WÜRTH ELEKTRONIK

How do I solve EMI on PCB level?

Speaker:

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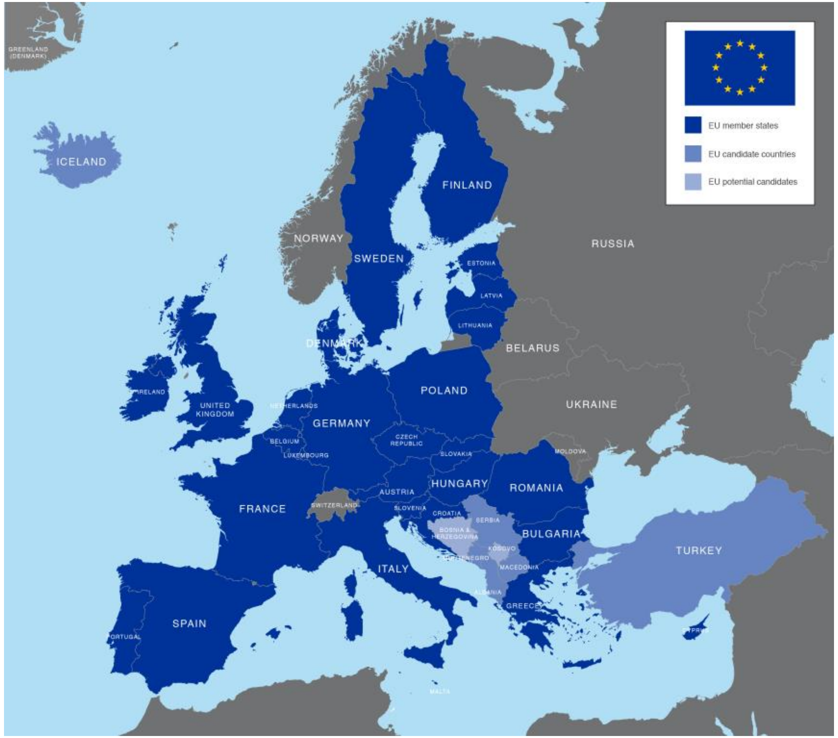
REQUIREMENTS IN EMC

CE Marking

- With the formation of the single European market, standardization was required to remove technical barriers to trade.
- New Approach Directives were introduced to remove these barriers to trade

- 20 regulations and directives:
  - LVD - Low Voltage Directive 2014/35/EU
  - EMC - Electromagnetic Compatibility 2014/30/EU
  - R.E.D. - Radio Equipped Directive 2014/53/EU
  - MD - Machinery Directive 2014/90/EU



Other International EMC approval marks

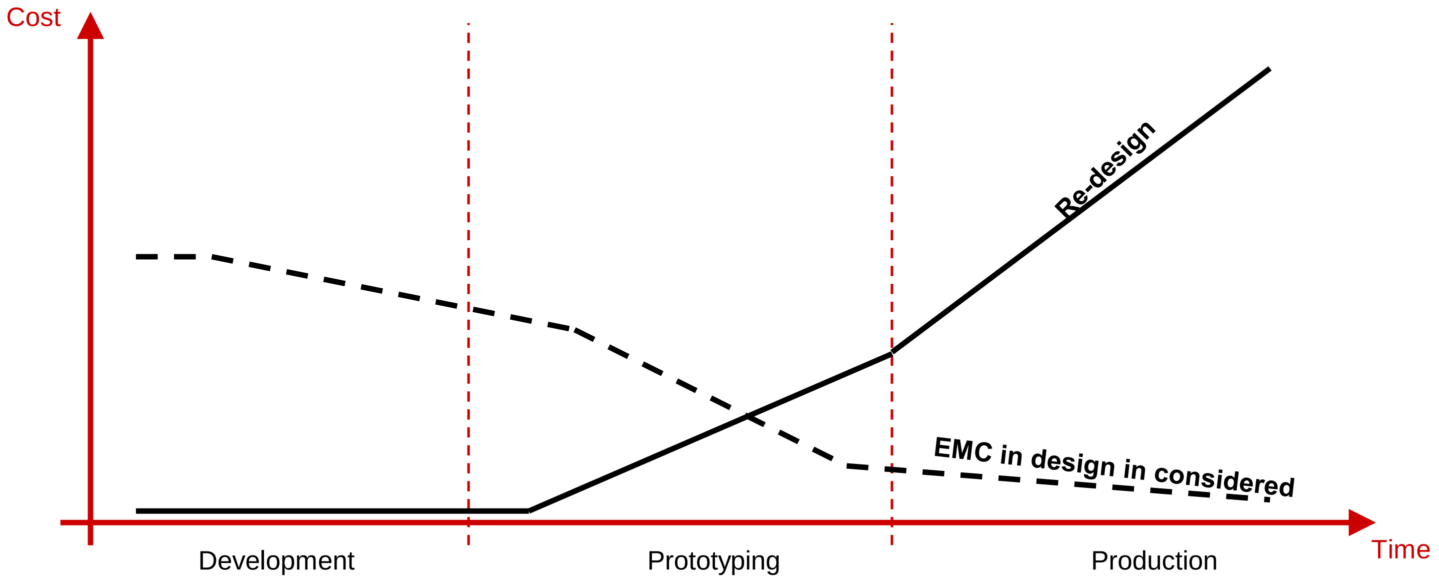
- Federal Communications Commission

- Voluntary Control Council for Interference

- Australian Communications and Media Authority

Design phase for EMC

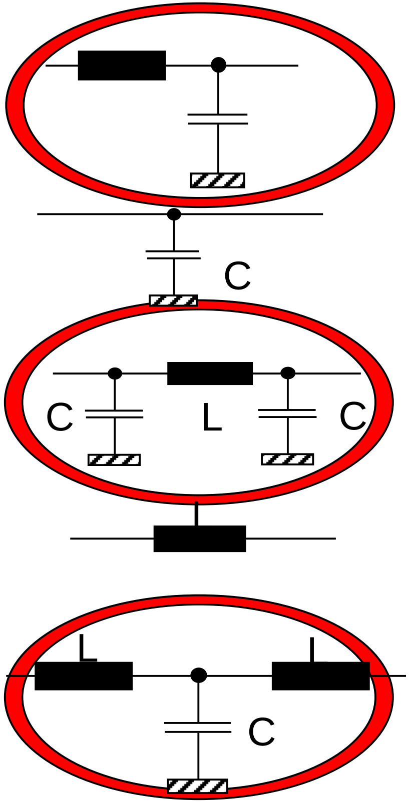
- Economical point of view:
- Depends on you when will start to design EMC conform



How can we check the EMC ?

Insertion loss – recommended filter topology

Source Impedance	Load Impedance
low	high
high	high
high or unknown	high or unknown
low	low
low or unknown	low or unknown



→ small C = higher SRF

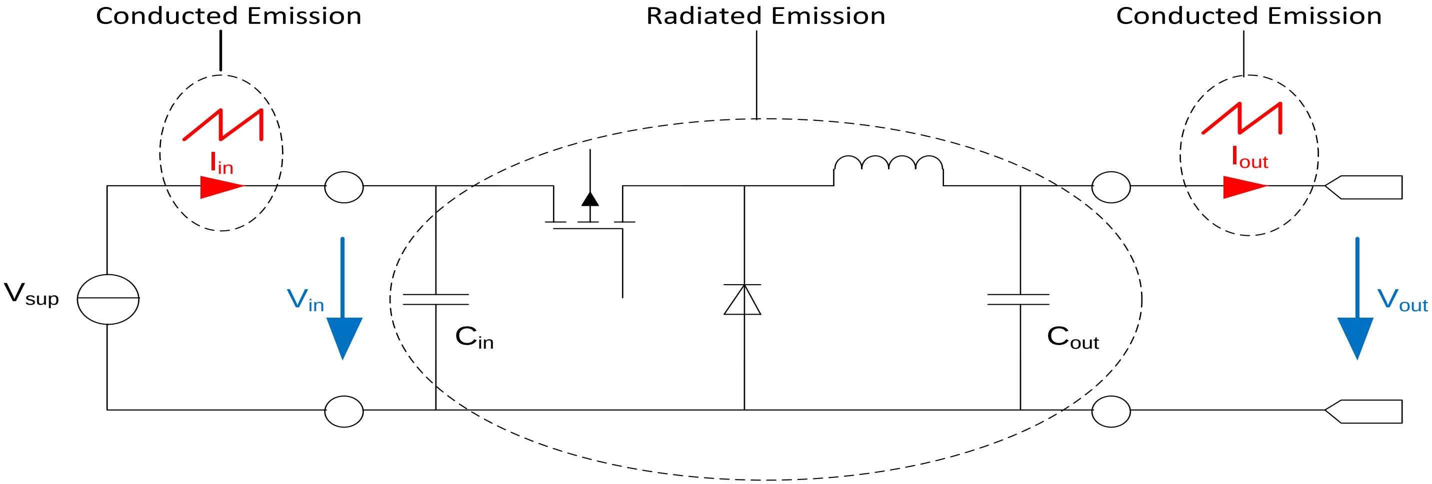
Choose ferrite bead or inductors L which
= build no resonance with C
= broadband filter

