# Compact, lightweight and cost-effective high-voltage motor control inverter with GaN

*Ester Spitale*
*Technical Marketing Manager*
*STMicroelectronics*

**Bodo's Wide Bandgap Event 2025**

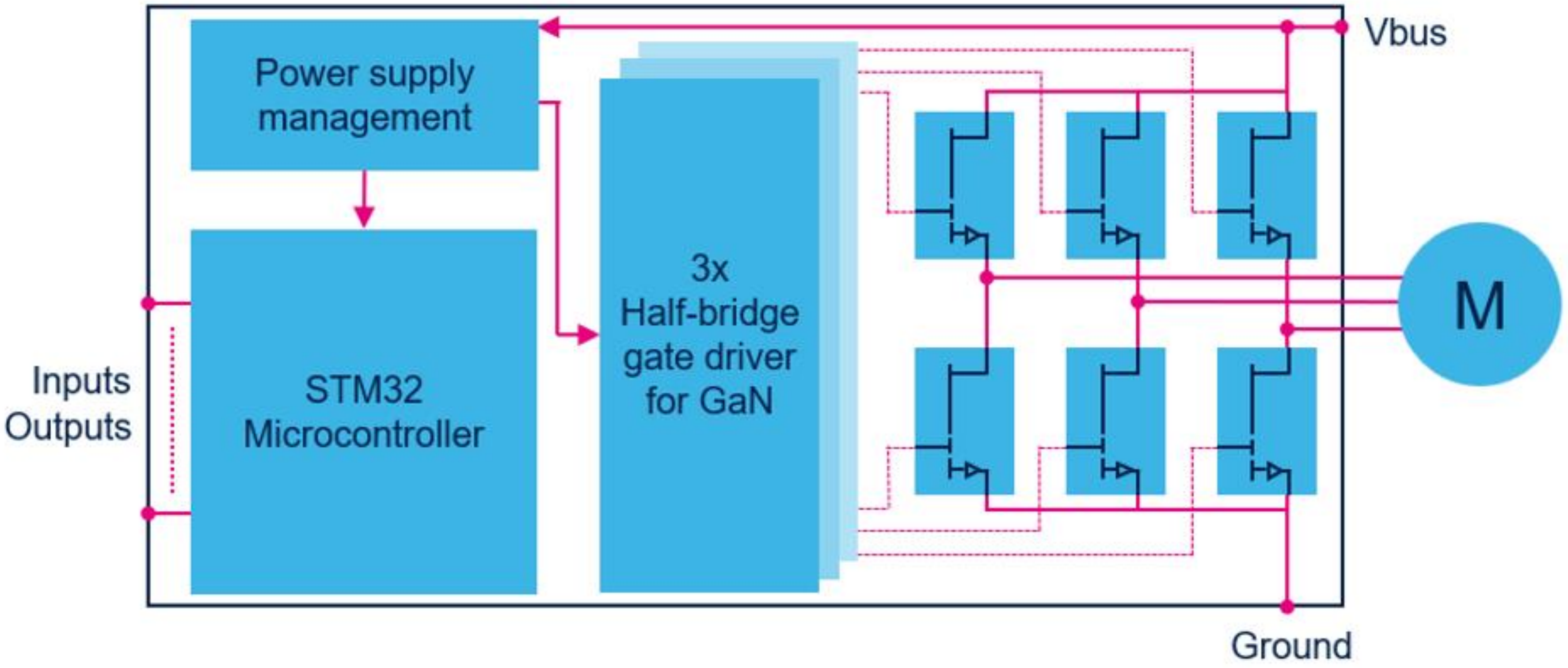
*Making WBG Designs Happen*

GaN

# Agenda

# GaN in a Motor Inverter: Washing Machine Use Case

# Motor Control Power Inverter with GaN
## Simplified Block Diagram



# Used Inverter
## 1kW, GaN Based

### Activity details

- Based on **PowerFLAT 8x8 mm** PowerGaNs + GaN Drivers
- Complete Inverter including power supply and EMI filter, designed on a **2-layer PCB, 35µm Cu Thickness**
- **Operates with passive cooling only, without a heatsink**
- Compatible with the latest ST FOC feature: high sensitivity observer, for very low speed operation in sensorless mode

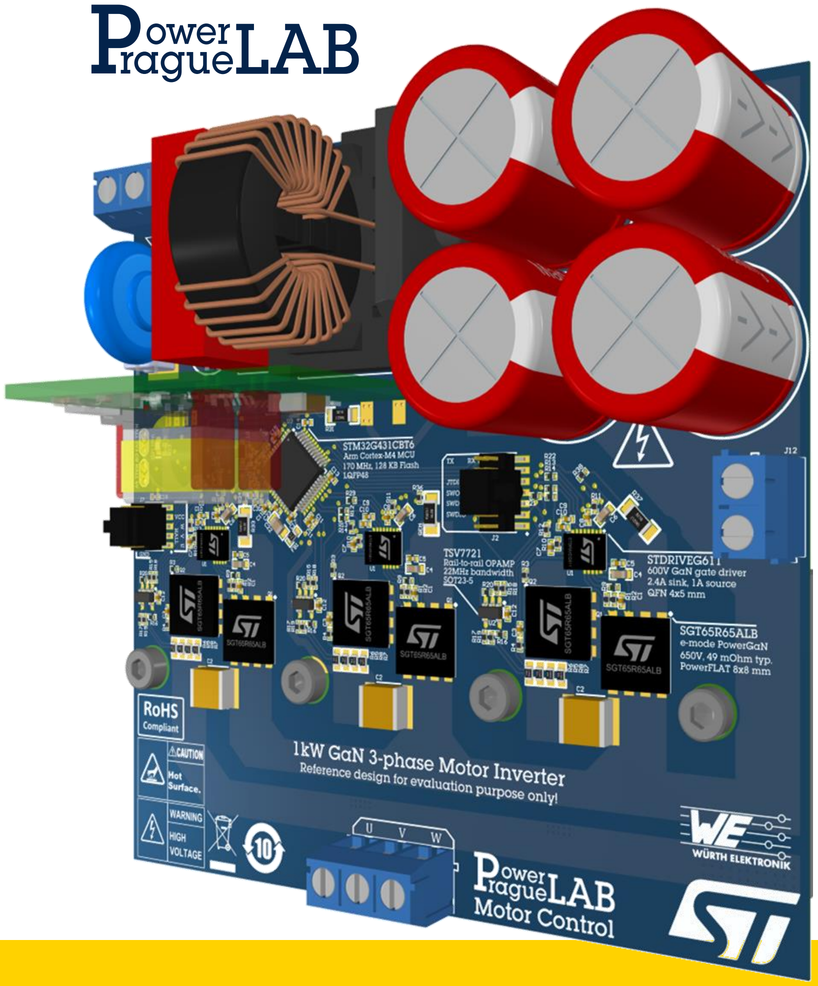
**SGT080R70ILB PowerGaN**
700 V, 60 mΩ typ.
PowerFLAT 8x8 mm

