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GaN Power ICs Drive Efficiency and Size Improvements in BLDC Motor Drive Applications

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Navitas Semiconductor

Messe Frankfurt Group

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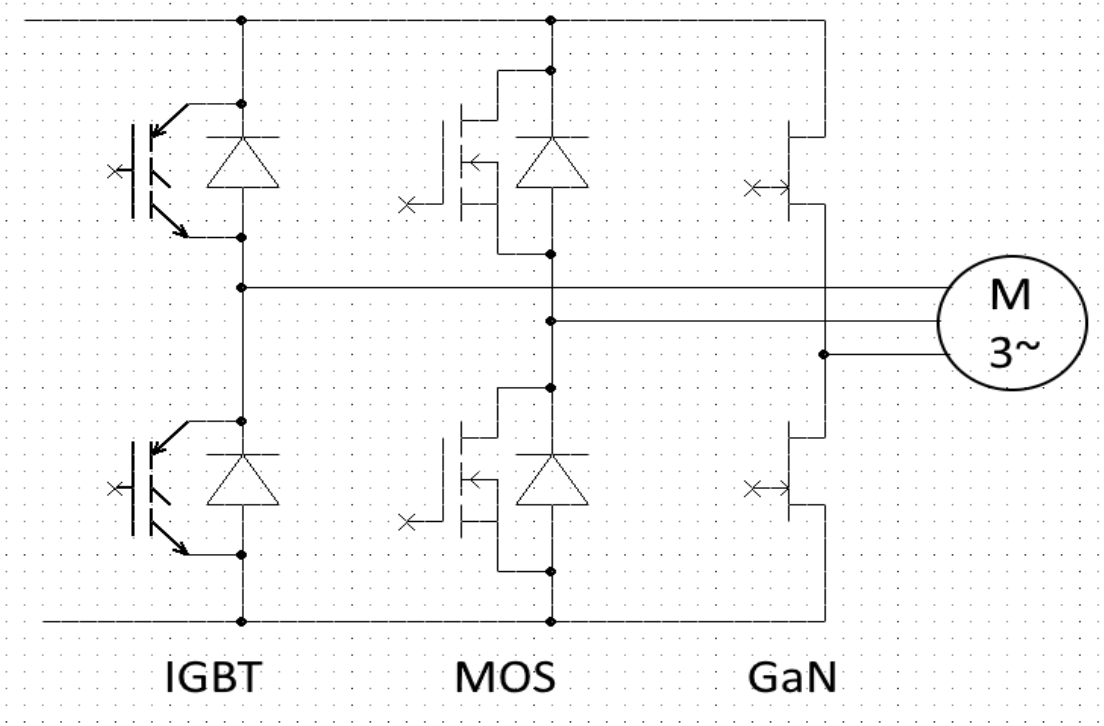
- Introduction
- Selection criteria for GaN power switches in motor inverters
- Design considerations
- Experimental results
- Conclusions and future works

Comparison of power switches for motor inverters



Motor inverters: 3-phase topology

- IGBT: "Workhorse" of the industry; slow switching speed, low losses at high power
- MOSFET: Faster switching, better light-load efficiency
- GaN: Almost no switching losses, no reverse recovery

	Light load efficiency	Full load efficiency	Switching losses	Dead time	Switching frequencies	Bus voltages	Power range
IGBT	-	++	-	> 2 µs	up to 20 kHz	high	up to MW
MOSFET	++	+	-	> 2 µs	up to 60 kHz	400 V	4 kW
GaN	+++	+++	+++	< 100 ns	> 100 kHz	400 V	4 kW

GaN FETs have lowest switching losses

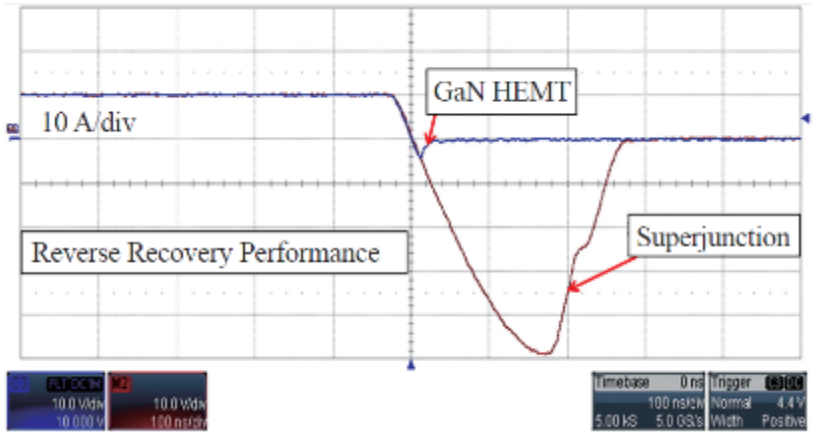
- IGBTs and silicon MOSFETs show „reverse recovery“
  - PN junctions in the current flow: Charge removal needed for blocking voltage
- Recovery time can be 1 µs or longer (>3% of the total switching period at 16 kHz, not available for the control loop)
  - Large current peaks cause noise
- GaN FETs do not have reverse recovery → dead time in the halfbridge topology can be reduced to < 100 ns

