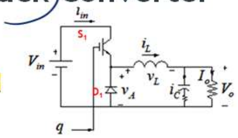


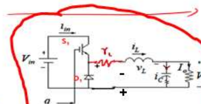
- Lower $\frac{r_L}{R}$ ratio will yield better results.
- Maximum boost ratio by design should be limited to 3 for better performance & higher efficiency
- MOSFET / Inductor / Capacitor section become very important for better performance

13

DC-DC Buck Converter - DC-DC Boost Converter

1. $V_0 = D V_{in}$
2. $\Delta I_L = \frac{V_0(1-D)T}{L}$
3. $L_{min} = \frac{(1-D)R}{2f}$
4. $I_L = I_0 = \frac{V_0}{R}$; $T = \frac{1}{f}$
5. (Input Power) $V_{in} I_{in} = V_0 I_0$ (output power); $I_{in} = \frac{V_0}{V_{in}} \cdot I_0 = D \cdot I_0 = D I_L$
6. $C = \frac{(1-D)}{\left(\frac{\Delta V_o}{V_o}\right) * 8 * L * f^2}$





$$V_o = \frac{V_{in} * D}{1+\frac{r_L}{R}}$$

$$\eta = \frac{1}{1+\frac{r_L}{R}}$$

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

$\Delta I_L = \frac{V_{in}*DT}{L}$; $L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$

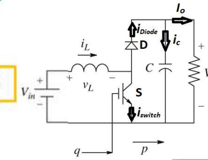
$$L_{min} = \frac{D*(1-D)^2*R}{2*f}$$

$V_{in} * I_L = V_o * I_o$

$I_{Diode} = I_o = \frac{V_o}{R}$

$I_{switch} = I_L * D$

$$C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f}$$

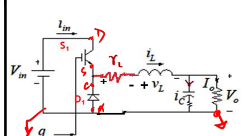


$$\frac{V_o}{V_{in}} = \left(\frac{1}{1-D}\right)\left(\frac{1}{1+\frac{r_L}{R(1-D)^2}}\right)$$

$$\eta = \frac{1}{1+\frac{r_L}{R(1-D)^2}}$$

14

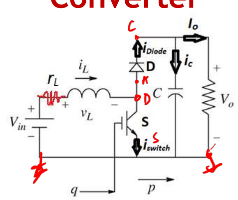
Buck Converter



1. $V_0 = D V_{in}$

$$V_o = \frac{V_{in} * D}{1+\frac{r_L}{R}}$$

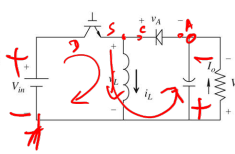
Boost Converter



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

$$\frac{V_o}{V_{in}} = \left(\frac{1}{1-D}\right)\left(\frac{1}{1+\frac{r_L}{R(1-D)^2}}\right)$$

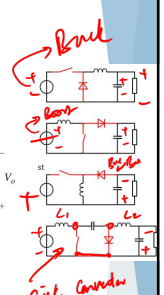
Buck/Boost Converter



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

https://en.wikipedia.org/wiki/Buck%E2%80%93boost_converter

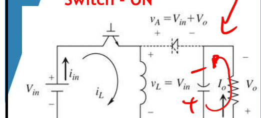
Buck, Boost, Buck-Boost, Cuk Converter



15

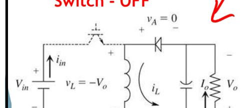
DC - DC Buck-Boost Converter

Switch - ON



$$v_L = L\frac{di_L}{dt} = V_{in} \qquad \Delta I_L = \frac{V_{in}*DT}{L}$$

Switch - OFF



$$v_L = L\frac{di_L}{dt} = -V_o$$

$$\Delta I_L = \frac{(-V_o)*(1-D)T}{L}$$

Inductor volt-sec balance:

$$V_{in} * DT + (-V_o) * (1-D)T = 0$$

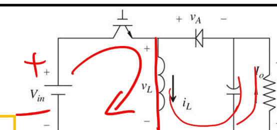
$$\frac{V_o}{V_{in}} = \frac{D}{1-D}$$

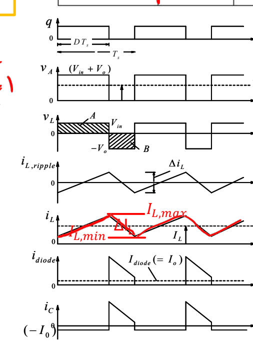
$D = 0.5$, $V_o/V_{in} = 1$

$0 < D < 0.5 \rightarrow Buck$

$0.5 < D < 1 \rightarrow Boost$

- Both Buck & Boost functions are possible.
- Addresses particular applications





16

DC - DC Buck-Boost Converter Summary

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

2. $\Delta I_L = \frac{V_{in}*DT}{L}$; $L = \frac{V_{in}*DT}{\Delta I_L} = \frac{V_{in}*D}{f*\Delta I_L}$

