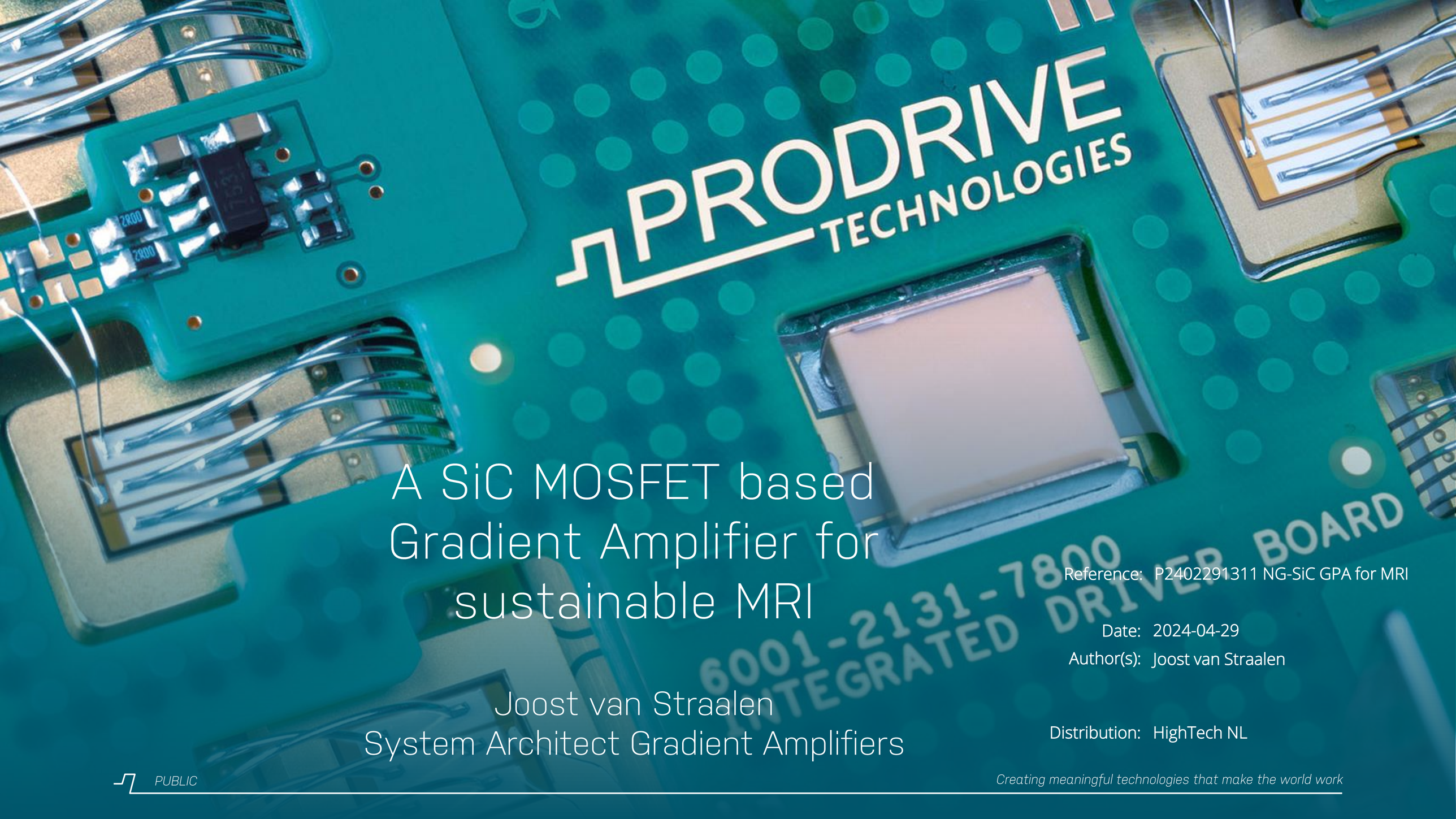

A SiC MOSFET based Gradient Amplifier for sustainable MRI

Joost van Straalen
System Architect Gradient Amplifiers

Reference: P2402291311 NG-SiC GPA for MRI

Date: 2024-04-29

Author(s): Joost van Straalen

Distribution: HighTech NL

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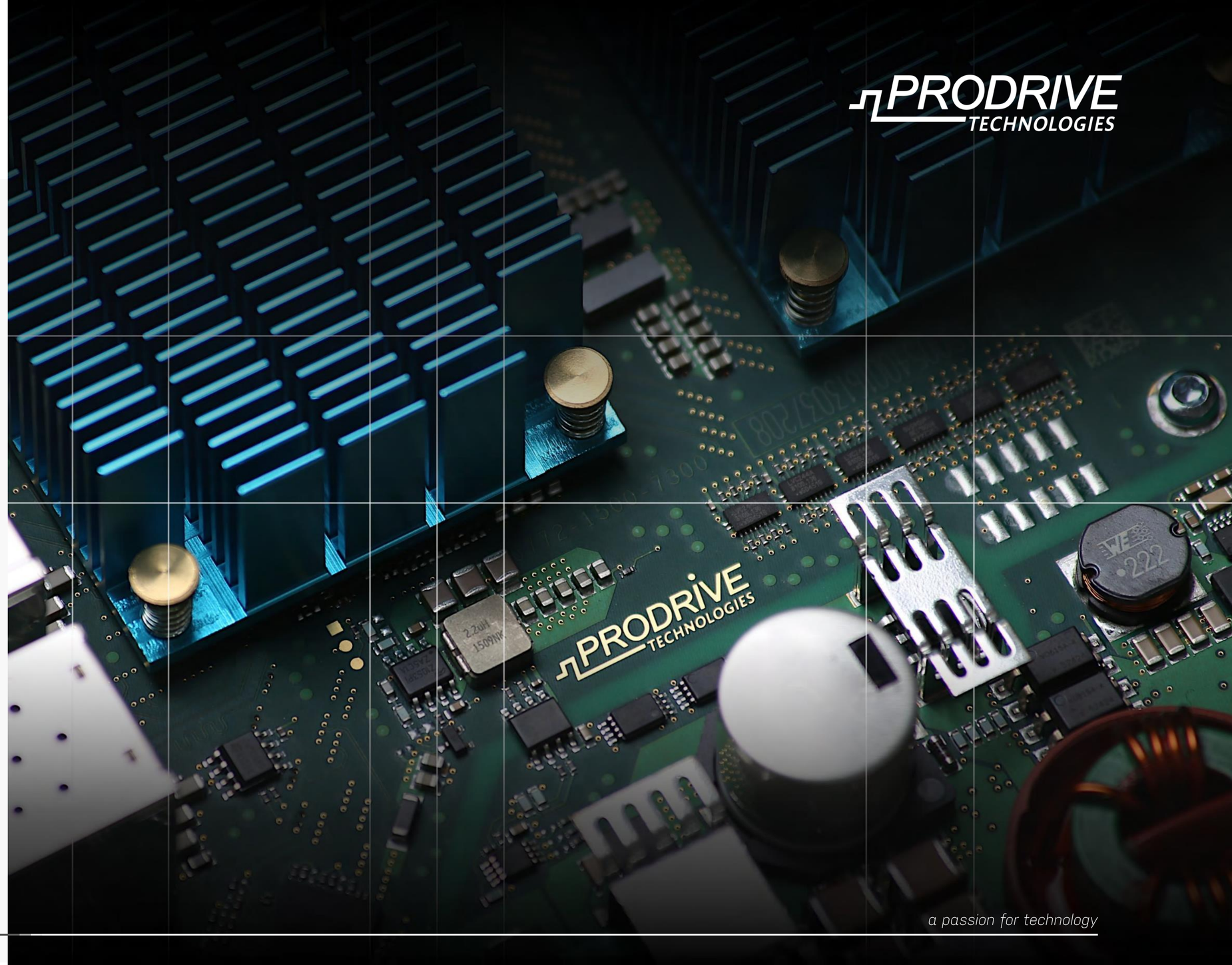
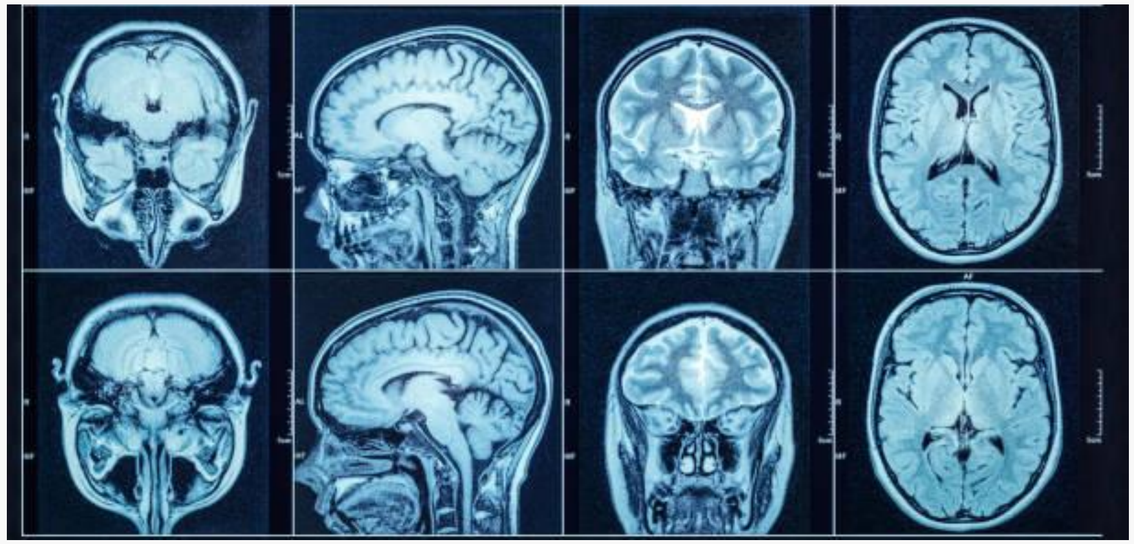
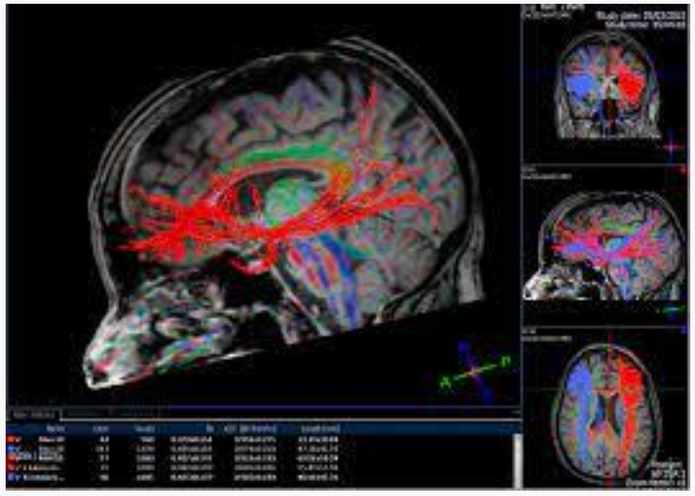
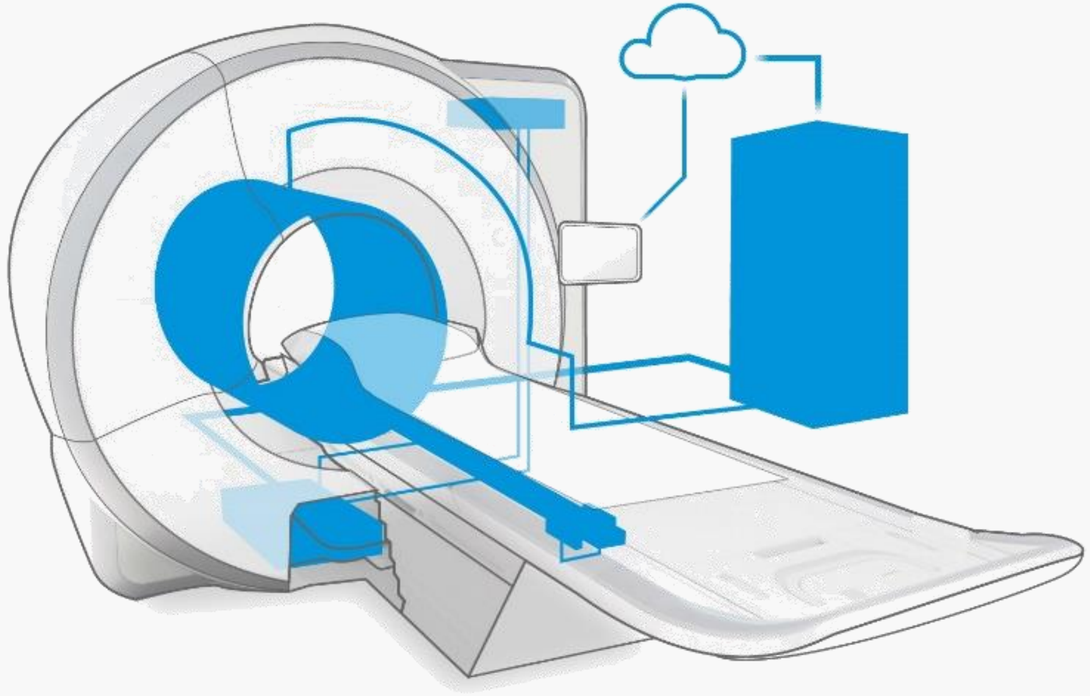


