High VOLT Interactive

Where power supply design meets collaboration

Designing reliable and high density power solutions with GaN

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What will I get out of this session?

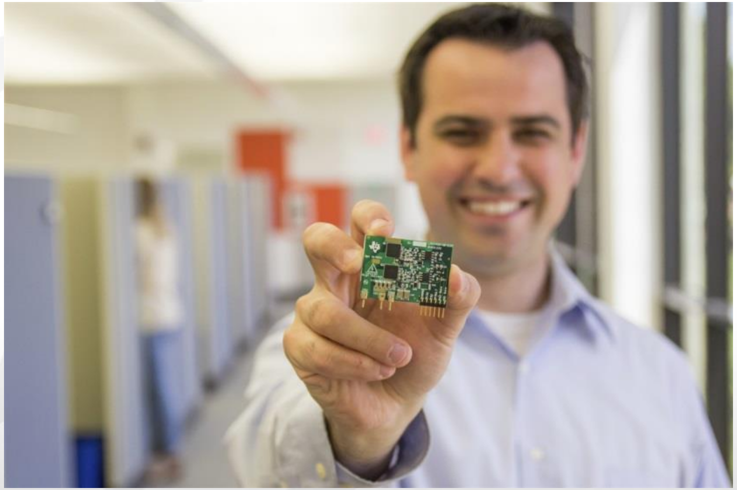
- GaN is enabling new levels of power density and efficiency.
- Integration for System Performance and Reliability
- GaN Applications

- **Relevant Part Numbers**
  - LMG3410Rxxx/LMG3411Rxxx
  - LMG5200

Why GaN?

GaN: Ready to Take you Beyond Silicon Today

- GaN devices are enabling solutions with twice the power density of what is possible with best-in-class superjunction FETs
- TI GaN solutions, such as LMG5200 and LMG3410R070, are in mass production and in many customer systems
- These systems are not only smaller and more efficient, but are also in cost and system parity with their silicon predecessors.
- Lets find out how!



GaN: Unmatched Power Density from AC-to-Motor

SMALLER:
99% efficient 1.6kW
1MHz CrM PFC

FASTER:
1MHz 1kW Isolated
DC/DC LLC

COOLER:
48V/10A 3-Phase
100kHz Inverter

230V
AC

250 W/in³ (15 W/cm³)

105 x 80 mm

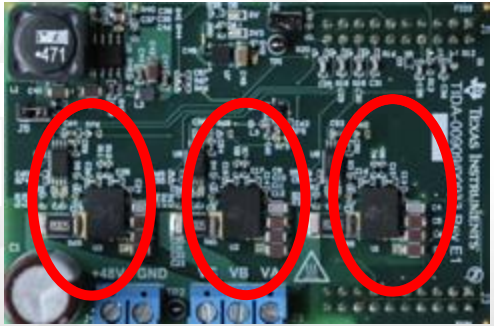
LMG3410x, UCD3138, UCC27714

400V
DC

140 W/in³ (8.5 W/cm³)

94 x 84 mm

48V
DC



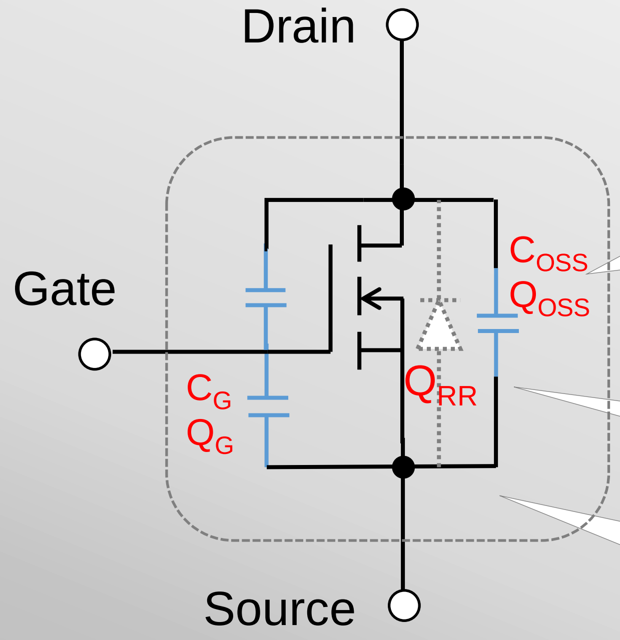
No Heatsink!