Follow the same procedure as detailed in buck & boost converter analysis to show the following

3. $L_{min} = \frac{R*(1-D)^2}{2*f}$

4. $C = \frac{I_o * DT}{\Delta V_o} = \frac{D}{R*\left(\frac{\Delta V_o}{V_o}\right)*f}$

$$V_{in} * I_{in} = V_o * I_o$$

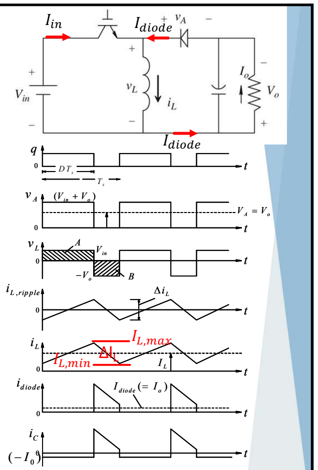
$$I_{in} = \frac{V_o}{V_{in}} I_o = \frac{D}{1-D} I_o$$

$$I_L = I_{in} + I_o$$

$$I_L = I_{in} + I_o = \frac{1}{1-D} I_o = \frac{1}{1-D}\frac{V_o}{R}$$

$$I_{Diode} = I_o = \frac{V_o}{R}$$

* Buck Boost ✓



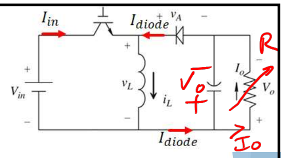
17

DC - DC Buck-Boost Converter

Input voltage	V_{in}	=	20V to 60V
Output voltage	V_o	=	30V ± 2%
Output power	P_o	=	25 W (max)
Switching frequency	f	=	300kHz

$P = \frac{V_o^2}{R}$ $R = \frac{V_o^2}{P}$

Note: Continuous conduction is desired from 25% load to 100% load. Assume ideal components for this design



Case # 1: V_{in} = 20V, V_o = 30V

$\frac{V_o}{V_s} = \frac{D}{1-D}$ soln $D = \frac{V_o/V_s}{1+V_o/V_s} = 0.6$

$R|_{100\%} = \frac{(V_o)^2}{P_o} = 36\,\Omega$ $R|_{25\%} = 4 \times 36 = 144\,\Omega$

$\boxed{L_{min} = \frac{(1-D)^2 R}{2f}} = 38.4\,\mu H$

$C = \frac{D}{\frac{\Delta V_o}{V_o} R f} = 1.39\,\mu F$ 0.02

Case # 1: V_{in} = 60V, V_o = 30V

$\frac{V_o}{V_s} = \frac{D}{1-D}$ soln $D = \frac{V_o/V_s}{1+V_o/V_s} = 0.33$

$L_{min} = 107.7\,\mu H$; $C = 0.764\,\mu F$

Select Largest L and C

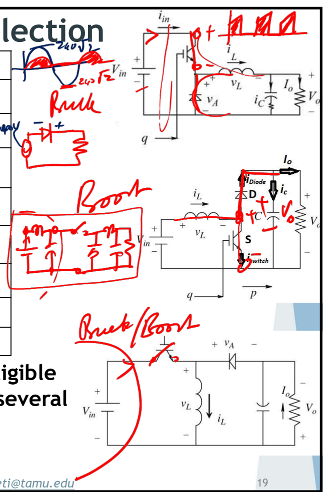
L ≈ 110 uH ; C ≈ 1.4 uF

18

DC - DC Converter - Topology Selection

Criterion		Buck	Boost	Buck-Boost
Transistor $\hat{V}$		V_{in} ✓	V_o ✓	$(V_{in}+V_o)$
Transistor $\hat{I}$		I_o	I_{in}	$I_{in}+I_o$
I_{rms}	Transistor	$\sqrt{D}I_o$	$\sqrt{D}I_{in}$	$\sqrt{D}(I_{in}+I_o)$
I_{avg}	Transistor	DI_o	DI_{in}	$D(I_{in}+I_o)$
	Diode	$(1-D)I_o$	$(1-D)I_{in}$	$(1-D)(I_{in}+I_o)$
I_L		I_o	I_{in}	$I_{in}+I_o$
Effect of L on C		significant	little	little
Pulsating Current		input	output	both