Pay attention to:

SRF of used components

EMI NOISE SOURCES

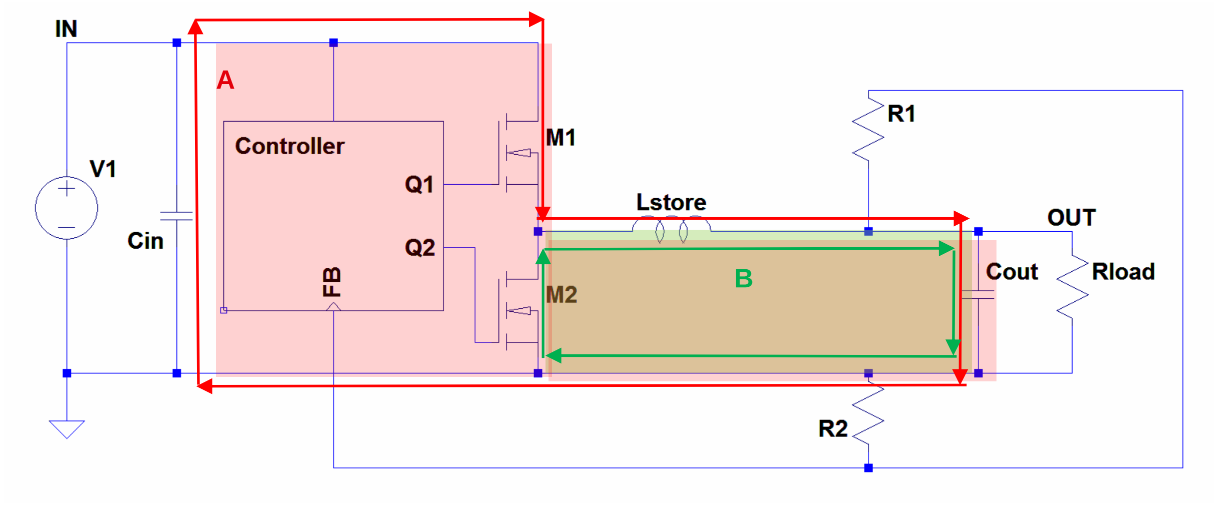
Representative noise sources



- Input current caused by voltage ripple → „Conducted Emission“
- Power traces and choke radiate EMI → „Radiated Emission“
- Output current caused by voltage ripple → „Conducted Emission“
- Radiated emission will increase by using long input / output lines(cables)

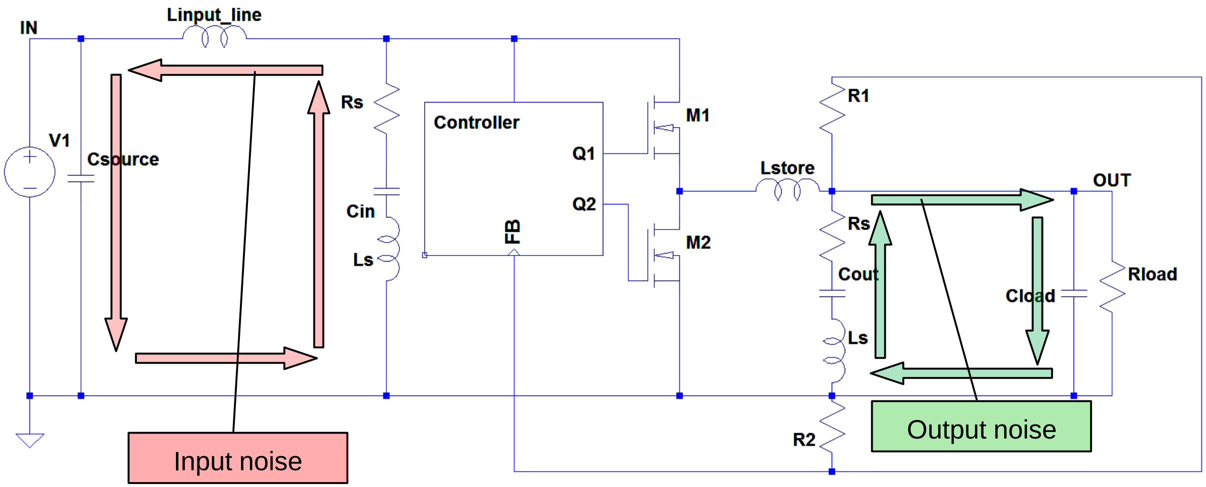
Noise loops in DC/DC buck converter

- From an EMI point of view, the current loop with the highest di/dt is the input area (“A”) , which will generate the most high frequency interference and should be considered the most critical loop in buck converters.
- The di/dt of the current in output area (“B”) is not as high as the input area (“A”) and normally generates less noise

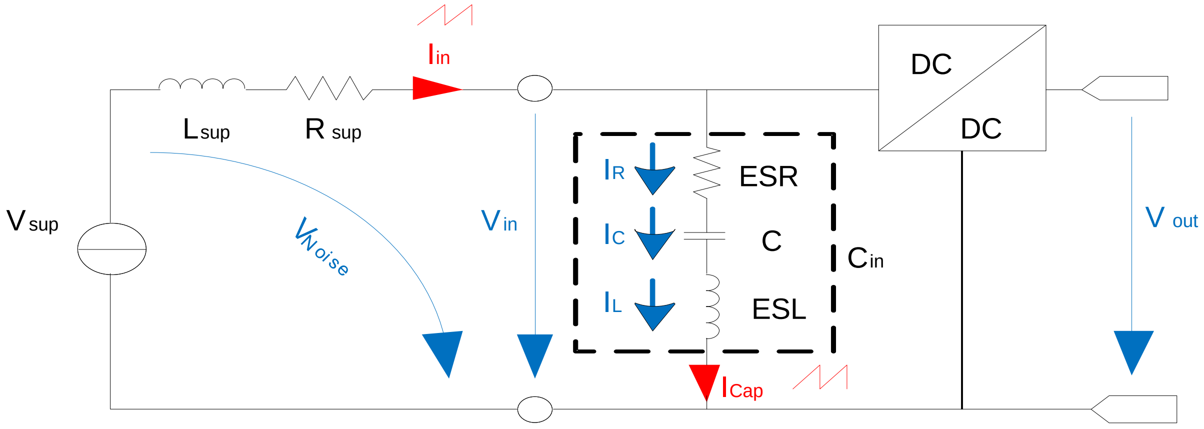


Noise loops in DC/DC buck converter

- Theoretically, the input and output capacitors are considered ideal at very low impedance for the buck converter switching currents. Unfortunately, in real life, capacitors have ESR (Rs) and ESL (Ls), which increase capacitor impedance and result in extra high frequency voltage drops across the capacitors
- This voltage will induce currents in the supply input line that also have parasitic inductance in addition to the output due the connections to the load