→ Control loop response can be optimized

→ Reduced motor current harmonics (noise, wear)

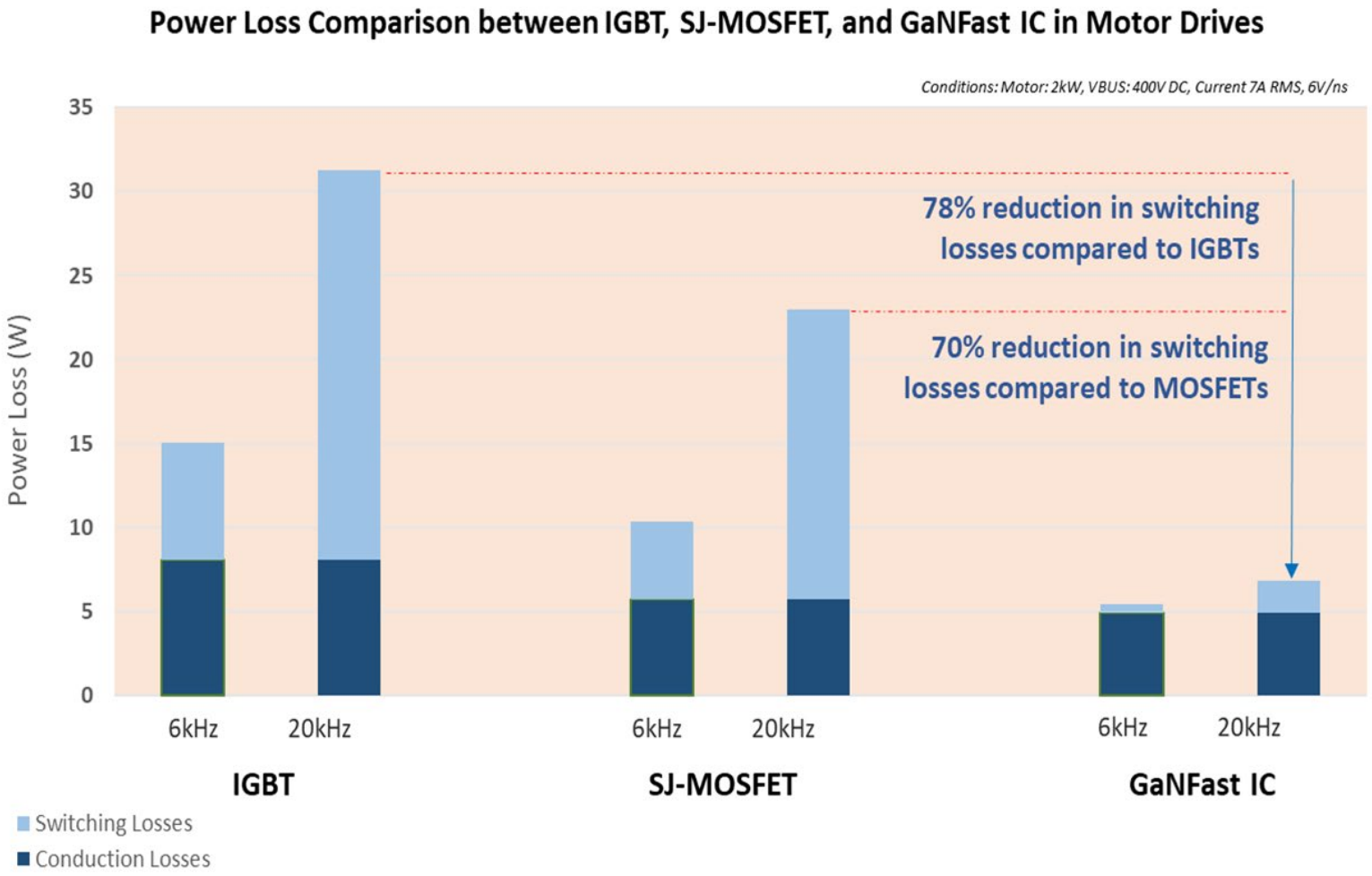
→ Much lower power losses

→ Reduced EMI



(Source: Infineon, CPSS, 2017)

Eliminate > 70% of the switching losses with GaN power ICs



Application case:

- Bus voltage 400 V
- Current 7 A RMS
- Motor power 2 kW
- Switching 6 V/ns
- GaN and MOSFET same conduction losses

Using GaN FETs, the inverter efficiency increases by 2.5% (96%→98,5%) and total losses are halved (15 W→6,8 W)

→Significant reduction in cost, weight and size of thermal mgmt (like heatsink, fans, other thermal components)

→ Benefit even larger at higher switching frequency

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Selection criteria – Power dissipation budget

- Previously, IGBTs and MOSFETs were selected for roughly equal conduction and switching losses at full load
- GaN power ICs offer **new options**:
  - Reduce total power dissipation budget to a point where no (or small) heatsinks are needed
  - Select higher $R_{DS(ON)}$ switch at lower cost to use the previous switching loss budget
  - Operate at higher carrier frequency for same (or lower) losses, enabling a change in modulation scheme
  - Operate at higher carrier frequency for same (or lower) losses, to enable new motor types and construction