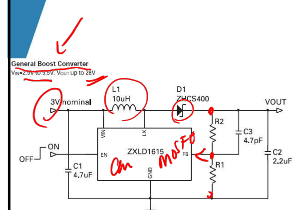
- Assumption - the inductor ripple current is negligible
- Conclusion: Buck-Boost converter suffers from several additional stresses
- Worst case design (select large L and C)



19

DC - DC Buck/Boost Converter - Component Selection

ZXLD1615



Capacitor selection

A ceramic capacitor grounded close to the GND pin of the package is recommended at the output of the device. Surface mount types offer the best performance due to their lower inductance. A minimum value of 0.22µF is advised, although higher values will lower switching frequency and improve efficiency especially at lower load currents. A higher value will also minimize ripple when using the device to provide an adjustable dc output current.

A good quality, low ESR capacitor should also be used for input decoupling, as the ESR of this capacitor is effectively in series with the source impedance and lowers overall efficiency. This capacitor has to supply the relatively high peak current to the coil and smooth the current ripple on the input supply. A minimum value of 4.7µF is acceptable if the input source is close to the device, but higher values will improve performance at lower input voltages, when the source impedance is high. The input capacitor should be mounted as close as possible to the IC.

For maximum stability over temperature, capacitors with X7R dielectric are recommended, as these have a much smaller temperature coefficient than other types.

A table of recommended manufacturers is provided below:

Manufacturer	Website
Murata	www.murata.com
Taiyo Yuden	www.t-yuden.com
Kemet	www.kement.com
AVX	www.avxcorp.com

Inductor selection

The choice of inductor will depend on available board space as well as required performance. Small value inductors have the advantage of smaller physical size and may offer lower series resistance and higher saturation current compared to larger values. A disadvantage of lower inductor values is that they result in higher frequency switching, which in turn causes reduced efficiency due to switch losses. Higher inductor values can provide better performance at lower supply voltages. However, if the inductance is too high, the output power will be limited by the internal oscillator, which will prevent the coil current from reaching its peak value. This condition will arise whenever the ramp time ($I_{LX(peak)}$ x L/V_{IN}) exceeds the nominal 5µs maximum 'on' time limit for the LX output.

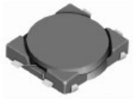
Recommended inductor values for the ZXLD1615 are in the range 6.8µH to 22µH. The inductor should be mounted as close to the device as possible with low resistance connections to the LX and V_{IN} pins.

Suitable coils for use with the ZXLD1615 are shown in the table below:

Part No.	L (µH)	DCR (Ω)	I_{SAT} (A)	Manufacturer
CMD4D11-100MC	10	0.457	0.5	Sumida www.sumida.com
DO1608-103	10	0.16	1.1	Coilcraft www.coilcraft.com
LQH31CN100	10	1.3	0.23	Murata www.murata.com
LB2012Y100MR	10	0.5	0.1	Taiyo Yuden www.t-yuden.com

20

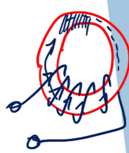
DC - DC Buck/Boost Converter - Component Selection



www.sumida.com

◆ Specification

Part No. ※	Stamp	Inductance (μH) [Within] 100kHz/1V	D.C.R.(mΩ) Max.(Typ.) (at 20℃)	Saturation Current (A) ※1	Temperature Rise current (A) ※2
CMD5D13NP-3R3M□	3R3	3.3±20%	81 (65)	1.90	1.25
CMD5D13NP-4R7M□	4R7	4.7±20%	106 (85)	1.50	1.20
CMD5D13NP-6R8M□	6R8	6.8±20%	144 (115)	1.40	0.90



Note: the ± 20% variation in inductor value

L_{max}

www.coilcraft.com

Part number *Click for samples*	Inductance1 ±20% (μH)	DCR max2 (mOhms)	SRF min (MHz)	Isat3 (A)	Irms (A)4 20°C rise	Irms (A)4 40°C rise
ED0006-AL	20	42	13	36.0	5.1	7.2

