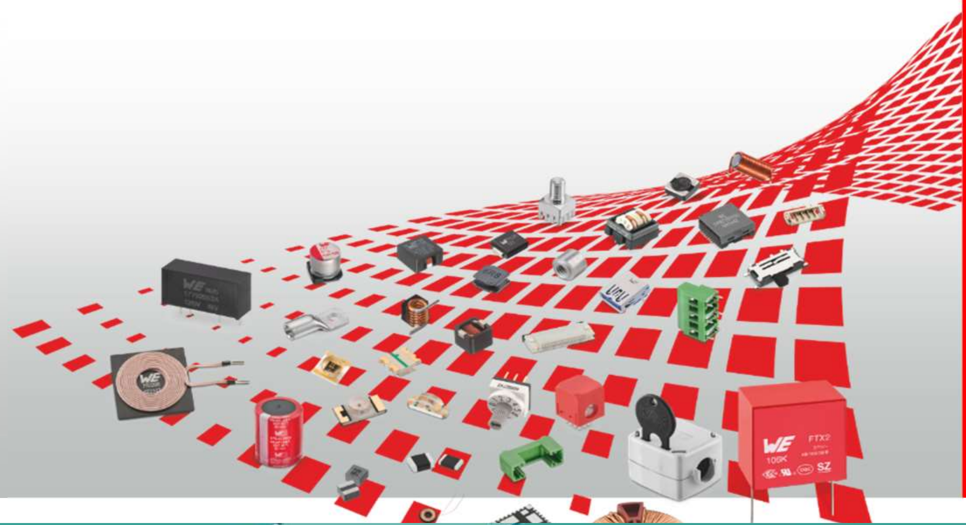
more than you expect

TECHNICAL ACADEMY

WÜRTH ELEKTRONIK

High Current Power inductors



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17/06/19

more than you expect

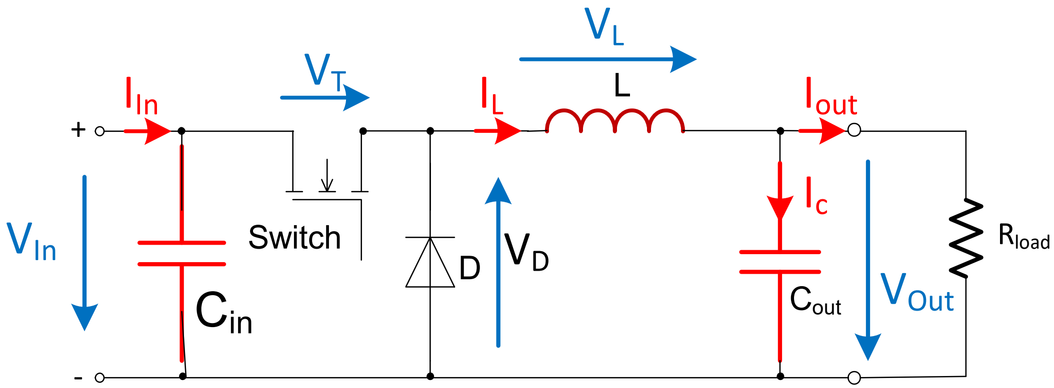
19 juni 2019
1931 Congrescentrum 's-Hertogenbosch

POWER ELECTRONICS 2019

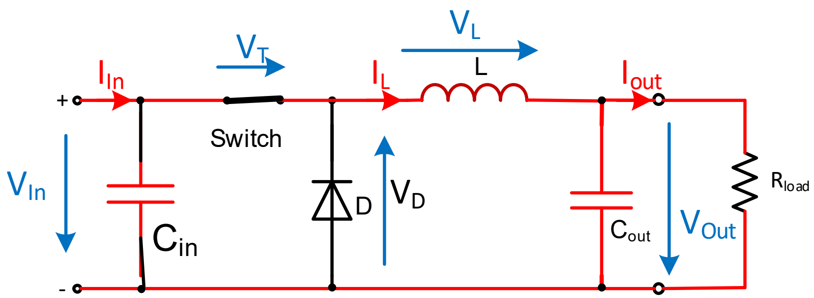
Agenda

- What is High Current
- Inductor losses
- Inductor Currents
- How to select the best inductor for a Buck?
- What about Capacitors?