Selection criteria – Driver & Protections

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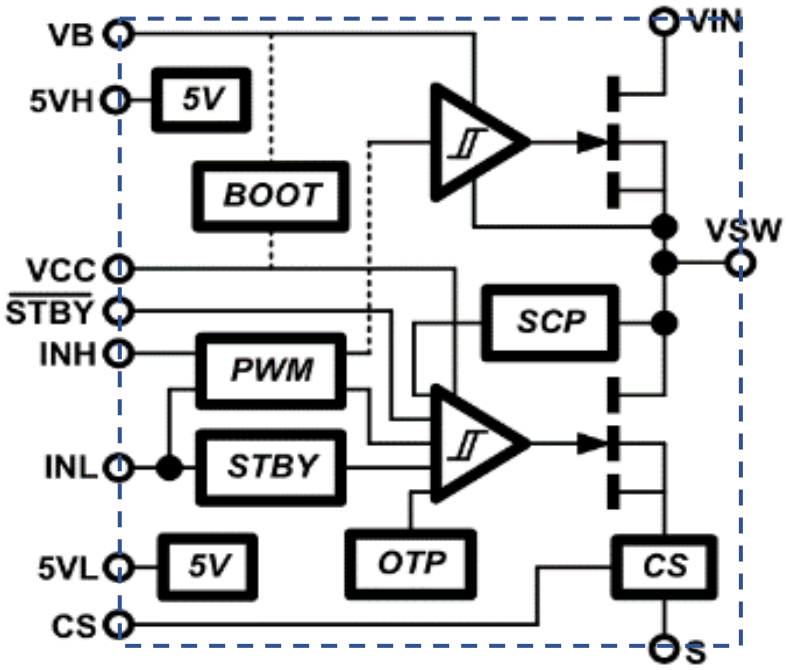
Simplified schematic

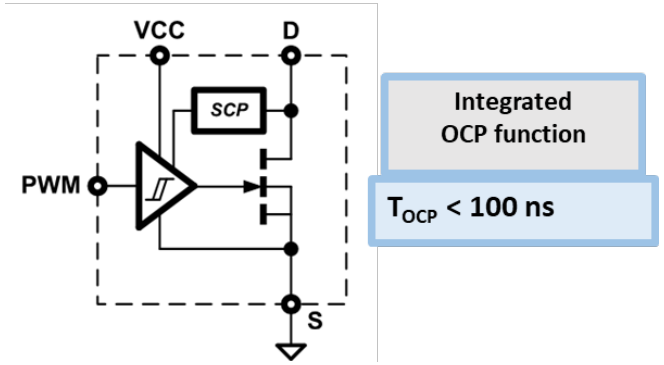


- **High, stable and repeatable performance** → design margins can be reduced
  - Very low prop delay for best control loop performance
- Controlled gate drive conditions enable **outstanding reliability**
- **Much reduced component count** → system size and cost reduced, enabling motor-integrated inverters
- Easy to use → **fast time to market**
- Lossless current sensing **removes shunt resistors** → cost, size, reliability and performance improvement
- Fast and precise overcurrent protection → improved **system robustness**
- On-chip temperature sensing for better thermal design margin
- Precise overtemperature turn-off→ improved **system robustness**

GaNSense™ enable digitally controlled power stages

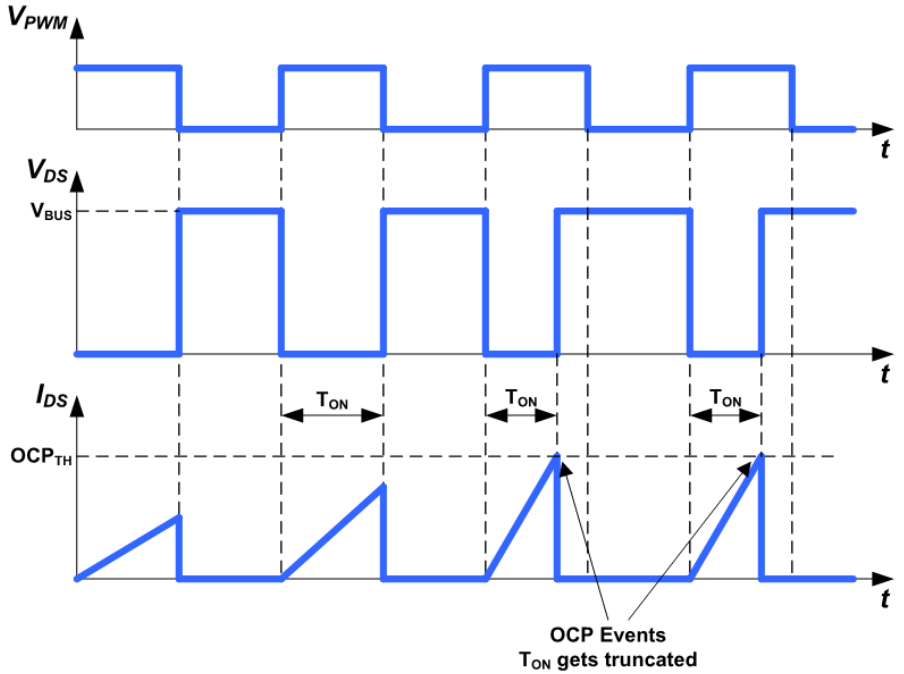
Selection criteria – Overcurrent protection