500 W/in³ (30 W/cm³)

79 x 53 mm

LMG5200, UCD9322

GaN 101: Key Advantages Over Silicon



Low C_G,Q_G gate capacitance/charge (1 nC-Ω vs Si 4 nC-Ω)
- ✓ faster turn-on and turn-off, higher switching speed
- ✓ reduced gate drive losses

Low C_{OSS},Q_{OSS} output capacitance/charge (5 nC-Ω vs Si 25 nC-Ω)
- ✓ faster switching, high switching frequencies
- ✓ reduced switching losses

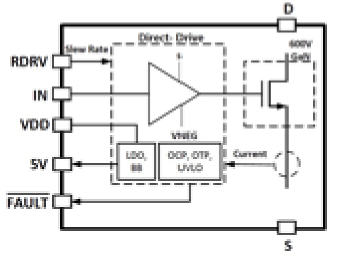
Low R_{DSON} (5 mΩ-cm^2 vs Si >10 mΩ-cm^2)
- ✓ lower conduction losses

Zero Q_{RR} No 'body diode'
- ✓ No reverse recovery losses
- ✓ Reduces ringing on switch node and EMI

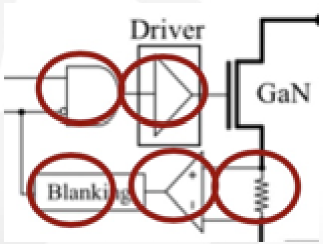
Driver and Protection Integration for Higher System Performance

Not All GaN is Created Equal

TI GaN: Fully Integrated



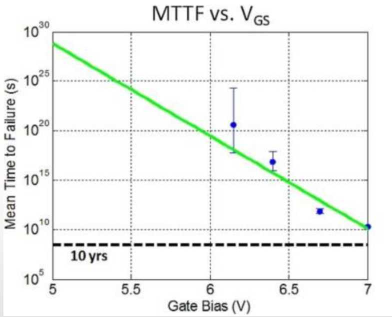
Discrete GaN



Driver	Integrated	External
EMI Control	Integrated	External
100ns OCP	Integrated	External
Added PCB Area	0	>400mm^2

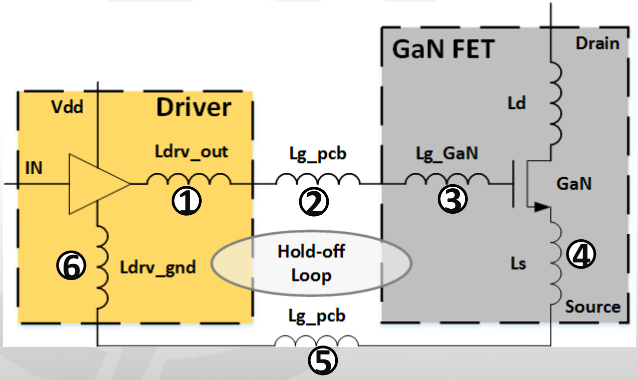
Challenges of GaN Designs with External Driver and Protection

