600W LLC Demo Board

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IFAT PMM APS SE AC
HV DC/DC Converters Applications

Table of contents

- **General description**
- **Efficiency results**
- **Design Concept**

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Prototype Specifications

Half Bridge LLC with synchronous rectification in center tap configuration	
V_{in}	350-410V_{DC}
V_{in_nom}	380V_{DC}
V_{out_nom}	12V_{DC}
I_{out}	50A
P_o	600W
$f_{res}=f_0$	157kHz
f_{min}	90kHz
f_{max}	210kHz
Transformer turns ratio	16:1
C_r	66nF
L_r	15.5uH
L_m	195uH

Primary HV MOSFETs

- **CoolMOS™ IPP60R190P6**
- *Reduced Gate Charge (Q_g)*
- *Reduced E_{off}*
- *High body diode ruggedness*

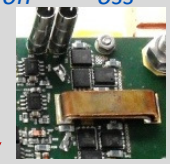
SR MOSFETs

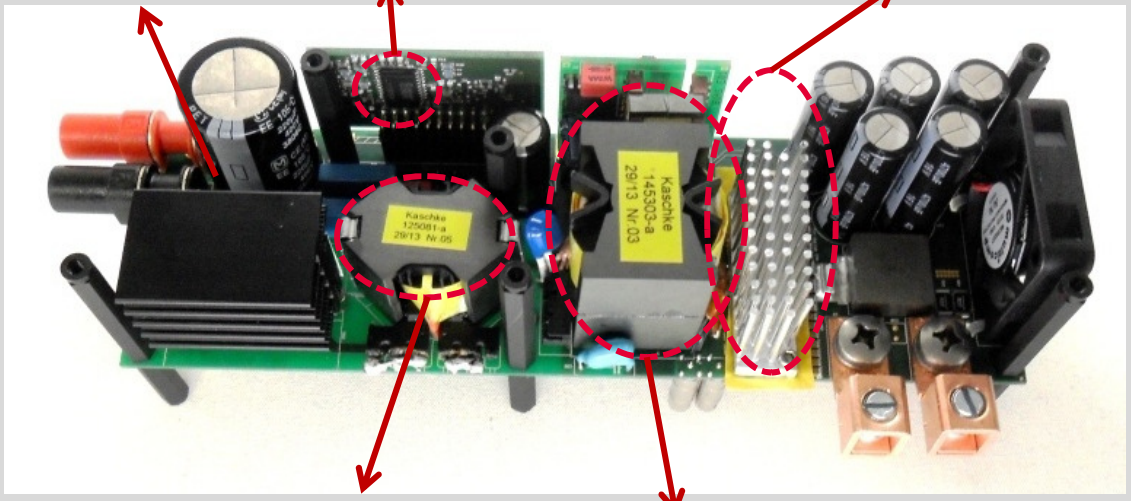
- **OptiMOS™ BSC010N04LS**
- *New generation*
- *Best FOM $R_{ds,on}$ x Qg*
- *Best FOM $R_{ds,on}$ x Q_{oss}*



LLC analog controller
ICE2HS01G
HB Gate Drive IC
2EDL05N06PF

Bias QR Flyback controller
ICE2QR2280Z



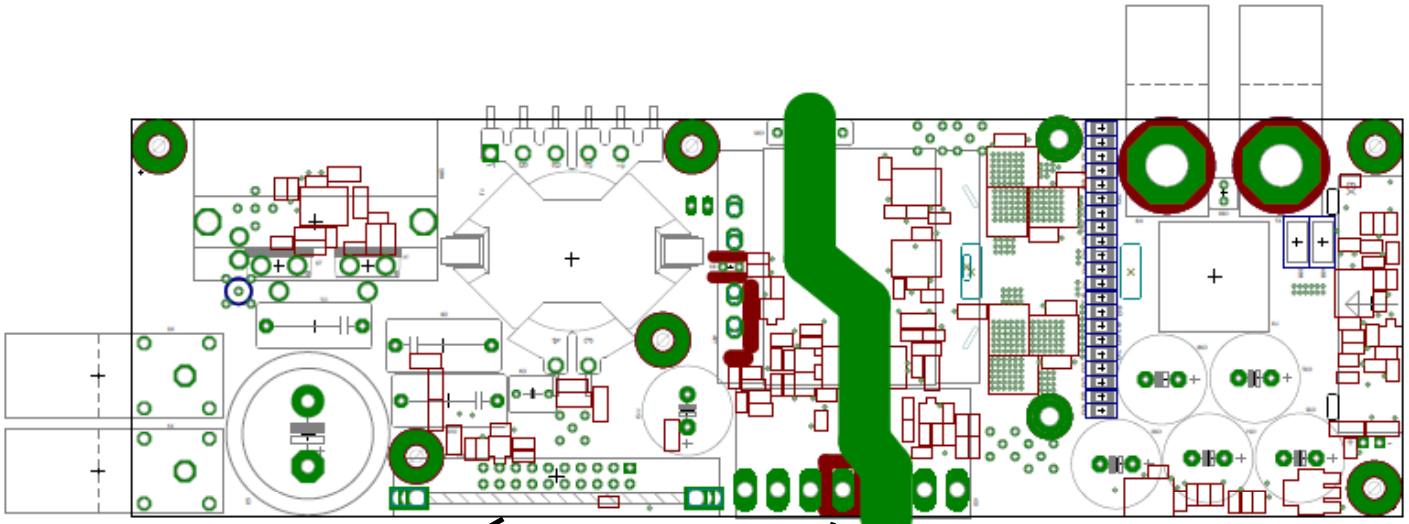


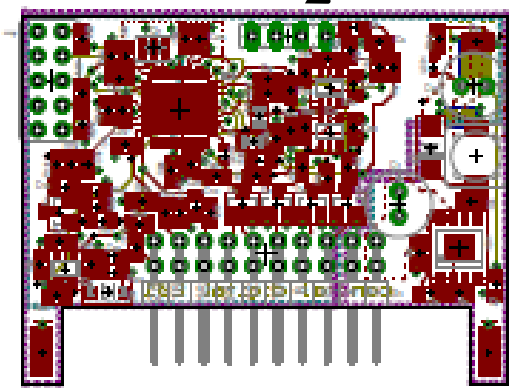
Resonant inductor
RM12 core

Transformer
PQ35/35 core

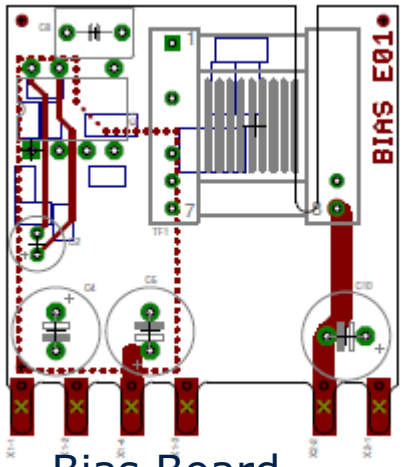
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PCB Boards Layout: main power board and Control and Bias daughter boards





