Reducing System Cost with GaN HEMTs in Motor Drive Applications

Alfred Hesener, Navitas Semiconductor

Navitas

Presenter biography

Alfred Hesener is Senior Director Industrial and Consumer Applications with Navitas Semiconductor, Torrance CA (USA), located in Munich (Germany). His current work is focusing on driving the state of the art in industrial power conversion and electric motor applications using wide bandgap semiconductors. Previous positions include Head of Application Engineering and Product Definition for Infineon Technologies, Industrial Products Division, and Head of Regional Marketing and Application Engineering, Fairchild Semiconductor. He holds an MSEE in Microelectronics from Darmstadt University of Technology.

Contact: alfred.hesener@navitassemi.com

Navitas

Agenda

- Introduction – key challenges and changes
- Starting point: The silicon solution
  - Electrical and thermal design considerations
- The next level: GaN-based motor inverter
  - GaNSense™ half-bridge features explained
- Implementation considerations
  - PCB layout and thermal design without heatsink
  - Electrical design with proper protections
  - Auxiliary supply
- Conclusions

Key challenges and changes

- Using GaN power ICs in motor inverters can reduce system cost
  - Removal of heatsink, higher integration, automated assembly
- Higher efficiency reduces energy cost, improves ratings / labeling
- Legacy solutions using silicon switches are well-known in the industry, and perceived to be more robust
  - Not every application requires higher power density

Reducing System Cost with GaN power ICs in Motor Drive Applications

Key challenges and changes

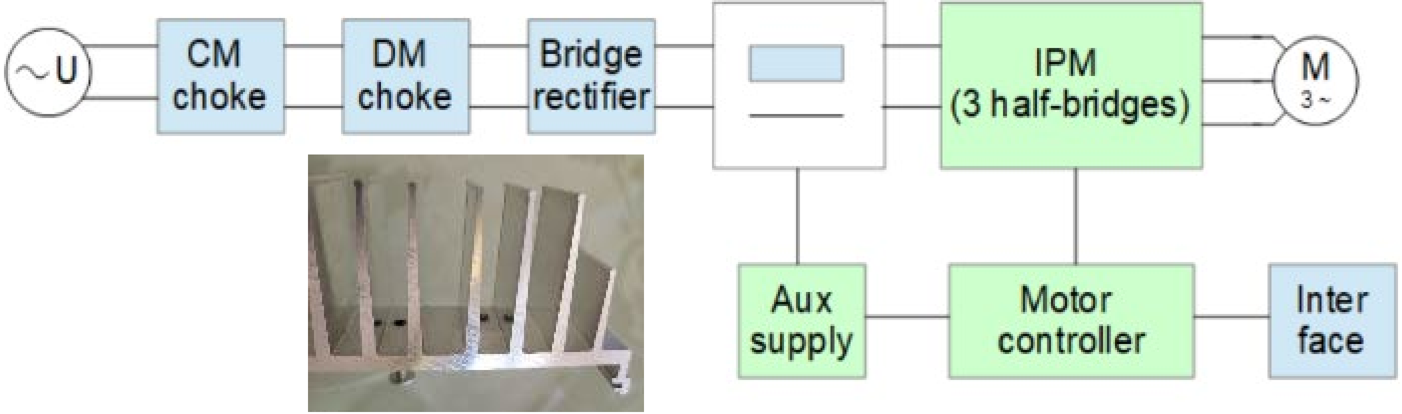
Feature	Impact	Benefit
Very low switching losses	Reduce losses by >20% over SiC, >50% over Si	Small or no heatsink, easier thermal design, higher reliability
Very high switching frequency possible (50 kHz+)	Sinusoidal modulation Lower motor inductance	2% better efficiency, less harmonics; smaller , up to 30% lower cost motor, 20% smaller EMI filter
Precise switch timing with low latency and dead time	Improved control loop performance, low EMI	Smaller EMI filter , better dynamic performance under load steps
High voltage ratings (650V DC / 800V transient)	High robustness against transient overvoltage peaks	10x lower field failure rate
Integrated gate driver and voltage regulator	Excellent reliability through precise gate drive conditions	Improved lifetime and low field failure rate
Integrated lossless current sensing and temperature sensor	Excellent robustness through very fast and precise action	Robust, protected application and low failure rate; 1% better efficiency
High level of integration – less components on PCB	Very compact size and higher reliability	10% smaller system size and cost, and very easy to use