Conducted noise at converter input



- **Conducted Emission is generated by voltage drop across R_{Sup} and ESR_L**

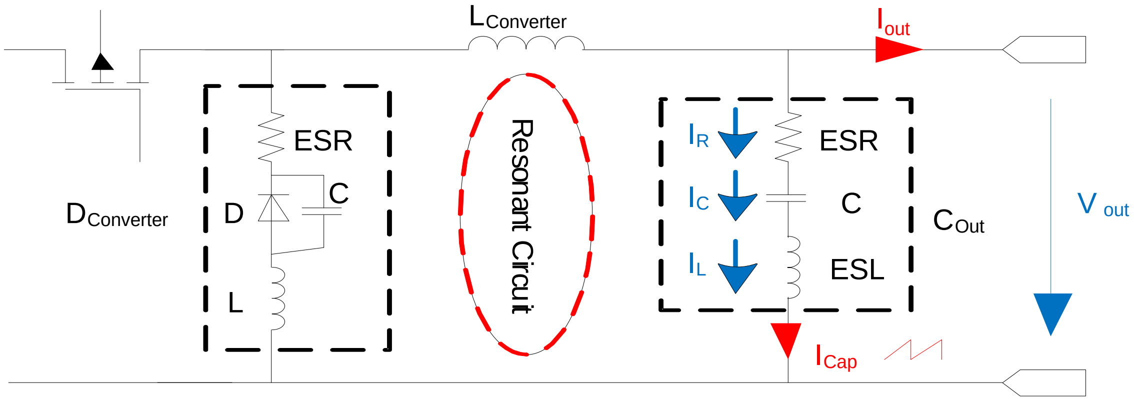
$$V_{Noise} = Rsup * Iin + ESR * ICap$$

- **VNoise = Rsup * Iin + ESR*ICap**
- **Resonance circuit is formed by L_{sup}, C_{in} and ESL_{Cin}**

$f_0 = 1 / 2\Pi\sqrt{(Lsup-ESL)*Cin}$

- **Different harmonics due to fundamental frequency from $f_{DC/DC}$ and $f_{Resonance\ Circuit}$**

Conducted noise at converter output



- **Conducted emission is generated by voltage drop at ESR_C**

$$U_{Noise} = ESR_{Cout} * ICout$$

- **Resonance circuit is formed by $C_{Dconverter}$, C_{Out}, $L_{Converter}$, and ESL_{Cout}**

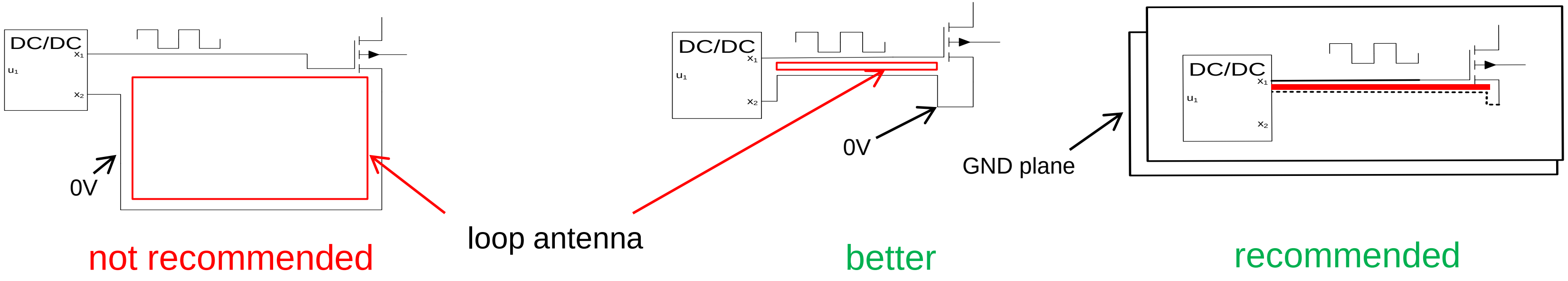
$$f_0 = \frac{1}{2\pi\sqrt{(ESL_{Cout})*COut}}$$

- **Different harmonics due to fundamental frequency from $f_{DC/DC}$ and $f_{Resonance\ Circuit}$**

Radiation of PCB traces

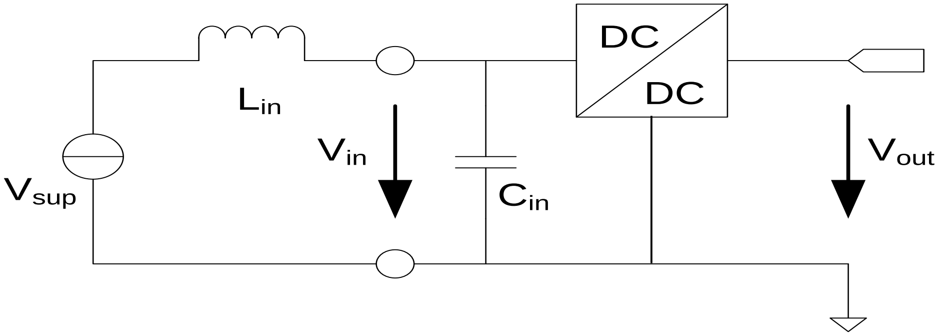
- **Power and signal loops have antenna characteristics**
- **Radiation can occur over the entire power and signal loops**
- **Field strength depends on spanned loop, peak value of alternating current, frequency, distance between noise source and noise receiver**

- **Design recommendations:**
  - ➢ **Keep power and signal traces as short as possible**
  - ➢ **Keep power and signal loops as small as possible**
  - ➢ **Route the trace over GND plane**



FILTER DESIGN

„L“ Input filter
(minimal recommend filter)



- **Simple L-Filter**
  - **Input filter reduce current ripple on input line**
  - **Input filter reduce differential mode noise on input line**
  - **Input filter reduce radiated emission via input traces**

Attention!!! This filter is not efficient to reduce common mode noise on input lines

Calculating rated current I_L

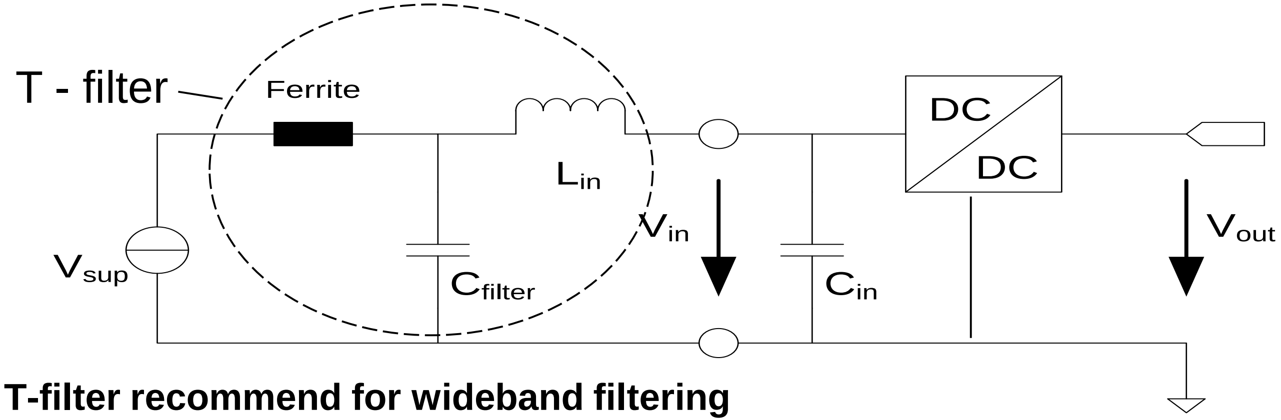
- $\mathbf{I}_L = \frac{(Vout)(Iout)}{(Vin)(E)}$
- Vout =Output Voltage Ex: 5V
- Iout= Output Current Ex: 4A
- Vin= Input Voltage Ex: 20V
- E= Efficiency (/100) Ex: 80% min.