Controller Board

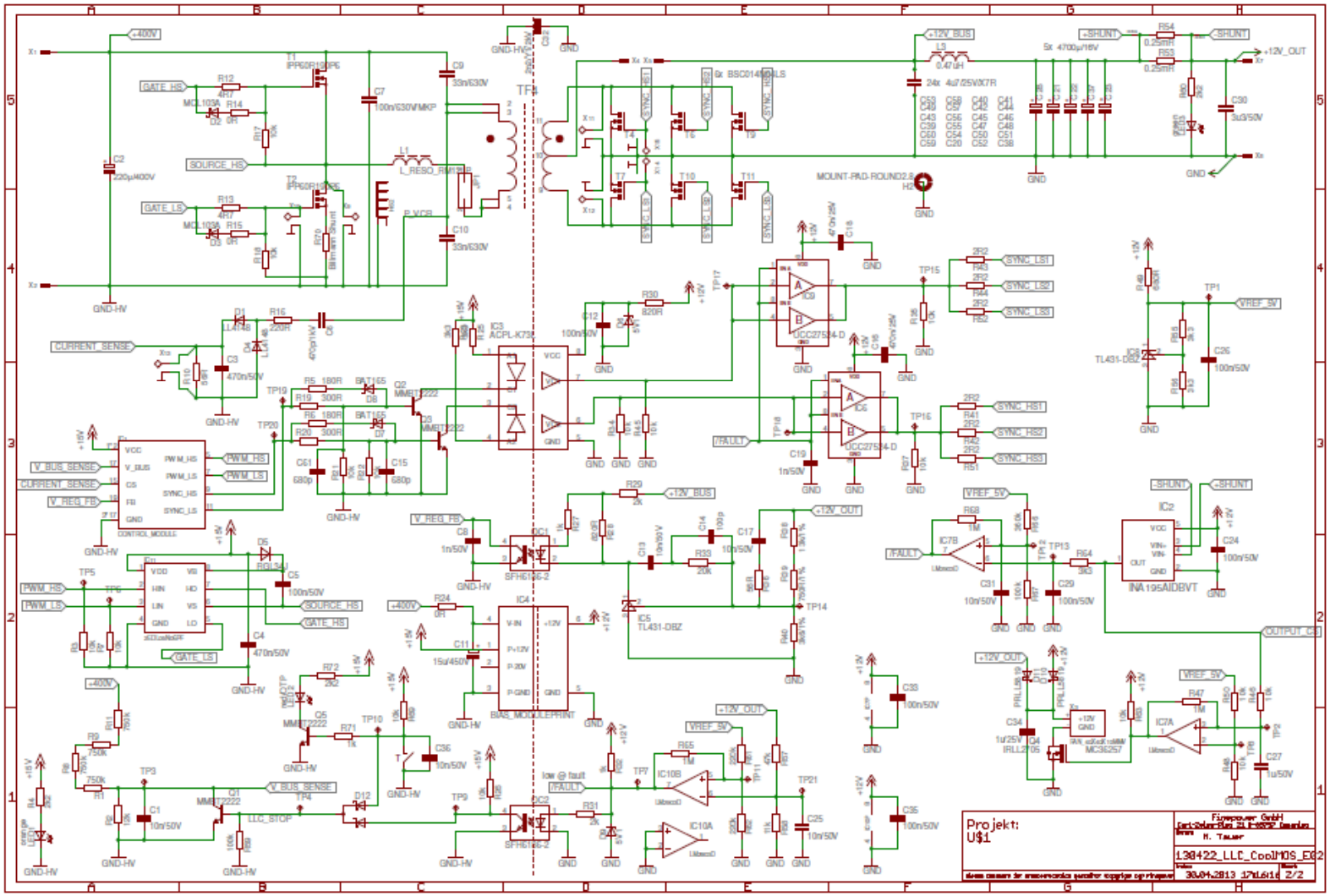


Bias Board

- Power Density>20W/inch^3

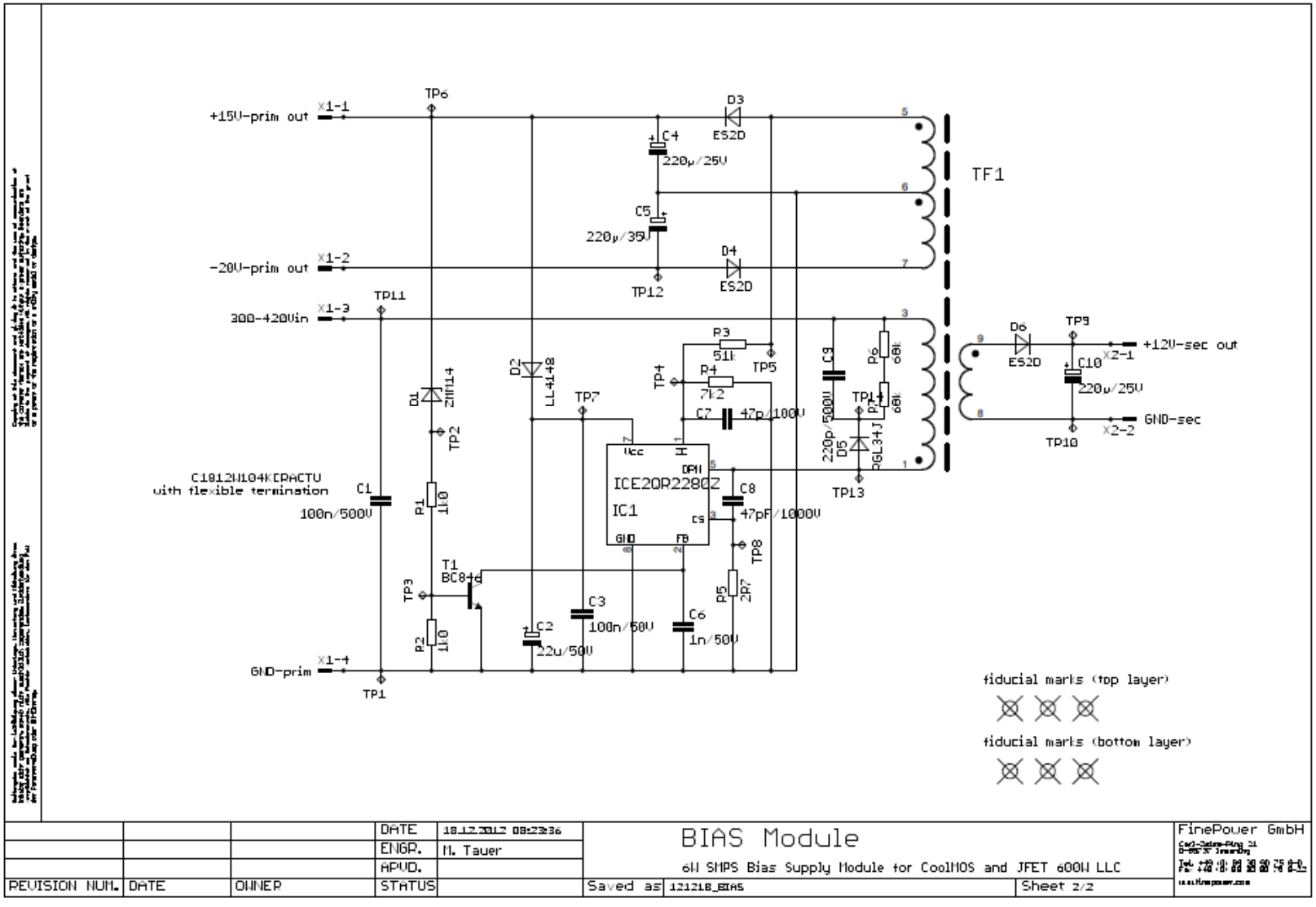
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Main Power Board Schematic



