

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

*Marco Palma*



# GaN Motor Drive Myth Dispelled

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

- Experimental validation showed:

- Higher system efficiency



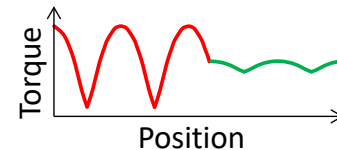
- Lower audible emission



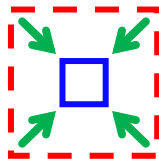
- Improved precision



- 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



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



Lower dead time

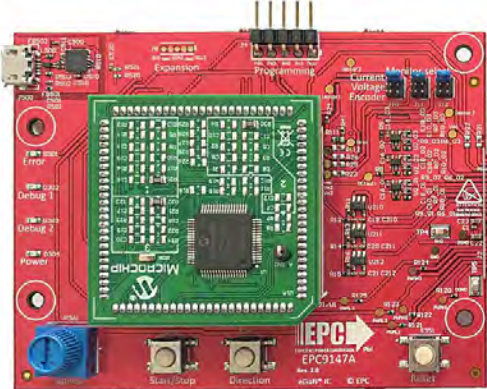


Higher torque per Ampere





# Available GaN Motor Drive Inverters



Microchip  
dsPIC33



EPC9146 -> EPC2152 IC



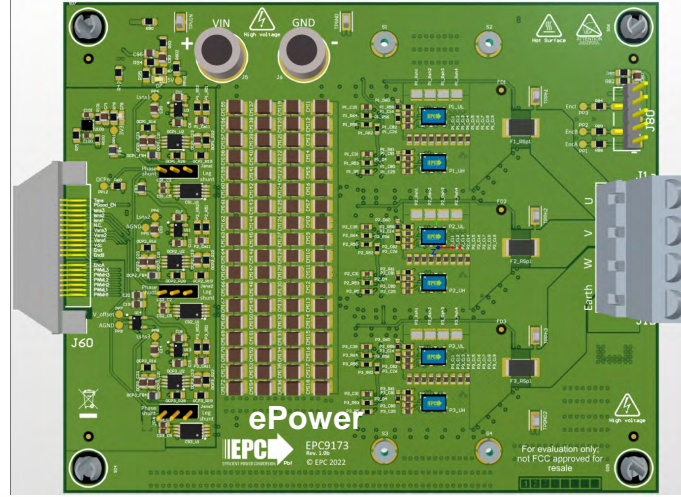
EPC9167HC -> EPC2065



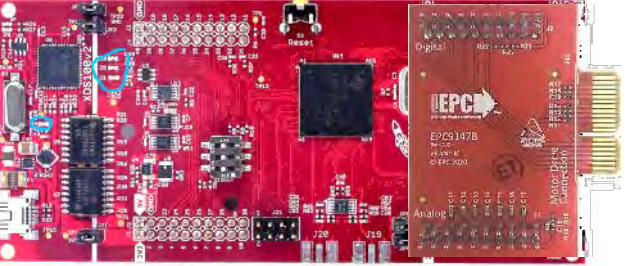
ST  
Nucleo



EPC9176 -> EPC23102 IC



EPC9173 -> EPC23101 IC

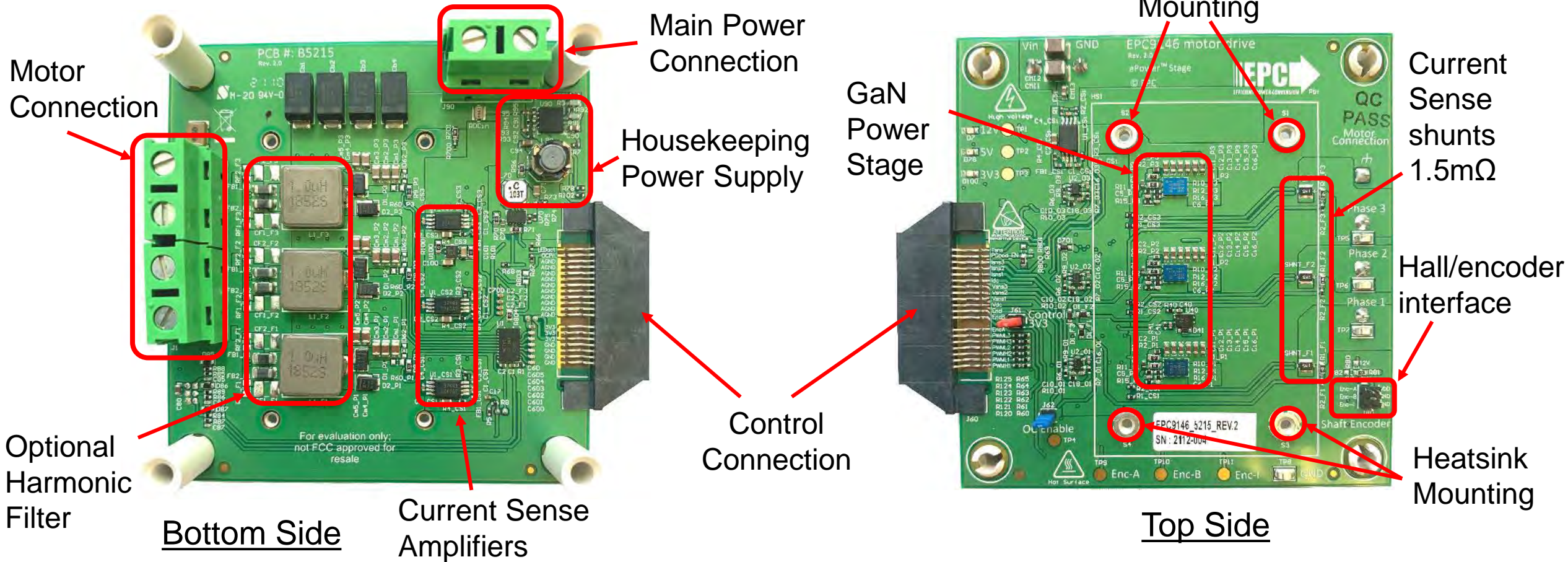


TI Piccolo  
In development



# EPC9146

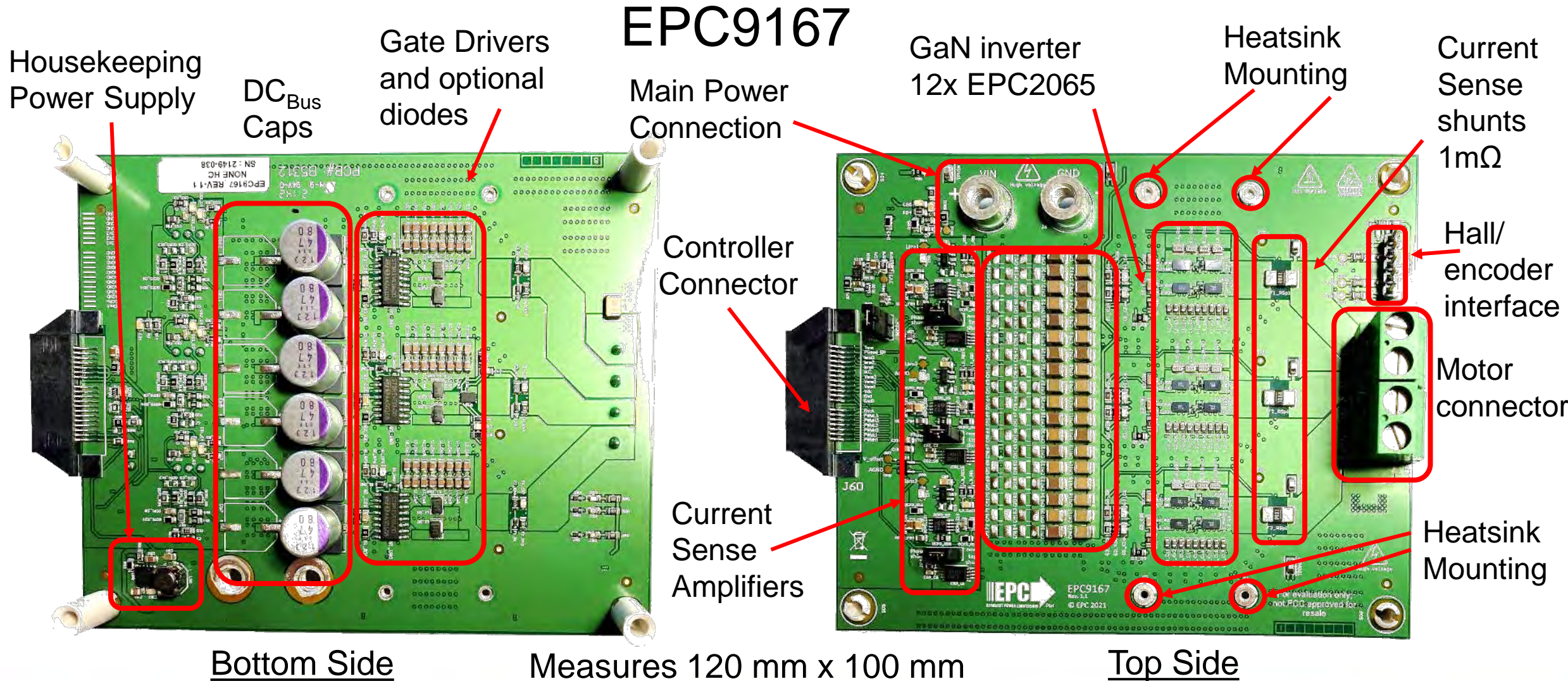
## EPC9146



Measures 81 mm x 75 mm

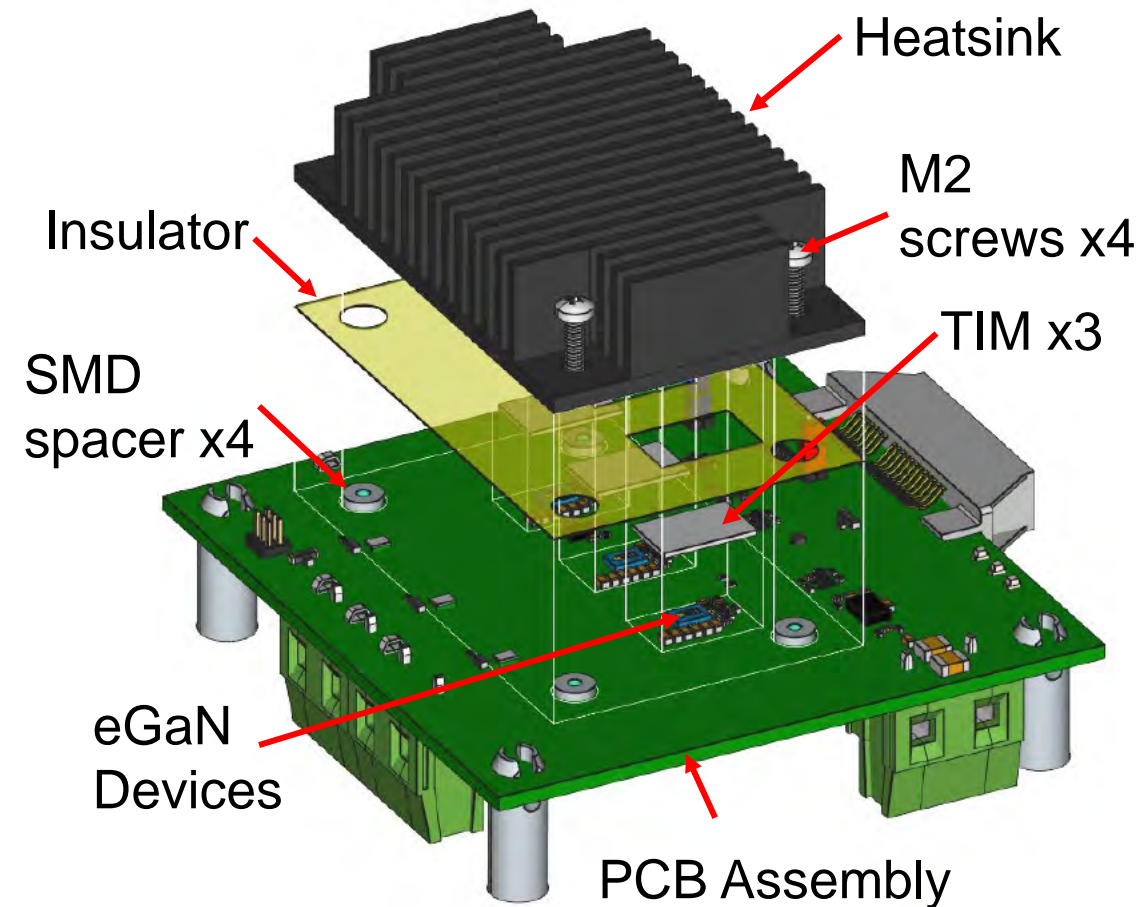


# EPC9167



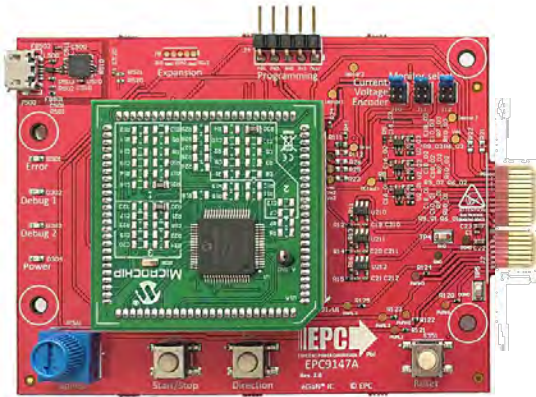
# Thermal Implementation

- 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



The screenshot shows the MPLAB X IDE v5.45 interface. The 'Resource Management' window is open, showing the 'Libraries' section with 'motorBench® Development SW' highlighted. The 'PMSM Motor' configuration window is also open, displaying various parameters for the motor.