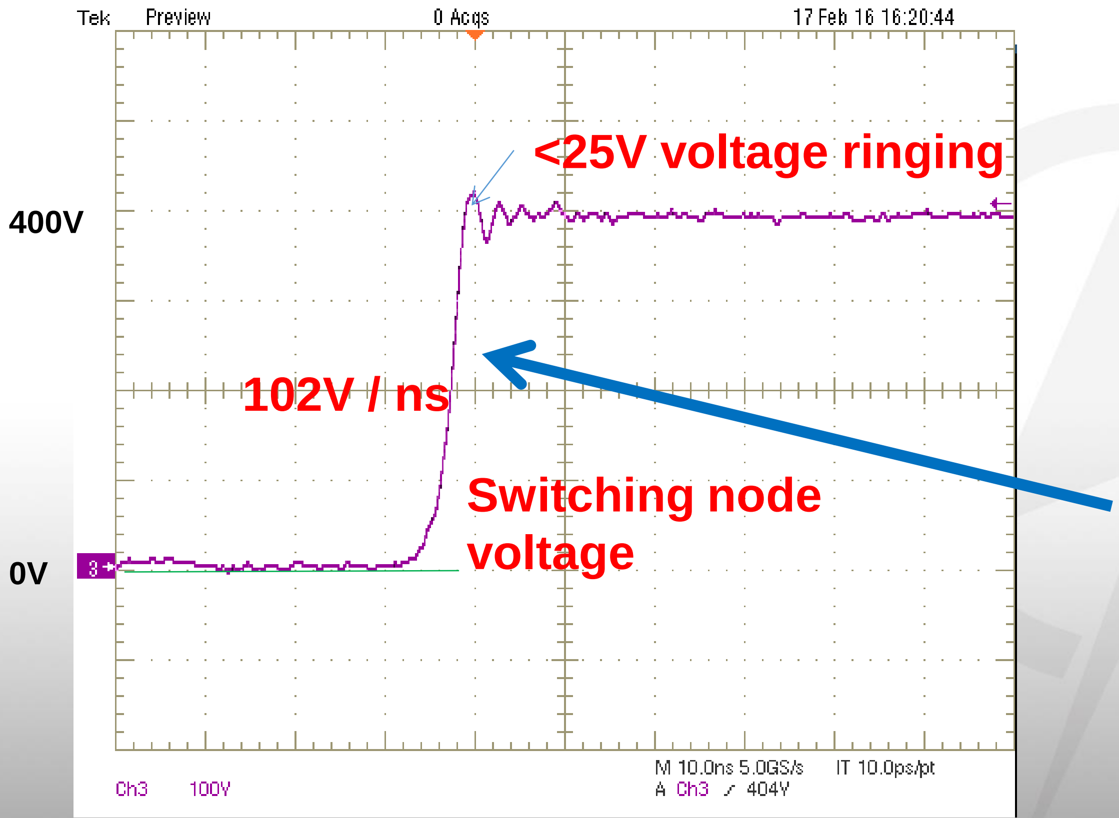
- Driver Bias Voltage: GaN gate bias is critical to its performance and long-term device reliability



- Protection: Designing a robust overcurrent protection circuit at MHz frequency and high slew rate is difficult and costly.

- Parasitic Inductance: causes switching loss, ringing and reliability issues, especially at high GaN frequencies





Zero to 400V in <4ns With TI-GaN

Captured with 1GHz Passive Voltage Probe – Tektronix TPP1000

Overcurrent and Shoot-through Protection

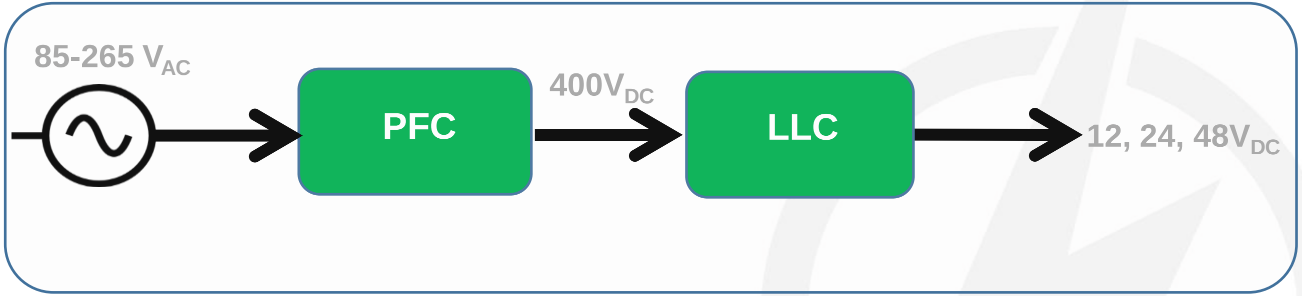
OCP Option	OCP Performance	System Impact	Cost
Resistive Shunt	• Poor SNR	• High power loop inductance • Power losses	• Sense resistor • High speed comparator (--)
TI GAN- Integrated OCP	<100ns Response	None	No external components

- High value sense resistor is needed for SNR
- Increases power loop which slows down the dv/dt for the given overshoot (100V/ns drops to 80V/ns)
- Increased power losses due lower dv/dt and sense resistor