**STDRIVEG611 GaN Gate Driver**
600 V, 350/200 mA sink/source

**STM32G431 MCU**
170 MHz M4 core,
LQFP48 package

**VIPer06 Flyback Controller**
800 V, 60 kHz

**TSV7721 OpAmps**
High bandwidth – 22 MHz
Low offset – 200 µV



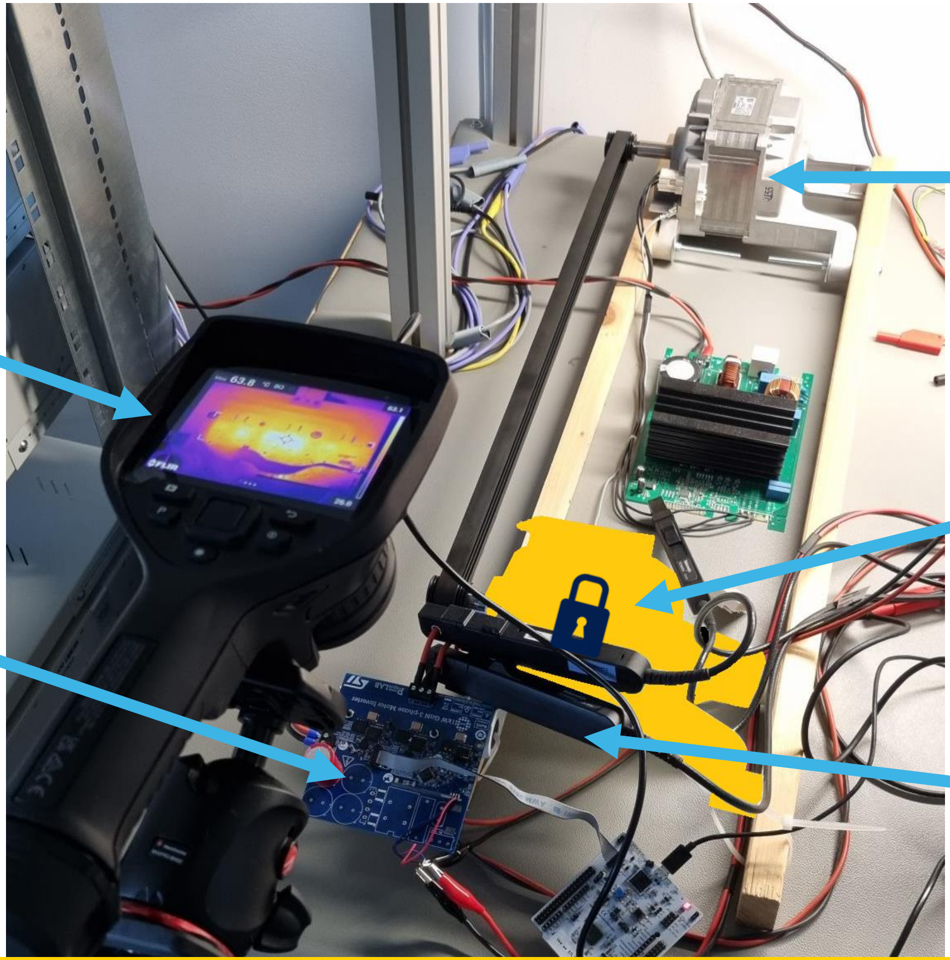
# Test Bench
## Washing Machine Motor Use Case

### Test bench

- A thermal camera was used to measure temperature without influencing the results
- A **washing machine motor** was connected to another washing machine motor used as a brake, with energy recuperated via a bidirectional power supply
- TCP0030A oscilloscope current probes were used to measure phase current

Thermal camera

GaN Inverter



Load motor (brake)

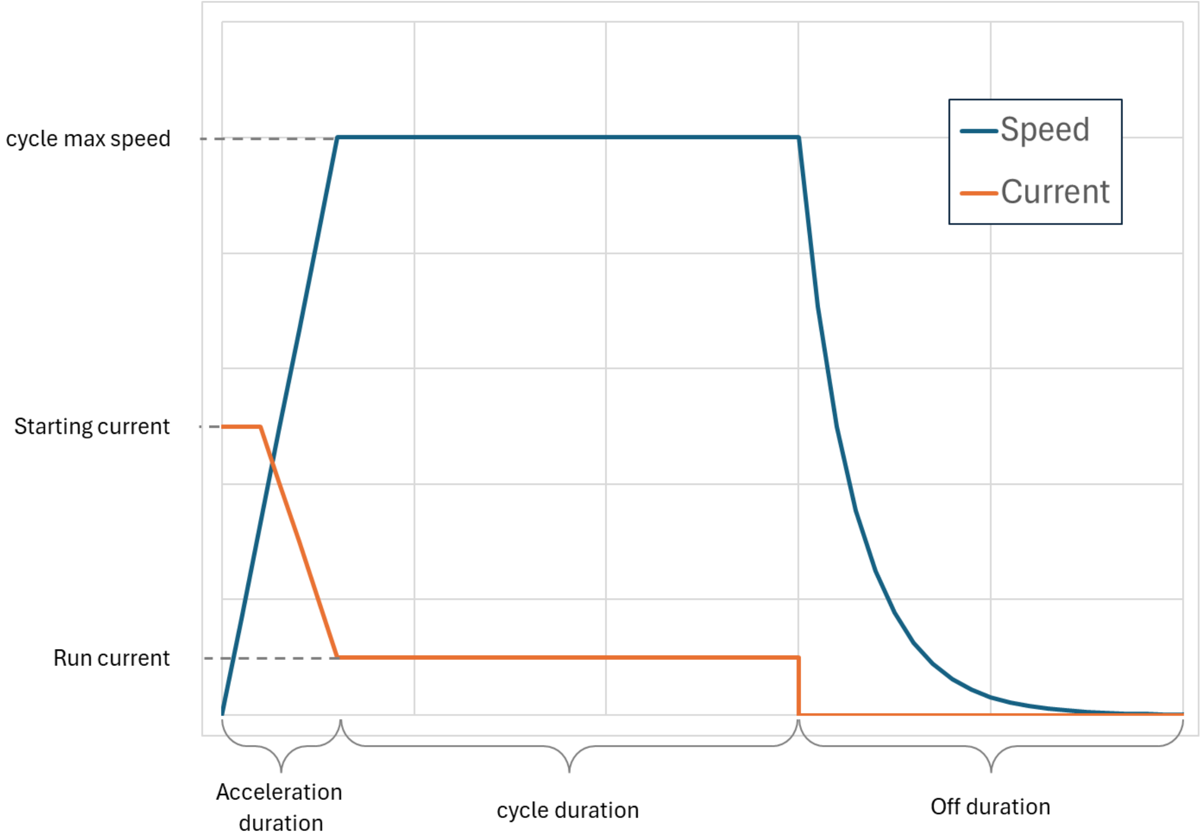
Motor under test

Current measurement

# Mission profile
## Washing Machine Motor Use Case

- Motor speed was set to 640 RPM (rinse cycle), but this parameter doesn't have big influence on thermal behavior of the inverter

