

How do I solve EMI on PCB level?



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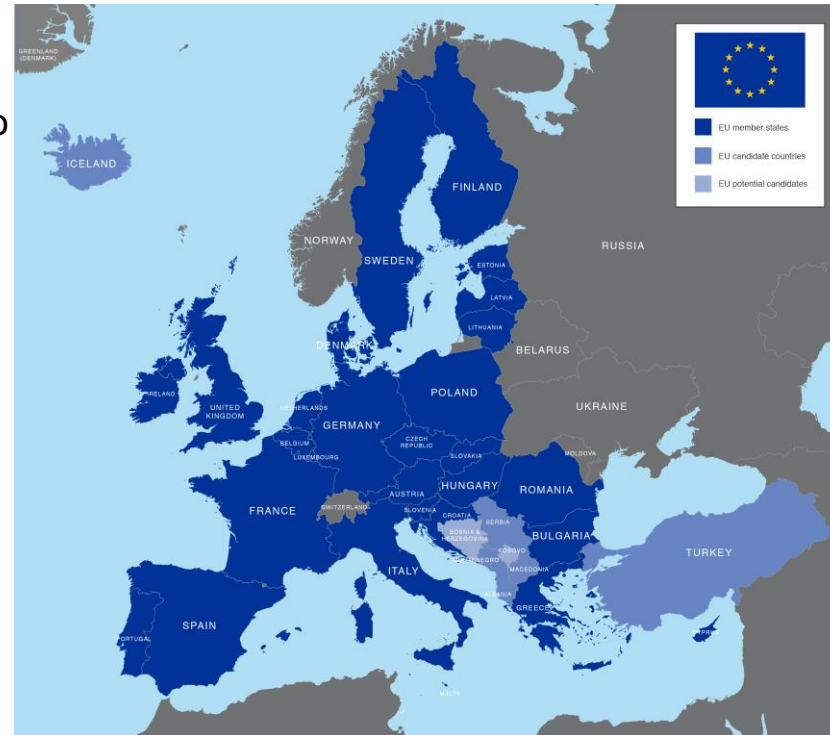
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REQUIREMENTS IN EMC

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**

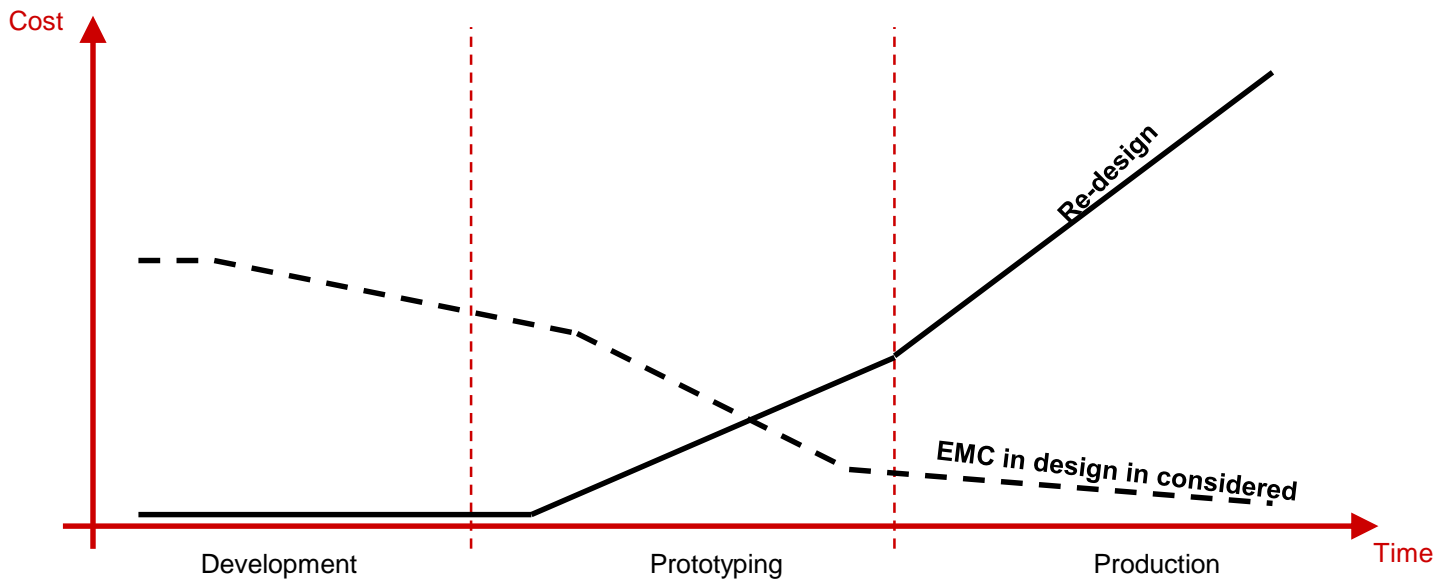


- **Australian Communications and Media Authority**



Design phase for EMC

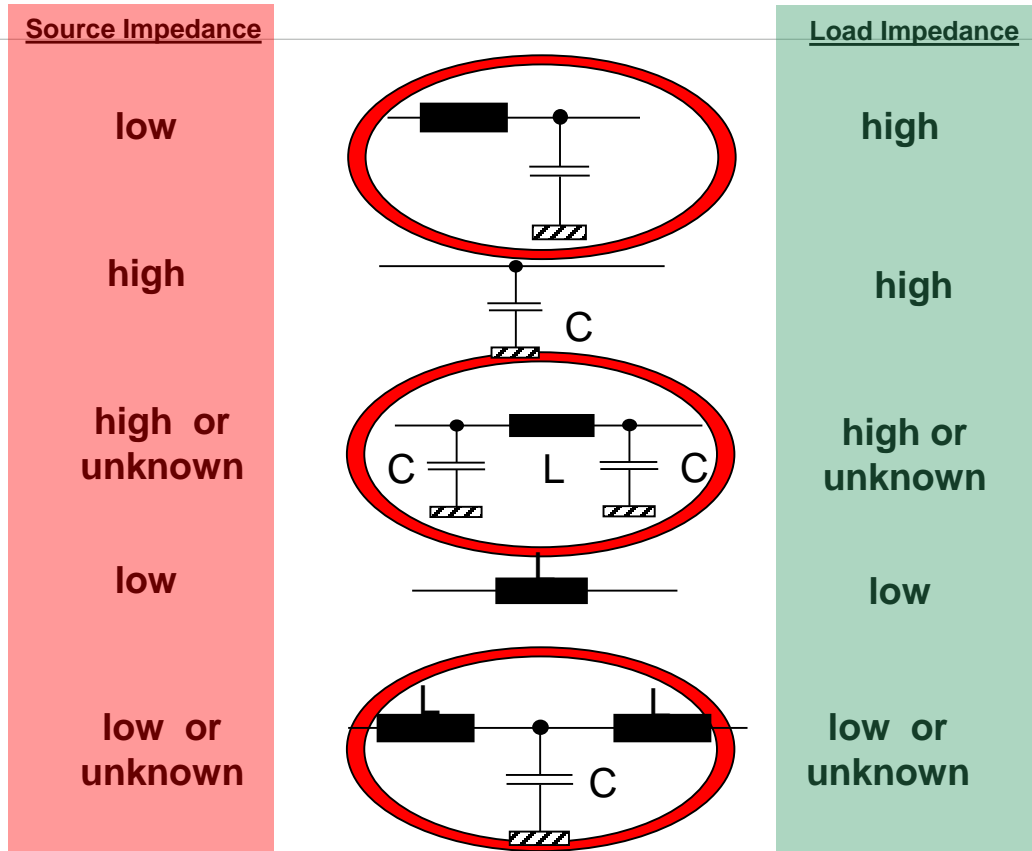
- Economical point of view:
- Depends on you when will start to design EMC conform



How can we check the EMC ?



