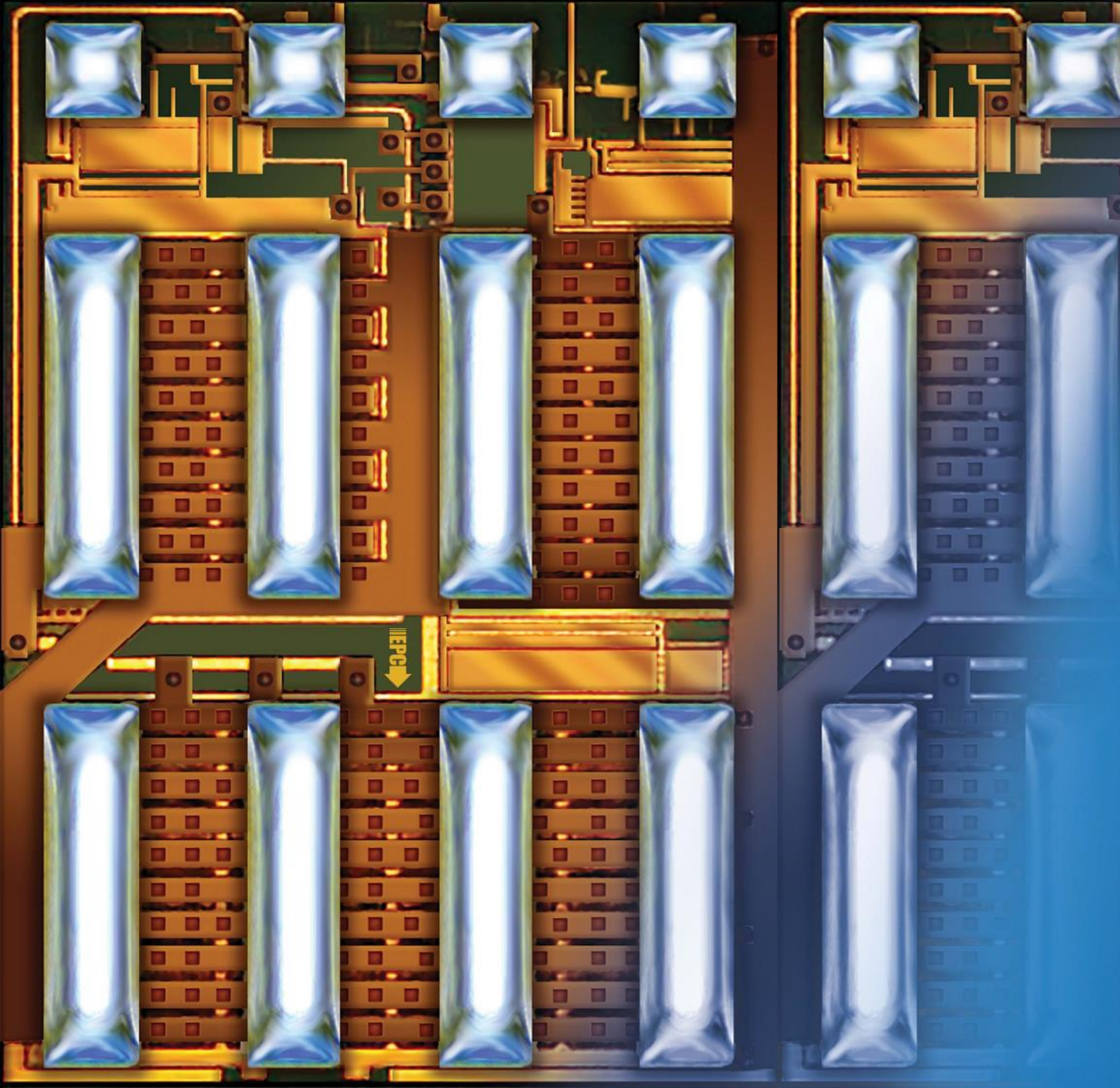
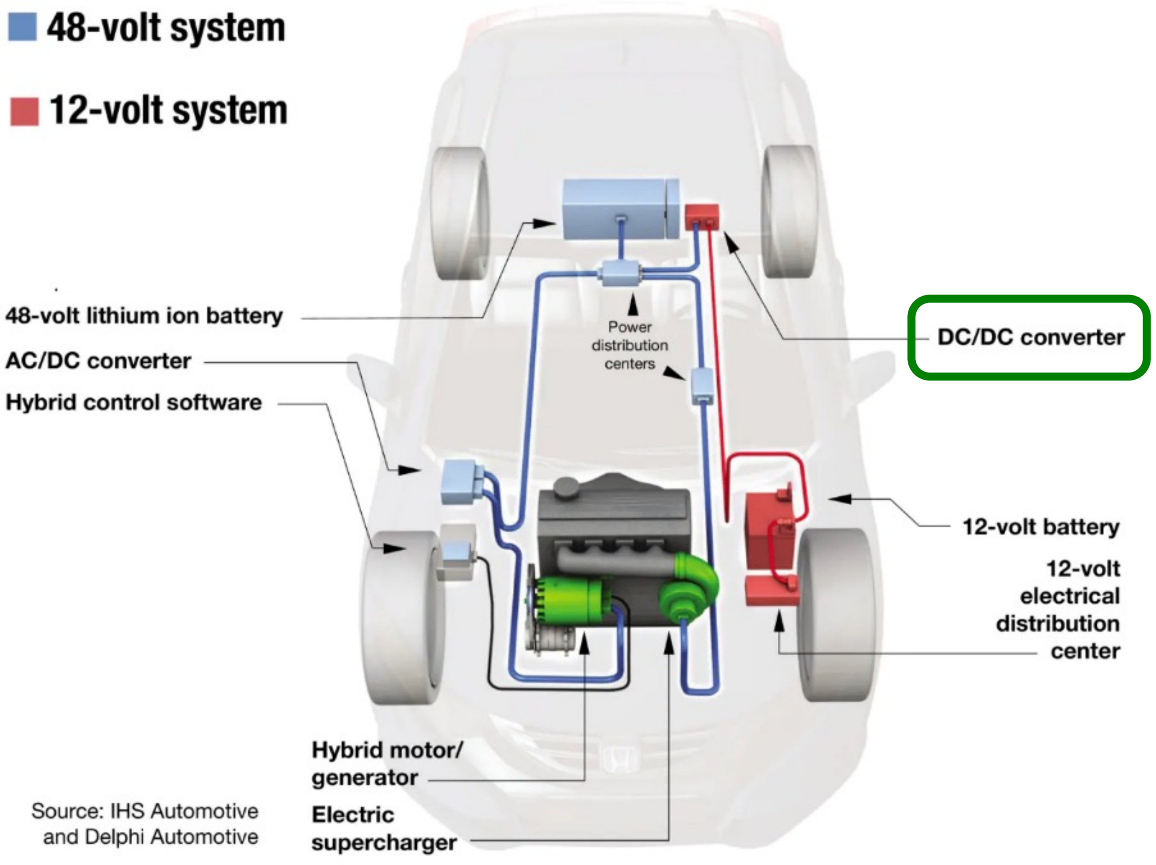


