TECHNICAL ACADEMY

WÜRTH ELEKTRONIK

Reducing inductor size

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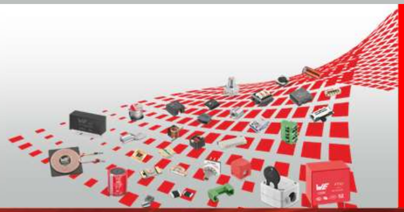

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DESIGN AUTOMATION & EMBEDDED SYSTEMS

8 OKT VAN DER VALK HOTEL EINDHOVEN D&E event 2019

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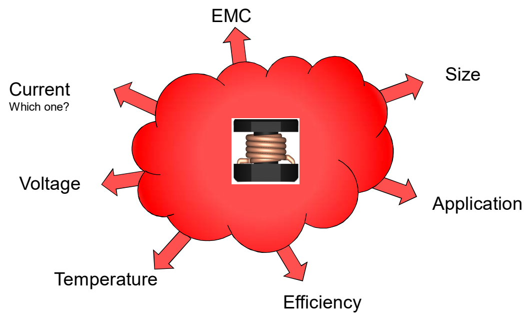
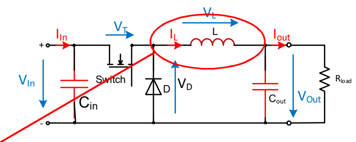
- Todays challenges in Power design
- Inductor Caculation
- Shrinking the inductor
- Summery
- Questions and answers.

HOW TO CHOOSE A POWER INDUCTOR

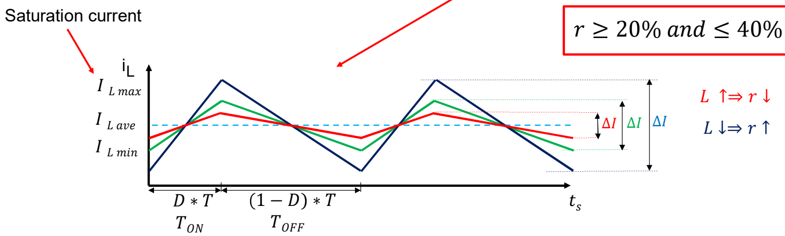


BUCK CONVERTER : Inductor calculation

$$L = \frac{(V_{in} - Vout) * D}{f_{switch} * r * Iout}$$



$$r \geq 20\% \; and \leq 40\% \; of \; Iout$$



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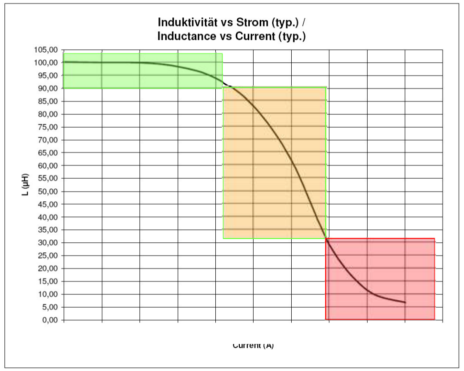
INDUCTOR SELECTION : L vs Current



safe operation area

critical operating area

total saturation area

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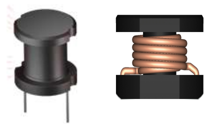
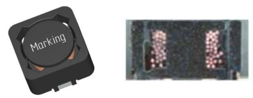
INDUCTOR DESIGN : Standard design

Toroidal coil : Iron Powder
WE-SI, WE-FI

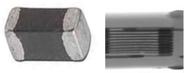


Solenoid coil :
NiZn / MnZn
WE-Tix, PD2



Solenoid coil + Shielding
NiZn / MnZn
WE-PD, WE-TPC, WE-PD2SR

INDUCTOR DESIGN : Standard design



Small size : 0603 to 1210

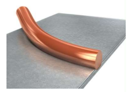
Multilayer
NiZn and Metal Alloy
WE-PMI, WE-PMCI

