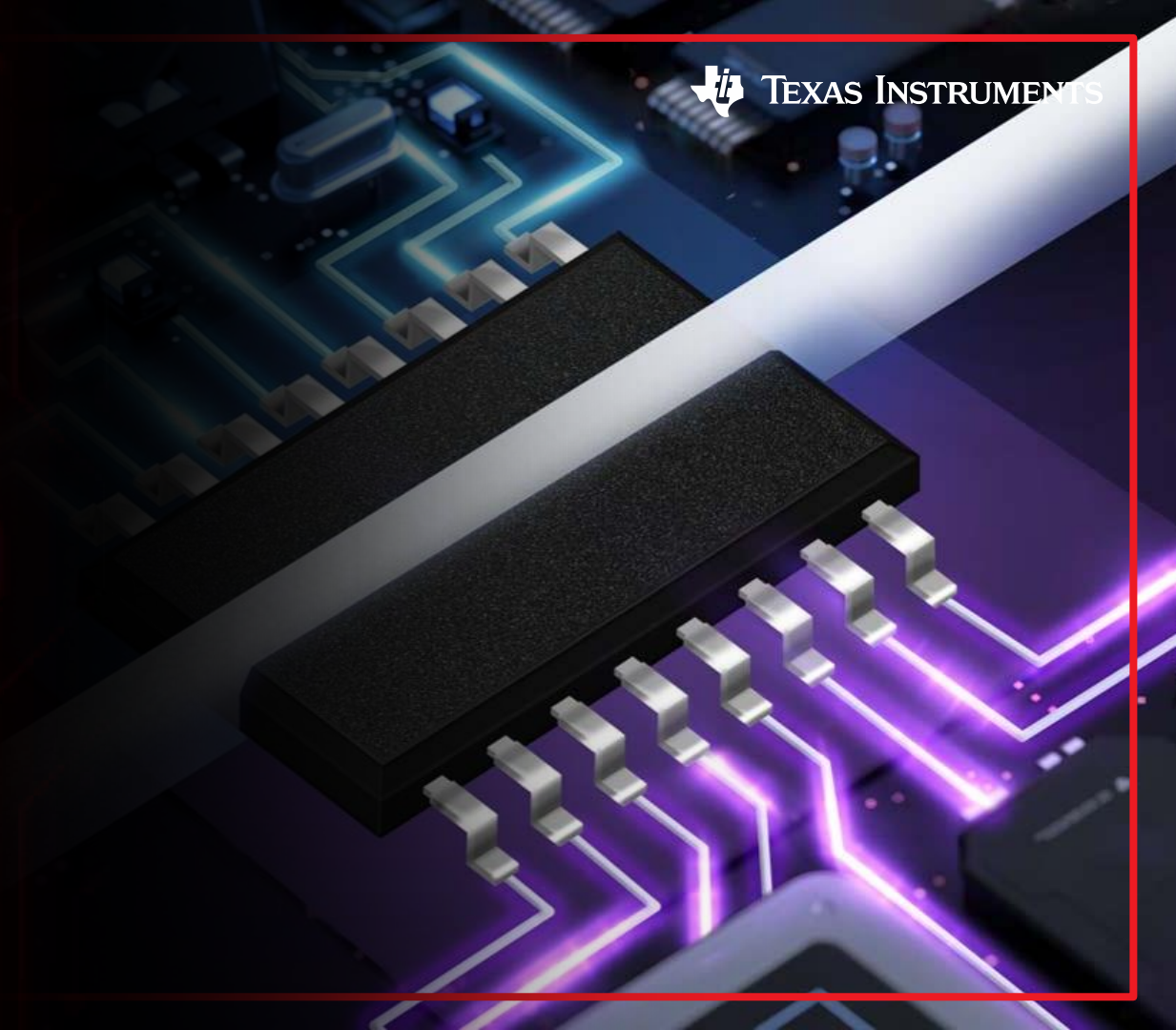
TI High-Voltage Seminar

Increasing motor drive efficiency with TI GaN

Kyle Wolf

Applications Engineer, GaN



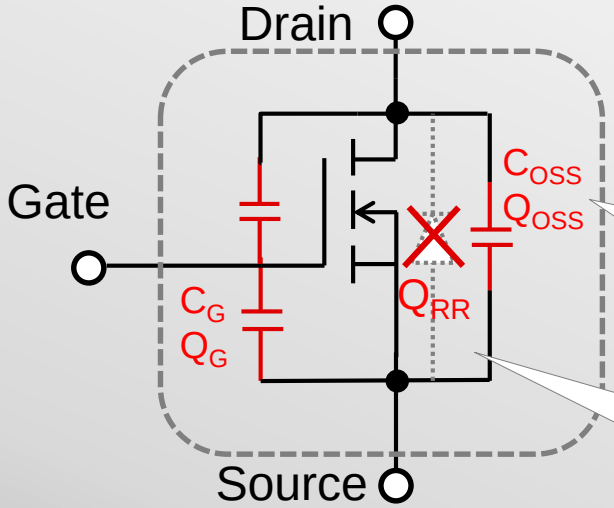
Agenda

- Introduction to GaN-based motor drives
- GaN in motor drives
  - Properties of GaN
  - Benefits of GaN in motor drives
- Challenges in motor drives
  - High dv/dt

Size and efficiency trade-off

- Si-based motor drive
  - Increasing efficiency requires lowering switching frequency and increase in size
  - Decreasing size requires an increase in switching frequency and decrease in efficiency
- GaN-based motor drive
  - With no reverse recovery losses and lower Coss losses switching efficiency is increased
  - Reduce switching losses to increase system efficiency and remove the heat sink
  - Increase switching frequency to lower the DC link capacitance and filter requirements
  - Reduce layout size with GaN's smaller device size

Properties of GaN



Device type	Rdson (mohm)	Die area (mm^2)	RSP ($mm^2 * mohm$)