Parameter	Resistive Shunt 2X 12mΩ (25mΩ /2)
Added PCB Area	233 mm^2
Added Power Loop Inductance	1.2nH
dv/dt	80V/ns
Additional Power Loss at 100kHz Po=1.2kW	0.9W

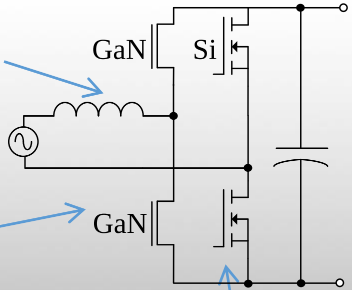
GaN Application Examples

AC/DC: Applications and Topology



Typical AC/DC PSU for industrial, medical, telecomm and server applications.

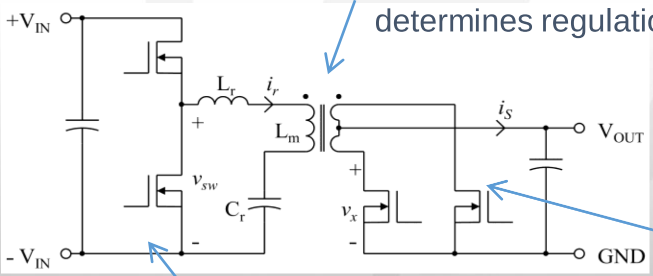
PFC inductor is used to regulate input current in phase with the input voltage



600V GaN

Line frequency Silicon MOSFET active rectifier

Resonance set up with Lr, Cr (& Lm), this network determines regulation characteristics



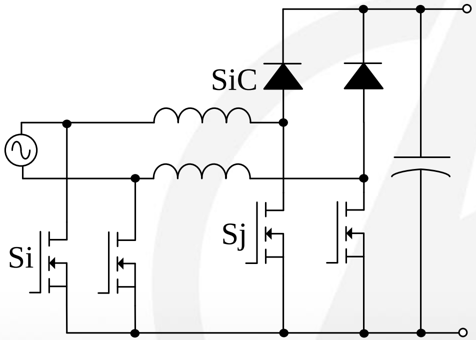
600VGaN

Low-voltage Si or GaN synchronous rectifier

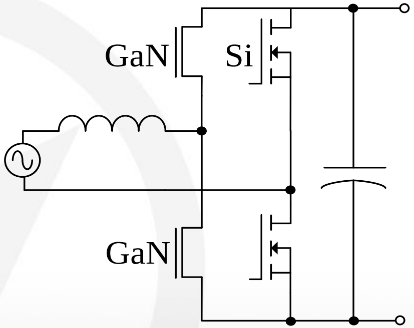
GaN CCM Solution: Superior Power Supply Design

- **Higher efficiency**
  - Reduced power loss by 36%
- **Higher power density**
  - 3X power density in Totem-pole PFC versus Silicon
- **Solution cost parity**
  - Reduced magnetics and external components bring total solution cost down

Dual boost PFC



Totem-pole PFC



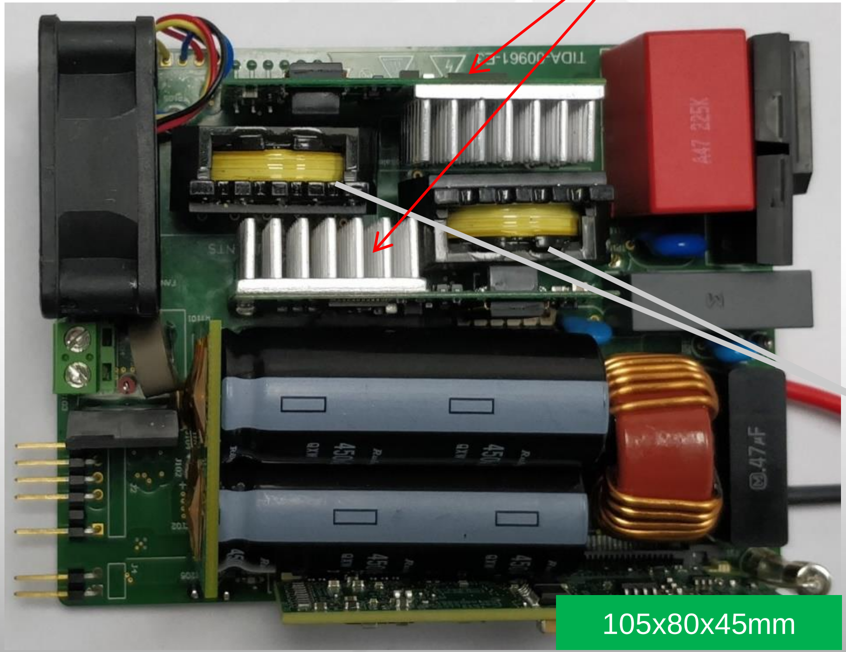
Loss Mechanism	Dual Boost PFC with Silicon	Totem-pole PFC with GaN
Switching FET Cond.	0.6 W	2.06 W
SiC Diode Cond.	2.75W	-
FET E_{oss} / SiC Diode Q_{oss}	3.9 W	2.4W
I-V Overlap	1.47 W	0.95W
Rect. Diodes / FETs	0.45 W (FET)	0.45 W (FET)
Total Power Losses	9.17W	5.86W