Semi Shielded
NiZn
WE-LQS

Plastic Molded
NiZn
WE-GF, WE-GFH

INDUCTOR DESIGN : MOLDED INDUCTOR

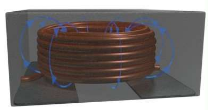
Lead frame free-design for best co-planarity



No solder or welding joints for highest reliability

Greatest core utilization for highest current handling

Reduce parasitic capacitances for lowed AC losses



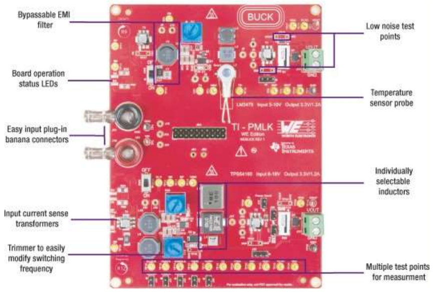
Self shieling construction for best EMI performance

Protective coating for perfect robustness

TI-PMLK Buck Würth Elektronik Edition

- The board allows to analyze:
  - The inherent properties of power inductors, including saturation, losses and thermal effects, and their correlation with physical characteristics
  - The impact of switching regulators operating conditions on the inductors characteristics
  - The impact of inductors characteristics on the operation and performances of switching regulators

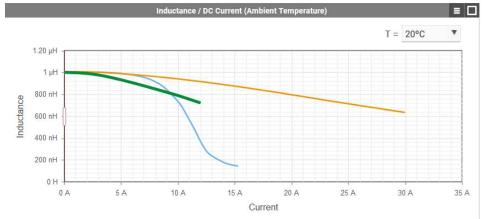
LM3475, hysteretic controller



TPS54160, peak current controller

Downsizing the inductor, what can we do?

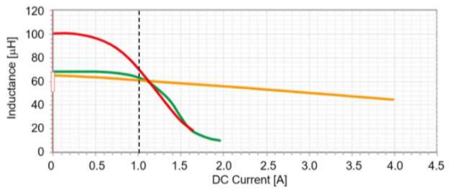
- Increase switching frequency
  - Lower inductance
  - Higher core losses in the inductor
  - Lower DC losses in the inductor
  - Higher switching losses MOSFET
- Change core material
  - Optimize core losses in the inductor for higher switching frequencies.
  - Different saturation behavior due to difference in BH-curve and inductor construction.

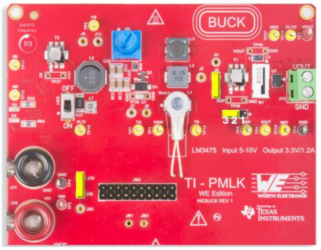


	Order Code	Series	Material	Size	L_0...	$R_{DC,typ}$	I_R	I_{sat}
✔	74438357010	WE-MAPI	Metal Alloy	4030	1.00 µH	11.6 mΩ	7.40 A	9.60 A
✔	7447779001	WE-PD	NiZn	7345	1.00 µH	10.0 mΩ	5.30 A	9.50 A
✔	74437349010	WE-LHMI	Iron Powder	7050	1.00 µH	6.10 mΩ	10.0 A	19.5 A

We can also use saturation behavior!

Input	Output	Switch	Inductor	Diode
10.0 V 5.00-10.0 V	3.30 V 1.00 A	500 kHz	40 % Single	0.40 V





	L_{nom} [µH]	R_L [mΩ]	L_{out}@1A [µH]	D@L_{nom}	Δi_{Lpp}@L_{nom} [mA]	D@L_{out}	Δi_{Lpp}@L_{out} [mA]
L1	100	270	70	0.380	69	0.380	48
L2	68	386	60	0.391	82	0.391	72
L3	68	239	63	0.377	77	0.377	71

