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Power Electronics Conference
5th December 2017
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Thermal Management of GaN Power Semiconductors in SMD Package

GaN power semiconductors in the news as …
G A M E C H A N G E R ?

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…switching speed, small size, competitive cost and high reliability give the **GaN transistor** the positive trajectory to broadly **displace the silicon MOSFET in power conversion applications.**

2017, K.Chen et all [1]

… I have no doubt that **GaN will take over the power transistor business,** over the next decade…

2014, A.Lidow [2]

"**GaN delivers** total cost on par with silicon at nearly **double power density.**"

2017, A.Bahai [3]

Why there are not more products with GaN semiconductors on the market?

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What are major challenges using GaN power semiconductors?

… from Power Electronics System view

In power electronics you have to master a wide range of different disciplines

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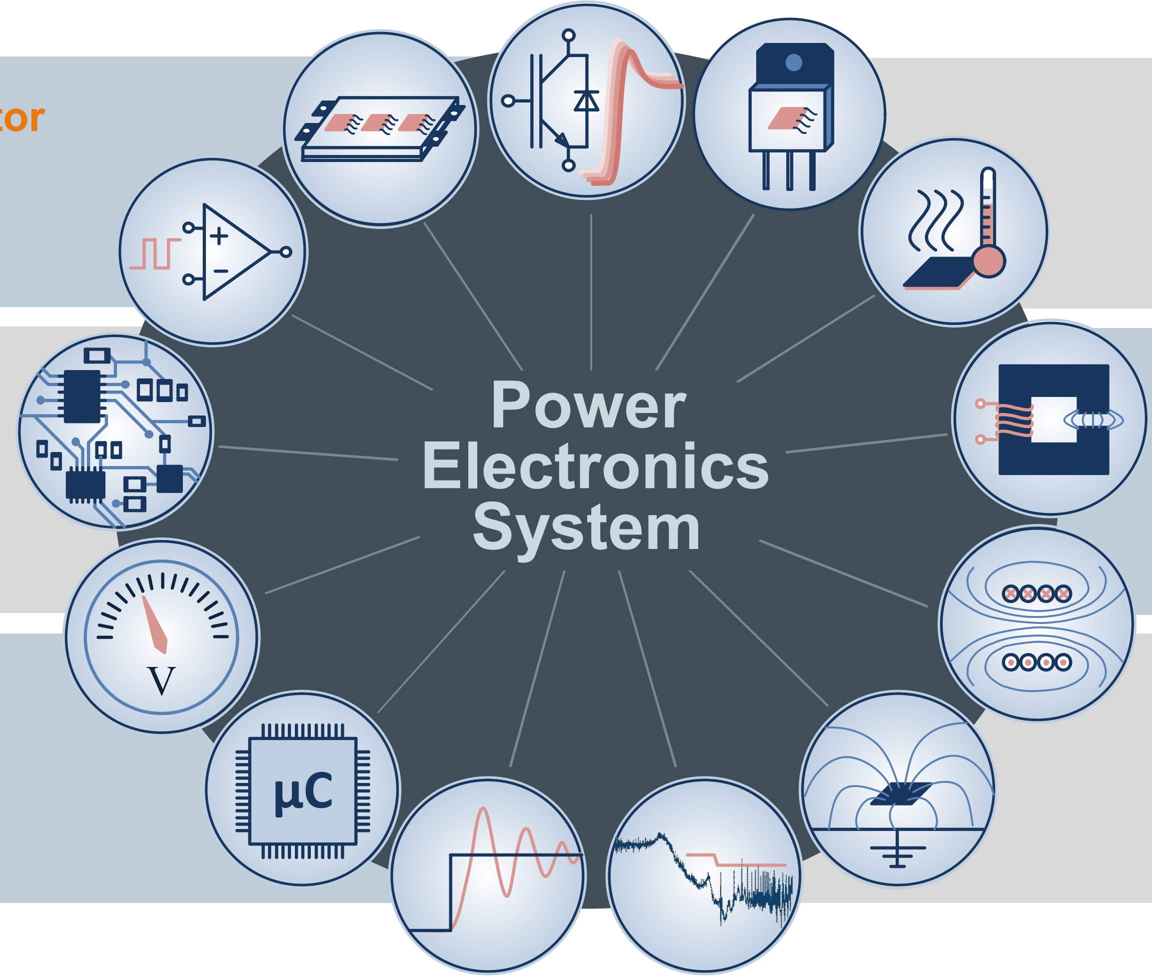
Power Semiconductor
- power module
- discrete device
- thermal design