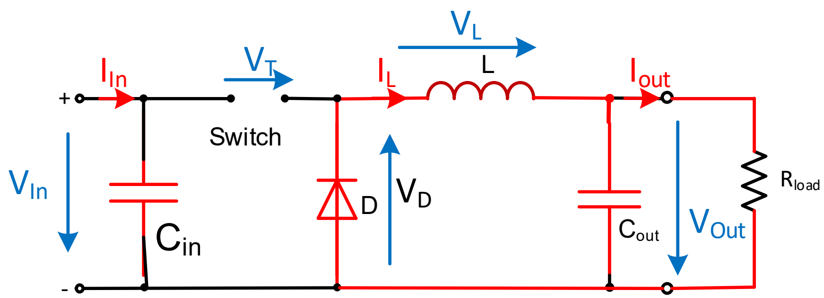
BUCK CONVERTER : Topology



Switch Closed



Switch Open



What is High Current?

- Depends on the perspective of the engineer/application
- For an inductor the following is important
- *DC-losses in an inductor*
  - $P_{winding} = I^2 . R_{dc}$
- AC losses in an inductor
  - Cores losses + wire losses

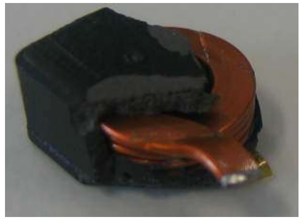
How to optimize for DC-losses?

- *DC-losses in an inductor*
  - $P_{winding} = I^2 . c$
  - $I^2 = I_{out^2}$
  - $R_{DC} = \rho \, . \, \frac{l}{A}$

D Electrical Properties:

Properties	Test conditions		Value	Unit	Tol.
Inductance	1 kHz/ 250 mV	L	10	µH	±20%
Rated current	ΔT = 40 K	I_R	7.1	A	max.
Saturation current	|ΔL/L| < 10%	I_{sat}	10.5	A	typ.
DC Resistance	@ 20°C	R_{DC}	0.013	Ω	typ.
DC Resistance	@ 20°C	R_{DC}	0.021	Ω	max.
Self resonant frequency		f_{res}	21	MHz	typ.

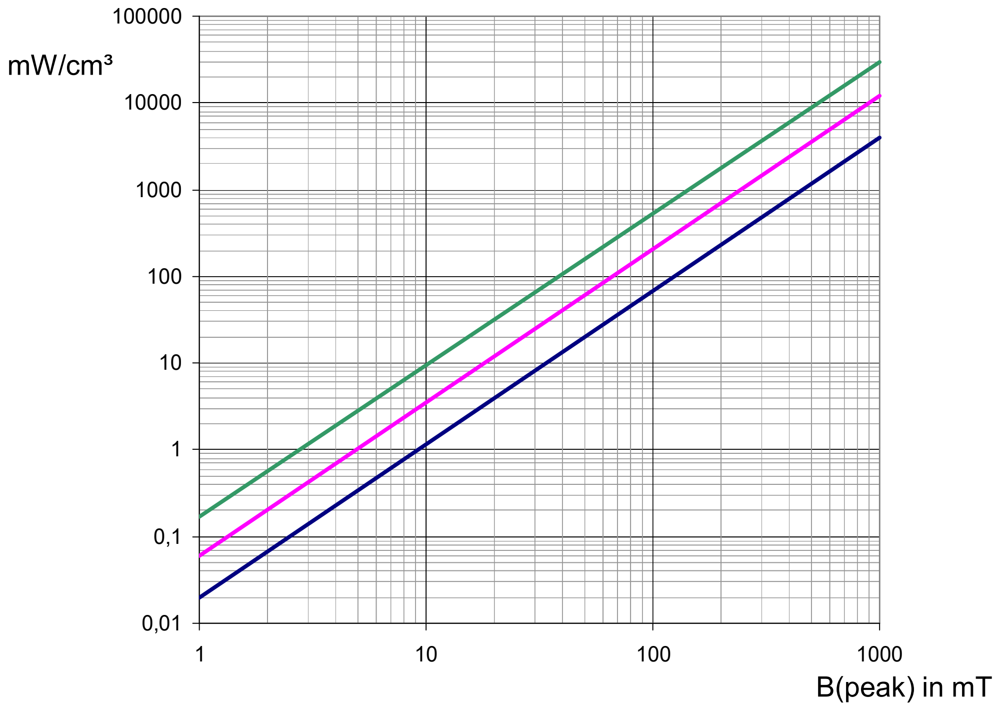
- So what can we do?
  - We can lower the R_{dc}
    - By lowering the length of the wire
    - Increasing the surface area of the wire
    - Change the wire construction



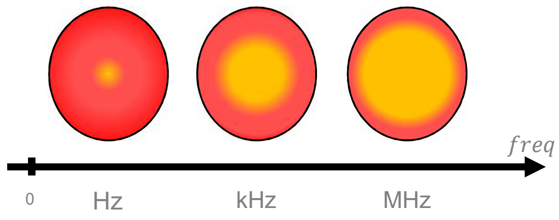
    - Choosing a different conductor material

How to optimize for AC-losses?