MRI Scanners







NG Series portfolio

Gradient

NG500 1.2
- *990V*
- *630A$_{PEAK}$*
- *230A$_{RMS}$*

NG500 1.3
- *1035V*
- *1000A$_{PEAK}$*
- *380A$_{RMS}$*

NG2250-XP
- *2100V*
- *1200A$_{PEAK}$*
- *400A$_{RMS}$*

NG1850-XP
- *1980V*
- *900A$_{PEAK}$*
- *400A$_{RMS}$*

NG SiC MOSFET
- *In development*

RF/shim

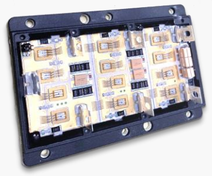
NGRF1500
- 20kW PEP
- 1.5T
- 1 channel
- Ask for availability

NGRF3000
- *2x20kW PEP*
- *3.0T*
- *2 channels*

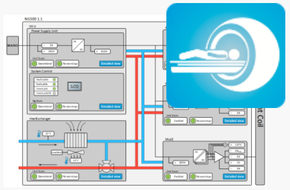
NGS130-6
- *≥ 6 channels*
- *30V / 7A*
- *650W total*

Misc.

XPCS1200
- *1200A$_{PEAK}$*
- *Extremely linear*



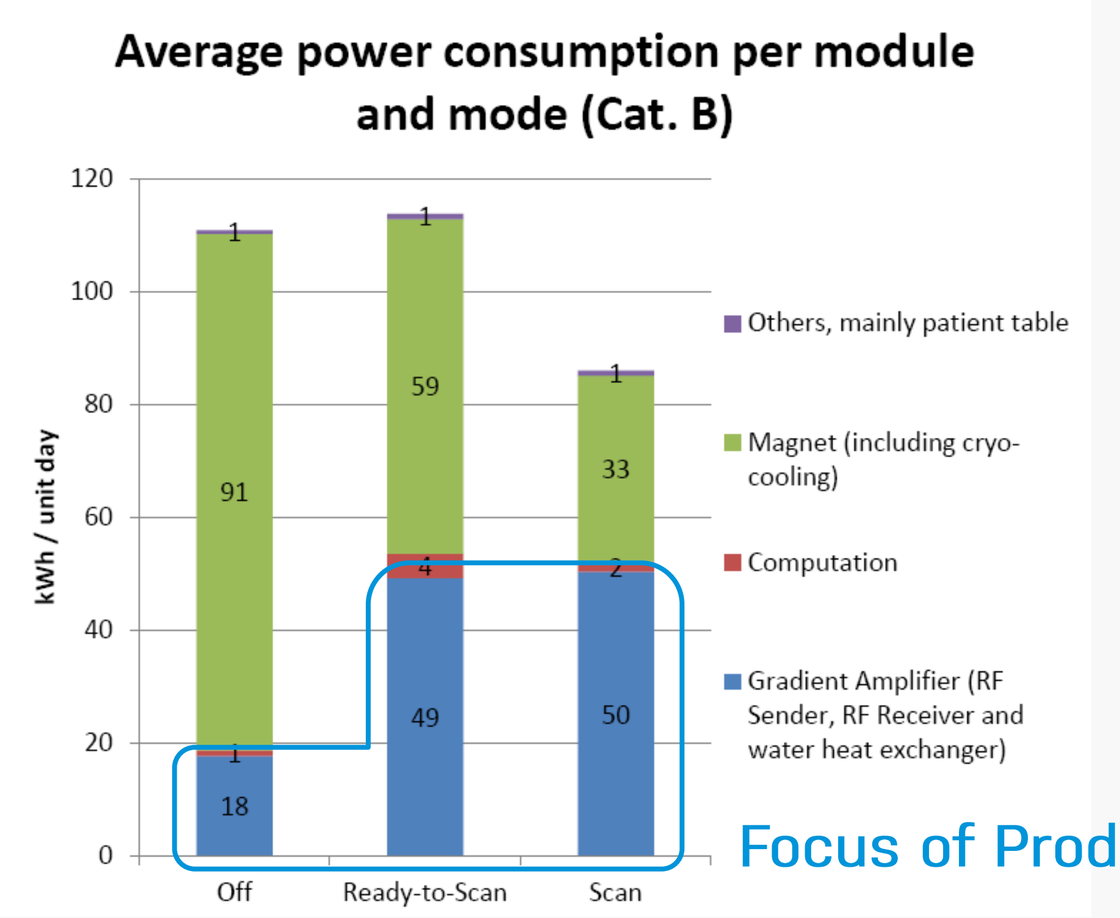
SiC Power module
- *In-house design & manufacturing*
- *Optimized for MRI*



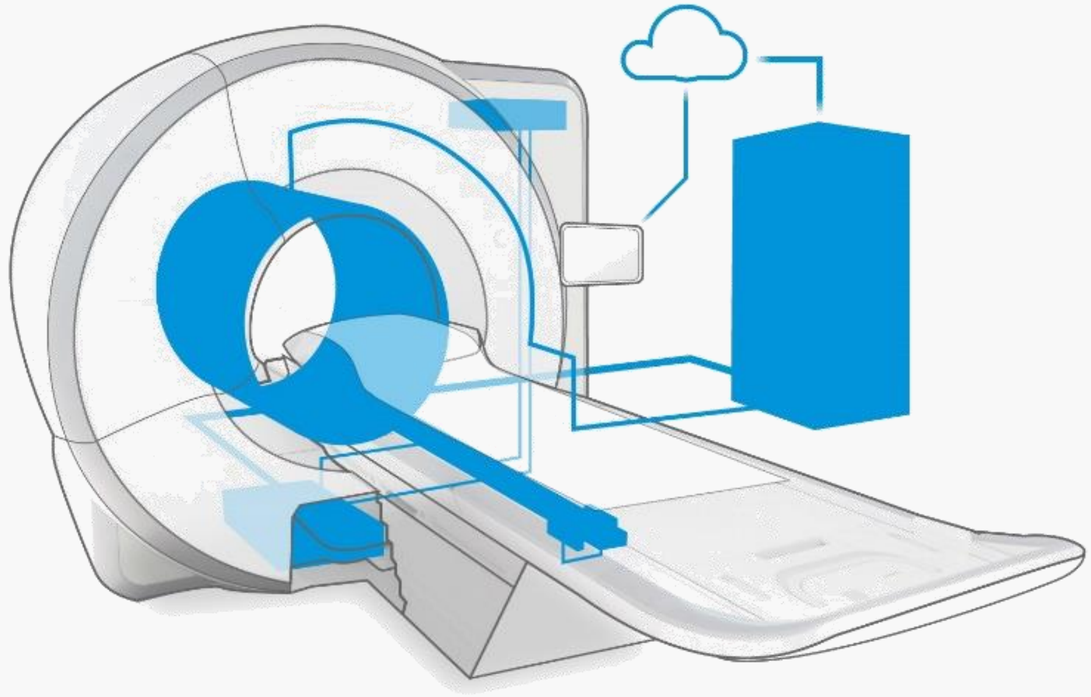
NG Tool Suite
- *Graphical HMI*
- *NG-products supported*
- *Remote diagnostics*