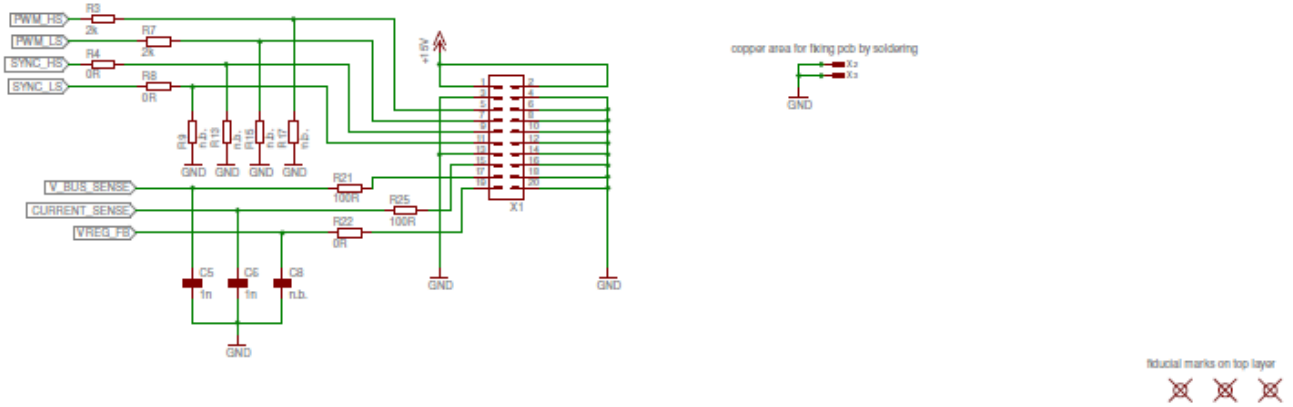
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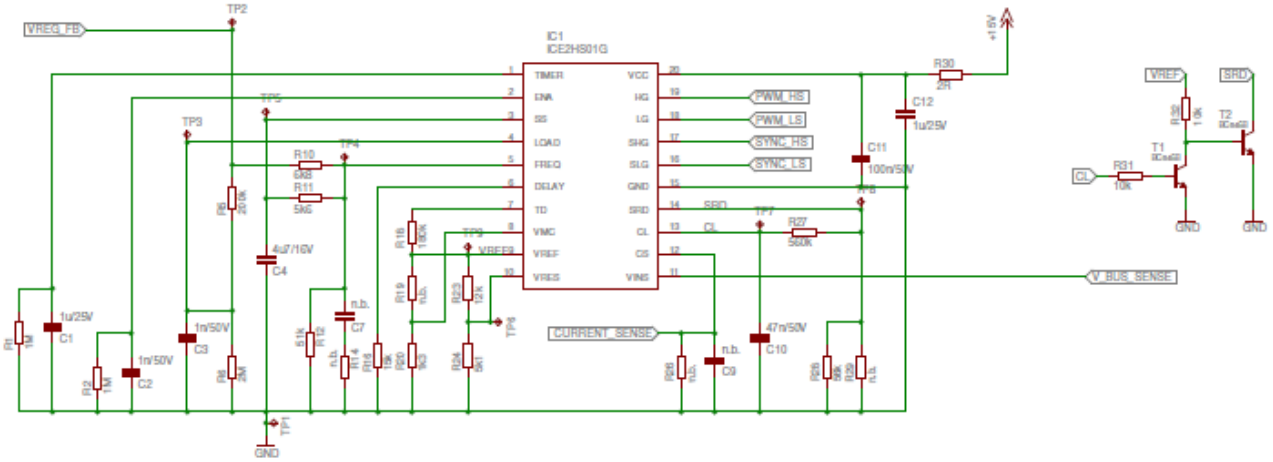
Bias Board Schematic



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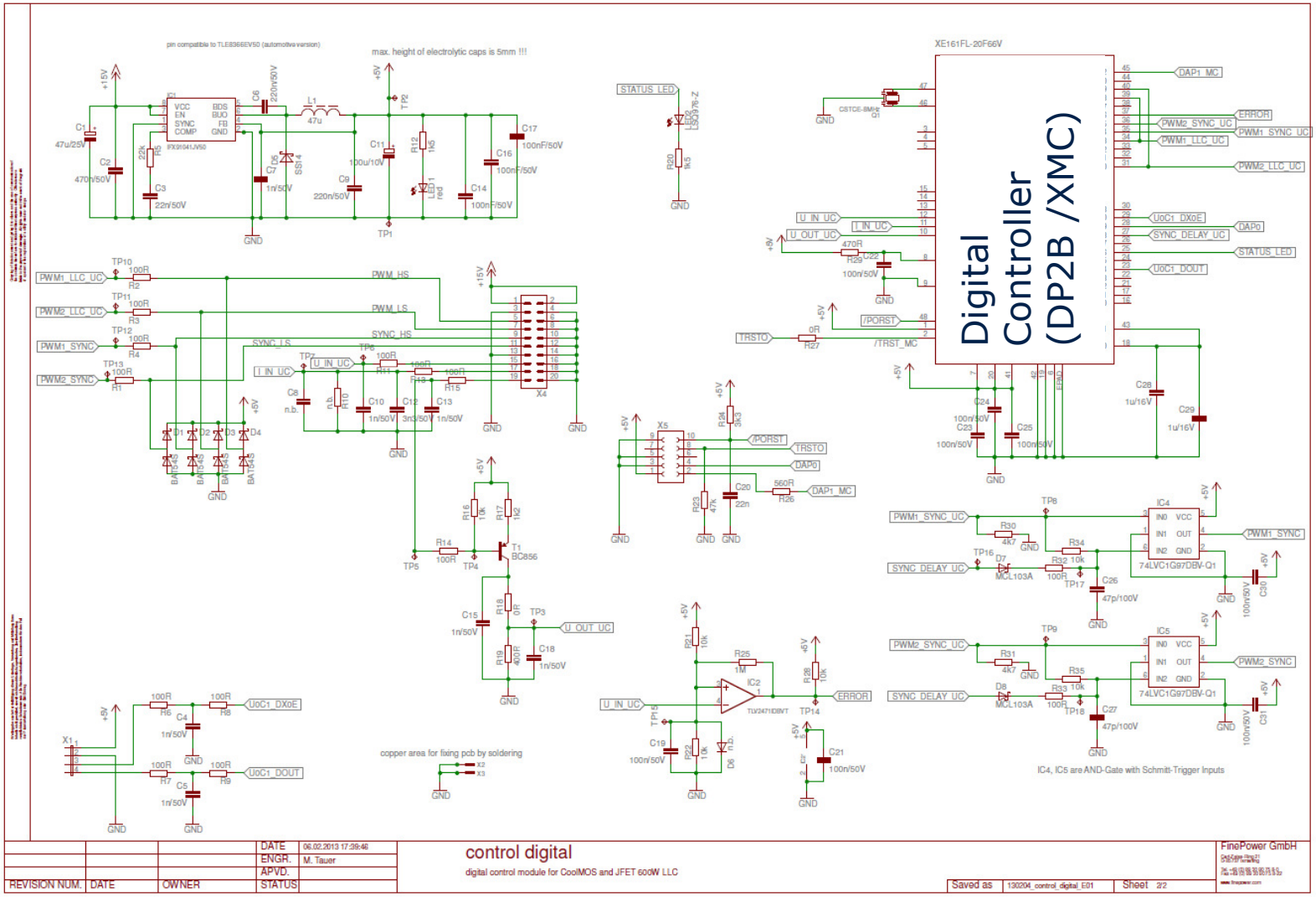
Analog Control Board Schematic