GaN CrM Solution: 1.6kW Totem-Pole PFC

Parameter	Value
Input Voltage	85 – 265 V_{AC}
Input Frequency	50 – 60 Hz
Output Voltage	385 V_{DC}
Output Power	1 kW
Switching Frequency	100 kHz / 140 kHz

Power Density: 250 W/in³ (9.5 W/cm³)

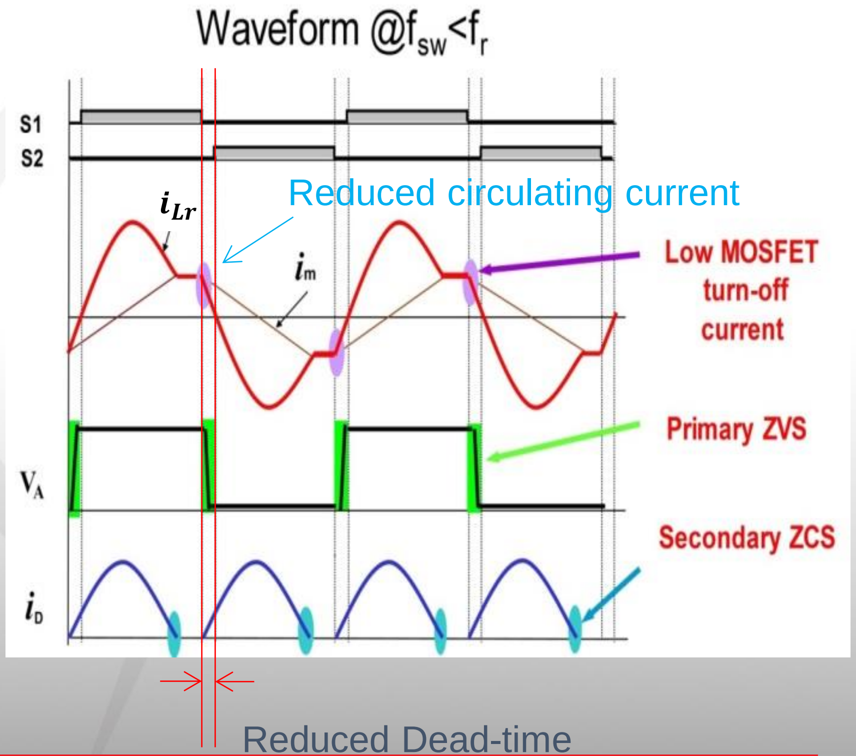
GaN FETs (LMG3410-HB-EVM)