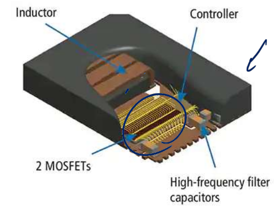
1 Inductance measured at 100 kHz, 100 mVrms, 0 A using an Agilent/HP 4132 impedance analyzer or equivalent.
2 DCR measured on a Valhalla 4105 ATC digital ohmmeter or equivalent.
3 Isat: DC current at which the inductance drops 10% (typ) from its value without current. Details
4 Irms: Current that causes the specified temperature rise from +25°C ambient. Details
5 **Ambient temperature range:** –40°C to +125°C with Irms current. +125°C to +165°C with derated current. Derating curve
6 **Storage temperature range:** Component: –40°C to +125°C; Packaging trays: –40°C to +80°C
7 Electrical specifications at 25°C.

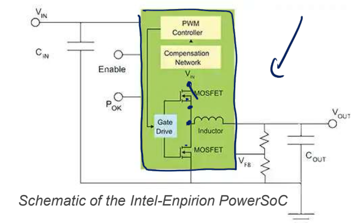
21

Power Supply on a Chip - PowerSoc-Conferences

Intel® Enpirion® Power Solutions

Digital Power Management Solutions





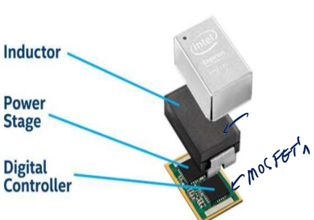
Schematic of the Intel-Enpirion PowerSoC

- Packages that combine an IC and inductor into a single device.
- Such packages are larger than conventional power modules, but take up less board space than a power module plus a discrete inductor.
- The designer does not face the hassle of selecting and designing-in a suitable inductor as the supplier has already done the job.

22

Intel® Enpirion® Power Solutions

Digital Power Management Solutions



What Are Intel® Enpirion® Digital PowerSoC Modules?

Intel® Enpirion® digital PowerSoC modules are DC-DC step-down power converters that integrate a digital controller, power stages, inductor, and compensation into a small, power dense form factor. The family utilizes a digital control architecture and includes a digital communication and control interface.

The digital control architecture features two digital PID (proportional integral derivative) control loop compensators: One for steady-state operation, and one optimized for load transients. This multi-mode control enables Enpirion digital PowerSoCs to achieve high accuracy, low output ripple, and excellent transient response while minimizing the amount of output capacitance required.

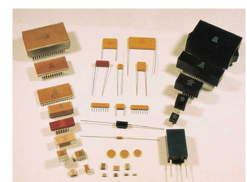
An integrated PMBus-compatible digital communication and control interface enables dynamic device programmability, access to real-time system telemetry, and programmable fault protection and diagnostics.

https://www.intel.com/content/www/us/en/power/programmable/enpirion-em2xxx-digital-powersoc.html

Also Read: The Advantages (and Drawbacks) of DC-to-DC Voltage Converters with Integrated Inductors

23

DC - DC Buck/Boost Converter - Component Selection

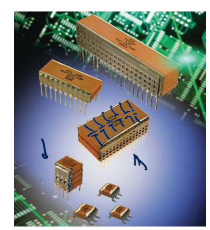


High speed switch mode power supplies require extremely low equivalent series resistance (ESR) and equivalent series inductance (ESL) capacitors for input and output filtering. *These requirements are beyond the practical limits of electrolytic capacitors, both aluminum and tantalums, but are readily met by multilayer ceramic (MLCs) capacitors (Figure 1).*

http://www.avx.com/products/film-capacitors/

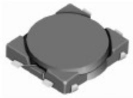
Typical ESR Performance (mΩ)

	Aluminum Electrolytic 100μF/50V	Low ESR Solid Tantalum 100μF/10V	Solid Aluminum Electrolytic 100μF/16V	MLCC SMPS 100μF/50V	MLCC SMPS 4.7μF/50V
ESR @ 10KHz	300	72	29	3	66
ESR @ 50KHz	285	67	22	2	23
ESR @ 100KHz	280	62	20	2.5	15
ESR @ 500KHz	265	56	18	4	8
ESR @ 1MHz	265	56	17	7	7.5
ESR @ 5MHz	335	72	17	12.5	8
ESR @ 10MHz	560	91	22	20	14