Insertion loss – recommended filter topology



→ small C = higher SRF

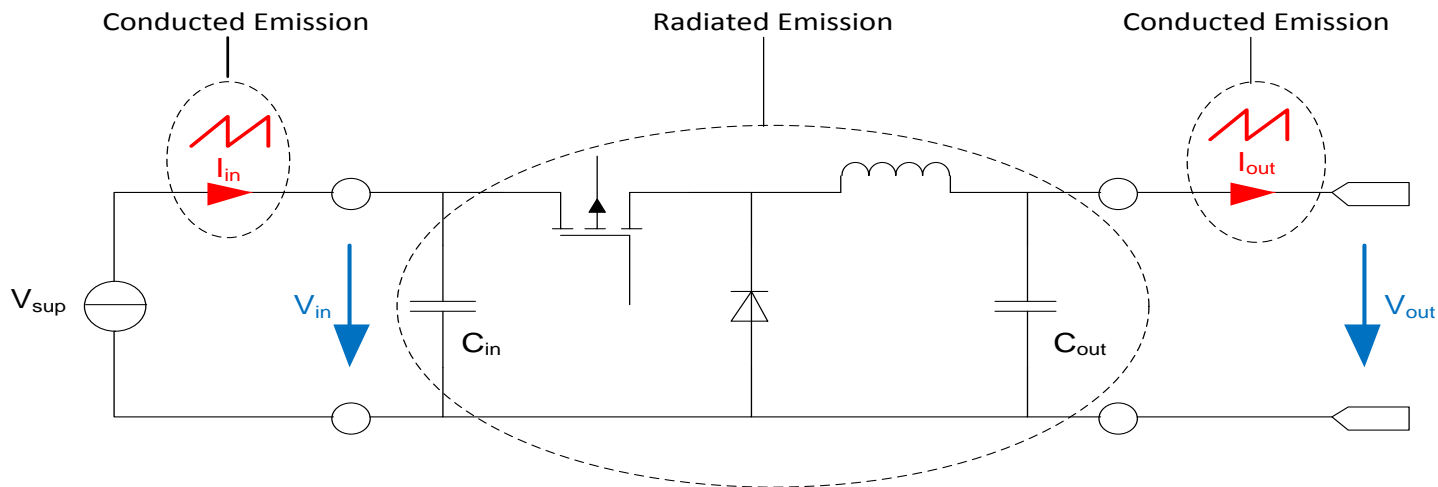
Choose ferrite bead or inductors L which = build no resonance with C = broadband filter

Pay attention to:
SRF of used components



EMI NOISE SOURCES

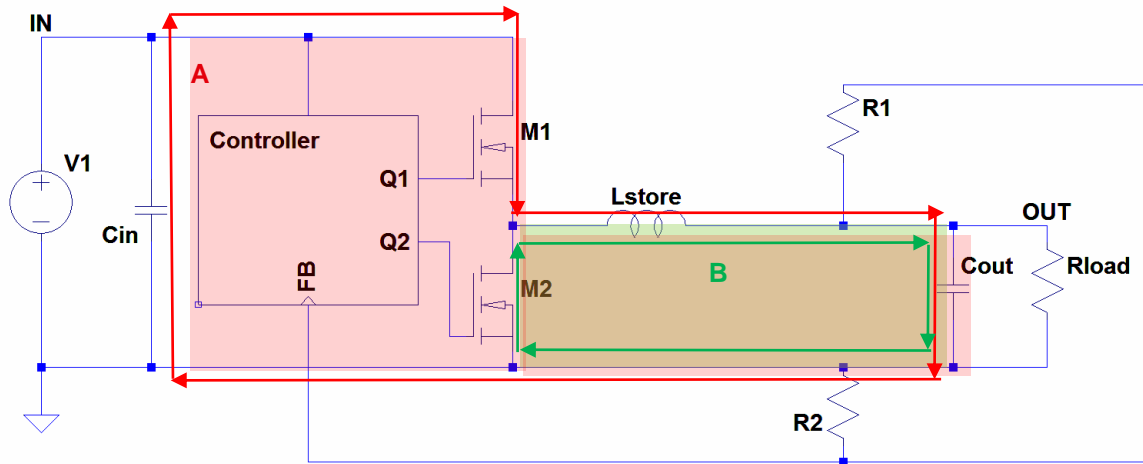
Representative noise sources



- 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)

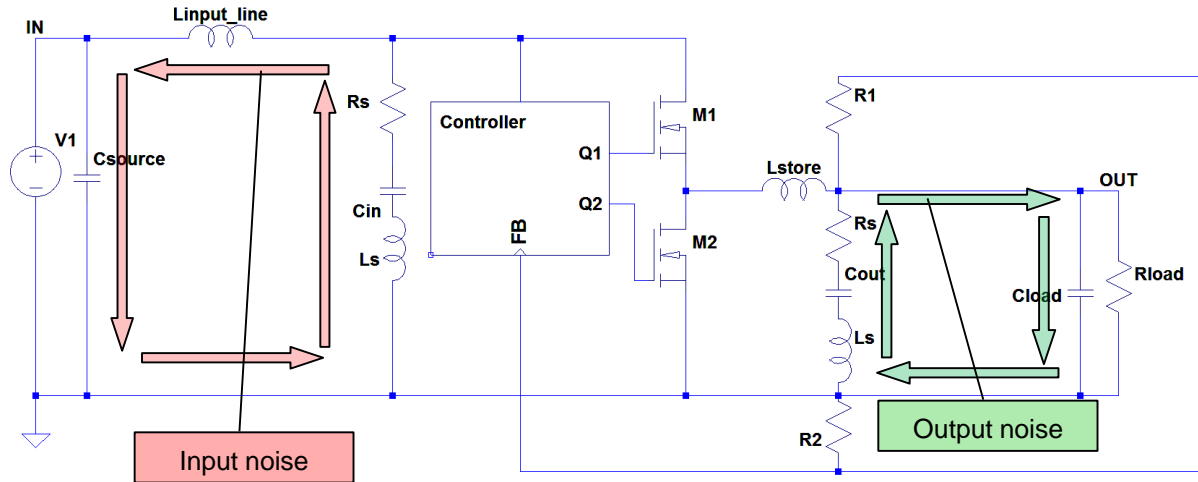
Noise loops in DC/DC buck converter

- 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

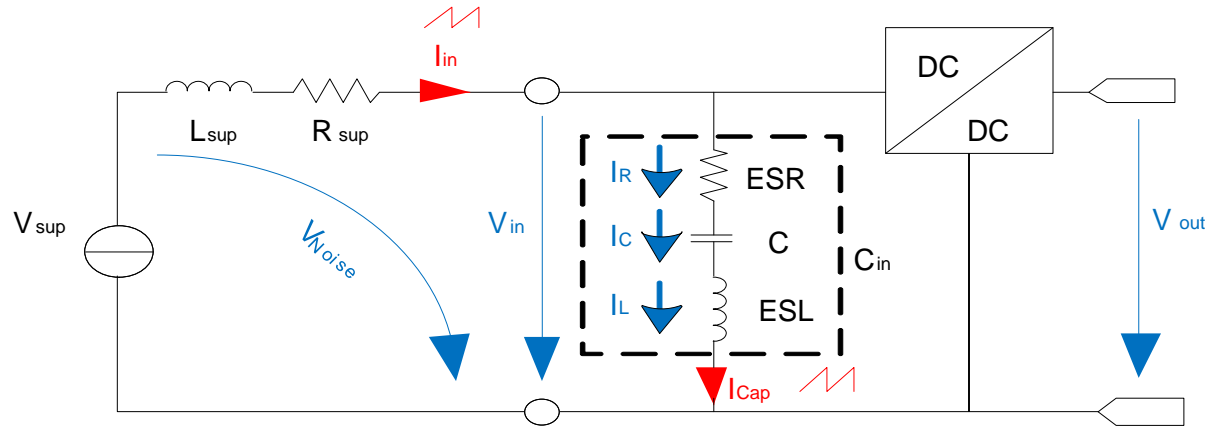


Noise loops in DC/DC buck converter

- 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 (R_s) and ESL (L_s), 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