Inductors

GaN in LCC: Superior Power Supply Design

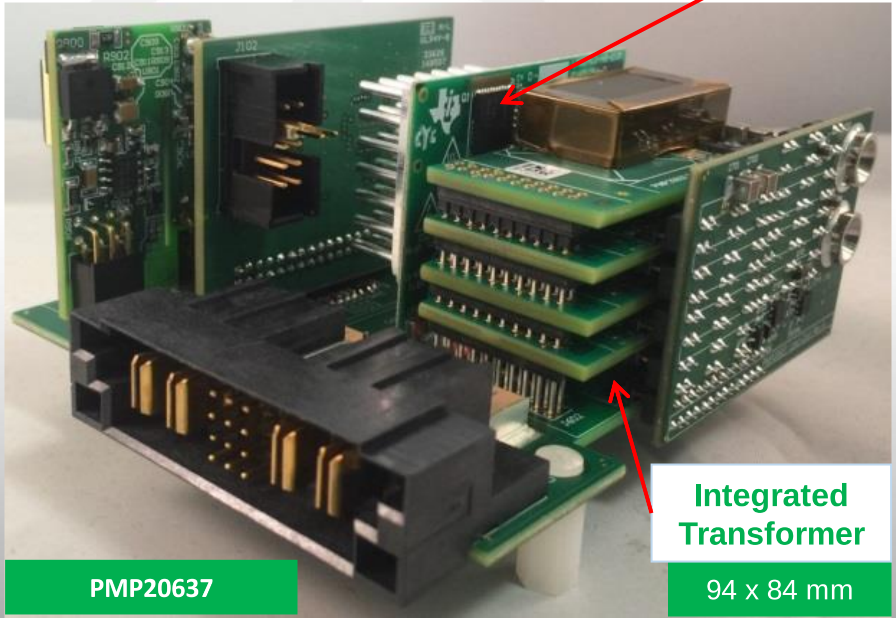
- **Reduced Output Capacitance C_{OSS}**
  - reduces dead-time, increasing the time when current delivered to the output
  - allows larger magnetizing inductance and lower circulating current losses as well as transformer fringe-field losses
- **Reduced Gate Driver Losses**
- **System Optimization**
  - GaN enables higher switching frequency to reduce magnetic components significantly
  - GaN enables LLC converter with higher efficiency and higher power density



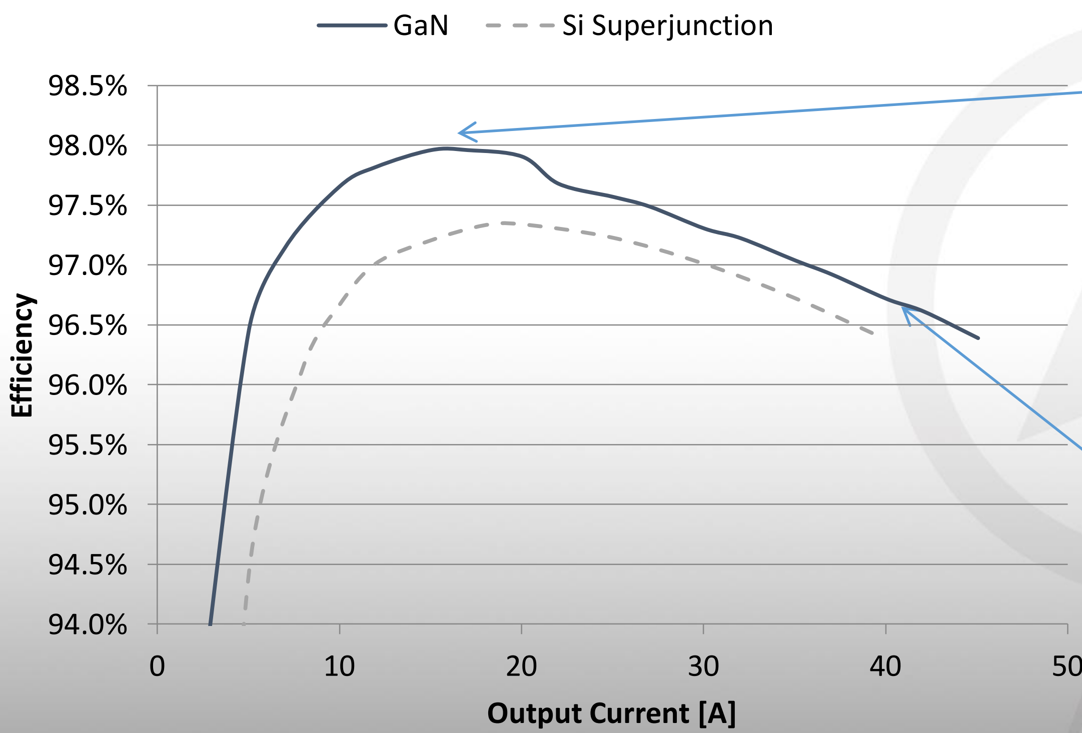
TI-GaN: 1MHz Isolated LLC DCDC Converter

