Whitepaper

Enabling high-efficiency 48 V motor drives with GaN: Diode-less operation and ultra-short dead time in 70 A / 100 kHz systems

Authors Nexperia: Filippo Scrimizzi - Regional System Application Director, Sebastian Heinz - Senior Principal Regional System Application Engineer, Tim Lischka - Senior GaN Application Engineer, Pradip Chatterjee - Senior Regional Marketing Manager

Motor control systems used in robotics, industrial automation, power tools, drones, and light electric mobility continue to demand greater power density, improved efficiency, and reduced thermal constraints. Conventional silicon MOSFET-based inverter designs are often limited by reverse recovery losses, switching frequency restrictions, and dead-time requirements, introducing efficiency penalties and current waveform distortion. This paper evaluates a 48 V three-phase motor drive based on Nexperia's enhancement-mode GaN HEMT technology operating at switching frequencies up to 100 kHz, phase currents up to 70 A, and dead times as low as 25-30 ns. Experimental testing demonstrates stable diode-less operation, excellent thermal robustness, and system efficiencies exceeding 96%. The results highlight how GaN technology enables higher switching frequencies, reduced motor losses, lower winding temperatures, simplified hardware architectures, and increased power density for next-generation motor control applications.

1. Introduction & Background

The electrification of industrial systems, collaborative robotics, autonomous platforms, drones, and low-voltage mobility solutions is accelerating demand for power converters capable of delivering greater efficiency within increasingly constrained physical footprints.
Traditional silicon MOSFET motor drives have provided reliable performance for decades. However, as switching frequencies increase and efficiency requirements become more stringent, several limitations emerge:

- Reverse recovery losses in body diodes
- Long dead-time requirements
- Increased switching losses
- Larger magnetic components
- Higher thermal dissipation requirements

These limitations impact both system efficiency and power density.

Gallium Nitride (GaN) power semiconductors represent a significant advancement for low-voltage motor drive applications. Their combination of low RDS(on), low gate charge (Qg), negligible reverse recovery charge (Qrr), and fast switching capability enables motor-drive architectures that were previously difficult to implement using silicon devices.
This paper investigates a 48 V GaN-based three-phase motor inverter specifically designed to evaluate the benefits of ultra-short dead-time operation and elimination of external freewheeling diodes.

2. Problem definition

Motor drive designers are increasingly challenged to improve efficiency while simultaneously reducing system size, weight, cooling requirements, and overall cost.

Several technical bottlenecks exist in conventional silicon-based designs:

2.1 Dead-time losses

Dead time is intentionally introduced between switching transitions to prevent shoot-through failure in inverter legs. However, excessive dead time causes:

- Equivalent diode emulation mode losses
- Distortion of motor phase currents
- Torque ripple
- Reduced efficiency
- Audible acoustic noise

Dead-time losses can become particularly significant at higher current /power working conditions.

2.2 Reverse recovery losses

When body diodes conduct during commutation, stored charge must be removed during turn-on.

This creates:

$$E_{rr} = Q_{rr} \times V_{BUS}$$

Where:

- E_{rr} = reverse recovery energy
- Q_{rr} = reverse recovery charge
- V_{BUS} = DC bus voltage

As switching frequency increases, reverse recovery losses become increasingly dominant.

2.3 Thermal constraints

Higher losses directly increase device temperature:

$$P_{LOSS} = P_{COND} + P_{SW}$$

Where:

Pcond=I^2*RDSon@TJ (TEMPERATURE FIXED BY THE AMBIENT STARTING CONDITION PLUS SELF HEATING EFFECT DUE TO POWER DISSIPATION)

Psw= ½*Vin*IDS*(Trise+Tfall)*fsw

Where Rdson is the channel resistance in ON status of the device and IDS is the current flowing through the device, Vin is the battery voltage or input of the system and Trise and Tfall are the transition time for turning ON and OFF the device.

Those time gaps define the crossing of voltage and current across the power switch implying the relevant switching losses. If switching and conduction losses are higher, then the average working temperature of the device is higher.

As a result, larger heatsinks and cooling systems are typically required to fix properly the thermal budget.

2.4 Current ripple and motor heating

Lower switching frequencies generate greater current ripple:

$$\Delta I = \frac{V \times T}{L}$$

This increases RMS current levels and winding temperatures, reducing overall motor efficiency.

3. GaN-based 48 V motor drive architecture

Nexperia developed a dedicated 48 V three-phase inverter platform to evaluate the benefits of modern e-mode GaN HEMTs in motor control applications.