$$V_{Noise} = R_{sup} * I_{in} + ESR * I_{Cap}$$

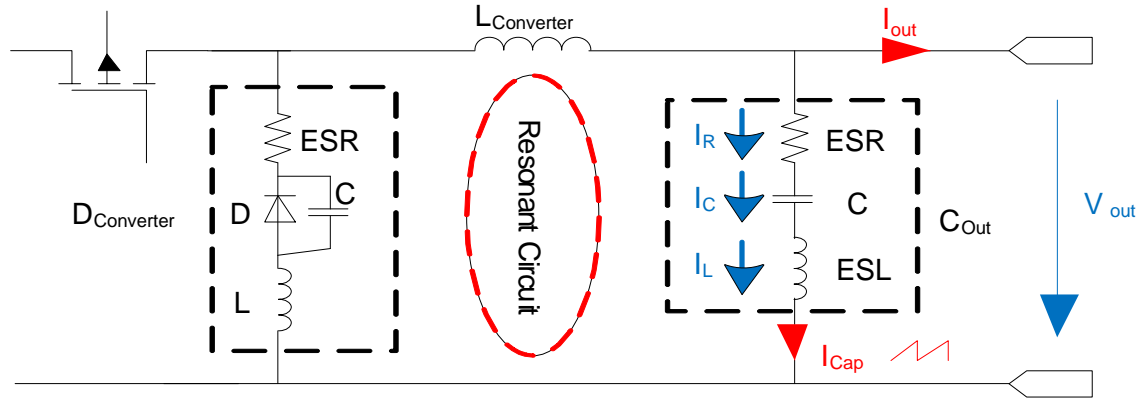
- $V_{Noise} = R_{sup} * I_{in} + ESR * I_{Cap}$

- Resonance circuit is formed by L_{sup} , C_{in} and ESL_{Cin}

$$f_0 = 1 / 2\pi \sqrt{(L_{sup} - ESL) * C_{in}}$$

- 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

$$U_{\text{Noise}} = ESR_{C_{\text{out}}} * I_{C_{\text{out}}}$$

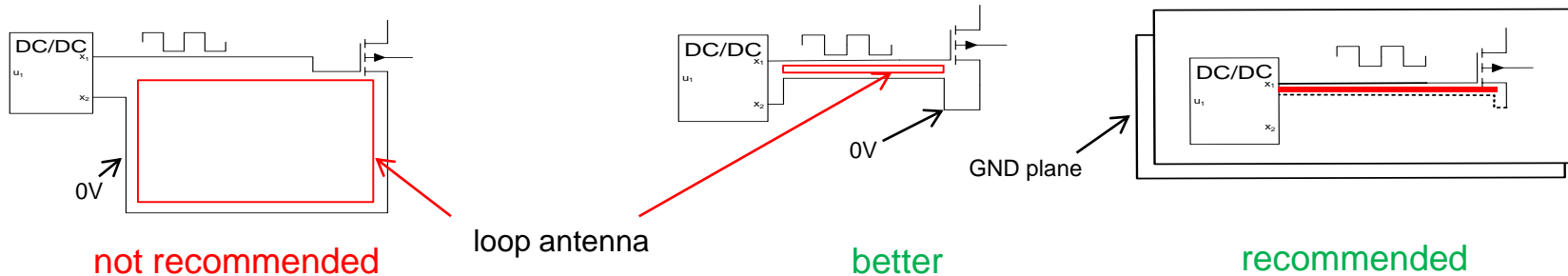
- Resonance circuit is formed by $C_{\text{Dconverter}}$, C_{Out} , $L_{\text{Converter}}$, and $ESL_{C_{\text{out}}}$

$$f_0 = \frac{1}{2\pi\sqrt{(ESL_{C_{\text{out}}}) * C_{\text{Out}}}}$$

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

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

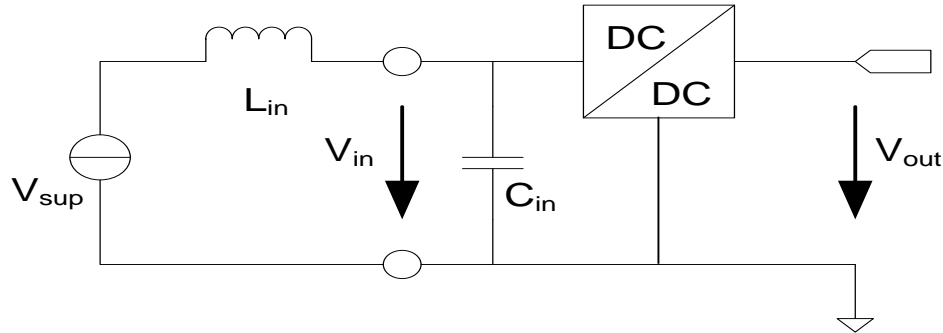




FILTER DESIGN

„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

$$I_L = \frac{(V_{out})(I_{out})}{(V_{in})(E)}$$

- V_{out} = Output Voltage Ex: 5V
- I_{out} = Output Current Ex: 4A
- V_{in} = Input Voltage Ex: 20V
- E = Efficiency (/100) Ex: 80% min.

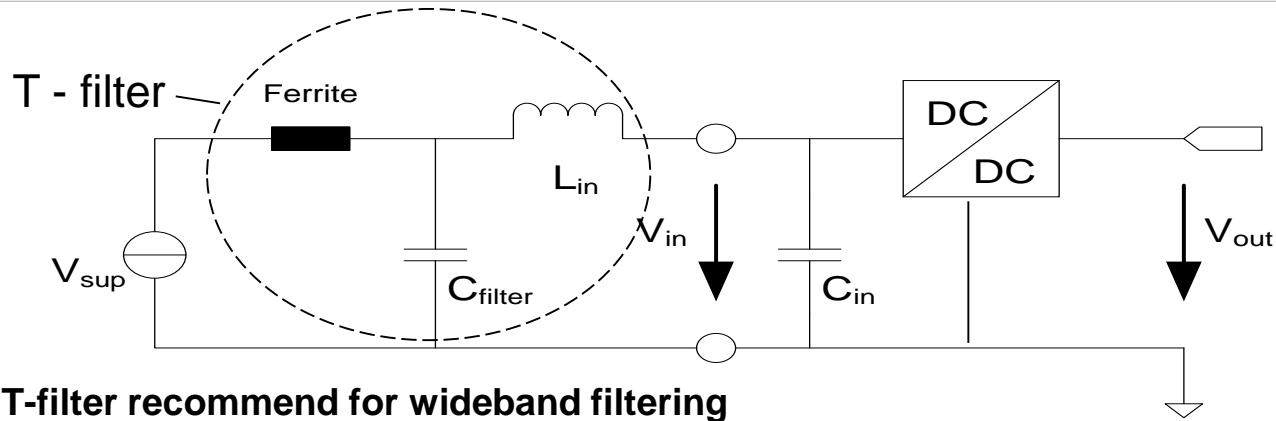
- For Example:

$$I_L = \frac{(5V)(4A)}{(20V)(0,8)} = 1,25A$$

- **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

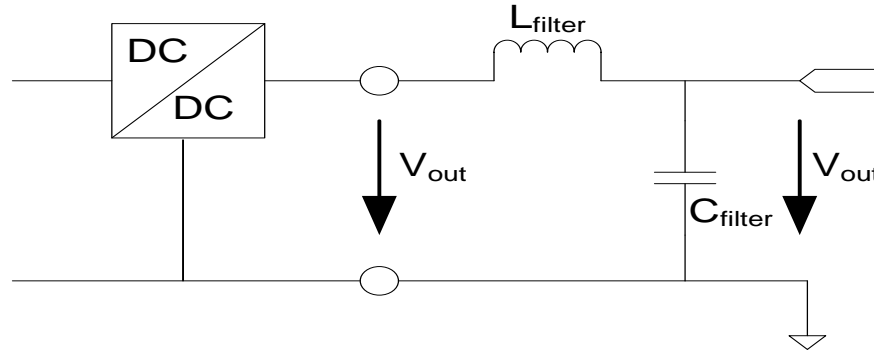
(recommended filter solution)