The silicon solution - overview

- Motor control board for washing machine
  - Peak motor power 600W
  - Switching frequency 8kHz
- Power components: IPM and bridge rectifier (both under heatsink)
- Situated in plastic case, protecting against environmental influence but also restricting airflow

Reducing System Cost with GaN power ICs in Motor Drive Applications

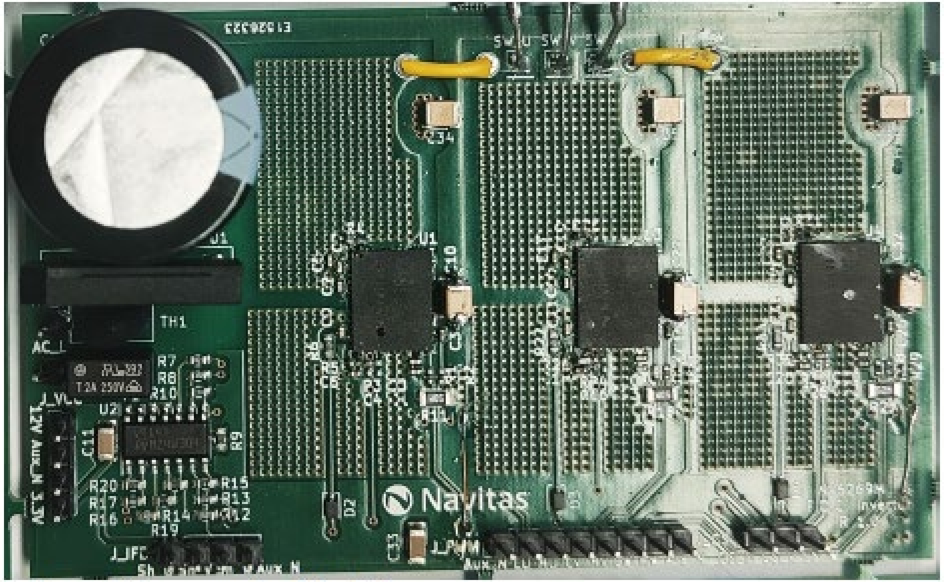
The silicon solution – block diagram



- Straightforward topology without active power factor correction
- DC link capacitor 220µF, CM choke 3mH and physically large (IGBT switching noise), DM choke small (slow speed switching)
- Large and complex heatsink (128mm x 39mm x 25mm, weight 89g)
  - est. R_{THCA} = 2.4K/W

GaN-based motor inverter

- No heatsink – cooling is done via copper areas on the board
- Very small number of external components
- Most SMD components
- Contains only power stage (rectifier, DC link capacitor 82µF, 3x GaN power IC in half-bridge configuration, current sense)



Reducing System Cost with GaN power ICs in Motor Drive Applications

GaNSense™ half-bridge overview

Complete Integration

- Full integration of Half-bridge circuit (Control, Drive, Power, Protection)
- Integrated level-shifter & Bootstrap
- 2MHz switching frequency
- 2kV ESD protection
- Fast (C) or slow (M) versions

GaNSense™ Technology

- Adjustable switching speed for turn-on
- Integrated loss-less current sensing
- Over-current protection / Short circuit protection
- Over-temperature protection
- Autonomous low-current standby mode
- Auto-standby enable input

Small, low profile SMT QFN

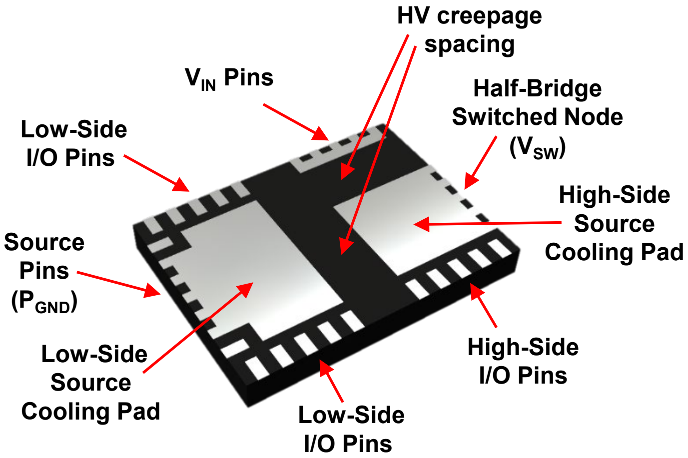
- 6x8 / 8x10 mm footprint, 0.85 mm profile
- Minimized package inductance
- Enlarged cooling pads