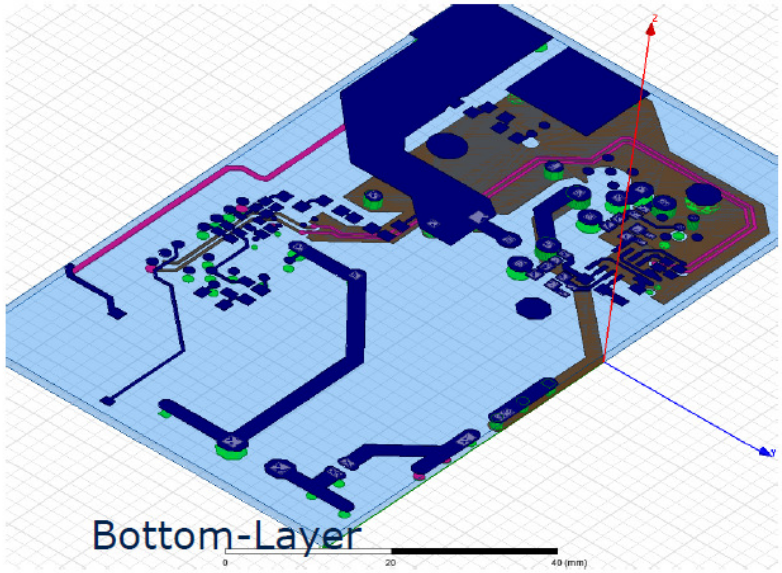
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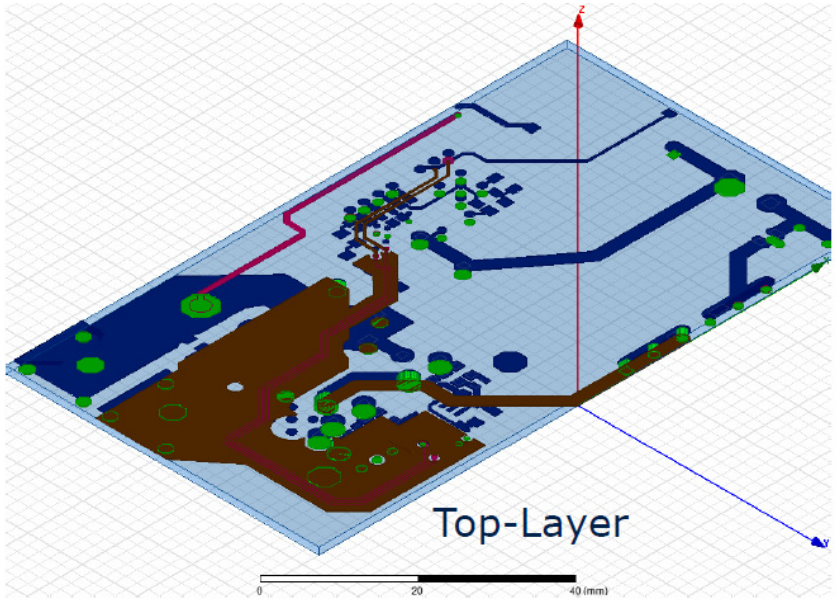
Digital Control Daughter Board Schematic



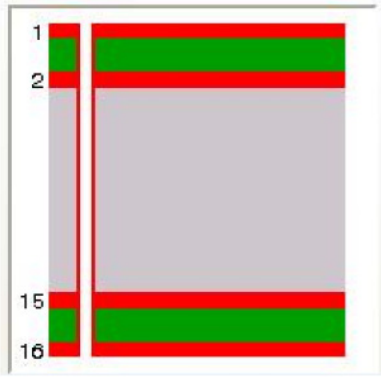
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PCB structure