Parameter	Value
Input Voltage	380 – 400V
Switching Frequency	≤ 1MHz
Output Voltage	48V
Output Power	1 kW
Switching Frequency	≤ 1MHz
Efficiency	>97%

Power Density: 140 W/in3 (8.5 W/cm3)



Efficiency: Comparison with MOSFET



Reduced capacitance & circulating currents dramatically improve light-load efficiency

Resistance Limited (slight improvement)

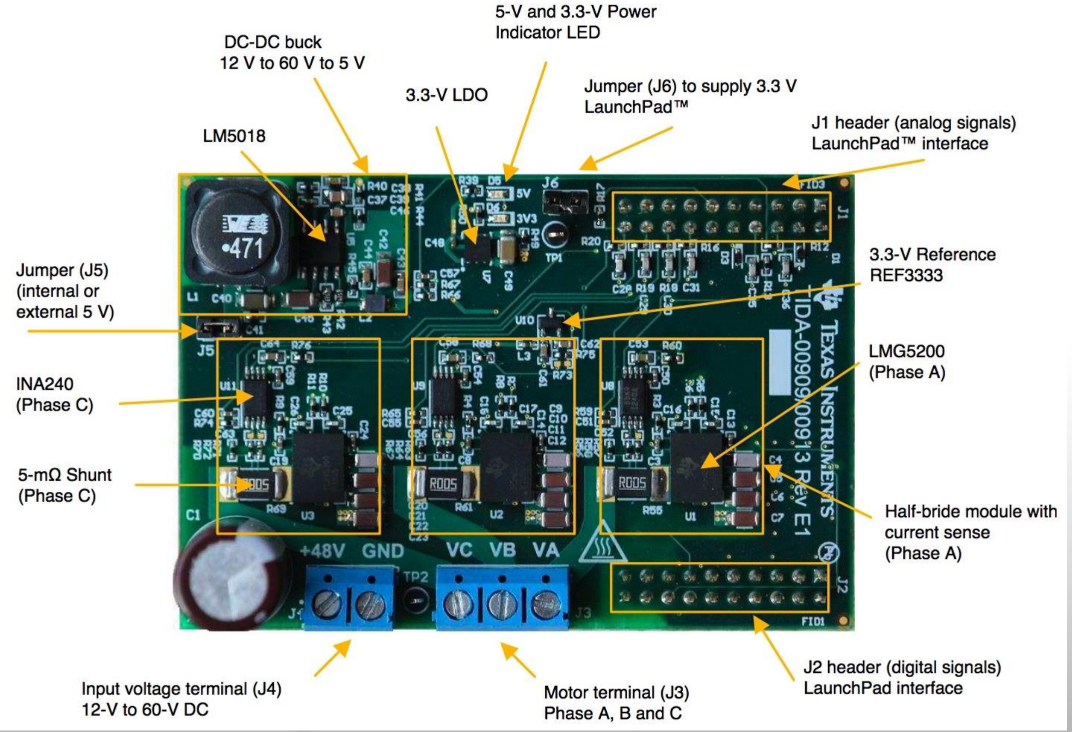
GaN: Enabling Smart Motor Drive

- GaN reduces or eliminates heatsink
- GaN reduces or eliminates switch node oscillations
  - Lower radiated EMI, no additional snubber network (space, losses) required
- GaN increases PWM frequency and reduces switching losses
  - Drive very low inductance PM synchronous motors or BLDC motors
  - Precise positioning in servo drives/steppers through minimum torque ripple
  - High-speed motors (e.g. drone) achieves sinusoidal voltage above 1-2kHz frequency
- GaN eliminates dead-time distortions of phase voltage
  - Better light load and THD performance

48V 10A 3Φ Inverter for High-Speed Motors

Parameter	Value
Input Voltage	12 – 60 V_{DC}
Input Power	400W
Output Voltage	48 V_{DC}
Output Current	10-A_{Peak}
Switching Frequency	100 kHz
Peak Efficiency	98.5%