Si	4.5	17.3	77.8
GaN	4.4	3.8	16.5

Low C_G,Q_G gate capacitance/charge
- ✓ Faster turn-on and turn-off, higher switching speed
- ✓ Reduced gate drive losses

Low C_{OSS},Q_{OSS} output cap/charge
- ✓ Faster switching, high switching frequencies
- ✓ Reduced switching losses

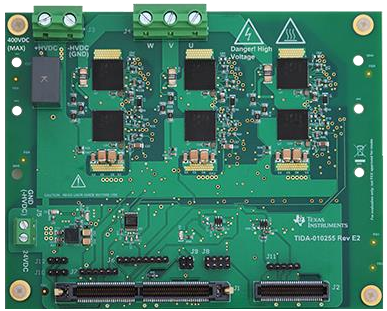
Only GaN: Zero Q_{RR} no ‘body diode’
- ✓ No reverse recovery losses
- ✓ Reduces ringing on switch node and EMI

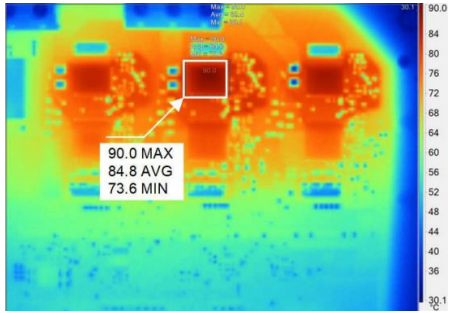
Low Rsp die area times on resistance
- ✓ Lower Rdson, lower conduction losses
- ✓ Smaller device footprint

Benefits of GaN in motor drives

Increase switching efficiency

- Remove heat sink
- Reduce system power loss
- Mount directly to motor and remove Cu cable

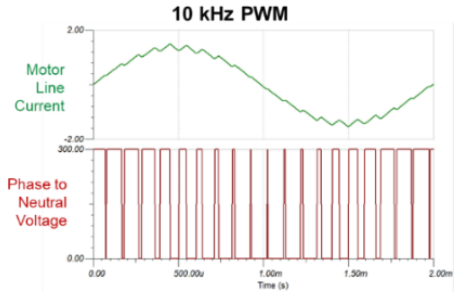


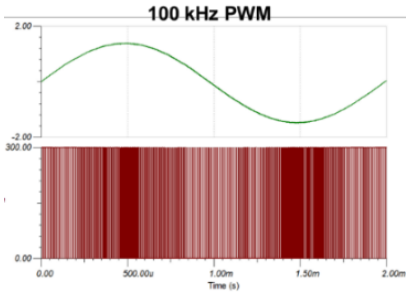


TIDA-010255: 2kW GaN motor drive with no heat sink at full load

Increase switching frequency

- Reduce DC link capacitance
- Reduce filter component size
- Reduce current ripple, lower RMS current





