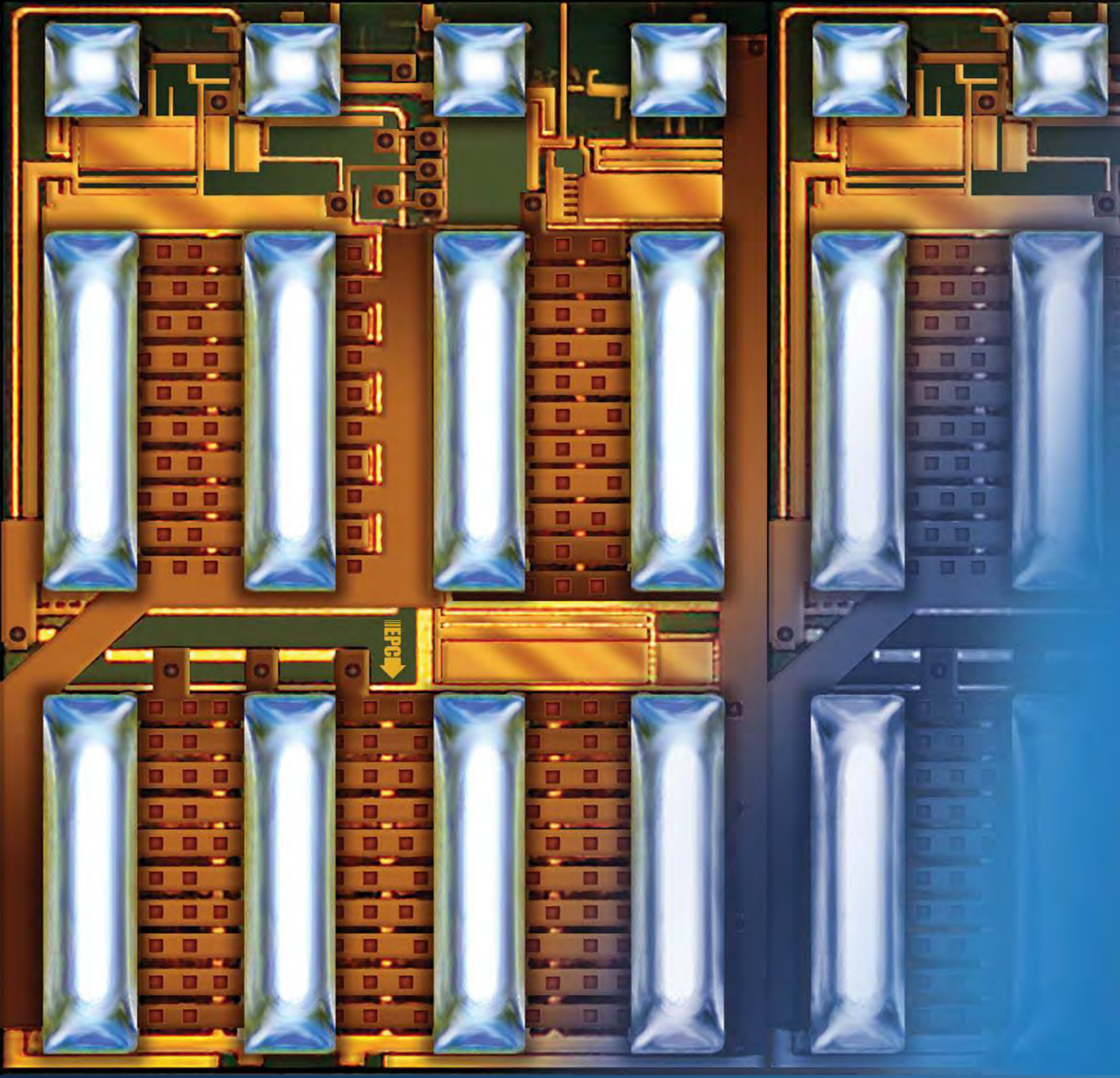


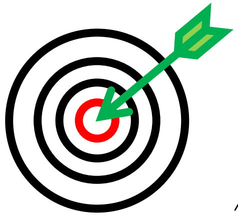
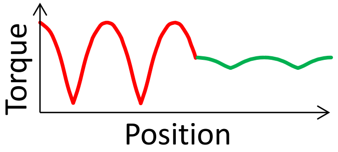
Design Smaller, Lighter, More Efficient Motor Drives with EPC Motor Reference Designs

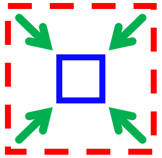
Marco Palma

EFFICIENT POWER CONVERSION

GaN Motor Drive Myth Dispelled

There is a benefit to using GaN devices in BLDC Motor drives

- Experimental validation showed:
  - Higher system efficiency 
  - Lower audible emission 
  - Improved precision 
  - Lower torque ripple 

  - Smaller size 

GaN Benefits in BLDC Motor Drives

GaN FET/ICs switch fast with $Q_{RR} = 0$

Higher switching frequency

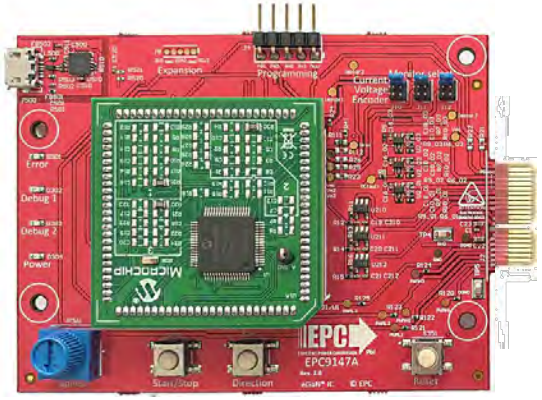
- Input filter reduction
- Electrolytic capacitor elimination

Lower dead time

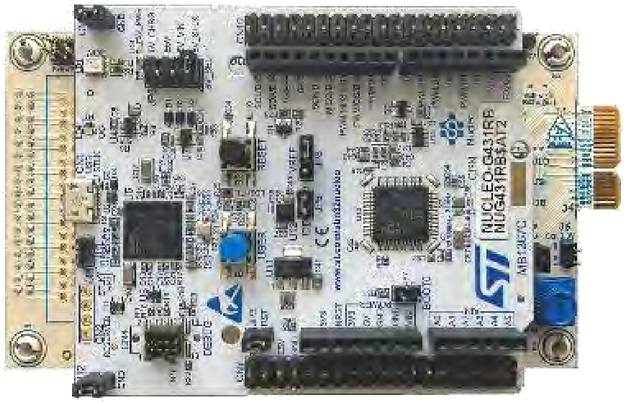
Higher torque per Ampere

- Improves inverter & motor system efficiency
- Reduces size & weight by integrating the inverter inside the motor