24

DC - DC Buck/Boost Converter - Component Selection



www.sumida.com

◆ Specification

Part No. ※	Stamp	Inductance (μH) [Within] 100kHz/1V	D.C.R.(mΩ) Max.(Typ.) (at 20℃)	Saturation Current (A) ※1	Temperature Rise current (A) ※2
CMD5D13NP-3R3M□	3R3	3.3±20%	81 (65)	1.90	1.25
CMD5D13NP-4R7M□	4R7	4.7±20%	106 (85)	1.50	1.20
CMD5D13NP-6R8M□	6R8	6.8±20%	144 (115)	1.40	0.90

Note: the ± 20% variation in inductor value

www.coilcraft.com

Part number Click for samples	Inductance1 ±20% (μH)	DCR max2 (mOhms)	SRF min (MHz)	Isat3 (A)	Irms (A)4 20°C rise	Irms (A)4 40°C rise
ED0006-AL	20	42	13	36.0	5.1	7.2

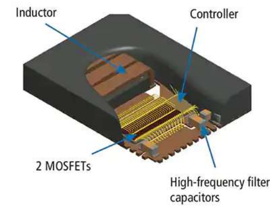
1 Inductance measured at 100 kHz, 100 mVrms, 0 A using an Agilent/HP 4132 impedance analyzer or equivalent.
2 DCR measured on a Valhalla 4105 ATC digital ohmmeter or equivalent.
3 Isat: DC current at which the inductance drops 10% (typ) from its value without current. Details
4 Irms: Current that causes the specified temperature rise from +25°C ambient. Details
5 **Ambient temperature range:** –40°C to +125°C with Irms current. +125°C to +165°C with derated current. Derating curve
6 **Storage temperature range:** Component: –40°C to +125°C. Packaging trays: –40°C to +80°C
7 Electrical specifications at 25°C.

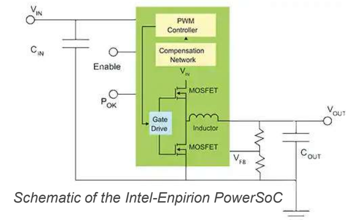
25

Power Supply on a Chip - PowerSoc-Conferences

Intel® Enpirion® Power Solutions

Digital Power Management Solutions





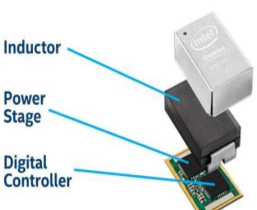
Schematic of the Intel-Enpirion PowerSoC

- Packages that combine an IC and inductor into a single device.
- Such packages are larger than conventional power modules, but take up less board space than a power module plus a discrete inductor.
- The designer does not face the hassle of selecting and designing-in a suitable inductor as the supplier has already done the job.

26

Intel® Enpirion® Power Solutions

Digital Power Management Solutions



What Are Intel® Enpirion® Digital PowerSoC Modules?

Intel® Enpirion® digital PowerSoC modules are DC-DC step-down power converters that integrate a digital controller, power stages, inductor, and compensation into a small, power dense form factor. The family utilizes a digital control architecture and includes a digital communication and control interface.

The digital control architecture features two digital PID (proportional integral derivative) control loop compensators: One for steady-state operation, and one optimized for load transients. This multi-mode control enables Enpirion digital PowerSoCs to achieve high accuracy, low output ripple, and excellent transient response while minimizing the amount of output capacitance required.

An integrated PMBus-compatible digital communication and control interface enables dynamic device programmability, access to real-time system telemetry, and programmable fault protection and diagnostics.

https://www.intel.com/content/www/us/en/power/programmable/enpirion-em2xxx-digital-powersoc.html

Also Read: The Advantages (and Drawbacks) of DC-to-DC Voltage Converters with Integrated Inductors

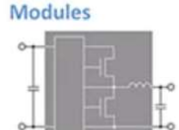
27

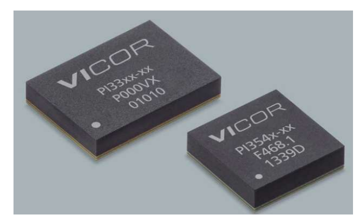
White Paper VICOR

Optimizing the integration of point-of-load buck converters

As electronic products have grown in complexity with highly evolved feature sets, system designers by necessity have developed correspondingly sophisticated schemes for load and power management. PCB-design intricacy, energy budgets, signal integrity, and, in some cases, thermal management issues have driven up the number of PoL (point-of-load) buck regulators typical systems use.