Motor line current as switching frequency is increased from 10kHz to 100kHz

TIDA-010255: 230VAC 2kW 3-phase GaN inverter for servo and robotics drives

Features

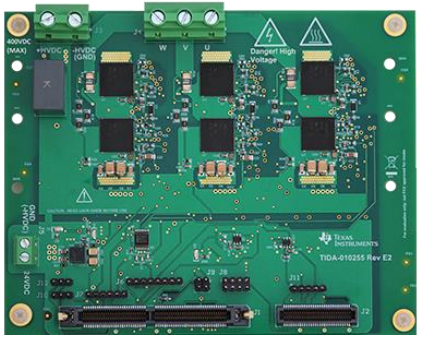
- 320-VDC input 3-phase GaN-FET power stage with hot-side control MCU.
- Tested **without heatsink** up to 7.6Arms at room temperature
- 12-V bootstrap gate drive supply reduce system cost and PCB space.

Applications

Single & multi axis servo drives, Industrial & collaborative robot

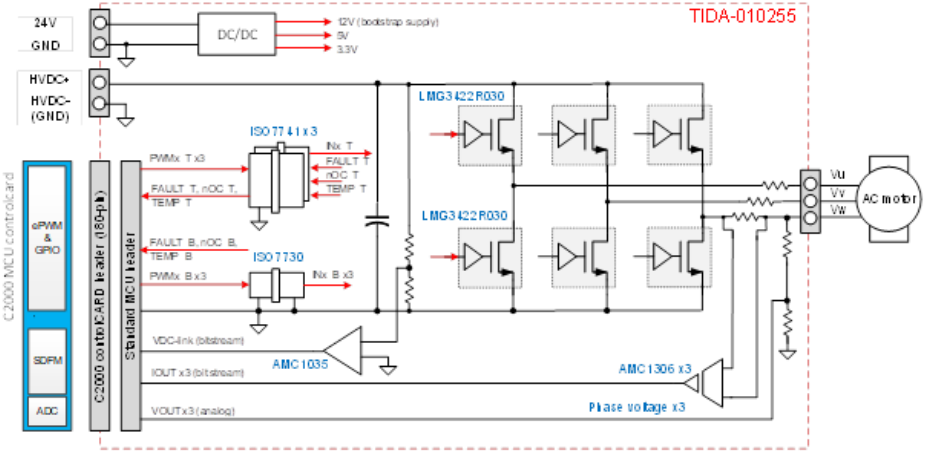
Tools & Resources

- TI GaN portfolio website
- Design files: Schematics, BOM, Gerbers, and more
- Test results (design guide)
- Device datasheets: LMG3422R030 , AMC1306M05, AMC1035, ISO7741F