GaNFast™ with GaNSense™



Integrated OCP function

T_{OCP} < 100 ns



Autonomous OCP:

- Fast-acting self-protection
- Cycle-by-cycle protection
- Excellent robustness
- GaN FET on-time gets truncated at each OCP event
- OCP latch gets reset at next PWM rising edge

Very fast overcurrent turn-off → excellent protection

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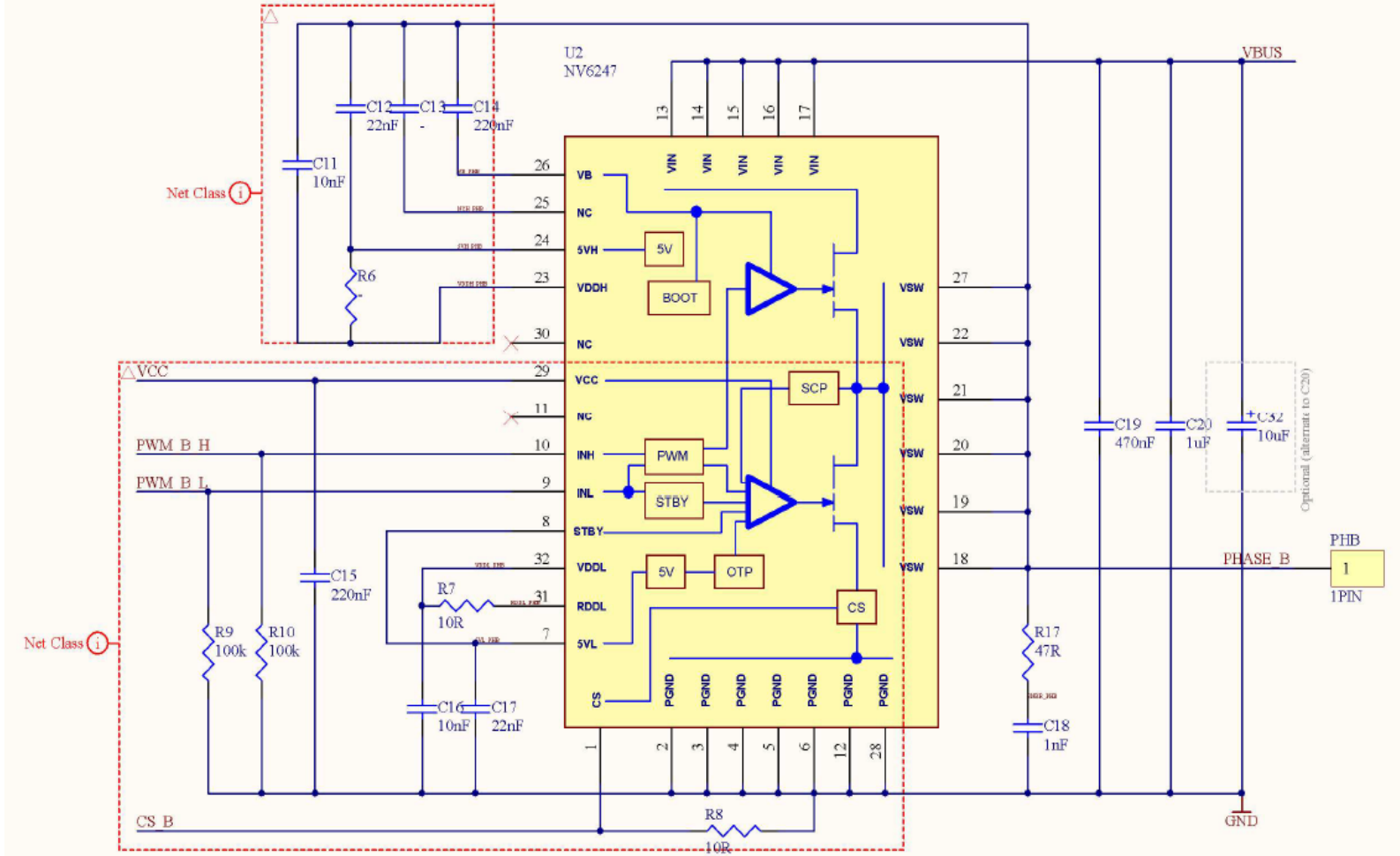
Reference design
300W motor integrated inverter

- Target: 300 W motor power at smallest size
- Using 3x NV6247 fully integrated GaN power half-bridge IC
- Inverter only (w/o supply, EMI filter, control)
- Works with most controllers



Schematic (one leg shown)

Halfbridge connection diagram
Straightforward PCB layout

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Low-side VCC Supply
(9 to 24 V)