Modules





https://www.vicorpower.com/resource-library/white-papers/optimizing-the-integration-of-point-of-load-buck-converters

28

Single Inductor Multiple Output DC-DC Converter

ECEN 738 - Course Project

United States Patent [19] **Li**

[11] **Patent Number:** 6,075,295
[45] **Date of Patent:** Jun. 13, 2000

[54] **SINGLE INDUCTOR MULTIPLE OUTPUT BOOST REGULATOR**

[75] Inventor: **Thomas Li**, Mountain View, Calif.

[73] Assignee: **Micro Linear Corporation**, San Jose, Calif.

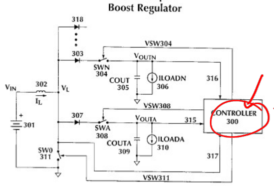
[21] Appl. No.: **08/840,279**

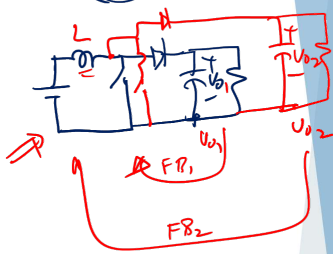
[22] Filed: **Apr. 14, 1997**

[51] **Int. Cl.**[7] **H02J 1/00**
[52] **U.S. Cl.** **307/39**; 307/38; 307/41
[58] **Field of Search** 307/38, 39, 41; 323/222

"Analysis of the Flyback Converter Operating in Current–Mode Pulse–Frequency Modulation", Urs Mader and K. Kit Sum, Micro Linear Corporation.
"ML4861 Low Voltage Boost Regulator", Micro Linear Corporation, Jun. 1993.
"11. Variable Frequency Converters", K. Kit Sum, pp. 96–97, 134–35, 1993.
"3.3V/5V/Adjustable Output, Set–up, DC–DC Converters", Maxim Integrated Products, pp. 1–8, 1993.
"ML4821 Power Factor Controller," Micro Linear Corporation, Jun. 1992.
"Application Note 16—Theory and Application of the ML4821 Average Current Mode PFC Controller," Micro Linear Corporation, Jan. 1992.

Multi-output Boost Regulator





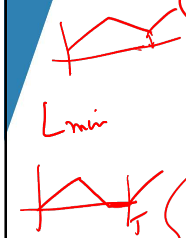
https://patentimages.storage.googleapis.com/.../3/25/a9756d222f6b70/US6075295.pdf

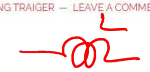
29

PoL buck-regulator modules with integrated inductor enable space-efficient designs

JULY 14, 2022 BY REDDING TRAIGER — LEAVE A COMMENT

Point of Load (PoL)

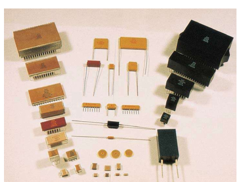




Contemporary server, communication, and network storage applications struggle to minimize power losses and solution size. Meanwhile, the rapidly changing market also requires system solution providers to address market needs faster than usual. Therefore, Infineon Technologies AG now introduces highly efficient and reliable step-down DC-DC converter modules. Adding to its point of load (POL) family, these modules are ideal for system designers looking for a compact, fully integrated, and easy-to-design POL products to help expedite time-to-market. They primarily address space and thermally constrained applications, telecom and datacom applications, servers, and network storage.

30

DC - DC Buck/Boost Converter - Component Selection

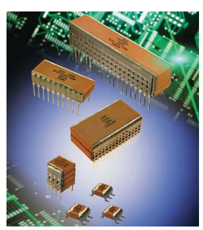


High speed switch mode power supplies require extremely low equivalent series resistance (ESR) and equivalent series inductance (ESL) capacitors for input and output filtering. *These requirements are beyond the practical limits of electrolytic capacitors, both aluminum and tantalums, but are readily met by multilayer ceramic (MLCs) capacitors (Figure 1).*

http://www.avx.com/products/film-capacitors/

Typical ESR Performance (mΩ)

	Aluminum Electrolytic 100µF/50V	Low ESR Solid Tantalum 100µF/10V	Solid Aluminum Electrolytic 100µF/16V	MLCC SMPS 100µF/50V	MLCC SMPS 4.7µF/50V
ESR @ 10KHz	300	72	29	3	66
ESR @ 50KHz	285	67	22	2	23
ESR @ 100KHz	280	62	20	2.5	15
ESR @ 500KHz	265	56	18	4	8
ESR @ 1MHz	265	56	17	7	7.5
ESR @ 5MHz	335	72	17	12.5	8
ESR @ 10MHz	560	91	22	20	14



31