Electronic Design
- gate driver
- measurement design
- auxiliary electronics

Power Electronics System Control
- power circuit control
- embedded controller



Thermal Design
- passive/active cooling
- mechanical design

Power Inductor
- core and winding design
- thermal design

EMC Management
- handle EMC emission
- avoid parasitic elements

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New challenges came up in fast switching power electronics

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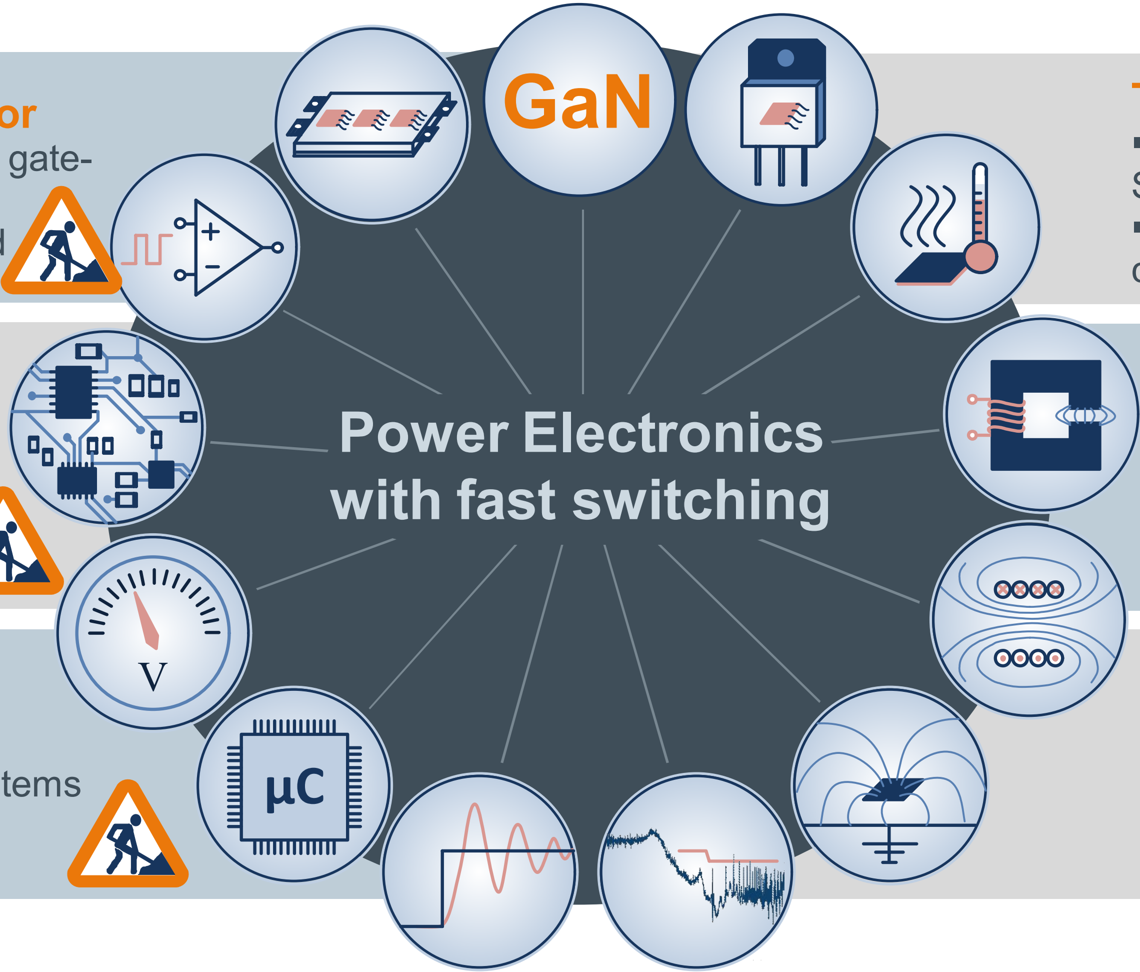
Power Semiconductor
- low stray inductance in gate- and power-circuit
- control switching speed