Multi-phase Converters for Mild Hybrid Automotive 48 V to 12 V Systems

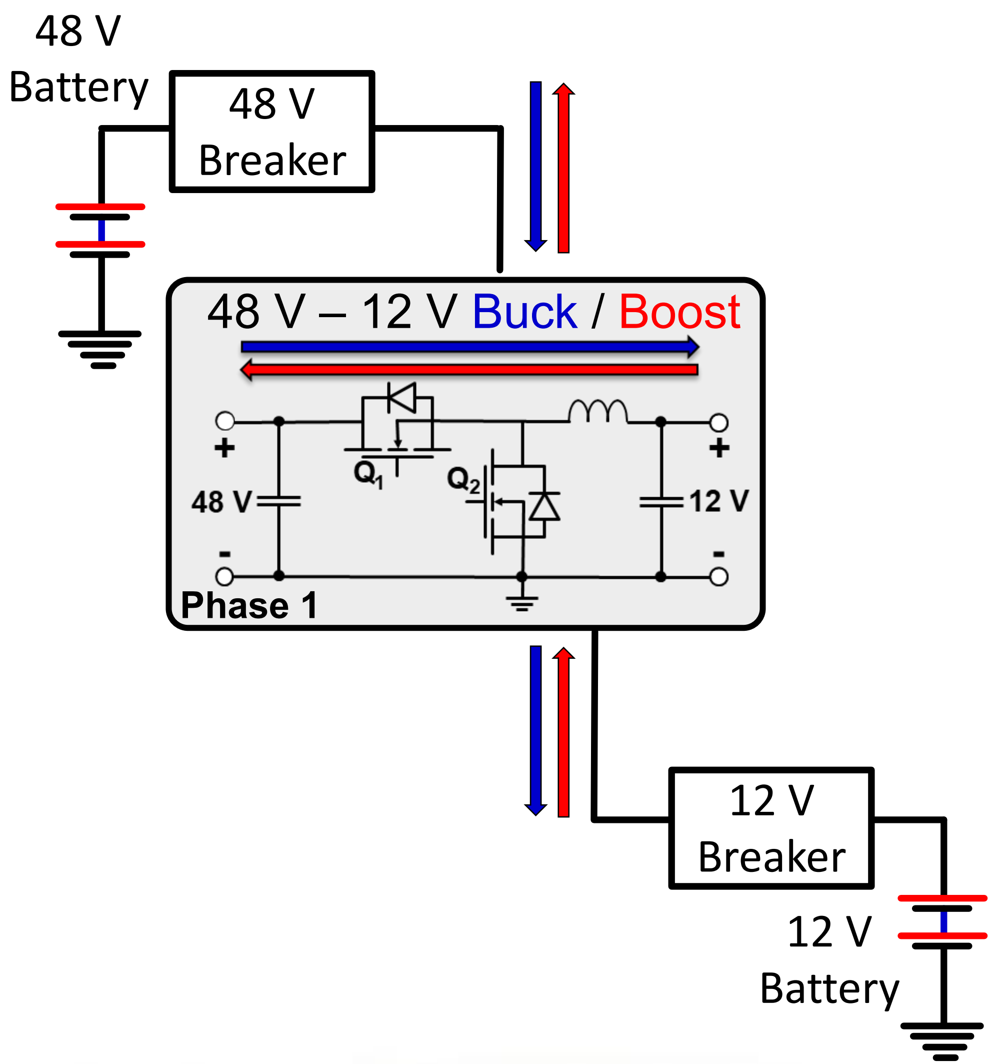
EPC
EFFICIENT POWER CONVERSION

Overview 48 V Mild Hybrid

Bi-directional DC-to-DC converter interconnects the dual voltage system



Source: IHS Automotive and Delphi Automotive



Ref: https://www.delphi.com/innovations/48-volt-mild-hybrid

Automotive Background

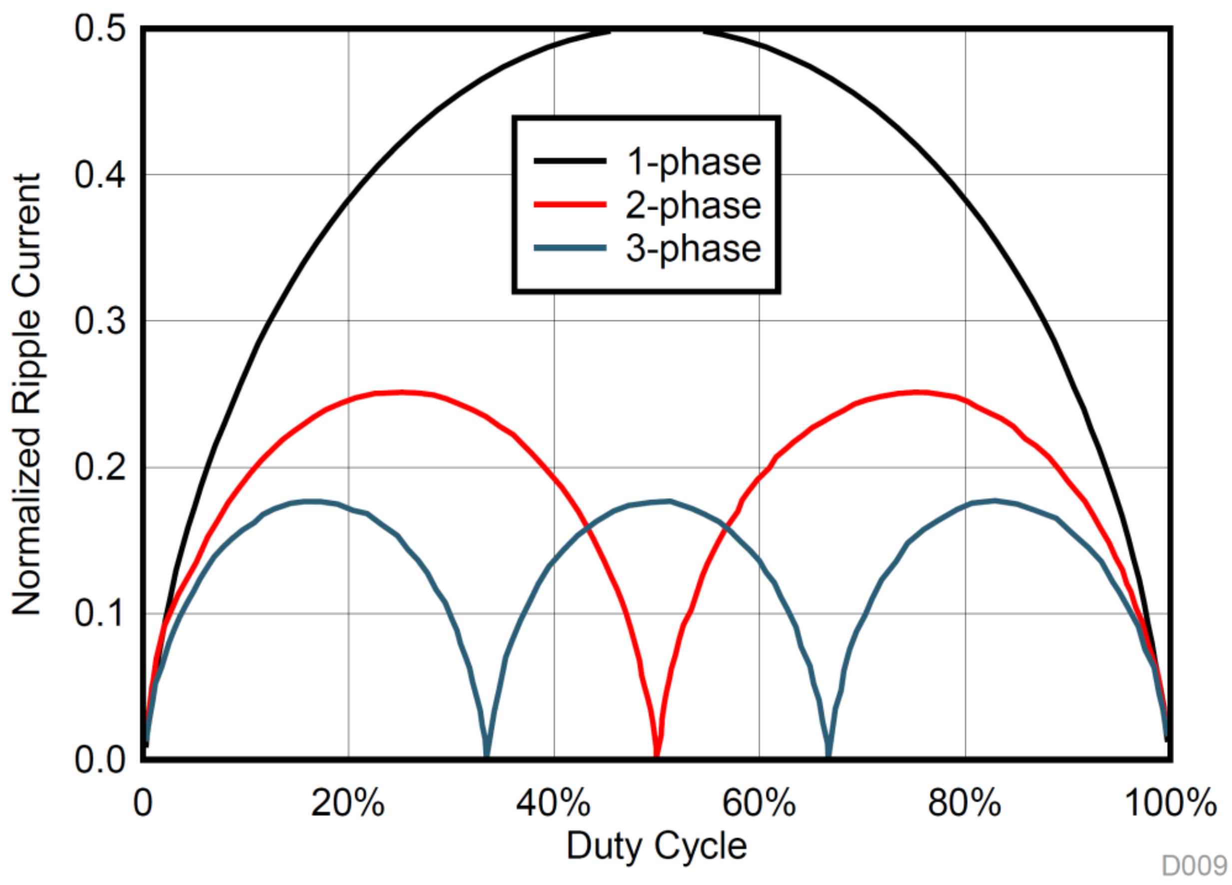
- AEC qualified components
- “Infinite” cooling available
- Restrictions on PCB techniques and thermal solutions
  - Cost
  - Vibration
  - Risk
  - Size
  - Weight

How GaN addressed Automotive

- ✓AEC qualified FETs
- ✓Cost – Competitive pricing, Higher power density
- ✓Vibration – Less prone to coming loose
- ✓Risk – Easy to use, reliable
- ✓Size – Higher power density
- ✓Weight – Higher power density

Why Multi-Phase Approach

- Inductor size reduction
- RMS current loss reduction
- Reduced ripple current on 12 V bus by interleaving phases
- Power dissipation distribution
- Phase shedding efficiency optimization

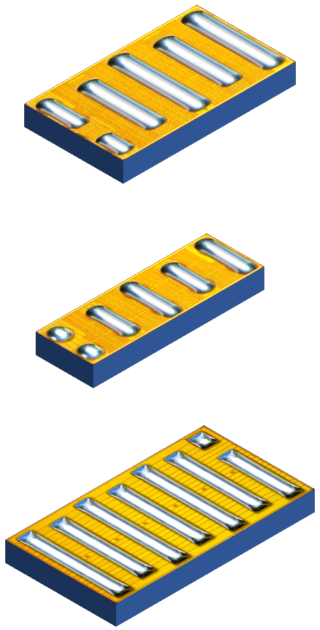


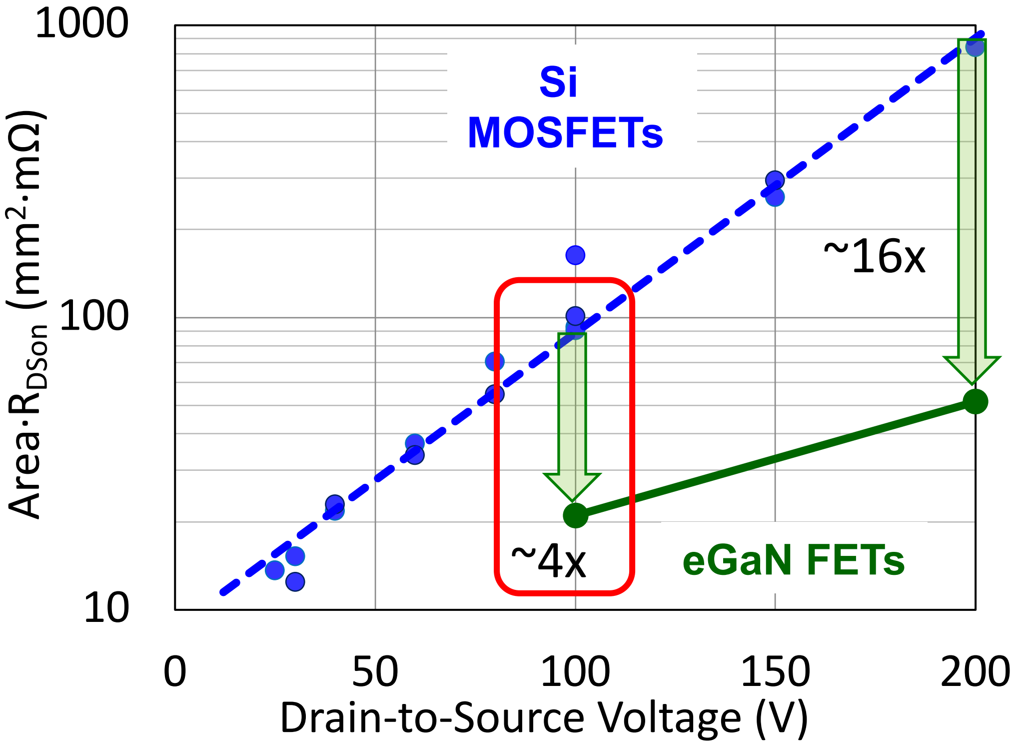
Ref: TIDUCS2B-June 2017-Revised March 2018, Bidirectional DC-DC Converter Reference Design for12-V/48-V Automotive Systems, Texas Instruments