**Motor Parameters:**

Parameter	Active Value	Unit	Measurement
$R_s$	0.800		0
$L_d$	1.00		0
$L_q$	1.00		0
$K_e$	10.2		0
$B$	$301 \times 10^{-6}$		0
$T_f$	0.0746		0
$J$	$867 \times 10^{-4}$		0

**Motor Identification:**

- ID: Teknic
- Motor Name: EPC Demo standard motc
- Company Name: Teknic
- Part Number: M-3411P-LN-08D
- Additional Info: rshunt=1.0ohm
- MicrochipDIRECT Part Number: [Empty]

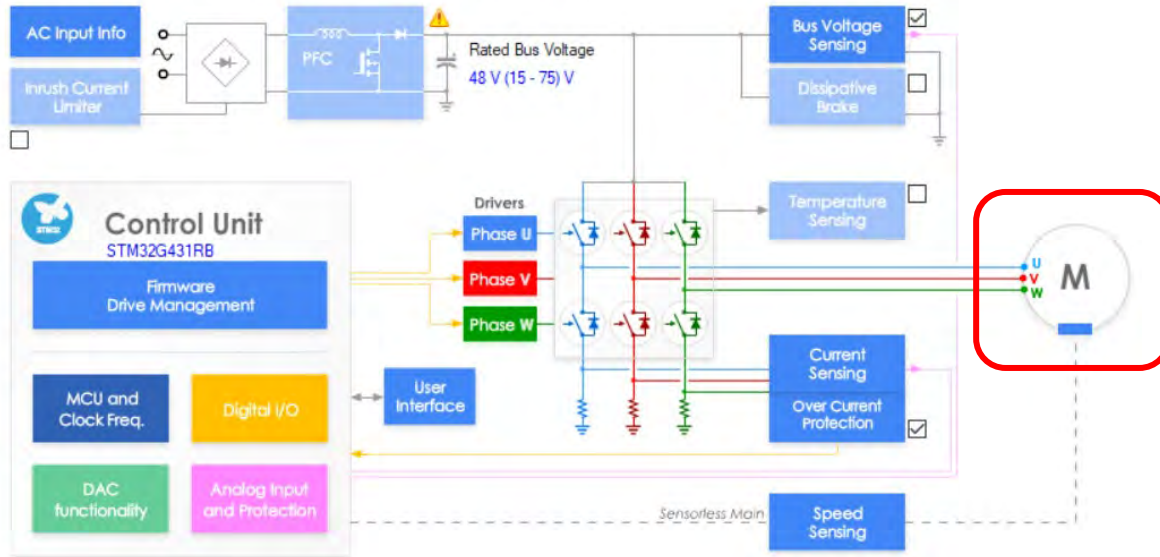
**Motor Nameplate:**

- Rated Current : Continuous: 14.0 A
- Rated Current : Peak: 14.0 A
- Rated Voltage: 48.0 V
- Nominal Speed: 1300.0 RPM
- Maximum Speed: 1300.0 RPM
- Number of Pole Pairs: 4.00



# ST Motor Control Workbench

Motor: *Dummy Nema34* - Control Board: *NUCLEO-G431RB* - Power Board: *X-NUCLEO-IHM08M1*



Motor - Parameters

Motor Sensors

Magnetic structure: Surface Mounted PMSM

Electrical parameters:

- Pole Pairs: 4
- Max. Application Speed: 3000 rpm
- Nominal Current: 6.00 Apk
- Nominal DC Voltage: 48.0 V
- Rs: 0.40 Ohm
- Ls: 0.466 mH
- B-Emf constant: 10.2 Vms/krpm

Motor - Parameters

Motor Sensors

Sensors:

- Hall sensors
  - Sensors displacement: 120 deg
  - Placement electrical angle: 300 deg
- Quadrature encoder
  - Pulses per mechanical revolution: 400
- Encoder Alignment

ST Motor Control Workbench [G431-EPC9145-DummyNema34\_50k\_100n]

File Tools Help Documentation

Port: COM5 | 115200 | Close Monitor

Status: **Firmware: ST MC SDK Ver. 5.4.5**

Basic Advanced Registers Configuration

Faults:

- Fault over
- FOC duration
- Over voltage
- Under voltage
- Overheat
- Start-up failure
- Speed feedback
- Over current
- Software error

Monitor: Measured speed (rpm) 0

Bus Voltage (Volt): 47

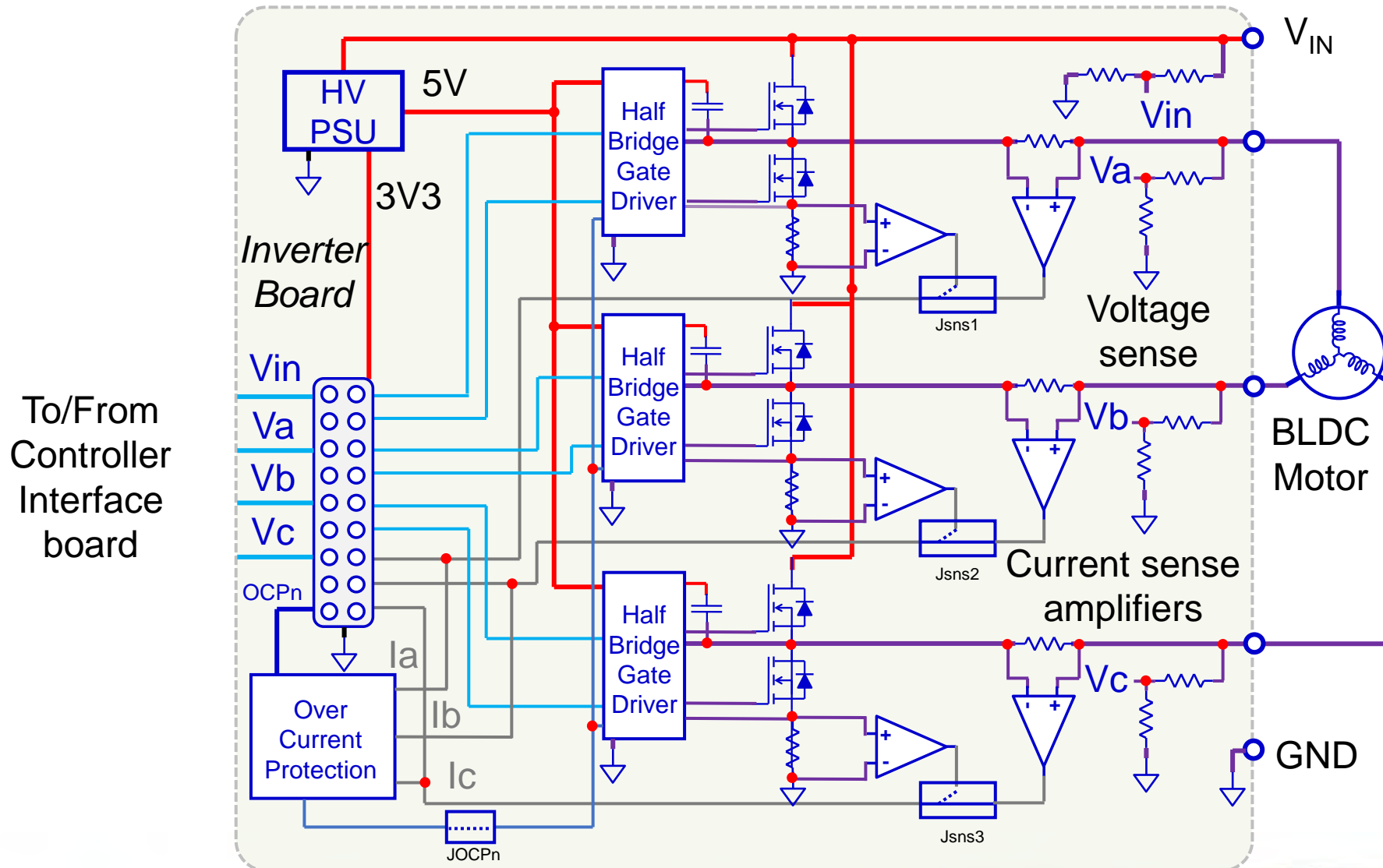
Motor Power (W): 0

Heatink: 25

Measured speed (rpm): 0

Final ramp speed (rpm): 1278

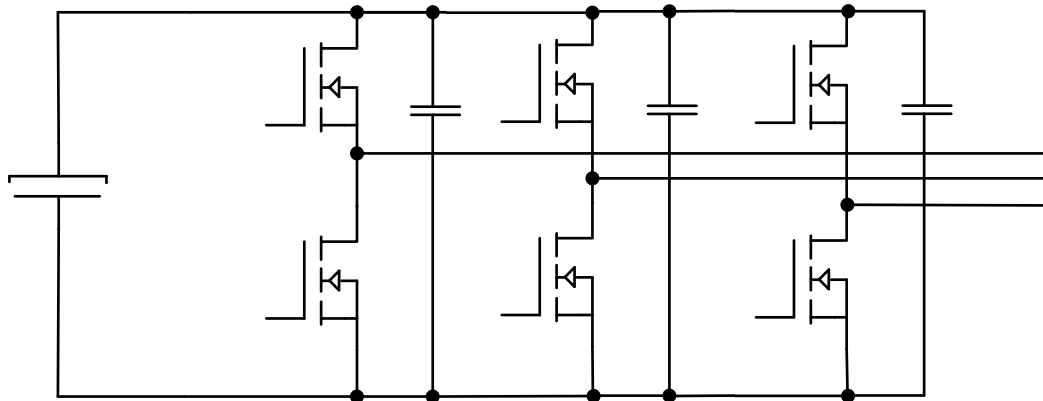
# BLDC Motor Drive Overview





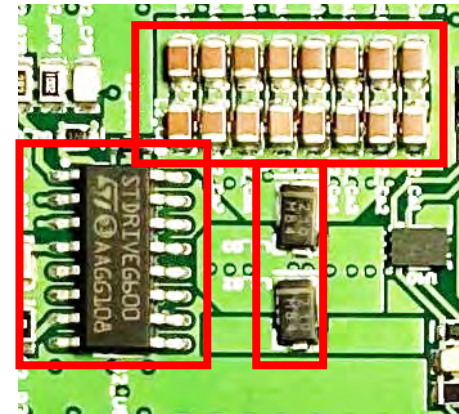
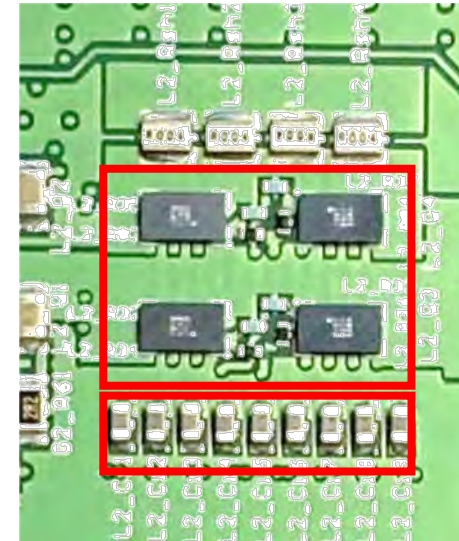
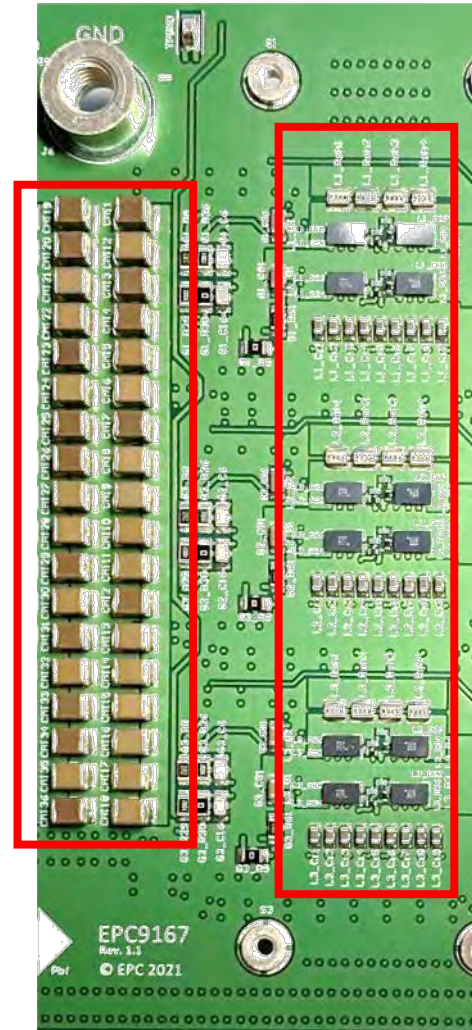
# GaN Inverter Basic Schematic