Available GaN Motor Drive Inverters



Microchip
dsPIC33

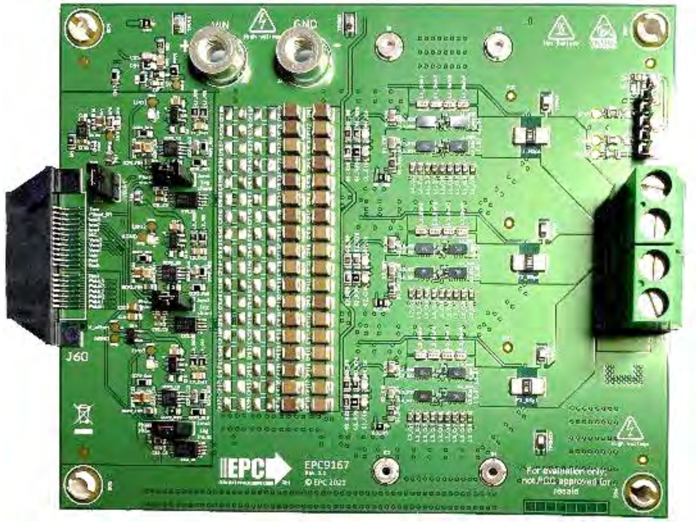


ST
Nucleo

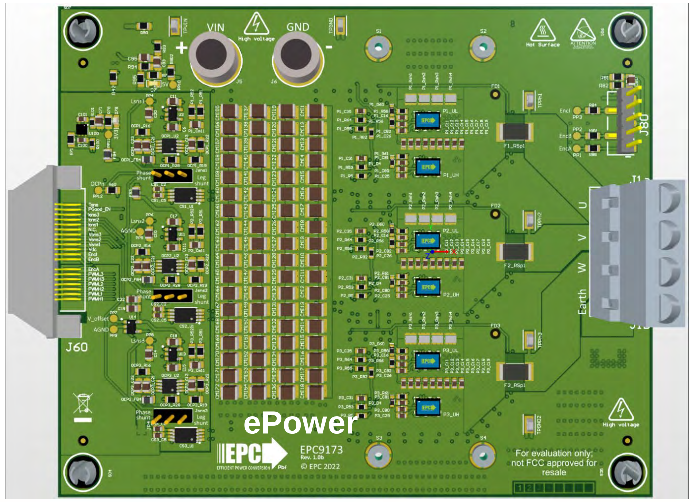
TI Piccolo
In development

EPC9146 -> EPC2152 IC

EPC9176 -> EPC23102 IC



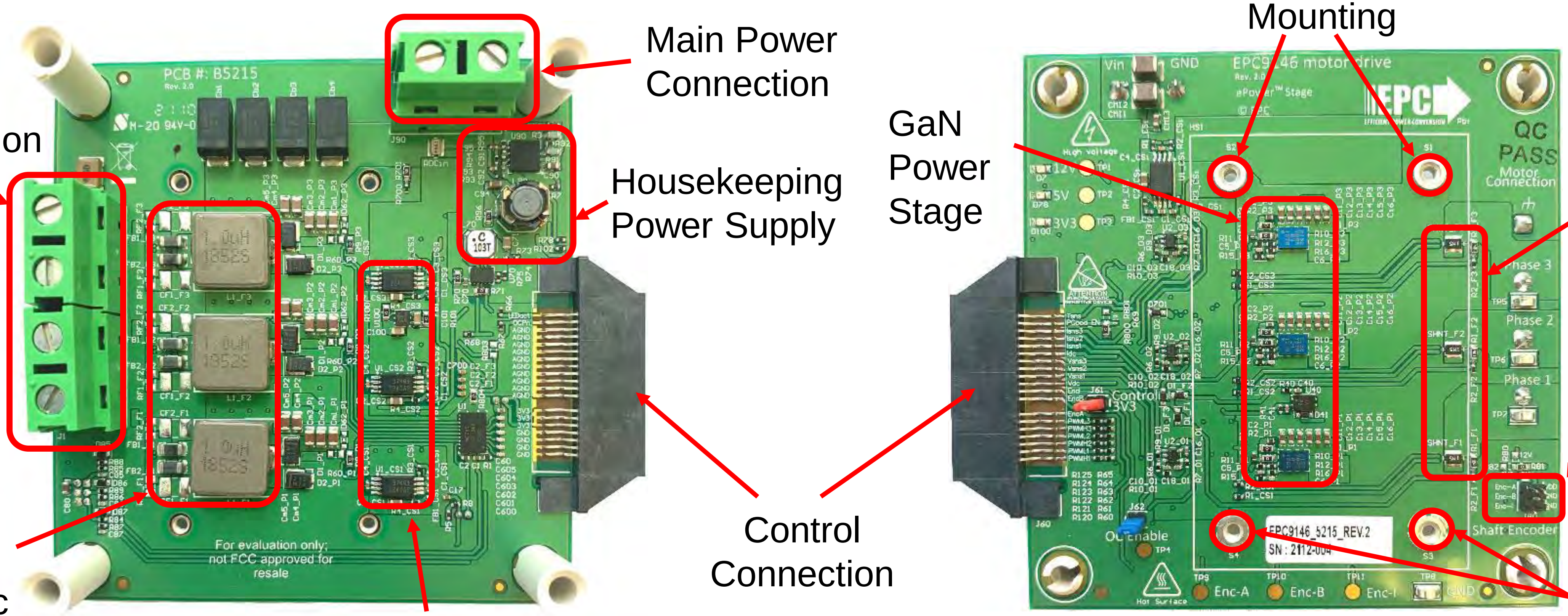
EPC9167HC -> EPC2065



EPC9173 -> EPC23101 IC

EPC9146

EPC9146



Measures 81 mm x 75 mm

EPC9167

EPC9167

Housekeeping Power Supply

DC_{Bus} Caps

Gate Drivers and optional diodes

Main Power Connection

GaN inverter 12x EPC2065

Heatsink Mounting

Current Sense shunts 1mΩ

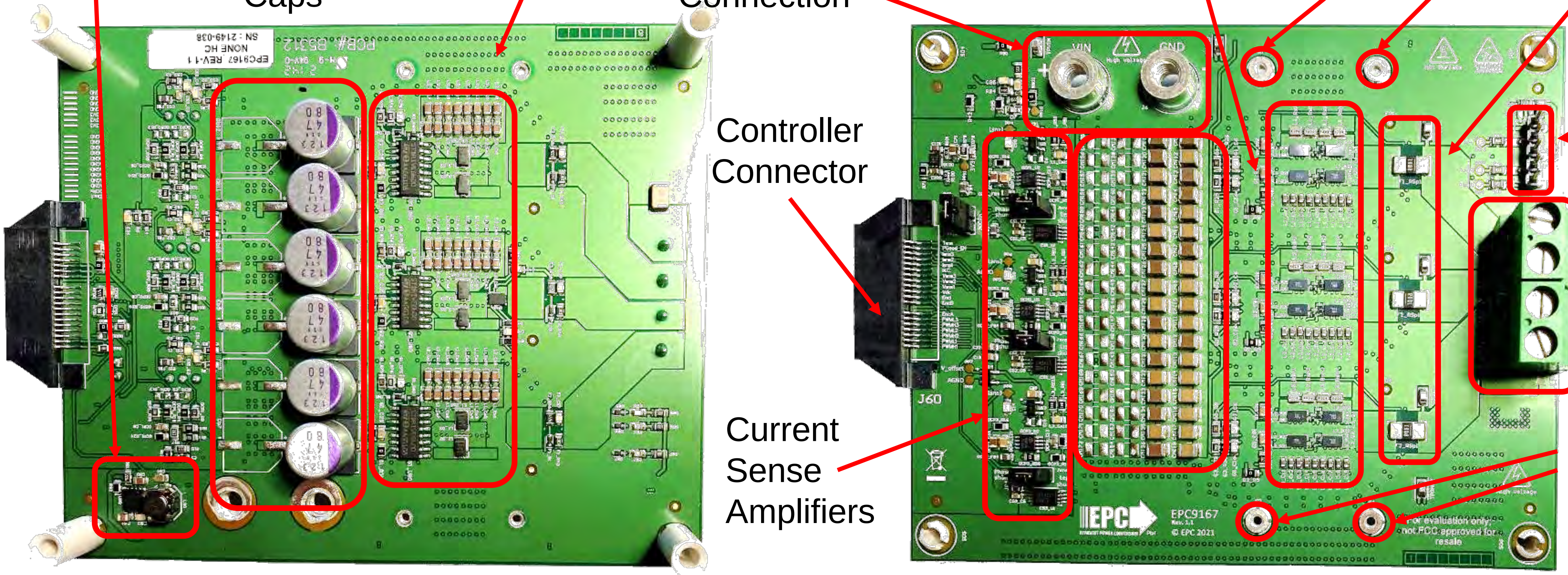
Controller Connector

Hall/ encoder interface

Motor connector

Current Sense Amplifiers

Heatsink Mounting



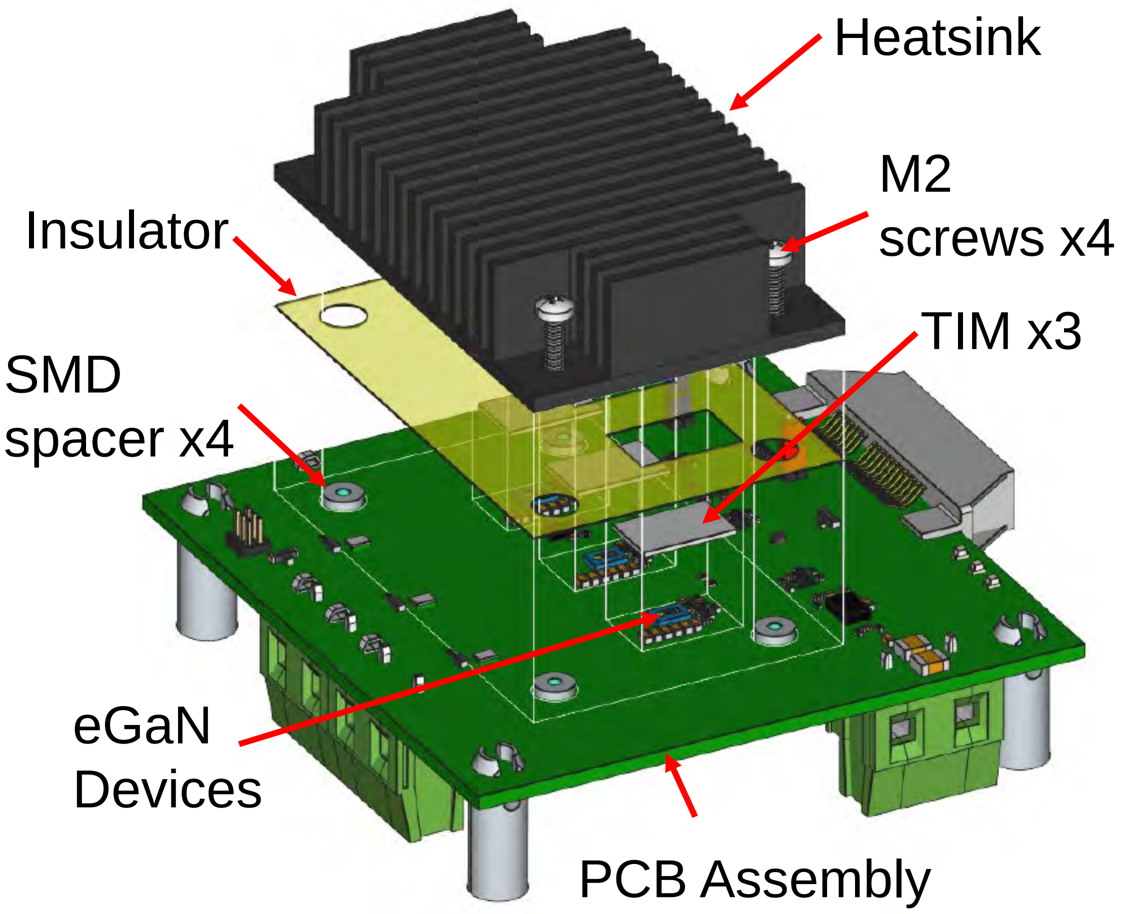
Bottom Side

Measures 120 mm x 100 mm

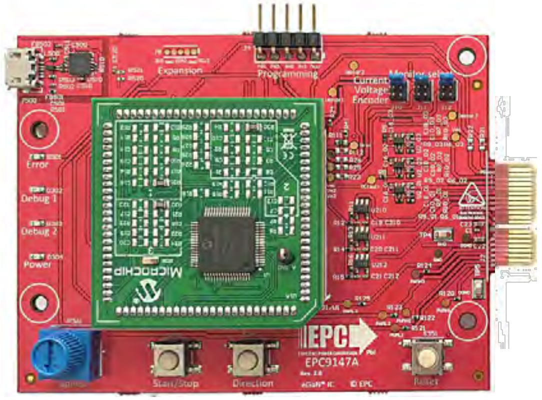
Top Side

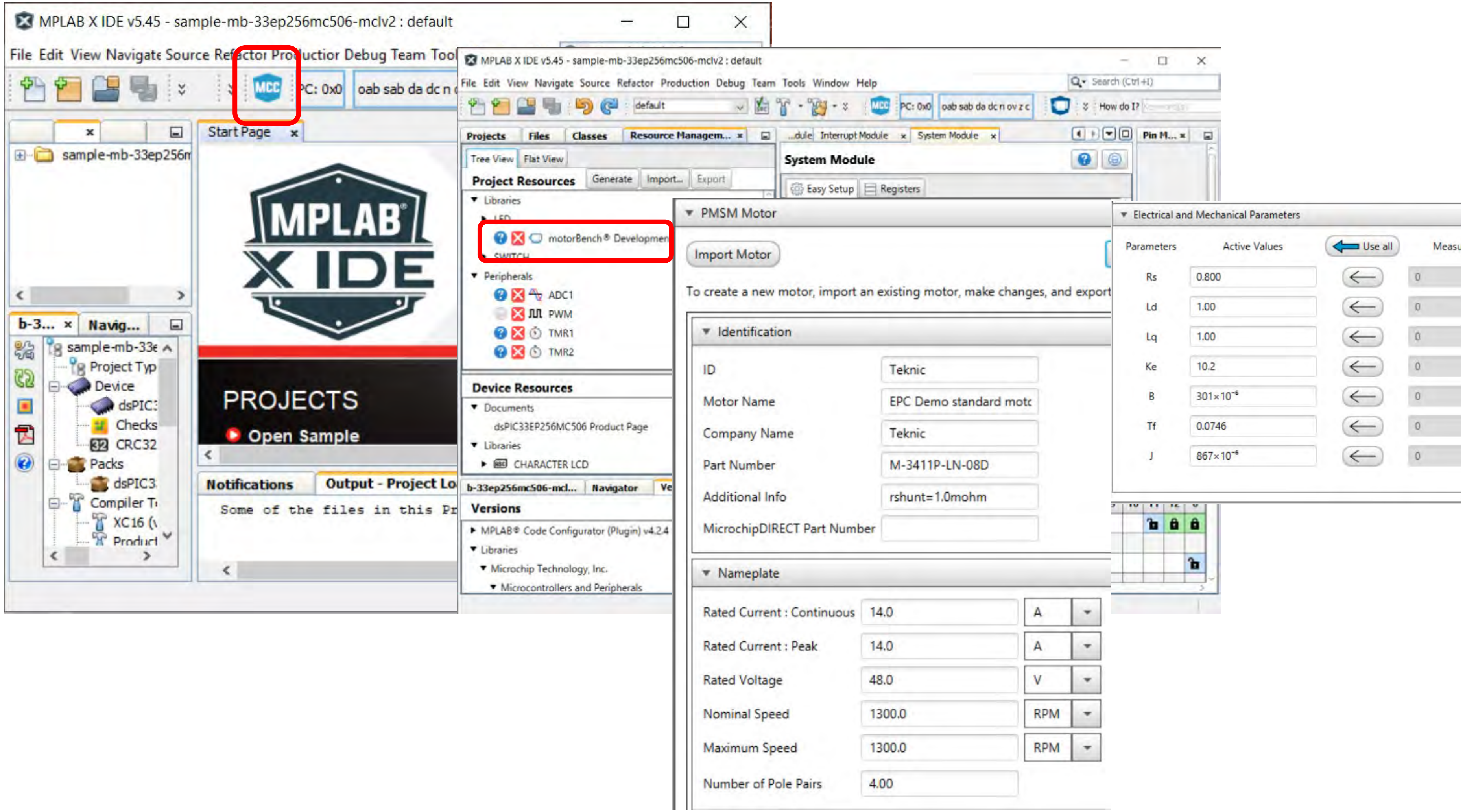
Thermal Implementation

- Heatsink
- Thermal Interface Material
- Spacer on PCB
  - Würth Elektronik: 9774010243R
- M2 6mm screws
  - McMaster Carr: 95836A107
- Insulator – custom shape
  - Laird: Tgard K52 A14692-30 with thickness of 0.051 mm