PCB-Stackup



Nr	Copper	Isolation
1	0.07mm	0.15mm
2	0.07mm	0.93mm
15	0.07mm	0.15mm
16	0.07mm	

Gesamt: 1.51mm

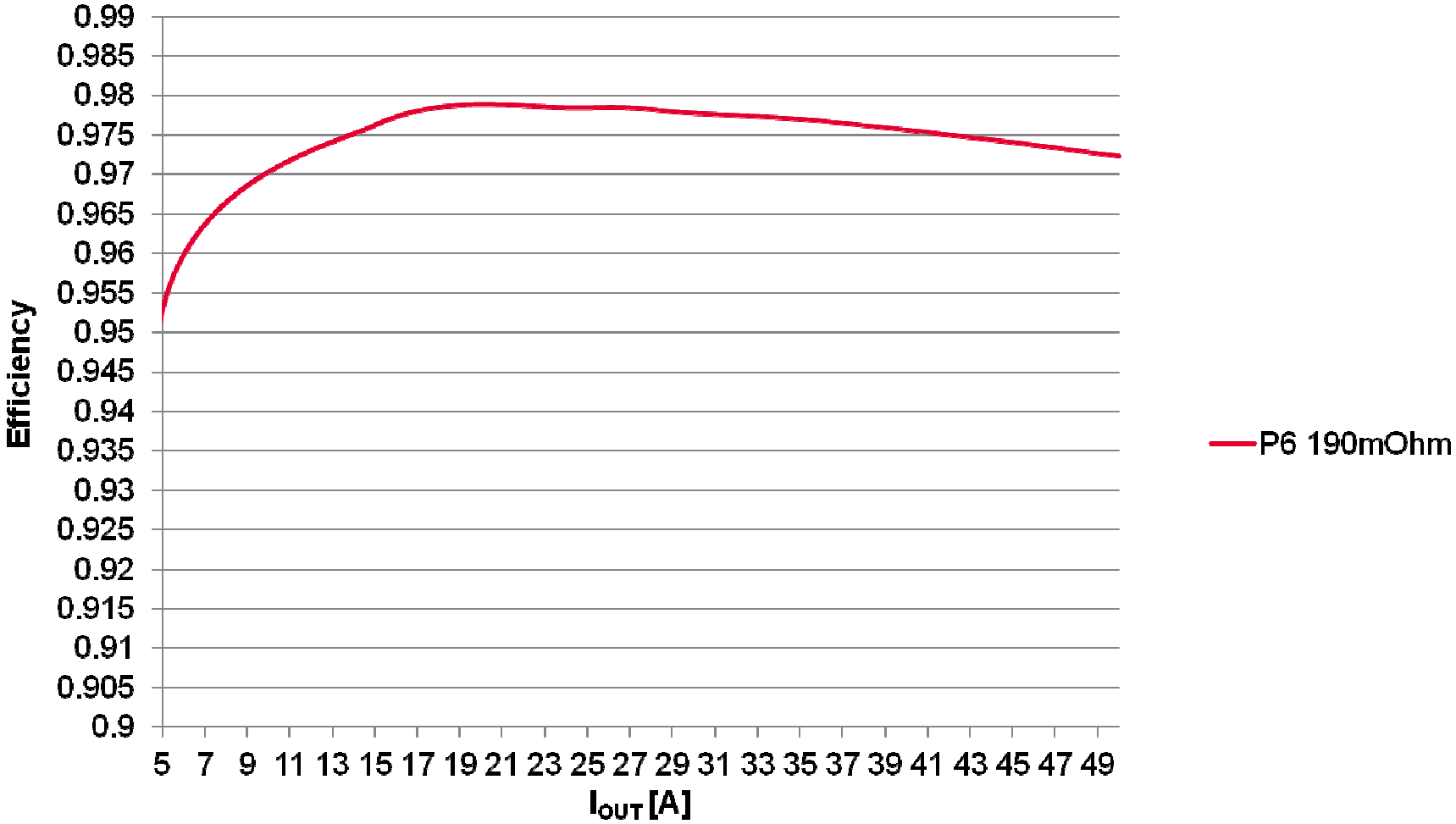
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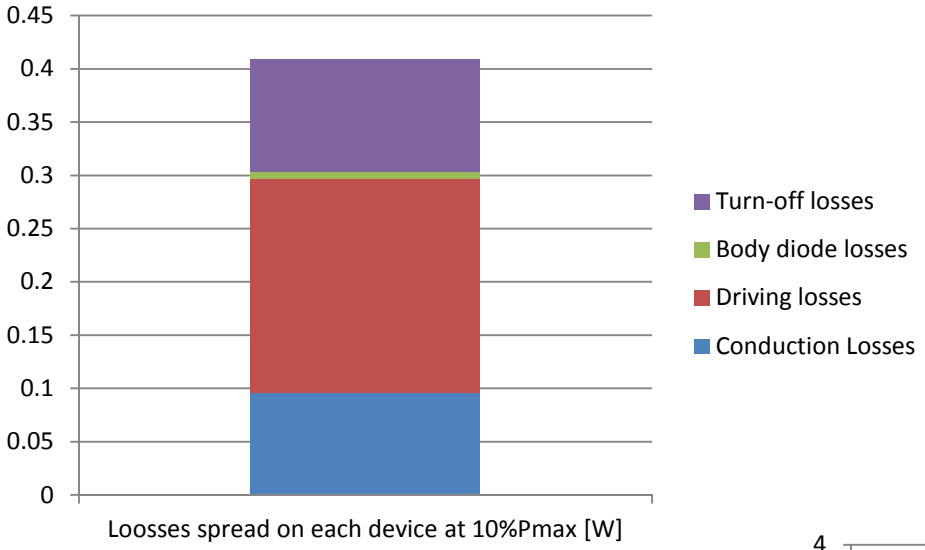
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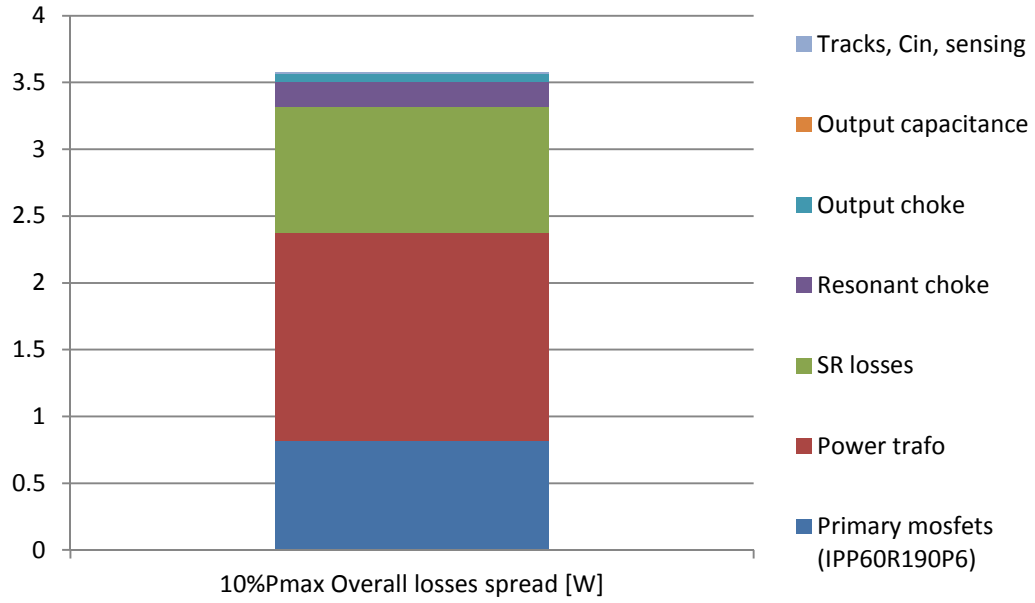
Efficiency plot at Vin=380Vdc (Bias consumption not included)



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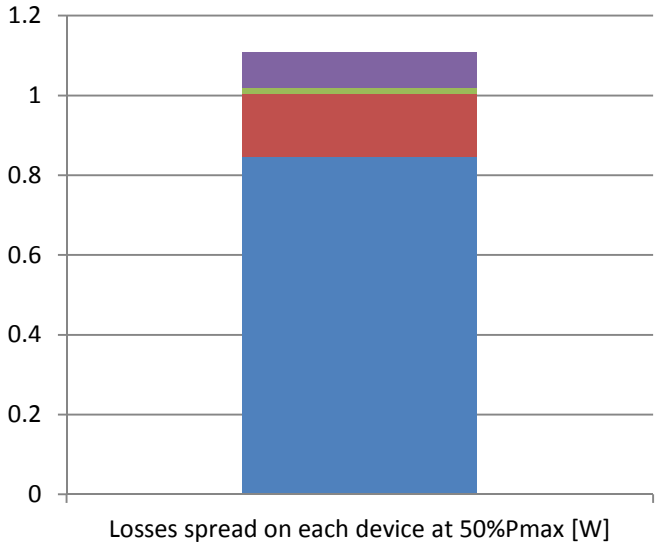
10%Pmax Vin=380Vdc