GaN Inverter

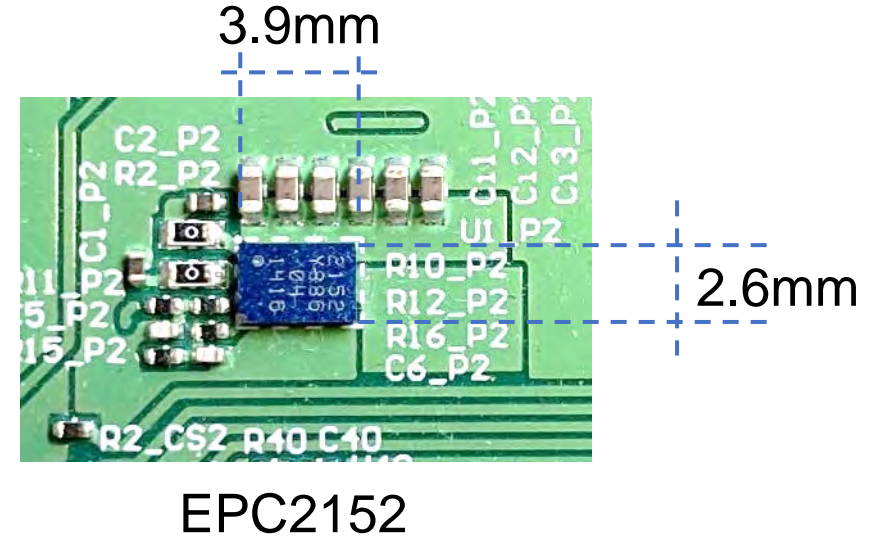
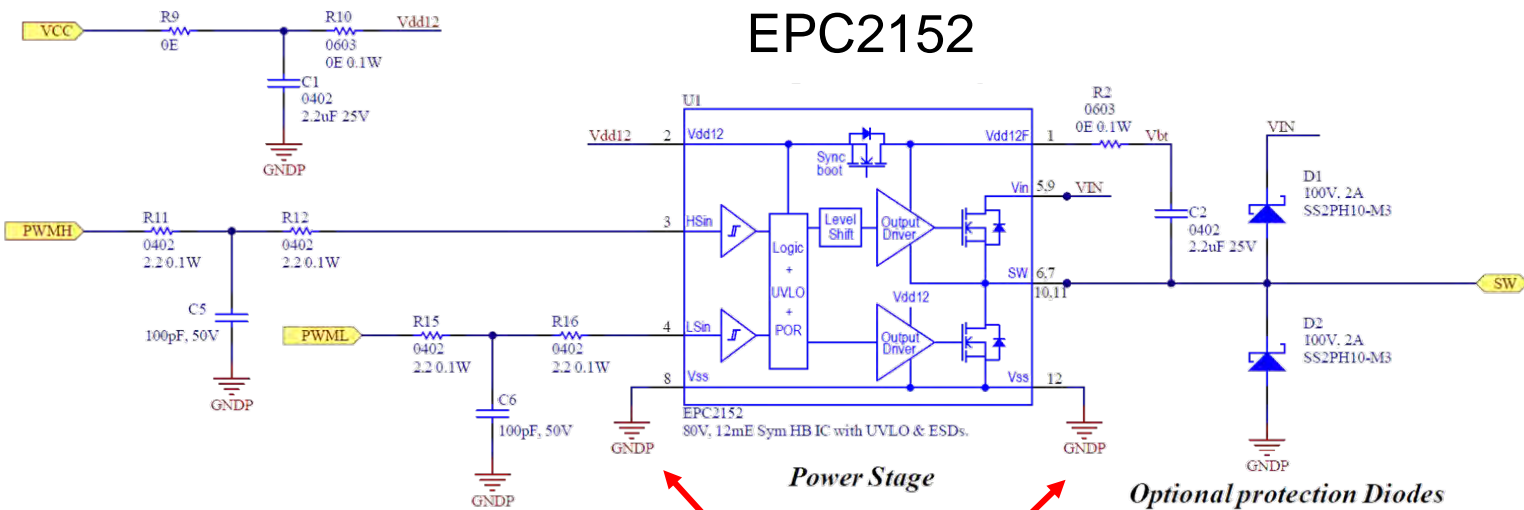


Low and Middle Frequency capacitor

High Frequency capacitors



# Integrated Power Devices for Motor Drive



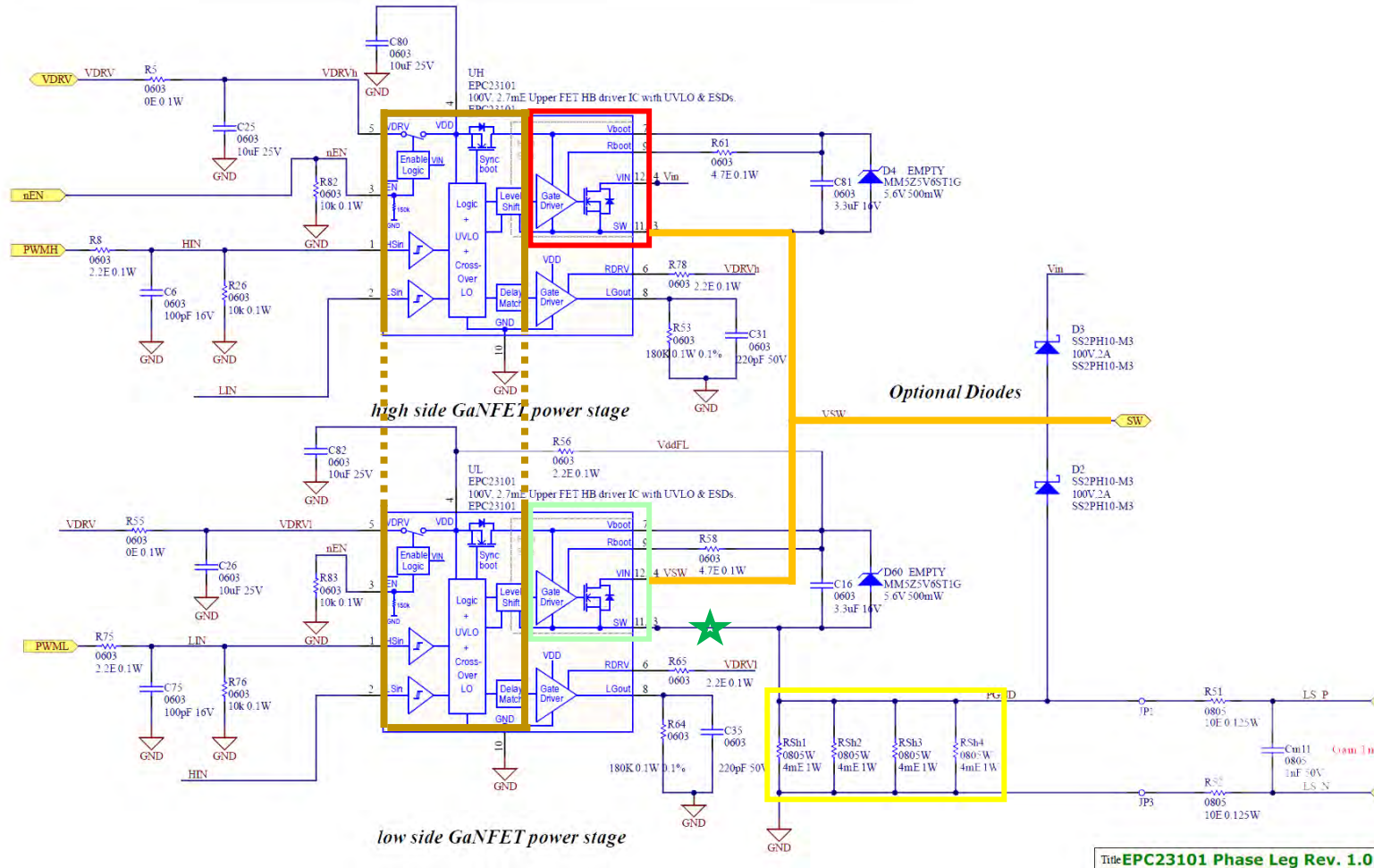
Same ground: can only be used with phase current sensing

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

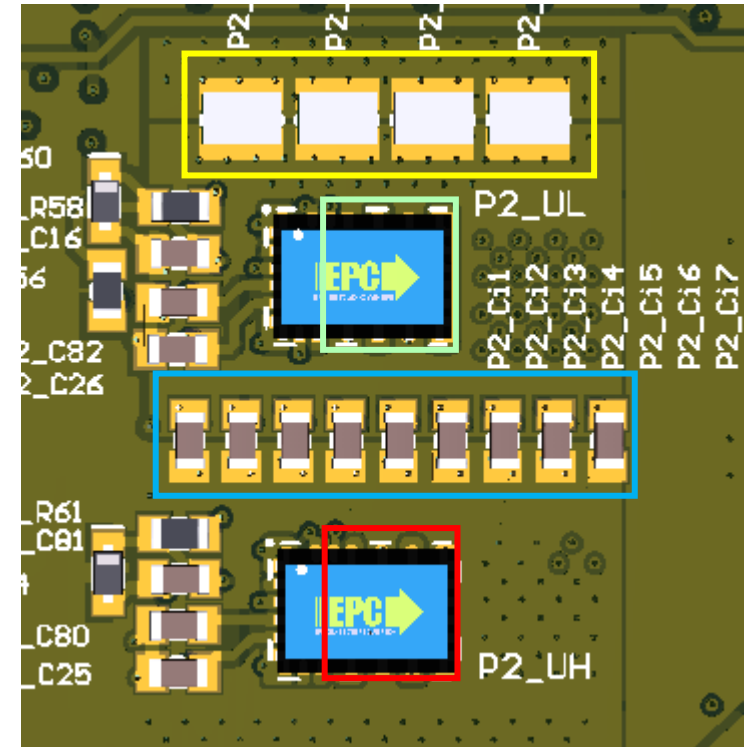




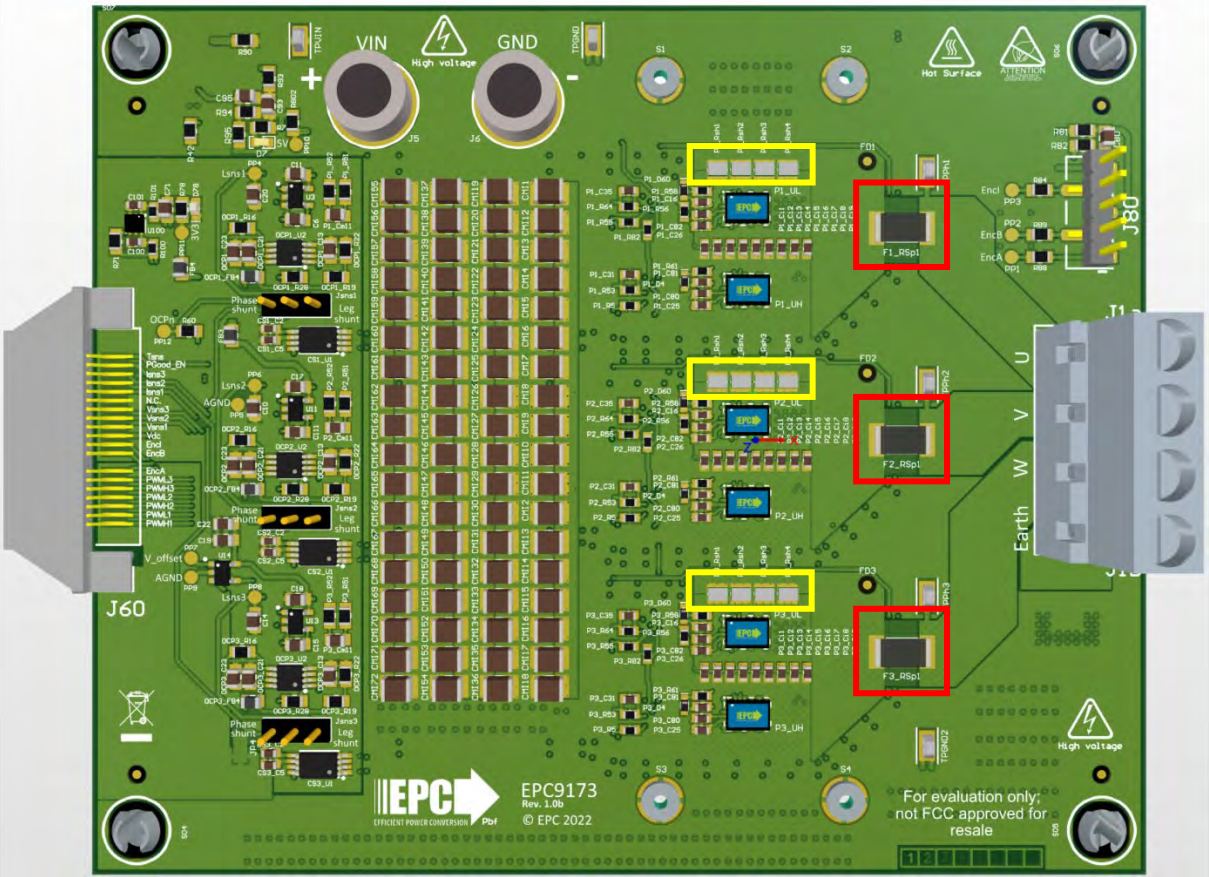
# Integrated Power Devices for Motor Drive