GaN vs Silicon in 48 V

With respect to MOSFETs:

- Reduced FOM ~ 4 times
- Lower Q_G ~ 5 -10 times
- Lower R_{DSon} at V_{GS} = 5 V
- Lower Q_{OSS}
- Lower Q_{GD}
- Zero Q_{RR}
- Smaller

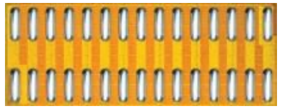




NVMFS6H800N
6.05 mm x 5.15 mm
AEC Q101 Qualified
V_{DSmax} = 80 V Si MOSFET
1.8 mΩ typical

56% smaller footprint

EPC2206
6.05 mm x 2.3 mm
AEC Q101 Qualified
V_{DSmax} = 80 V eGaN FET
1.8 mΩ typical



Higher Efficiency : 48 V – 12 V

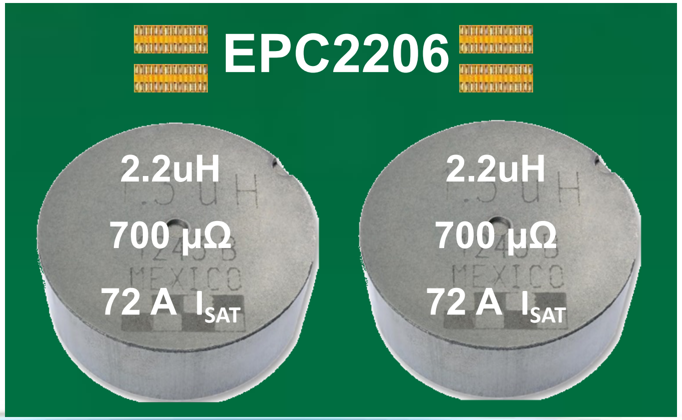
Step 1: Higher Efficiency

- GaN FETs switch faster
  - Higher frequency (125 kHz → 250 kHz)
  - Higher efficiency
    - Lower FET loss
    - Lower Inductor loss
- Reduced 12 V Capacitance
- Example: EPC9137

MOSFET Solution

700 W/phase

eGaN FET Solution



750 W/phase

Higher Power Density : 48 V – 12 V

EFFICIENT POWER CONVERSION

<u>Step 2:</u> Higher Power Density

- Paralleled GaN FETs
  - Even higher frequency (125 kHz → 500 kHz)
  - Higher efficiency
    - Lower Inductor loss
- Higher power per phase (750 W → 1000 W)
- Reduced 12 V Capacitance
- Example: EPC9163C

~700 W/phase

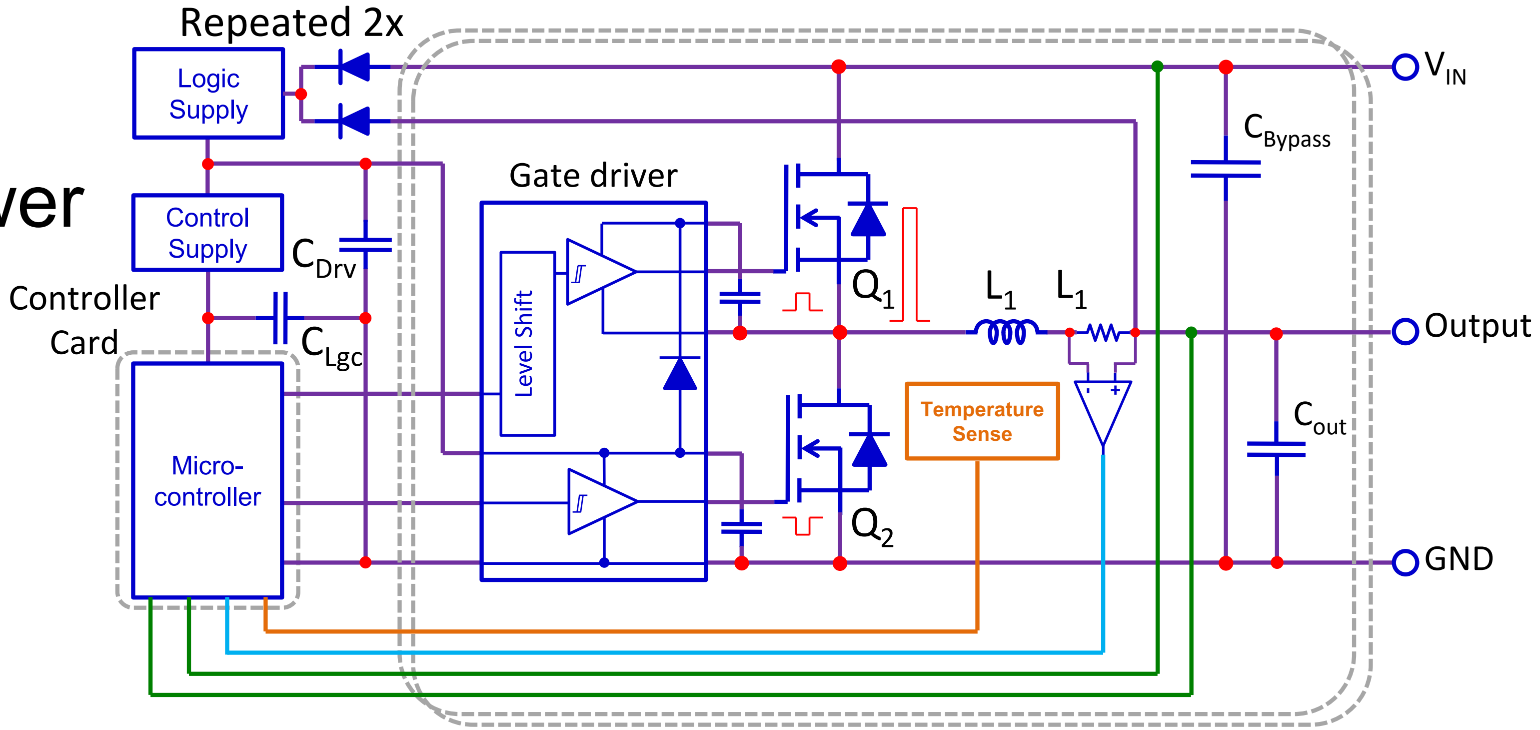
1000 W/phase

MOSFET Solution

eGaN FET Solution

Demonstration Design Approach

- 2-phase building block
- Hard-switching synchronous buck / reverse boost converter
- Digital Control
- Includes Housekeeping power supply



Design 1: EPC9137

Higher Efficiency Solution

- Bi-directional 48 V ↔ 12 V
- 750 W / phase into 12.0 V (62.5 A) from 48 V
- Infinite heatsink, T_{max} = 60°C
- > 96% efficiency

Approach:

- 250 kHz switching frequency
- 2-phase building block
- EPC2206

Design 2: EPC9163C

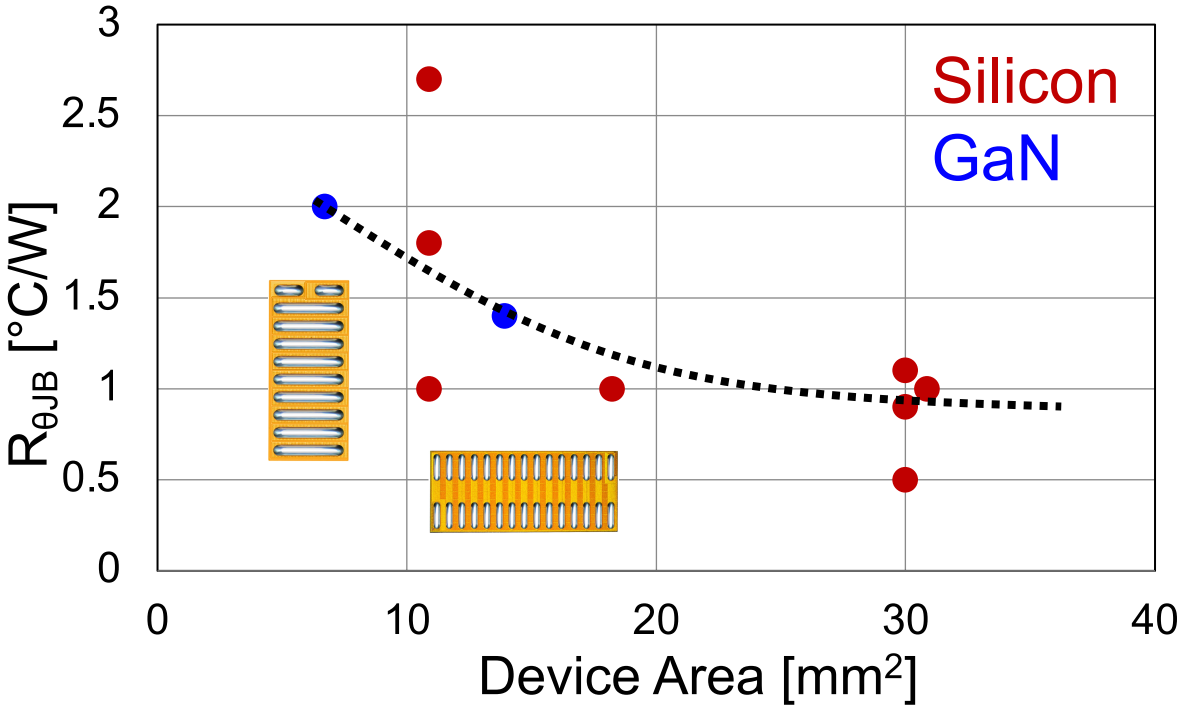
Higher Power Density Solution

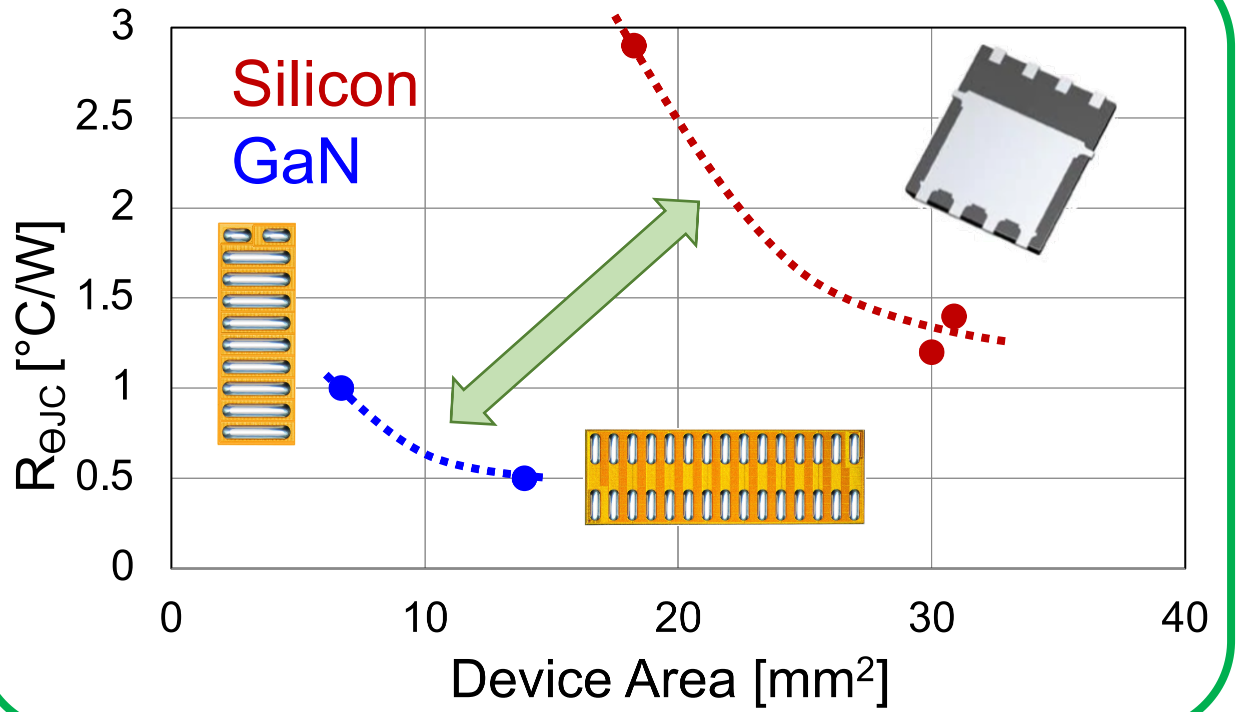
- Bi-directional 48 V ↔ 12 V
- 1 kW / phase into 13.8 V (70 A) from 48 V
- Infinite heatsink, T_{max} = 60°C
- > 96% efficiency

Approach:

- 500 kHz switching frequency
- 2-phase building block
- Paralleled EPC2218

Device Thermal Resistance Comparisons

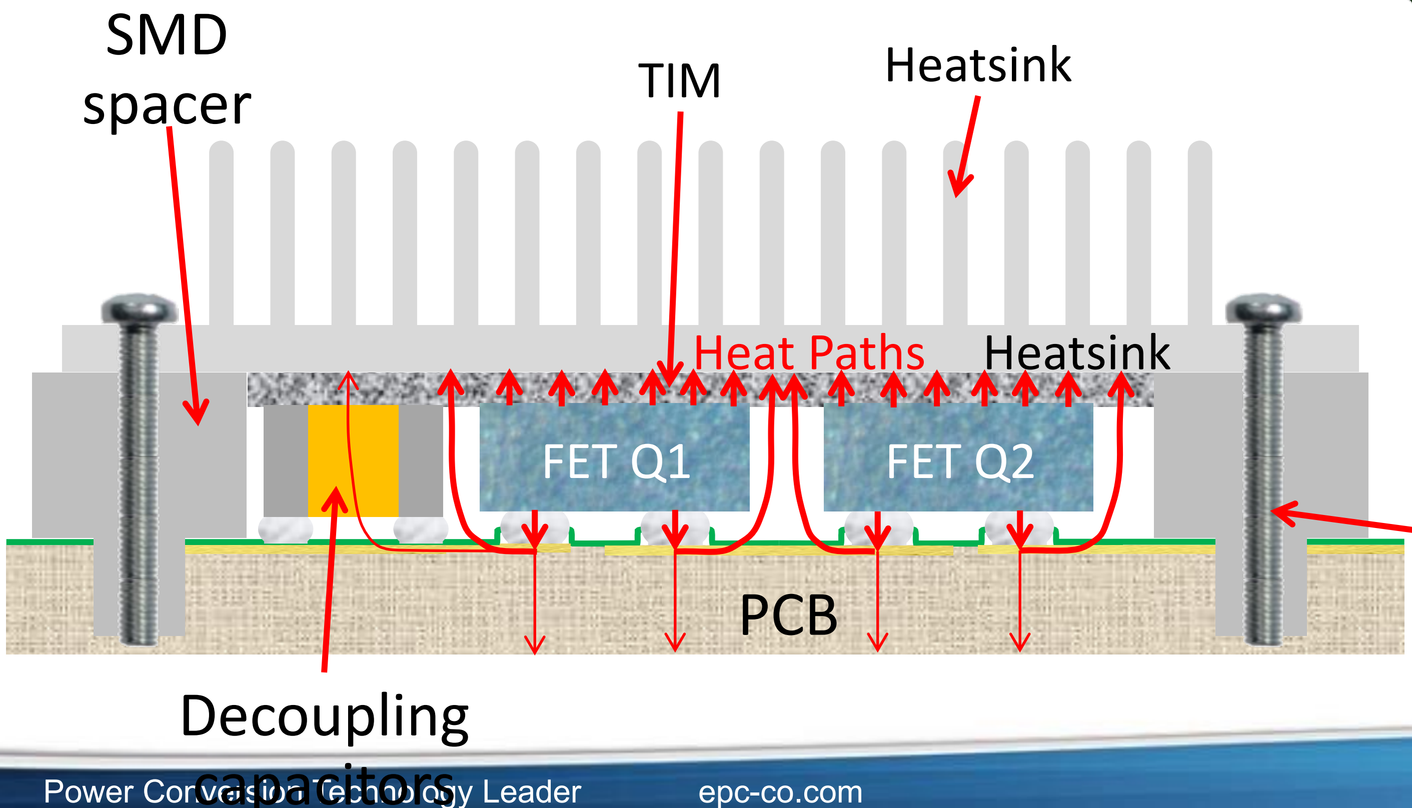


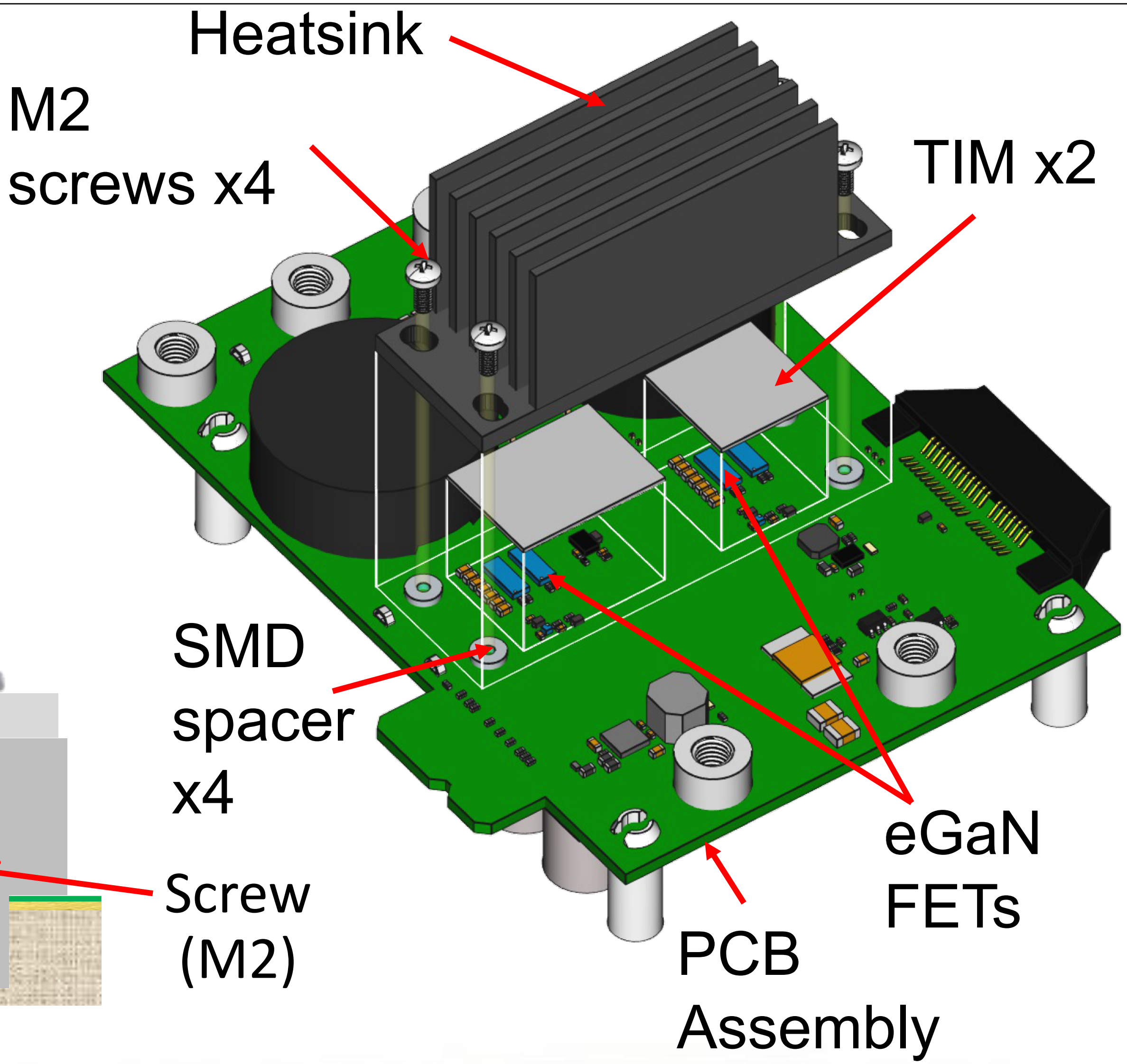


- Small chip scale devices **can** be adequately cooled
- There are simple methods to ensure best thermal practice
- $R_{\theta JC}$ can be used to significant advantage

Thermal Approach

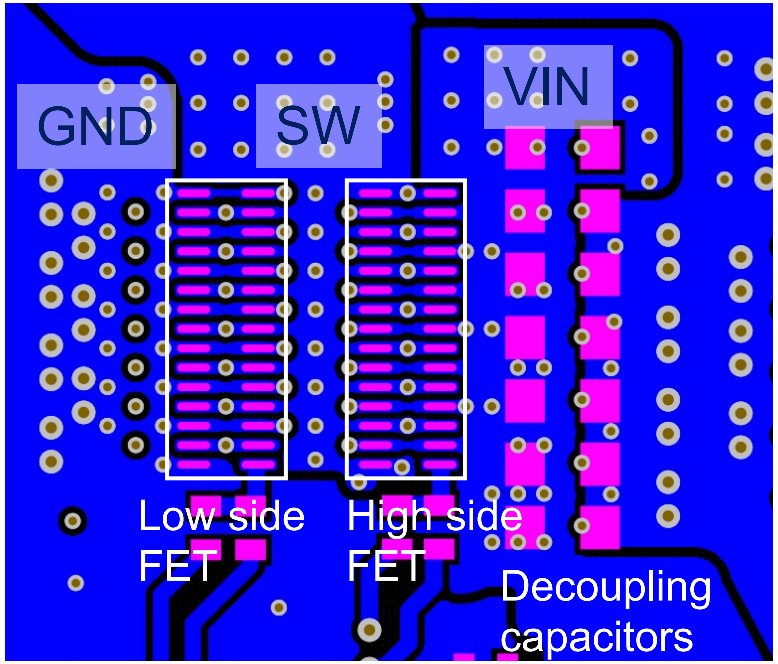
- Back-side cooling
- High performance TIM



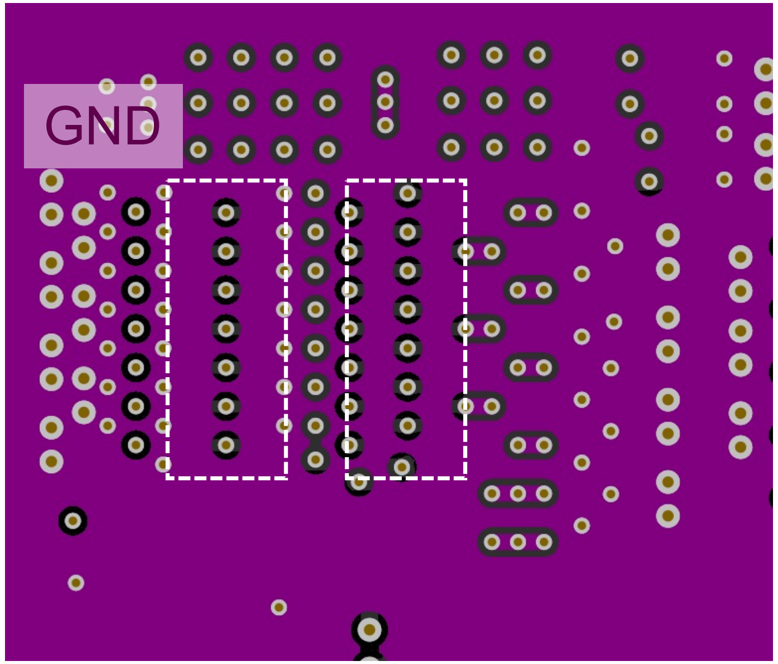


FET Layout Details – EPC9137

- Follows “internal vertical” layout recommendation
- Only 2 layers out of 8 shown