- **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

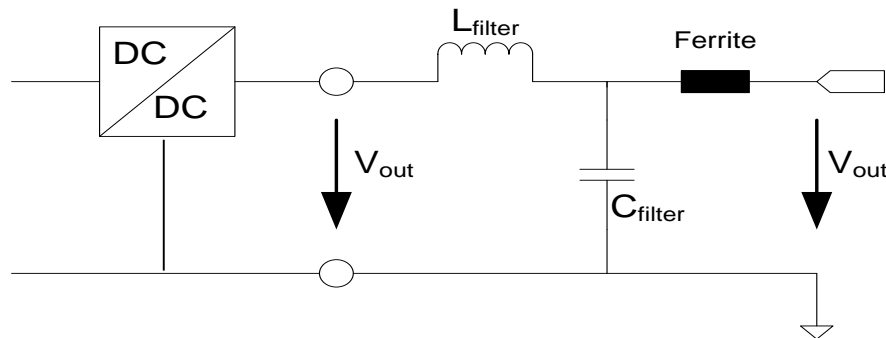
„L / C“ output filter (minimal recommended filter)



- **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)

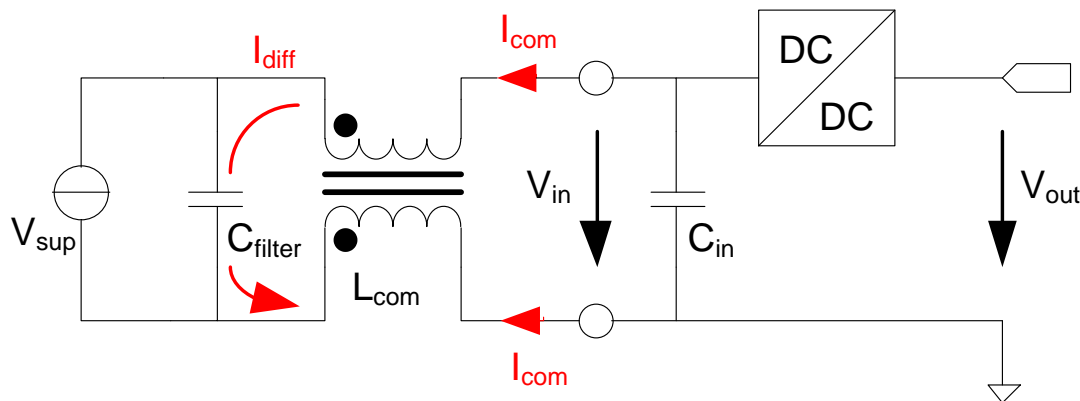


- **T-filter recommend for wide bandwidth filtering**
 - **L_{filter} for low frequency filtering (DC/DC converter switching frequency)**
 - **Ferrite for high frequency filtering**
 - **This kind of output filter is for powering radio devices high recommended**

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

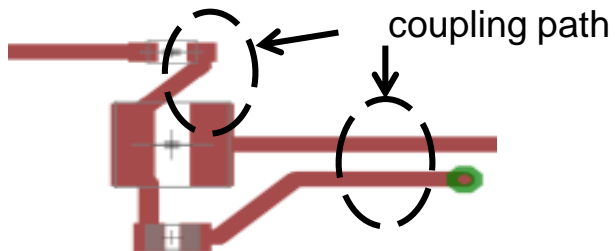




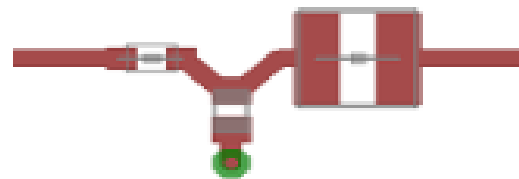
PCB - LAYOUT RECOMMENDATIONS

PCB-Layout recommendations

T-filter



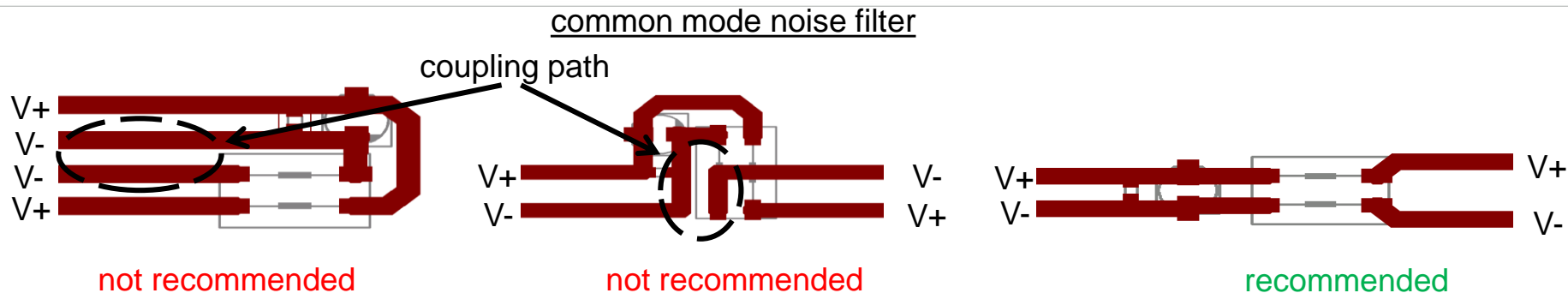
not recommended



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

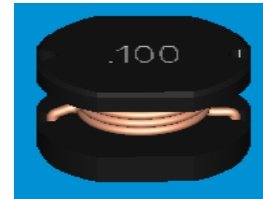
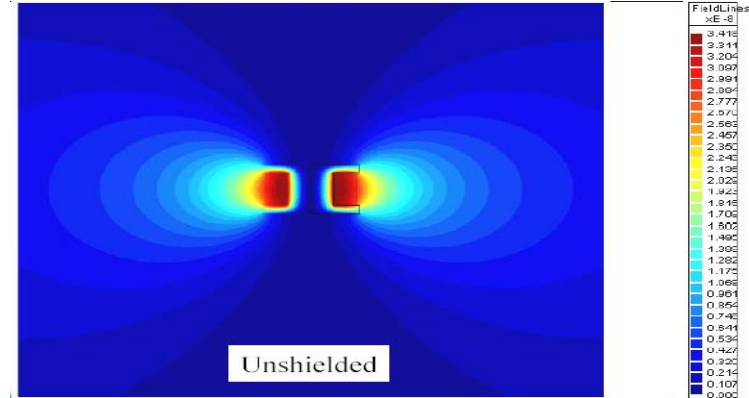
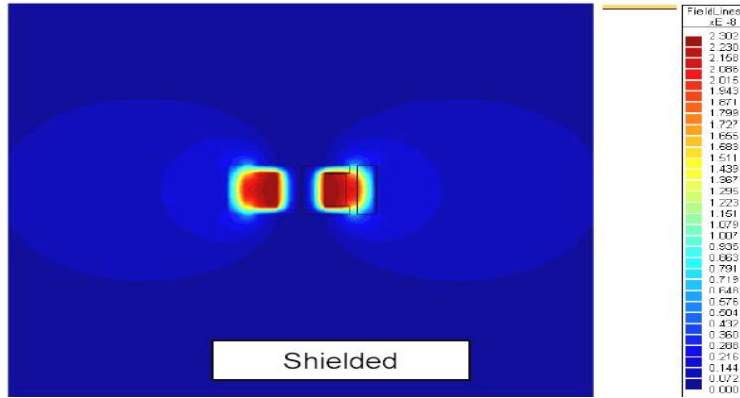