Sustainability

- RoHS, Pb-free, REACH-compliant
- Up to 40% energy savings vs Si solutions
- System level 4 kg CO_2 Carbon Footprint reduction

Product Reliability

- 20-year limited product warranty



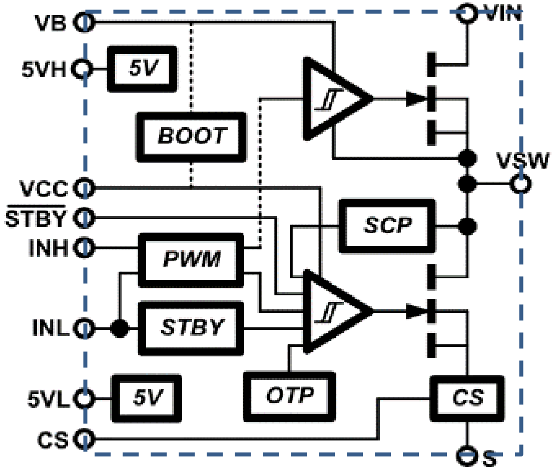
Part #	Type	$V_{DS(CONT)}$ (V)	$R_{DS(ON)}$ (mΩ, typ)	Package	Status	Motor power*
NV6245C	Half-Bridge	650	275/275	PQFN 6x8	Production	200
NV6247C	Half-Bridge		160/160	PQFN 6x8	Production	400
NV6269C	Half-Bridge		70/70	PQFN 8x10	Production	600
NV6245M	Half-Bridge		275/275	PQFN 6x8	Samples	200
NV6247M	Half-Bridge		160/160	PQFN 6x8	Production	400
NV6269M	Half-Bridge		70/70	PQFN 8x10	Samples	600

(* Motor power estimated and depending on application conditions, in particular thermal design)

Reducing System Cost with GaN power ICs in Motor Drive Applications

GaNSense™ half-bridge features and protections

GaNSense™ Half-bridge



- **High, stable and repeatable performance** → design margins can be reduced
  - Low prop delay for best control loop performance
- Controlled gate drive conditions enable **outstanding reliability**
- Adjustable switching speed to **control EMI**
- **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**
- Overtemperature turn-off→ **system robustness**

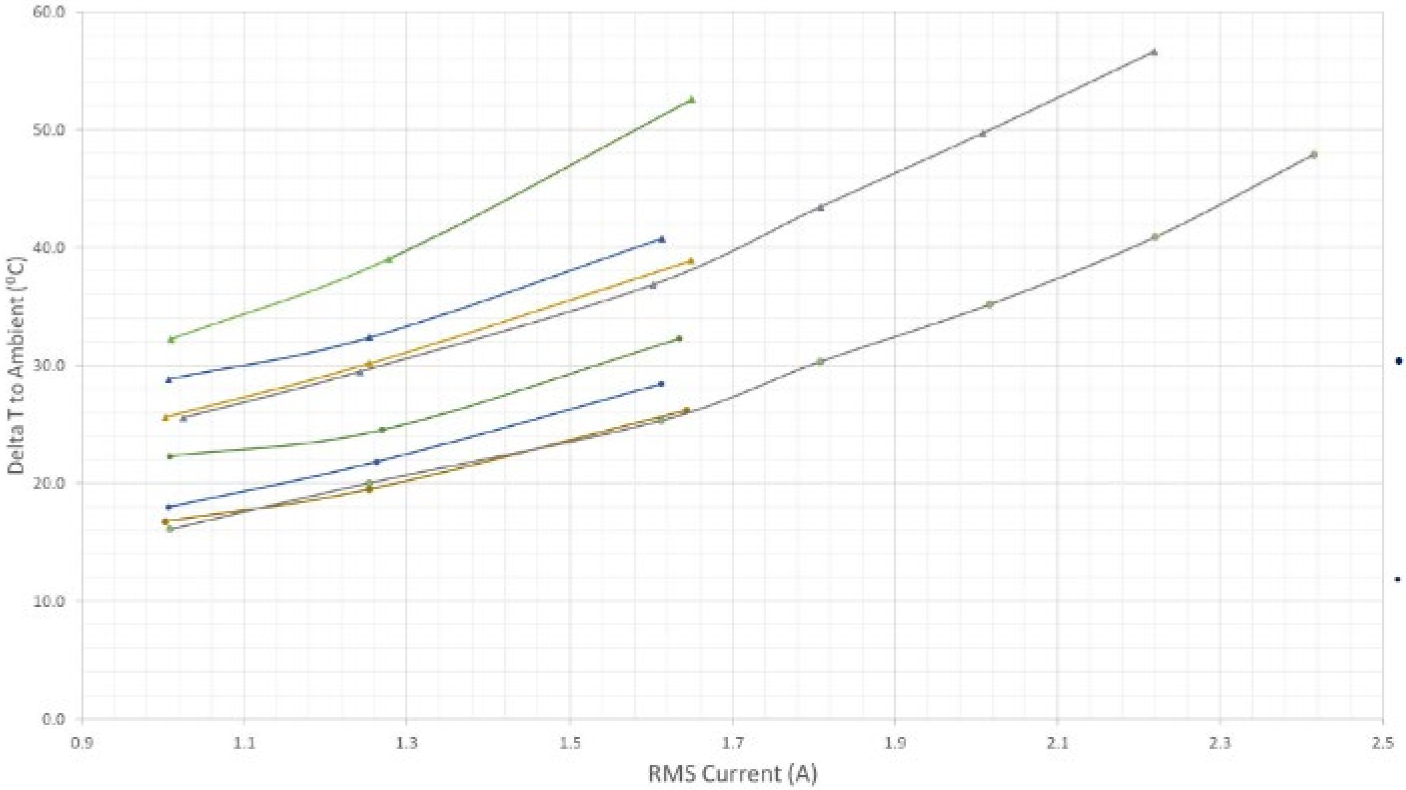
Reducing System Cost with GaN power ICs in Motor Drive Applications