- For Example:
- $\mathbf{I}_L = \frac{(5V)(4A)}{(20V)(0{,}8)} = 1{,}25A$

- **To avoid saturation & heat considerations choose a choke with higher rating current**
- **To avoid losses in efficiency choose a choke with low DCR**

Wideband input filter

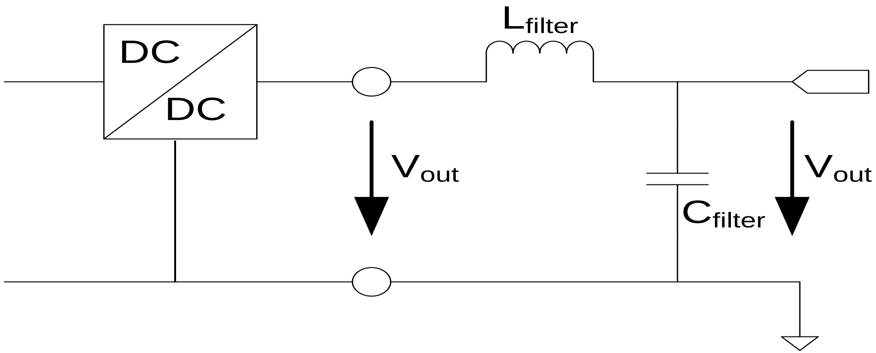
(recommended filter solution)



- **T-filter recommend for wideband filtering**
  - **L_{in} for low frequency filtering (DC/DC converter switching frequency)**
  - **Ferrite for high frequency filtering**
  - **C_{filter} shorting ACnoise to GND (220pF < C_{filter} < 1nF, low ESR)**

Attention!!! This filter is not efficient to reduce common mode noise on input lines

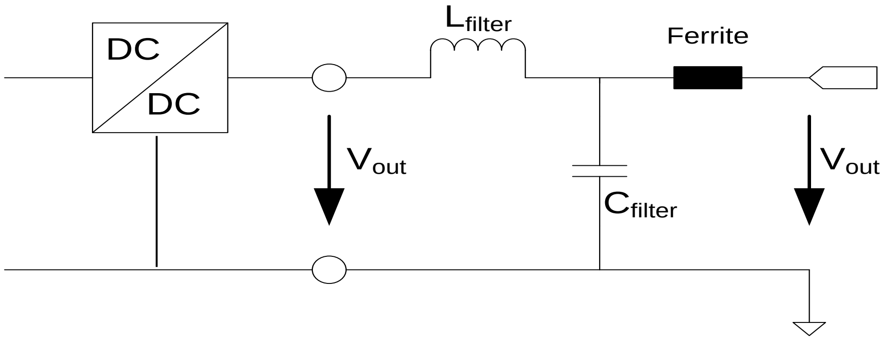
„L / C“ output filter
(minimal recommended filter)



- **Simple L/C Filter**
  - **Output filter reduce voltage ripple on output traces (Conducted Emission)**
  - **Output filter reduce radiated emission via output traces (Radiated Emission)**
  - **Not an optimal solution for RF powered devices**

Attention!!! This filter is not efficient to reduce common mode noise on output lines

„T“ - output filter
(recommended filter solution)

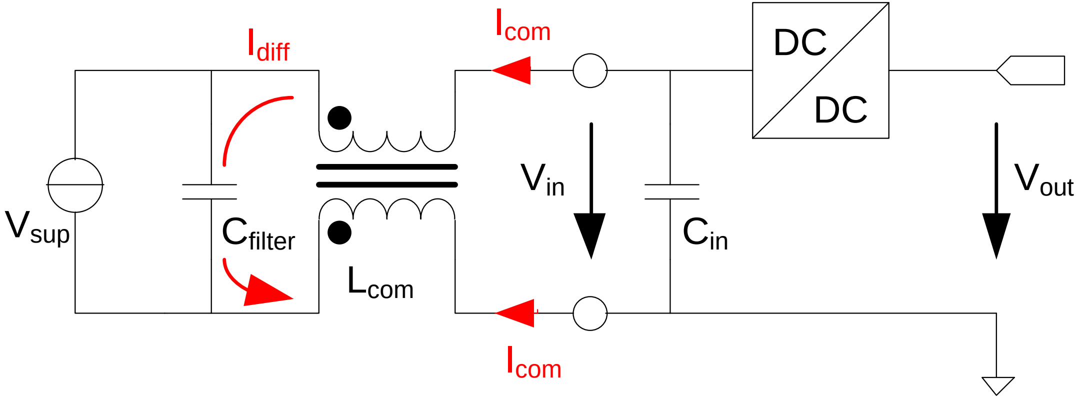


- **T-filter recommend for wide bandwidth filtering**
  - **L_{filter} for low frequency filtering (DC/DC converter switching frequency)**
  - **Ferrite for high frequency filtering**
  - **This kind of output filter is for powering radio devices high recommended**

Attention!!! This filter is not efficient to reduce common mode noise on output line

Decoupling common mode noise

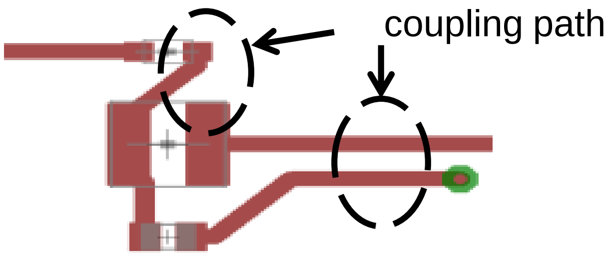
- For common mode rejection use common mode chokes
- For supplying over long distance common mode chokes are recommended
- Additional capacitor reduce differential mode noise
  - Small value for ceramic capacitor is recommended
  - Capacitor and common mode choke act as a LC - filter for differential mode noise
- Can be used for input and output lines



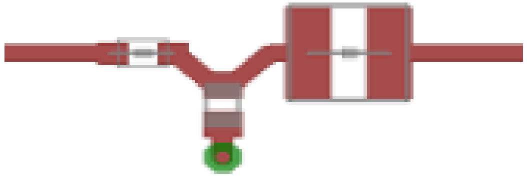
PCB - LAYOUT RECOMMENDATIONS

PCB-Layout recommendations

T-filter



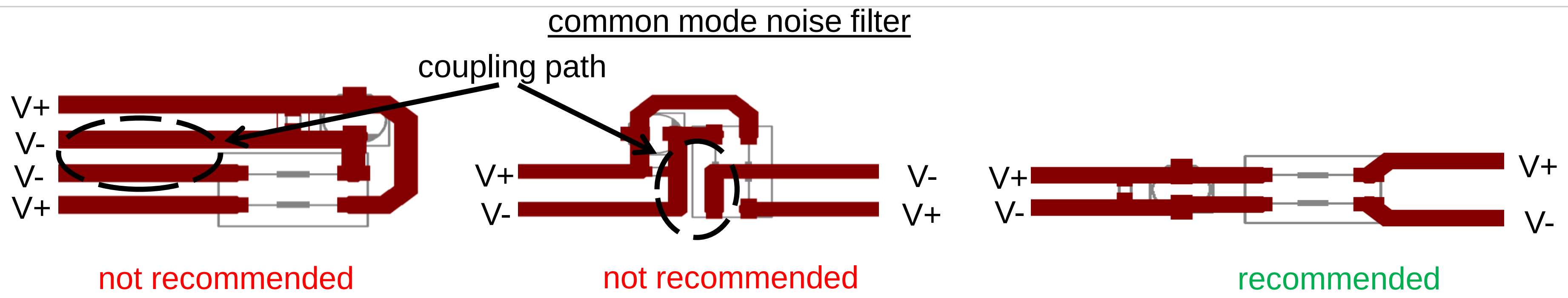
not recommended



recommended

- **Keep PCB traces as short as possible**
- **Avoid indirect trace routing**
- **Avoid any kind coupling → "*capacitive*", "*inductive*"**
- **AC-current should flow across capacitor**
- **Short way for AC-current direct to GND (place double via's to GND)**