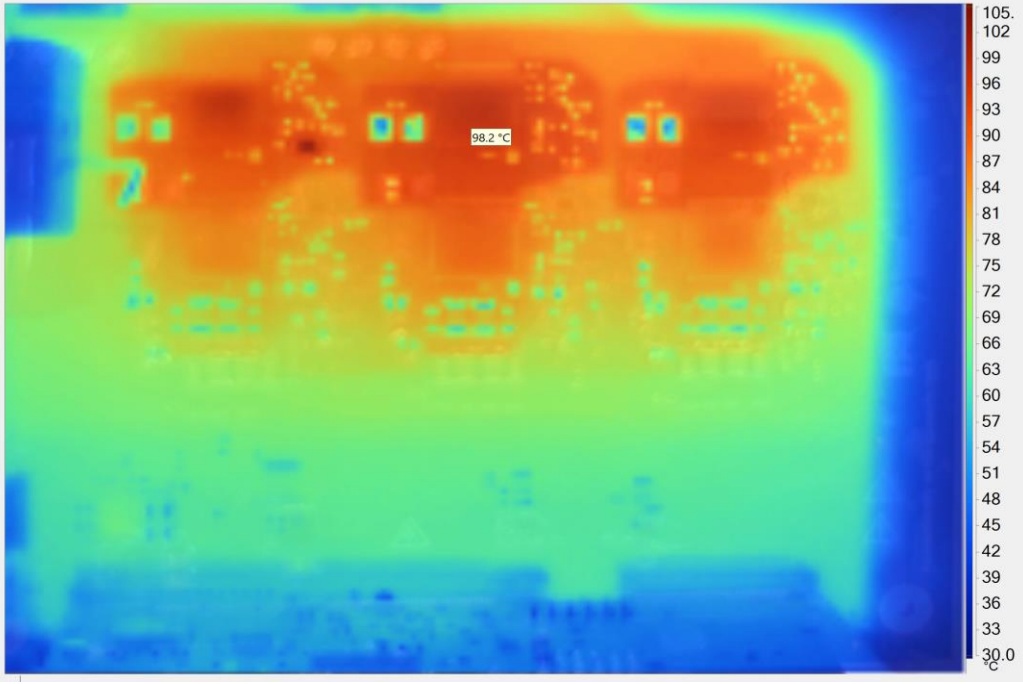
Benefits

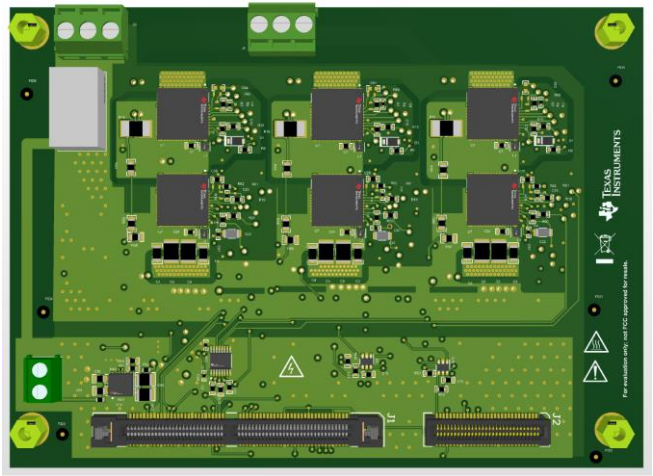
- **High-efficiency (99.4% peak)** at 16kHz PWM at 320V
- TI GaN integrated protection features
- **Zero reverse recovery** losses reduce switch node oscillations and EMI
- Low deadtime to minimize phase voltage distortions (120ns)



Eliminate heatsink: Thermal performance of LMG3422R030 GaN inverter at 7Arms, 30C ambient

Temperature measurement (7ARMS, NO HEATSINK)



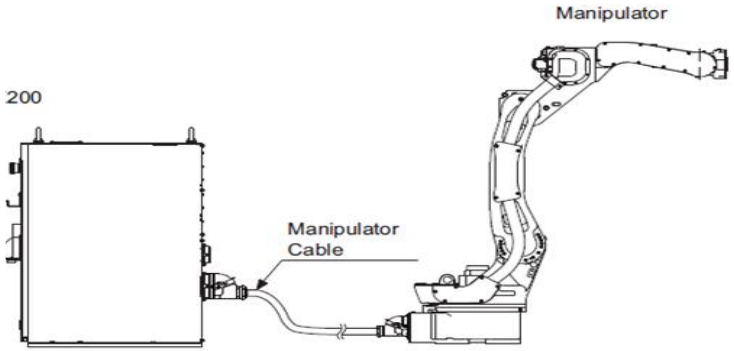


Parameters

- Vdc = 320 V
- PWM frequency: 16 kHz
- PWM deadtime GaN: 100 ns
- No heatsink

System block diagram

Robot – Centralized



Robot System Controller Cabinet

AC mains

Circuit Braker

Servo drive power supply module

FAN

Robot Controller

- Path/Trajectory Planning
- Goal Determination
- Motion Control
- Position Control
- Speed Control

Factory floor Connection

Robot teach pendant (HMI)

Maintenance and Cloud Connection

Functional safety

E-stop

Servo drive control panel

Point-to-point or daisy-chain

Robot sensing module

Functional safety

Manipulator

Servo drive

Current Control

Brake Resistor

Functional safety

Holding Brake

PMSM

Gear

Angle Encoder

Optional axis controller depending on gear

Axis 1

Axis 2

Axis N

N is typically between 3 to 8

Position feedback aggregator

Angel Encoder Interface

Functional safety

Point-to-point or daisy-chain

End Effector(Tool)