Implementation considerations - Thermals

Power switch		GaN power IC					IGBT-IPM			
Load		20%	40%	60%	100%		20%	40%	60%	100%
Bus voltage	V	310	310	310	310		310	310	310	310
Phase RMS current	A	0,52	1,03	1,55	2,60		0,52	1,03	1,55	2,60
Switching frequency	kHz	16,0	16,0	16,0	16,0		8,0	8,0	8,0	8,0
Switching speed	V/ns	10,0	10,0	10,0	10,0		6,0	6,0	6,0	6,0
Switching losses	W	0,50	0,81	1,19	2,15		20,88	20,88	20,88	20,88
Conduction losses	W	0,11	0,43	0,98	2,76		1,87	3,82	5,94	10,59
Total losses	**W**	**0,61**	**1,24**	**2,17**	**4,91**		**22,75**	**24,70**	**26,82**	**31,47**
Motor output power	W	120	238	359	602		120	238	359	602
Ambient temperature	°C	60,0	60,0	60,0	60,0		60,0	60,0	60,0	60,0
Thermal resistance	K/W	12,00	12,00	12,00	12,00		2,40	2,40	2,40	2,40
Junction temperature	°C	67,5	75,3	86,7	120,4		122,1	128,3	135,4	151,7

Comparison of total losses for different operating conditions – for the GaN implementation, a higher thermal resistance of 12K/W is sufficient

GaN-based motor inverter – thermal performance



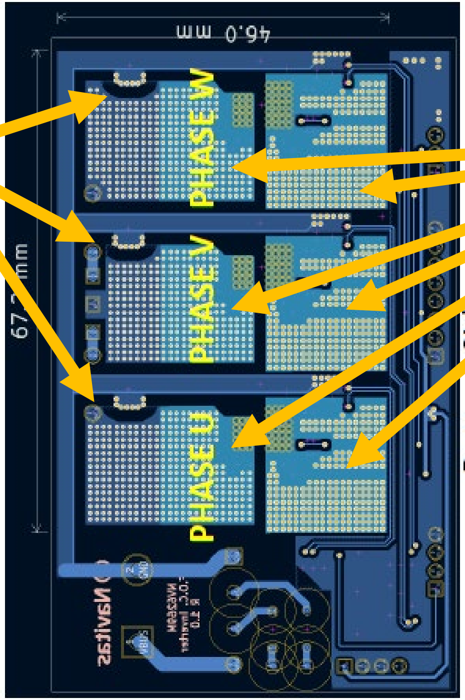
- 325VDC Input, 28ºC ambient
  - 800ns dead-time
  - 30 min soaking time
  - board standing vertically
  - back and bottom panel @ 8.5cm
  - side panels @ 10cm
  - free convection
- Motor 1BS6530-8AC (BSH)
  - 16755RPM, 2.4A
  - 4 pole pairs
  - Ld=12.4mH, Rs=2.20Ω
  - C_{U-PE}=224pF
  - C_{V-PE}=289pF
  - C_{W-PE}=259pF