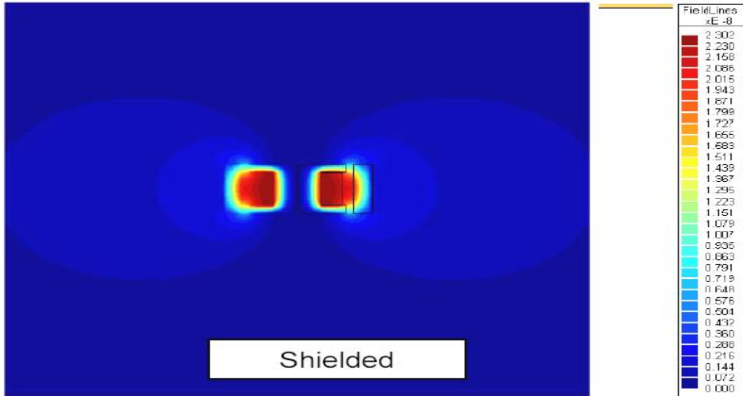
PCB-Layout recommendations

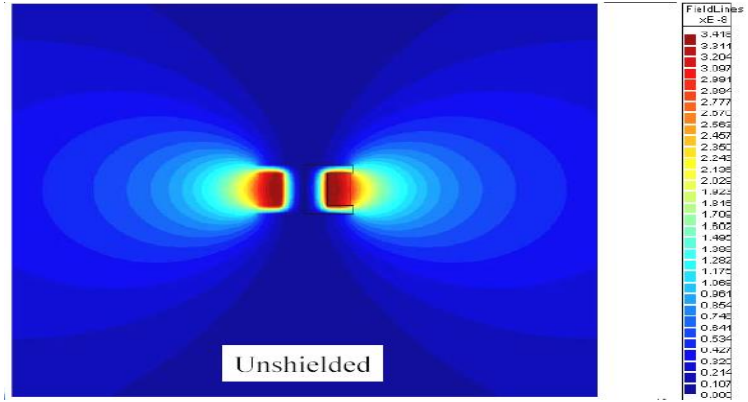


- **Avoid indirect routing of power traces**
- **Avoid any kind of couplings → "*capacitive*", "*inductive*"**
- **AC-current should flow across common mode choke**
- **Route power traces on component layer**
- **Do not use vias**

SHIELD VS. UNSHIELD

Magnetic field leakage





Radiation by inductor

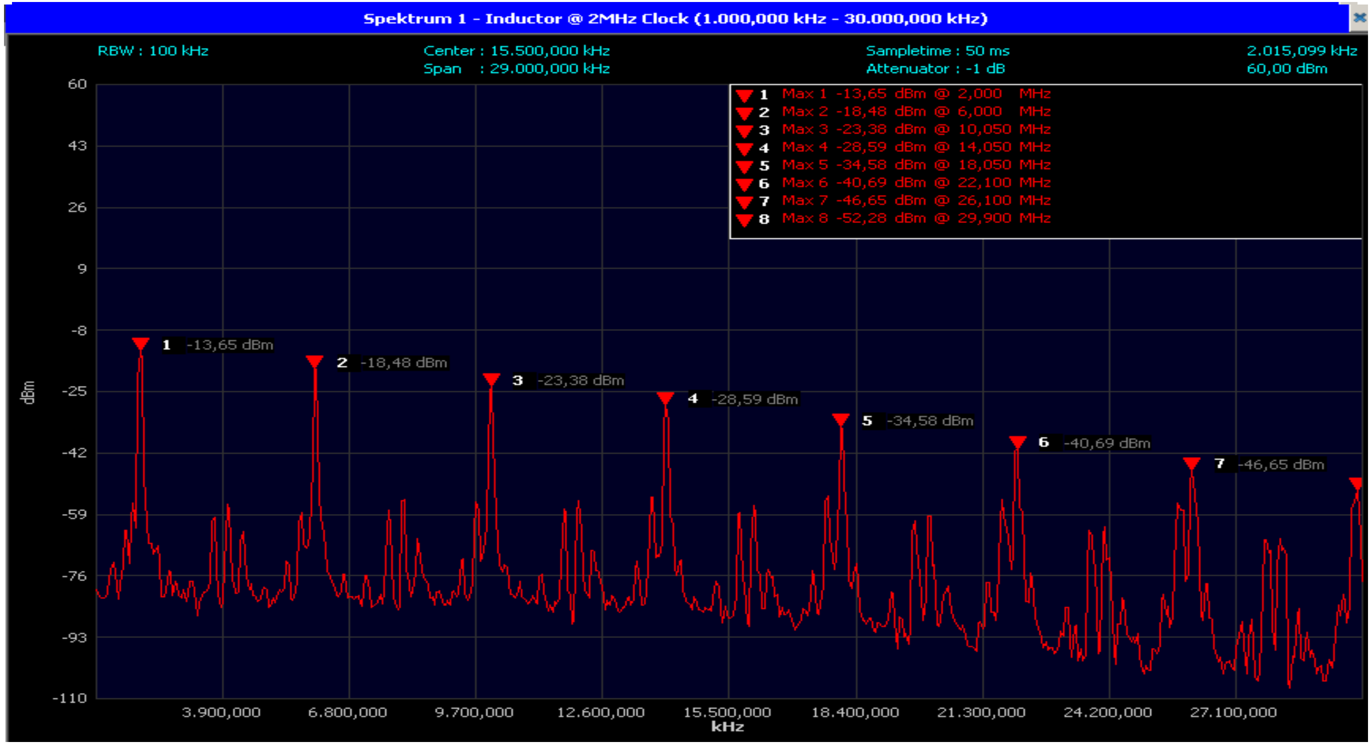
WE - PD2 unshielded

10µH, 2MHz Clock, 1A

WE – PD shielded

10µH, 2MHz Clock, 1A

19dBm difference



Magnetic leakage shielded vs. unshielded

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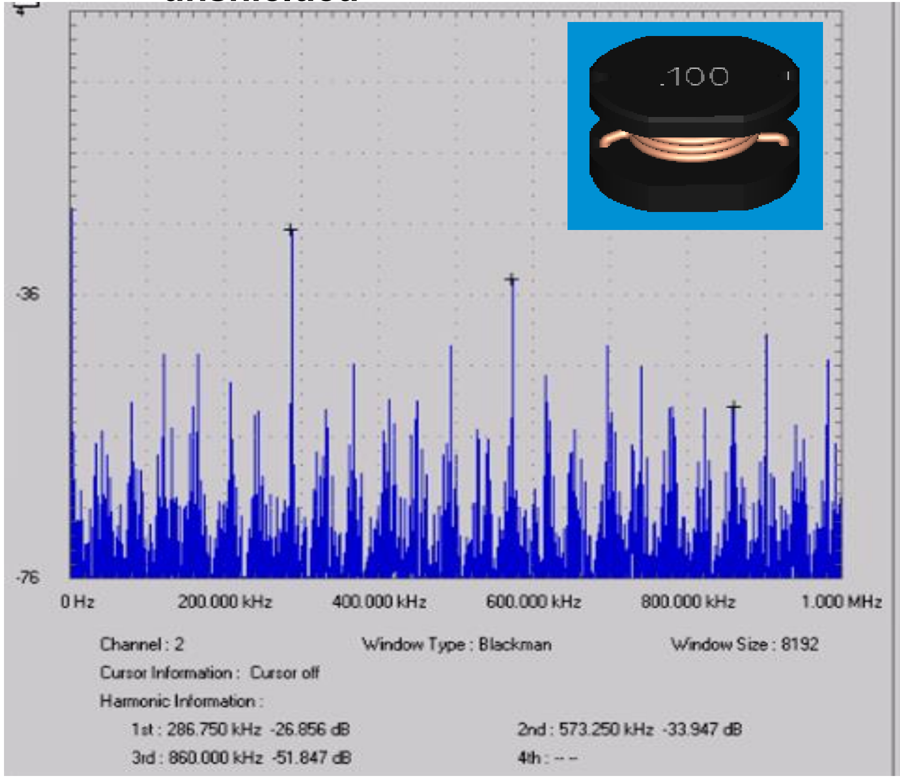
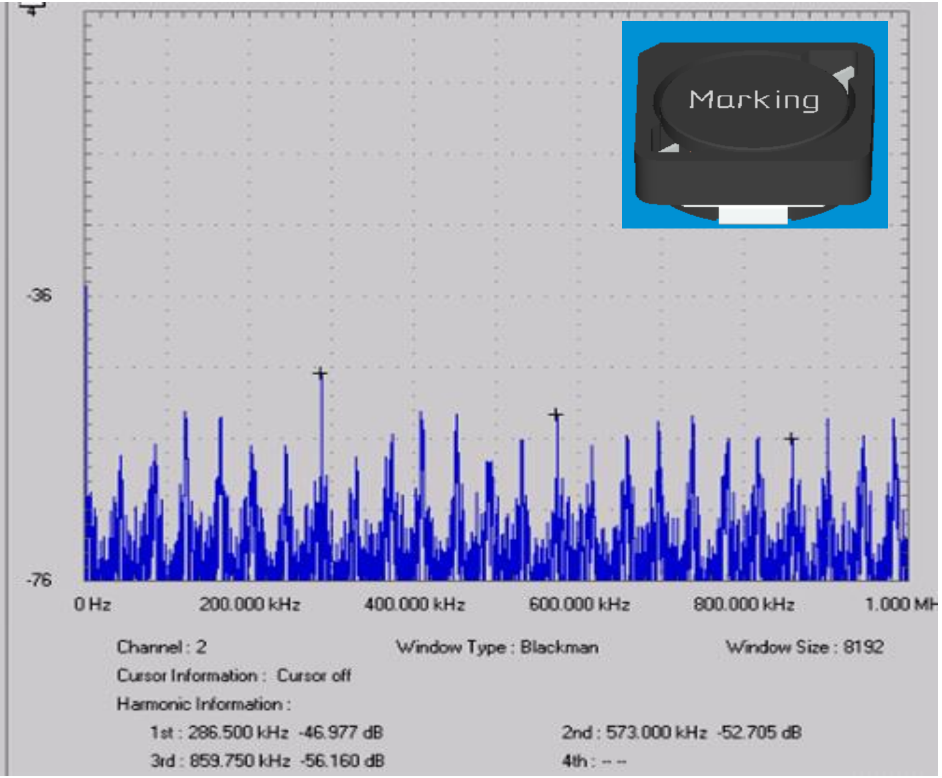
unshielded