Electronic Design
- higher dV/dt and EMC immunity
- faster measurement

Power Electronics System Control
- handle low damped systems
- fast control algorithm



Thermal Design
- cooling concepts for SMD packages
- handle capacitive coupling

Power Inductor
- high frequency design
- handle fringing effect

EMC Management
- higher EMC emission
- reduce parasitic capacitance and inductances

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SMD package and thermal management

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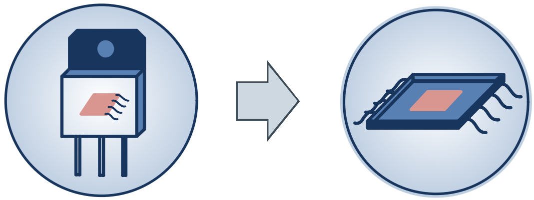


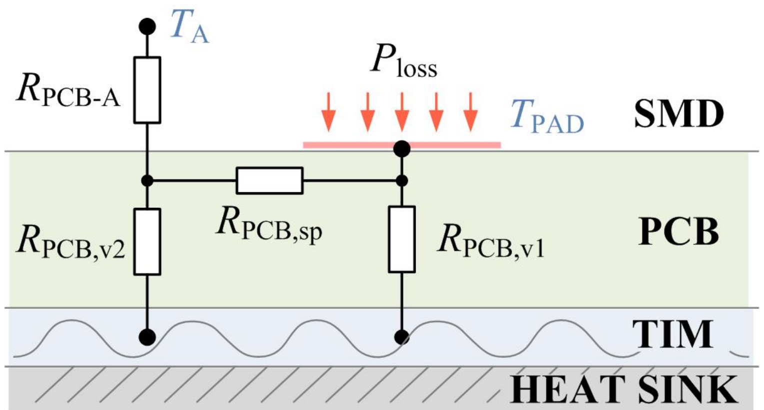
discrete
TO packages

discrete
SMD package

Why do we need power semiconductors in SMD packages?

- lower stray inductance in the power circuit
- better control of the gate voltage
- easy and full automated manufacturing

Thermal equivalent circuit of the PCB



$R_{PCB,v1}$: Local thermal resistance from device pad vertical trough PCB to TIM
$R_{PCB,v2}$: Distributed vertical thermal resistance trough PCB
$R_{PCB,sp}$: Spreading resistance within the copper layers of the PCB
$R_{PCB\text{-}A}$: Convection resistance from the PCB surface to ambient

How can we influence/optimize the thermal management of SMD power semiconductor on a standard PCB?