NEW

Energy consumption



Focus of Prodrive



Source: Dr Constantin Herrmann Annekristin Rock. March 2012. Magnetic resonance Equipment (MRI) - Study on the potential for environmental improvement by the aspect of energy efficiency

Developments in sustainability

Magnet

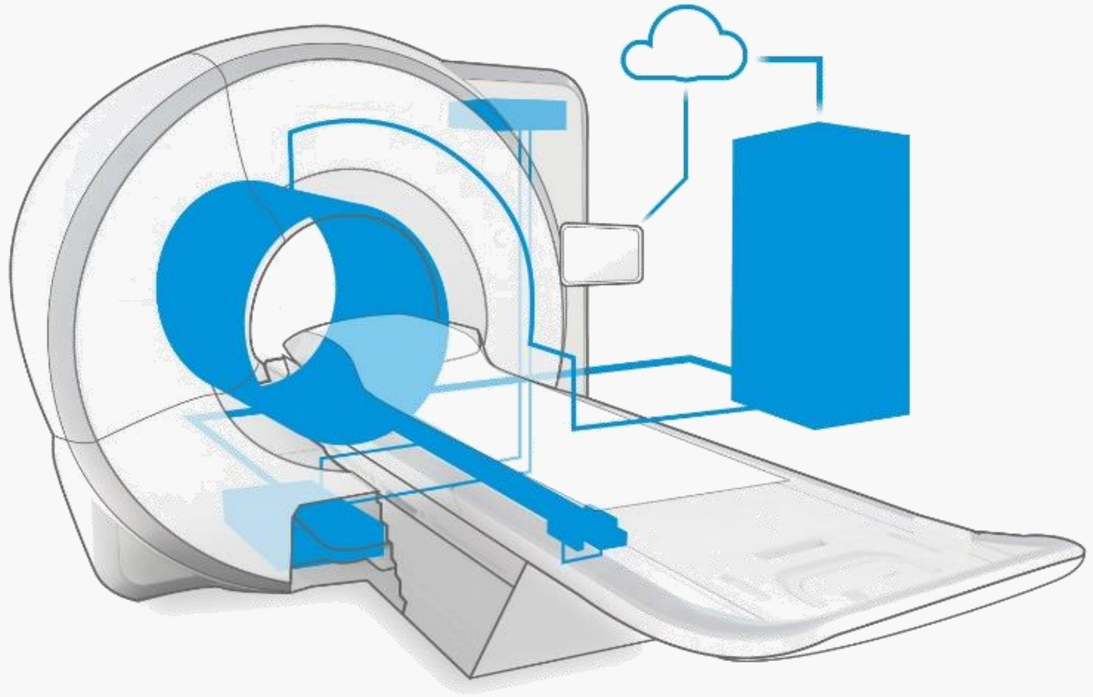
- Low helium systems
- Cooling system optimizations
- New super conductor material (NbTi → MgB2)

Gradient

- SiC MOSFET based gradient amplifiers
- Variable speed coolant pump
- Variable bus voltage

Reconstruction

- Artificial intelligence
- …



From IGBTs to SiC MOSFETs

Current Gradient Amplifier of Prodrive (NG2250-XP)

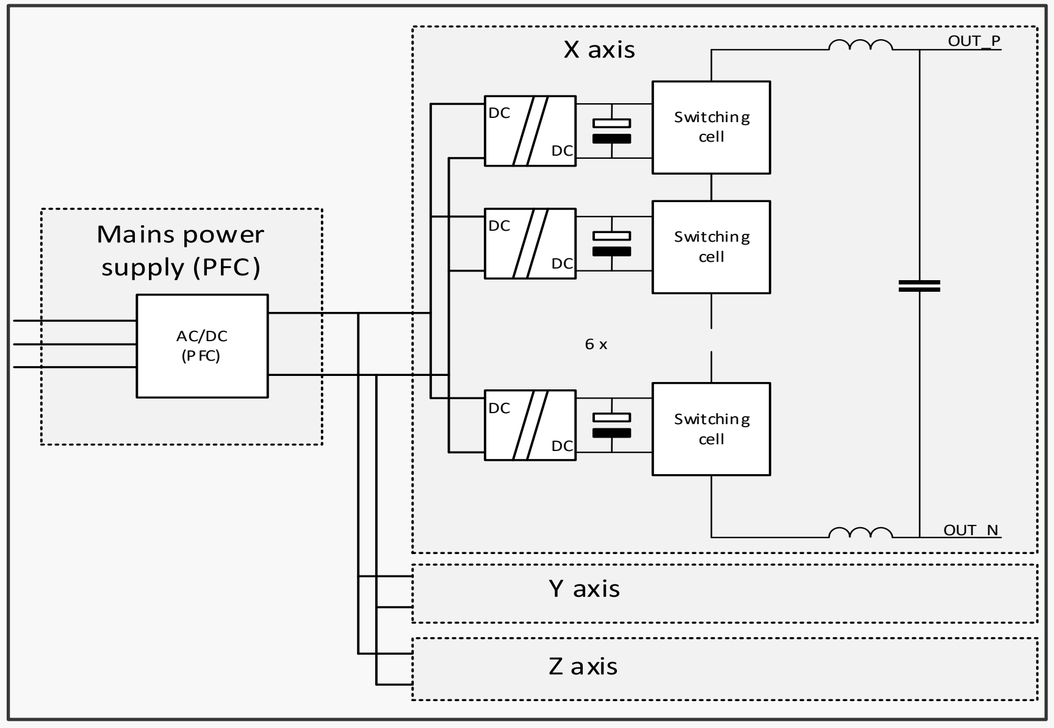
- Stacked H-Bridge cells
- Series interleaving
- Si IGBT modules

New amplifier (NG SiC)

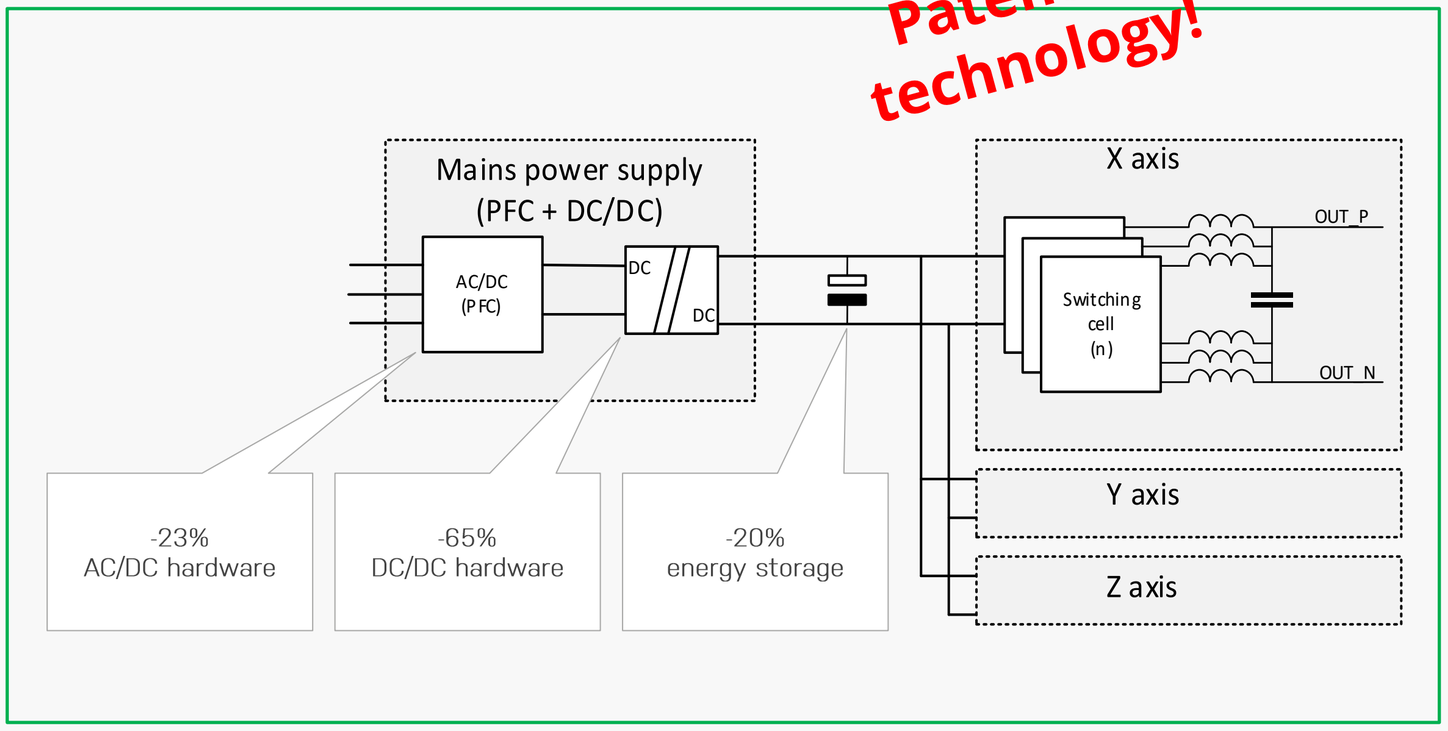
- Multi-level FC cells **(shared DC-bus)**
- Series + parallel interleaving
- SiC MOSFETs

Benefits

- Energy efficiency
- Reduction of energy storage hardware
- Controlled current sharing over paralleled MOSFETs
- High speed control



Patented technology!