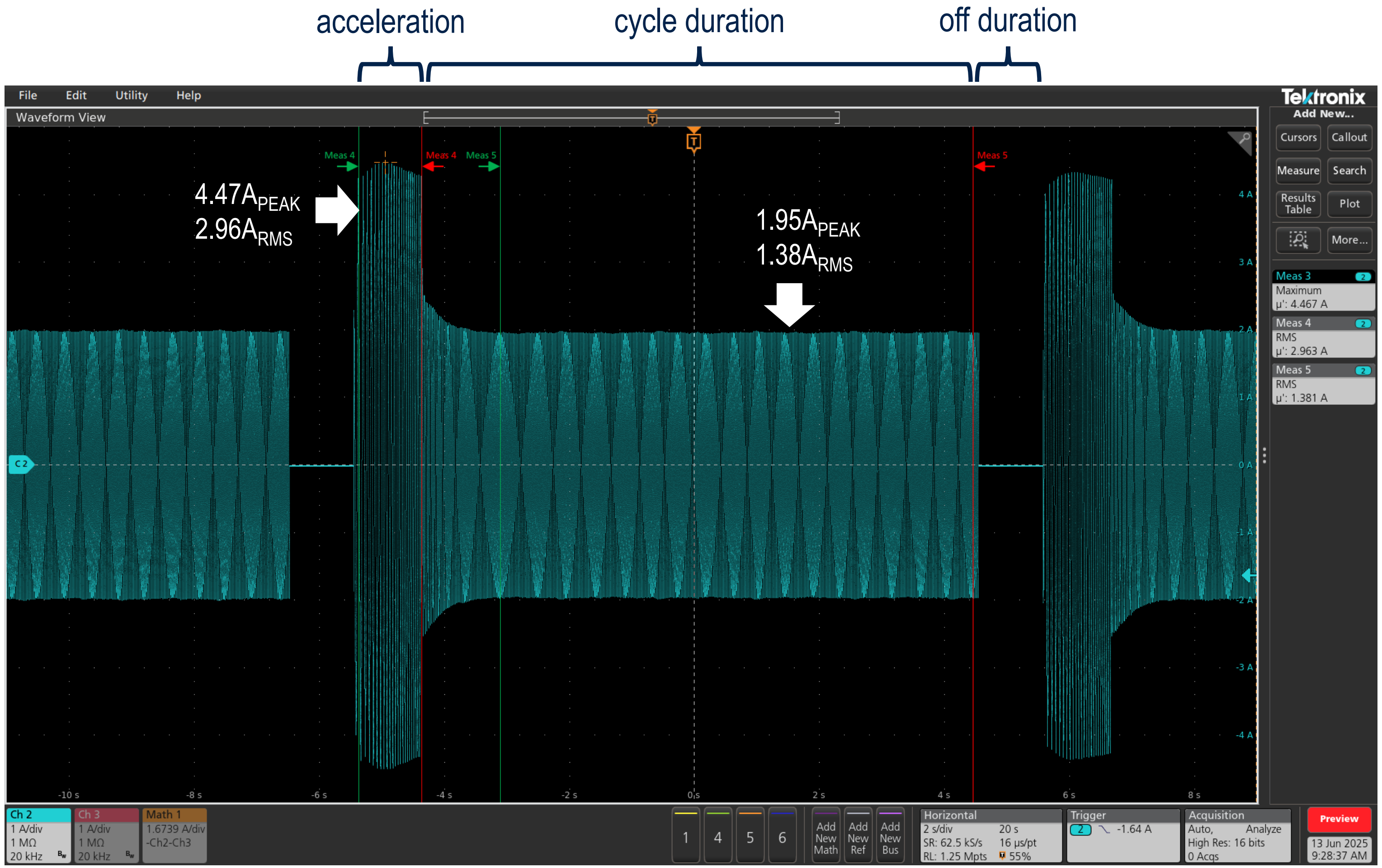
| Mission Profile | |
|---|---|
| Starting current (A) / ($A_{RMS}$) | 4.2 / 2.97 |
| Starting current duration (s) | 1.3 |
| Run current (A) / ($A_{RMS}$) | 2.0 / 1.41 |
| Cycle max speed (Motor RPM) | 640 |
| Acceleration duration (s) | 1.13 |
| Cycle duration (s) | 10 |
| Off duration (s) | 1 |



# Mission profile

- Applied mission profile closely matches requirements
- After each cycle, the motor's rotation direction was reversed
- The defined cycles were continuously repeated for a duration of one hour

| Mission Profile | |
|---|---|
| Starting current (A) / ($A_{RMS}$) | 4.2 / 2.97 |
| Starting current duration (s) | 1.3 |
| Run current (A) / ($A_{RMS}$) | 2.0 / 1.41 |
| Cycle max speed (Motor RPM) | 640 |
| Acceleration duration (s) | 1.13 |
| Cycle duration (s) | 10 |
| Off duration (s) | 1 |