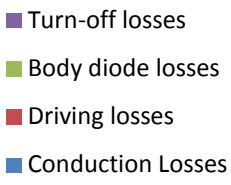


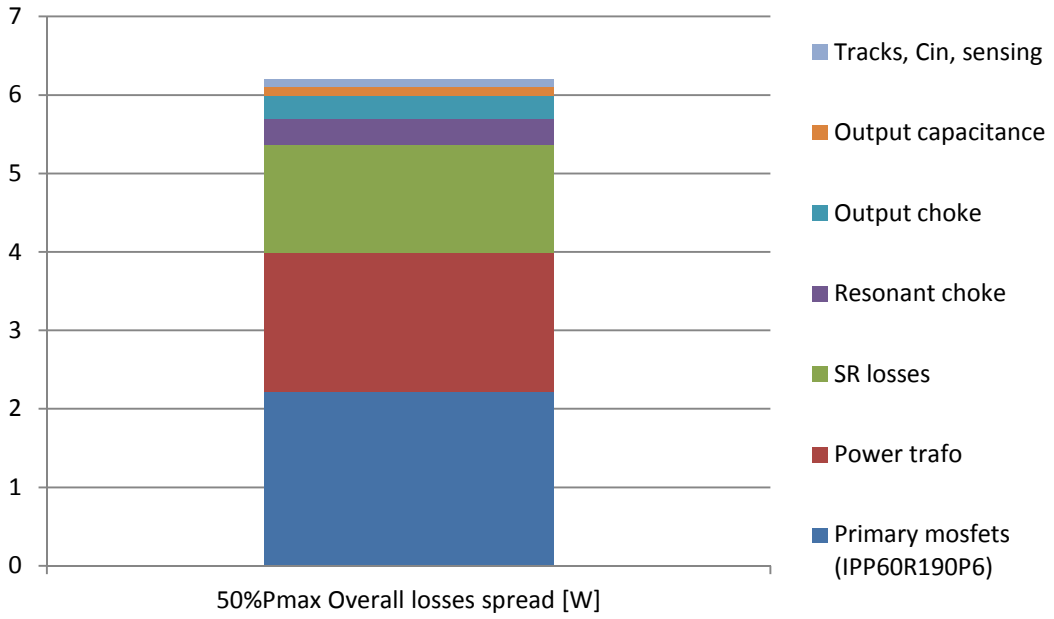


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50%Pmax Vin=380Vdc

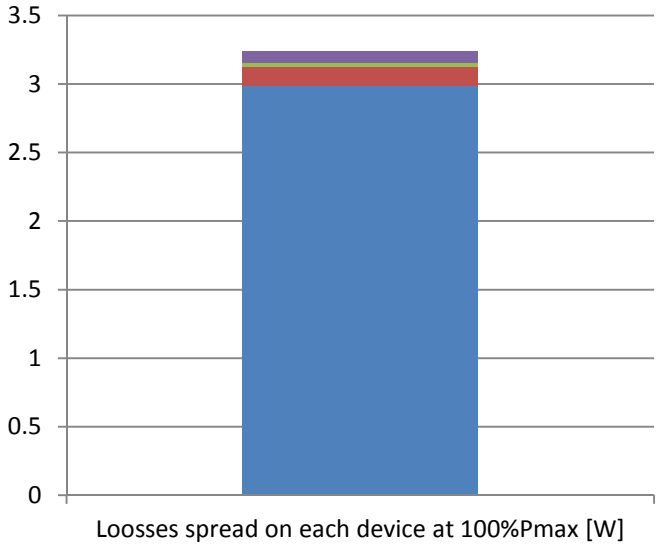


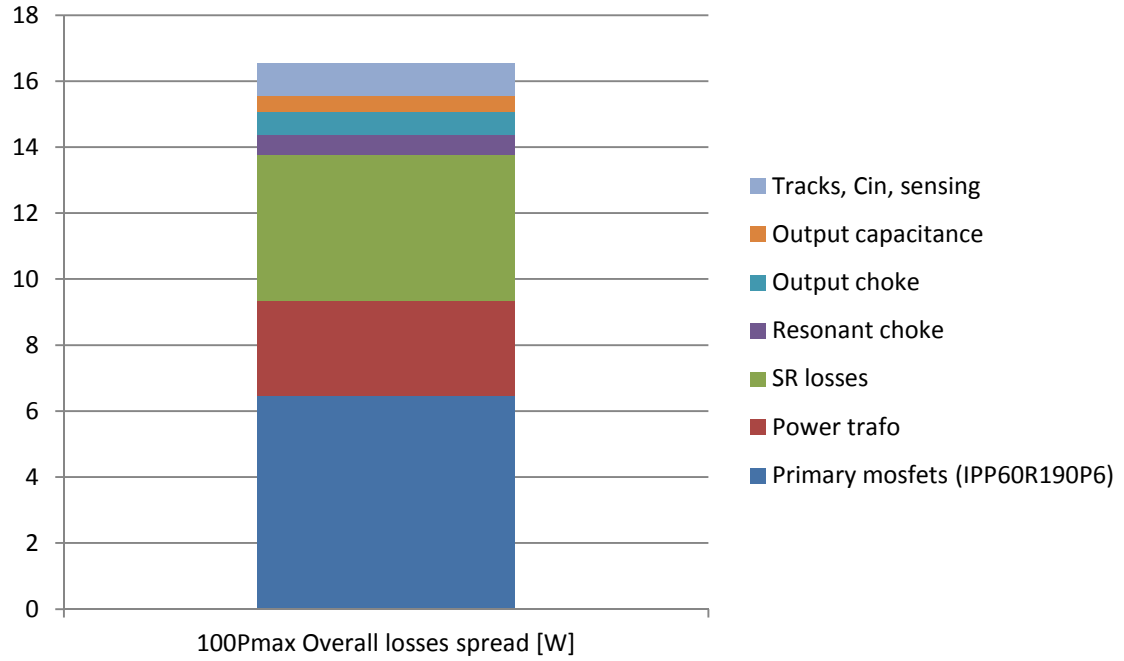




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100%Pmax Vin=380Vdc





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Design procedure: input data

$$n = \frac{V_{in_nom}}{2 \cdot V_{out_nom}}$$

$$M_{\min} \equiv K_{\min}(Q, m, F_x) = \frac{n \cdot V_{o_\min}}{V_{in_\max}/2}$$

$$M_{\max} \equiv K_{\max}(Q, m, F_x) = \frac{n \cdot V_{o_\max}}{V_{in_\min}/2}$$

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Resonant tank components and related resonant frequencies