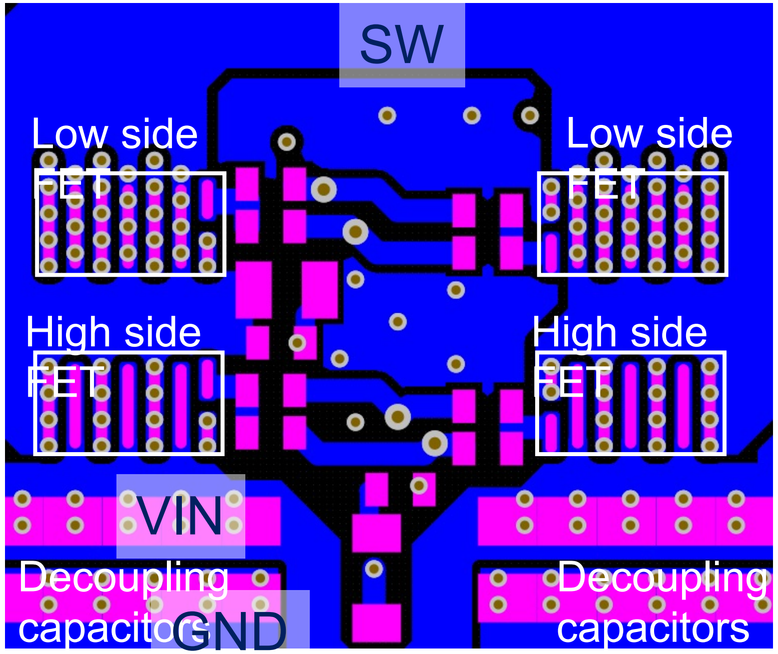
Top Layer



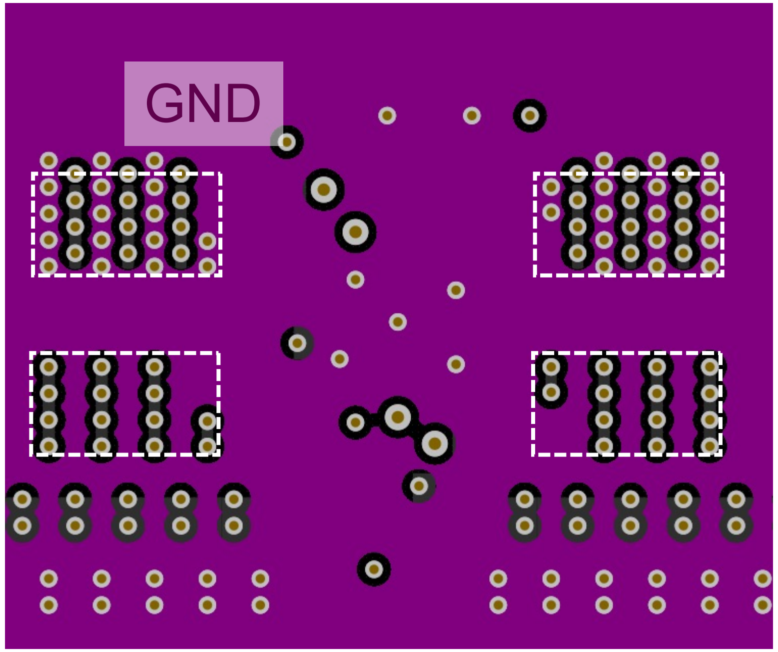
Inner Layer 1

FET Layout Details – EPC9163C

- Follows “internal vertical” layout recommendation
- Follows paralleling layout recommendation
- Only 2 layers out of 8 shown



Top Layer



Inner Layer 1

Experimental

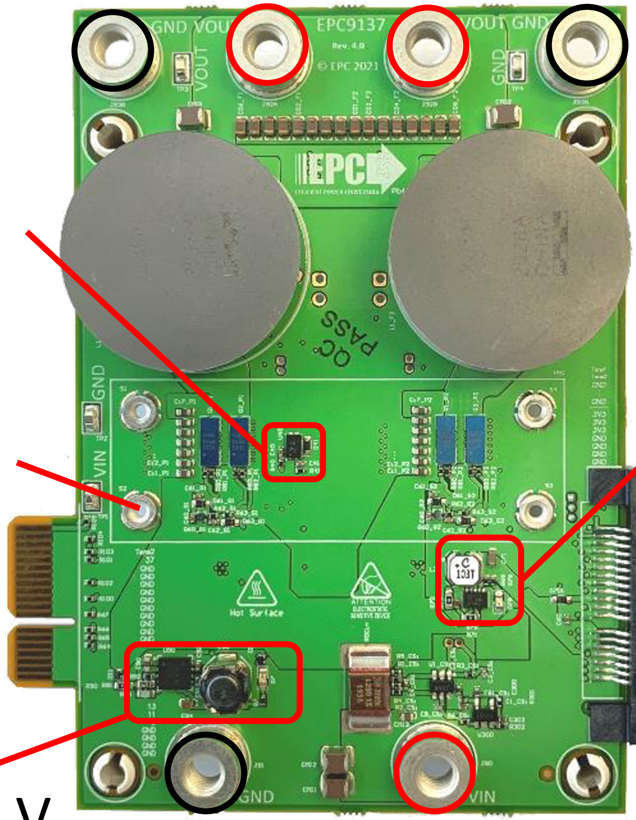
EPC9137 Overview

GND (-) 12 V (+) GND (-)

Temperature sensor

Heatsink mounting x4

Housekeeping Power supply 5 V



3.3 V supply

EPC9528

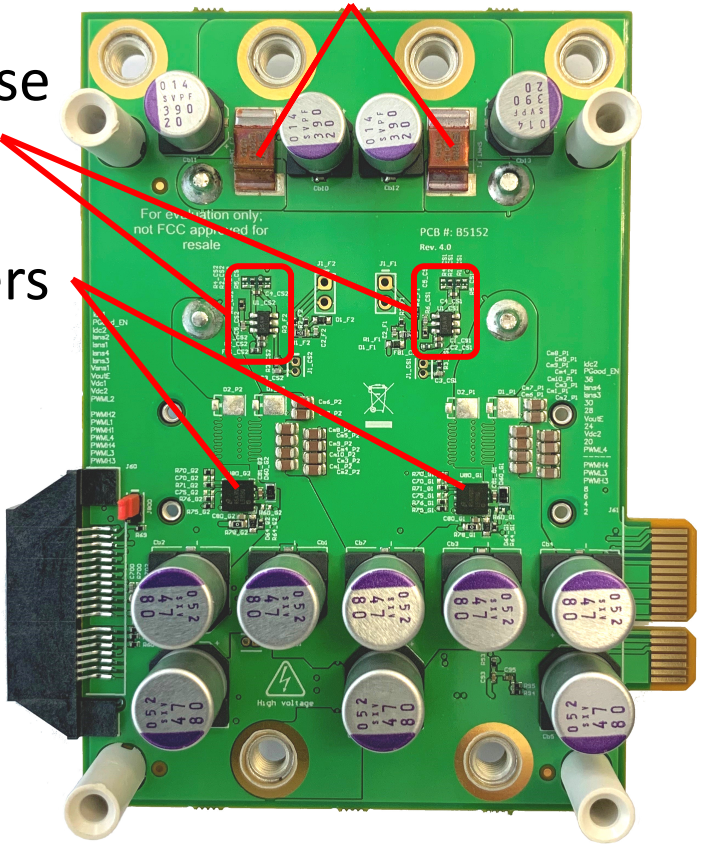
GND (-) 48 V (+)