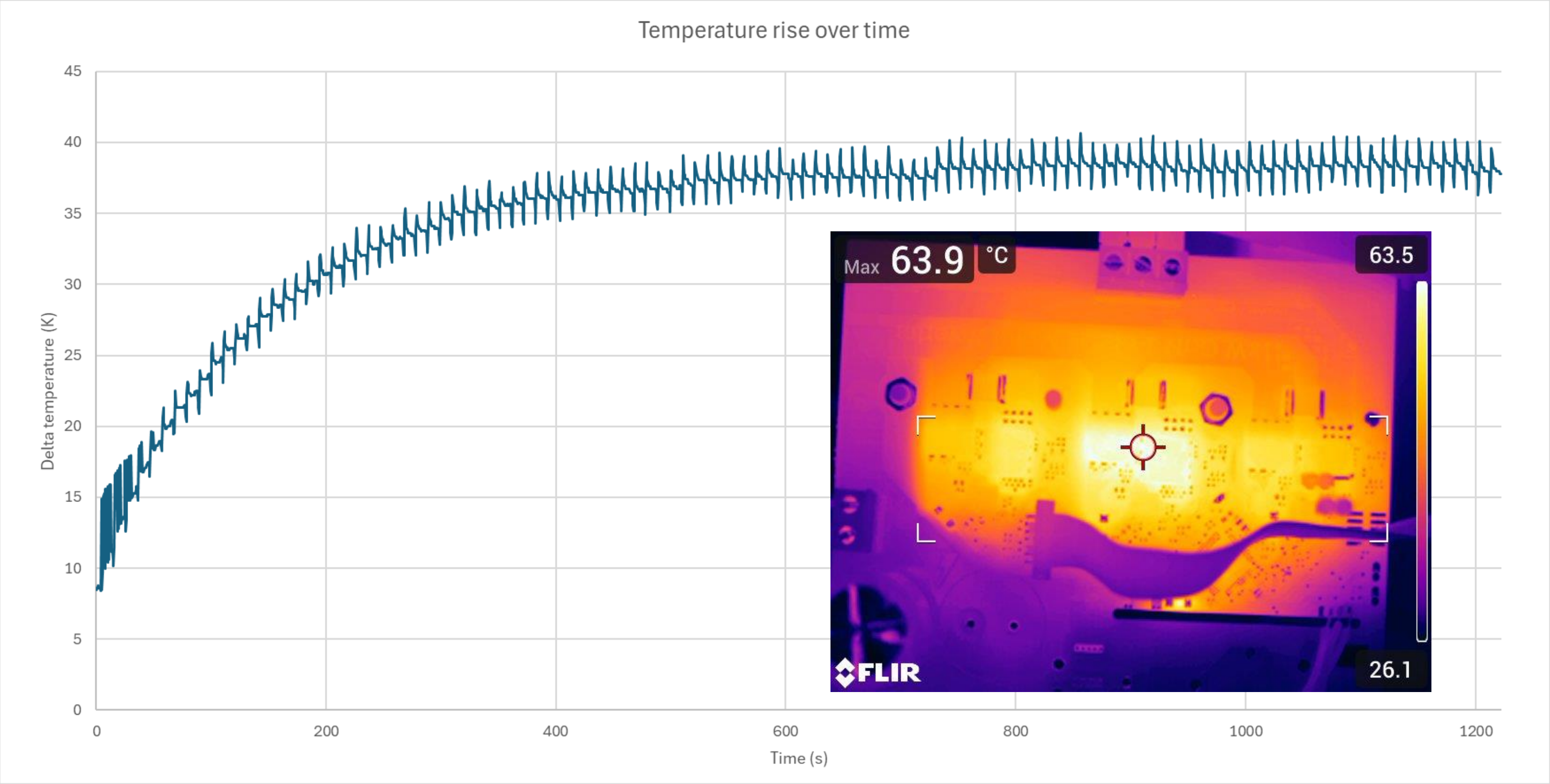


# Application Test Results

# Temperature measurements
## Washing Machine Motor Use Case

### Measurement results

- The inverter temperature stabilized after 10 minutes of operation.
- Temperature rise of the transistors was ~40 K in maximum
- Highest transistor temperature was 63,9°C @ 25,7°C ambient
- Temperature was sampled every 0,5 s and a camera effective resolution is 0,2°C.
- Thermal image shows the GaN inverter



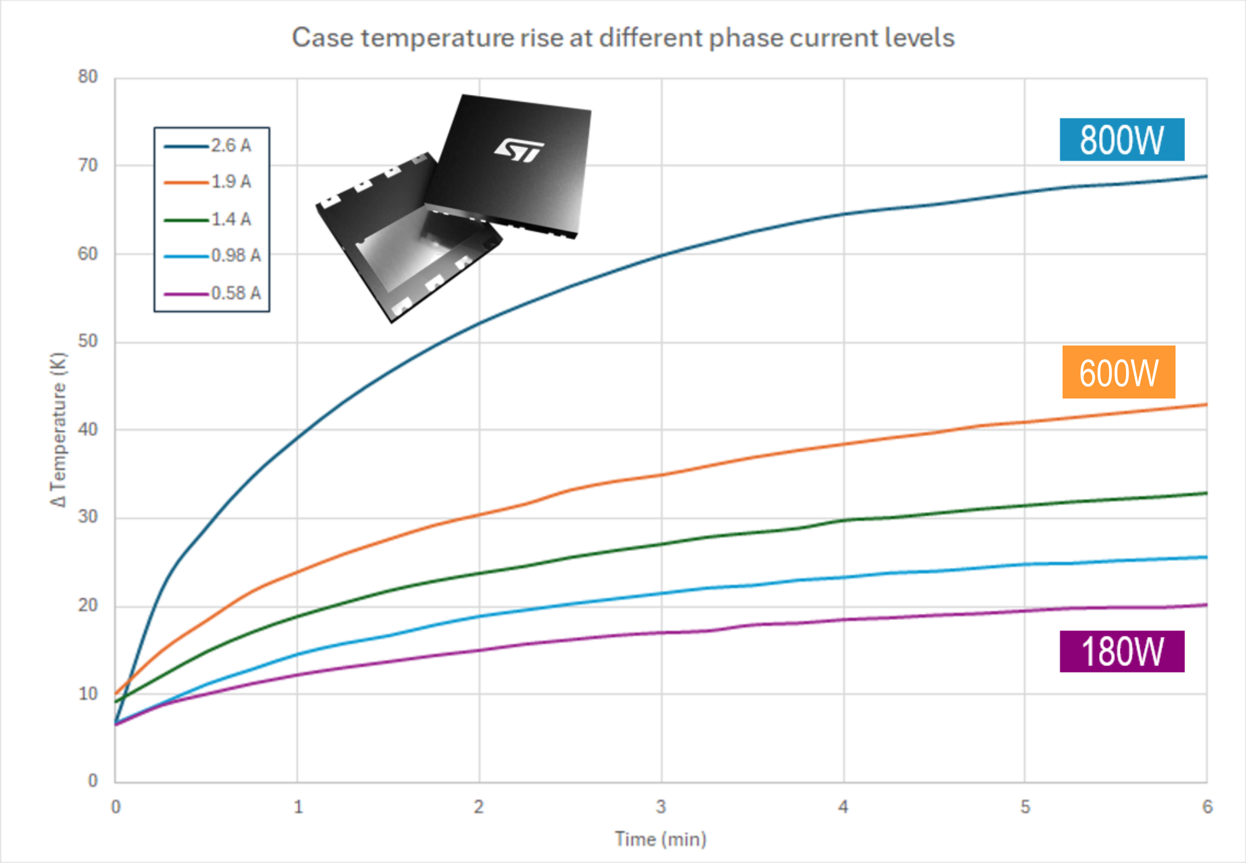

**2 LAYERS PCB WITH 35µm COPPER LAYERS**

# Temperature measurements
## Continuous Power

### Test Outcome

- Working at 800W brings in ΔT <70 C
- The inverter can work up to 600W without any form of heatsink (ΔT <45C )
- In the 200W-400W there is plenty of room to downsize the solution with either higher $R_{DSON}$ transistors (also with integrated solutions)

**HOW TO STRETCH FURTHER THE NO-HEATSINK SOLUTION AT HIGHER POWER?**

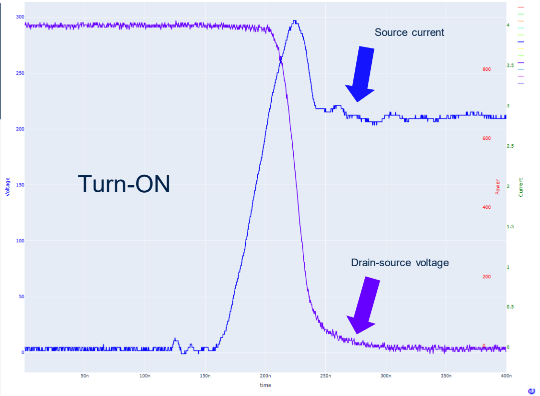


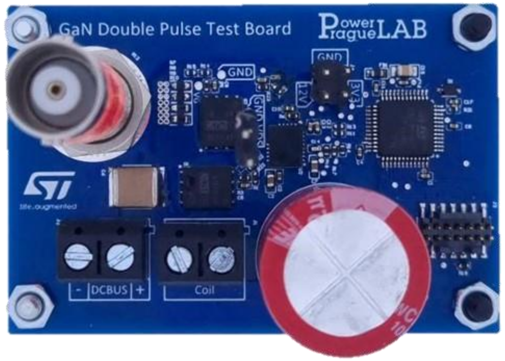
# Tips and Tricks to Maximize Efficiency