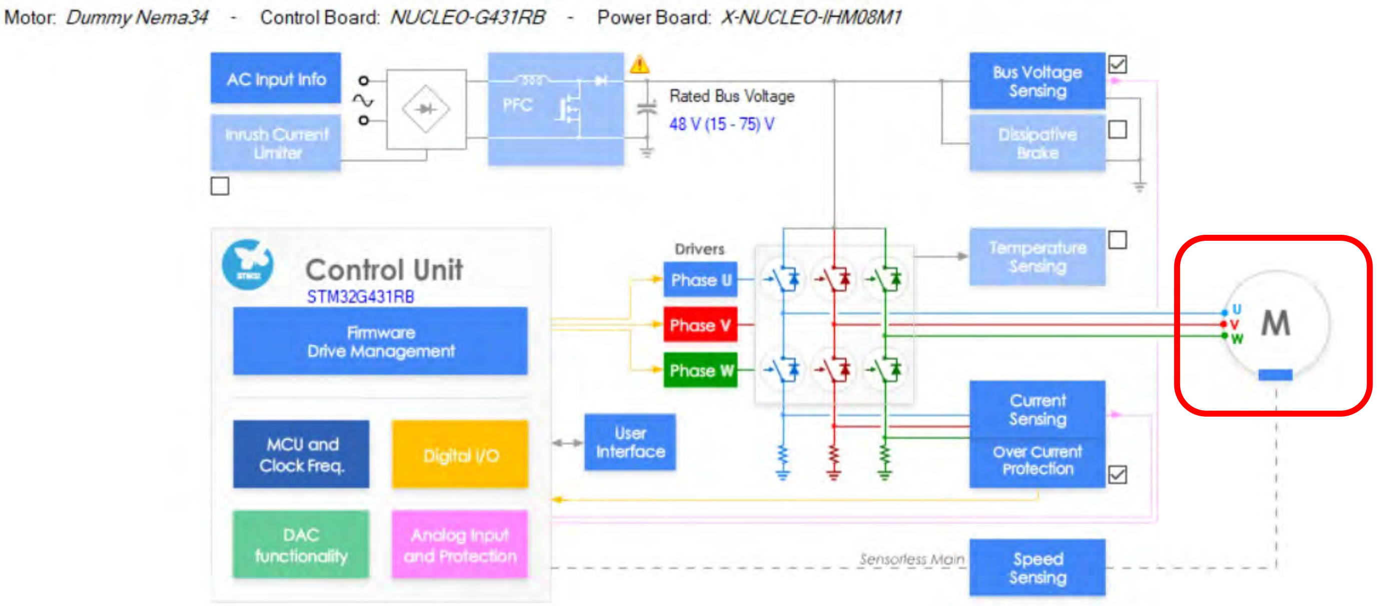


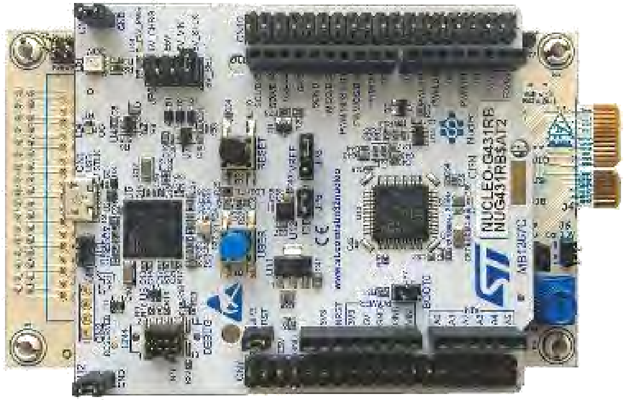
Microchip MotorBench

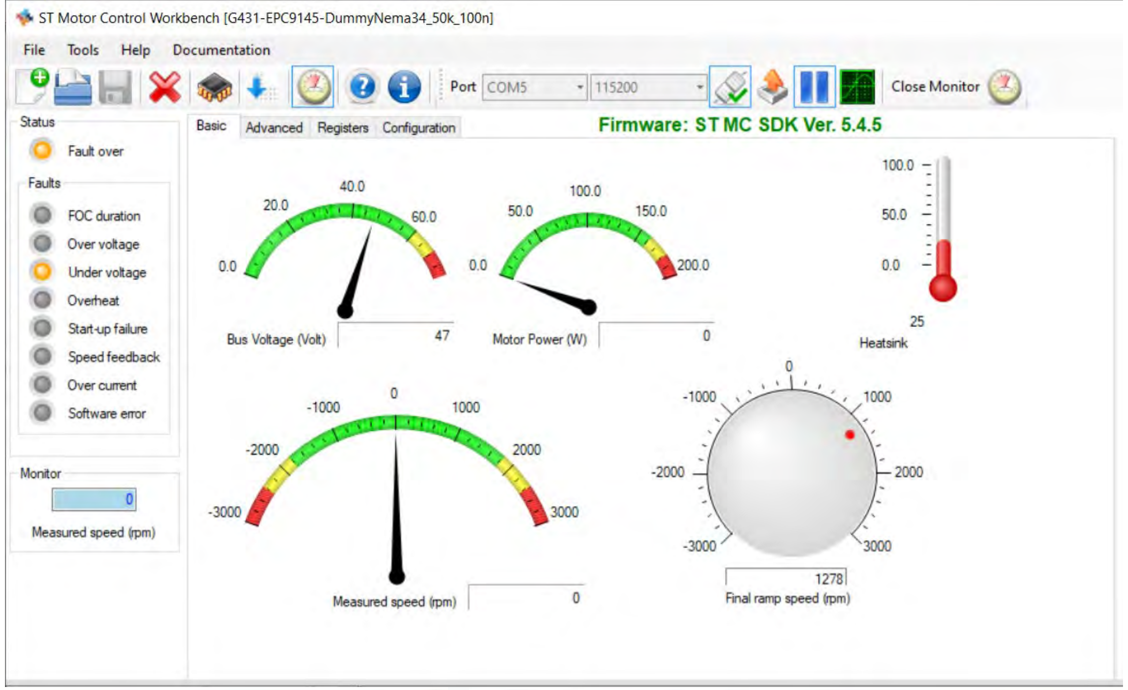


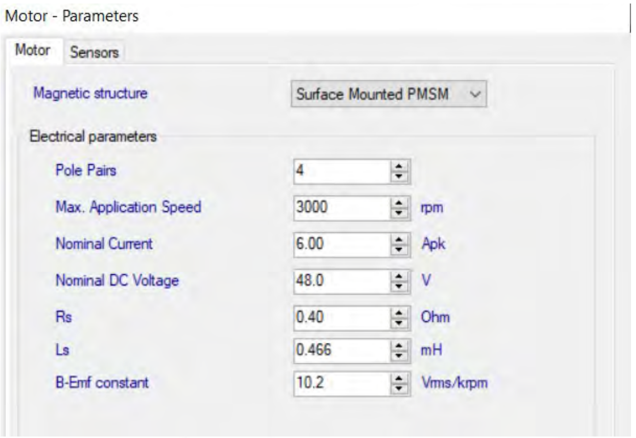


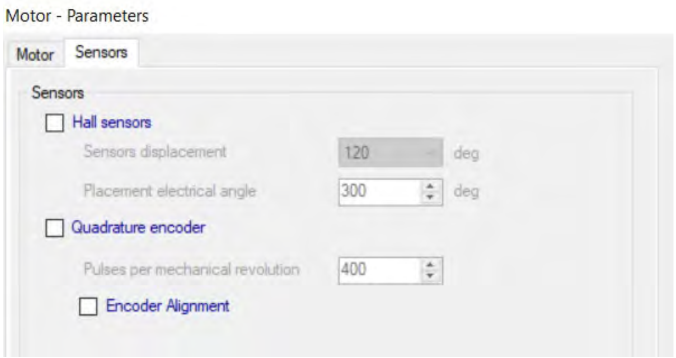
ST Motor Control Workbench





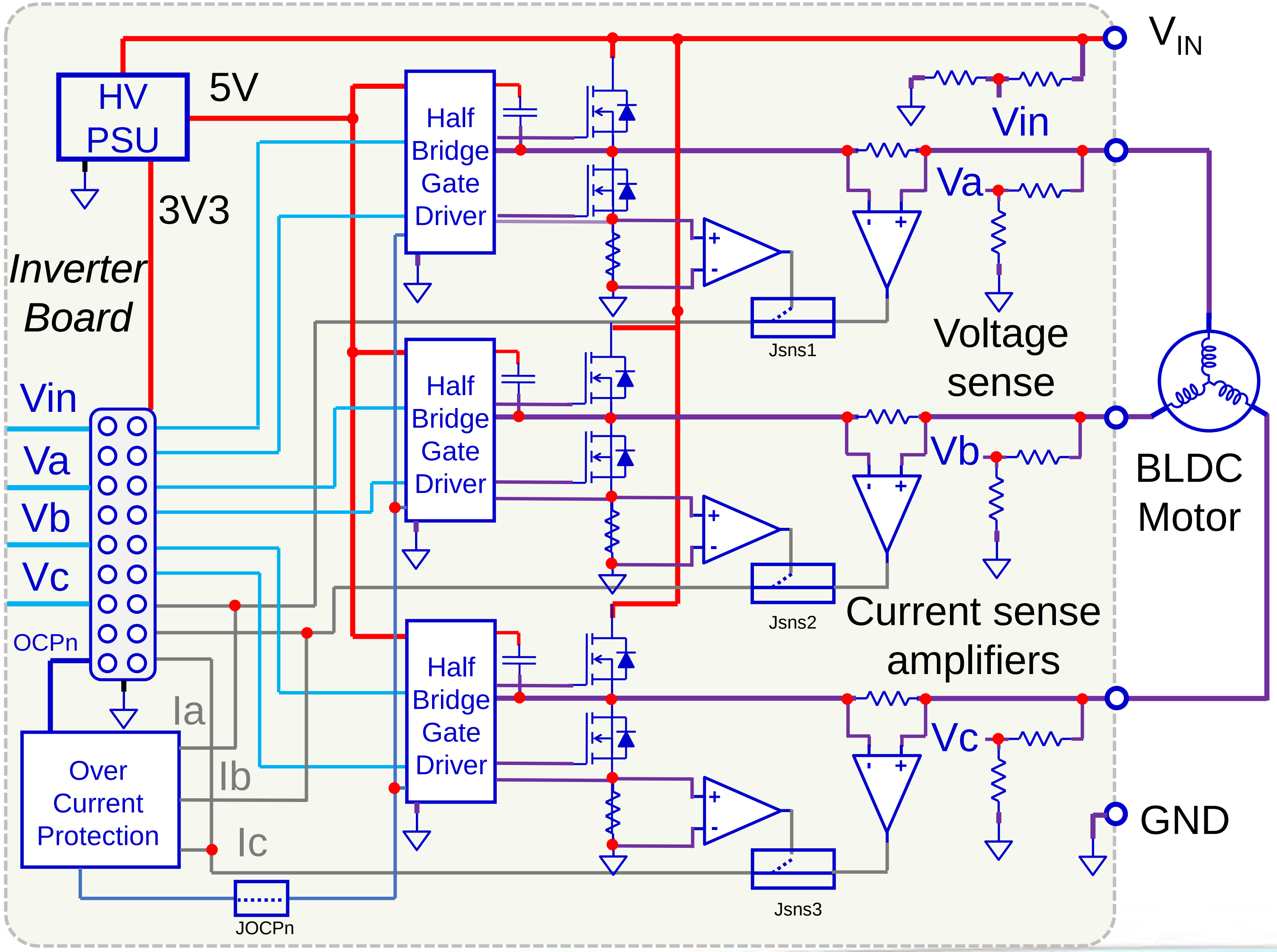






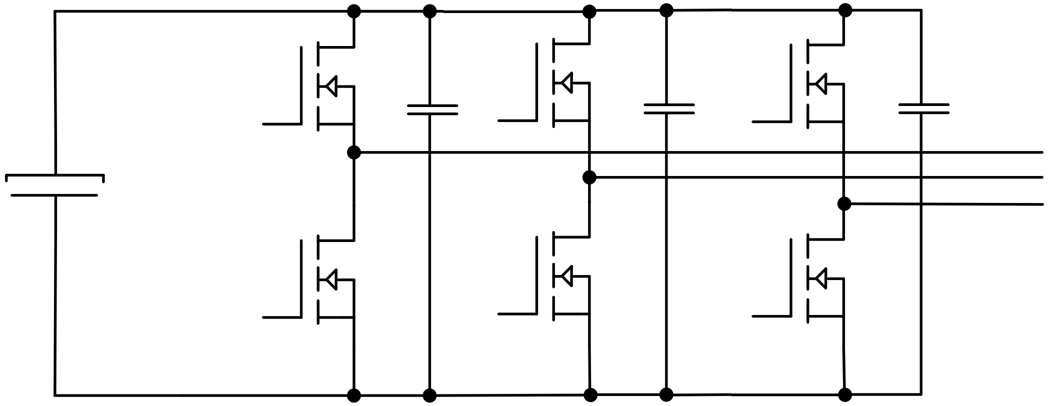
BLDC Motor Drive Overview

To/From Controller Interface board



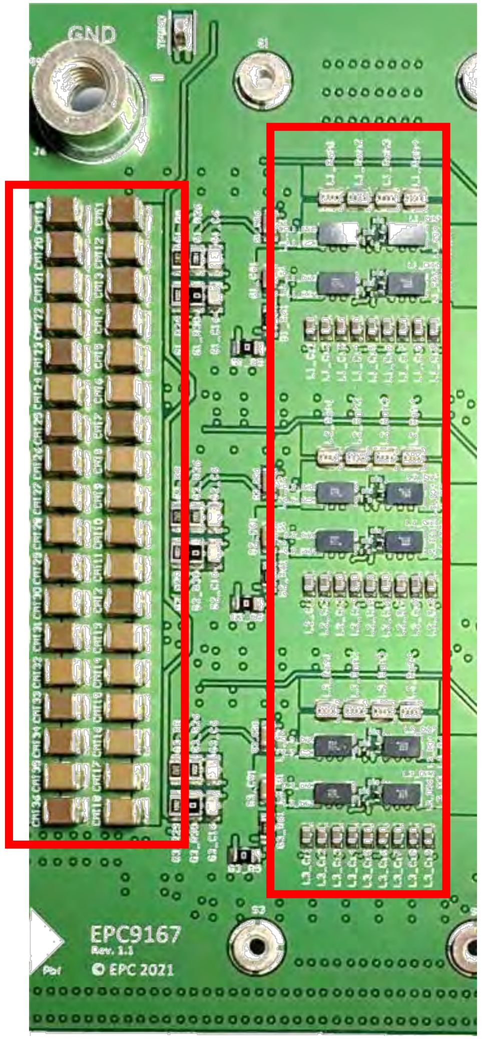
GaN Inverter Basic Schematic

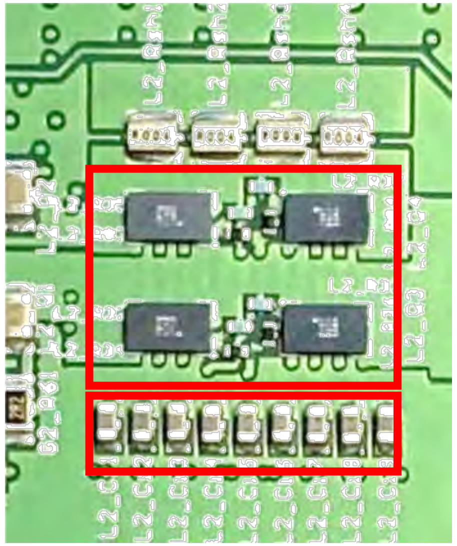
GaN Inverter

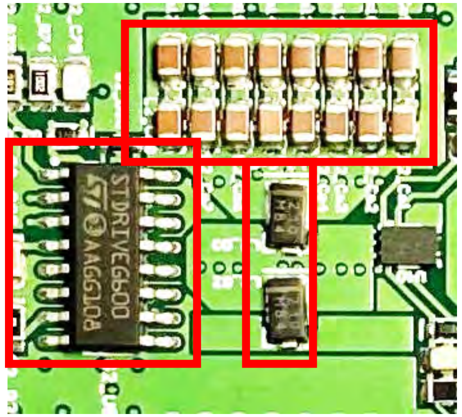


Low and Middle Frequency capacitor

High Frequency capacitors

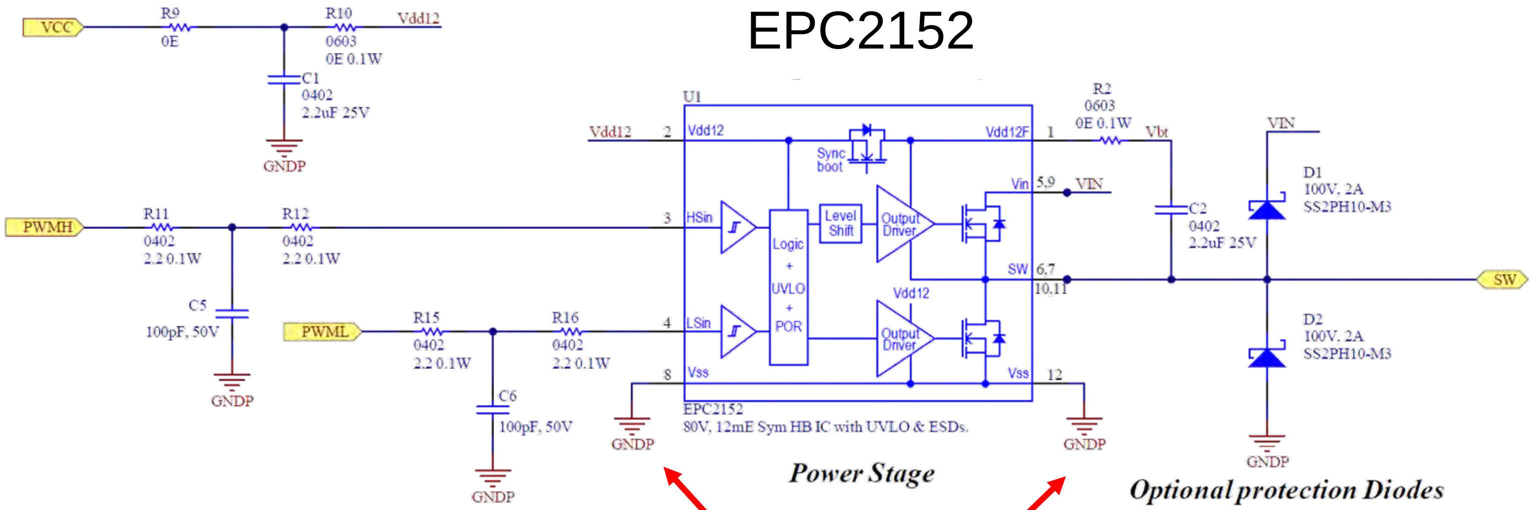






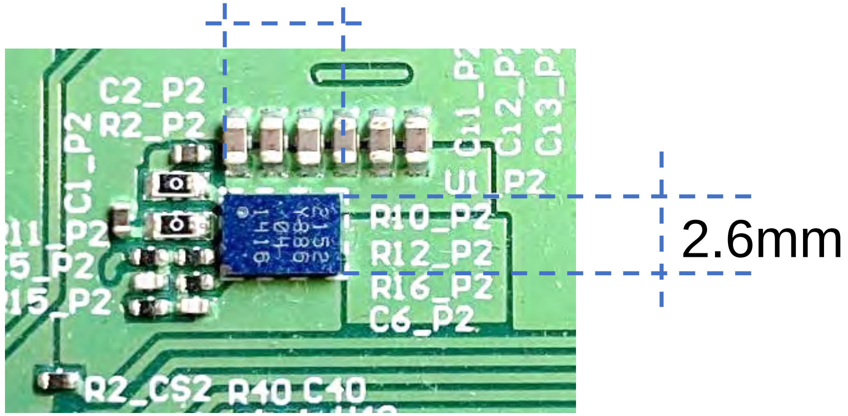
Integrated Power Devices for Motor Drive