- Avoid indirect routing of power traces
- Avoid any kind of couplings → “capacitive”, “inductive”
- AC-current should flow across common mode choke
- Route power traces on component layer
- Do not use vias



SHIELD VS. UNSHIELD

Magnetic field leakage



Radiation by inductor

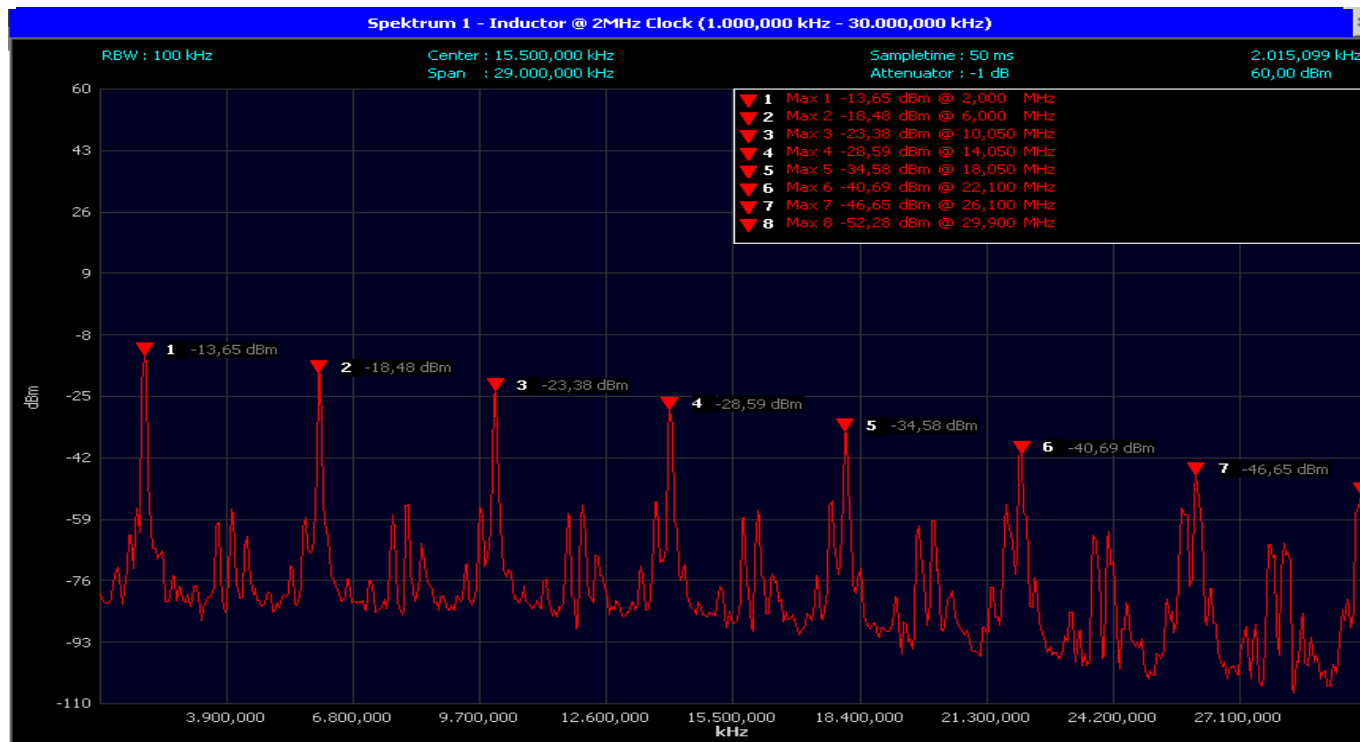
WE - PD2 unshielded
10 μ H, 2MHz Clock, 1A