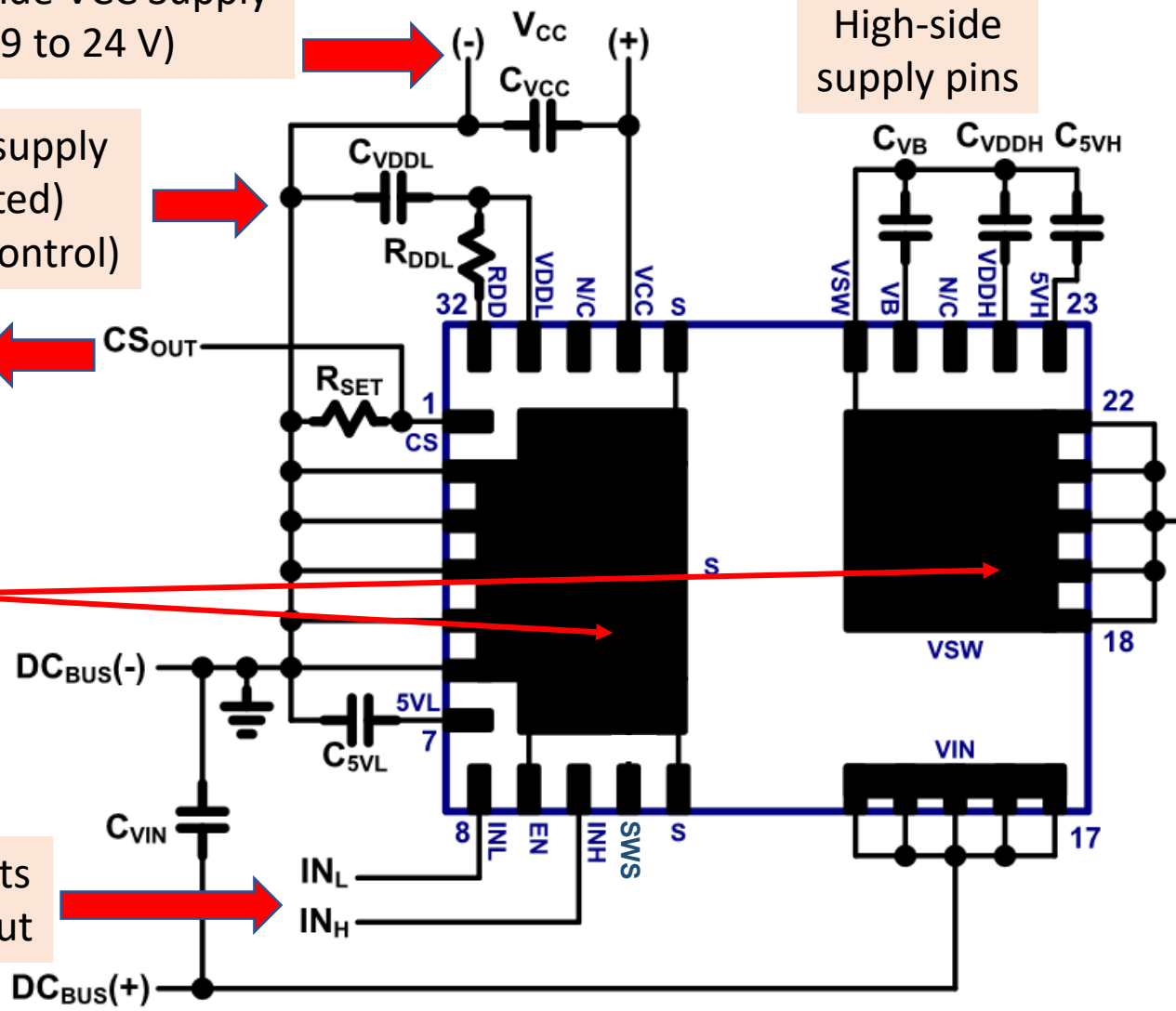
Low-side gate drive supply
(internally generated)
(with RDDL turn-on control)

CS output
(loss-less current-sensing
programmable with RSET)