# Switching performance
## GaN transients in Motor Control

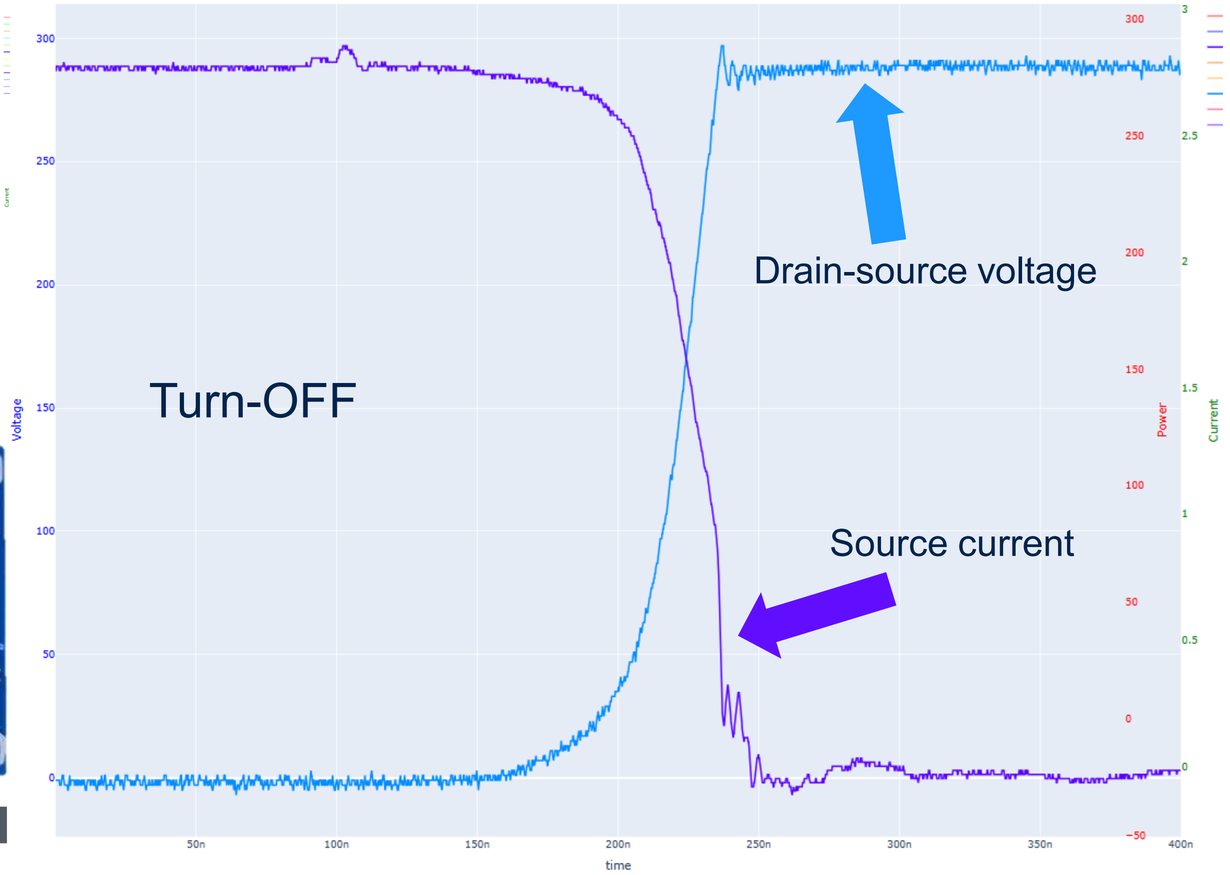
### Measurement conclusions

- Switching tuned to 10 V/ns
- Complete switching transient within 100 ns
- Tests performed on real setup with motor
- Switching of the GaN is very clean without major oscillations – beneficial for EMI performance
- Very minor $V_{DS}$ overshoot