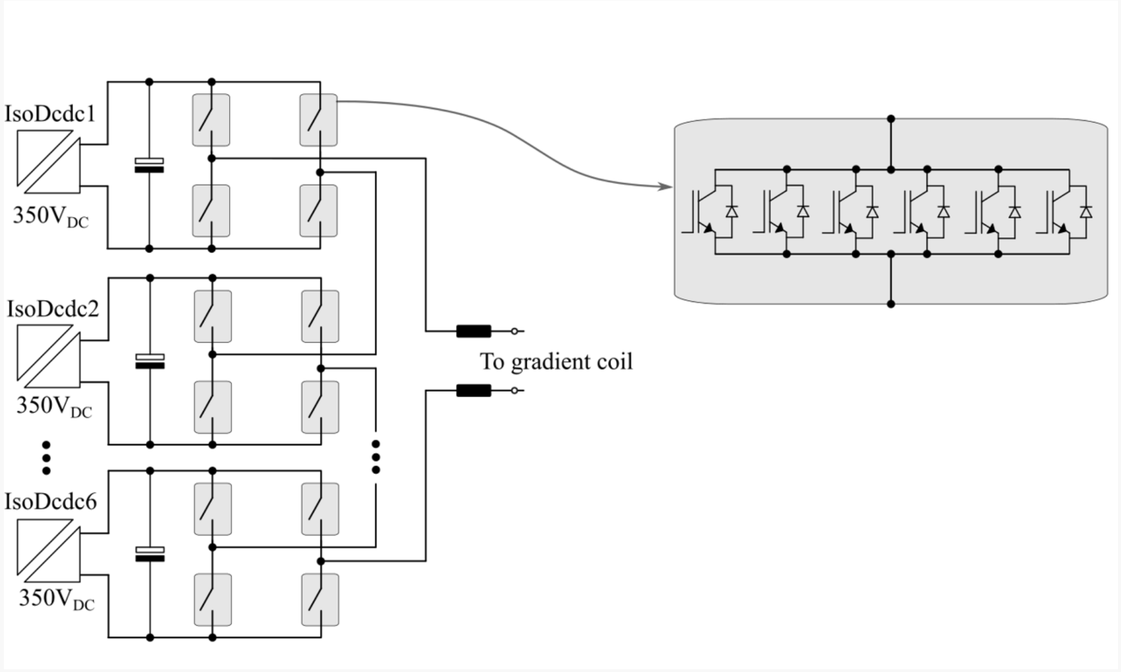
Benefit of the new NG SiC topology

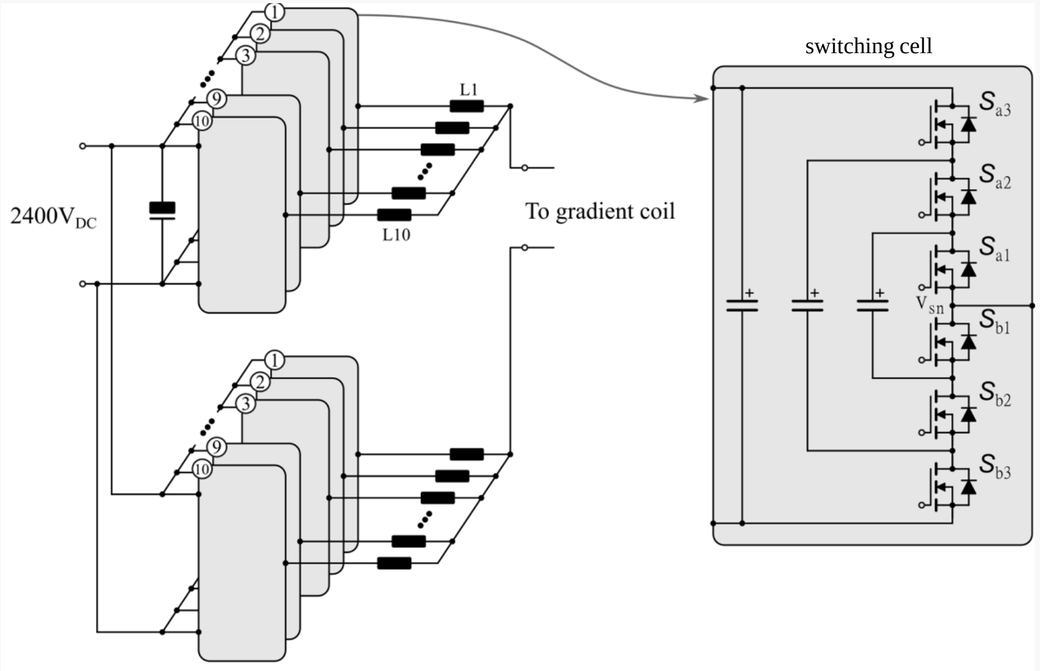
Current amplifier (NG2250-XP)

- IGBT switches
- Single path for the current
- Current sharing depends on device characteristcs

New amplifier (NG SiC)

- SiC MOSFET switches
- Parallel branches
- Current sharing accurately controlled

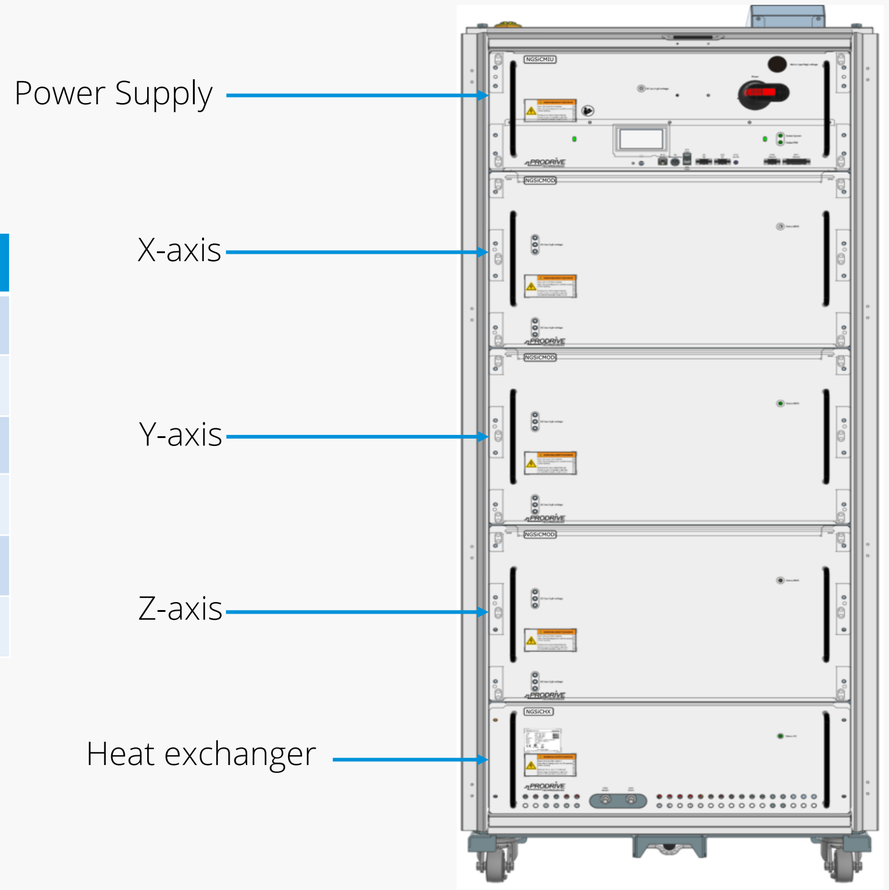




Integrated gradient amplifier cabinet

NG SiC Amplifier cabinet target specifications:

Parameter	Value	Unit	Notes
Output current	1250	[A]	Peak current
Bus voltage	2500	[V]	Shared among axis
MVA rating	3.0	[MVA]	Peak output voltage x peak output current
Mains input power	90	[kW]	380-480V 50/60Hz with PFC
Output power	60	[kW]	Per axis, or combined power of 3 axis.
Control bandwidth	50	[kHz]	Closed-loop (feedback)



Energy Efficiency (Si IGBT+Diode vs SiC MOSFET)

NG SiC Amplifier improved efficiency:

- Factor 2 .. 3 reduction of energy loss compared to IGBTs
- Specifically for low currents

Cost benefits:

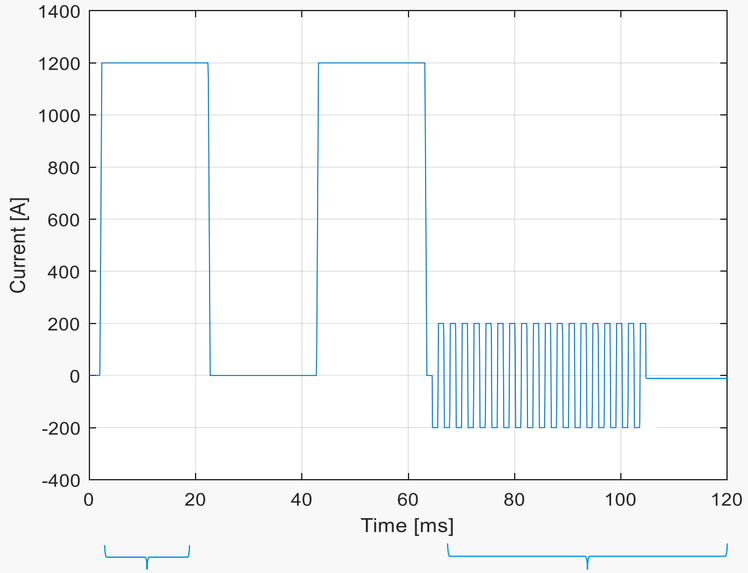
- Smaller power supply
- Smaller capacitor bank

Hospital benefits:

- Potential energy saving: **41 MWhr/yr (!)**

Insight:

- Majority of the time the current < 200A.
- Low current efficiency is critical.