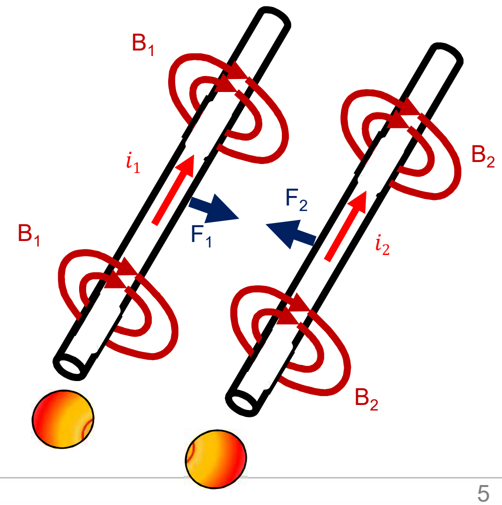
- *AC-losses in an inductor*
  - $P_{core} = K \,.\, f^{a} \,.\, B^{b}$



- AC-losses in a wire structure
  - Skin Effect



  - Proximity effect



How to optimize for AC-losses?

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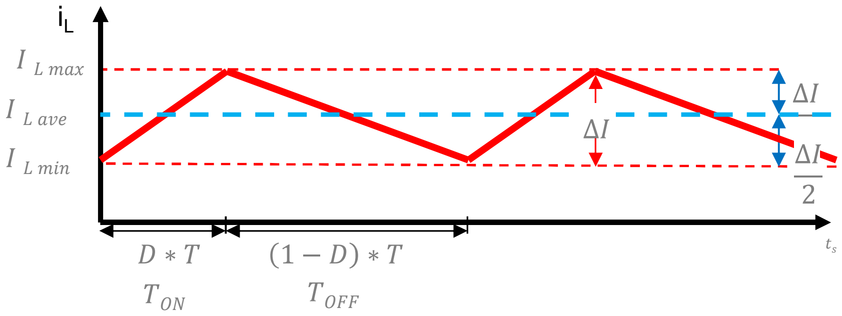
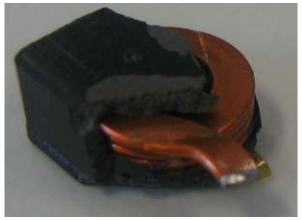
- *AC-losses in an inductor*
  - $P_{core} = K \,.\, f^{a} \,.\, B^{b}$
- *So what can we do to lower core losses?*
  - *Lower switching frequency*
  - *Lower peak currents*
  - *Increase core size*
  - *Change core material*



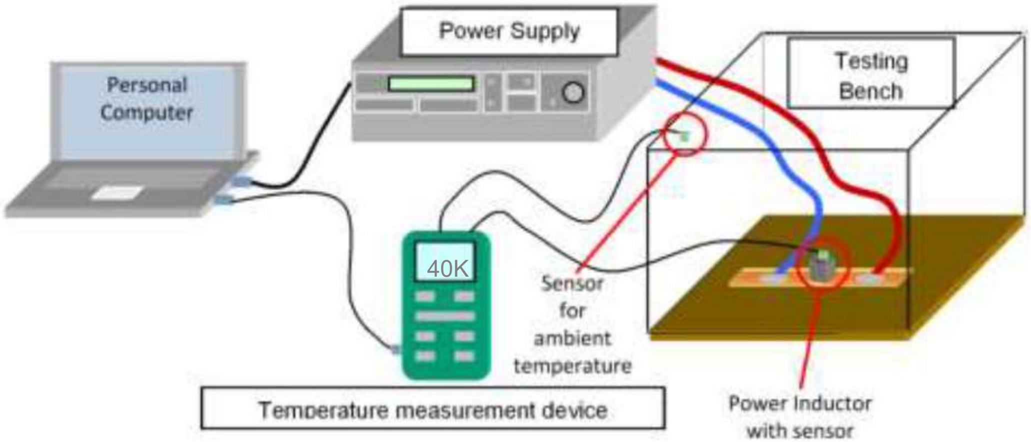
- AC-losses in a wire structure
- How to optimize skin effect?
  - Use flat wire or Litz wire to increase skin



- How to optimize Proximity effect?
  - Optimize winding structure to minimize interaction and parasitic effects.