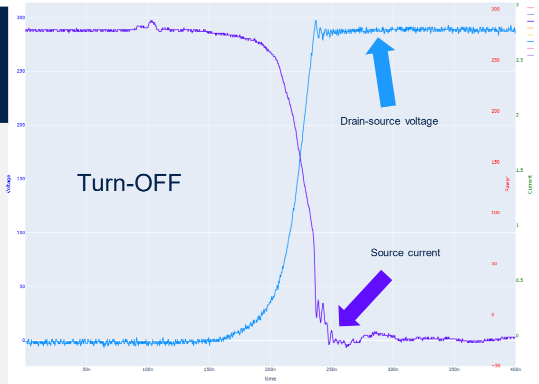

Double pulse test platform

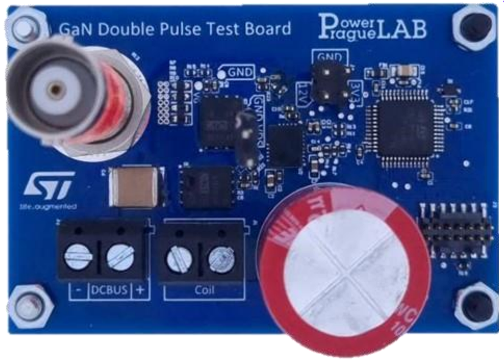


# Switching performance
## GaN transients in Motor Control

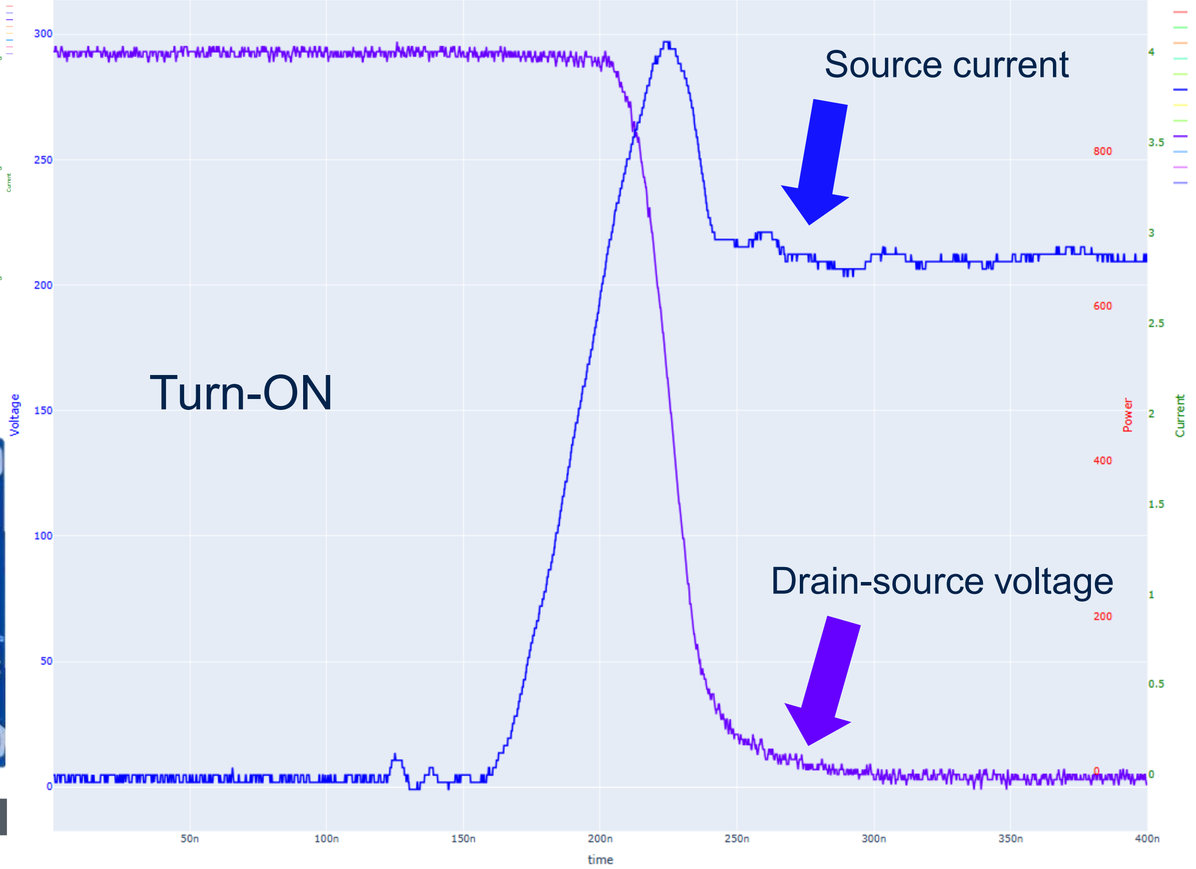
### Measurement conclusions

- Switching tuned to 10 V/ns
- Complete switching transient within 100 ns
- Tests performed on real setup with motor
- Switching of the GaN is very clean without major oscillations – beneficial for EMI performance
- Very minor $V_{DS}$ overshoot



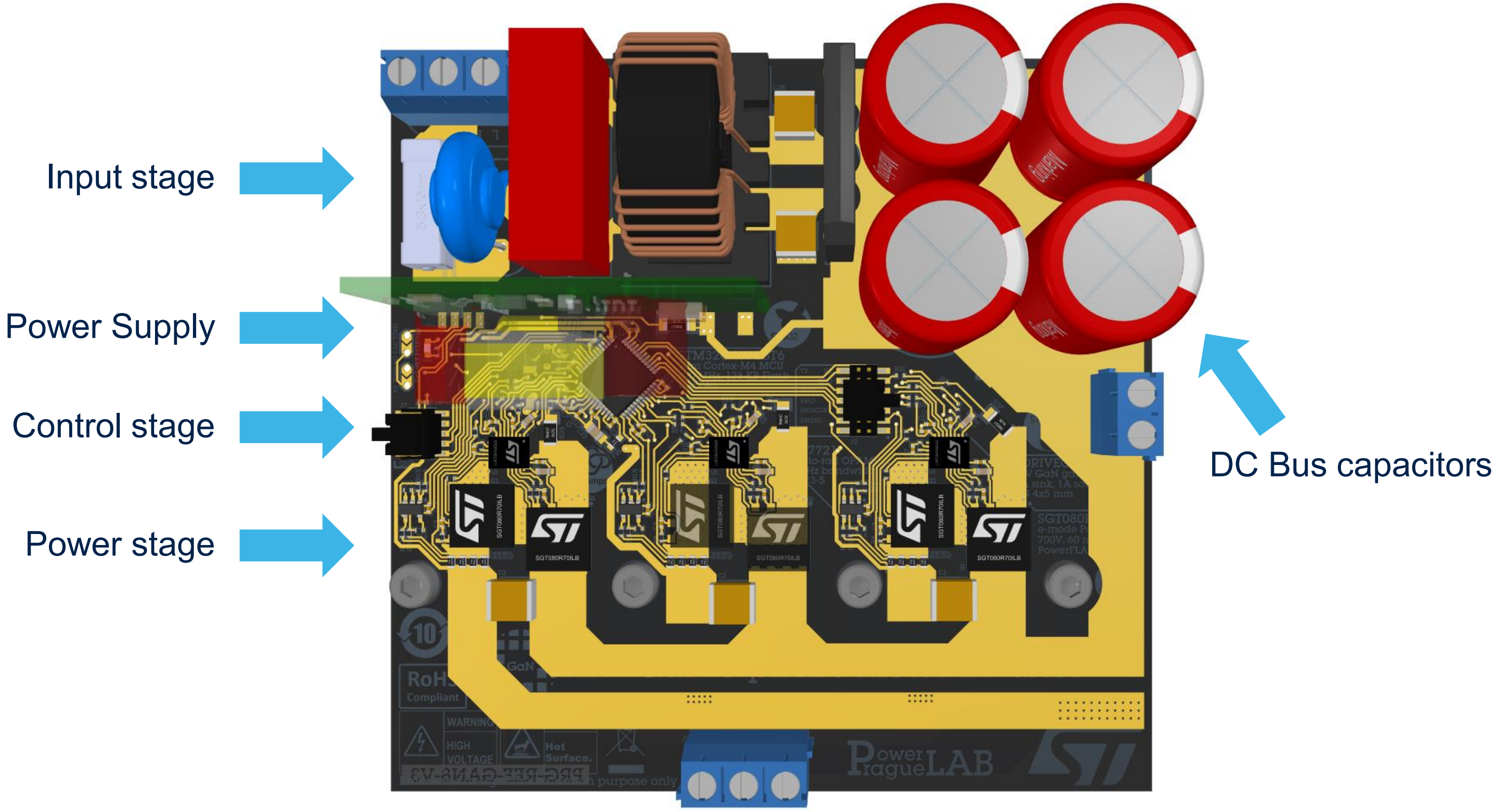

Double pulse test platform



# Layout considerations
## Minimal current loops

### Layout recommendations

- Goal is to have current loops as small as possible in terms of area
- Most important current loops:
    - Main commutation loop
    - Gate current loop
    - DC bus loop
- Important to have good quality ceramic capacitors as a source
- To remove external heatsink, PCB must be able to dissipate all the losses – make the cooling area as big as possible, better with thick plating