Analyzing the thermal PCB design –
Example definition

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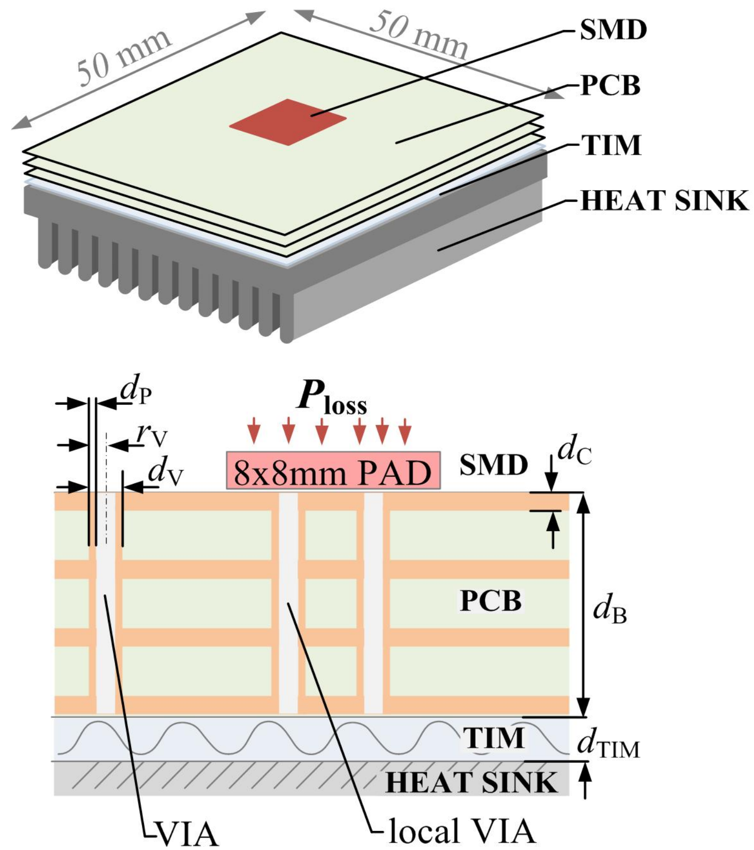
Analyzing passive cooling and a variation of the PCB parameters

PCB parameters	Value	Symbol [Unit]
Given (fix) design parameters		
PCB size	50x50	A_B [mm²]
PCB substrate material	FR4	-
Amount of layers	4	n [-]
VIA diameter	0.70	d_V [mm]
PAD size	8x8	A_{PAD} [mm²]
Parameters to be analyzed		
PCB thickness	{1, 2, 3}	d_B [mm]
Copper thickness	{35, 70, 105}	d_C [µm]
VIA plating thickness	{20, 30, 40}	d_P [µm]
Simulation parameters		
Ambient temperature	25	T_A [°C]
Power losses	4	P_{loss} [W]
PCB orientation	vertical	-



Analyzing the thermal PCB design –
Thermal spreading within the PCB

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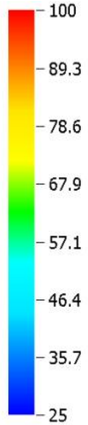
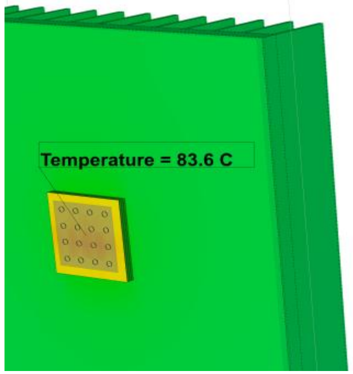
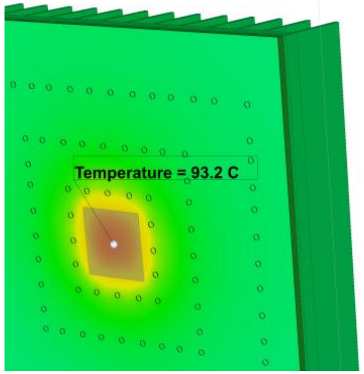
Temperature [°C]



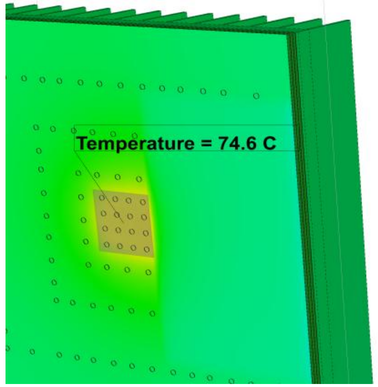
Setup I
- with local thermal VIAs
- without thermal spreading