INDUCTOR SELECTION : Rated Current

Rated Current : I_R



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INDUCTOR SELECTION : Rated Current

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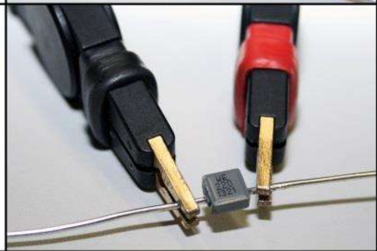
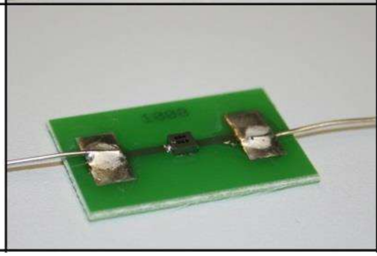
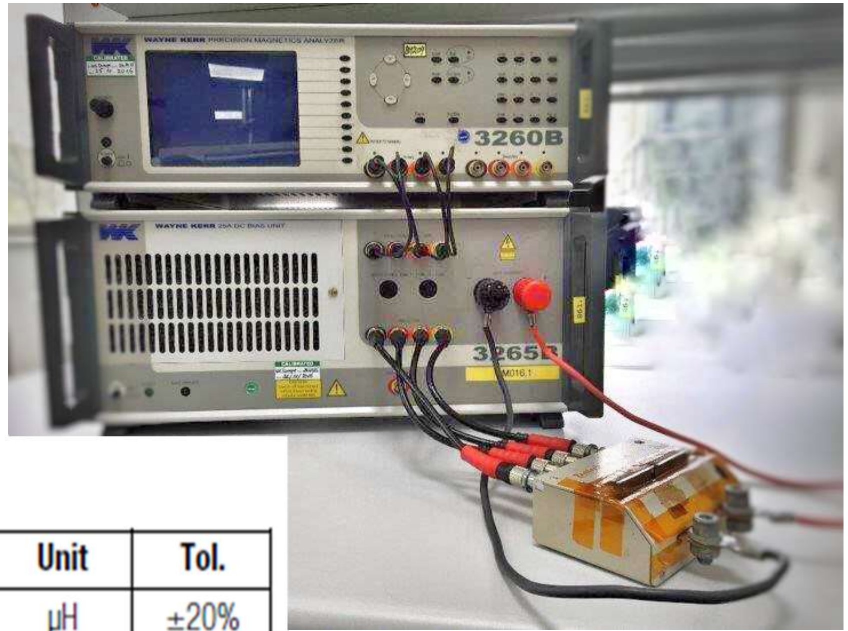
- Impact of the setup

- Rated current is link to the R_{DC} of the Inductor

Contacting The Inductor		ΔT @ 9 A
- WE-LHMI 7030 - 74437346220 - inductor on wires - huge clamps		30,9 K
- WE-LHMI 7030 - 74437346220 - inductor on wires - small clamps		35,8 K
- WE-LHMI 7030 - 74437346220 - inductor on PCB - recommended pad design		40,0 K

INDUCTOR SELECTION : Saturation Current

- Saturation current definition
  - The current that causes an inductance drop compared to it initial inductance value. In most cases for our inductors a drop of 10% - 30% is specified. Depending on inductor core material.