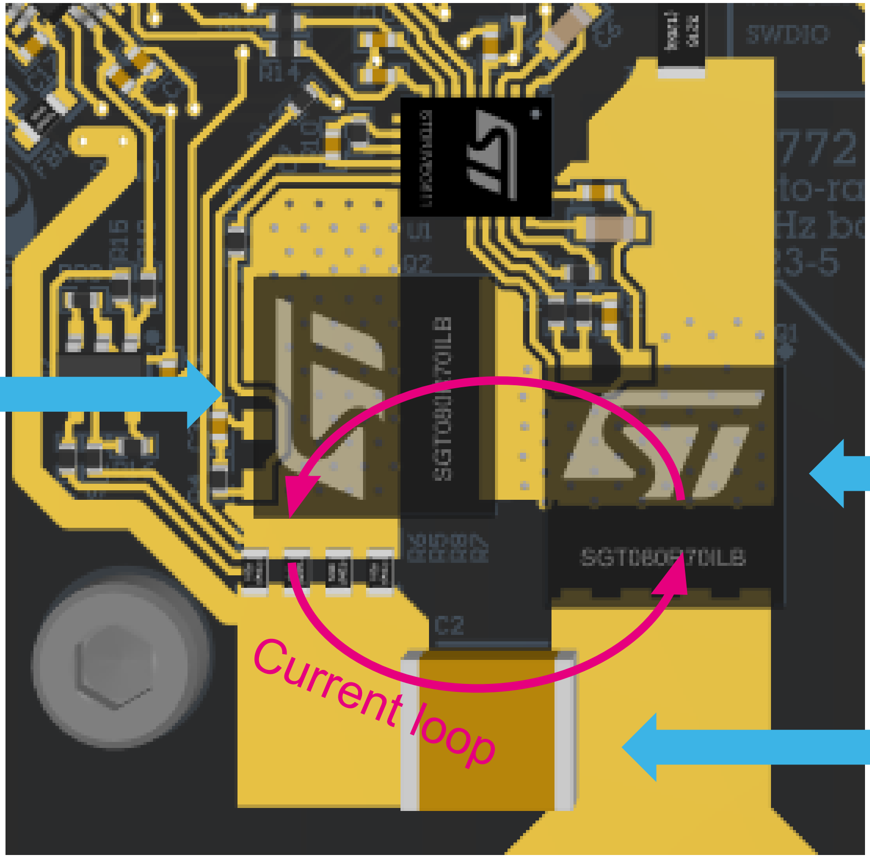



**Dissipation area size & symmetry** → ΔT ~5C  estimation

# Layout considerations
## Minimal current loops

**Layout recommendations**

- Goal is to have current loops as small as possible in terms of area
- Most important current loops:
    - Main commutation loop
    - Gate current loop
    - DC bus loop
- Important to have good quality ceramic capacitors as a source
- To remove external heatsink, PCB must be able to dissipate all the losses – make the cooling area as big as possible, better with thick plating

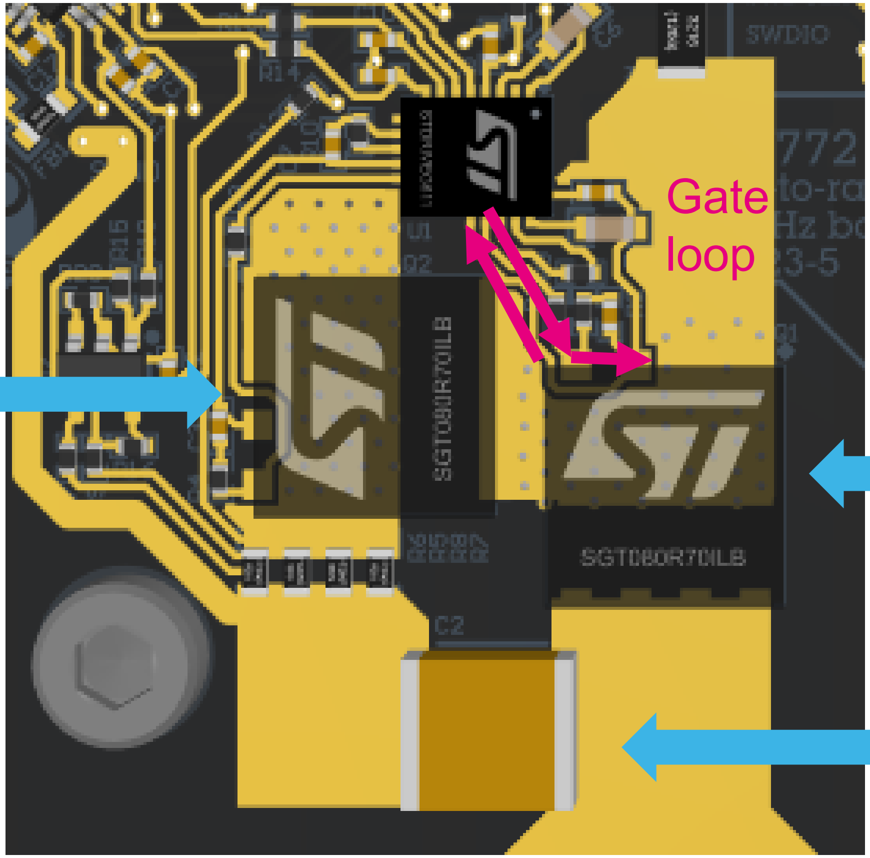



Main commutation loop as small as possible respecting isolation requirements

# Layout considerations
## Minimal current loops

### Layout recommendations

- Goal is to have current loops as small as possible in terms of area
- Most important current loops:
  - Main commutation loop
  - Gate current loop
  - DC bus loop
- Important to have good quality ceramic capacitors as a source
- To remove external heatsink, PCB must be able to dissipate all the losses – make the cooling area as big as possible, better with thick plating