Implementation considerations – PCB layout

Wide connections to shunts

Use both sides of the PCB for cooling

Avoid bottom-side components



Fill with thermal vias

Large, low-inductance connections

HS components close to output node

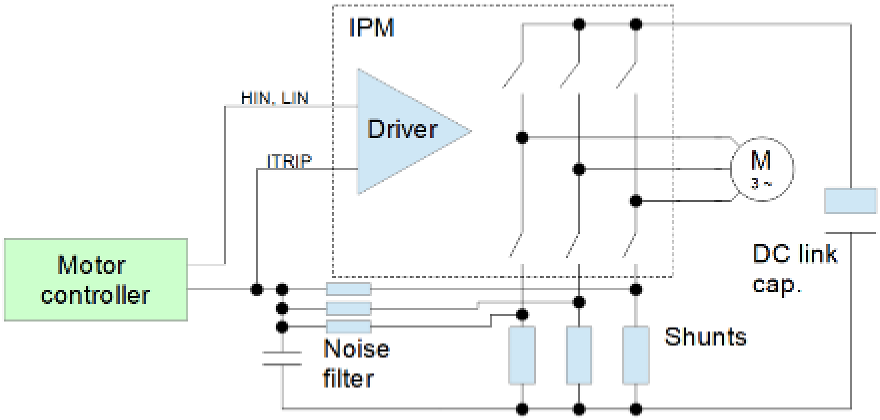
Fully documented layout guidelines available in the datasheet and reference design documentation

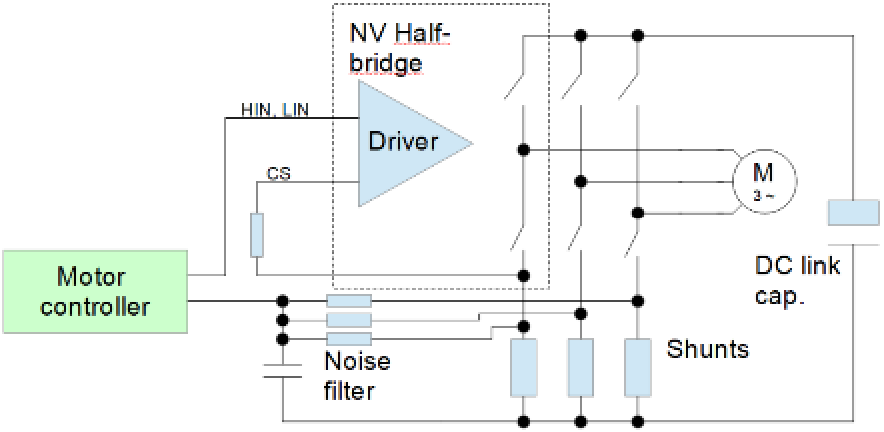
Thermal design - considerations

- Heatsink represents large thermal “capacitance” and can store a lot of transient energy (abnormal operation, e.g. rotor blocking)
- PCB layout cooling does not have high storage → are higher peak temperatures to be expected?

1. Heatsink is selected for thermal resistance, not thermal impedance, and is typically oversized for the energy of abnormal events
2. Lower heat generation reduces the problem to begin with
3. Overcurrent protection will turn off the power switches very fast
4. Thermal throttling should be implemented (depending on application conditions)