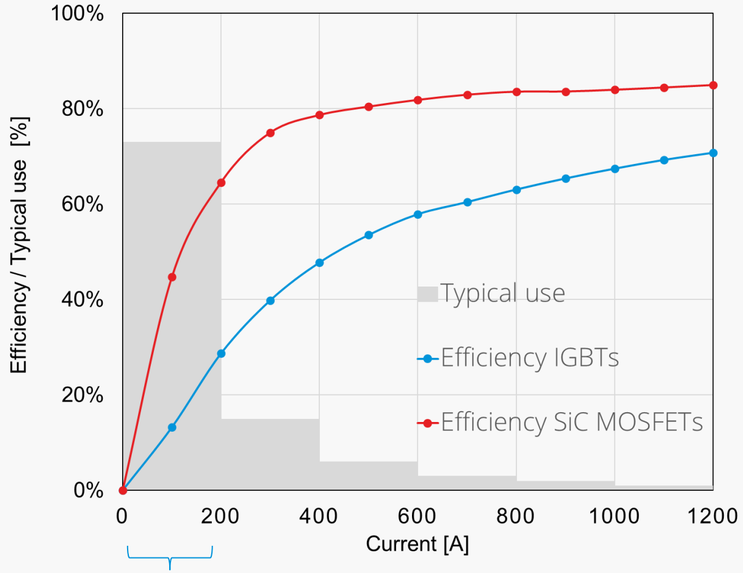


High current

~Factor 2 reduction of losses

Low current

~Factor 3 reduction of losses



75% of the time

Current < 200A

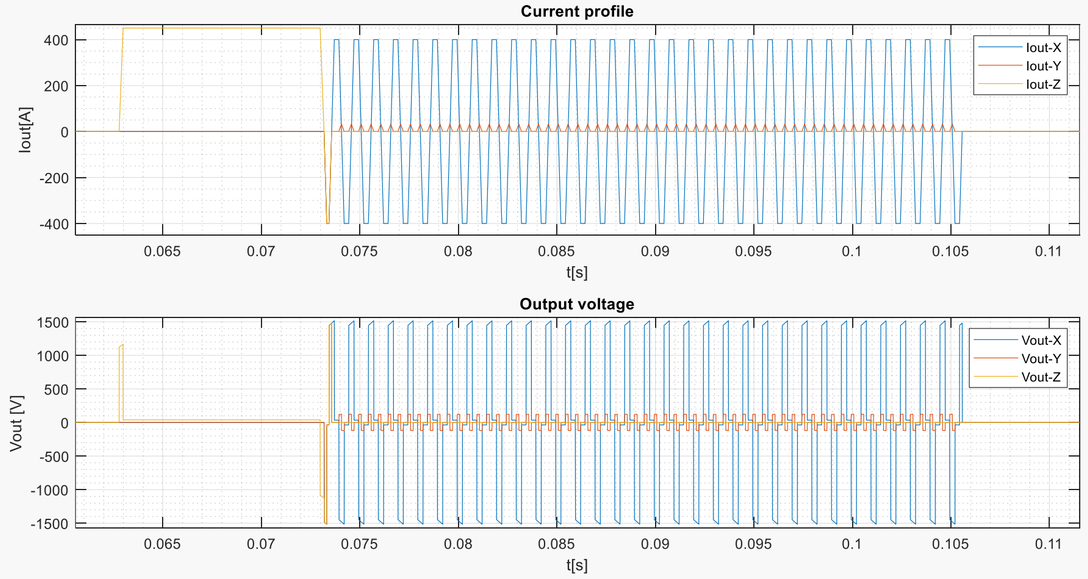
Notes:

- *Efficiency is determined using a highly efficient, low-ohmic gradient coil*
- *Comparison is based on an NG2250-XP (IGBT based) gradient amplifier*

Software feature: Variable bus voltage

Benefits

- Power loss reduction
- Reliability improvement
- 30% loss reduction



Test profile:

- 400A peak EPI
- 145Arms average
- 1500V on the gradient coil

Bus voltage	Gradient amplifier losses
2500 V	8.5 kW
1800 V	6.0 kW

-30%!

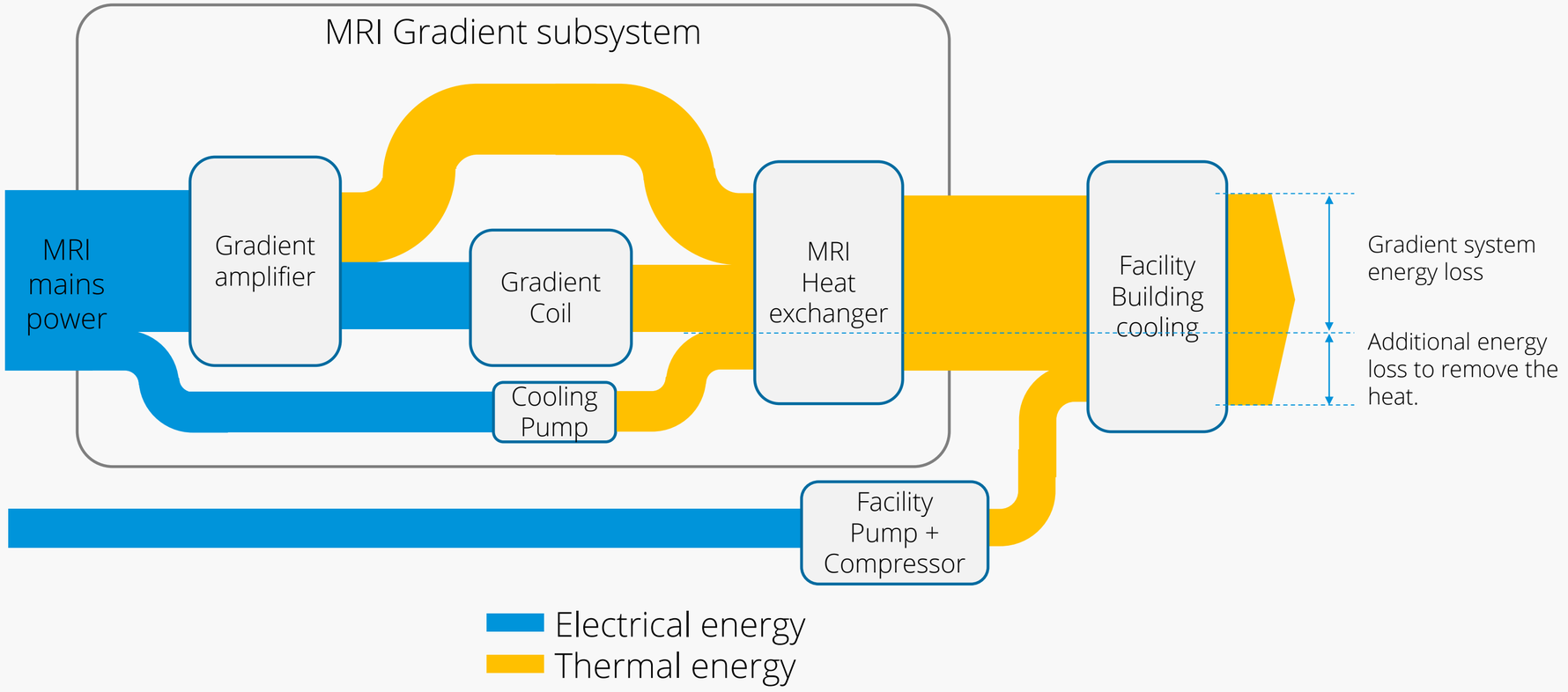
Software feature: Variable coolant flow

Variable coolant flow:

- Gradient amplifier software feature
- Reduce cooling pump speed at low-load conditions

Estimated savings: 16 MWhr/yr (!)

- Additional savings in building cooling pump + compressor

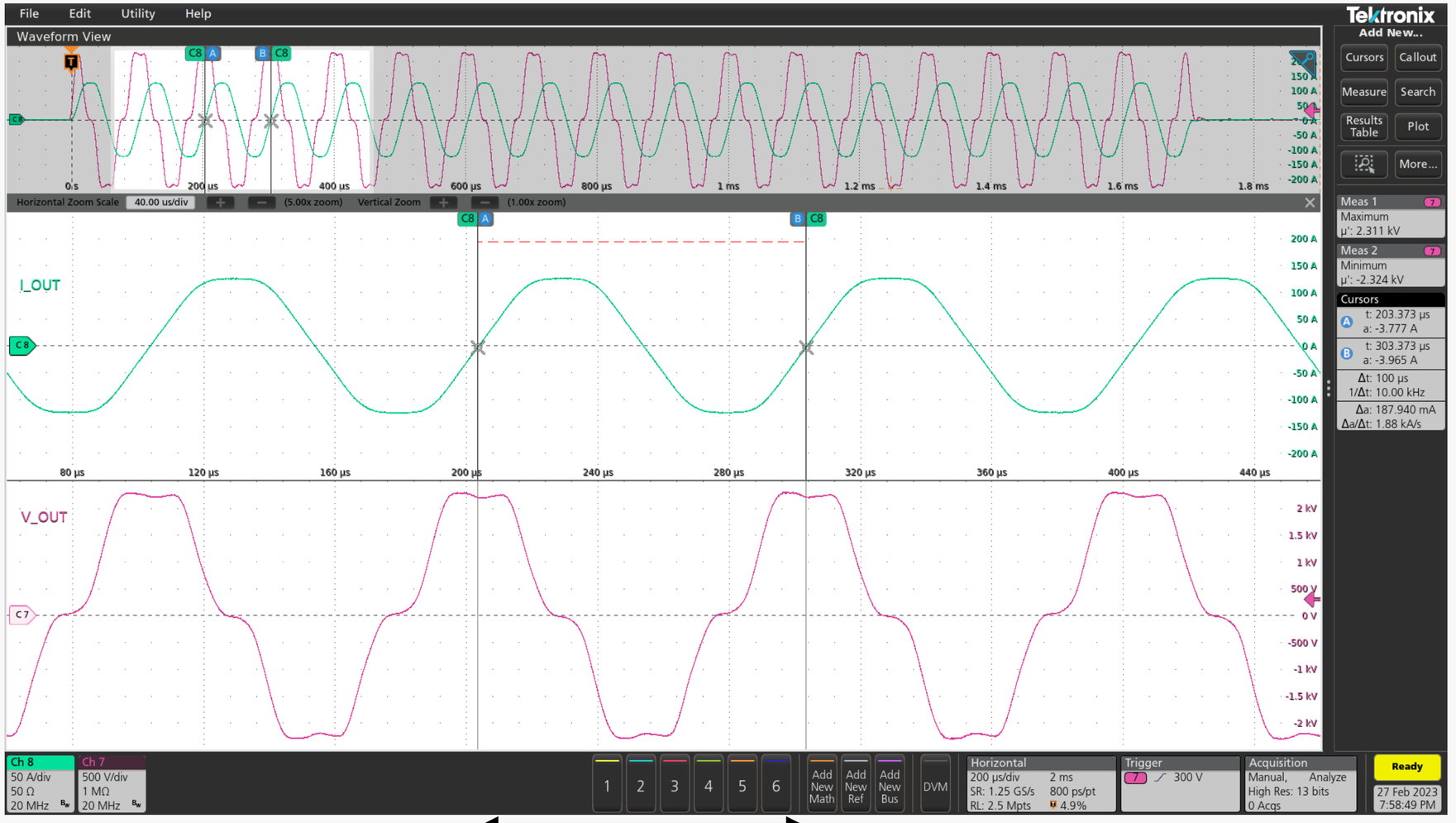


Note: Comparison is based on throttled fixed frequency pump that is 50% of the time on.