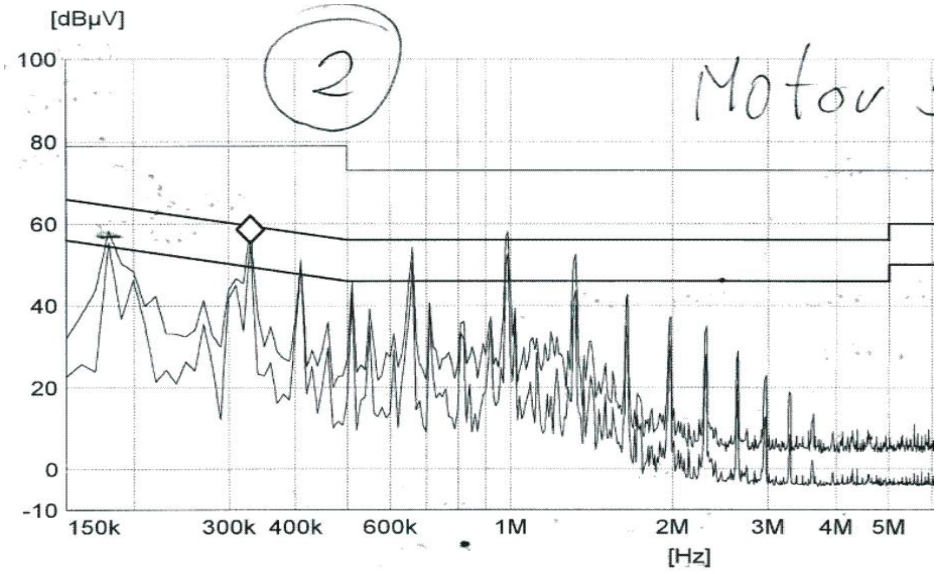


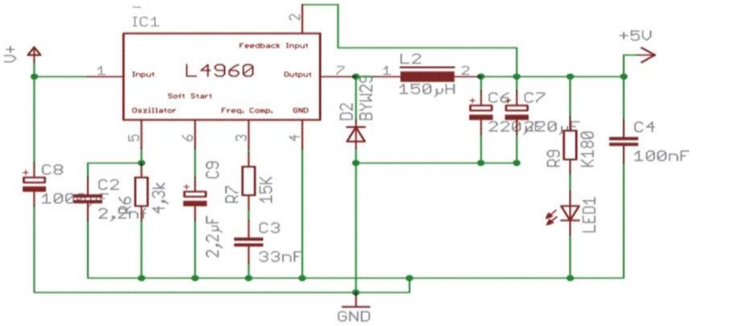
shielded



Magnetic Fields – Conducted Emission Measurement

Power supply V 1.0

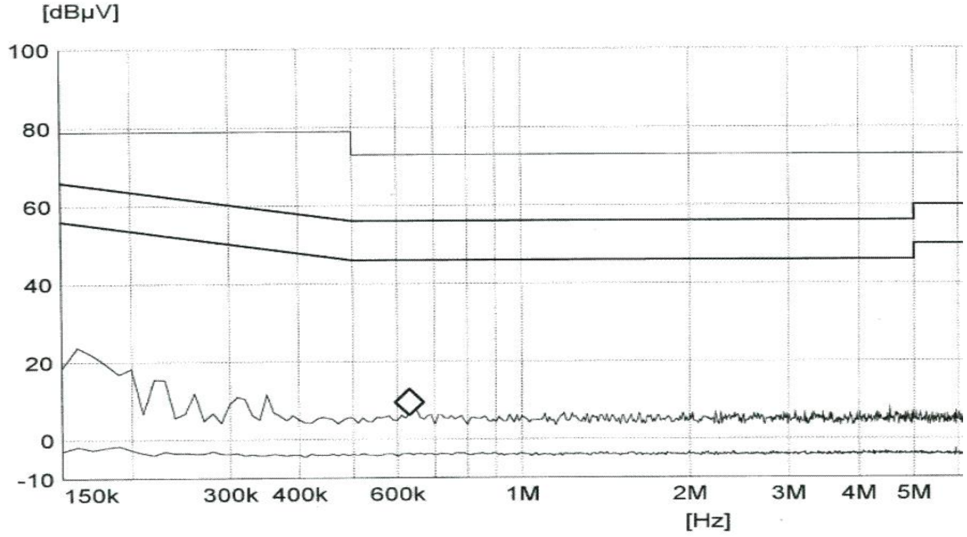


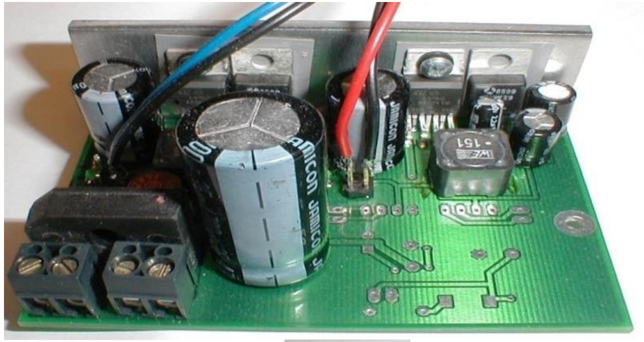


Buck Converter Iout=2.5A @fsw 85-115KHz

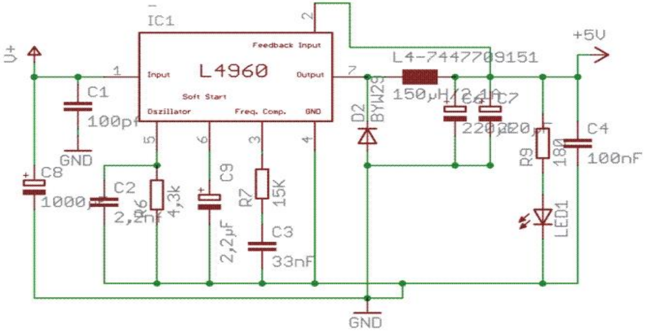
Magnetic Fields – Conducted Emission Measurement

Power supply V 1.1





PCB



Schematic

REDEXPERT

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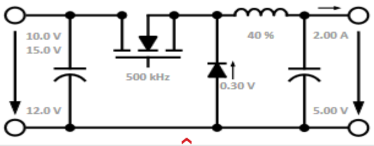
Inductors REDEXPERT®

Buck Converter

PARAMETERS



Input

$V_{in,min}$ 10 V | $V_{in,nom}$ 12 V | $V_{in,max}$ 15 V

Output

V_{out} 5 V | I_{out} 2 A

Switch

f_{sw} 500 kHz

Inductor

ΔI 40 %

Diode

V_f 0.3 V

Display details

Filters: Type = Single | I_R ≥ 2.00 A | I_{sat} ≥ 2.40 A | 5.28 µH ≤ L ≤ 9.80 µH — 100 items