Setup II
- without local thermal VIAs
- with thermal spreading



Setup III
- with local thermal VIAs
- with thermal spreading



	Setup I	Setup II			Setup III
$R_{th,PAD-HS}$ from device pad to heat sink	**5.8 K/W** 100 %	**8.2 K/W** 141 %	**4.8 K/W** 83 %	**3.4 K/W** 59 %	**3.5 K/W** 60 %
Copper layers (4 layers)	35 µm	35 µm	70 µm	105 µm	70 µm
Design guide	Amount of local thermal VIAs should be chosen by considering the whole thermal resistance	Thermal spreading is important to reach good thermal properties. The copper thickness has a major influence			With the combination of local VIAs and thermal spreading a good performance can be reached with a standard PCB

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Analyzing the thermal PCB design –
Variation of cooling method

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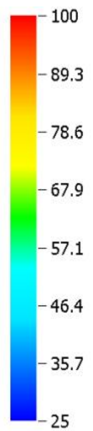
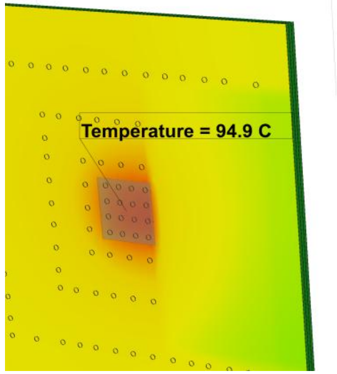
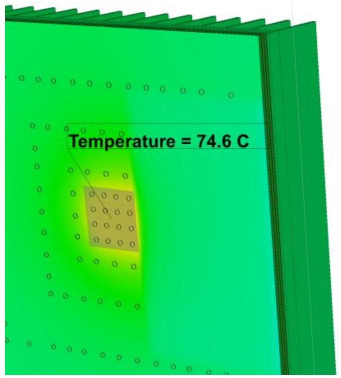


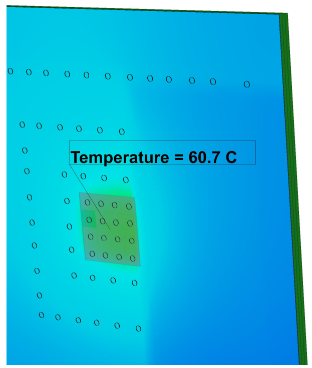
Setup I
- without fan
- without heat sink



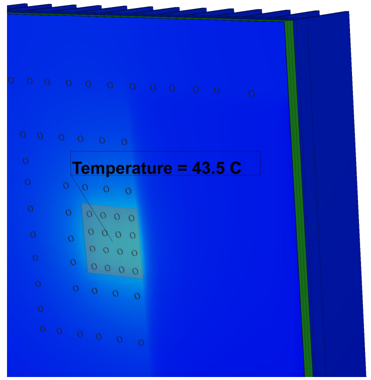
Setup II
- without fan
- with heat sink



Setup III
- with fan
- without heat sink



Setup IV
- with fan
- with heat sink



	Setup I	Setup II	Setup III	Setup IV
$R_{th,PAD-A}$ from device pad to ambient	**17.5 K/W** 100 %	**12.4 K/W** 71 %	**8.93 K/W** 51 %	**4.63 K/W** 26 %
Power losses at $\Delta T = 60$ K	3.43 W	4.84 W	6.72 W	13.0 W
Properties/ Application	▪ passive cooling ▪ small size and low weight ▪ easy manufacturing ▪ cheap	▪ passive cooling ▪ sealed housing/enclosure	▪ small size and low weight ▪ easy manufacturing ▪ cheap	▪ maximum power losses ▪ higher cost

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Analyzing the thermal PCB design –
How to influence the thermal performance?