EPC2152



Same ground: can only be used with phase current sensing

3.9mm

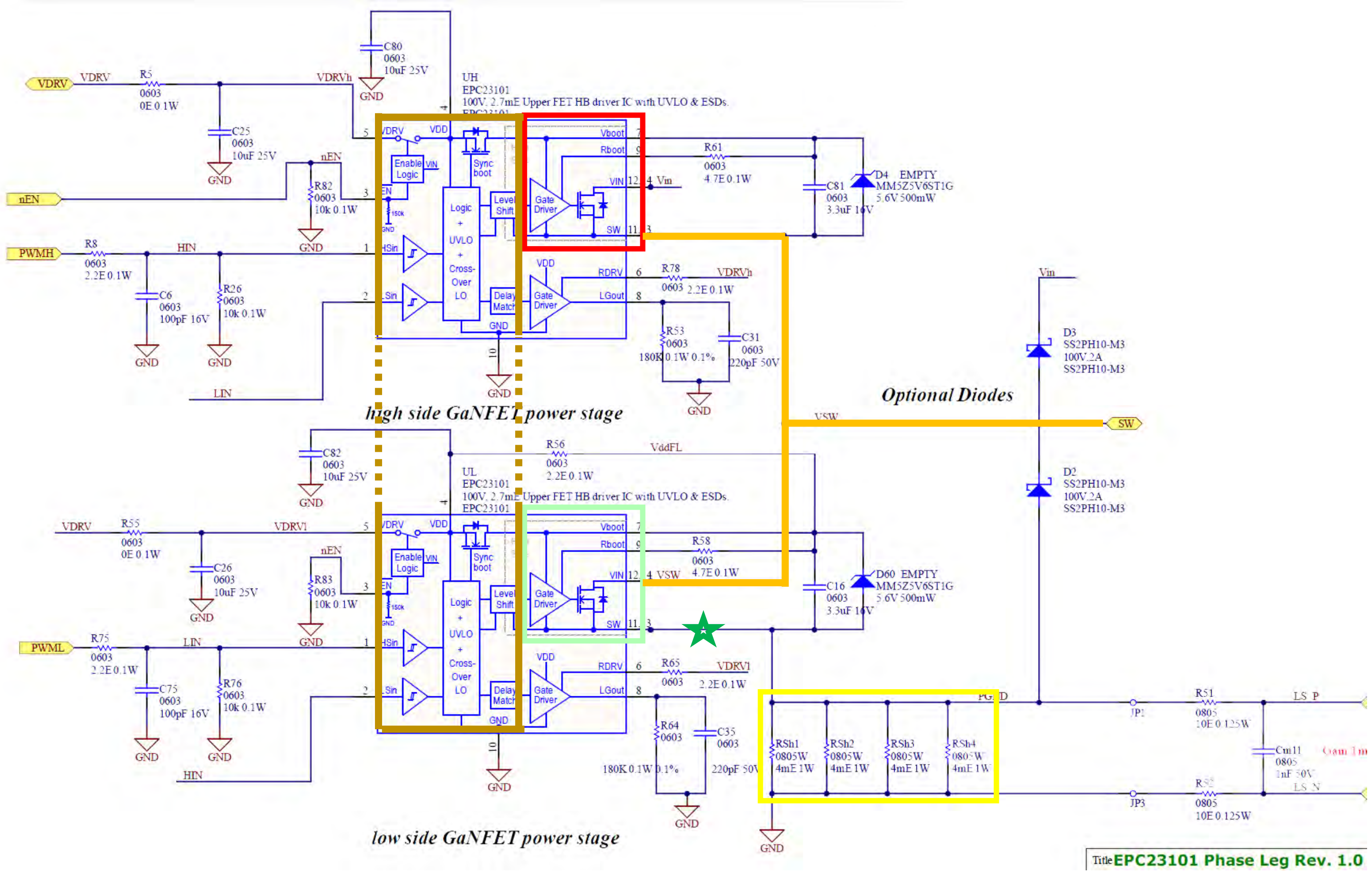


2.6mm

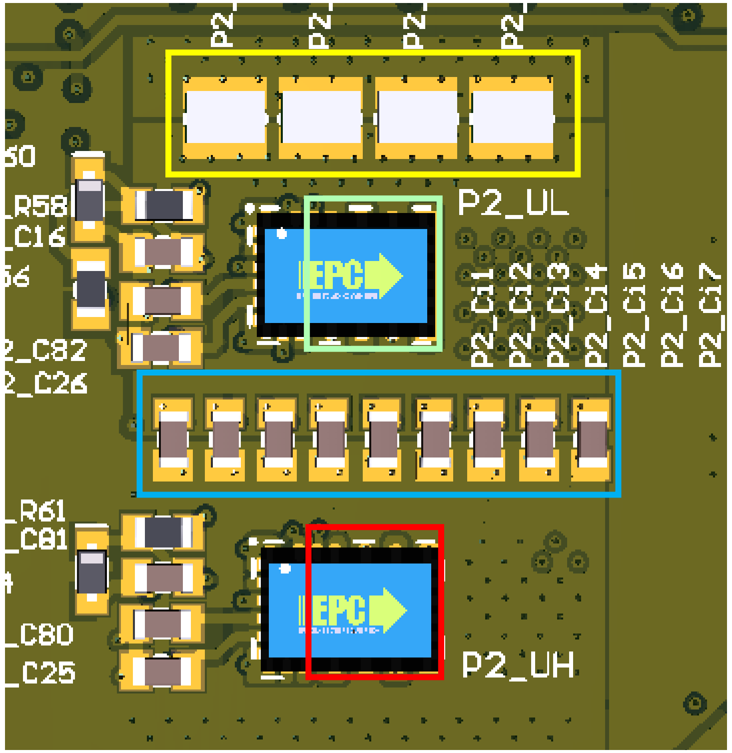
EPC2152

EPC9146 inverter board
With 3x EPC2152
Capable of 10Arms 48V 100kHz

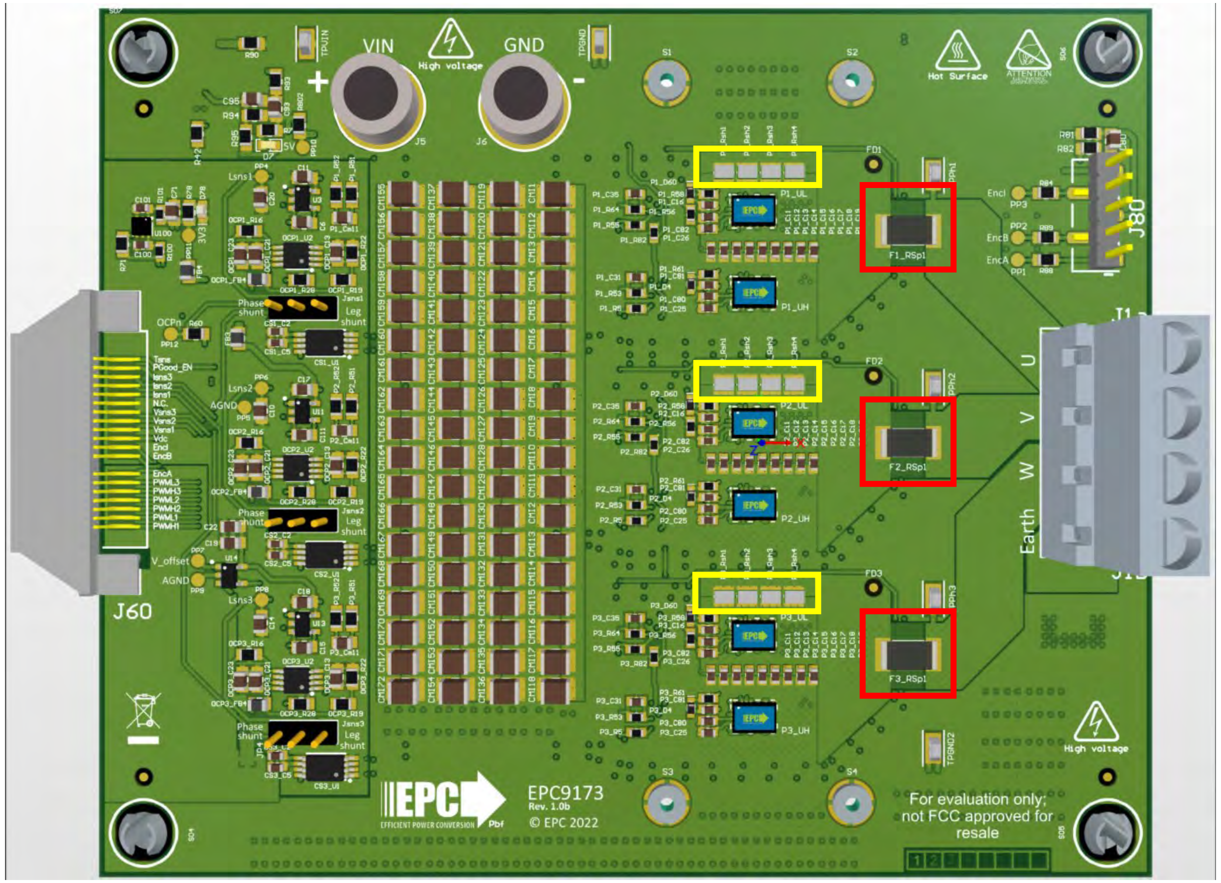
Integrated Power Devices for Motor Drive