Compare of L4, L5 and L6

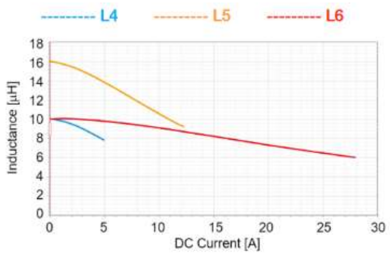
ind.	f_{sw} [kHz]	300		
	I_{out} [mA]	400	800	1200
L1	Δi_{Lpp} [mA]	102	120	170
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	43.4	173.1	389.5
	P_{ind} [mW] REDEXPERT	5.1	5.7	7.9
	P_{loss} [mW]	274.4	548.8	963.2
	η [%]	83.1	83.1	80.7
L2	Δi_{Lpp} [mA]	122	125	128
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	62.2	247.5	556.4
	P_{ind} [mW] REDEXPERT	4.6	5.1	5.7
	P_{loss} [mW]	334.0	690.0	1284.0
	η [%]	80.1	79.6	75.9
L3	Δi_{Lpp} [mA]	130	135	188
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	38.6	153.3	344.9
	P_{ind} [mW] REDEXPERT	5.3	5.5	7.2
	P_{loss} [mW]	314.4	618.8	1103.2
	η [%]	81.1	81.3	78.5

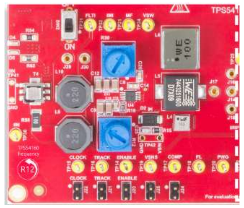
- WE-TPC
- Size 8043
- L = 100uH

- WE-LHMI
- Size 7050
- L = 68uH

- WE-PD
- Size 7043
- L = 68uH

Or use totally different inductors.





	L [µH]	R_L [mΩ]	series	size	core material	length [mm]	width [mm]	height [mm]	vol [mm³]
L4	10	101	WE-MAPI	4030	Met. Alloy	4.1	4.1	3.1	52.1
L5	16	34.5	WE-HCI	1050	Superflux	10.5	10.2	5.0	535.5
L6	10	11.4	WE-XHMI	1090	Hyperflux	11.6	10.5	9.1	1108

Compare of L4, L5 and L6

ind.	f_{sw} [kHz]	300		
	I_{out} [mA]	400	800	1200
L4	Δi_{Lpp} [mA]	773	803	815
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	23.1	76.3	164.5
	P_{ind} [mW] REDEXPERT	31.6	31.0	30.3
	P_{loss} [mW]	265.2	530.4	935.6
	η [%]	83.4	83.4	81.1
L5	Δi_{Lpp} [mA]	455	461	466
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	6.1	22.7	50.3
	P_{ind} [mW] REDEXPERT	17.3	17.1	17.0
	P_{loss} [mW]	334.0	690.0	1284.0
	η [%]	85.0	85.0	83.1
L6	Δi_{Lpp} [mA]	805	807	808
	$P_{wDC} + P_{wAC}$ [mW] eqs. (11)(12)	2.4	7.9	17.0
	P_{ind} [mW] REDEXPERT	36.3	36.3	36.3
	P_{loss} [mW]	265.2	490.4	825.6
	η [%]	83.4	84.5	82.9

- WE-MAPI
- Size 4030
- L = 10uH

- WE-HCI
- Size 1050
- L = 16uH

- WE-XHMI
- Size 1090
- L = 10uH

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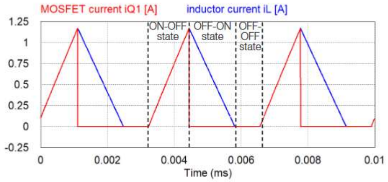
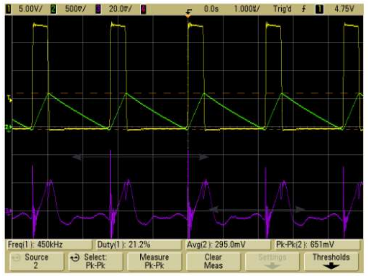
CCM & DCM

- At low load conditions the convertor drops from CCM into DCM or Boundary mode.
  - For the inductor this lead to higher peak currents
  - Efficient of the convertor will drop
  - Not good for EMI
  - Ripple voltage on output will increase





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RedExpert simulation. 18Vin, 300KHz, 300mA Iout.