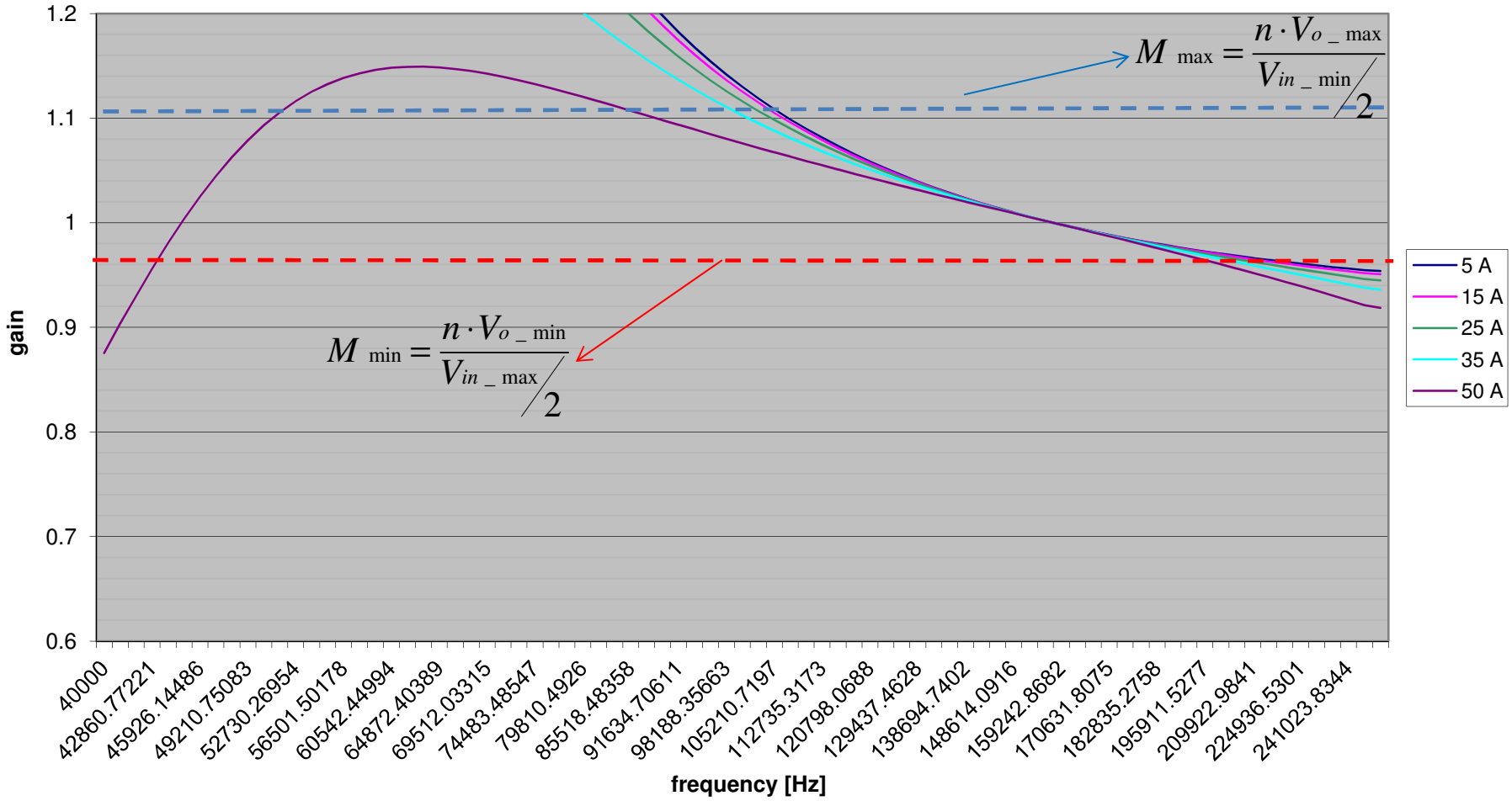
- $n=V_{in_nom}/(2xV_o)=380/(2*12)\approx16$
- Lm=195µH
- Lr=15.5µH
- Ln=Lm/Lr=12.5
- Cr=66nF

$$fo=\frac{1}{2\pi\cdot\sqrt{Lr\cdot Cr}}=157kHz$$

$$fp=\frac{1}{2\pi\cdot\sqrt{(Lr+Lm)\cdot Cr}}=42.7kHz$$

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dc-gain curve (600W LLC hardware revision E02)



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Energy related calculations (ref. IPP60R190P6 device parameters)

$$\mathrm{I}_{m\,ag_\min} = \frac{2\cdot\sqrt{2}}{\pi}\cdot\frac{n\cdot V_o}{2\pi\cdot f_{sw_\max}\cdot L_m} = 0.672A$$

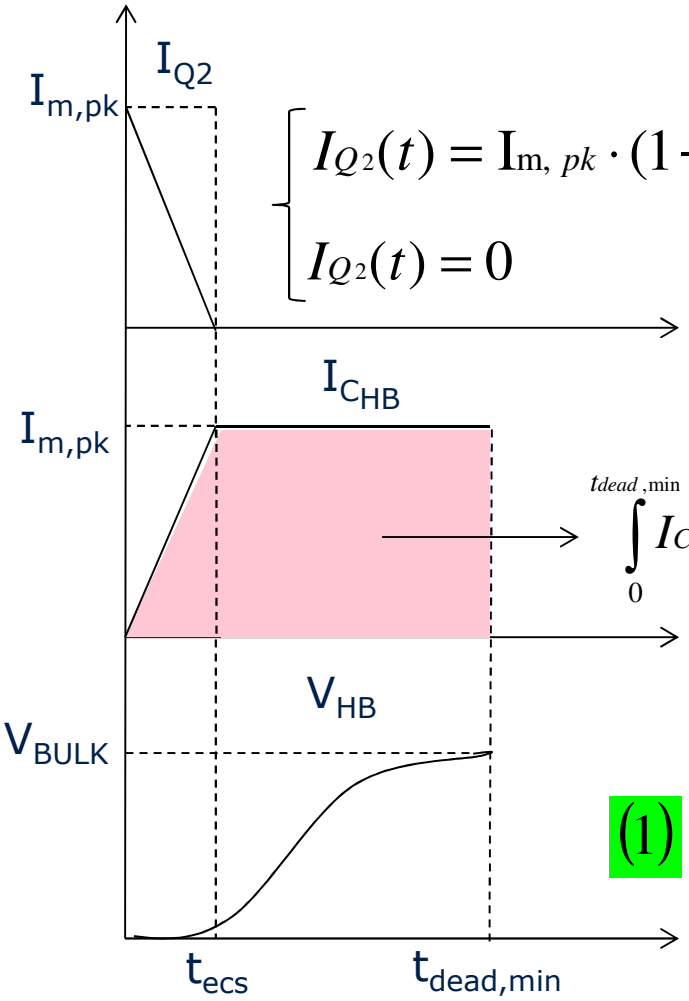
$$En_{res_\min} = \frac{1}{2}\cdot(L_m + L_r)\cdot I^2_{mag_\min} = 95.1\mu J$$

$$En_{cap_\max} = \frac{1}{2}\cdot(2Co(er))\cdot V^2_{DS_\max} \approx 9\mu J$$

$$\Rightarrow \quad En_{res_\min} > En_{cap_\max}$$

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Q_{oss}, $I_{mag,pk}$, $t_{dead,min}$, t_{ecs} relationship



$$\begin{cases} I_{Q2}(t) = \mathrm{I}_{m,\,pk} \cdot \left(1 - \dfrac{t}{t_{ecs}}\right) & \forall t \le t_{ecs} \\ I_{Q2}(t) = 0 & \forall t \ge t_{ecs} \end{cases}$$

$$t_{ecs} = f\left(R_{g,\,tot}, V_{gs,\,th}, \frac{C_{ds}}{C_{gd}}\right)$$

$$\int_0^{t_{dead,\,\min}} I_{CHB}(t)\,dt = \frac{1}{2} \cdot \mathrm{I}_{m,\,pk} \cdot t_{ecs} + \mathrm{I}_{m,\,pk} \cdot \left(t_{dead,\,\min} - t_{ecs}\right) = 2 \cdot Qoss,_{@\ 400V}$$

(1)

$$t_{dead,\,\min} = \frac{t_{ecs}}{2} + \frac{2 \cdot Q_{oss,\,@\ 400V}}{\mathrm{I}_{m,\,pk}}$$

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Time related calculations (ref. IPP60R190P6 device parameters)

$$\mathrm{I}_{\mathrm{m}\,ag\,_\,\mathrm{min}} = \frac{2\cdot\sqrt{2}}{\pi}\cdot\frac{n\cdot V_o}{2\pi\cdot f_{sw\,_\,\mathrm{max}}\cdot L_m} = 0.672A$$

$$\mathrm{I}_{\mathrm{m}\,ag\,_\,\mathrm{max}} = \frac{2\cdot\sqrt{2}}{\pi}\cdot\frac{n\cdot V_o}{2\pi\cdot f_{sw\,_\,\mathrm{min}}\cdot L_m} = 1.66A$$

$$t_{dead,\,\mathrm{min}} = \frac{t_{ecs}}{2} + \frac{2\cdot Q_{oss,\,@\,400V}}{\mathrm{I}_{\mathrm{m}\,ag,\,\mathrm{max}}} \approx 130n\,\mathrm{sec}$$