EPC23101

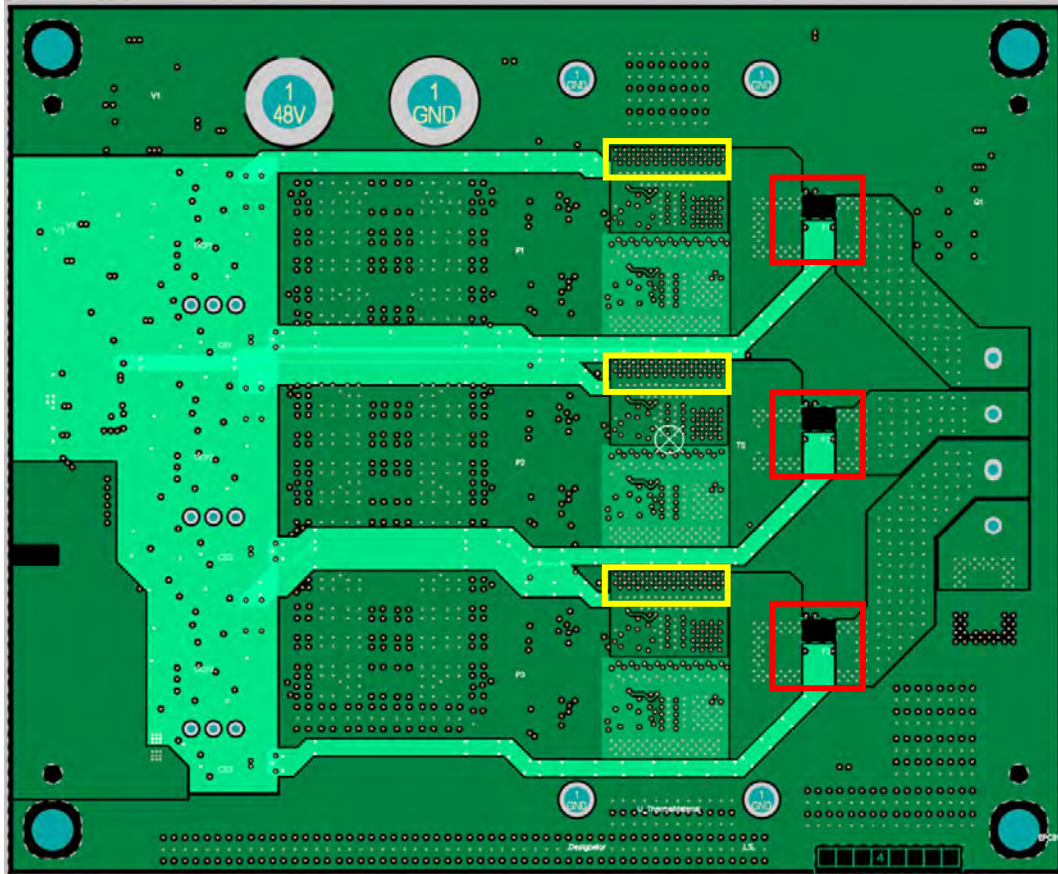


# Shunt Signal Kelvin Sensing

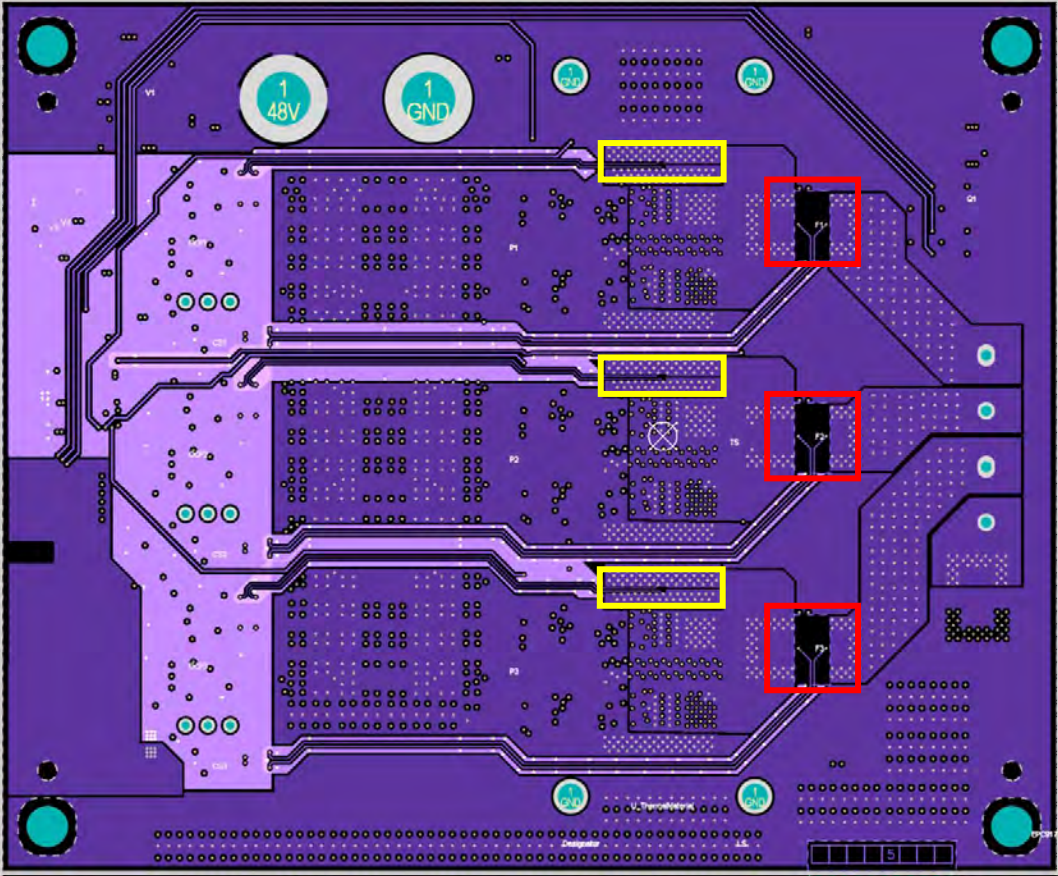




# Shunt Signal Kelvin Sensing

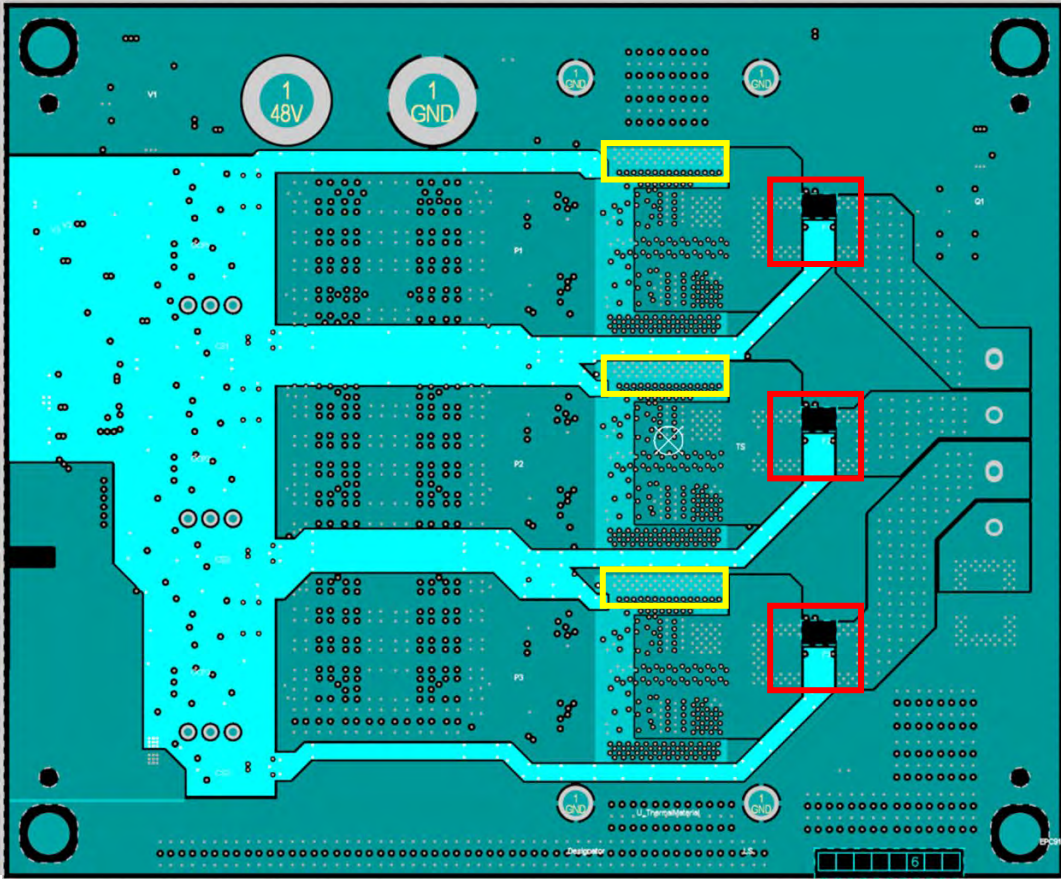


# Shunt Signal Kelvin Sensing

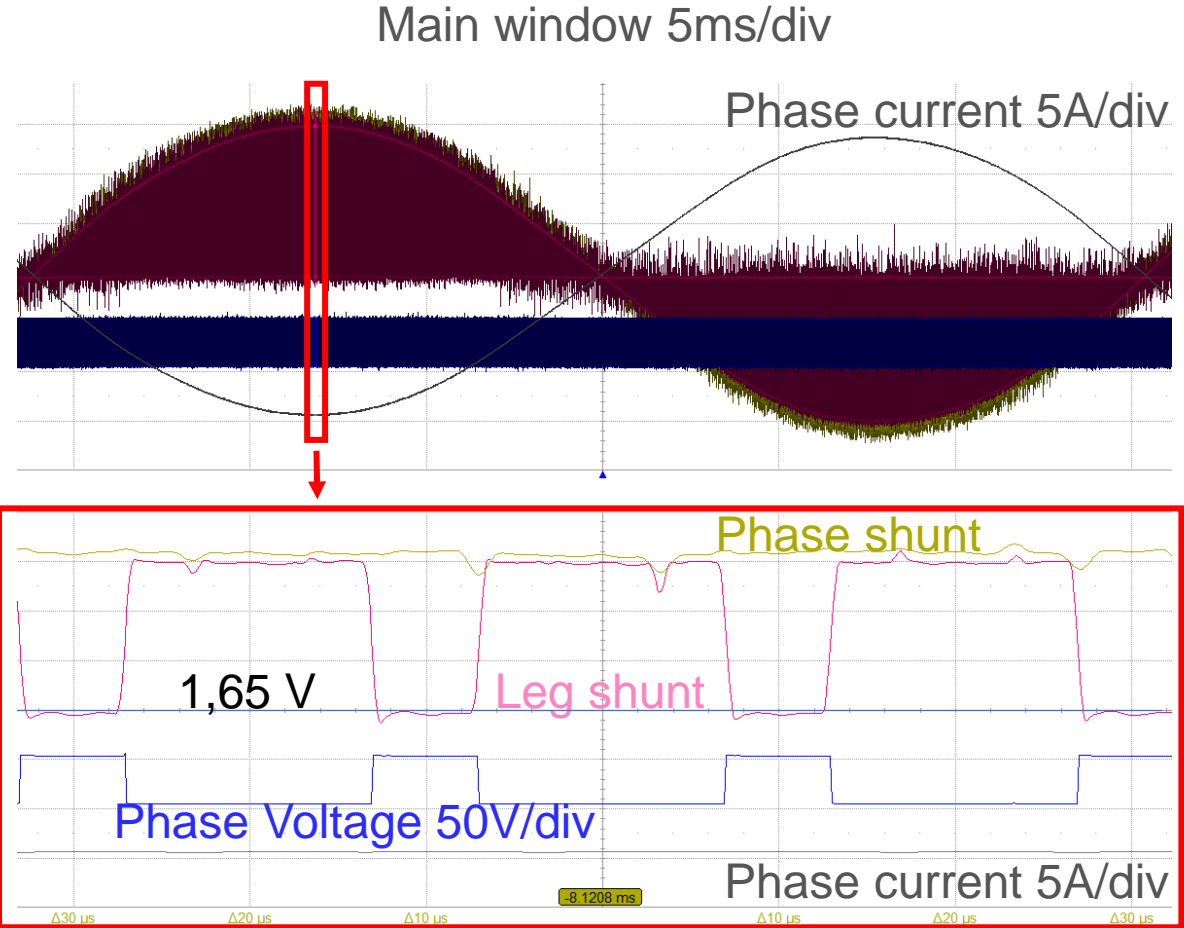
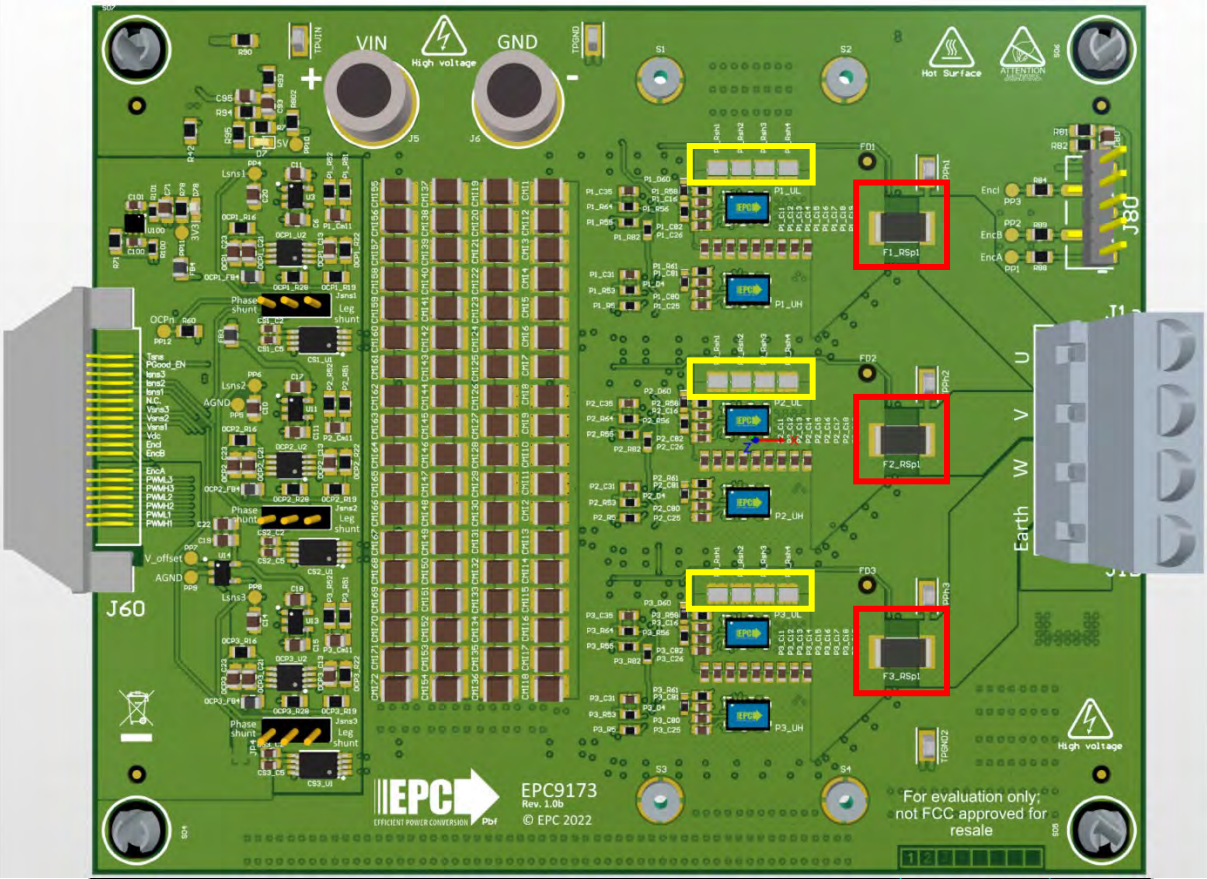