Silent MRI with near-ultra-sonic EPI

10kHz EPI waveform

Application:
Silent MRI system as demonstrated by UMC Utrecht



NG SiC Test Results

NG SiC Amplifier axis tests

- ✓ – **3MVA** Peak current, peak voltage
- ✓ – Short rise-time
- ✓ – Fidelity / reproducibility
- ✓ – Current Settling
- ✓ – Continuous RMS Current (**400Arms**)
- ✓ – Single pulse capability
- ✓ – Closed-loop control bandwidth (**50kHz**)
- ✓ – High frequency EPI **(10kHz !)**

NG SiC MOSFET Amplifier
(single axis)

NG SiC Test Results

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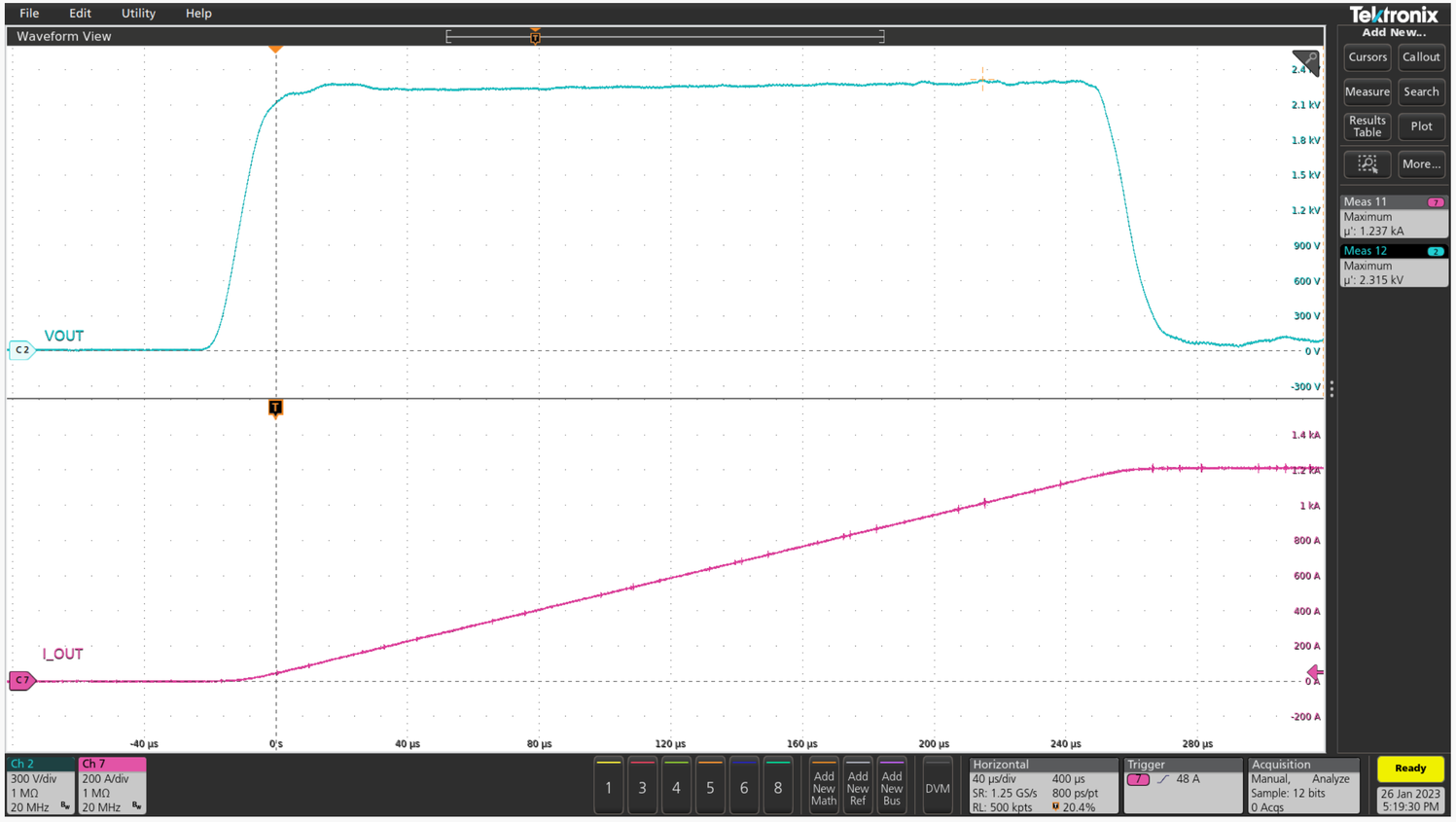

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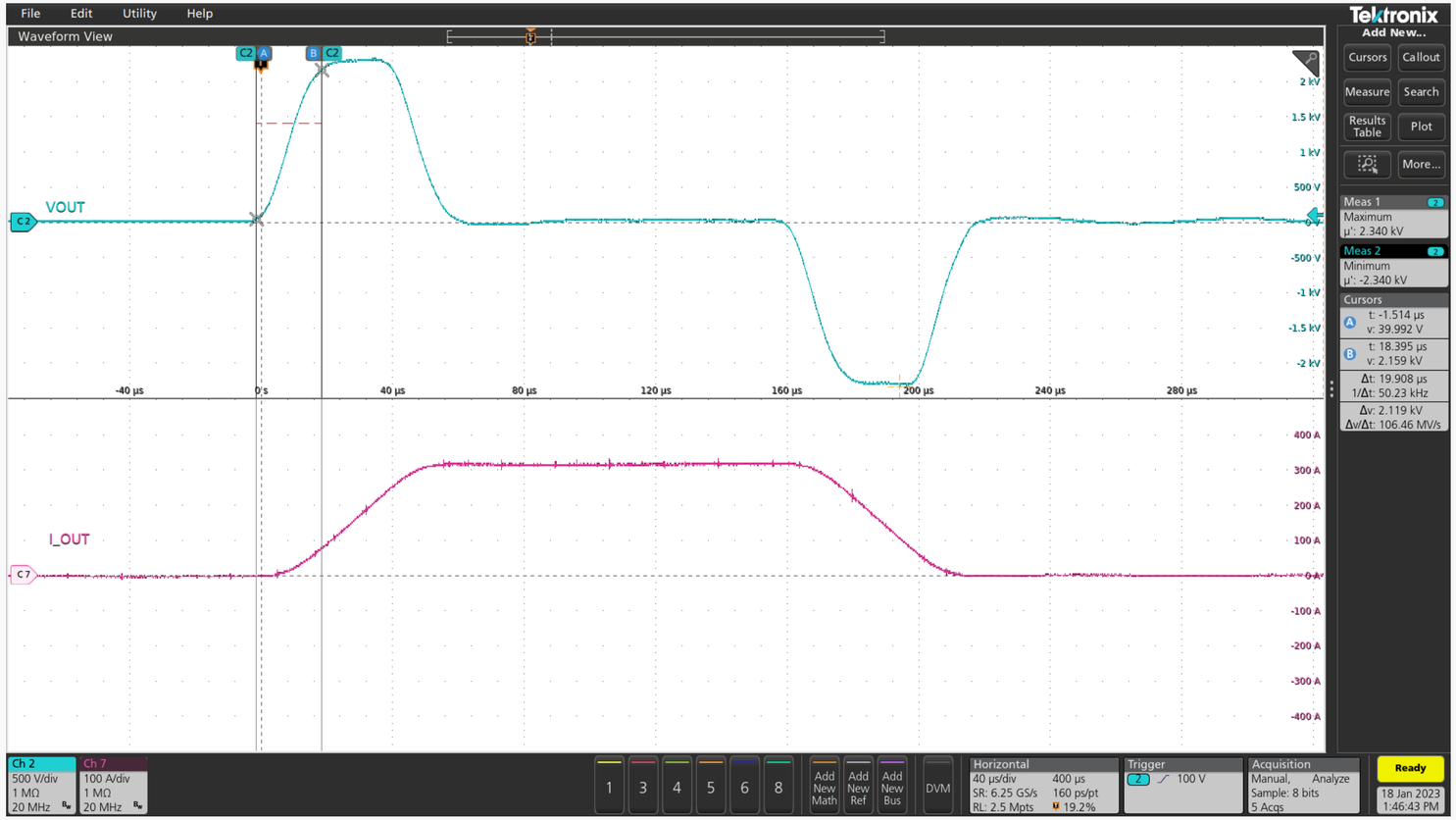