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Thermal spreading within the PCB is as important as the use of local thermal VIAs

- the thickness has a major influence to the PCB spreading resistance
- a good thermal spreading decreases the negative influence of a TIM and the board thickness
- less local VIAs allow a degree of freedom for the electrical design of the power cell
- a thermal PCB resistance of 3 to 4 K/W can be reached with a standard PCB with passive cooling

The relevance of the thermal PCB design depends on the cooling method and application

Application with ***low power losses***
- passive cooling without heat sink and fan is possible
- easy and high volume manufacturing can be achieved
- low cost for manufacturing and maintenance

Application with ***high power losses***
- a fan and heat sink is needed

An optimal thermal PCB design needs in any case further investigations and calculations

The paper shows examples to understand the possibilities and limits of the thermal PCB design

GaN converter prototype with a thermal management only by the PCB design

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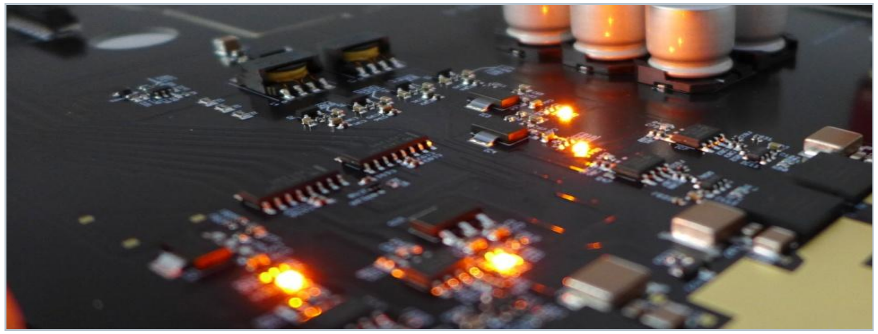
Converter prototype with GaN SMD power semiconductors demonstrates a passive cooling without heat sink and fan

Application	DC/AC-Converter (three phases)
Topology	3L-ANPC
Power Semiconductor	TPH3208
Package	PQFN
Power Range	5 kW
DC-Input voltage	700 V
AC-Output voltage	400 V (line-to-line) 230 V (per phase)
Switching frequency	175 kHz
Cooling method	Passive via PCB
Fan	No
Heat sink	No



PCB parameter	Value
PCB material	FR4
Amount of copper layers	4
Copper layer thickness	70 µm
PCB thickness	1.6 mm
VIA plating	20 µm

GaN converter prototype

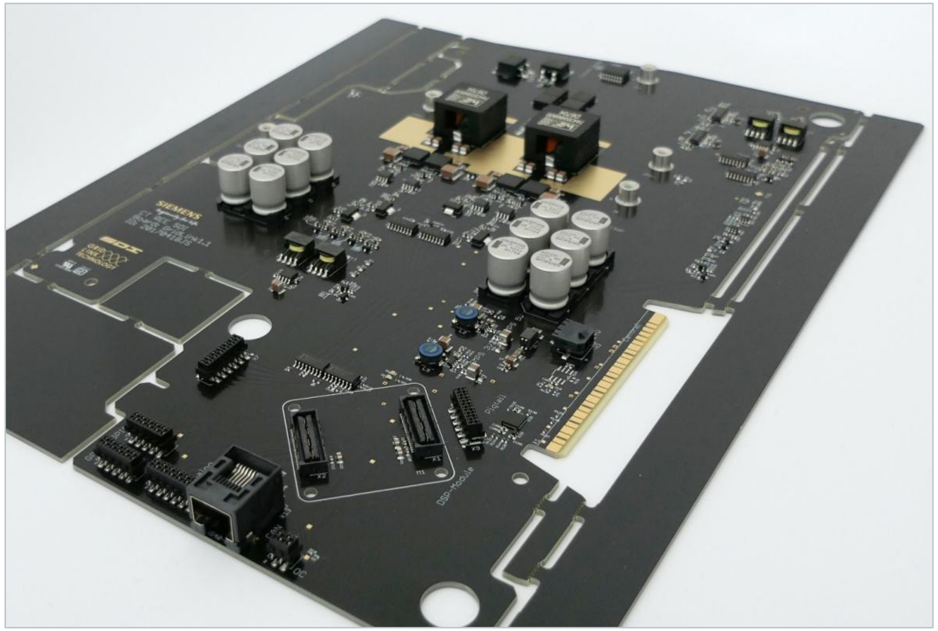
Measurement results (single phase)