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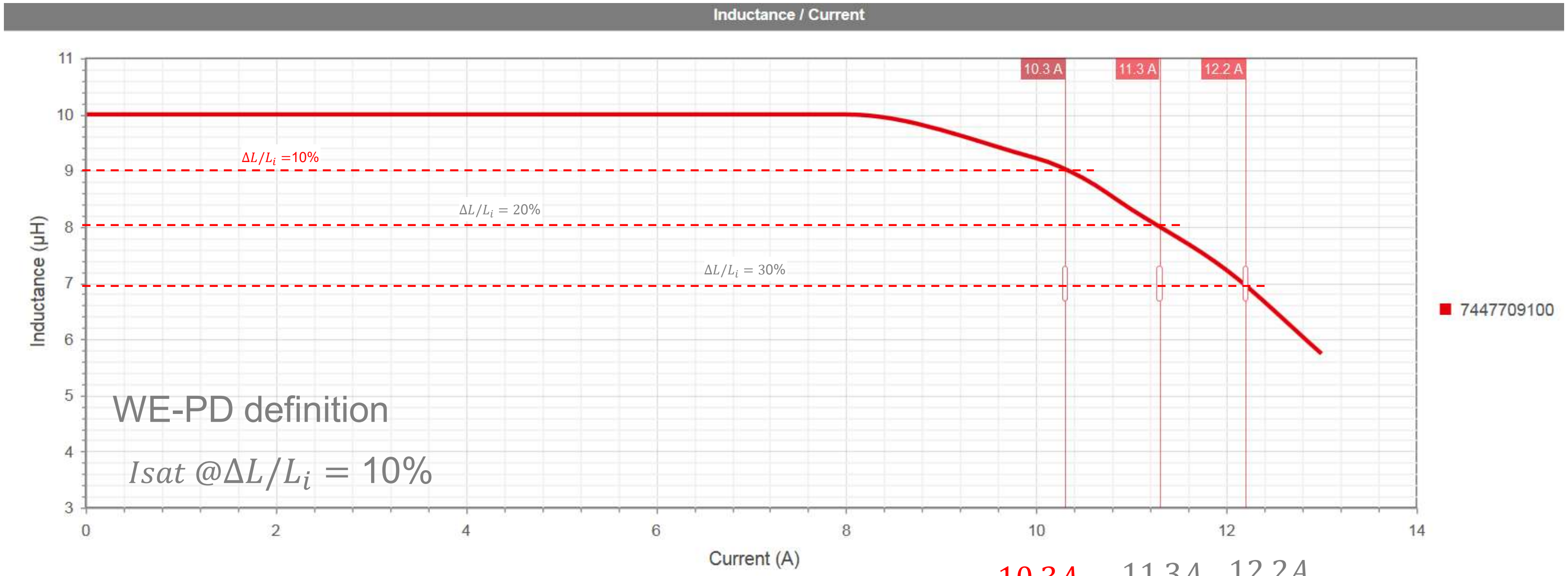
INDUCTOR SELECTION : Saturation Current

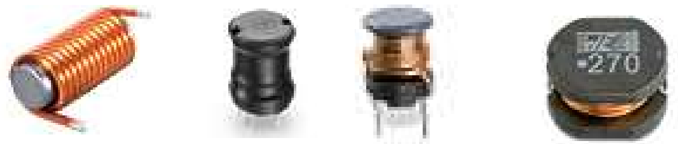


$10{,}3A$ $11{,}3A$ $12{,}2A$

$Isat = Depend\ on\ the\ definition$

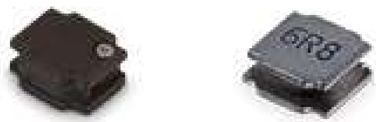
INDUCTOR DESIGN : Standard design

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



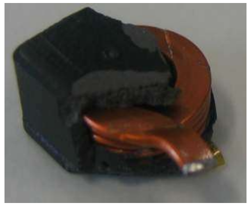
- Solenoid coil : NiZn / MnZn
  - WE-SD,WE-Tix, PD2

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



- Solenoid coil + Semi-shielding : NiZn / Metal Alloy
  - WE-LQS, WE-LQSH

INDUCTOR DESIGN : High Current








- **Flat wire Construction**
  - WE-PERM / MnZn/ NiZn and Superflux core
  - WE-PDF, WE-HCI, WE-HCF, WE-HCM
  - Rdc as low as 0,114mΩ
  - Saturation current as high as 125A
- **Round wire molded Construction**
  - Iron Powder and Metal Alloy core
  - WE-LHMI, WE-XHMI, WE-MAPI, WE-PMCI
  - Rdc as low as 0,510mΩ
  - Saturation current as high as 120A
- **Litz wire Construction**
  - MnZn core
  - WE-HCF Litz
  - Rdc as low as 15,3mΩ
  - Saturation current as high as 16,3A