- Power Connection
- Internal Interface
- Encoder Interface
- External Interface

TIDA-010936: 48V/16Arms small form factor 3-phase GaN inverter

Features

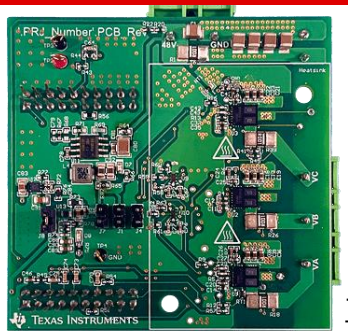
- Wide input voltage: 12-V to 60-V 3-phase GaN inverter 16Arms output current
- Compatible with 2.6mΩ or 4.4mΩ GaN half-bridge with integrated gate driver
- High switching frequency for 100kHz+ for reduced DC capacitance

Applications

Collaborative robot, servo drives, linear motor transport systems, stepper drives, non-military drones, AGV/AMR

Tools & Resources

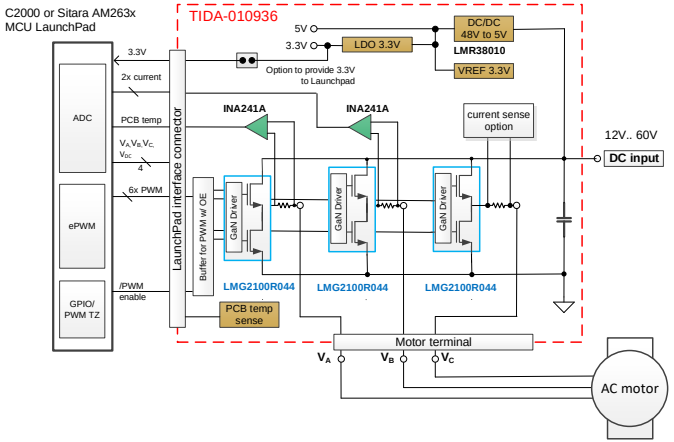
- TI GaN portfolio website
- Design files: Schematics, BOM, Gerbers, and more
- Test results (design guide)
- Device datasheets: LMG2100R044, LMG2100R026, INA241A, LMR38010



70x70mm²

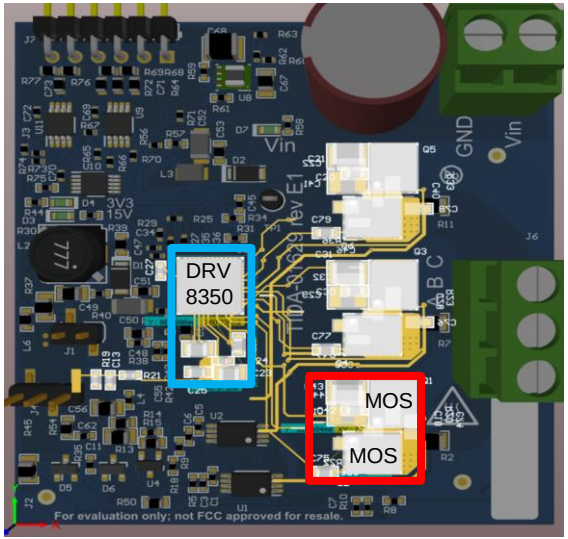
Benefits

- **High efficiency (99.3% peak)** at 40kHz PWM up to 16Arms continuous current without heatsink
- LMG2100R044 (4.5 x 5.5mm) half-bridge w/ integrated gate driver
- **Zero reverse recovery** losses reduce switch node oscillations and EMI
- Low deadtime to minimize phase voltage distortions (16ns)

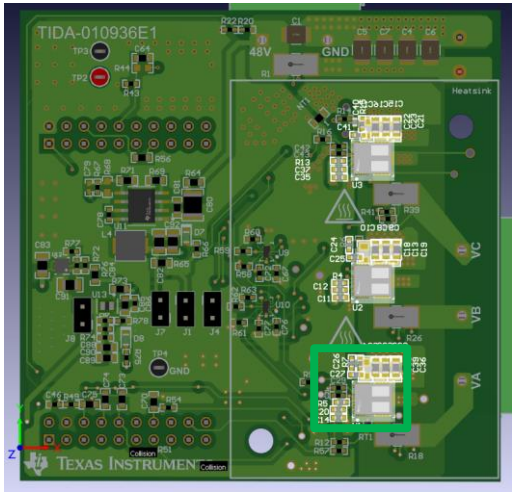


Texas Instruments

TI GaN: integrated driver → smaller size and easy layout



TIDA-01629: 48V/500W MOSFET solution
Total R+C: 34 components
Size: 187mm² x 3+ 158mm²=719mm²