3.1 System architecture

The inverter incorporates:

- Twelve Nexperia GANE1R8-100QBA GaN HEMTs
- Three independently controlled half-bridges
- Parallel high-side and low-side device configuration
- Dedicated motor-control controller
- Protection and fault management circuitry
- PWM generation hardware

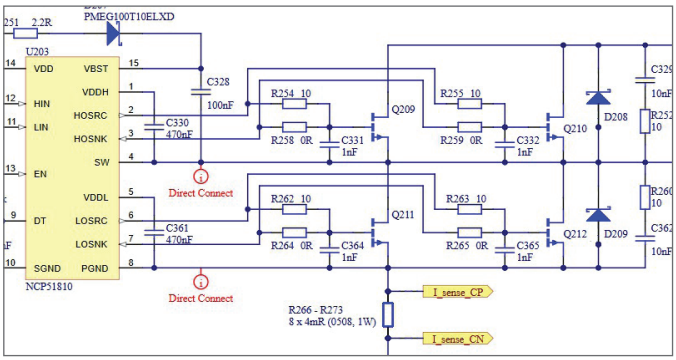

Figure 1: Single-phase schematic showing controller, half-bridge structure, and optional diode locations.

3.2 Parallel device configuration

Each phase leg consists of:

- Two parallel GaN devices on the high side
- Two parallel GaN devices on the low side

This configuration:

- Reduces conduction losses
- Improves current distribution
- Improves thermal balancing
- Enables operation at high phase currents

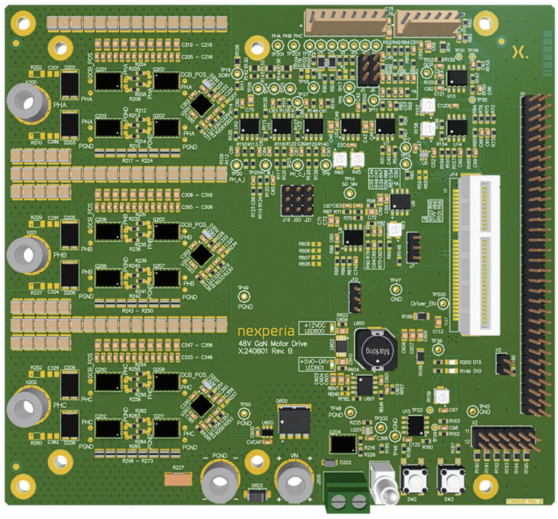

Figure 2: Power board PCB layout and physical implementation.

3.3 Gate driver optimization

Key operating parameters include:

Parameter	Value
System Switching Frequency	100 kHz
Gate Driver Switching Capability	>1 MHz
dV/dt Immunity	Up to 200 V/ns
Rg(on)	10 Ω
Rg(off)	0 Ω
Peak Driver Current	1 A Source / 2 A Sink

The gate driver is capable of supporting switching frequencies above 1 MHz; however, the system evaluated in this work was operated at 100 kHz.

Special attention was given to PCB layout optimization, minimizing gate-loop inductance and ensuring stable operation under extremely fast switching conditions.

4. GaN advantages for advanced motor control

The performance advantages of GaN stem directly from its physical device characteristics.

4.1 Switching performance benefits

Compared with conventional silicon solutions, GaN devices offer:

- Lower switching losses
- Negligible reverse recovery charge
- Reduced output capacitance losses
- Faster transition times
- Cleaner switching waveforms

This allows operation at switching frequencies well above conventional motor-drive architectures.

4.2 Reduced dead-time operation

The negligible reverse recovery behaviour of GaN allows dead times approaching:

$$t_{dead} \leq 30ns$$

Benefits include:

- Reduced third-quadrant conduction losses
- Reduced current waveform distortion
- Improved current-loop accuracy
- Smoother torque production

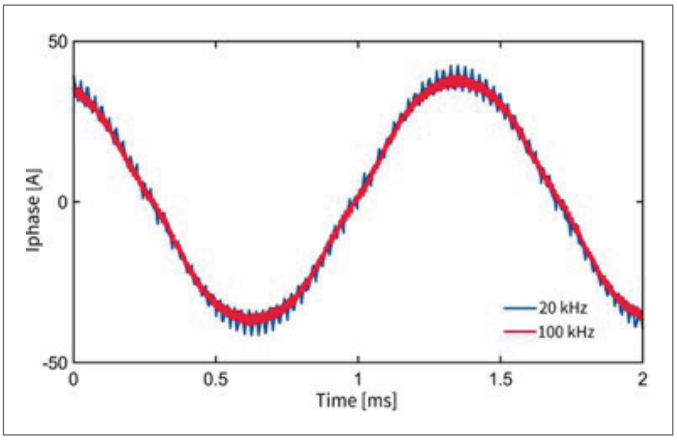

Figure 3a: Phase current ripple comparison.