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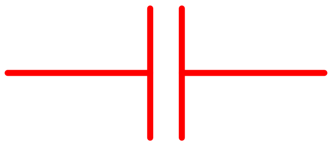
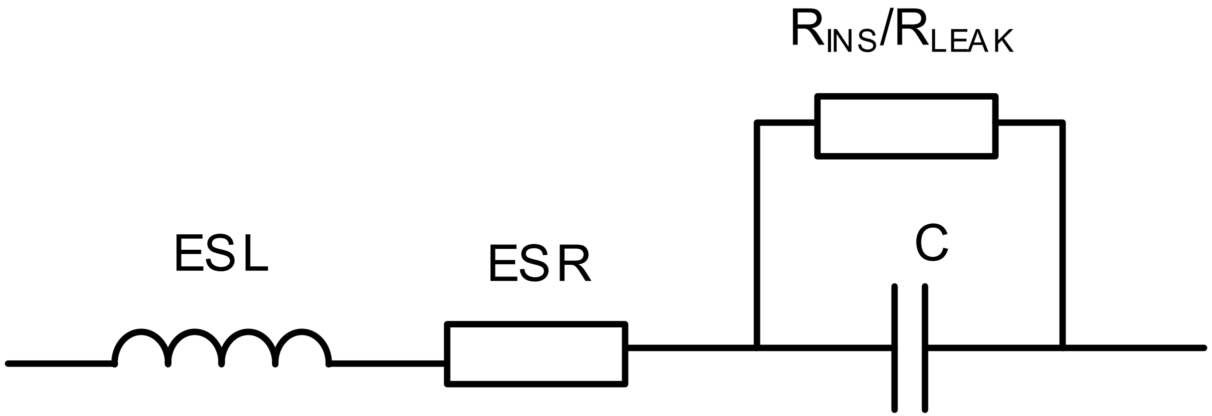
Capacitor : Equivalent Circuit





Output capacitor: RMS current

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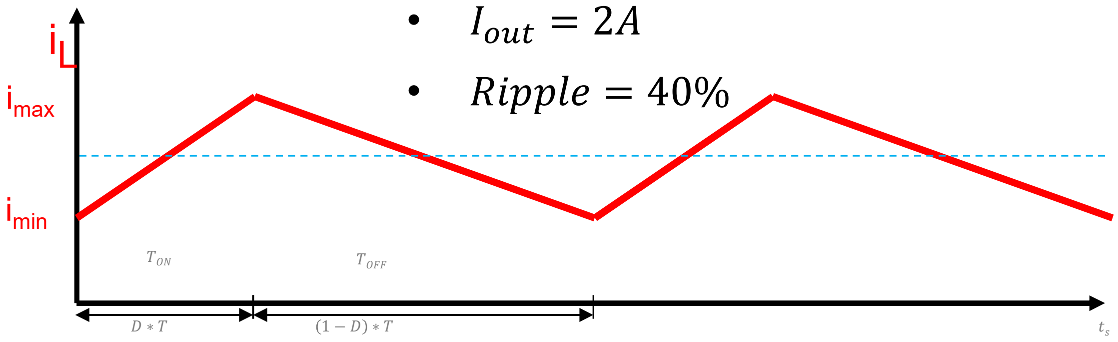
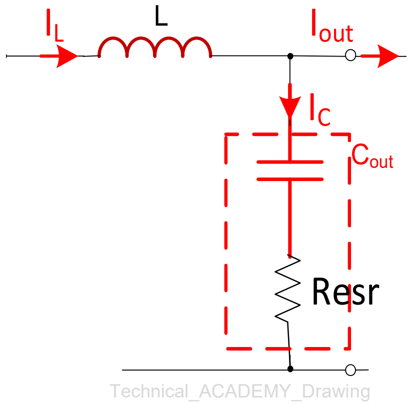
- $I_{out} = 2A$
- $Ripple = 40\%$





$$I_{Lmax} = Iout + \frac{\Delta IL}{2} \qquad I_{Lmin} = Iout - \frac{\Delta IL}{2}$$

$$I_{C,RMS} = \sqrt{I^2{}_{L,RMS} - I^2{}_{out}}$$

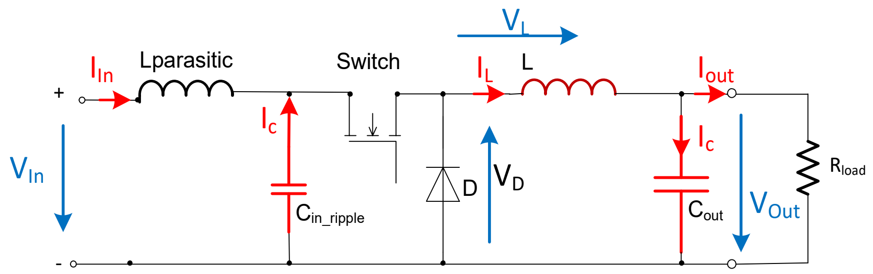
$$I_{L,rms} = \frac{\sqrt{12.I_{out}^2 + \Delta I^2}}{2\sqrt{3}} = 2{,}013A$$