Top side

Current sense Shunt

Current sense amplifiers

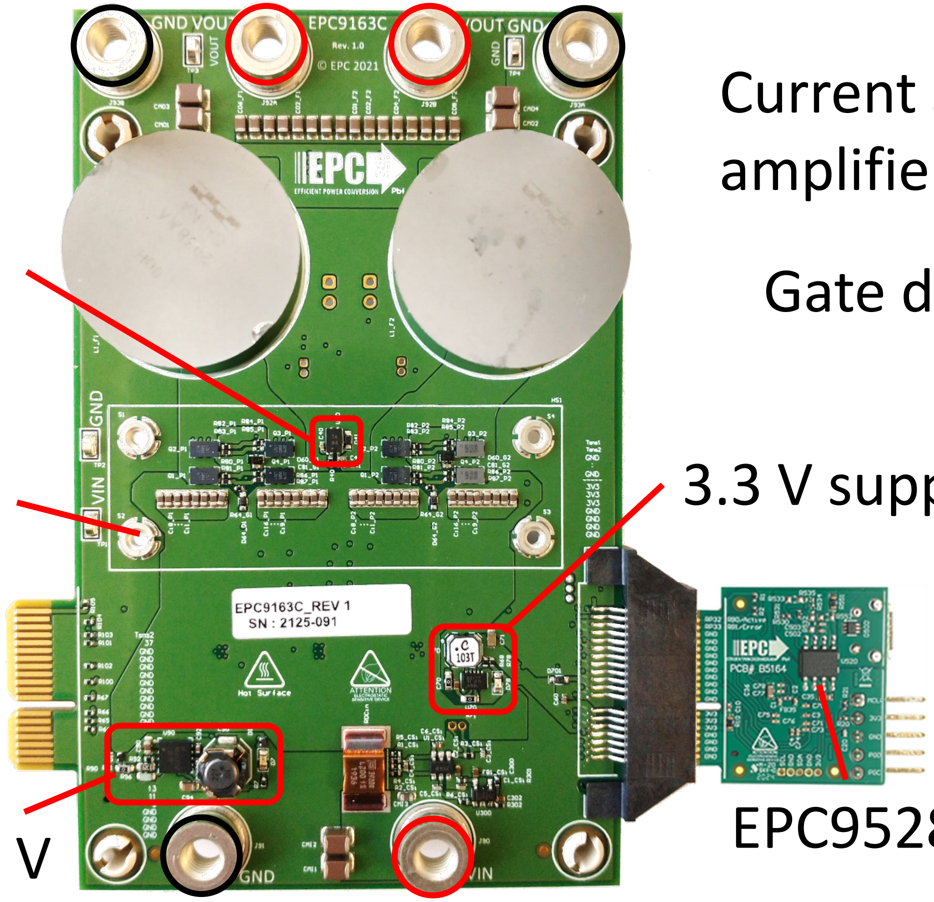
Gate drivers



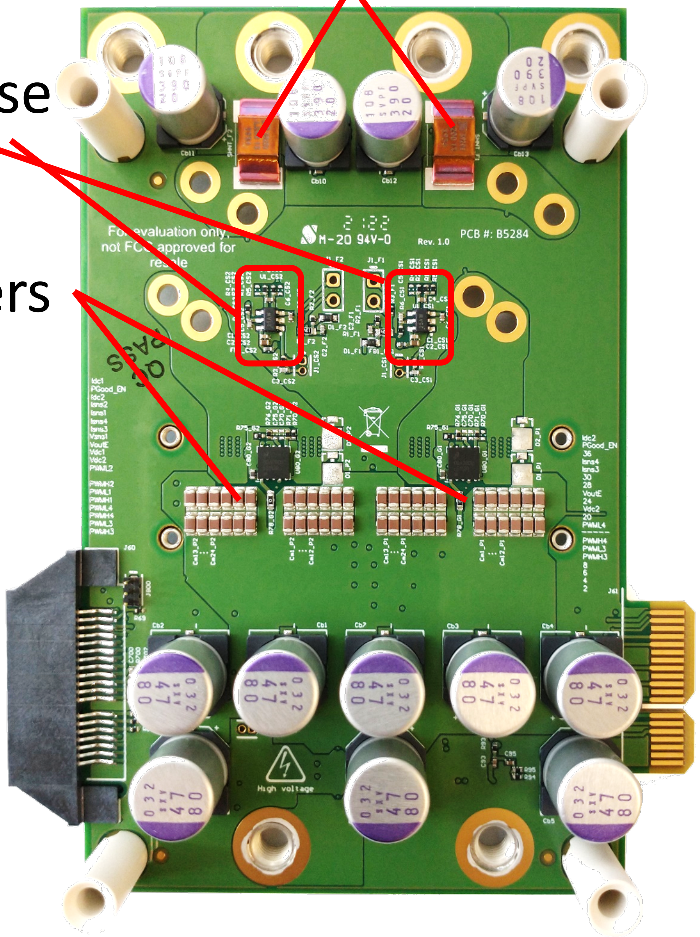
Bottom side

EPC9163C Overview

GND (-)
12 V (+)
GND (-)
Current sense Shunt
Current sense amplifiers
Temperature sensor
Gate drivers
Heatsink mounting x4
3.3 V supply
Housekeeping Power supply 5 V
EPC9528
GND (-)
48 V (+)