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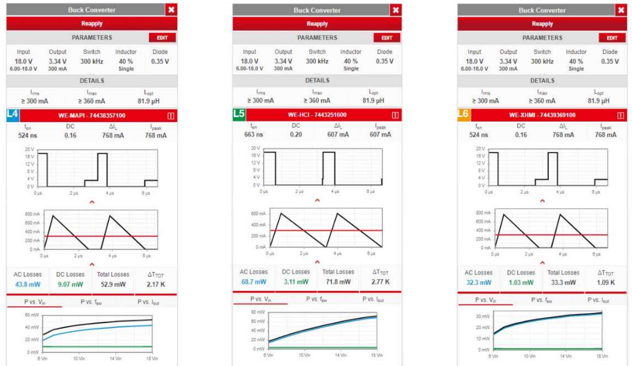

- we-online.com/redexpert

Summery measurements results

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Inductor	L4 (10 µH)		L5 (16 µH)		L6 (10 µH)	
V_{in} [V]	6	18	6	18	6	18
CCM/DCM operation mode	■ CCM □ DCM	□ CCM ■ DCM	■ CCM □ DCM	□ CCM ■ DCM	■ CCM □ DCM	□ CCM ■ DCM
DC input current I_{in} [mA]	187.1	76.5	184.9	75.8	186.6	76.8
DC output voltage V_{out} [V]	3.337	3.337	3.337	3.337	3.337	3.337
efficiency η [%]	87.7	71.5	88.7	72.2	87.9	71.2
peak-peak inductor ripple current Δi_{Lpp} [mA]	505	825	295	560	520	830
inductor average current I_L [mA]	295	295	295	295	295	295
peak-peak input ripple current Δi_{inpp} [mA]	21	38	20	31	22	44

RedExpert Simulation 18Vin, 450KHz, 300mA Iout

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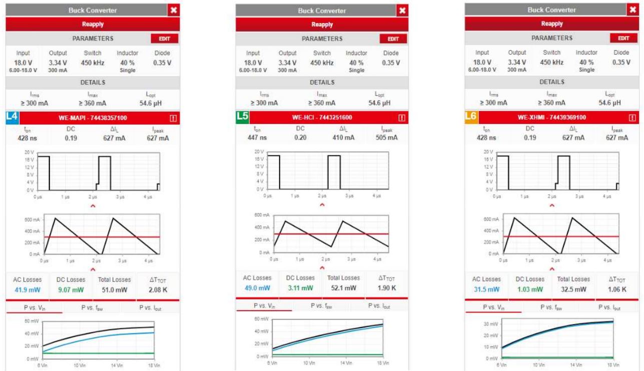

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Summery measurements results

fsw = 450 kHz and Iout = 0.3 A

Inductor	L4 (10 µH)		L5 (16 µH)		L6 (10 µH)	
V_{in} [V]	6	18	6	18	6	18
CCM/DCM operation mode	■ CCM □ DCM	□ CCM ■ DCM	■ CCM □ DCM	■ CCM □ DCM	■ CCM □ DCM	□ CCM ■ DCM
DC input current I_{in} [mA]	186.9	77.7	185.4	77.5	186.2	77.9
DC output voltage V_{out} [V]	3.337	3.337	3.337	3.337	3.337	3.337
efficiency η [%]	87.8	70.4	88.5	70.6	88.1	70.2
peak-peak inductor ripple current Δi_{Lpp} [mA]	340	650	200	380	350	665
inductor average current I_L [mA]	295	295	295	295	295	295
peak-peak input ripple current Δi_{inpp} [mA]	19	33	17	28	23	38

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Hands-on learning kit

- Investigate the impact of magnetics on the performance of a switching power supply
- Help to speed up your design
- Ideal for everyone new in the field of power design but also experienced designers to increase knowledge of magnetic components
- Developed in collaboration with Texas Instruments and with Dr. Nicola Femia, a renowned industry power expert and faculty at the University of Salerno, Italy.
- Get your kit at we-online.com or your local sales contact

Download the experiment book

Complete version - Rev B
The complete version of the PMLK Learning Kit Experiment book