$$I_{C,RMS} = 228\ mA$$

Input capacitor: RMS current

- $V_{in} = 24V$
- $V_{out} = 5V$
- $I_{out} = 2A$
- $F_{sw} = 535\ kHz$

$$D = \frac{V_{out}}{V_{in}} = 0{,}208$$



$$L = 10\mu H\ for\ 40\%\ ripple$$

$$Max\ intput\ ripple\ voltage\ 50\ mV$$

$$\Delta VC = 50\ mV$$

$$I_{sw,rms} = \frac{\sqrt{D(12.I_{out}^2 + \Delta I^2)}}{2\sqrt{3}}$$

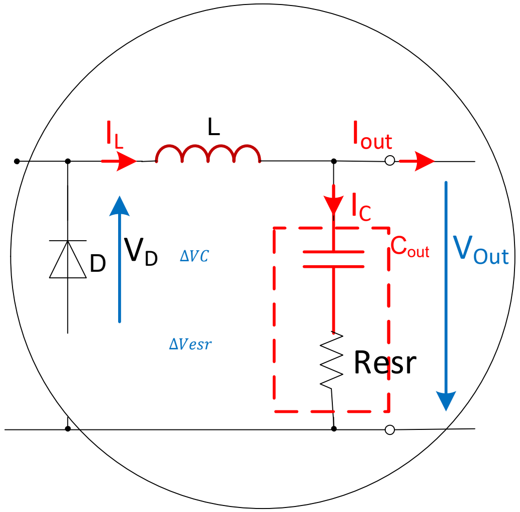
$$I_{C,\ RMS} = \sqrt{I^2{}_{sw,\ RMS} - I^2{}_{in,\ DC}}$$

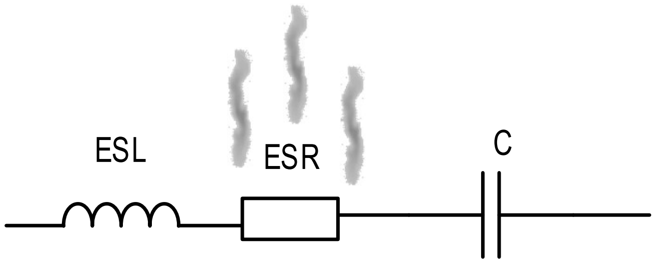
$$I_{in} = \frac{D * I_{out}}{\eta}$$

$$I_{C,\ RMS} = 793\ mA$$

$$@5A\ output\ current$$
$$I_{C,\ RMS} = 2.367\ mA$$

Capacitor : Ripple current





- <u>Aluminum Electrolytic Capacitors</u>
  - Ripple current can be critical, shortening of lifetime, and for too high ripple explosive failure, blown vent and electrolyte leakage

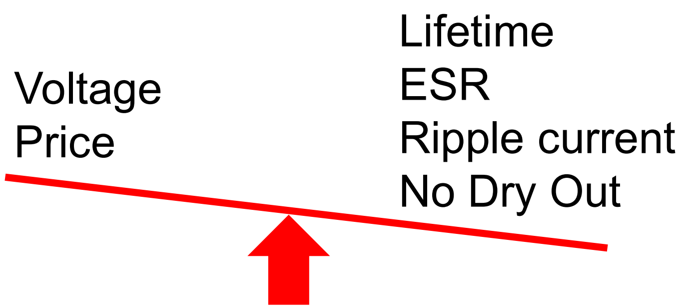
- <u>Ceramic Capacitors</u>
  - Lowest ESR /mostly have no ripple current limitation