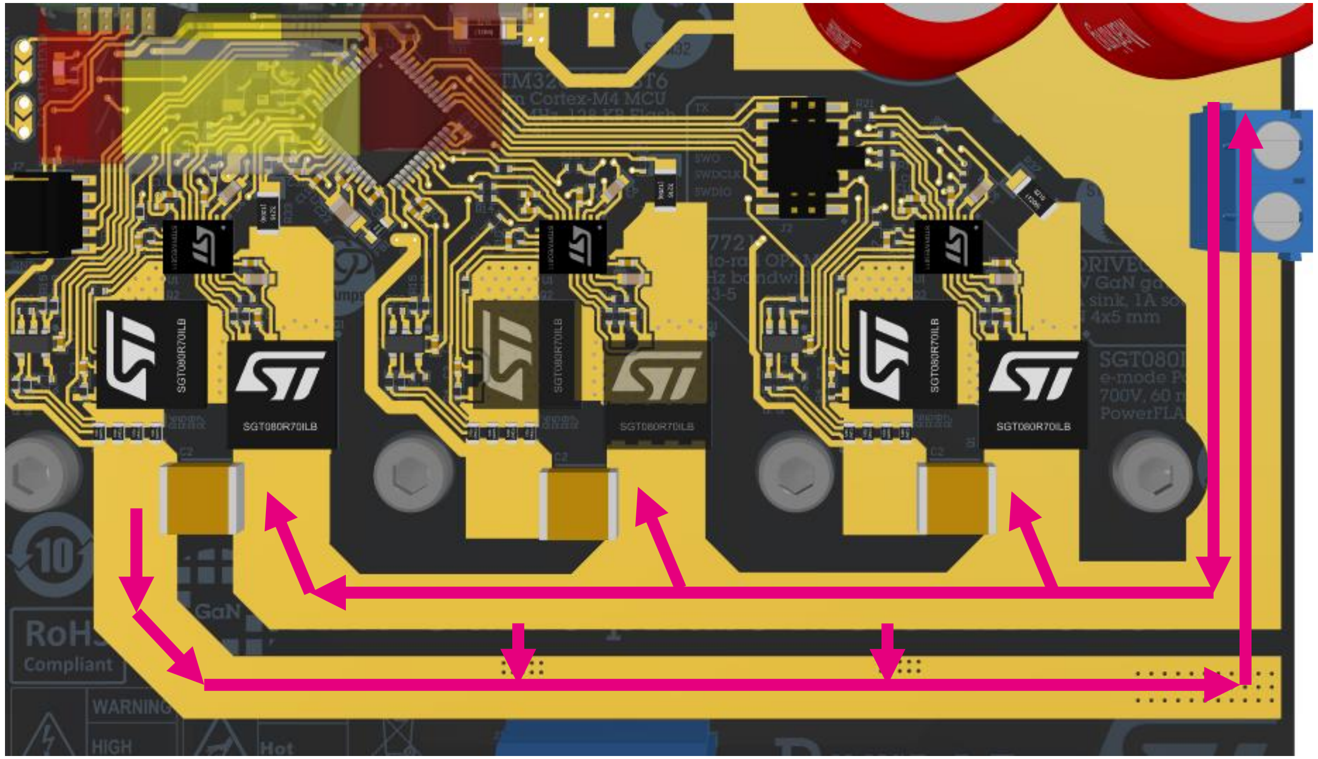



**Gate current supply and return paths are directly next to each other minimizing the area of the loop**

# Layout considerations
## Minimal current loops

**Layout recommendations**

- Goal is to have current loops as small as possible in terms of area
- Most important current loops:
  - Main commutation loop
  - Gate current loop
  - DC bus loop
- Important to have good quality ceramic capacitors as a source
- To remove external heatsink, PCB must be able to dissipate all the losses – make the cooling area as big as possible, better with thick plating

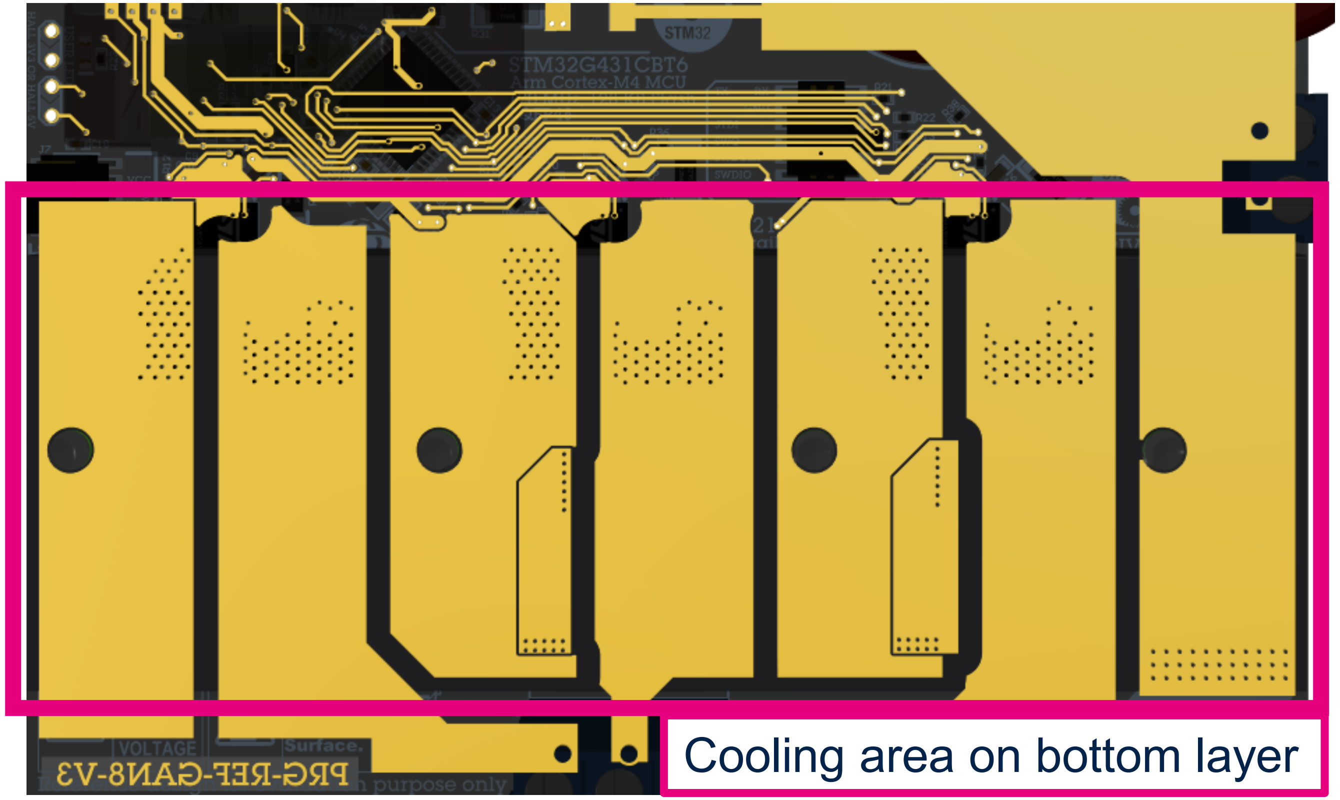


Considering challenges of 2-layer PCB, area of the DC bus loop is again as small possible

# Layout considerations
## PCB dissipation area

### Layout recommendations

- Goal is to have current loops as small as possible in terms of area
- Most important current loops:
  - Main commutation loop
  - Gate current loop
  - DC bus loop
- Important to have good quality ceramic capacitors as a source
- To remove external heatsink, PCB must be able to dissipate all the losses – make the cooling area as big as possible, better with thick plating



Cooling area on bottom layer

Try to keep cooling area as big as possible, consider 70µm plating for demanding applications (gain **ΔT~15°C**)

# Conclusions

# Conclusions

**All GaN based solutions bring a significant increase in power density and efficiency in Motor Control getting rid of heatsink and associated cost + manufacturing steps**

**Layout and PCB constructions are the key design elements for both electrical and thermal performances**

**Motor cable length strongly influence switching performance: the shorter, the better!**

**The future for GaN (and SiC): motors with possibility to work at higher dV/dt**

# Our technology starts with You

Find out more at www.st.com