Implementation considerations – Current sense and OCP



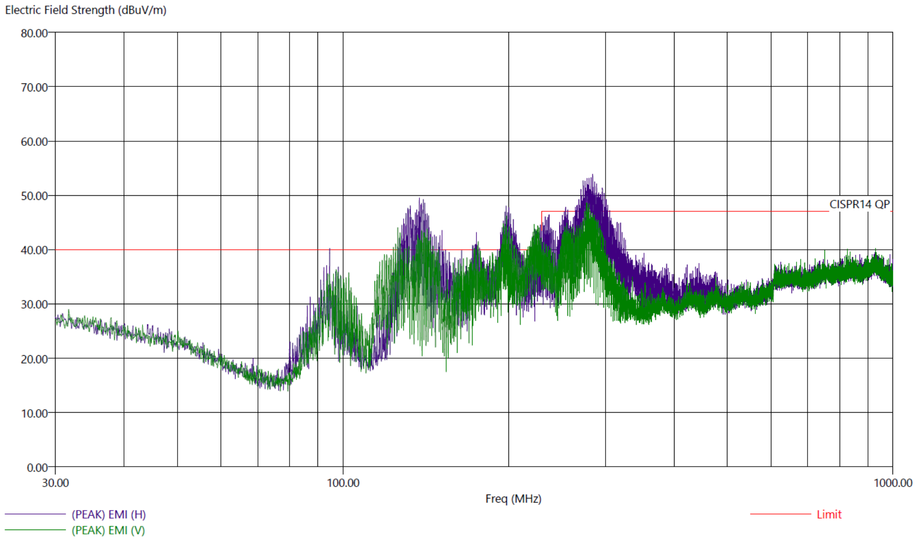


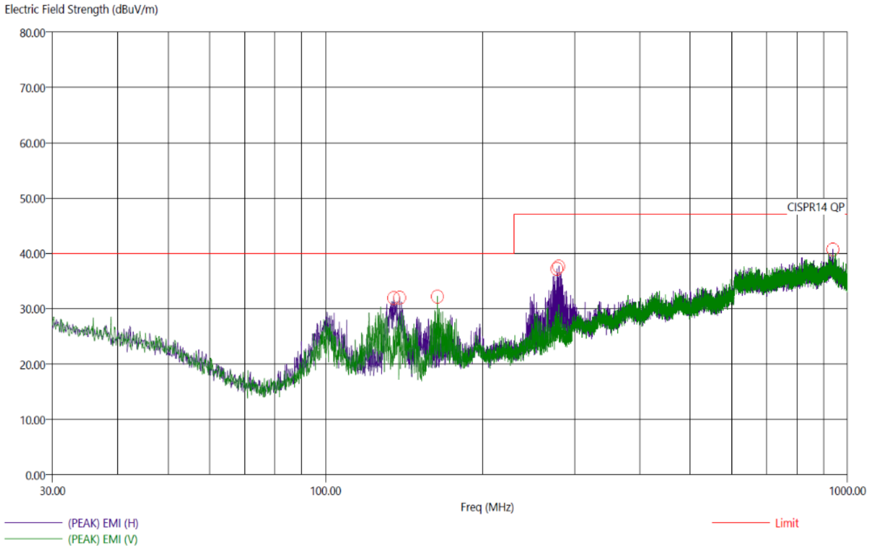
- Signal latency through the noise filter, comparator and gate driver easily adds up to 1…2µs
- Using the CS signal from GaNSense™ for overcurrent protection reliably turns off the power switch in < 100ns

Implementation considerations – DC link capacitor

- The DC link capacitor sizing is complex and sees many (sometimes conflicting) requirements: holdup time, 50Hz/60Hz bus ripple, ripple current requirements vs ESR vs self-heating, ambient temperature, drift and lifetime, surge capability, size and cost
- In GaN-based motor inverters, the DC link capacitor typically can be reduced:
  - Low switching losses of GaN enable higher switching frequency, enabling different control algorithms (sinusoidal modulation) and reduced ripple current
  - Lower power dissipation of GaN helps to reduce the ambient temperature
  - High breakdown voltage of GaN power switches enable better spread of the surge-related energy across all involved components

Implementation considerations – EMI





- Radiated emissions spectrum for identical operating conditions for NV6245C (left picture) and NV6245M (right picture), using same turn-on speed
- Diagrams are showing a clear improvement of more than 10dBµV/m

Conclusion

- Motor inverters using GaN power ICs can enable significant system cost savings:
    - Minimal or no heatsink
    - Better robustness through built-in protections
    - Reliable and repeatable operation with high performance
- Still, the thermal design needs consideration, especially for abnormal operating conditions
- Large portfolio of GaN power ICs (half-bridge and single switches) can address a large power range in many consumer and industrial applications
- Newer generations of GaN power ICs with further cost-down potential

Thank you for your interest!

Alfred Hesener, Navitas Semiconductor
Email: alfred.hesener@navitassemi.com
Industry session