- <u>Film capacitors</u>
  - Low ESR, but ripple current can cause damage

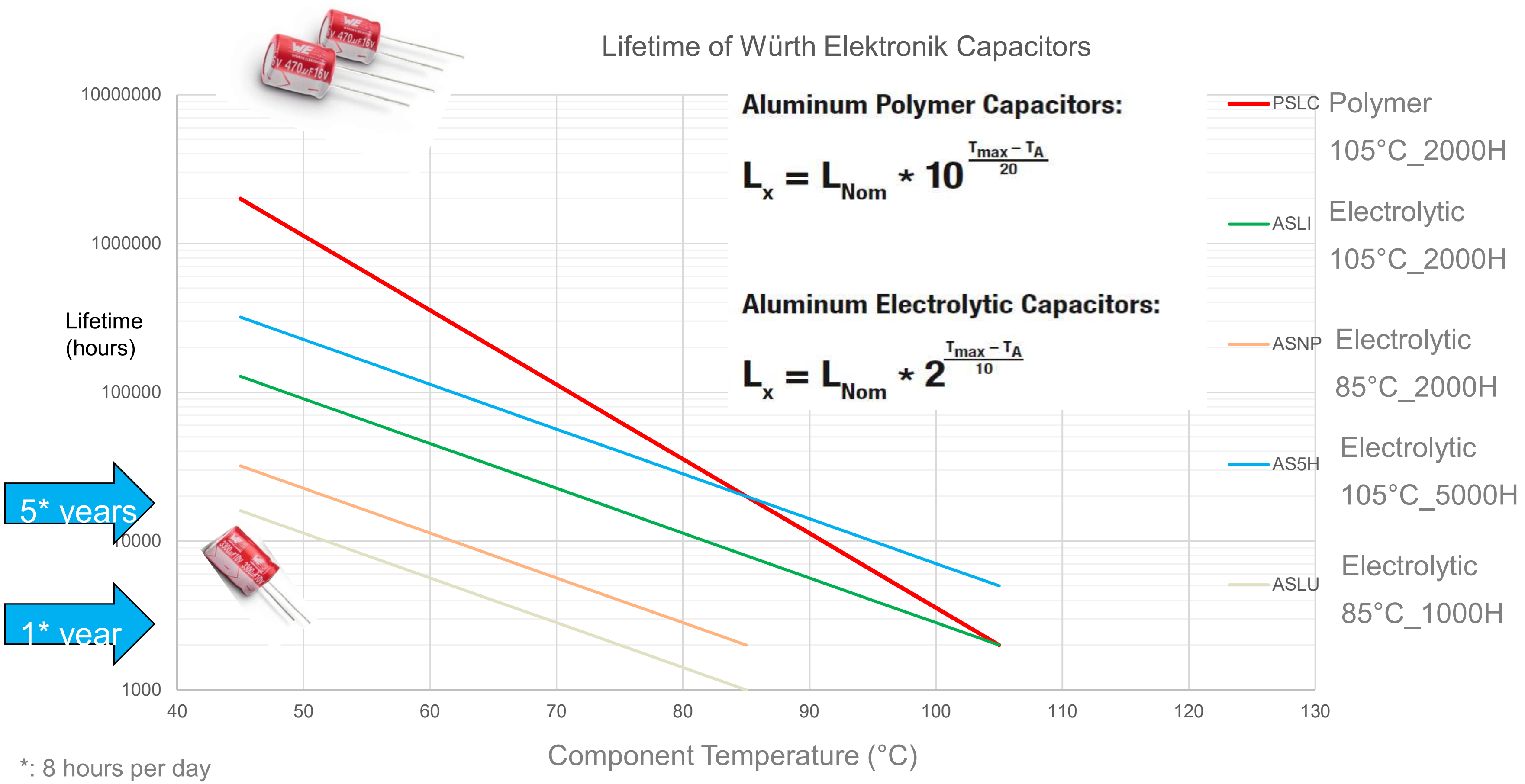
Electrolytic Capacitor: Polymer Vs Electrolytic

- Aluminum- Electrolytic-Capacitor
  - higher voltage ratings available (up to 600V)
  - Price advantage in same capacity and voltage rating
  - More capacitance per cm3

- Polymer- Electrolytic-Capacitor:
  - smaller ESR as an Alu-Cap >> higher allowed ripple current
  - No dry-out behavior like Alu-Cap (solid electrolytic)
  - higher expected lifetime / load life



Electrolytic Capacitor: Polymer Vs Electrolytic
Load life calculation



*: 8 hours per day

Electrolytic Capacitor: Polymer Vs Electrolytic
Load life calculation

Temperature	Poly-Cap	Alu-Cap	factor Poly vs. Alu	Alu-Cap	factor Poly vs. Alu
105 °C	2.000 h	2.000 h	1,00	5.000 h	0,40
95 °C	6.300 h	4.000 h	1,58	10.000 h	0,63
85 °C	20.000 h	8.000 h	2,50	20.000 h	1,00
75 °C	63.000 h	16.000 h	2,94	40.000 h	1,58
65 °C	200.000 h	32.000 h	5,25	80.000 h	2,50
55 °C	630.000 h	64.000 h	8,84	160.000 h	3,94
45 °C	2.000.000 h	128.000 h	14,62	320.000 h	6,25

Contactgegevens

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