WE – PD shielded
10 μ H, 2MHz Clock, 1A

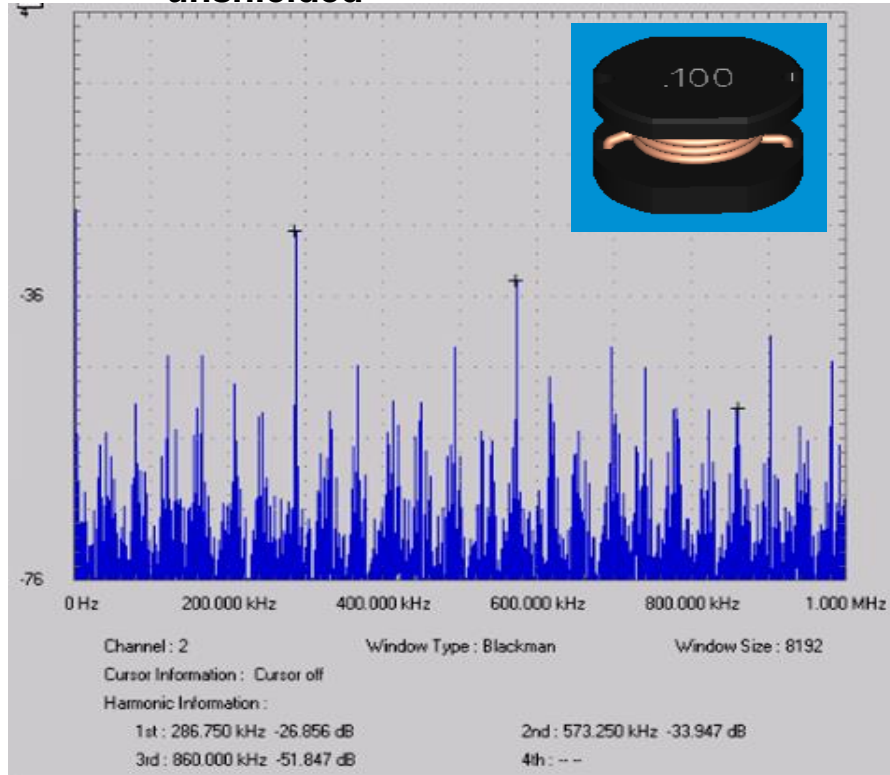


19dBm difference

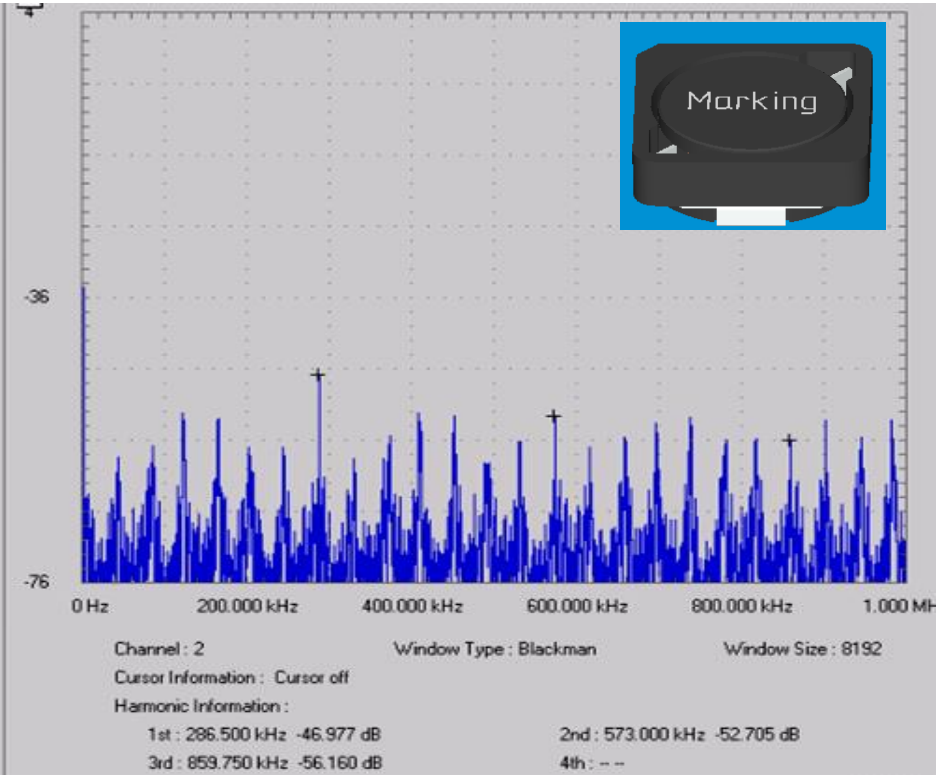


Magnetic leakage shielded vs. unshielded

unshielded

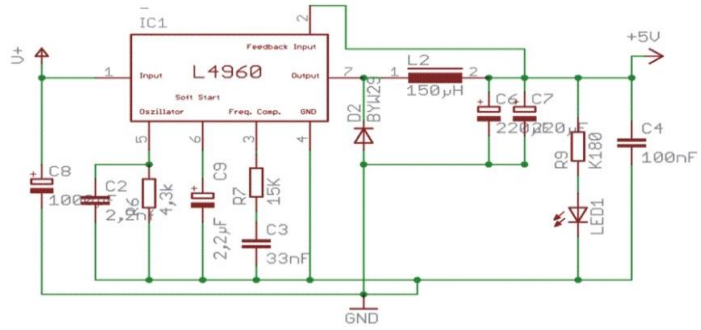
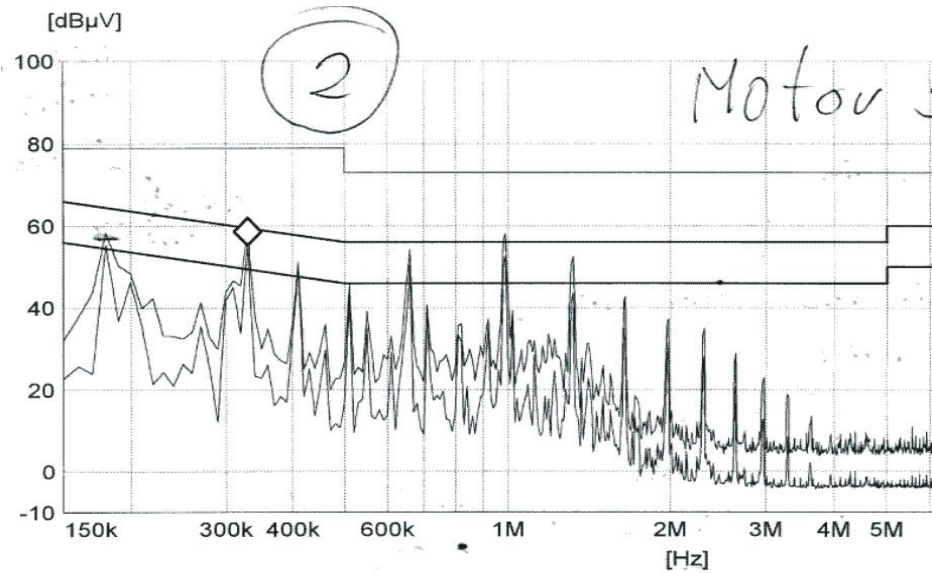


shielded



Magnetic Fields – Conducted Emission Measurement

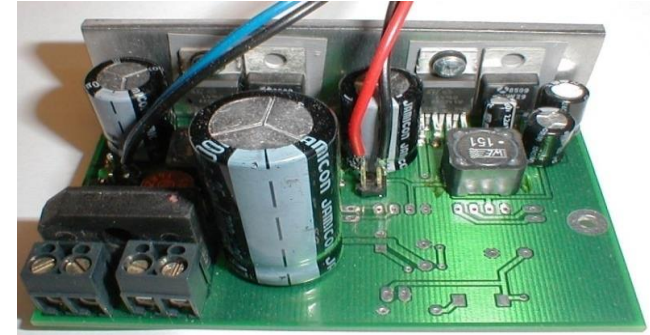
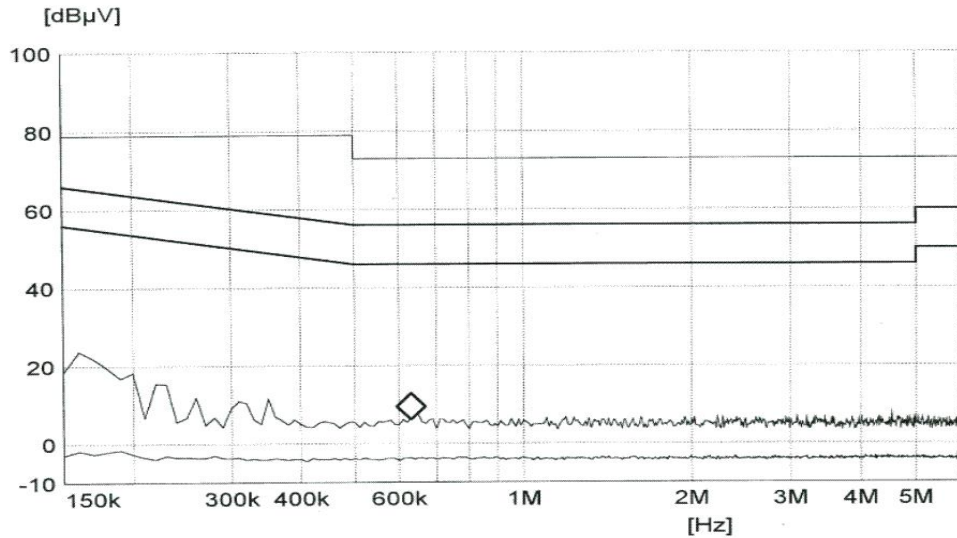
Power supply V 1.0



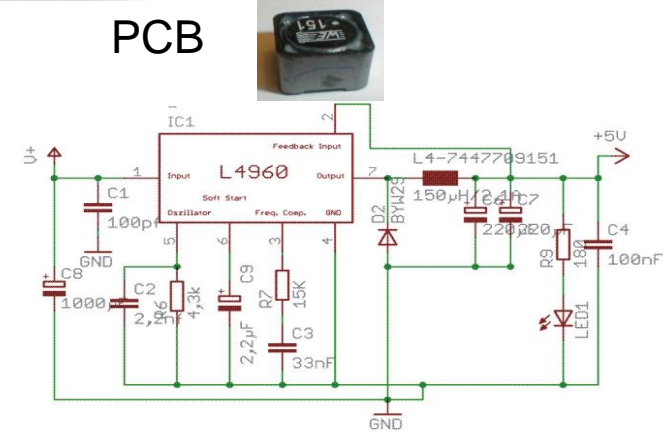
Buck Converter Iout=2.5A @fsw 85-115KHz

Magnetic Fields – Conducted Emission Measurement

Power supply V 1.1



PCB



Schematic

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 | $I_R \geq 2.00$ A | $I_{sat} \geq 2.40$ A | $5.28 \mu H \leq L \leq 9.80 \mu H$