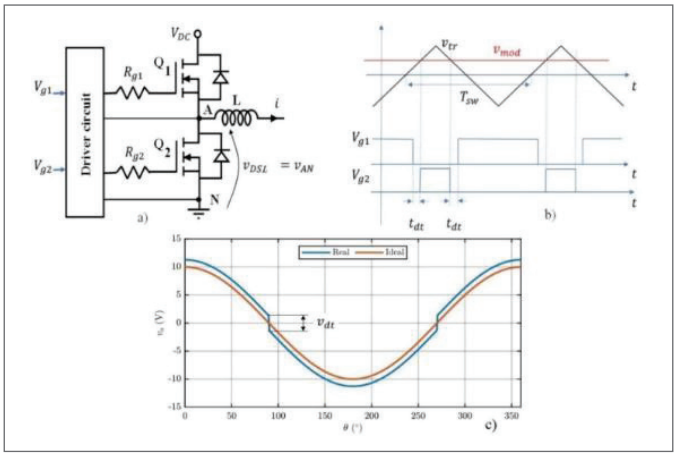

Figure 3b: Zero-crossing distortion reduction with optimized dead time.

5. Testing, simulation & validation

5.1 Ultra-short dead-time validation

Parameter	Value
Dead Time	25 ns
Peak Phase Current	70 A
Current Swing	120-150 A
Switching Frequency	100 kHz

A primary objective was validating stable operation at approximately 25 ns dead time.

Testing was performed at:
The measured waveforms demonstrated:
- Stable commutation
- No visible cross-conduction
- Limited diode conduction intervals
- Controlled EMI behaviour

These results would be extremely difficult to achieve using silicon MOSFET technology due to reverse recovery effects.

5.2 Diode-less operation validation

At the beginning the inverter was designed with anti-parallel diodes to clamp the flyback voltage at turn off and make easier the freewheeling of the current when both high side and low side switches are simultaneously OFF. This set up was showing huge dissipation into the diodes making very hot the area surrounding them in the PCB. A second phase of testing removed all six external freewheeling diodes.

Despite complete diode removal, the inverter maintained:
- Stable operation
- Clean switching transitions
- Full-power operation at 70 A
- Consistent 100 kHz switching

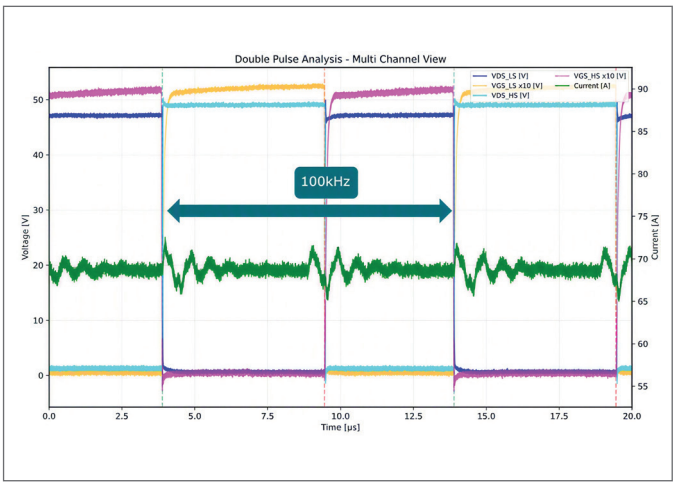

Figure 4a: Steady-state switching waveform at 70 A and 100 kHz.

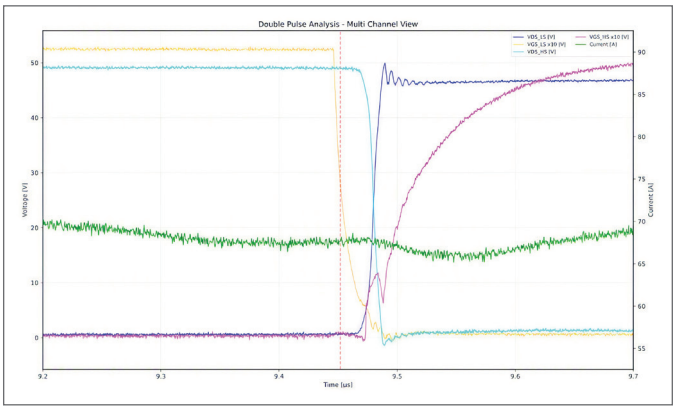

Figure 4b: Switching transient detail at 70 A and 100 kHz.