Current rise-time = **40us**
Voltage rise-time = **20us**

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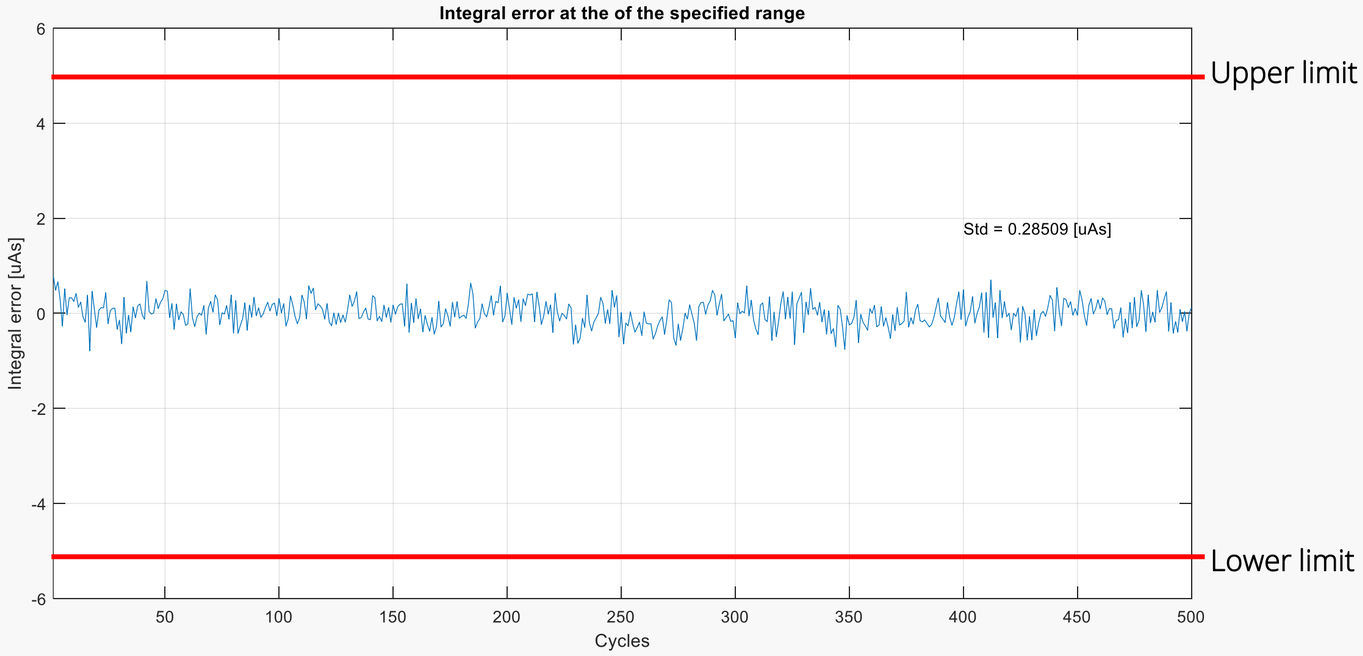

Exceptional gradient stability!

NG SiC Test Results

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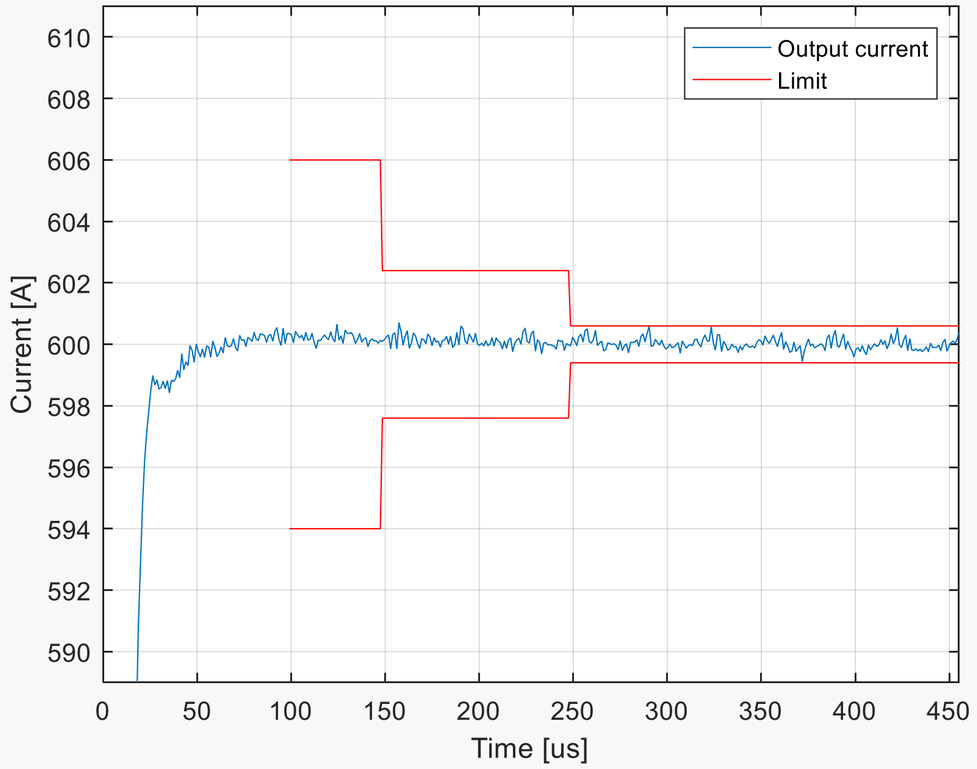

Very fast and stable current settling

NG SiC Test Results

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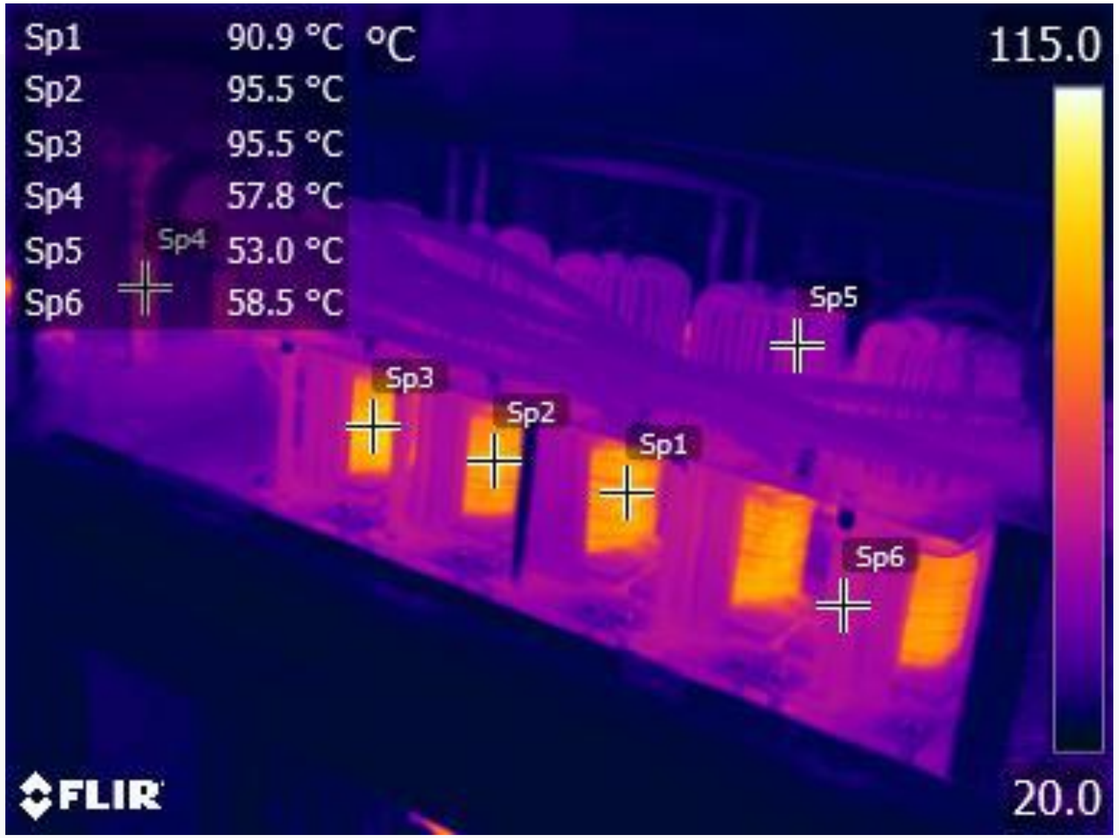

400A_{RMS} continuous operation.

NG SiC Test Results

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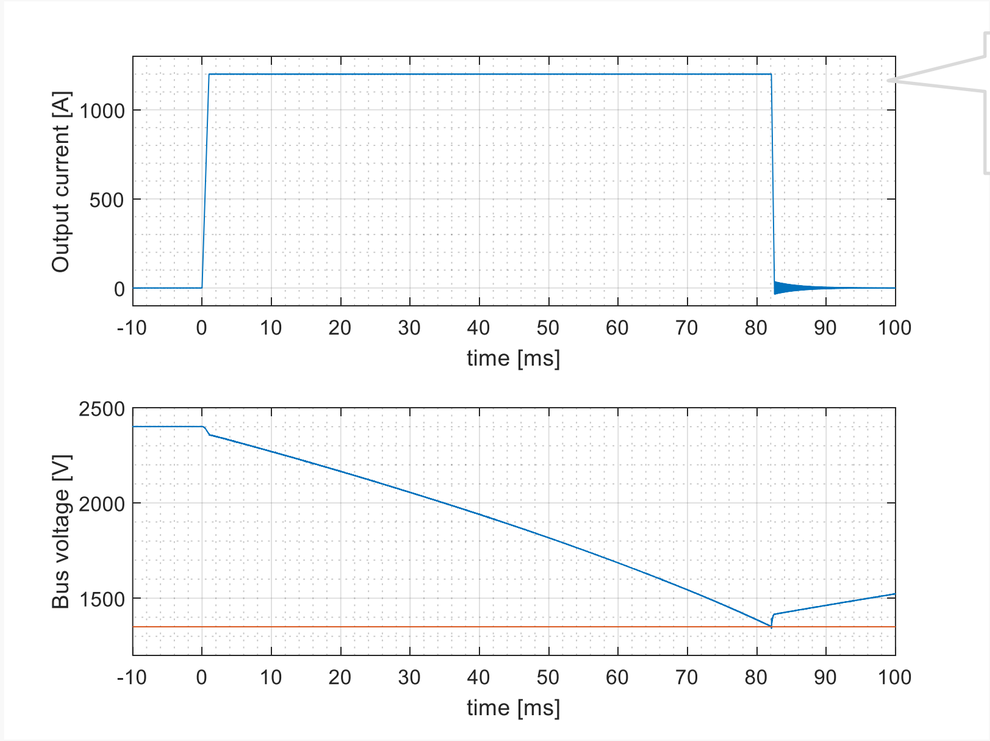