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

74438356056

WE-MAPI - Single
 5.60 μH · 68.0 m Ω
 2.80 A · 4.60 A

744071056

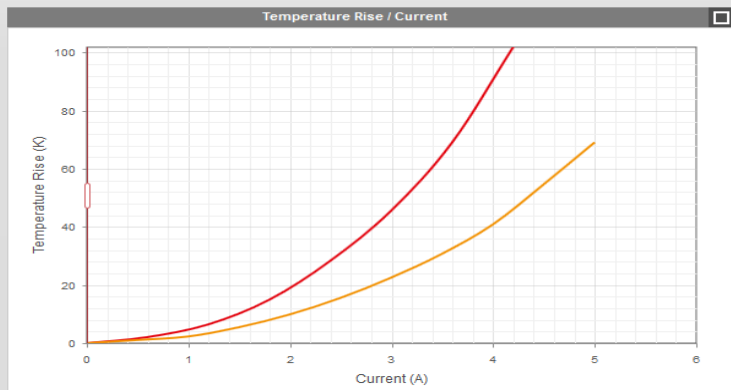
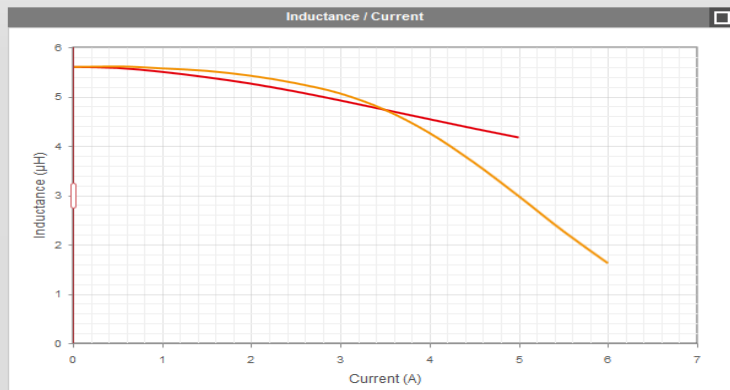
WE-TPC - Single
 5.60 μH · 20.0 m Ω
 4.00 A · 4.00 A

Please, register to add more parts

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Simulation – WEBENCH

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

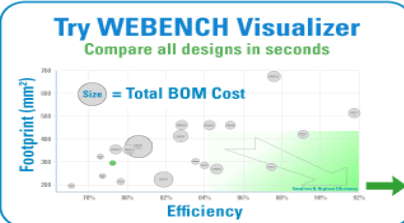
My Designs/Projects English | 日本語 | 简体中文 | 繁體中文 | 한국어 | Русский язык | Português | Deutsch | Welcome

New Solutions Visualizer Assistant

RECOMMENDED PARTS

Try WEBENCH Visualizer
Compare all designs in seconds



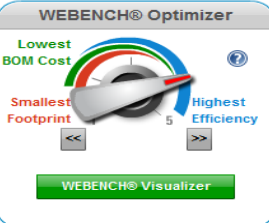
Efficiency

WEBENCH® Optimizer

Lowest BOM Cost

Smallest Footprint

Highest Efficiency



WEBENCH® Visualizer

Switching Regulator

LM3102

Open Design

Design Note	High Efficiency
Topology	Buck
Footprint (mm ²)	340
Efficiency (%)	87%
Frequency (kHz)	315
BOM Cost	\$4.59

Switching Regulator

LM25576

Open Design

Design Note	Fast Transient R...
Topology	Buck
Footprint (mm ²)	278
Efficiency (%)	85%
Frequency (kHz)	361
BOM Cost	\$5.69

Switching Regulator








LM22670-ADJ

Open Design

Design Note	Adjustable for V...
Topology	Buck
Footprint (mm ²)	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 (mm ²)	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>

The screenshot shows the LTSpice IV interface. The main window displays a plot of voltage $V(z)$ versus frequency from 0 to 100 MHz. The y-axis ranges from 0V to 900V. Multiple colored curves represent different simulation runs. A 'Component Attrs' dialog box is open, showing the properties for an inductor component with Part No. 74279252 and SpiceModel = 74279252. Below the plot, a schematic diagram shows an AC source labeled 'AC 1' and an inductor labeled 'U1' with value '74279252'. The simulation command is: `.ac dec 401 10Meg 1.8G` and `.step param ldc 0 3 .5`.

Select Stock Inductor

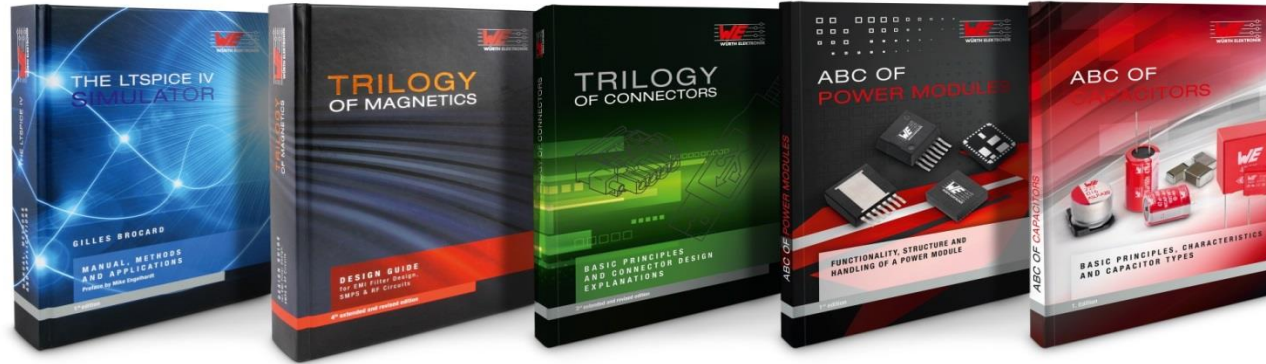
Quit and Edit Database [OK] [Cancel]