The results validate one of GaN's most significant motor-drive advantages: elimination of external freewheeling diodes without compromising reliability or performance.

5.3 Thermal characterization

Infrared thermal imaging was used to evaluate device temperatures under maximum current loading.

Test conditions:
Maximum measured junction-related temperature:

$$T_{MAX} = 135°C$$

Parameter	Value
Phase Current	75 A
Current Swing	150 A Peak-to-Peak
Switching Frequency	100 kHz
Dead Time	25 ns

The thermal performance confirms the suitability of GaN technology for demanding high-current motor control applications.

5.4 System efficiency validation

A dynamometer-based evaluation was conducted to quantify end-to-end system efficiency.

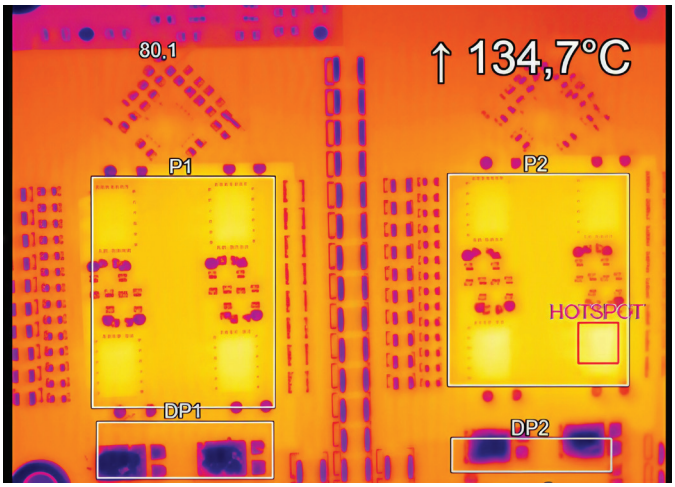

Figure 5: IR thermal image under full-load operation without diodes.

5.3 Thermal characterization

Infrared thermal imaging was used to evaluate device temperatures under maximum current loading.

Test conditions:
Maximum measured junction-related temperature:

$$T_{MAX} = 135°C$$

The thermal performance confirms the suitability of GaN technology for demanding high-current motor control applications.

5.4 System efficiency validation

A dynamometer-based evaluation was conducted to quantify end-to-end system efficiency.

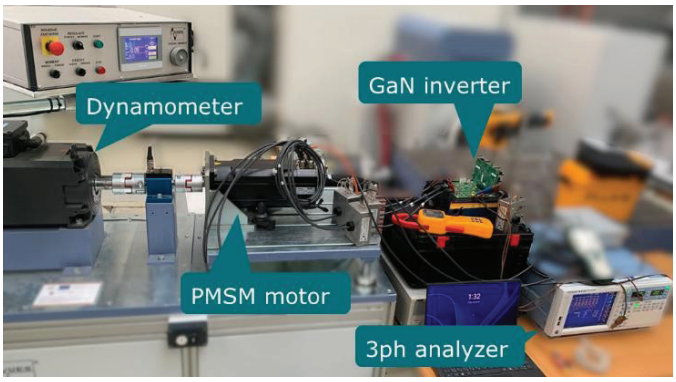

Figure 6: Efficiency measurement bench setup.

Test conditions	
PWM sw frequency	100kHz
Max output power	1200W
Max phase current Irms	44A
DC BUS voltage	24-60V
Dead Time	25 ns

Table 1: Test condition summary.

Test conditions included:

- Bus voltage: 24 V to 60 V
- Switching frequency: 100 kHz
- Output power: up to 1200 W
- RMS phase current: up to 44 A
- Dead time: 25 ns

Measured efficiency exceeded:

$$\eta > 96\%$$

across the tested operating range.