Large Thermal Pads

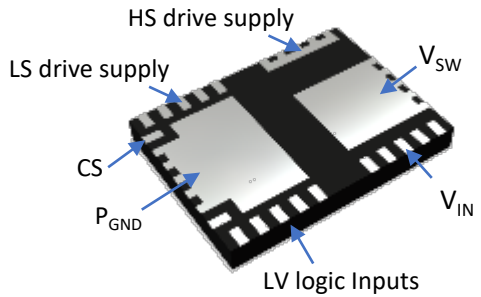
PWM inputs
Enable input

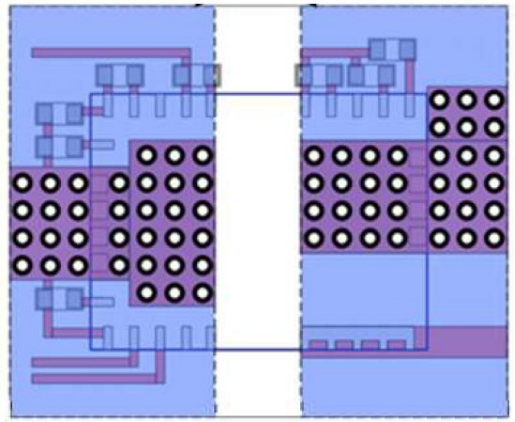
High-side
supply pins



Half-Bridge
Output

PQFN 6x8