Series	Order Code	Spec	Type	L	$R_{DC,typ}$	I_R	I_{sat}	Size	Length	Width
WE-MAPI	74438356056	PDF	Single	5.60 µH	68.0 mΩ	2.80 A	4.60 A	4020	4.1 mm	4.1 mm
WE-TPC	744071056	PDF	Single	5.60 µH	20.0 mΩ	4.00 A	4.00 A	8043	8.0 mm	8.0 mm
WE-TPC	7440650068	PDF	Single	6.80 µH	25.0 mΩ	4.20 A	3.60 A	1028	10 mm	10 mm
WE-TPC	7440650082	PDF	Single	8.20 µH	28.5 mΩ	3.80 A	2.80 A	1028	10 mm	10 mm
WE-TPC	7440660062	PDF	Single	6.20 µH	16.5 mΩ	4.30 A	4.50 A	1038	10 mm	10 mm
WE-SPC	74408943068	PDF	Single	6.80 µH	51.0 mΩ	2.00 A	2.70 A	4838	4.8 mm	4.8 mm

74438356056
WE-MAPI · Single
5.60 µH · 68.0 mΩ
2.80 A · 4.60 A

744071056
WE-TPC · Single
5.60 µH · 20.0 mΩ
4.00 A · 4.00 A

Please, register to add more parts

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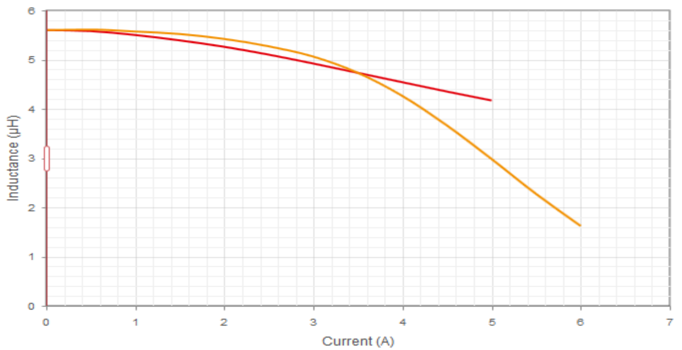
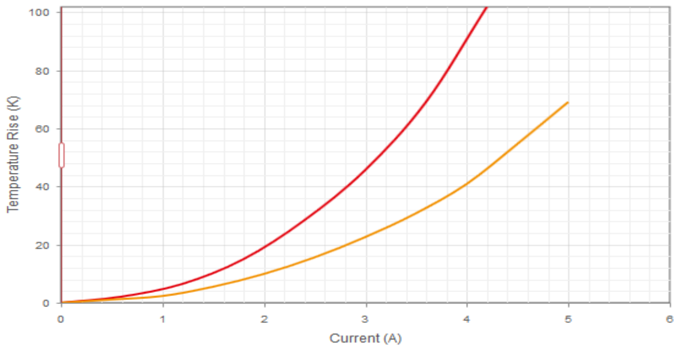
Inductance / Current



Temperature Rise / Current



Simulation – WEBENCH

- http://www.we-online.de/web/de/electronic_components/toolbox_pbs/webench.php

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RECOMMENDED PARTS

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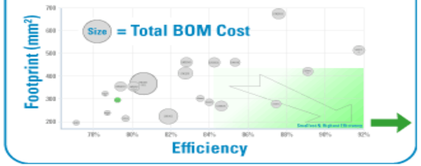


WEBENCH® Optimizer

WEBENCH® Visualizer

Switching Regulator	LM3102
Design Note	High Efficiency
Topology	Buck
Footprint (mm2)	340
Efficiency (%)	87%
Frequency (kHz)	315
BOM Cost	$4.59

Switching Regulator	LM25576
Design Note	Fast Transient R...
Topology	Buck
Footprint (mm2)	278
Efficiency (%)	85%
Frequency (kHz)	361
BOM Cost	$5.69

Switching Regulator	LM22670-ADJ
Design Note	Adjustable for V...
Topology	Buck
Footprint (mm2)	348
Efficiency (%)	83%
Frequency (kHz)	388
BOM Cost	$4.51

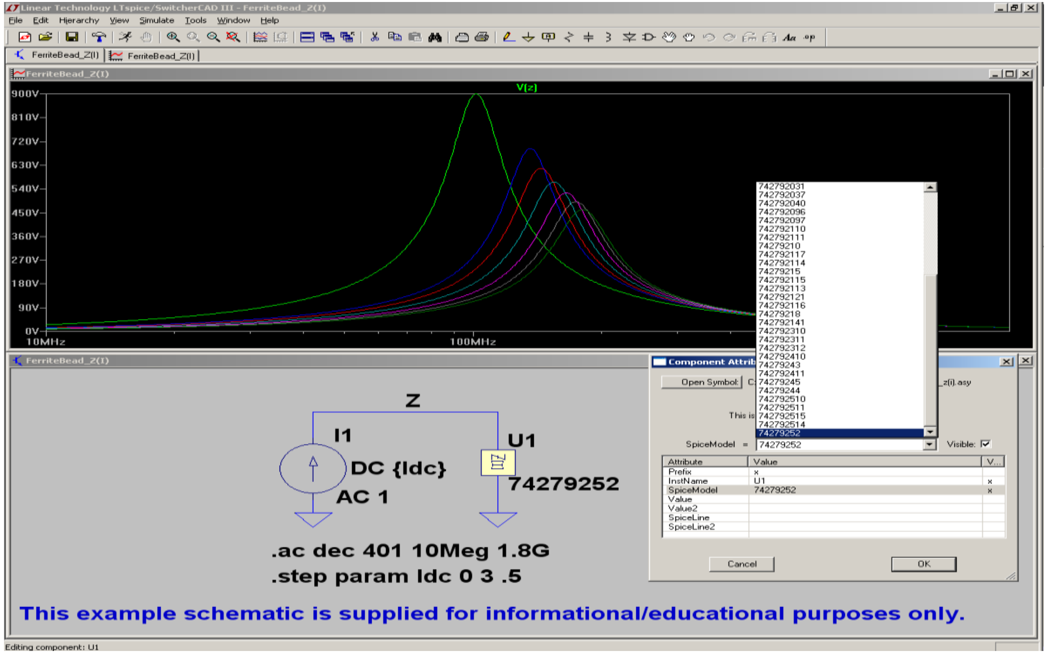
Switcher Solutions

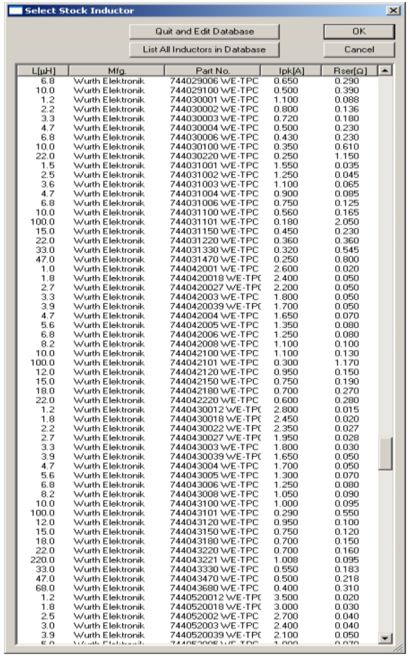
Switcher Solutions: (146 found) ☐ Show All Columns ☐ Show Alternate Topologies ☐ Show Only Modules

Part	Create	WEBENCH® Tools	Topology	Efficiency (%)	Footprint (mm2)	Frequency (kHz)	Vout p-p (mV)	Cross Freq (kHz)	Phase Margin (deg)	BOM Cost	BOM Count	Iout Max (A)	Design Considerations
LM3151-3.3	Open Design		Buck	91%	524	245	6.01	NA	NA	$5.15	10	12.00	SIMPLE SWITCHER(r) Controller
LM43602	Open Design		Buck	89%	326	350	1.90	14	75	$4.17	13	2.00	SIMPLE SWITCHER Buck Regulator
LM3150	Open Design		Buck	93%	443	255	5.52	NA	NA	$5.89	15	15.00	SIMPLE SWITCHER(r) Controller
TPS54339	Open Design		Buck	88%	285	646	4.69	NA	NA	$2.83	12	3.00	Wide Vin Buck Converter with EcoMode
TPS54239E	Open Design		Buck	88%	285	646	4.72	NA	NA	$2.73	12	2.00	Wide Vin Buck Converter with EcoMode
TPS54335A	Open Design		Buck	88%	340	270	1.66	16	59	$3.43	13	3.00	28V, 3A, Low Iq, Synchronous, monolithic buck converter with Eco-mode
LM43603	Open Design		Buck	89%	230	350	3.34	12	74	$5.53	13	3.00	SIMPLE SWITCHER Buck Regulator