# Shunt Signal Kelvin Sensing



# Shunt Signal Kelvin Sensing



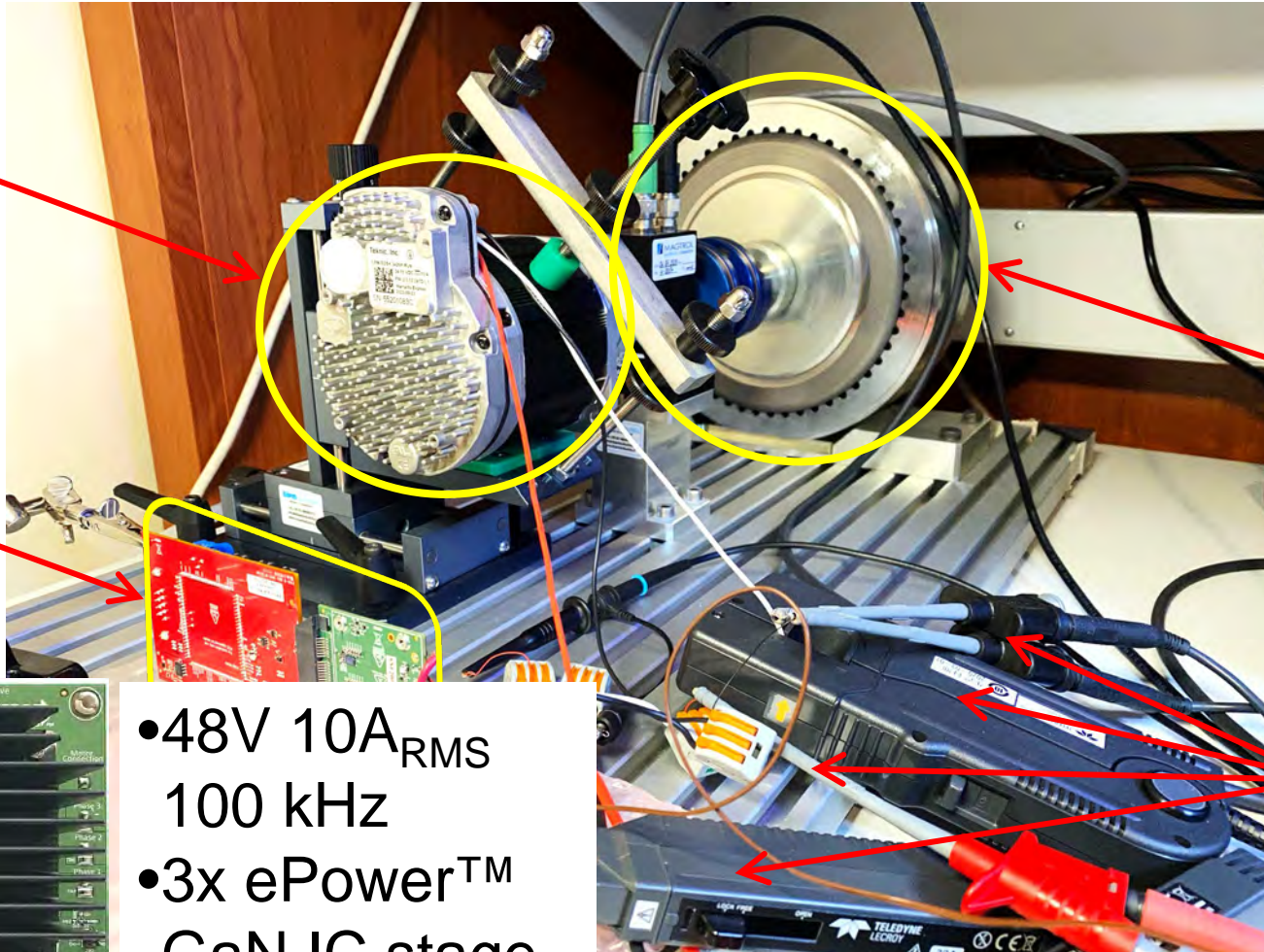
Zoom window 10µs/div



# Experimental Testing Setup #1

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

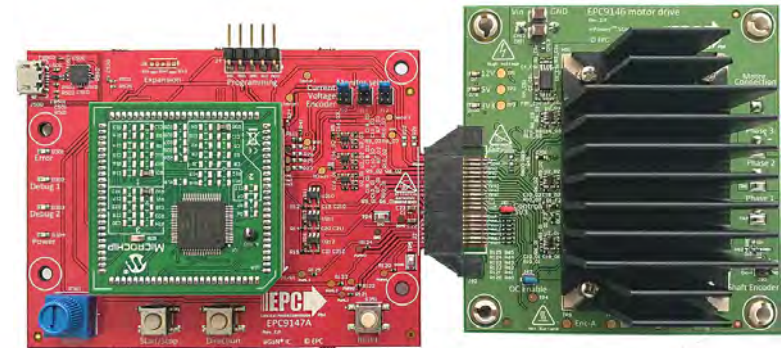
Motor drive:  
EPC9146 Inverter  
EPC9147A Controller



hysteresis  
brake  
dynamometer

Measurement  
Probes

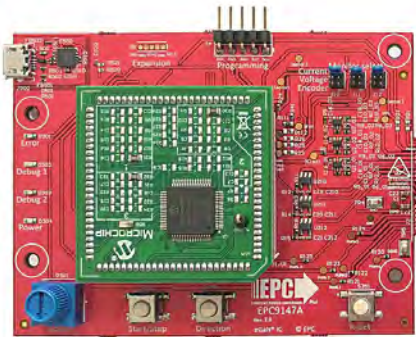
- 48V 10A<sub>RMS</sub>  
100 kHz
- 3x ePower™  
GaN IC stage



# Experimental Testing Setup #2

EPC9147A  
Controller

EPC9167 Inverter  
12x EPC2065 GaN FET stage



**This motor has**

$R_{L-L} = 90 \text{ m}\Omega$  line to line resistance

$L_{L-L} = 140 \text{ }\mu\text{H}$  line to line inductance

$pp = 36$  pole pairs

$K_e = 27.15 \text{ V}_{\text{rms}}/\text{krpm}$

Line to star center point

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

Specifications:

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

**Load Motor:**

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

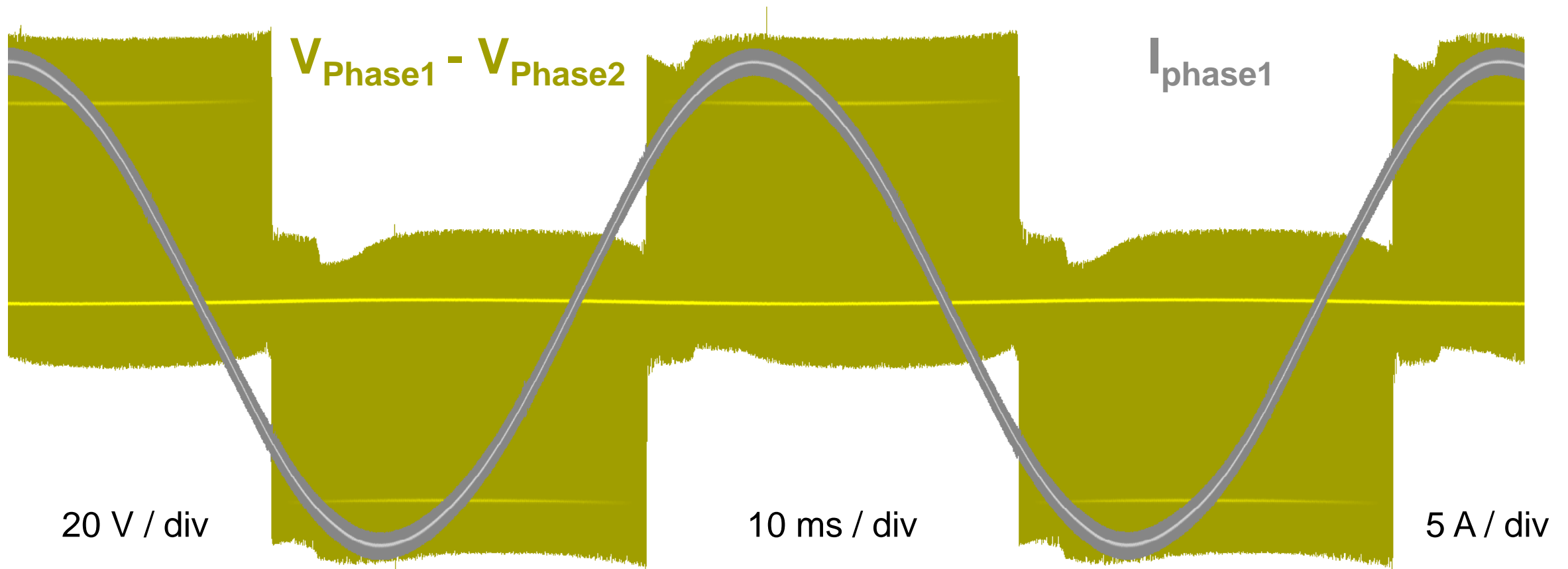
Testing with and without heatsink





# Setup #1 - Basic Operation

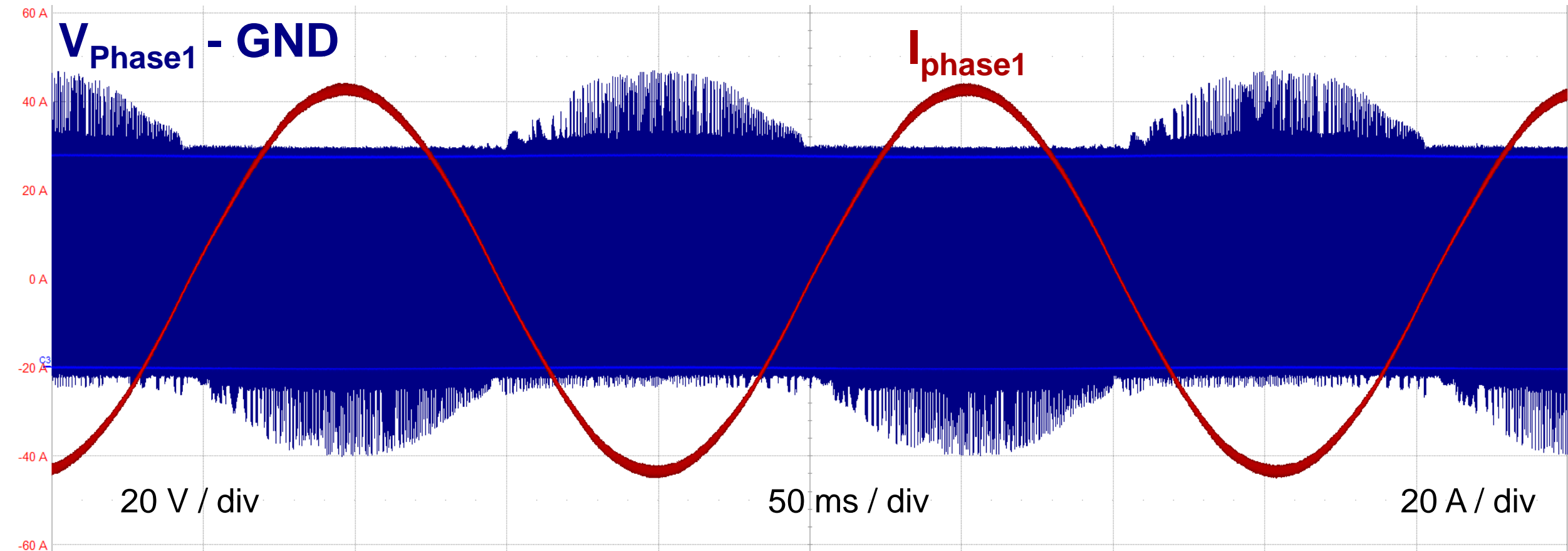
Clean low THD current waveform



$V_{\text{DC}} = 48\text{V}$ ,  $I_{\text{ph}} = 10\text{ A}_{\text{RMS}}$ ,  $f_{\text{SW}} = 100\text{ kHz}$ ,  $\text{DT} = 21\text{ ns}$ ,  $f_{\text{motor}} = 66\text{ Hz}$