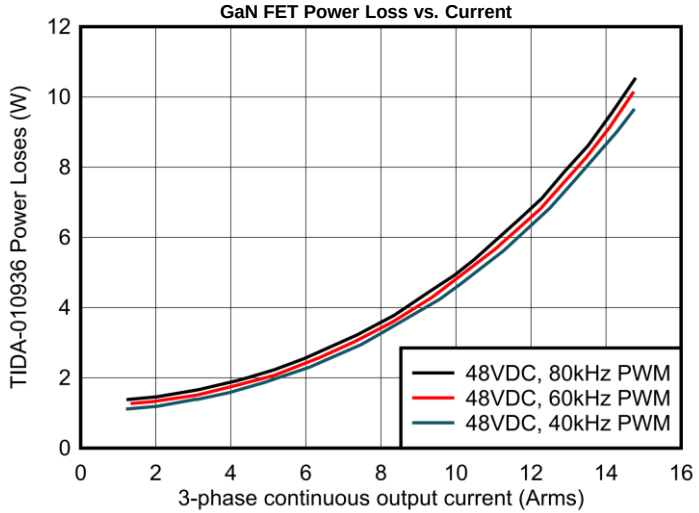


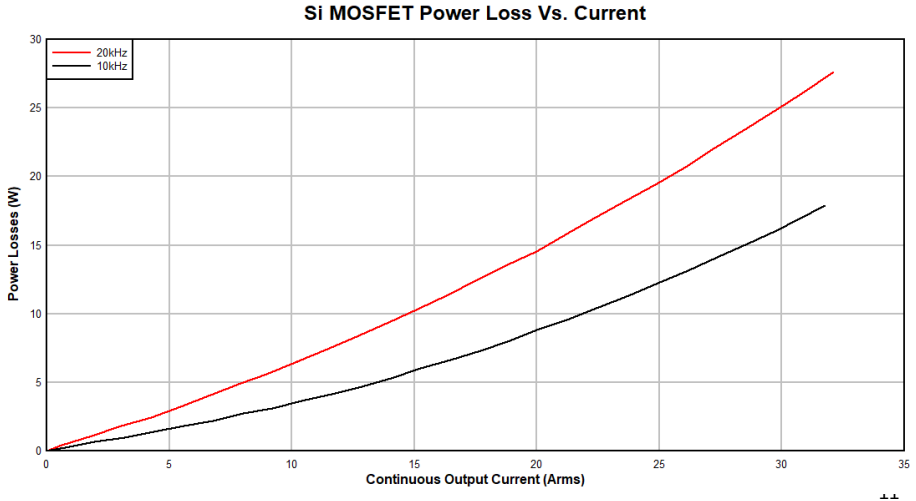
New GaN : LMG2100
TIDA-010936: 48V/15A 3 phase GaN inverter
Size: 105mm² x 3 = 317mm²

50% reduced!

Power loss comparison: GaN vs. MOSFET

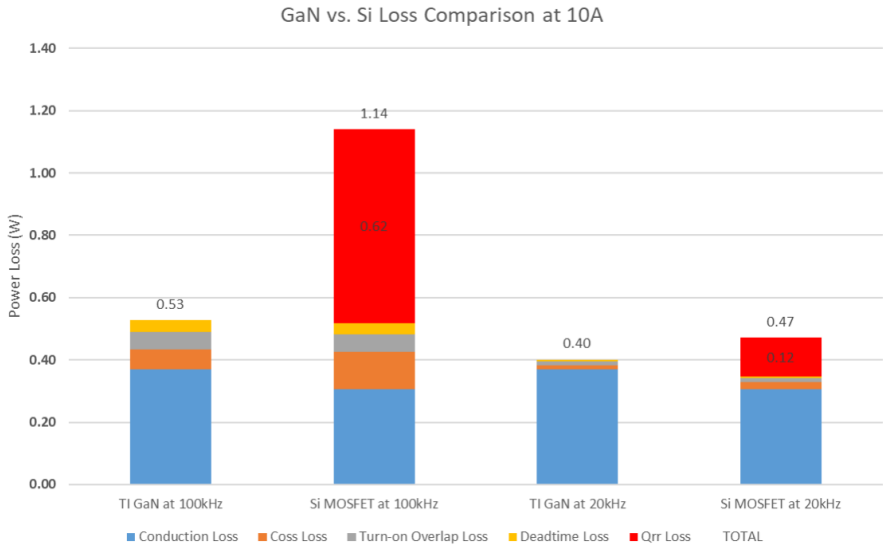
- Power loss increases at a faster rate as output current increases at higher switching frequencies with Si due to reverse recovery losses
- GaN is able to maintain consistent power losses with increased switching frequency and output current