Measurement conditions

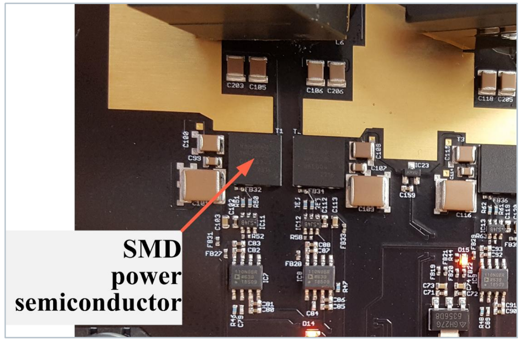
Power: 1 kW (single phase)

Switching frequency: 175 kHz

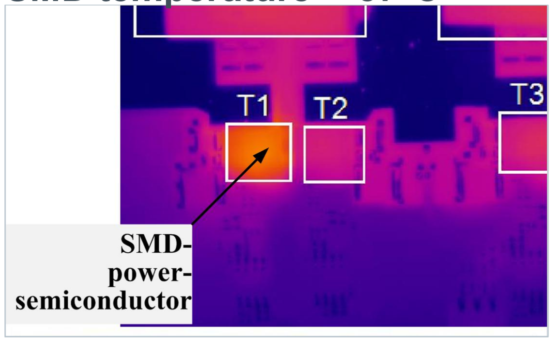
Cooling: Passive (no fan, no heat sink, $T_A = 25°C$)



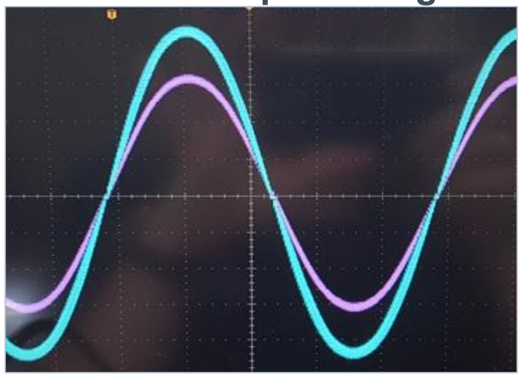
SMD in detail



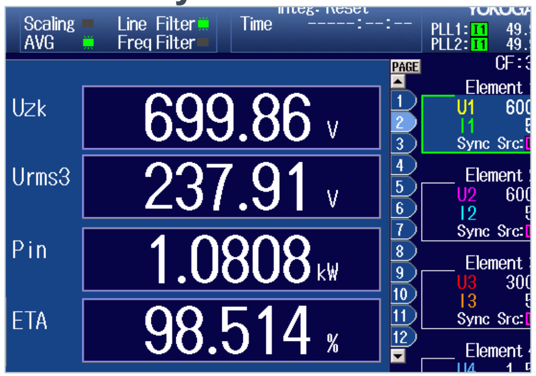
SMD temperature = 57°C



Sinusoidal output voltage



Efficiency measurement



Conclusion and outlook
Future trend: Integrated Power Electronics

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Challenges for future fast switching Integrated Power Electronics

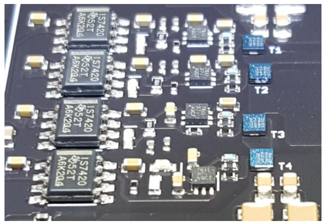
- cooling concepts for SMD power semiconductors
- power inductors for high switching frequency
- auxiliary electronics (gate-driver, isolators, measurements) with high EMC-immunity
- fast control concepts for PE systems with low damping
- concepts to handle high EMC emission
- new topologies for high switching speed and frequency