Kit Introduction - Rev B
The Kit introduction and and explanation of the board

Experiment 1 - Rev B
Investigate how the inductance of a power inductor changes depending on its physical characteristics and on the operating conditions

Experiment 2 - Rev B
Investigate the impact of inductor power losses on the efficiency of a DC-DC switching regulator

Experiment 3 - Rev B
Analyze the output filtering functions of inductors in DC-DC switching converters

Experiment 4 - Rev B
Analyze the input filtering functions of inductors in DC-DC switching converters

Experiment 5 - Rev B
Analyze the impact of inductors on continuous and discontinuous mode operation of DC-DC switching converters

Experiment 6 - Rev B
Analyze the impact of the inductor on the closed loop load-transient response of a peak-current mode controlled buck regulator

For questions and feedback: pmlk@we-online.com

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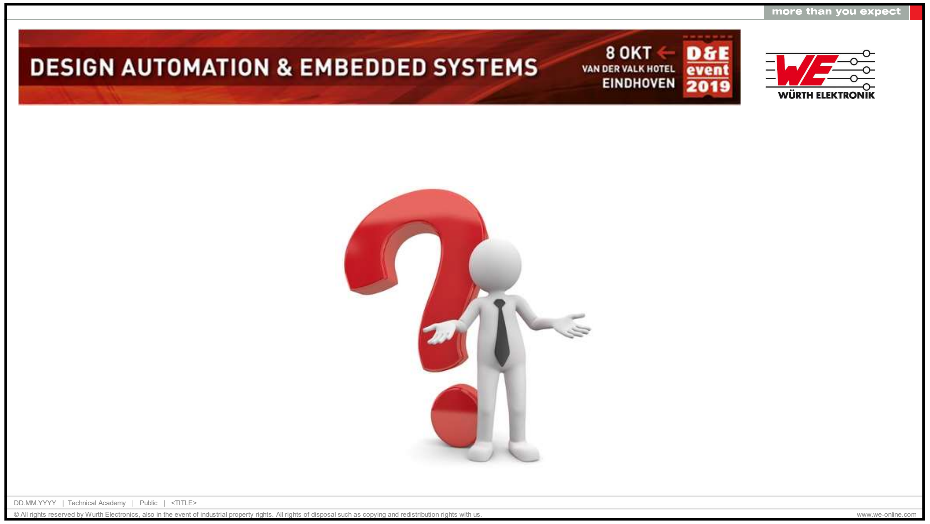
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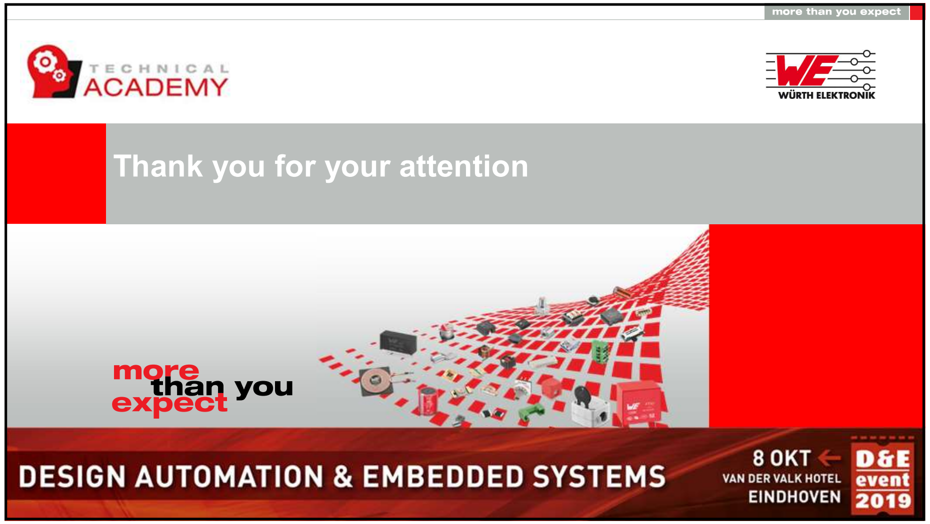
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