# Setup #2 - Basic Operation

Clean low THD current waveform



$$V_{\text{DC}} = 48\text{V}, I_{\text{ph}} = 30 \text{ A}_{\text{RMS}}, f_{\text{SW}} = 100 \text{ kHz}, \text{DT} = 50\text{ns}, f_{\text{motor}} = 5 \text{ Hz}$$

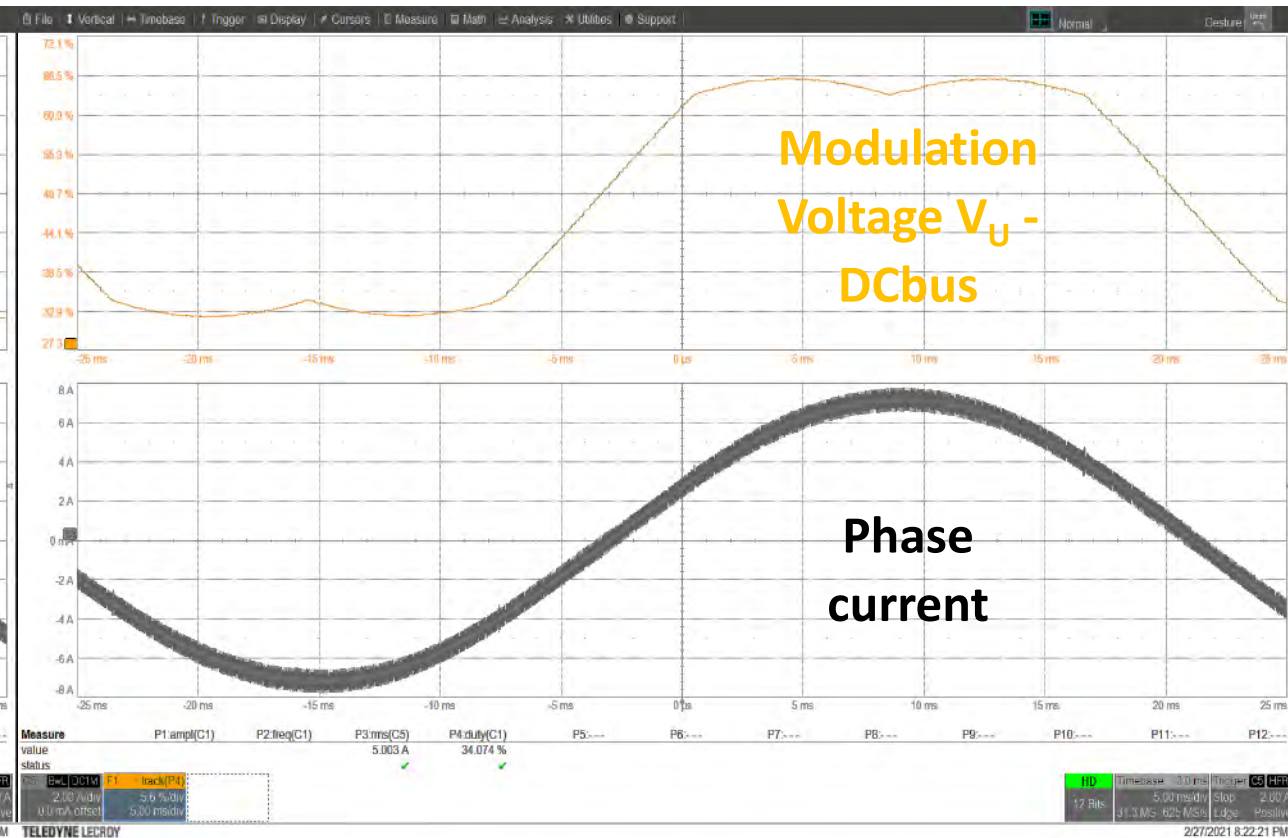
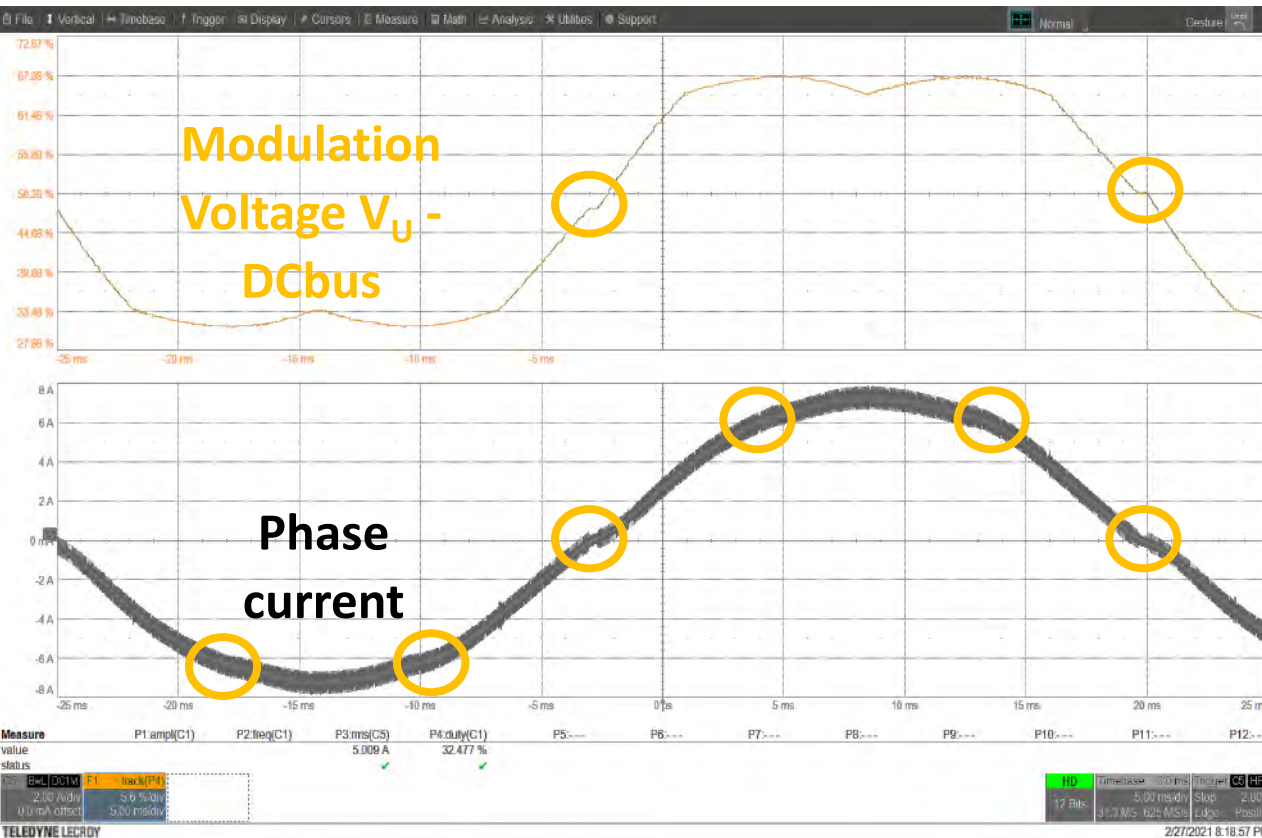


# Deadtime Effect – Torque Ripple

Reduction in current distortion = lower torque ripple

500 ns deadtime

21 ns deadtime



$$V_{DC} = 36 \text{ V} , I_{\text{phase}} = 5 \text{ A}_{\text{RMS}} , f_{\text{SW}} = 20 \text{ kHz}$$

# Deadtime Effect – Mechanical Loss

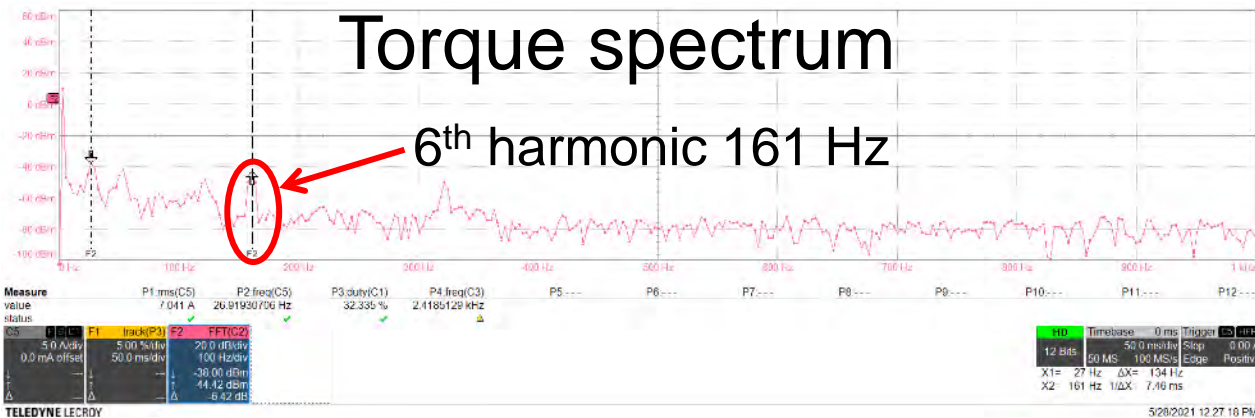
Reduction in 6<sup>th</sup> harmonic = lower mechanical loss

500 ns deadtime

21 ns deadtime

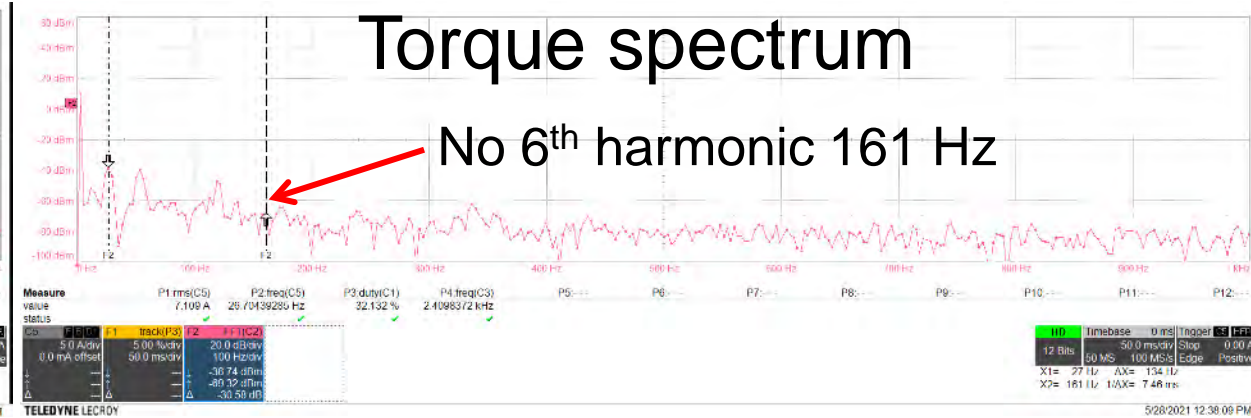
Torque spectrum

6<sup>th</sup> harmonic 161 Hz



Torque spectrum

No 6<sup>th</sup> harmonic 161 Hz



$$V_{DC} = 36 \text{ V} , I_{\text{phase}} = 5 \text{ A}_{\text{RMS}} , f_{\text{SW}} = 20 \text{ kHz} , 400 \text{ RPM}$$

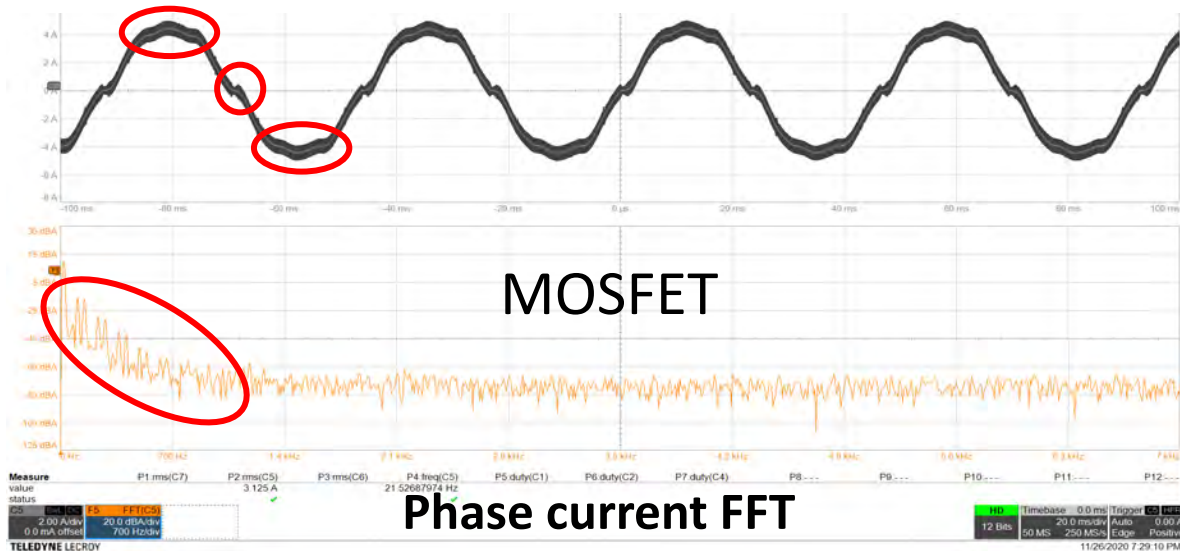
- Torque signal is obtained with a torque/speed transducer
- The 6<sup>th</sup> harmonic of the torque signal is removed when dead time is reduced to 21 ns -> phase current is converted in higher torque