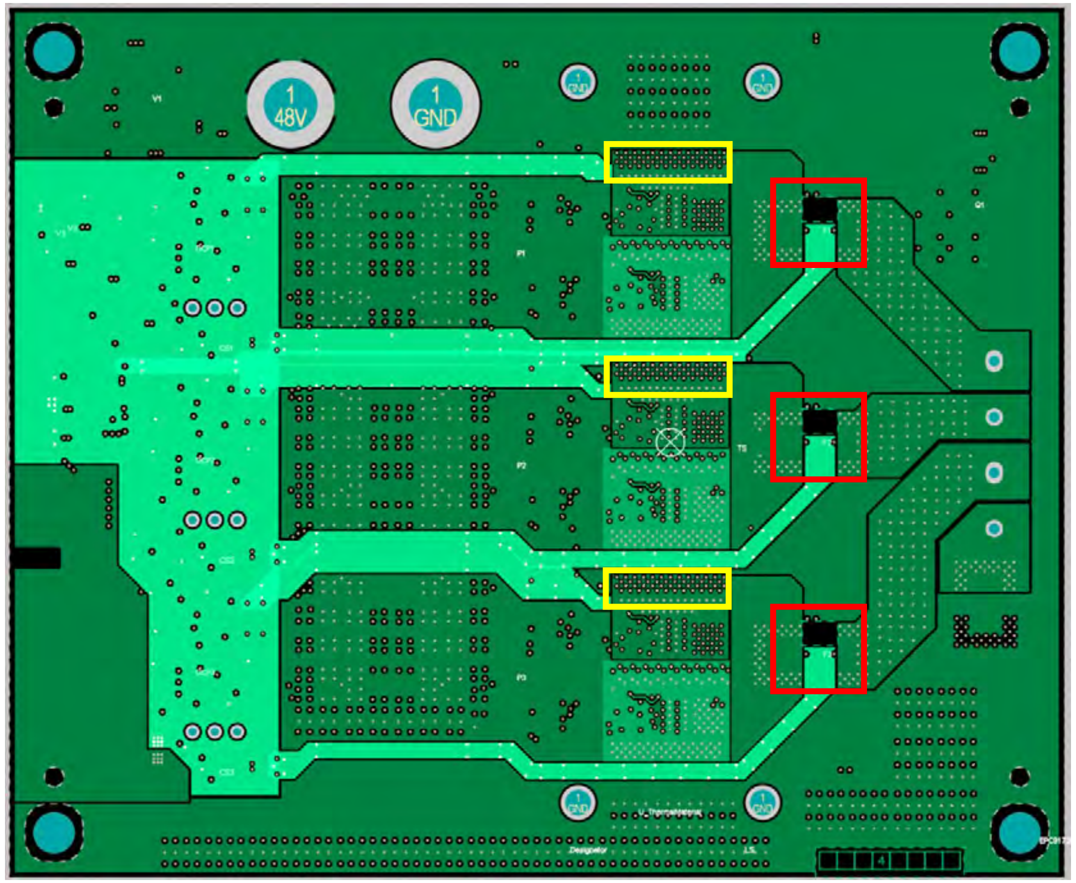
EPC23101



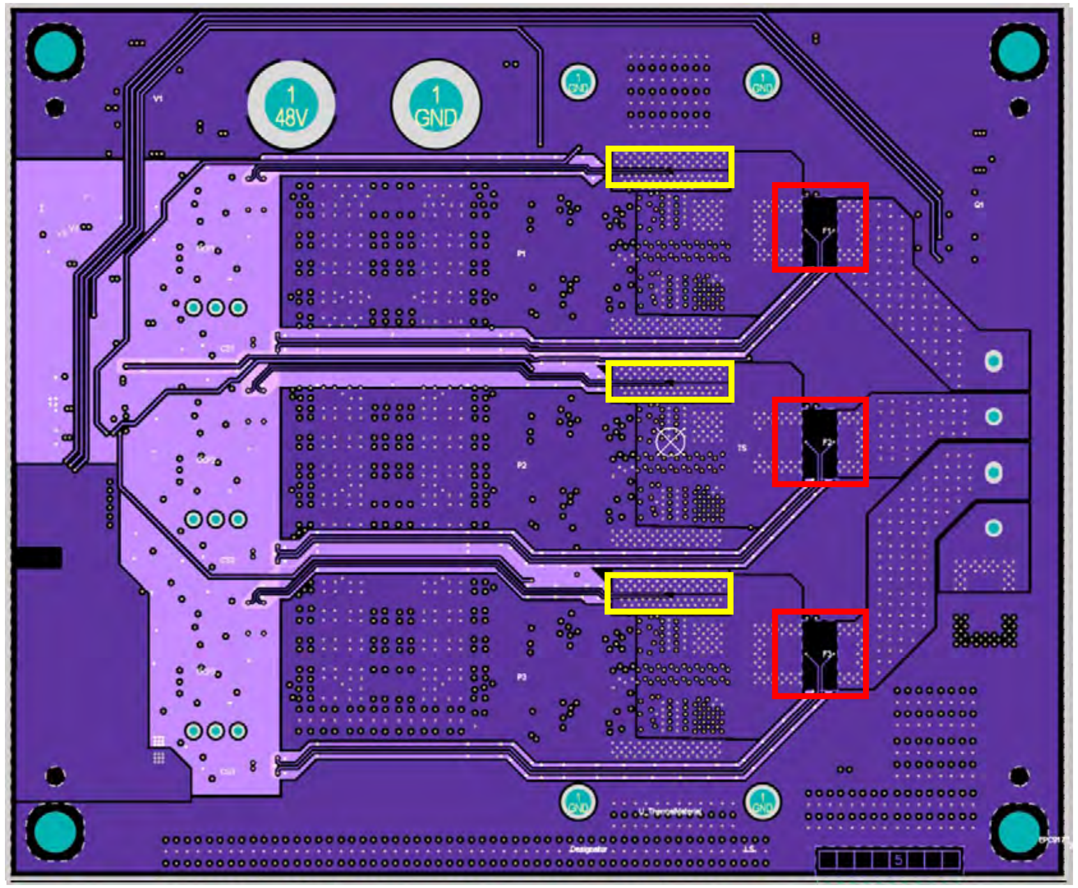
Shunt Signal Kelvin Sensing



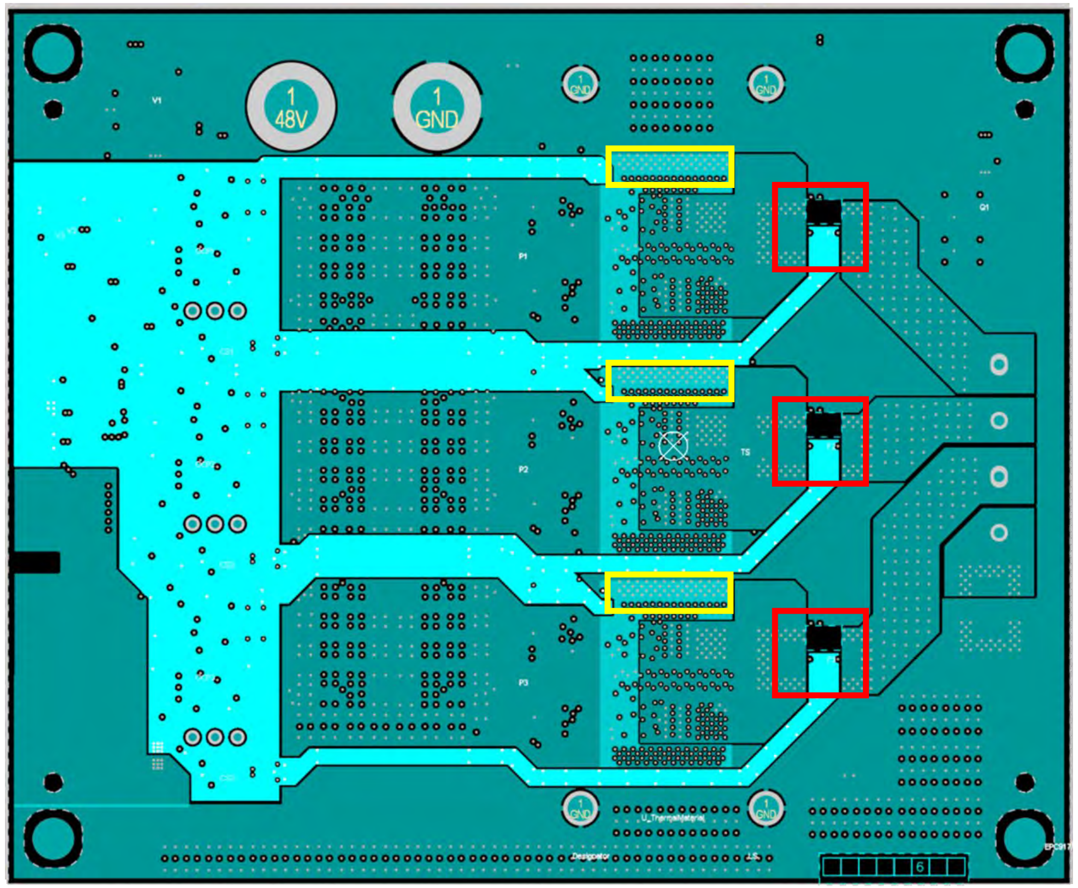
Shunt Signal Kelvin Sensing



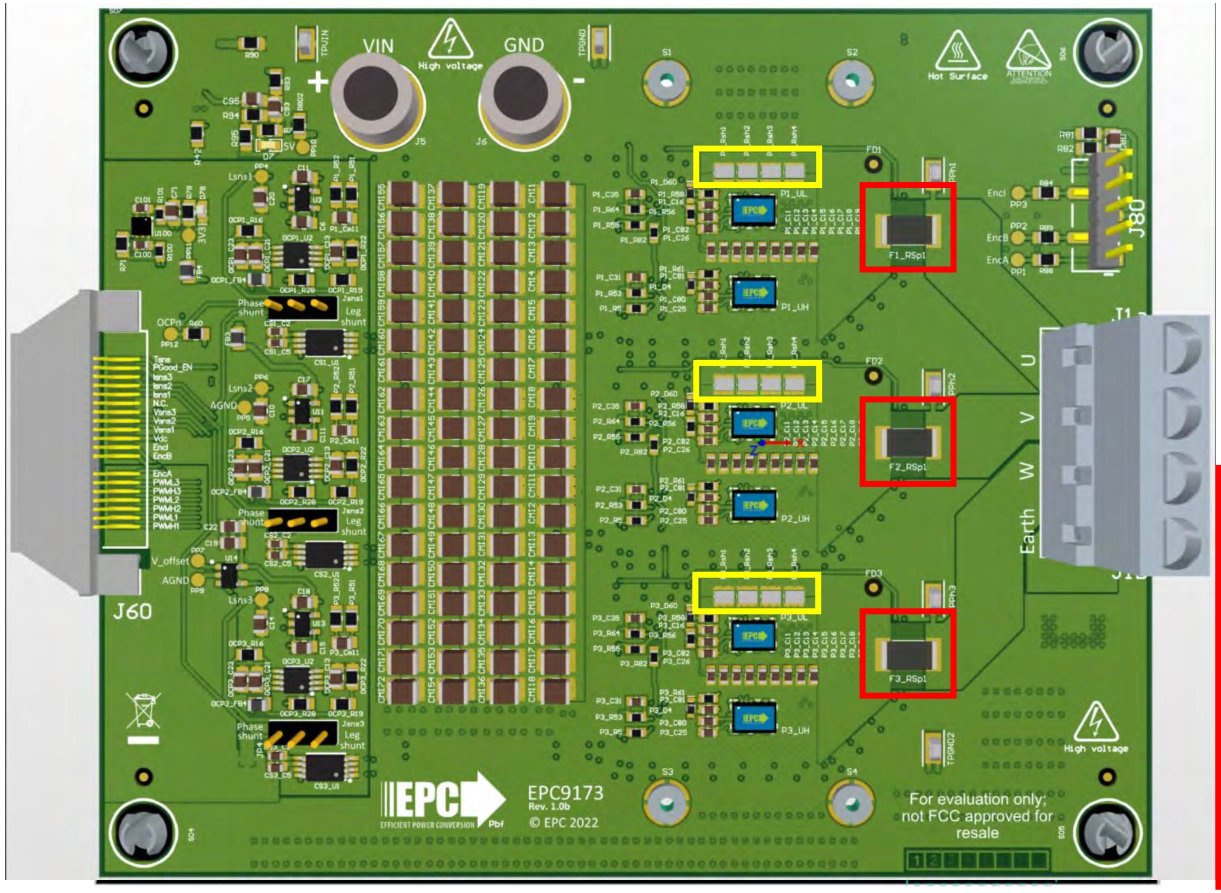
Shunt Signal Kelvin Sensing



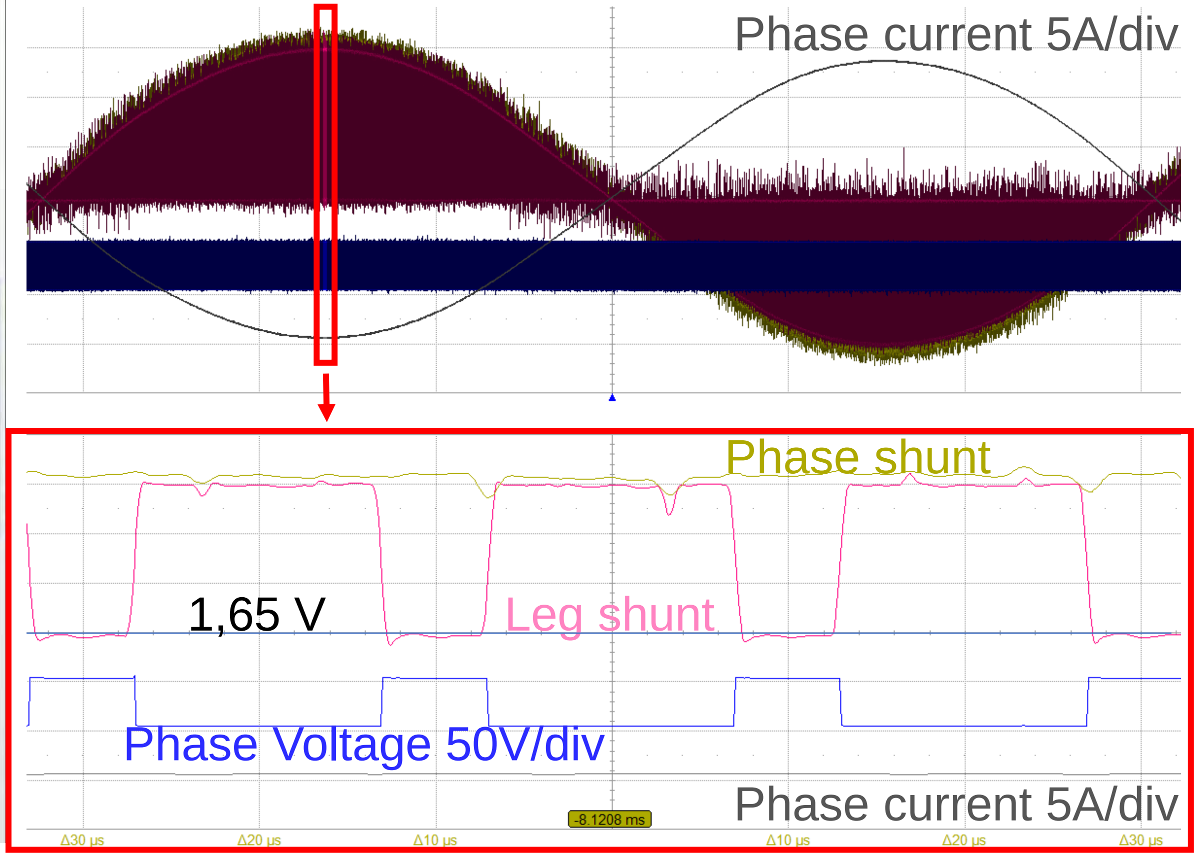
Shunt Signal Kelvin Sensing



Shunt Signal Kelvin Sensing



Main window 5ms/div

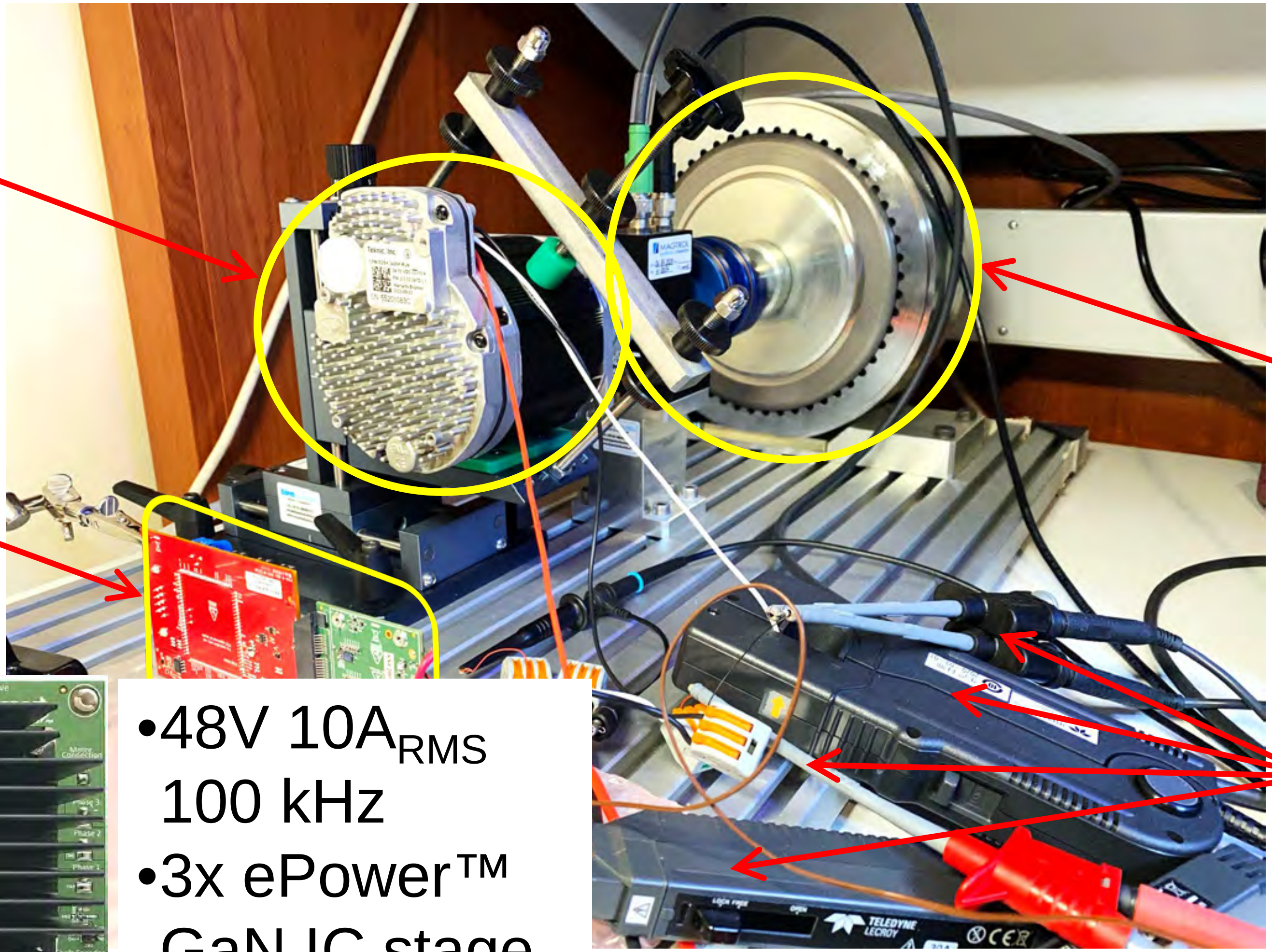


Zoom window 10µs/div

Experimental Testing Setup #1

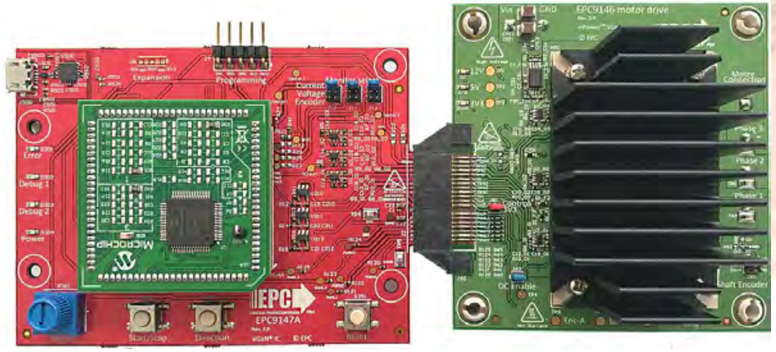
Load Motor
Teknic:
M-3411P-LN-08D

Motor drive:
EPC9146 Inverter
EPC9147A Controller



hysteresis
brake
dynamometer

Measurement
Probes

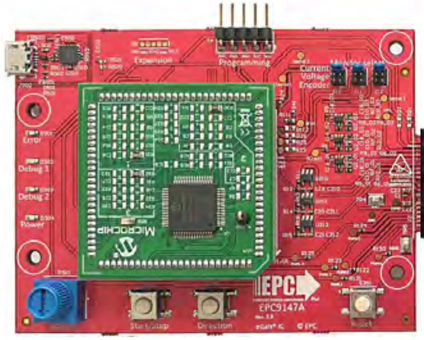


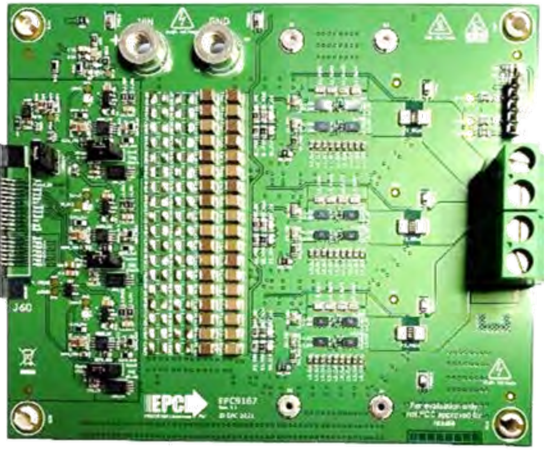
- 48V 10A_{RMS}
  100 kHz
- 3x ePower™
  GaN IC stage

Experimental Testing Setup #2

EPC9147A Controller

EPC9167 Inverter
12x EPC2065 GaN FET stage





This motor has

$R_{L\text{-}L}$ **= 90 mΩ** line to line resistance

$L_{L\text{-}L}$ **= 140 µH** line to line inductance

pp = 36 pole pairs

K_e **= 27.15** Vrms/krpm
Line to star center point

In a 26” wheel bike running at 32 km/h the motor spins at 300 rpm

Specifications:

- $V_{DC} = 48$ V
- $I_{phase} = 25\ A_{RMS}$
- Switching frequency 100kHz

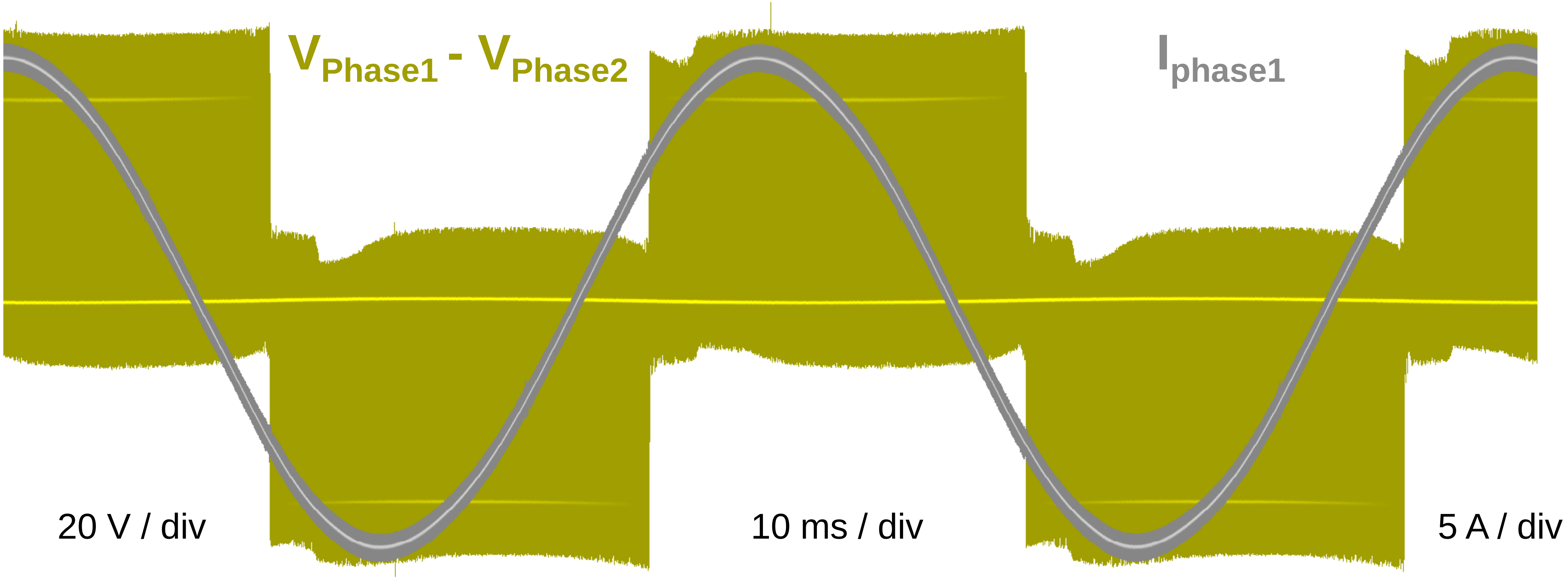
Load Motor:

Hub front wheel pedelec e-bike motor running in open loop (outer rotor removed)

Testing with and without heatsink

Setup #1 - Basic Operation

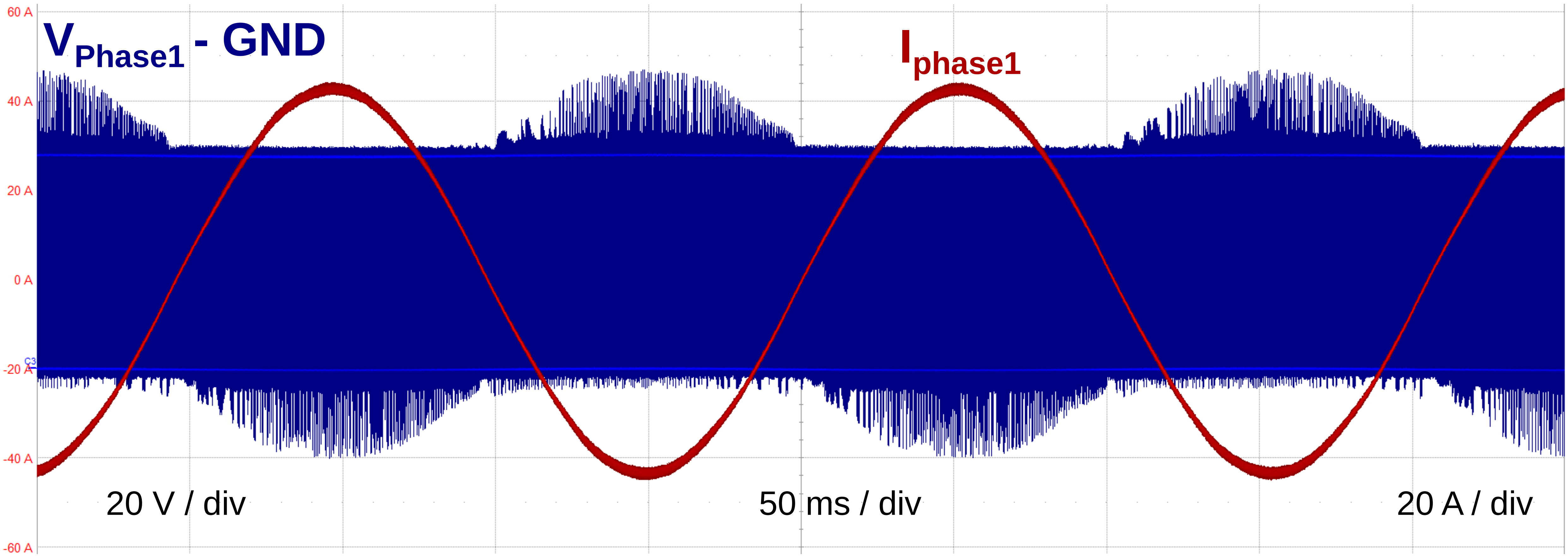
Clean low THD current waveform



V_{DC} = 48V, I_{ph} = 10 A_{RMS}, f_{SW} = 100 kHz, DT = 21ns, f_{motor} = 66 Hz

Setup #2 - Basic Operation

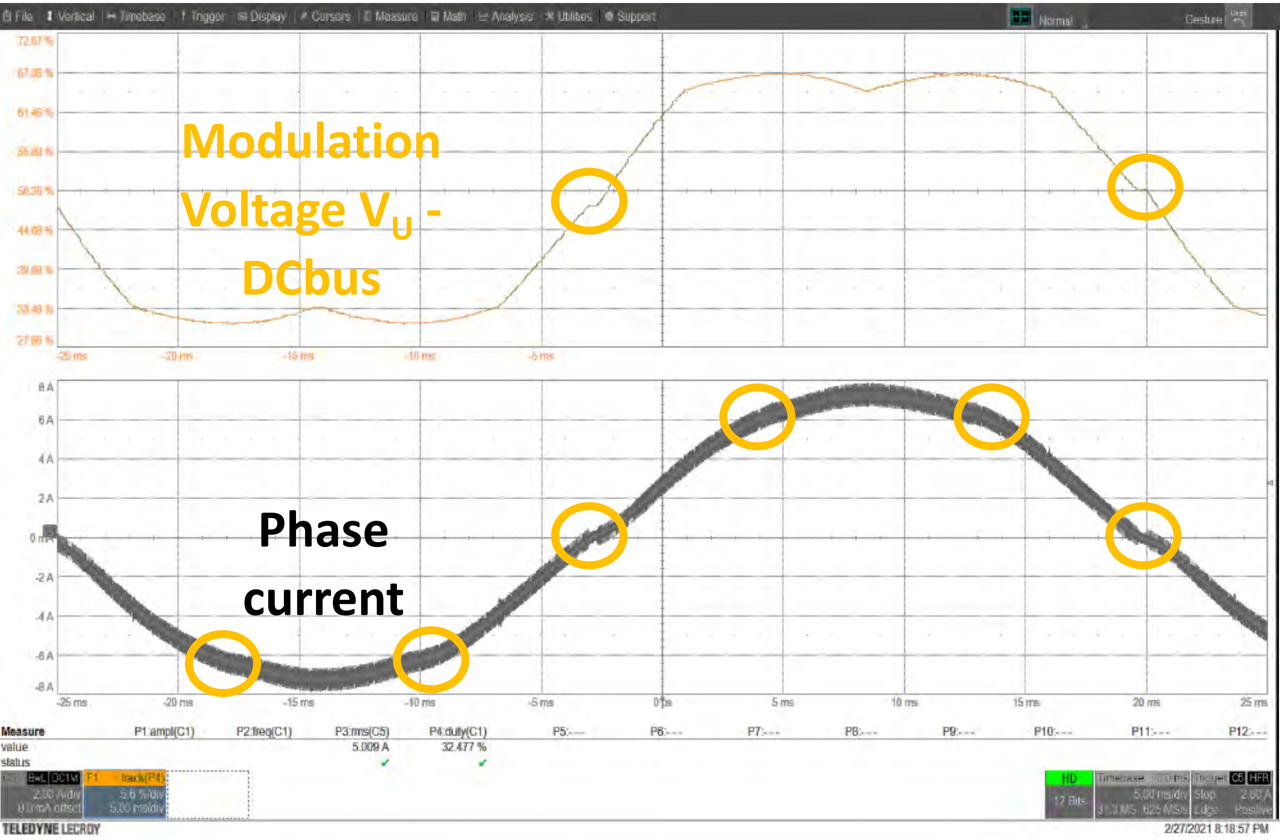
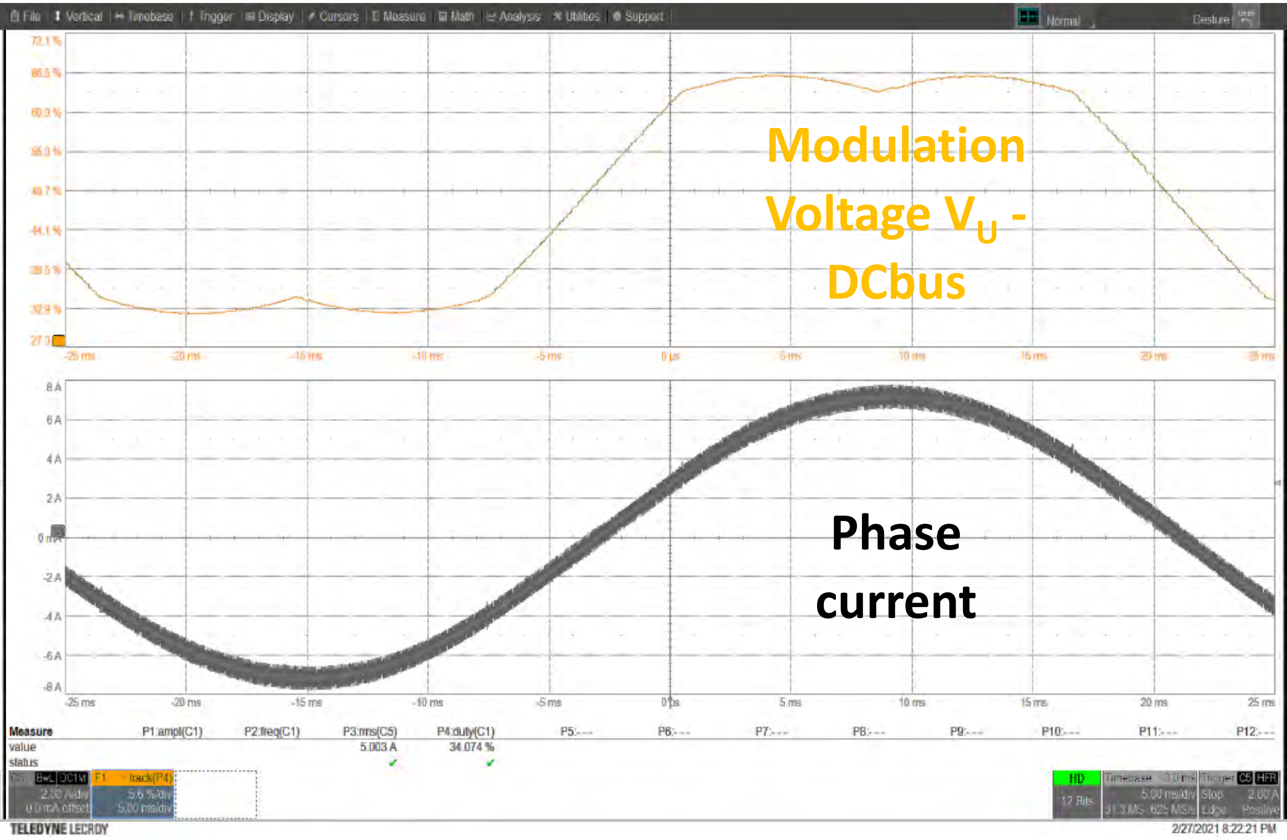
Clean low THD current waveform