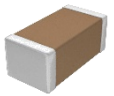


GaN vs. MOSFET power loss

- Without increasing switching frequency, GaN will lower power losses through more efficient switching and no reverse recovery losses
- GaN also enables increasing the switching frequency and maintaining low power losses by having no reverse recovery losses and higher switching efficiency



DC link Cap comparison

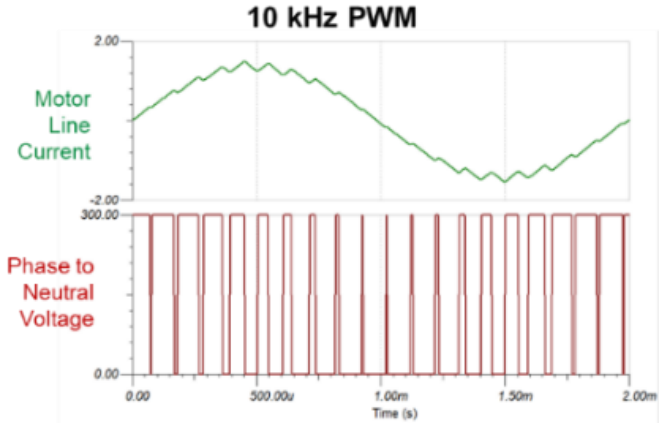


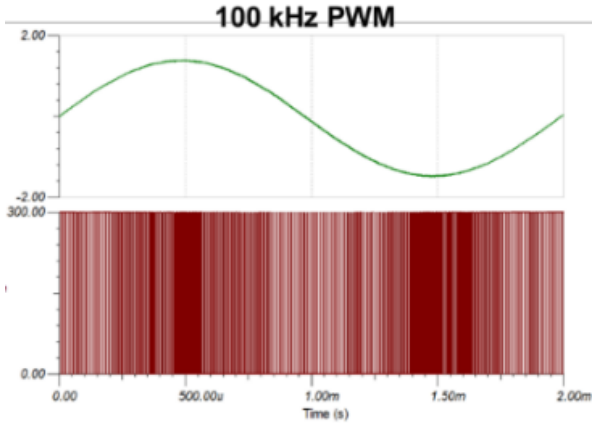
Sw. Frequency	16kHz	60kHz	100kHz
Type	Electrolytic	Ceramic	Ceramic
Capacitance	680uF	170uF (17x 10uF)	110uF (11x 10uF)
Footprint area	256 mm^2	136 mm^2	88 mm^2
Voltage rating	100V	100V	100V
Operating lifespan	~10k hours	~100k hours	~100k hours
Temp. stability	Low	High	High

Increasing switching frequency enables lower total capacitance and the use of ceramic capacitors for higher power density and longer lifetime

Reduce current ripple

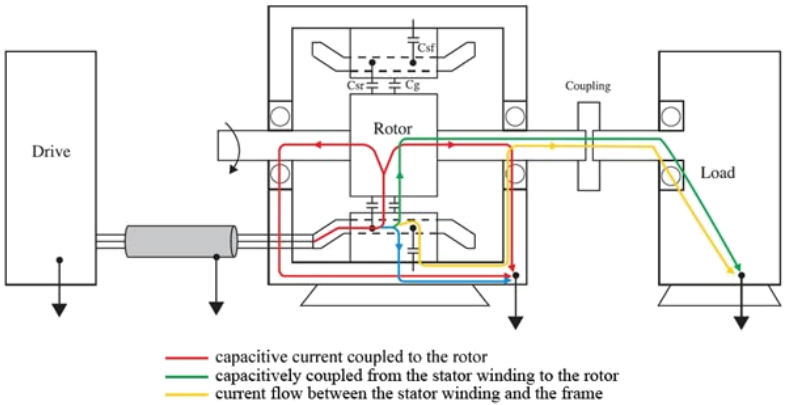
- The ripple current of the sine wave causes higher RMS current value
- Higher RMS current means larger conduction losses in the motor windings
- In the comparison, at 10A there was a **0.53Arms** difference between 100kHz & 10kHz sine wave