GaN Inverter Efficiency mapping 48V 100kHz 25ns DeadTime

I_{apeak} (A)	I_{arms} (A)	100 rpm	200 rpm	300 rpm	400 rpm	500 rpm	600 rpm	700 rpm	800 rpm	900 rpm	1000rpm
62.2	44.0	81.60	87.50	90.20	92.00	93.20	94.00	94.90	95.40	95.80	95.60
57.3	40.5	81.20	86.70	90.00	92.20	93.30	94.10	94.80	95.40	95.80	96.00
54.0	38.2	81.10	87.30	90.10	92.00	93.10	94.10	94.90	95.60	95.90	96.20
49.9	35.3	80.60	87.00	90.20	92.00	93.10	94.10	94.80	95.50	96.20	96.20
45.3	32.0	80.00	86.70	89.80	92.20	93.40	94.20	94.80	95.80	95.90	96.20
40.6	28.7	79.40	86.10	89.60	91.90	92.60	94.10	94.80	95.50	95.80	96.10
36.9	26.1	78.30	85.60	89.70	91.90	93.00	94.00	94.90	95.40	95.90	96.20
33.4	23.6	77.40	85.30	89.20	91.50	92.80	93.90	94.50	95.30	95.90	96.00
29.1	20.6	75.80	84.50	88.90	91.10	92.30	93.60	94.50	95.10	95.60	96.00
24.7	17.5	74.50	82.70	87.40	90.10	91.90	93.20	94.00	94.80	95.00	95.60
21.2	15.0	70.00	81.30	86.80	89.10	90.00	92.40	93.50	94.00	94.50	95.70
16.7	11.8	67.10	78.00	83.60	87.30	89.70	91.70	92.30	93.10	94.20	94.40
13.0	9.2	61.00	74.50	80.90	84.40	86.90	89.30	90.80	91.60	92.30	93.40
8.4	5.9	51.50	64.40	74.50	80.50	83.10	85.50	86.50	89.60	90.80	90.70
4.6	3.3	34.60	49.90	61.60	69.50	72.40	78.20	80.50	82.10	82.50	84.60

Phase Current Ia [A]

Figure 7: Efficiency results measured at Vin = 48 V.

6. Conclusion

The evaluation results demonstrate that Nexperia's enhancement-mode GaN technology enables a new class of compact, highly efficient motor-drive systems.

Key findings include:
- Stable operation at dead times below 30 ns
- Reliable switching at 100 kHz and 70 A phase current
- Successful elimination of external freewheeling diodes
- Maximum measured device temperature of only 135°C under full-load conditions
- Peak system efficiencies exceeding 96%
- Reduced current ripple and winding temperature
- Increased power density and simplified hardware architecture

These results confirm that GaN technology offers a compelling path toward next-generation motor drives for robotics, industrial automation, drones, battery-powered equipment, and emerging electrification platforms, where efficiency, compactness, and thermal performance remain critical design objectives.

References

1 Scrimizzi, F.; Heinz, S.; Lischka, T.; Chatterjee, P.; Lofti, N.,"48 V GaN Motor Drive with Diode-Less Operation and Short 30 ns Dead Time for 70 A / 100 kHz Systems," PCIM Asia Shenzhen 2026, Nexperia Conference Paper.

2 de Rooij, M., *eGaN FETs Are Low EMI Solutions!,* EPC GaN Talk Blog, 2020.

3 Palma, M., *How to Increase Power Density in Motor Drive Designs Using Gallium Nitride-Based Integrated Circuits,* January 2021.

4 Palma, M., *How to Reduce Audible Noise in Motor Drive Designs Using GaN Transistors and ICs,* October 2020.

5 Palma, M., Barba, V., Musumeci, S., Mandrile, F., Stella, F., *Investigation of Dead-Time Losses in an Inverter Switching Leg Operation,* Energies, 2024.

6 Scrimizzi, F., Cammarata, F., D'Agata, G., Nicolosi, G., Musumeci, S., Rizzo, S.A., *The GaN Breakthrough for Sustainable and Cost-Effective Mobility Electrification and Digitalization,* Electronics, 2022.

7 Basile, A., Scrimizzi, F., Rizzo, S.A., *Current Collapse Phenomena Investigation in Automotive-Grade Power GaN Transistors,* Energies.

About Nexperia

Headquartered in the Netherlands, Nexperia is a global semiconductor company with a rich European history and over 12,500 employees across Europe, Asia, and the United States. As a leading expert in the development and production of essential semiconductors, Nexperia's components enable the basic functionality of virtually every commercial electronic design in the world – from automotive and industrial to mobile and consumer applications.

The company serves a global customer base, shipping more than 100 billion products annually. These products are recognized as benchmarks in efficiency – in process, size, power, and performance. Nexperia's commitment to innovation, efficiency, sustainability, and stringent industry requirements is evident in its extensive IP portfolio, its expanding product range, and its certification to IATF 16949, ISO 9001, ISO 14001 and ISO 45001 standards.

Find your regional sales office here

© 2026 Nexperia B.V.
All rights reserved. Reproduction in whole or in part is prohibited without the prior written consent of the copyright owner. The information presented in this document does not form part of any quotation or contract, is believed to be accurate and reliable and may be changed without notice. No liability will be accepted by the publisher for any consequence of its use. Publication thereof does not convey nor imply any license under patent- or other industrial or intellectual property rights.

Date of release:
September 2026