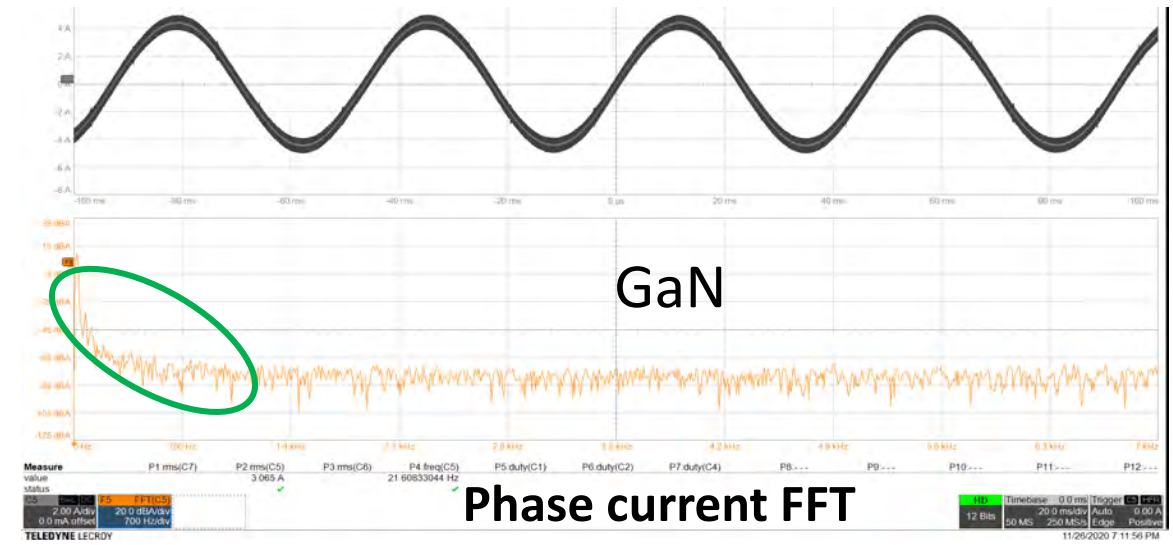
# Deadtime Effect – LF EMI Reduction

Reduction in Low Frequency Harmonics = Lower LF EMI

500 ns deadtime



21 ns deadtime



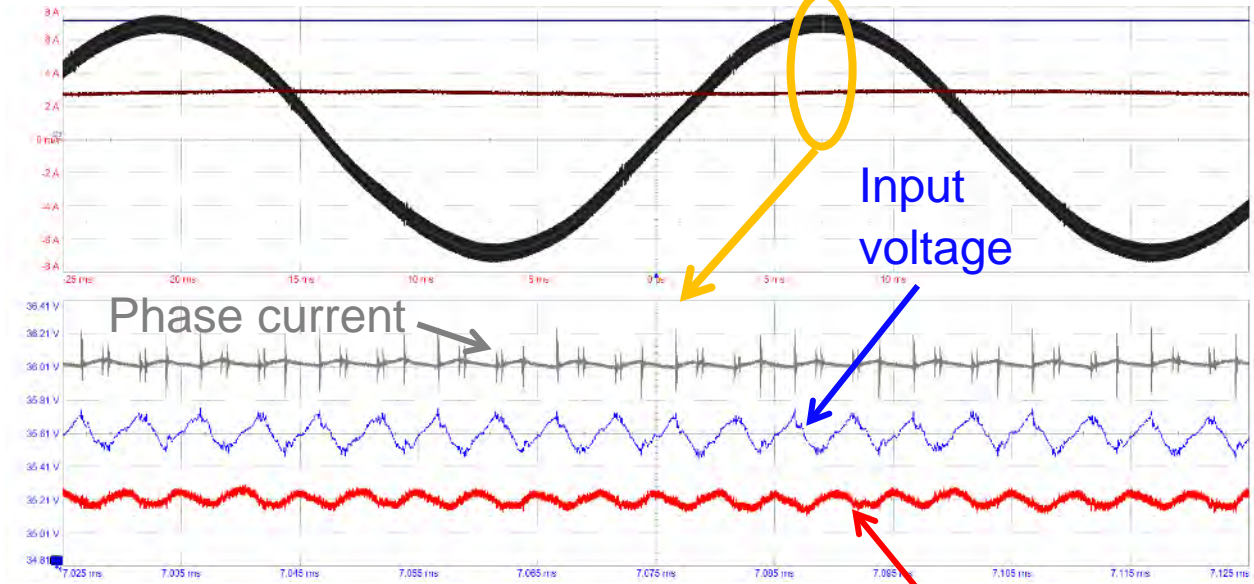
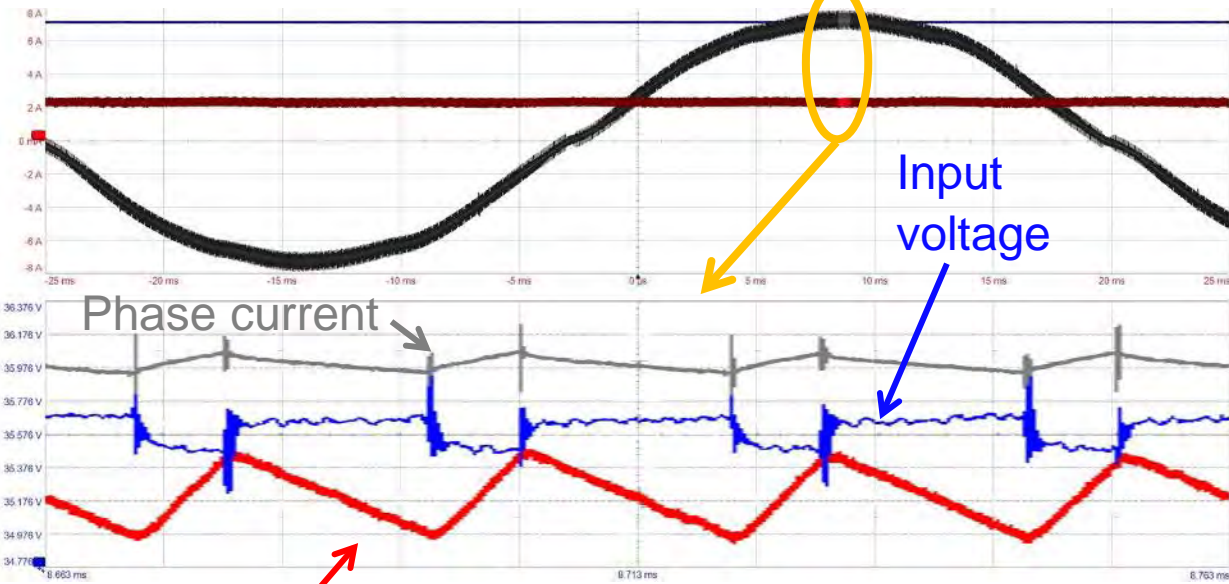
$$V_{DC} = 36 \text{ V} , I_{\text{phase}} = 5 \text{ A}_{\text{RMS}} , f_{\text{SW}} = 40 \text{ kHz}$$

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



Input current  $V_{DC} = 36$  V,  $I_{phase} = 5$  A<sub>RMS</sub>

Input current

Inverter Stage	
Input Power	121.3W
Output Power	119.6W
Motor Stage	
Mechanical Power	79.3W

Input filter  
2.7  $\mu$ H + 660  $\mu$ F



Inverter Stage	
Input Power	113.3W
Output Power	111.3W
Motor Stage	
Mechanical Power	81.4W

Input filter  
44 $\mu$ F



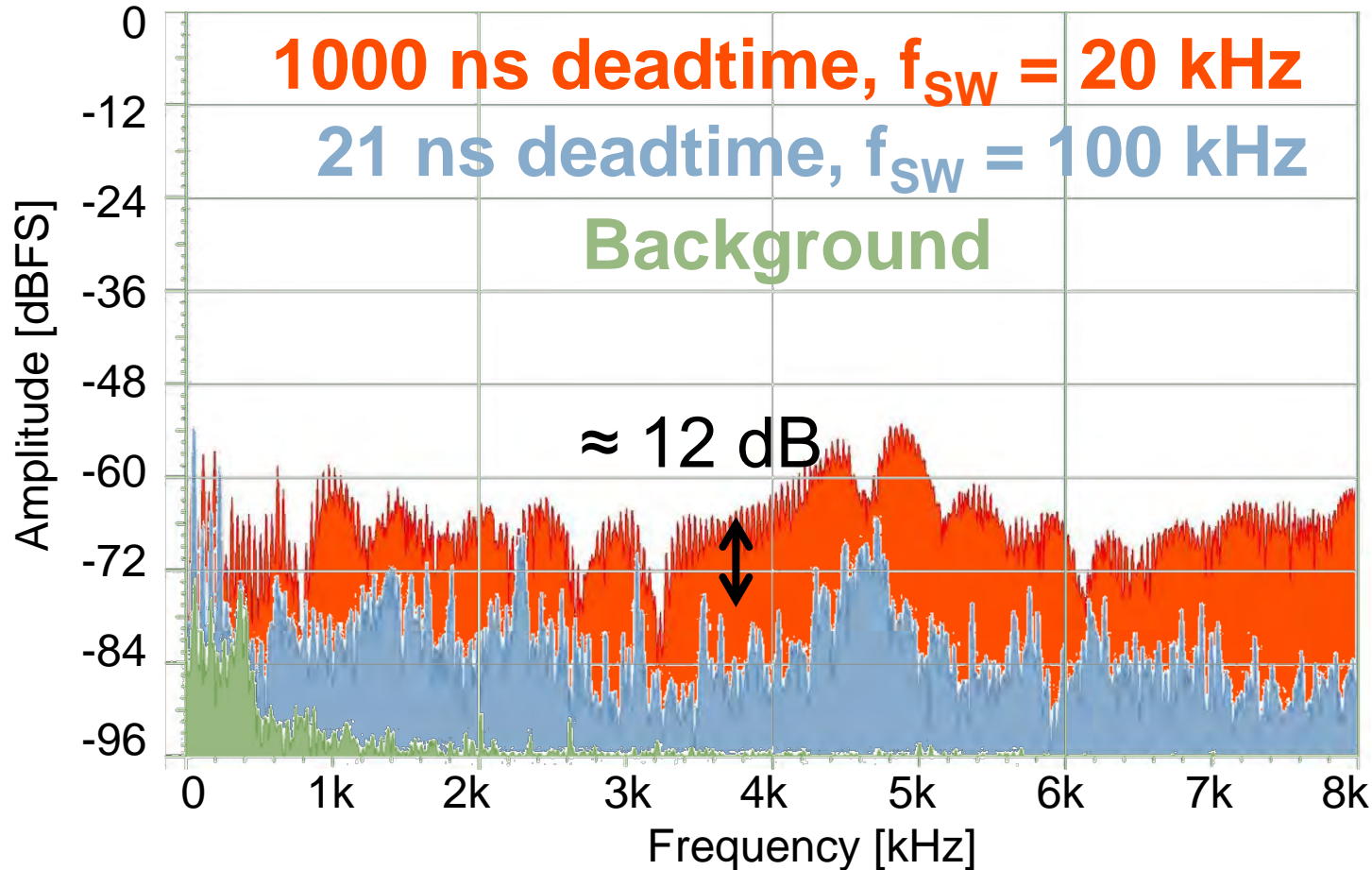


# Overall Effect of High Frequency

Setup	Inverter 20kHz 500ns dead time 400 RPM 5 Arms	GaN inverter 100kHz 14ns dead time 400 RPM 5 Arms
Input Inductance	2.7 $\mu$ H	None
Input capacitor	660 $\mu$ F electrolytic	44 $\mu$ F 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	<b>81.36 W</b>
$\eta_{motor}$	66.3 %	73.1 %
$\eta$ total efficiency	65.3 %	<b>71.8 %</b>

# 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>



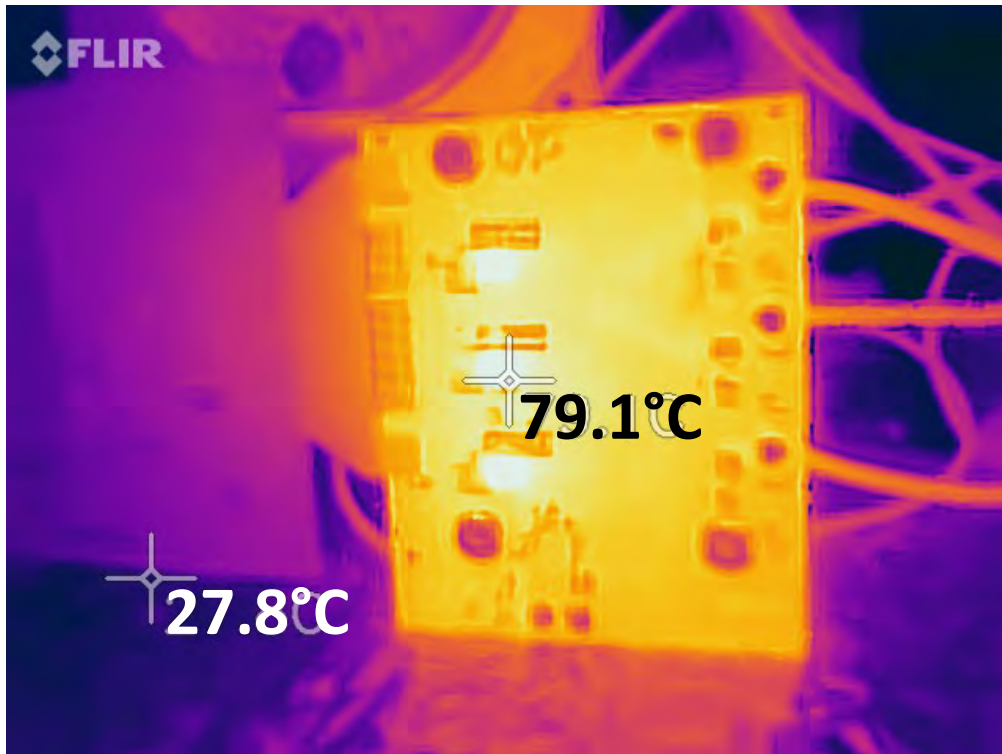
**SpectrumView**  
[Oxford Wave Research Ltd.](https://www.oxfordwave.com)