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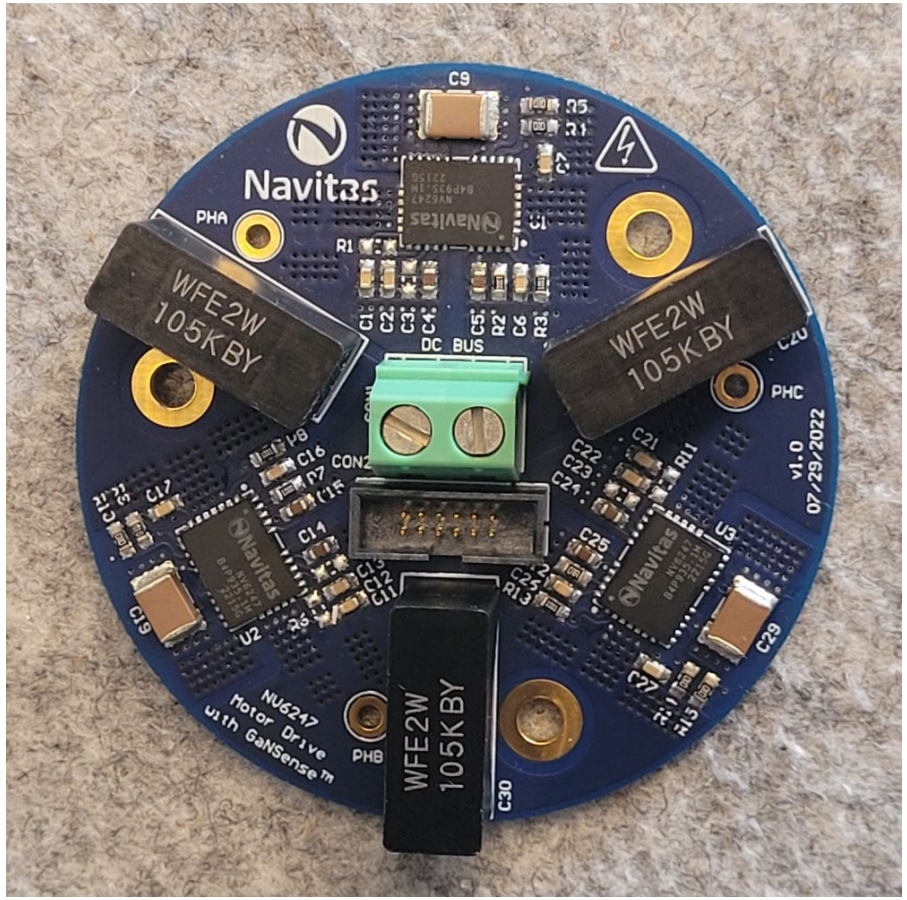
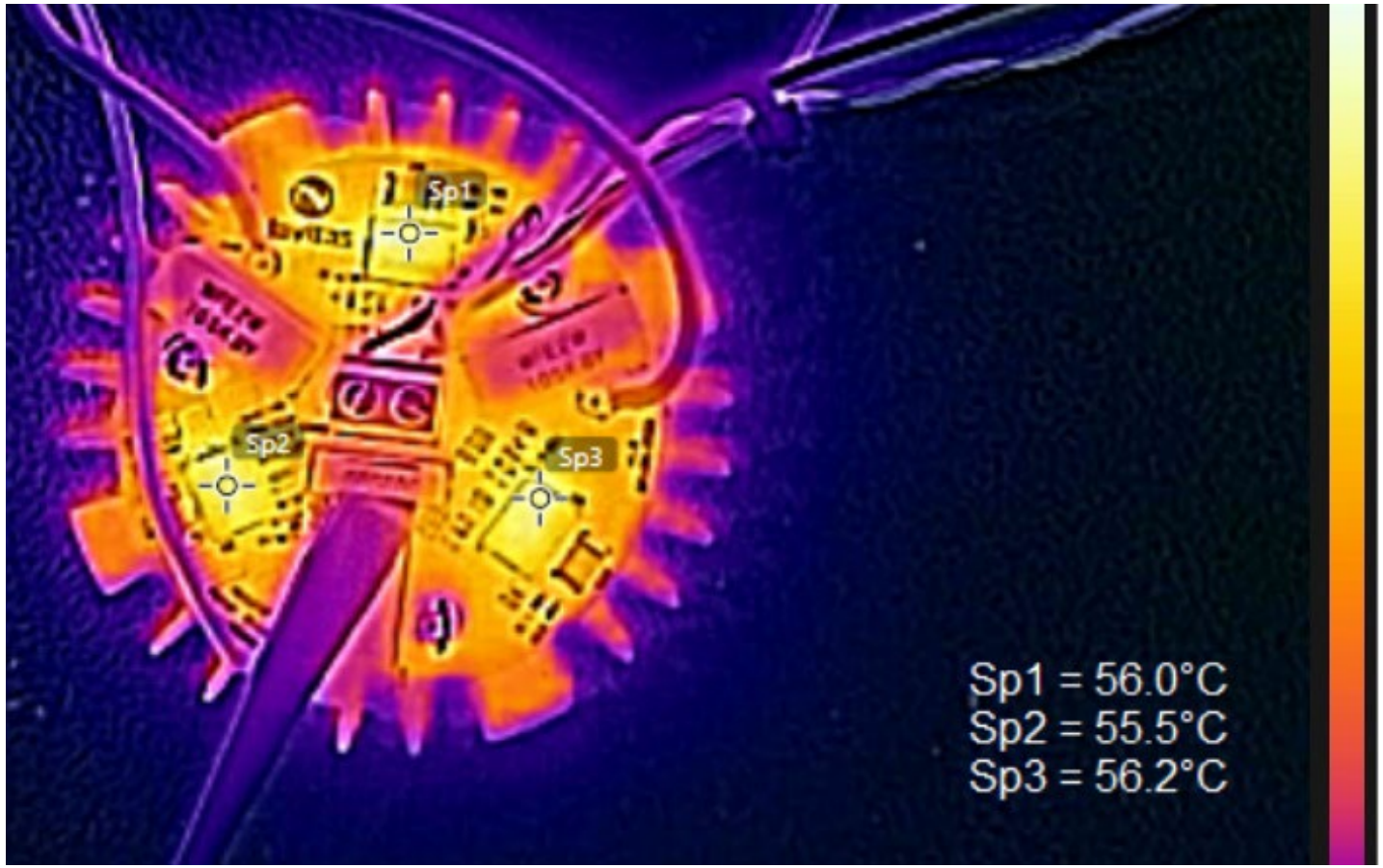
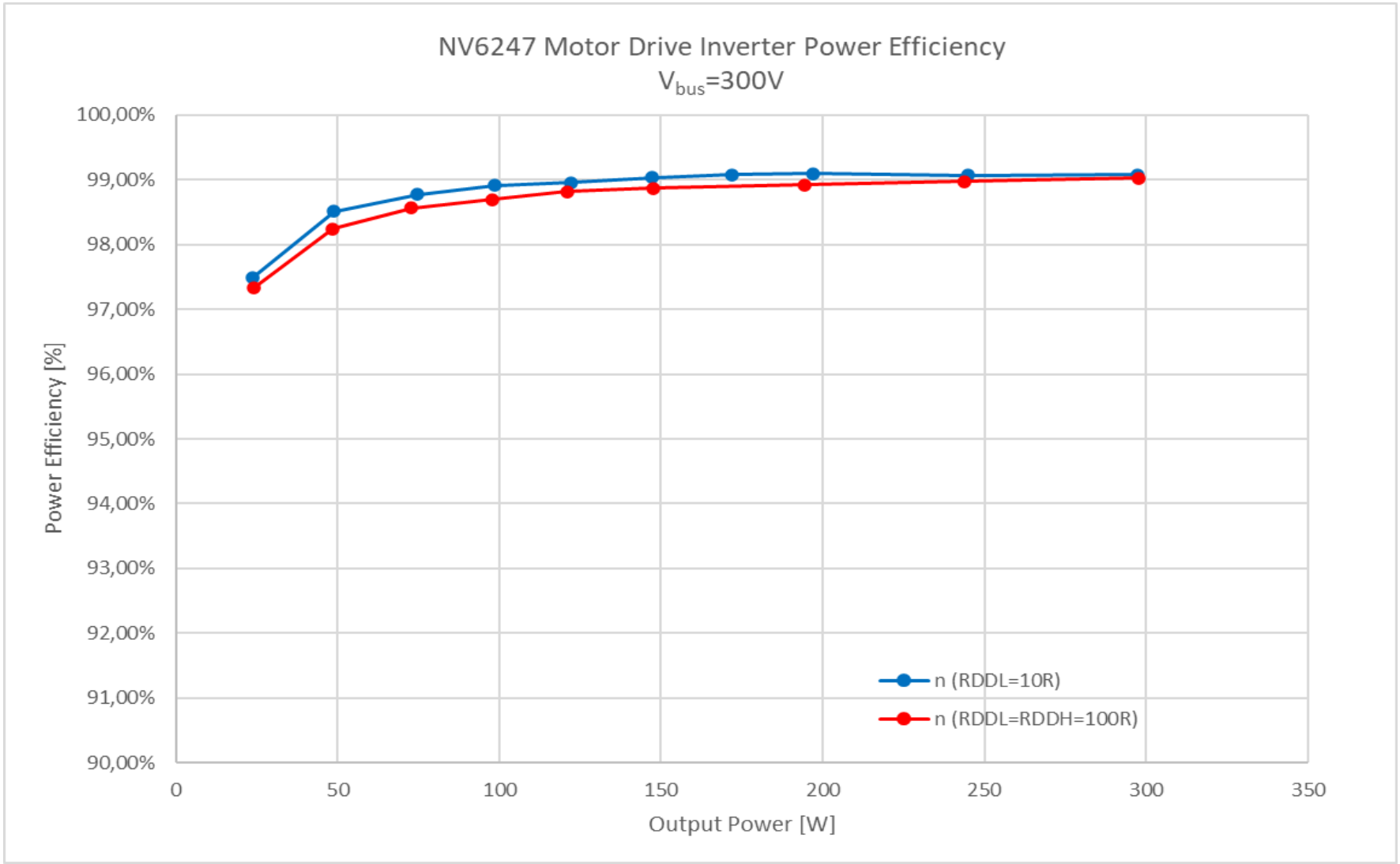