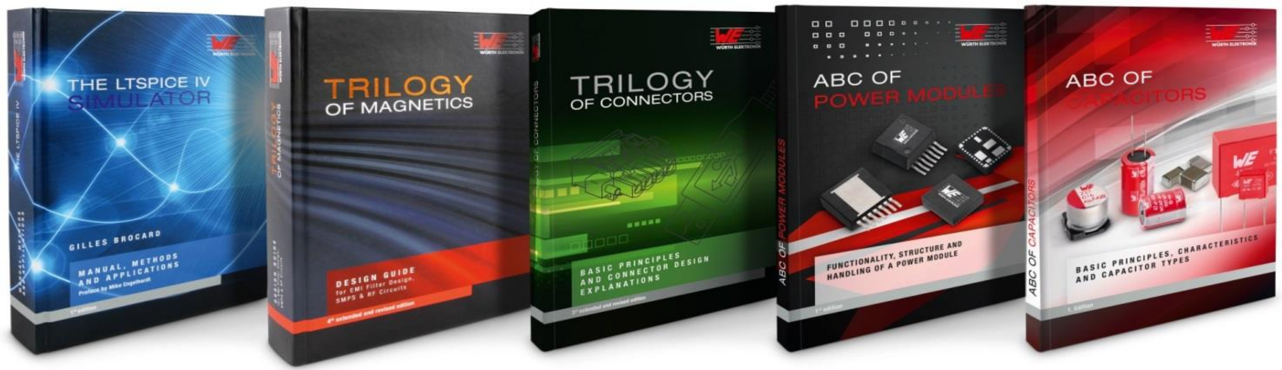
Simulation – LTSpice IV

- http://www.linear.com/designtools/software/#LTspice





Trilogies



- 1. **LTspice Book**

→ How to use and build spice models

- 2. **Trilogy of Magnetics**

→ Design Guide for EMI Filter Design, SMPS & RF Circuits

- 3. **Trilogy of Connectors**

→ Basic Principles and Connector Design Explanations

- 4. **ABC of Power Modules**

→ Functionality, Structure and Handling of a Power Module

- 5. **ABC of Capacitors**

→Basic principles, characteristics and capacitor types

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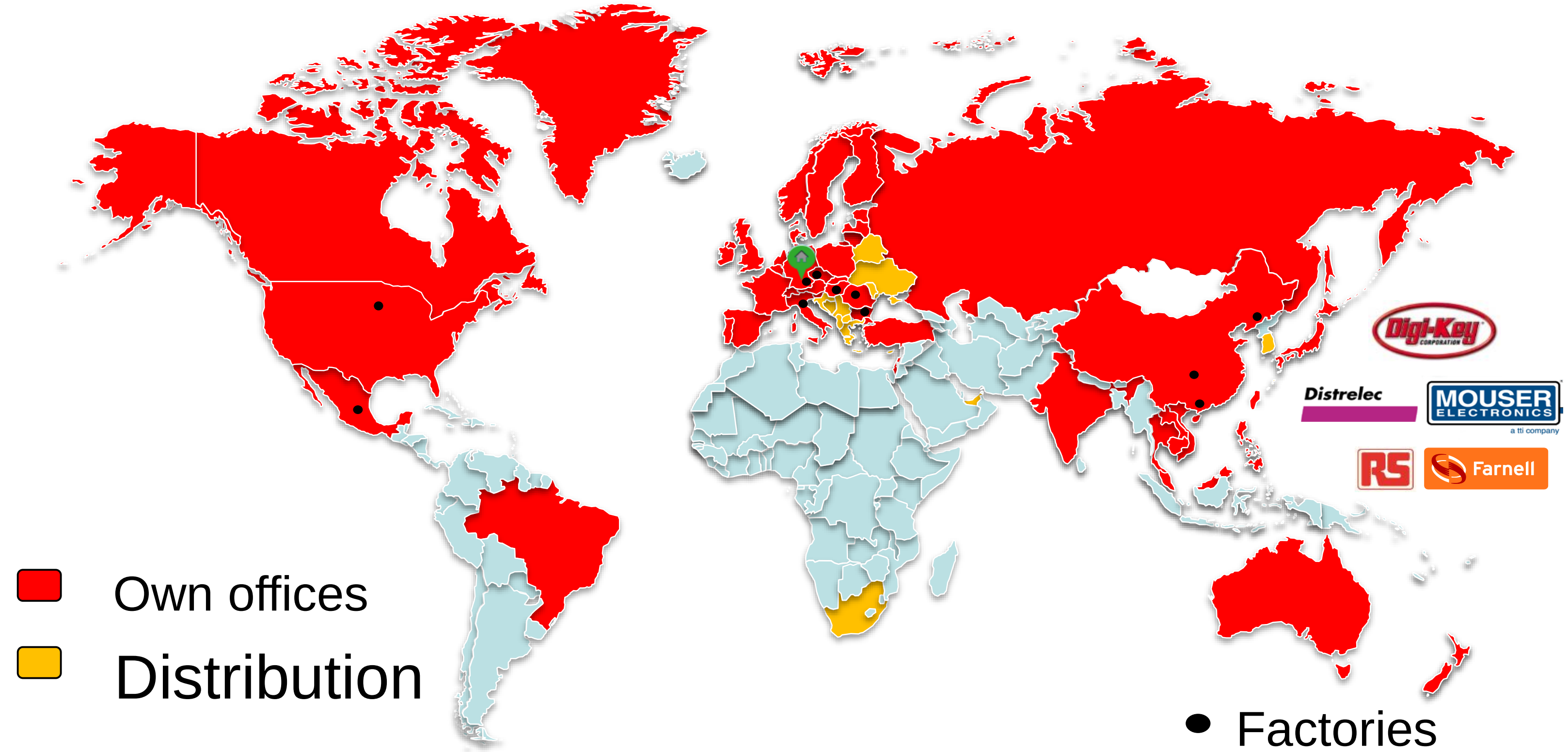

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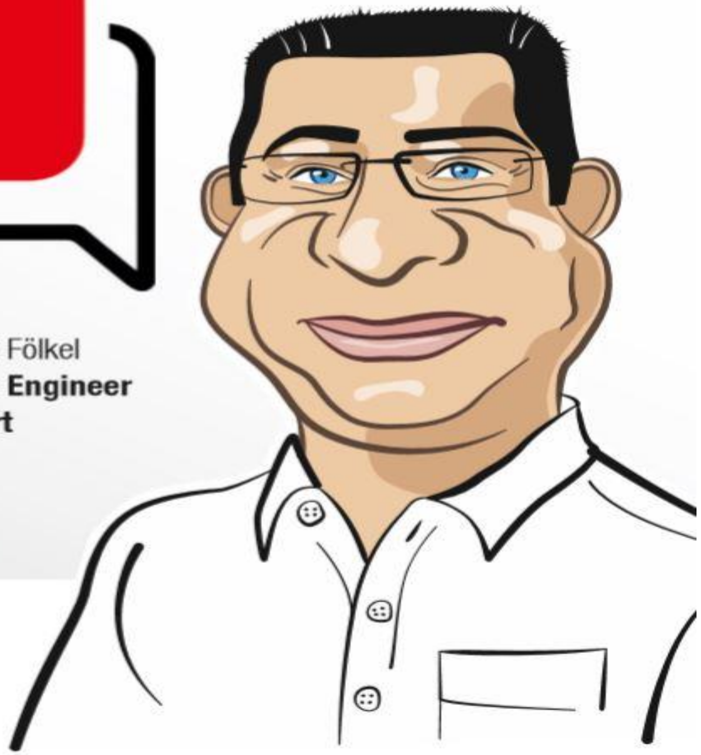
Lorandt Fölkel
Design Engineer at heart



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