V_{DC} = 48V, I_{ph} = 30 A_{RMS}, f_{SW} = 100 kHz, DT = 50ns, f_{motor} = 5 Hz

Deadtime Effect – Torque Ripple

Reduction in current distortion = lower torque ripple

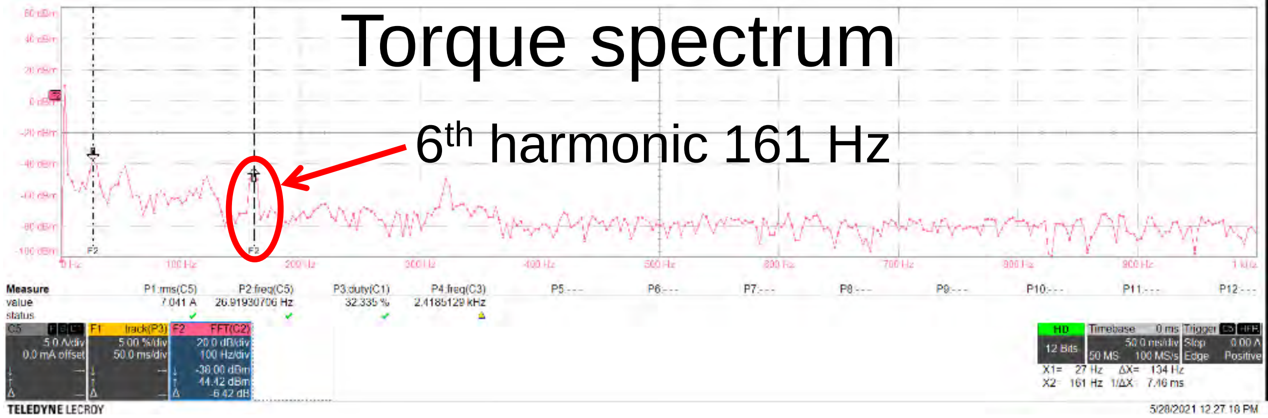
500 ns deadtime	21 ns deadtime
	

V_{DC} = 36 V , I_{phase} = 5 A_{RMS}, f_{SW} = 20 kHz

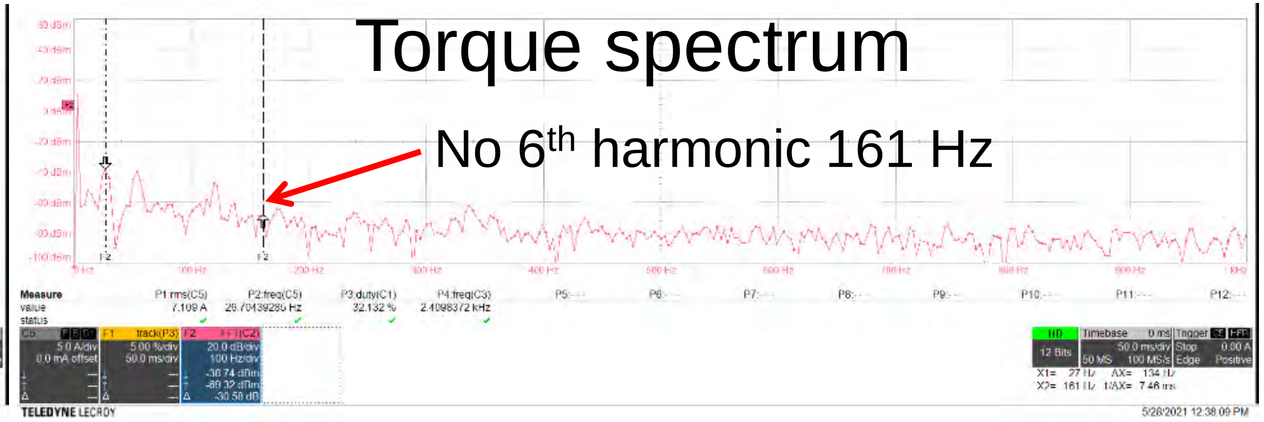
Deadtime Effect – Mechanical Loss

Reduction in 6th harmonic = lower mechanical loss

500 ns deadtime



21 ns deadtime



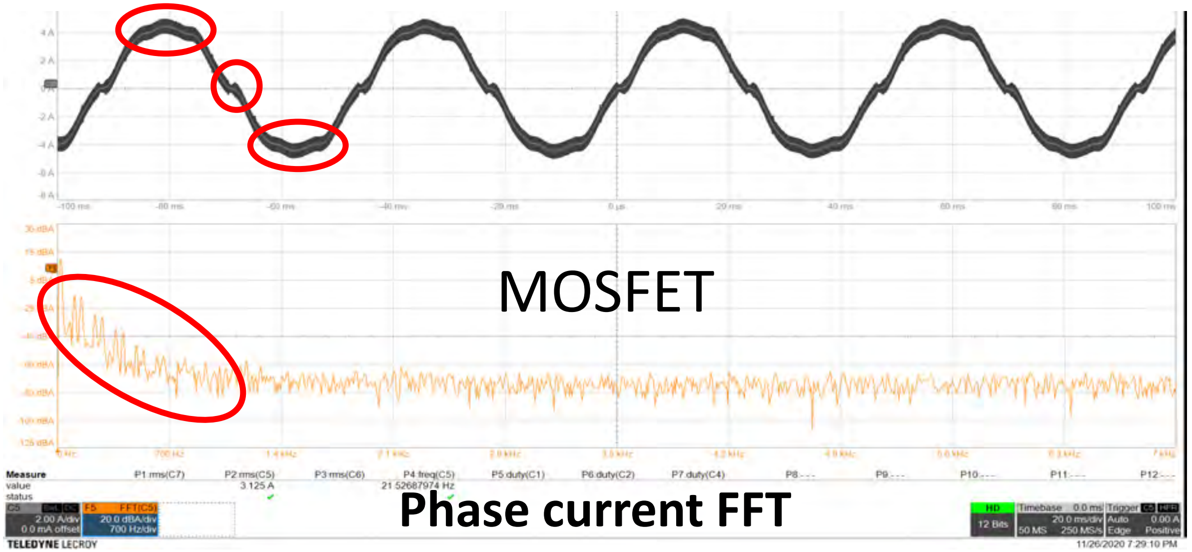
$V_{DC} = 36$ V , $I_{phase} = 5$ A_{RMS}, $f_{SW} = 20$ kHz, 400 RPM

- Torque signal is obtained with a torque/speed transducer
- The 6th harmonic of the torque signal is removed when dead time is reduced to 21ns -> phase current is converted in higher torque

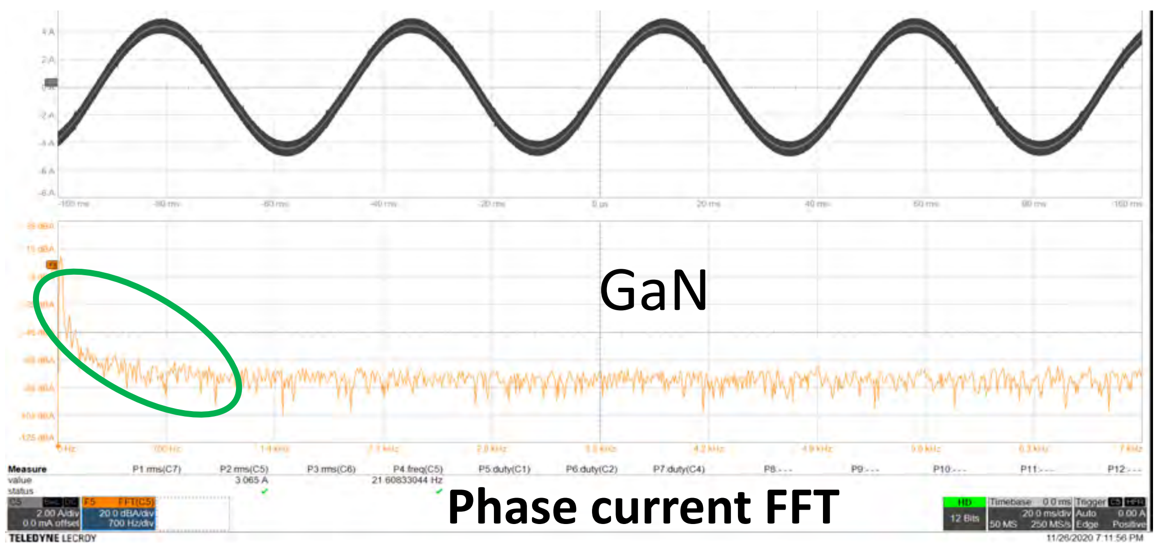
Deadtime Effect – LF EMI Reduction

Reduction in Low Frequency Harmonics = Lower LF EMI

500 ns deadtime



21 ns deadtime

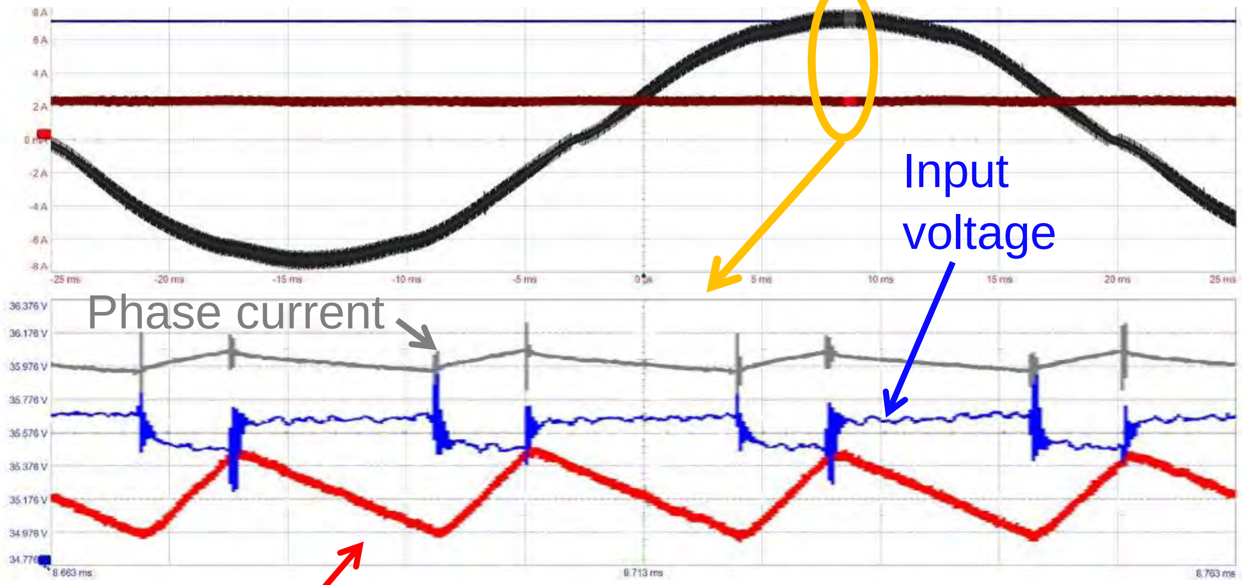


$V_{DC} = 36\ V\ ,\ I_{phase} = 5\ A_{RMS},\ f_{SW} = 40\ kHz$

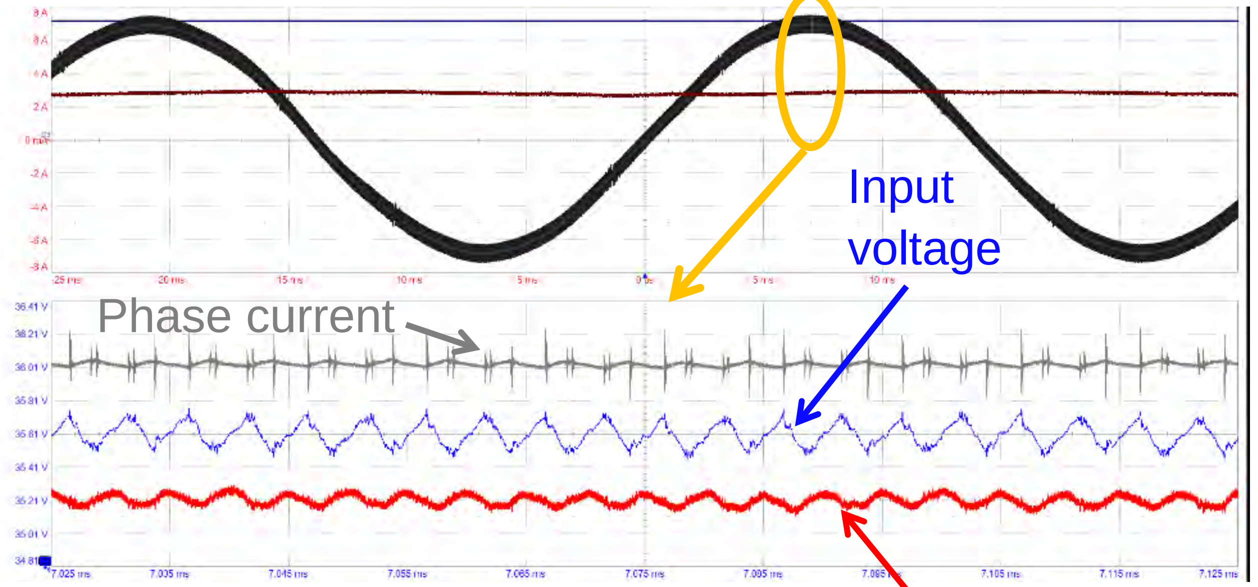
Very low deadtime improves the inverter linearity to almost ideal waveforms

Input Voltage and Current Ripple Comparison

500 ns deadtime, f_{SW} = 20 kHz



21 ns deadtime, f_{SW} = 100 kHz



V_{DC} = 36 V , I_{phase} = 5 A_{RMS}

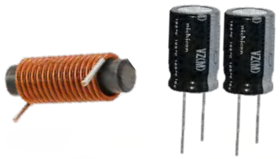
Inverter Stage

Input Power	**121.3**W
Output Power	119.6W

Motor Stage

Mechanical Power	**79.3**W

Input filter
2.7 µH + 660 µF



Inverter Stage

Input Power	**113.3**W
Output Power	111.3W

Motor Stage

Mechanical Power	**81.4**W

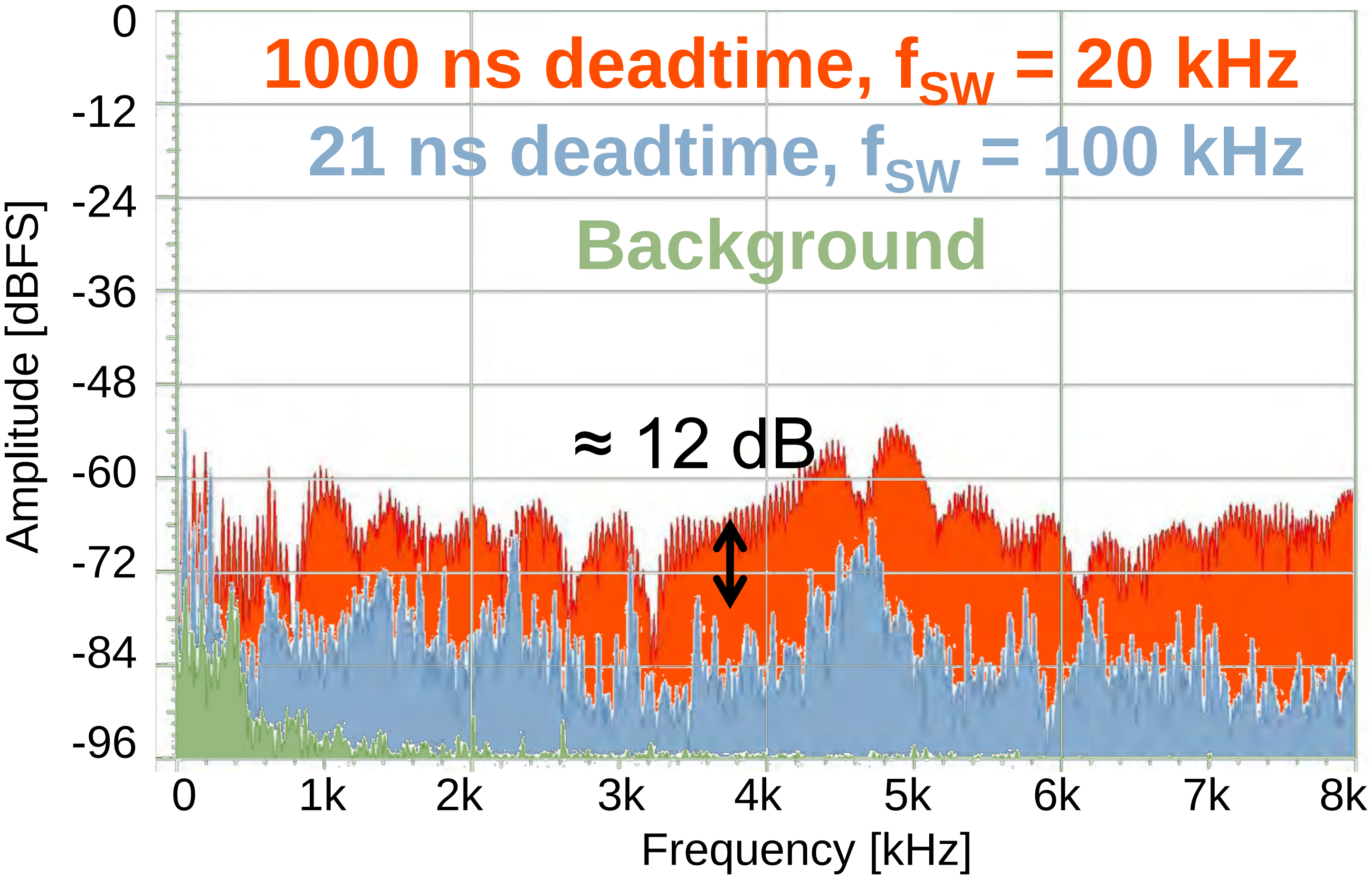
Input filter
44µF

Overall Effect of High Frequency

Setup	Inverter 20kHz 500ns dead time 400 RPM 5 Arms	GaN inverter 100kHz 14ns dead time 400 RPM 5 Arms
Input Inductance	2.7 μH	None
Input capacitor	660 μF electrolytic	44 μF ceramic
Pin	121.3 W	113.3 W
Pout	119.6 W	111.3 W
$\eta_{inverter}$	98.5 %	98.2%
Speed	42.25 rad/s	41.94 rad/s
Torque	1.876 N·m	1.940 N·m
Pmech	79.3 W	**81.36 W**
η_{motor}	66.3 %	73.1 %
η total efficiency	65.3 %	71.8 %