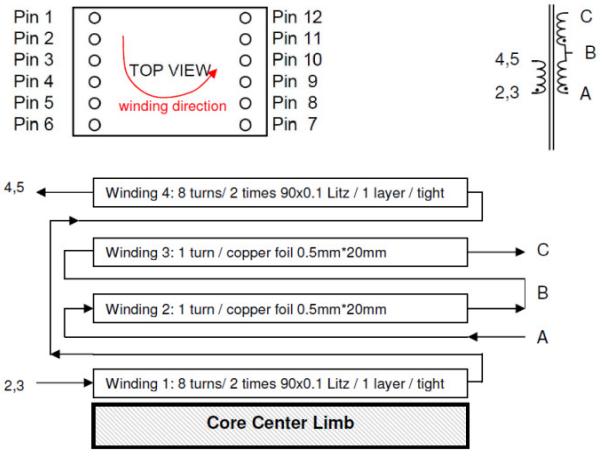
$$t_{dead,\,\mathrm{max}} = \frac{t_{ecs}}{2} + \frac{2\cdot Q_{oss,\,@\,400V}}{\mathrm{I}_{\mathrm{m}\,ag,\,\mathrm{min}}} \approx 311n\,\mathrm{sec}$$

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Main transformer structure: PQ35/35 core with TDK PC95 ferrite material

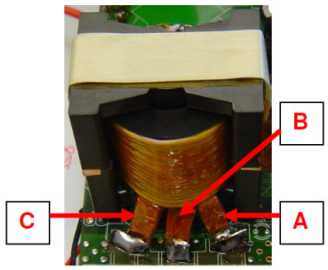
LLC main transformer

Core form and material	PQ35/35, PC95 (TDK)
Bobbin	Epcos, B65882E0012T001
Primary inductance L_p	195uH, measured between 2,3 and 4,5, other pins open
Leakage inductance L_{lk}	1.5uH, measured between 2,3 and 4,5, other pins shorted
Isolation voltage V_{iso}	2500V_{rms} / 50Hz, 1min (between 2,3,4,5 and A,B,C)



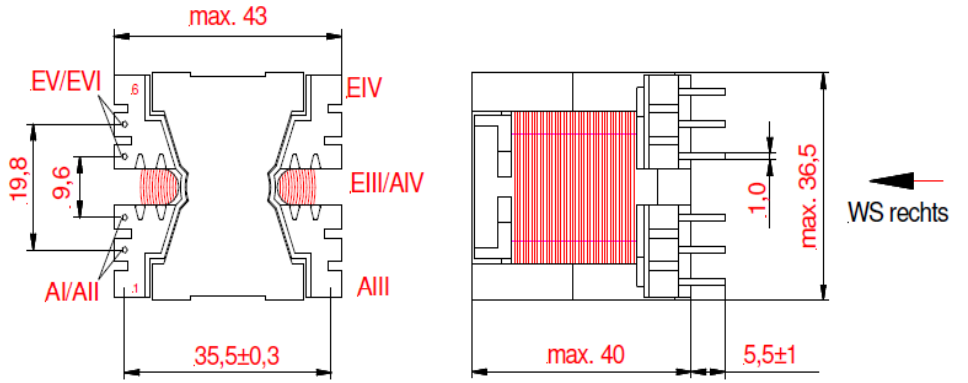
Windings	Start	End	Wire	Turns	Layers	Method
1	2,3	Float	2 times 90x0.1mm Litz	8	1	Tight
2	A	B	0.5mm*20mm copper foil	1	1	Tight
3	B	C	0.5mm*20mm copper foil	1	1	Tight
4	Float	4,5	2 times 90x0.1mm Litz	8	1	Tigh

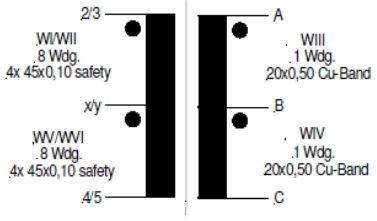
Connection of secondary copper foil:



Technical Data Sheet

Customer :	*Part designation :*	*Customer part number :*
Infineon Technologies	**SP-PQ 35/35**	





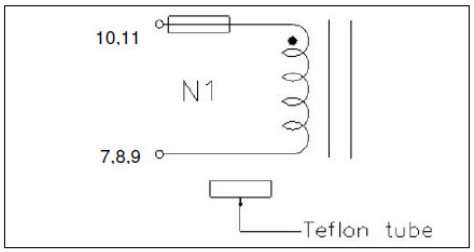
Core / material / air gap	PQ35/35 / K2008 or equiv. / 0,25
Nominal inductance	LI+LVI = 195µH ± 15%
Ratio of transformation	8 : 1 : 1 : 8
Dielectric strength (50Hz/1s)	2,5kV (prim - sec)
Leakage inductance	max. 3µH
Operating temperature	-25°C - +125°C
Storage temperature	-25°C - +85°C
Humidity- / application class	F (DIN 40040)

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Resonant choke: RM12 core, material N87

LLC resonant choke

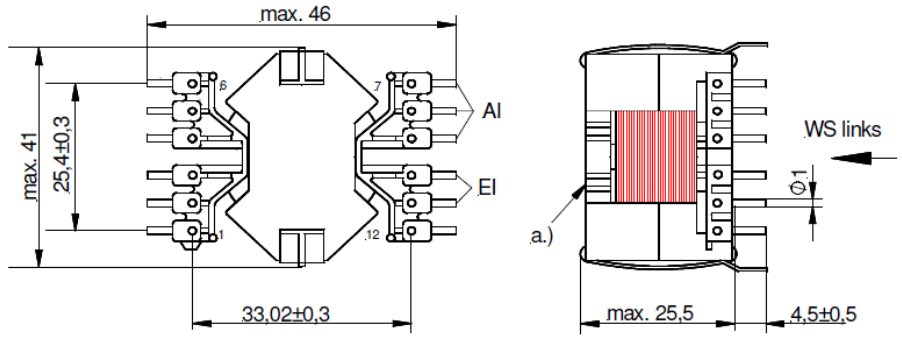
Core form and material	RM12, N87 (Epcos)
Bobbin	Epcos, B65816C1512T001
Inductance L	14uH

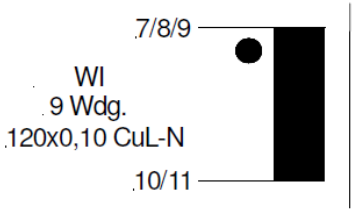


Windings	Start	End	Wire	Turns	Layers	Method
N1	7,8,9	10,11	120x0.1mm Litz	9	1	Tight

Technical Data Sheet

Customer :	*Part designation :*	*Customer part number :*
Infineon Technologies	**SP-RM 12**	





Core / material / air gap	RM12 / K2008 or equiv. / 1,1
Nominal inductance	L = 14µH ± 15%
Operating temperature	-25°C - +125°C
Storage temperature	-25°C - +85°C
Humidity- / application class	F (DIN 40040)

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