List All Inductors in Database

L[μH]	Mfg	Part No.	Ip[A]	Rise[D]
6.8	Würth Elektronik	744029006 WE-TPC	0.650	0.290
10.0	Würth Elektronik	744029100 WE-TPC	0.950	0.390
1.2	Würth Elektronik	744030001 WE-TPC	1.100	0.088
2.2	Würth Elektronik	744030002 WE-TPC	0.890	0.136
3.3	Würth Elektronik	744030003 WE-TPC	0.720	0.180
4.7	Würth Elektronik	744030004 WE-TPC	0.500	0.230
6.8	Würth Elektronik	744030005 WE-TPC	0.430	0.290
10.0	Würth Elektronik	744030100 WE-TPC	0.350	0.610
22.0	Würth Elektronik	744030220 WE-TPC	0.250	1.150
1.5	Würth Elektronik	744031001 WE-TPC	1.550	0.035
2.5	Würth Elektronik	744031002 WE-TPC	1.250	0.045
3.6	Würth Elektronik	744031003 WE-TPC	1.100	0.065
4.7	Würth Elektronik	744031004 WE-TPC	0.900	0.085
6.8	Würth Elektronik	744031006 WE-TPC	0.750	0.125
10.0	Würth Elektronik	744031100 WE-TPC	0.560	0.165
100.0	Würth Elektronik	744031101 WE-TPC	0.180	2.050
15.0	Würth Elektronik	744031150 WE-TPC	0.450	0.230
22.0	Würth Elektronik	744031220 WE-TPC	0.360	0.360
33.0	Würth Elektronik	744031330 WE-TPC	0.320	0.545
47.0	Würth Elektronik	744031470 WE-TPC	0.250	0.800
1.0	Würth Elektronik	744042001 WE-TPC	2.600	0.020
1.8	Würth Elektronik	7440420018 WE-TPC	2.400	0.050
2.7	Würth Elektronik	7440420027 WE-TPC	2.200	0.050
3.3	Würth Elektronik	744042003 WE-TPC	1.900	0.050
3.9	Würth Elektronik	7440420039 WE-TPC	1.700	0.050
4.7	Würth Elektronik	744042004 WE-TPC	1.650	0.070
6.8	Würth Elektronik	744042006 WE-TPC	1.250	0.080
6.8	Würth Elektronik	744042006 WE-TPC	1.250	0.080
8.2	Würth Elektronik	744042006 WE-TPC	1.100	0.100
10.0	Würth Elektronik	744042100 WE-TPC	1.100	0.130
100.0	Würth Elektronik	744042101 WE-TPC	0.390	1.170
12.0	Würth Elektronik	744042120 WE-TPC	0.950	0.150
15.0	Würth Elektronik	744042150 WE-TPC	0.750	0.190
18.0	Würth Elektronik	744042180 WE-TPC	0.700	0.270
22.0	Würth Elektronik	744042220 WE-TPC	0.600	0.280
1.2	Würth Elektronik	7440430012 WE-TPC	2.890	0.015
1.8	Würth Elektronik	7440430018 WE-TPC	2.450	0.020
2.2	Würth Elektronik	7440430022 WE-TPC	2.350	0.027
2.7	Würth Elektronik	7440430027 WE-TPC	1.950	0.029
3.3	Würth Elektronik	744043003 WE-TPC	1.800	0.030
3.9	Würth Elektronik	7440430039 WE-TPC	1.650	0.030
4.7	Würth Elektronik	744043004 WE-TPC	1.700	0.050
5.6	Würth Elektronik	744043005 WE-TPC	1.300	0.070
6.8	Würth Elektronik	744043006 WE-TPC	1.250	0.080
8.2	Würth Elektronik	744043008 WE-TPC	1.050	0.090
10.0	Würth Elektronik	744043100 WE-TPC	1.000	0.095
100.0	Würth Elektronik	744043101 WE-TPC	0.290	0.950
12.0	Würth Elektronik	744043120 WE-TPC	0.950	0.100
15.0	Würth Elektronik	744043150 WE-TPC	0.750	0.120
18.0	Würth Elektronik	744043180 WE-TPC	0.700	0.150
22.0	Würth Elektronik	744043220 WE-TPC	0.700	0.160
220.0	Würth Elektronik	744043221 WE-TPC	1.008	0.095
33.0	Würth Elektronik	744043330 WE-TPC	0.590	0.183
47.0	Würth Elektronik	744043470 WE-TPC	0.500	0.218
68.0	Würth Elektronik	744043680 WE-TPC	0.400	0.310
1.2	Würth Elektronik	7440520012 WE-TPC	0.500	0.020
1.8	Würth Elektronik	7440520018 WE-TPC	3.000	0.030
2.5	Würth Elektronik	744052002 WE-TPC	2.700	0.040
3.0	Würth Elektronik	744052003 WE-TPC	2.400	0.040
3.0	Würth Elektronik	7440520039 WE-TPC	2.100	0.050
4.7	Würth Elektronik	744052004 WE-TPC	2.100	0.050

This example schematic is supplied for informational/educational purposes only.

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

If you still have questions?

Just call us: we try to help you

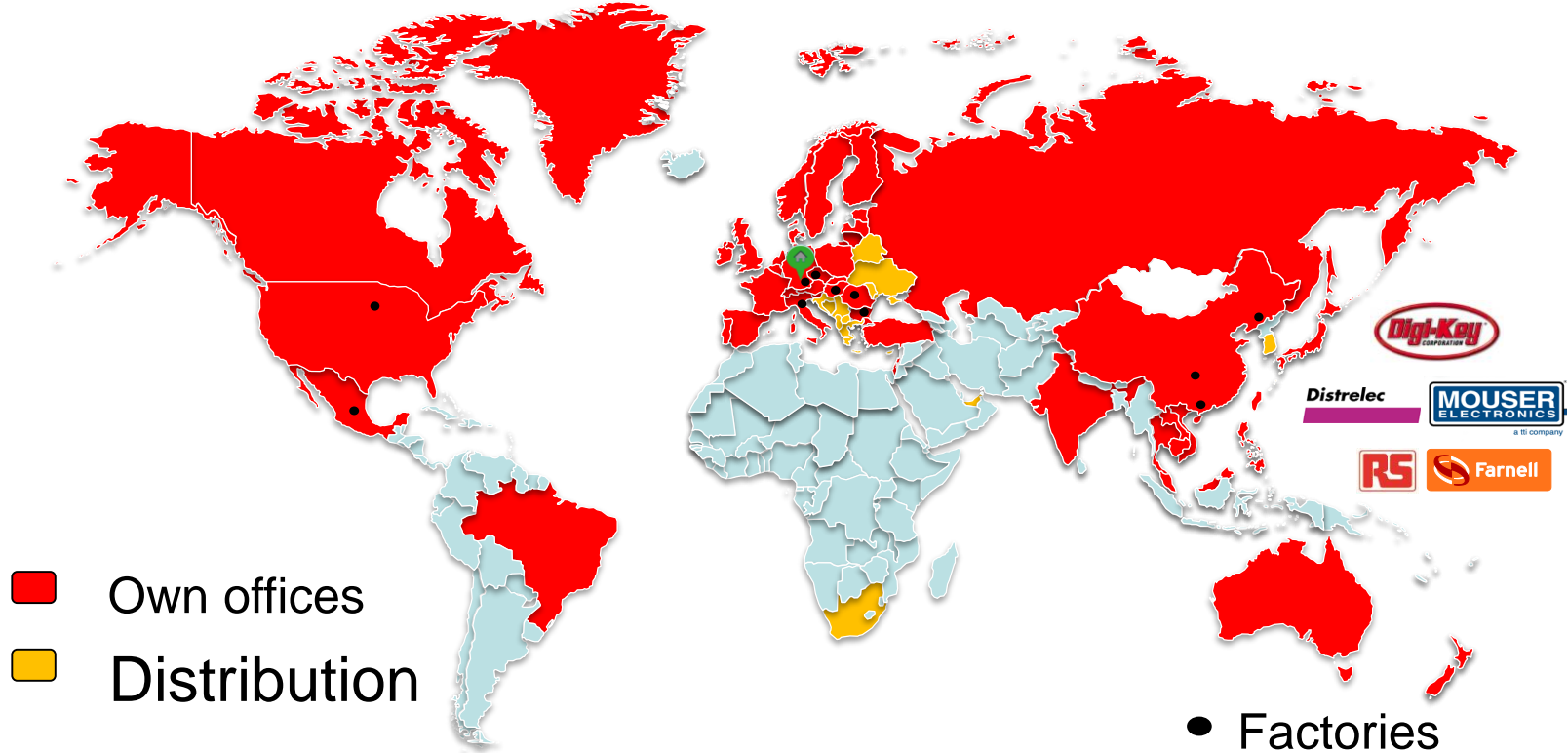
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Technical support needed?

Ask our design engineer Lorandt Fölkel

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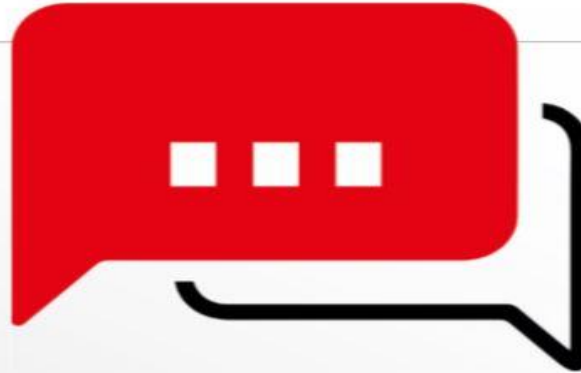
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