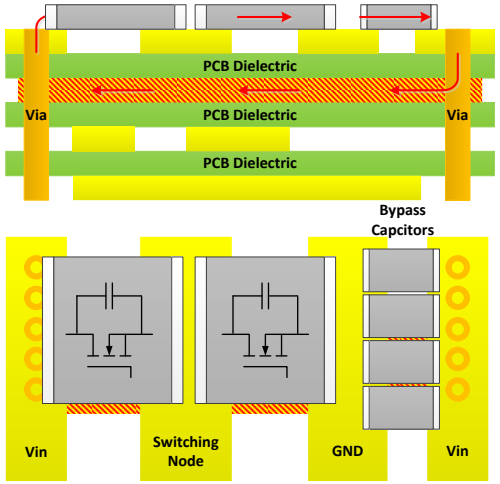
Challenges & solutions for high dv/dt & switching frequency

- Challenges with high dv/dt & higher switching frequencies
  - Motor winding wire's insulating layer breaks down
  - Increase bearing currents
- TI GaN introduces controllable slew rate
  - Controllable slew rate down to 3V/ns
- Motor cable inductance can be used to decouple motor winding



Reduce noise with power loop optimization

- Minimizing Power Loop Inductance
  - Reduce switching node peak voltage
  - Reduce ground bounce caused by inductance between low side FET source and decoupling caps
- Procedures
  - Reduce loop inductance by placing GaN devices and decoupling capacitors close together
  - Use multiple ceramic decoupling capacitors.
  - Use wide return path in the **adjacent layer** directly below current path through the GaN for inductance cancellation.



Layout illustration

LMG265x 650V Half-bridge GaN with integrated gate driver and lossless current sensing

Features

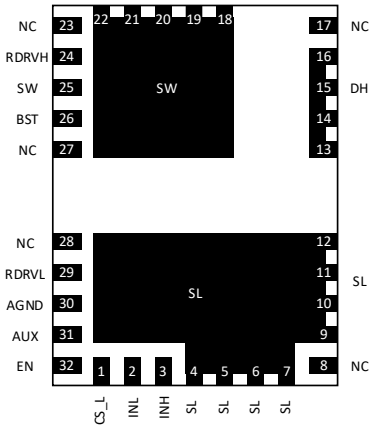
- 95, 140, 230 mΩ symmetric low-side and high-side 650V GaN FET
- Integrated lossless current sensing
- Integrated gate drivers with low propagation delays
- Adjustable slew rate control: **8 programmable settings**
- Smart-switched bootstrap diode function: 0 QRR
- High-side gate-drive level shifter
- Switching frequency: up to 1 MHz
- Low-side / high-side gate drive interlock
- Low-side current shunt emulation with high bandwidth and accuracy
- Fast high-side power up (< 8 µs)
- Low-side / high-side cycle-by-cycle overcurrent protection, OTP
- Maximum supply and input logic pin voltage: 26 V
- Low-side / high-side quiescent currents: 240 µA / 60 µA

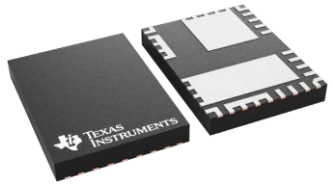
Applications

- **LLC**
  - Gaming / PoE / Monitor PSU, PD adapter
- **ACF, AHB**
  - PD adapter, Server Aux
- **TPPFC**
  - Gaming / PoE / Monitor PSU, PD adapter
- **Motor drive inverter**
  - hair dryer, vacuum, servo motor
- **Inverter / micro-inverter**
  - Solar, renewable energy

Benefits

- **Integrated gate drivers, gate-drive level shifter, and bootstrap diode**
  - Plug and play
- **Fully integrated half-bridge**
  - Minimum PCB space
- **Low idle and standby quiescent currents**
  - Meets government mandated light load
  - No load efficiency requirements





6x8 mm² QFN package with dual DAP

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