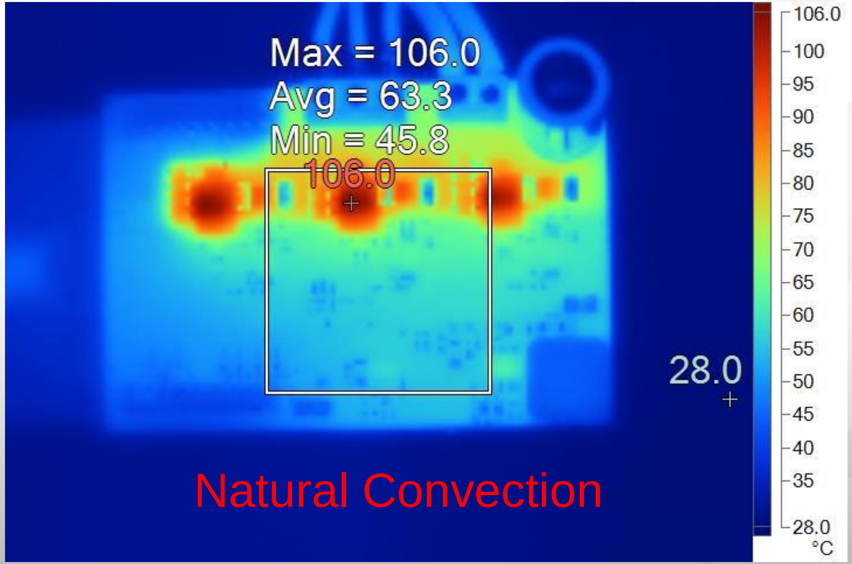
Power Density: 500 W/in³ (9.5 W/cm³)



Board dimension 54mm * 79mm

48V GaN Inverter: Thermal Performance

48V/10A with 98.5% Efficiency



No Heatsink!

Wrap-Up

Conclusion

- GaN is enabling a new generation of power conversion designs today, that were not possible before
- GaN enables 3X power density improvement from AC to Point-of-Load
- 1MHz isolated LLC design delivers 6x reduction in size and weight of the solution
- Integration of driver and GaN in a low inductance package provides an optimal solution for fast and reliable switching
- For products, designs, and training material, visit Ti.com/GaN

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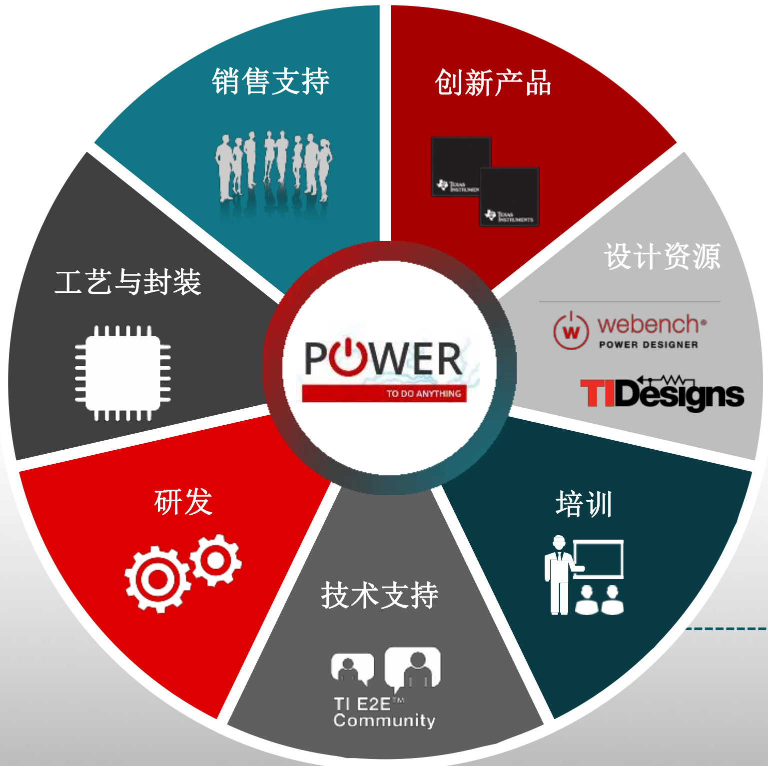

TI.com.cn/power

来自德州仪器和全集成PWM控制器之父Robert Mammano的

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