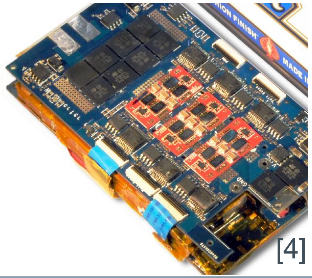
GaN enables new Power Electronics Systems

- higher switching speed
- higher efficiencies
- smaller passive components
- smaller and lighter converter systems
- easy and high volume manufacturing
- lower system cost
- easy power scaling
- higher system performance
- etc…

FUTURE

"all-digital" Integrated Power Electronics





[4]

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No.	Reference
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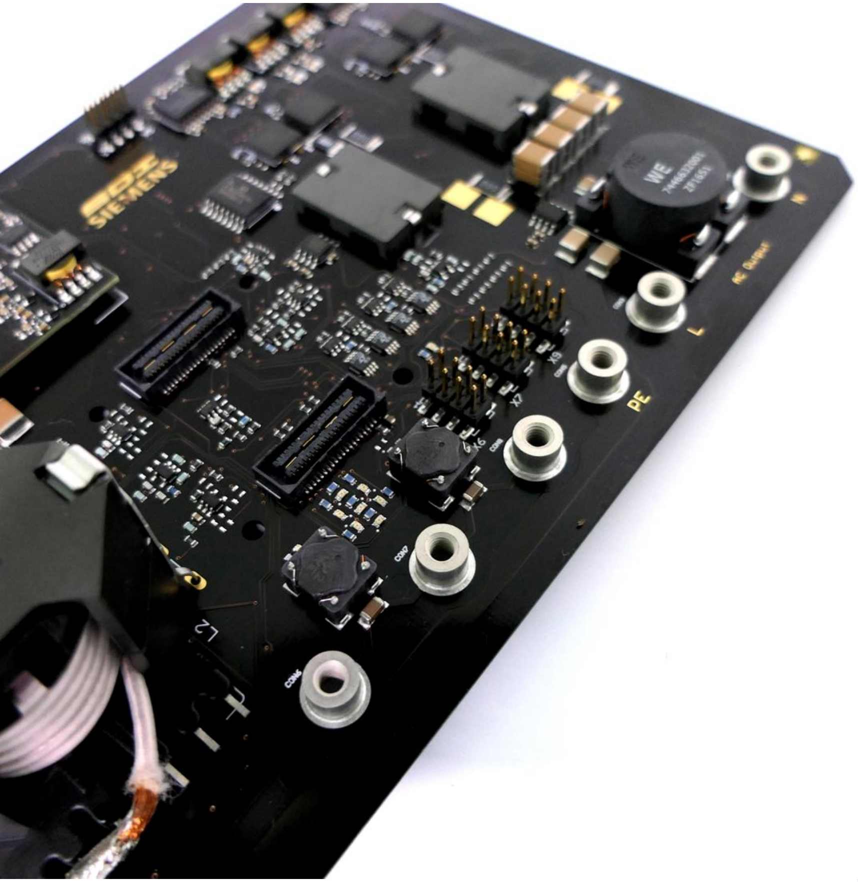
[2]	**Alex Lidow**, "EPC: GaN Ambition", Comound Semiconductor, July 2014, https://compoundsemiconductor.net/article/94531-epc-gan-ambition.html
[3]	**Tom Keim and Ashok Bindra**; „From Components to Power Systems – APEC showcases exceptional technologies across the board"; IEEE Power Electronics Magazine, June 2017 **Ahmad Bahai**; "Power semiconductor technology intelligence for tomorrow's solutions"; IEEE *Xplore, https://ieeetv.ieee*.org/mobile/video/keytalk-dr-ahmad-bahai-power-semiconductor-technologyintelligence-for-tomorrows-solutions-apec-2017
[4]	**Robert C.N. Pilawa-Podgurski**; Little Box Challenge Publication, UIUC Pilawa Group – 545-rk37Vu-57827

Contact



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Software Defined Inverter – Digital Power Electronics

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