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

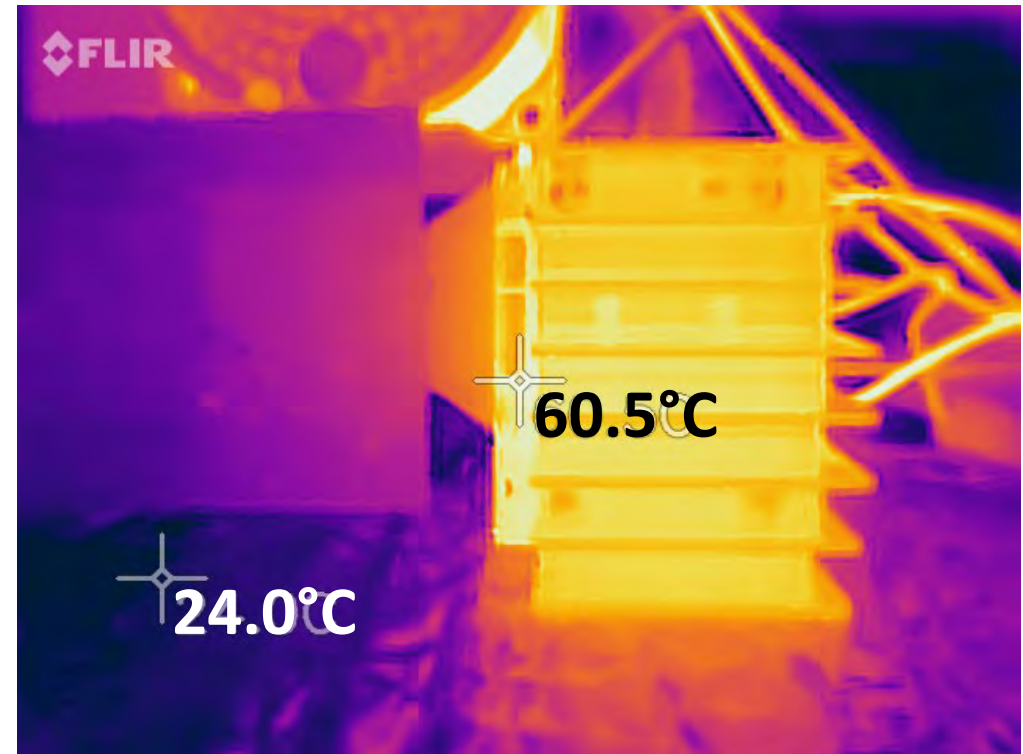


# Setup #1 Thermal Performance

- 6.0 A<sub>RMS</sub>
- No heatsink



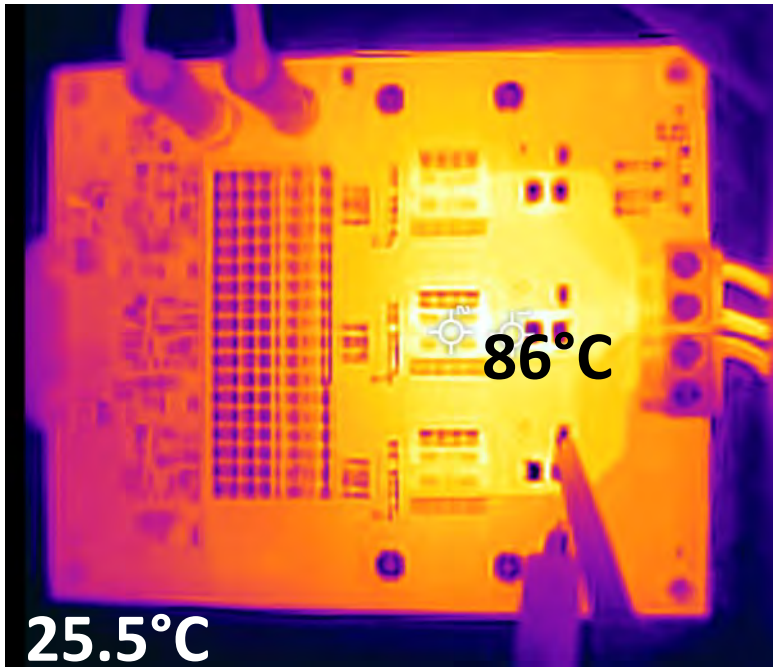
- 10 A<sub>RMS</sub>
- With heatsink mounted



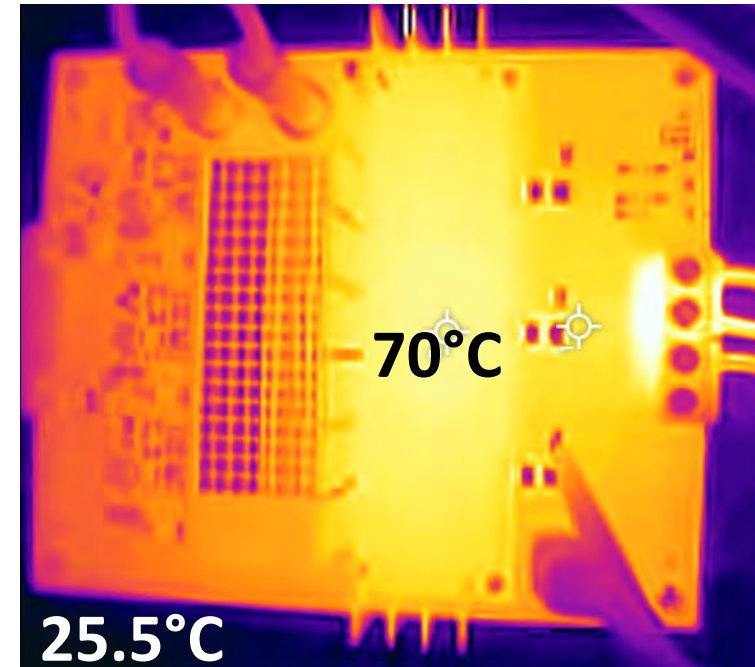
EPC9146 44 V<sub>DC</sub>, 40 kHz, 21 ns deadtime, Natural convection

# Setup #2 Thermal Performance

- 20 A<sub>RMS</sub>
- No heatsink



- 25 A<sub>RMS</sub>
- With heatsink mounted

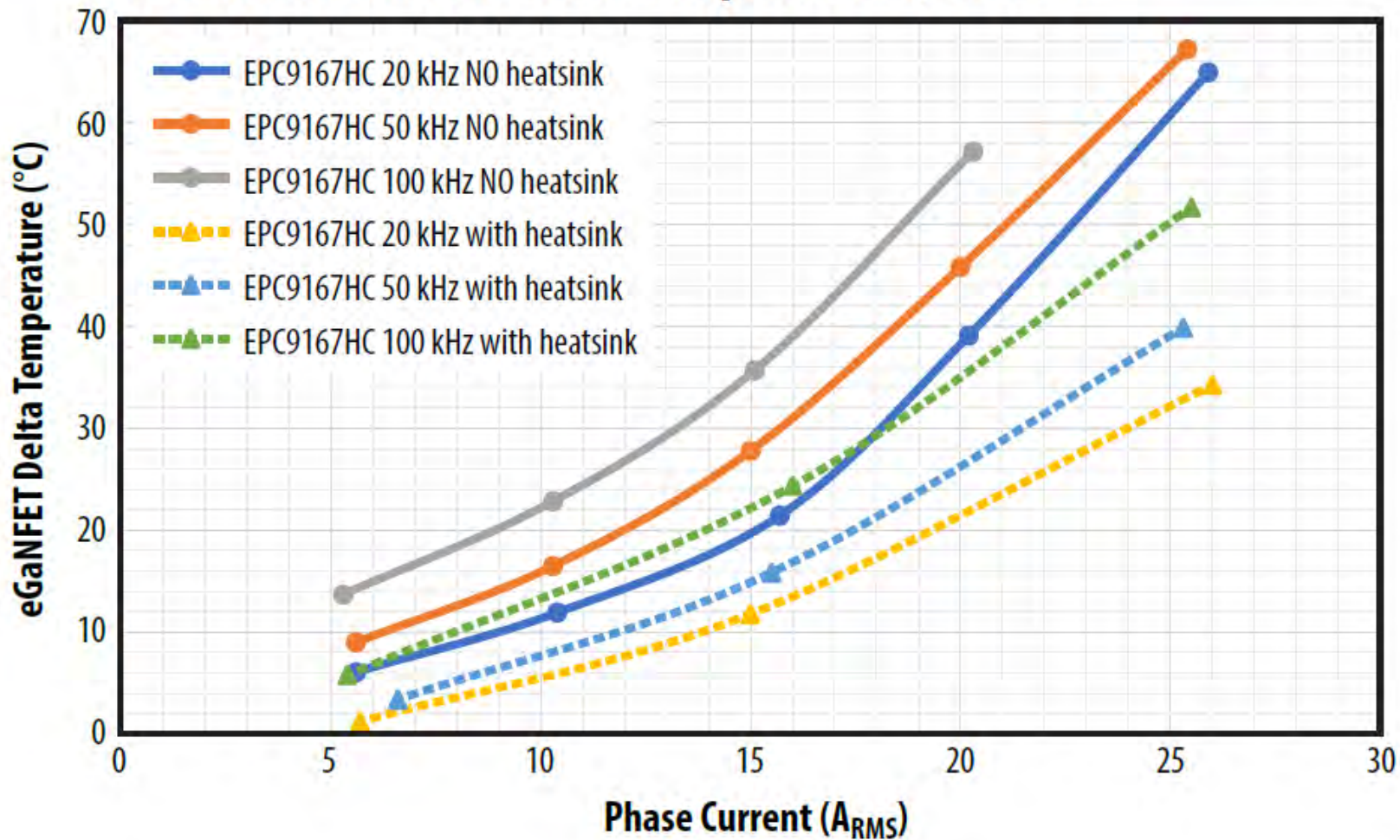


EPC9167HC 48 V<sub>DC</sub>, 100 kHz, 50 ns deadtime, Natural convection



# Setup #2 Thermal Performance

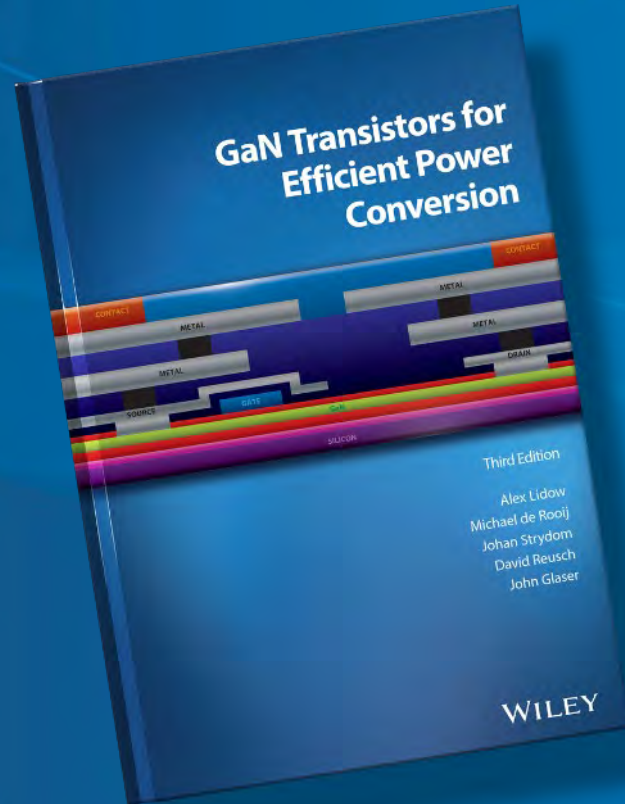
EPC9167HC GaNFET delta temperature @ 25.5°C



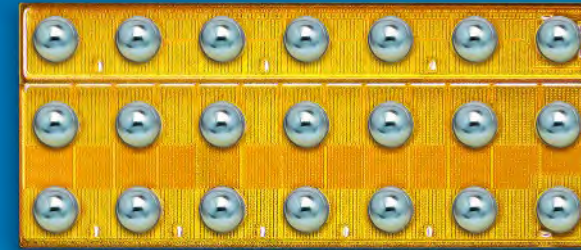


How To GaN Video Series

[epc-co.com](http://epc-co.com)



3<sup>rd</sup> Edition Textbook



eGaN<sup>®</sup> FETs and ICs

Evaluation  
Kits