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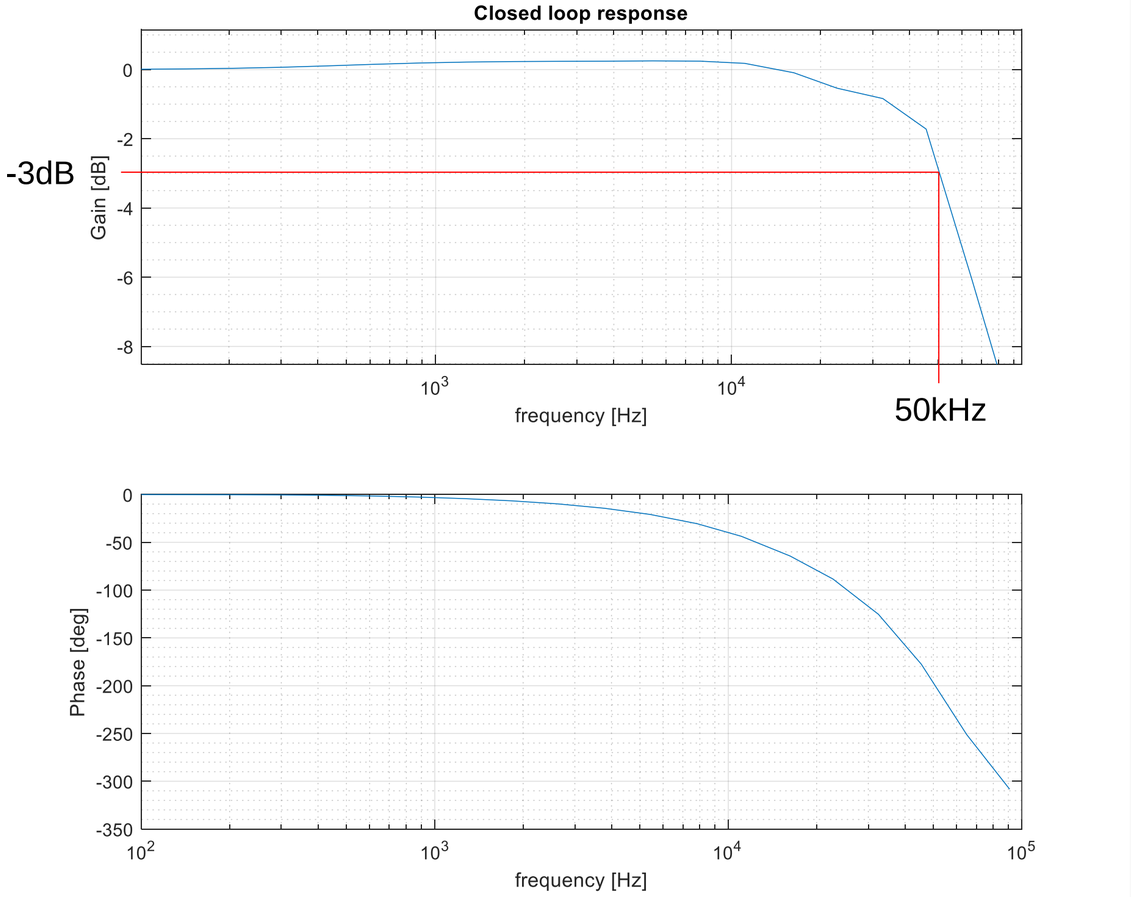

Closed-loop -3dB point at 50kHz!

NG SiC Test Results

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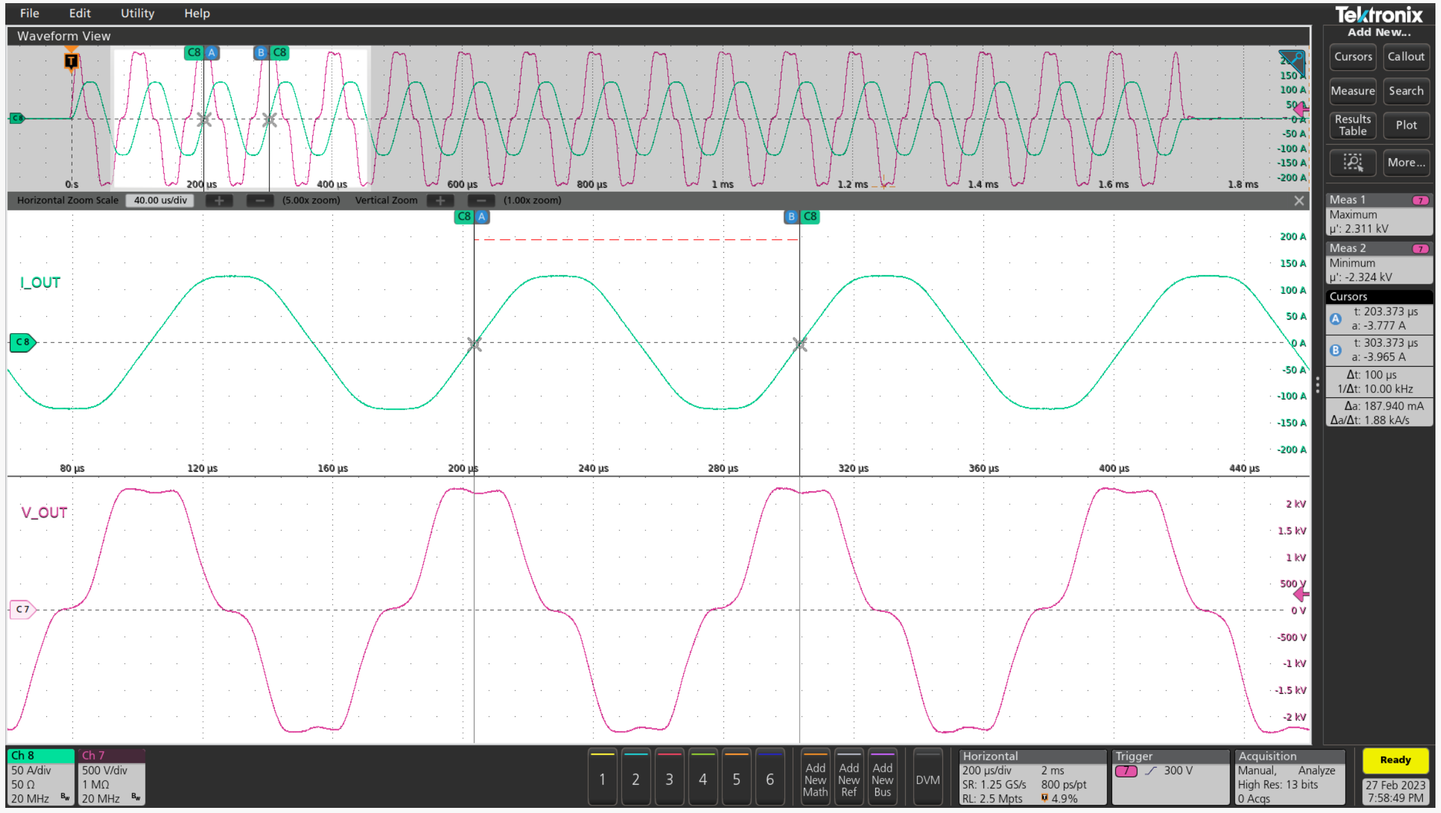
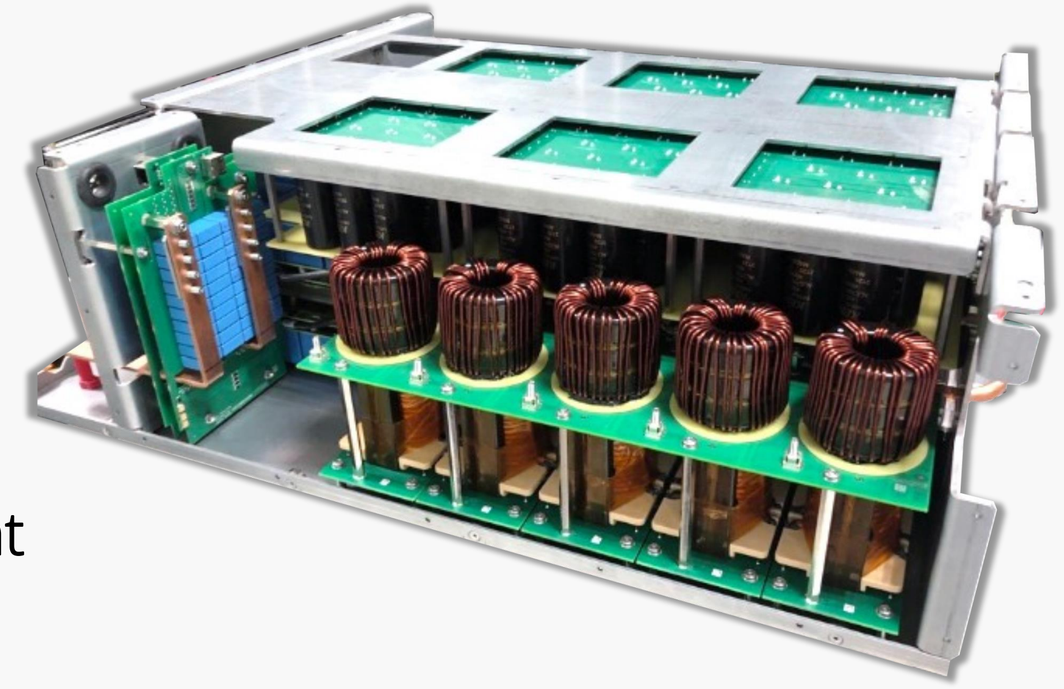


EPI at 10kHz for head insert gradient coils

Conclusion

- Significant **energy saving** when using SiC MOSFETs
- SiC MOSFET **price reduction** due to BEV
- A **new power topology** is required with SiC MOSFETs for accurate **current sharing**
- Superb gradient **stability** and **speed**. Enables **silent** MRI scanning.



Questions?

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