Board diameter 56 mm



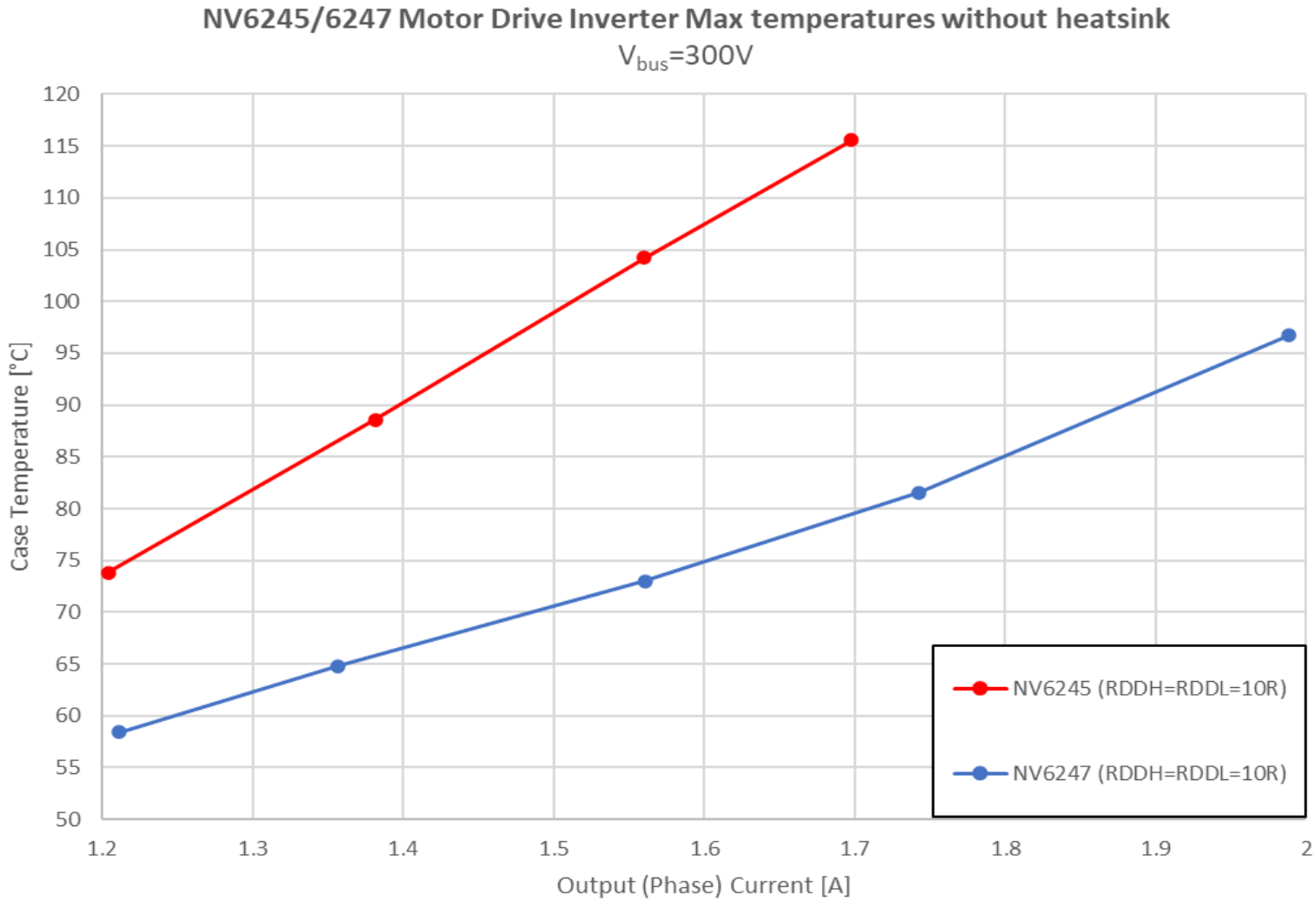
Thermal scan @ 300 W, 20 kHz

Reference design
99% inverter efficiency with GaN power ICs



- Very high inverter efficiency across whole load range
  - V_{bus} = 300V
  - f_{SW} = 20kHz
- Little impact of switching speed

Reference design
Cool operation at high speed



- Very high inverter efficiency across whole load range
  - V_{bus} = 300V
  - f_{SW} = 20kHz
- GaN power ICs with same footprint allow scaling of motor power and losses in same PCB
- NV6245: 2x 275 mΩ
- NV6247: 2x 170 mΩ

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Conclusion

- Through GaNFast™ / GaNSense™ integration, GaN power ICs are ready now
  - Reliable and repeatable performance of e-mode GaN power transistors
  - Smallest form factor and lowest losses
  - Easy to use digital power stage
- Massive performance improvement over silicon alternatives
- Potential to move to higher carrier frequency
- Very good availability and plentiful supply chain – re-using older silicon fabs with little additional expense and waste

GaN power ICs enable the next level of performance, reliability and robustness in motor inverter applications

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Thank you for your attention!

I‘m pleased to answer your questions.

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