Audible Emissions Comparison

Significant reduction in audible spectral content



More information links:
https://epc-co.com/epc/Applications/MotorDrive.aspx
Audio video:
https://www.youtube.com/watch?v=nr80sdYyL-M&t=58s

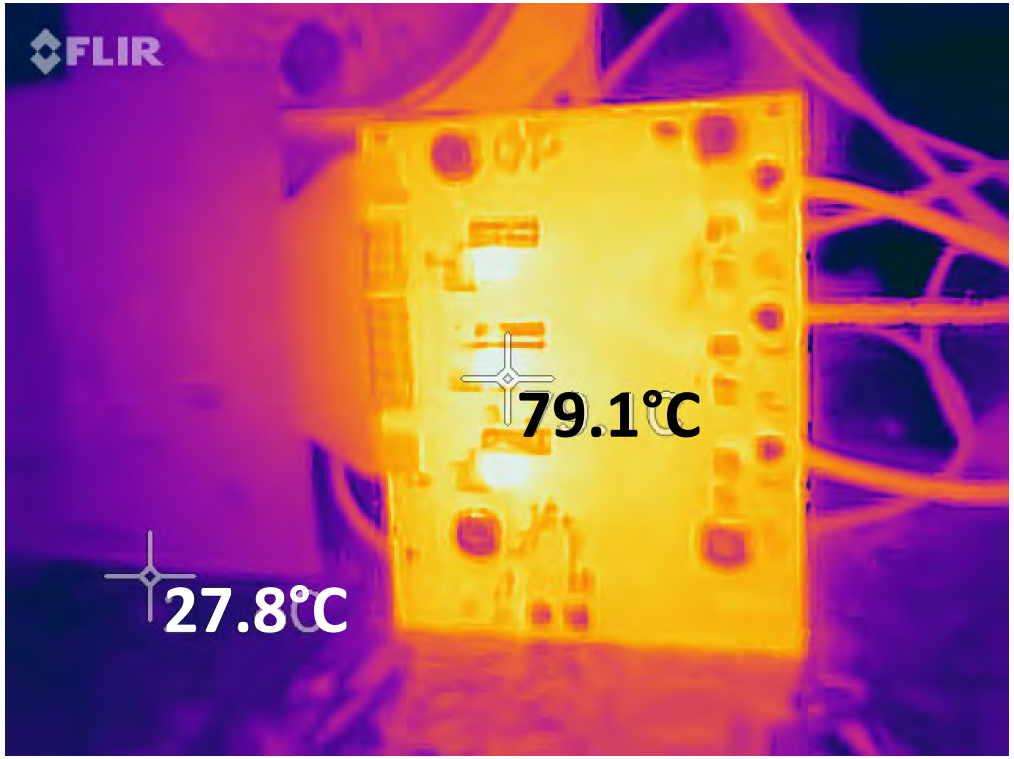
SpectrumView
Oxford Wave Research Ltd.

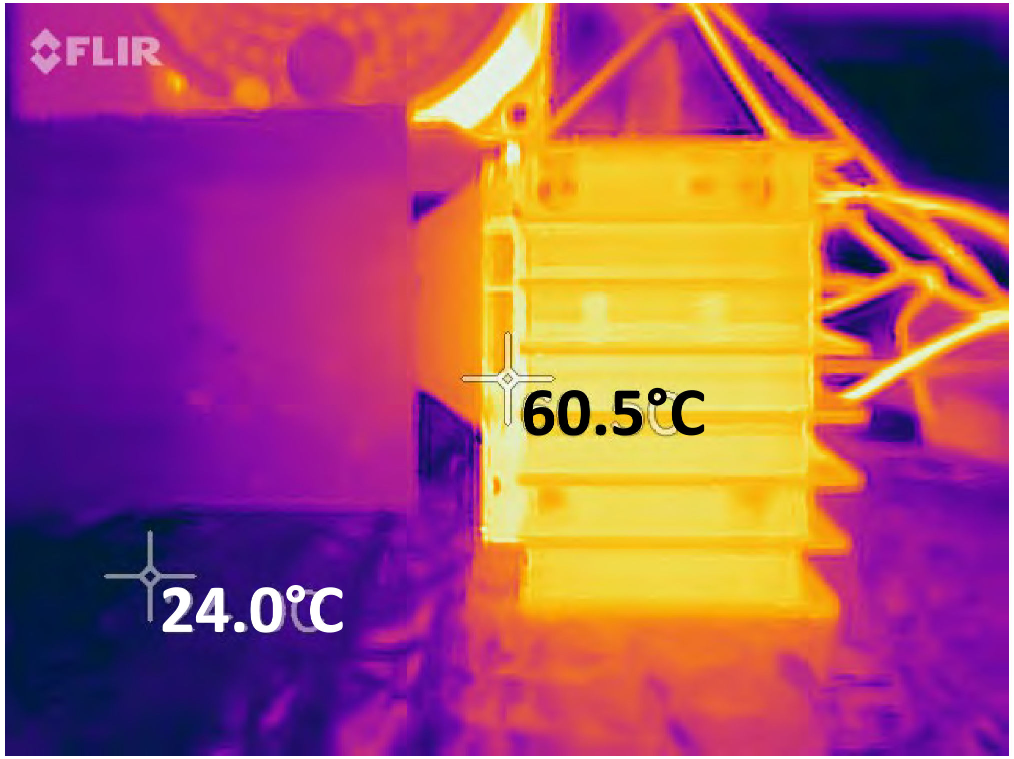
V_{DC} = 48V, I_{ph} = 0.5 A_{RMS} (unloaded motor), f_{motor} = 66 Hz

Setup #1 Thermal Performance

- 6.0 A_{RMS}
- No heatsink

- 10 A_{RMS}
- With heatsink mounted

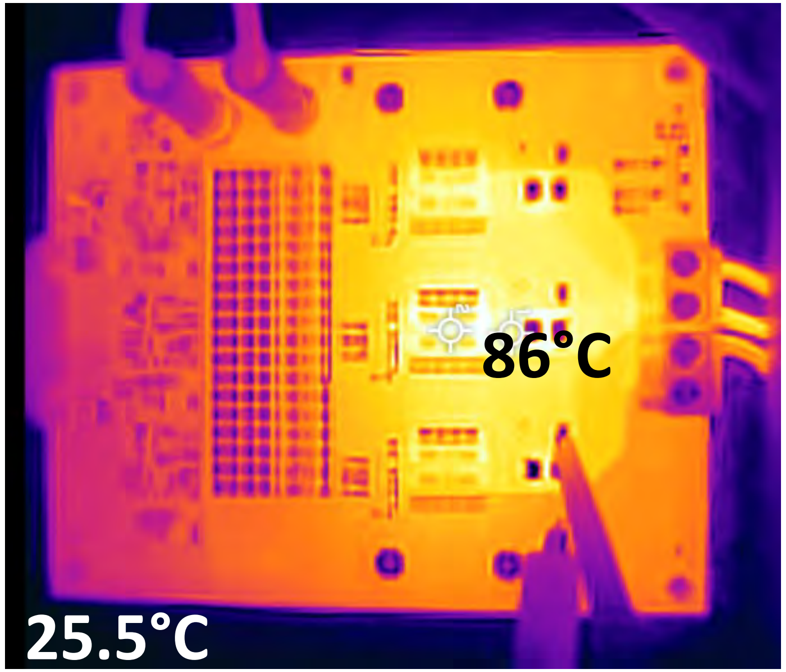




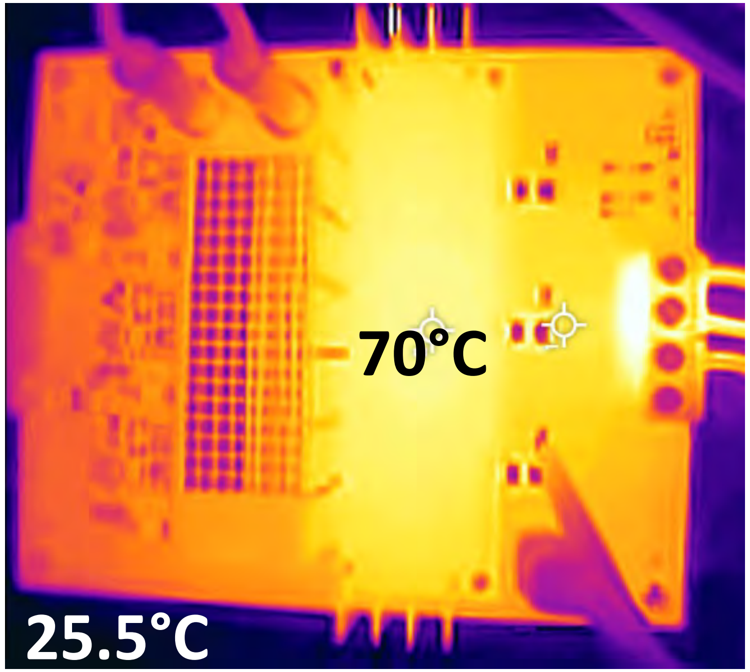
EPC9146 44 V_{DC}, 40 kHz, 21 ns deadtime, Natural convection

Setup #2 Thermal Performance

- 20 A_{RMS}
- No heatsink

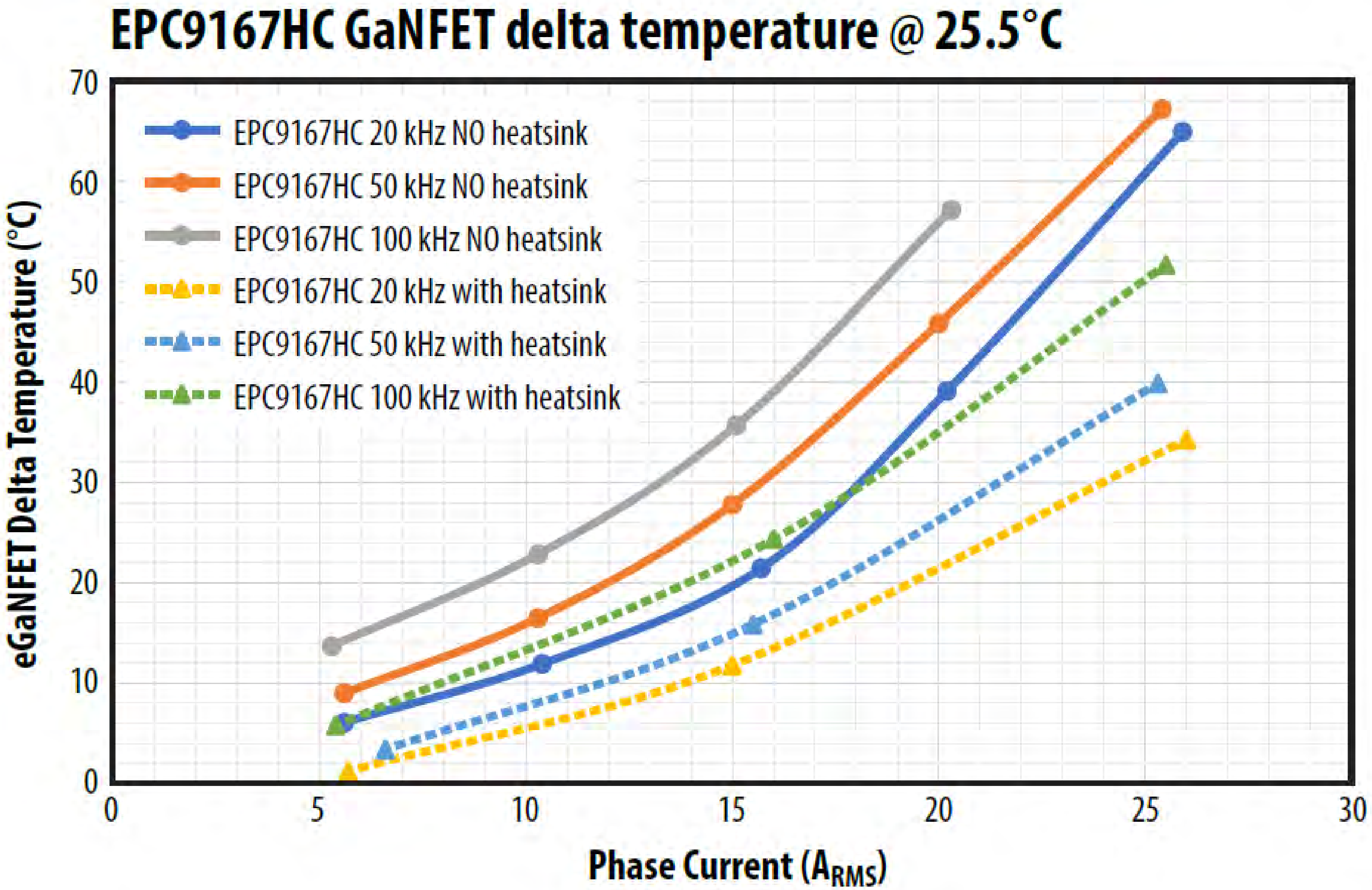


- 25 A_{RMS}
- With heatsink mounted



EPC9167HC 48 V_{DC}, 100 kHz, 50 ns deadtime, Natural convection

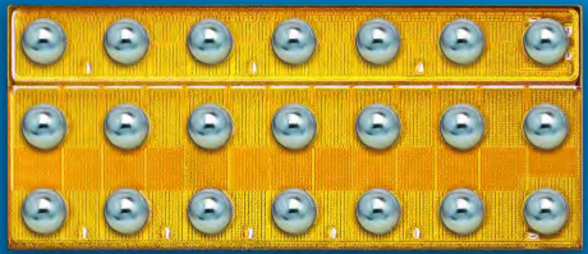
Setup #2 Thermal Performance



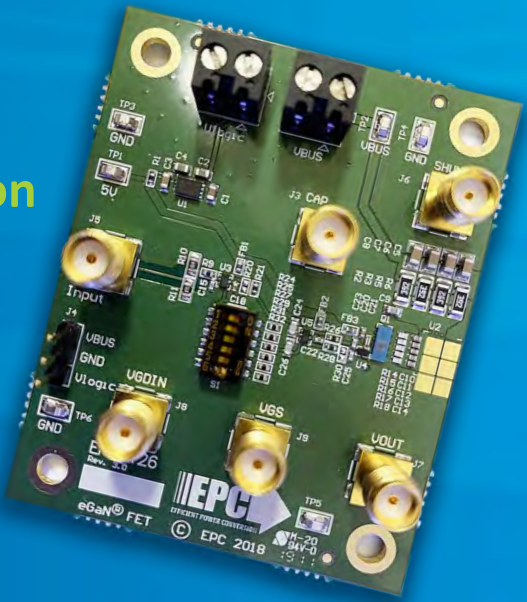
EPC
EFFICIENT POWER CONVERSION

How To GaN Video Series

3rd Edition Textbook



eGaN® FETs and ICs



Evaluation Kits

epc-co.com