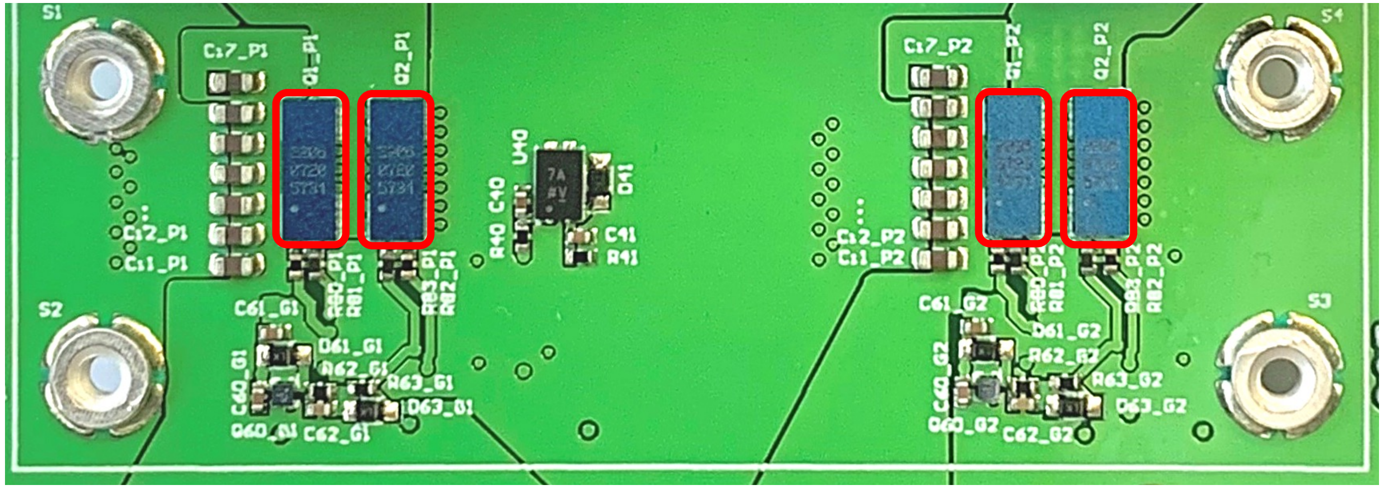


Top side

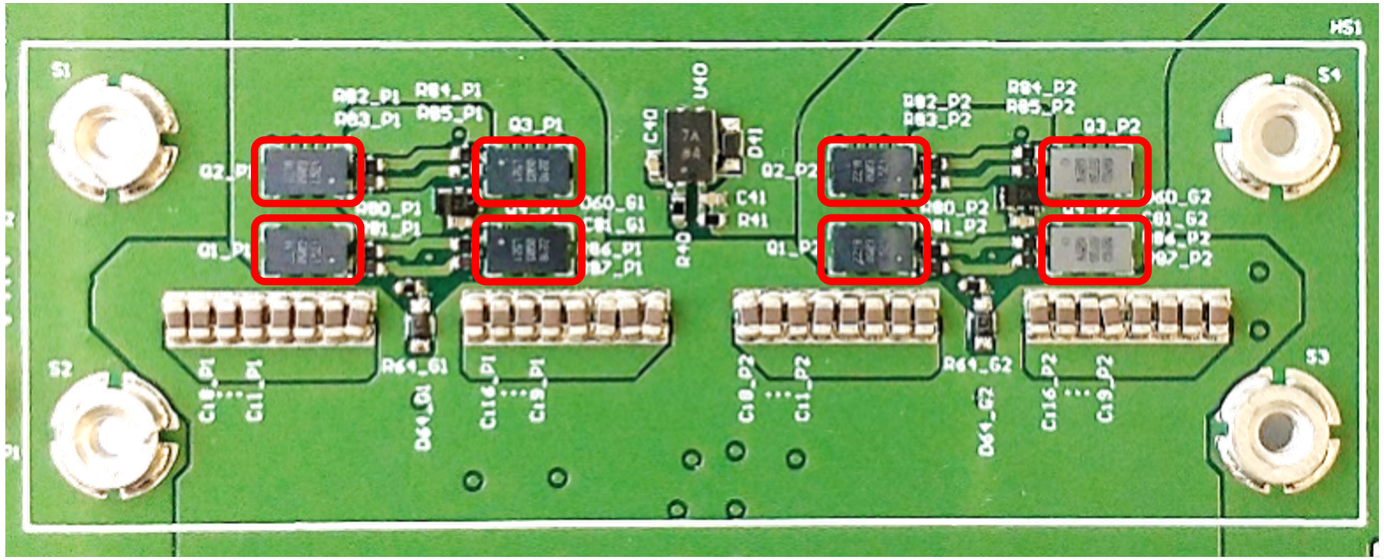


Bottom side

GaN FET Details



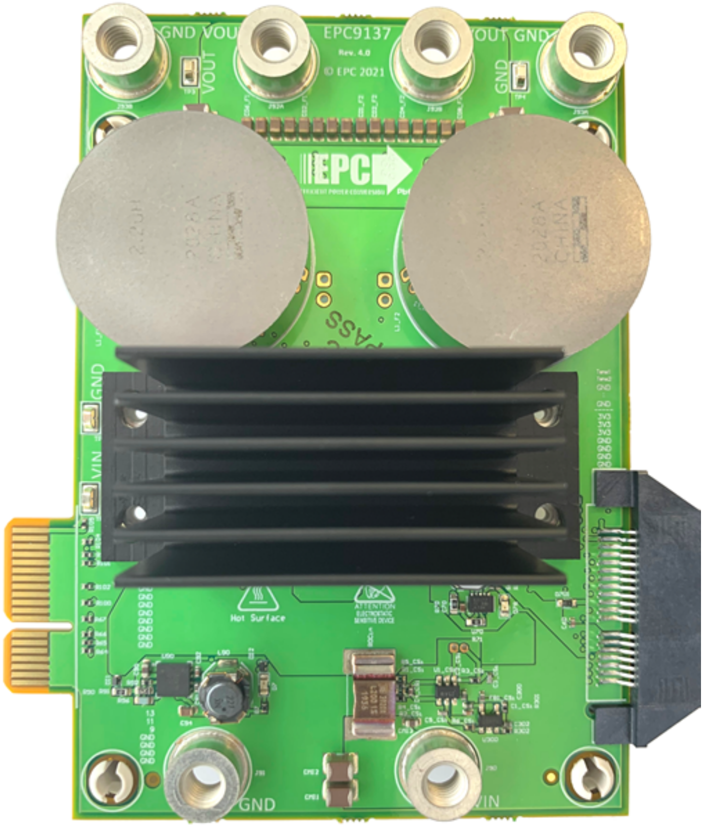
EPC9137
EPC2206 x4



EPC9163C
EPC2218 x8

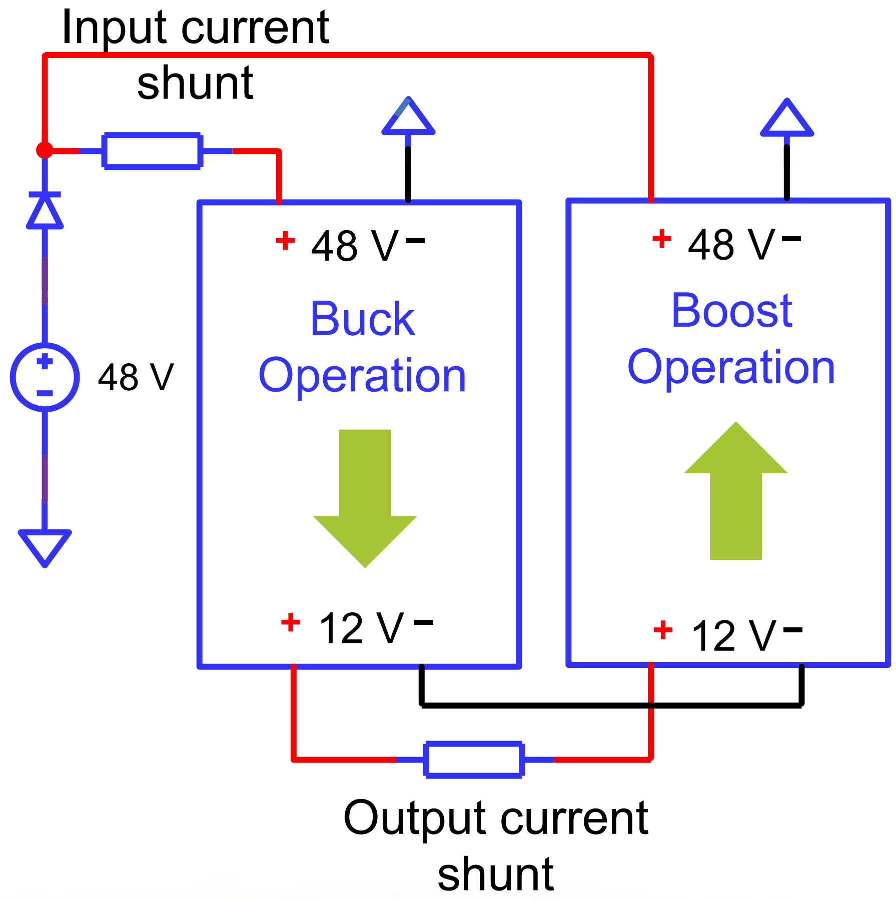
Heatsink Mount – Either Board

- Heatsink - ⅛ Brick Size
  - Wakefield: 567-94AB
- Thermal Interface Material
  - t-Global: TG-A1780 x 0.5 mm
- M2 6mm screws
  - McMaster Carr: 95836A107
- Spacer on PCB
  - Würth Elektronik: 9774010243R



Testing Setup

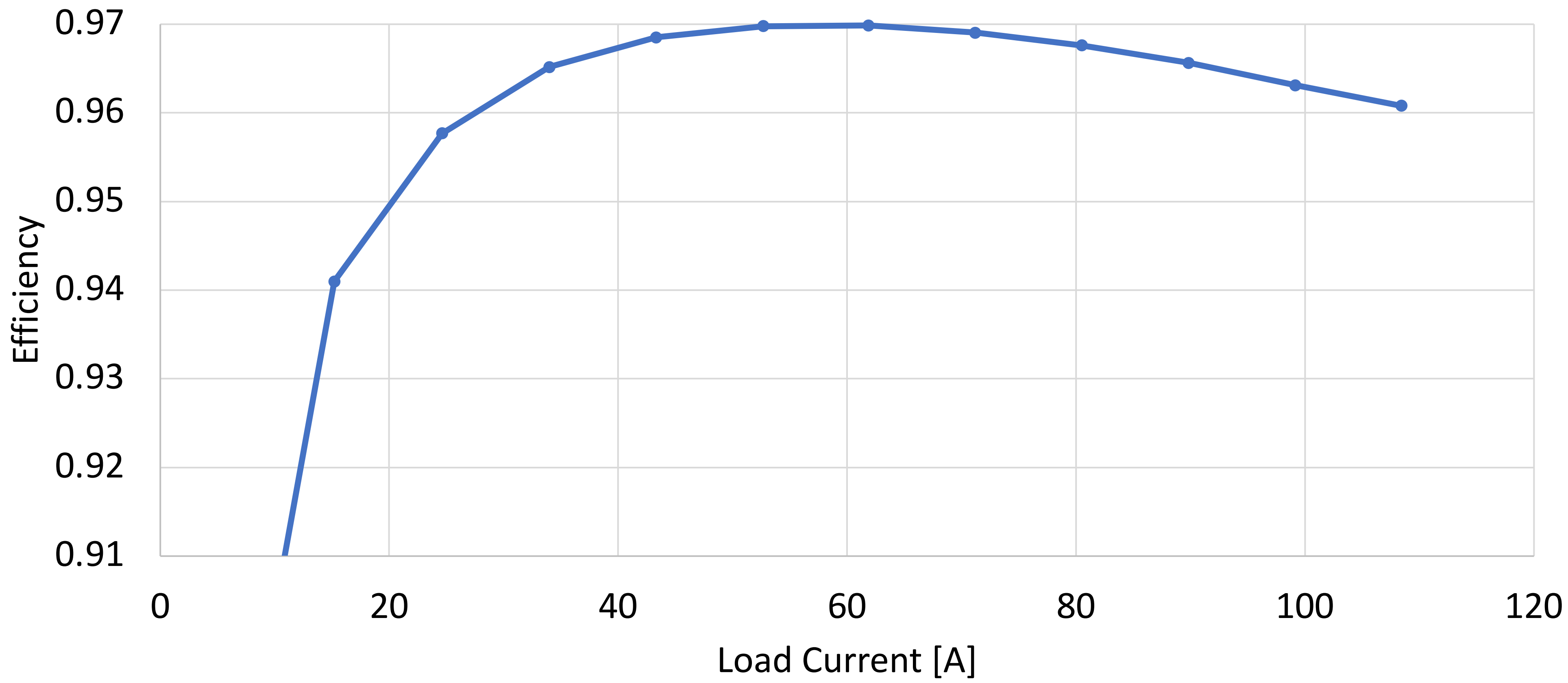
- Back-to-Back converters: Buck ↔ Boost.
  - Power supply covers losses only
- What being tested:
  - Efficiency
  - Current balance
  - Load transients
  - Startup



Power Converter Performance

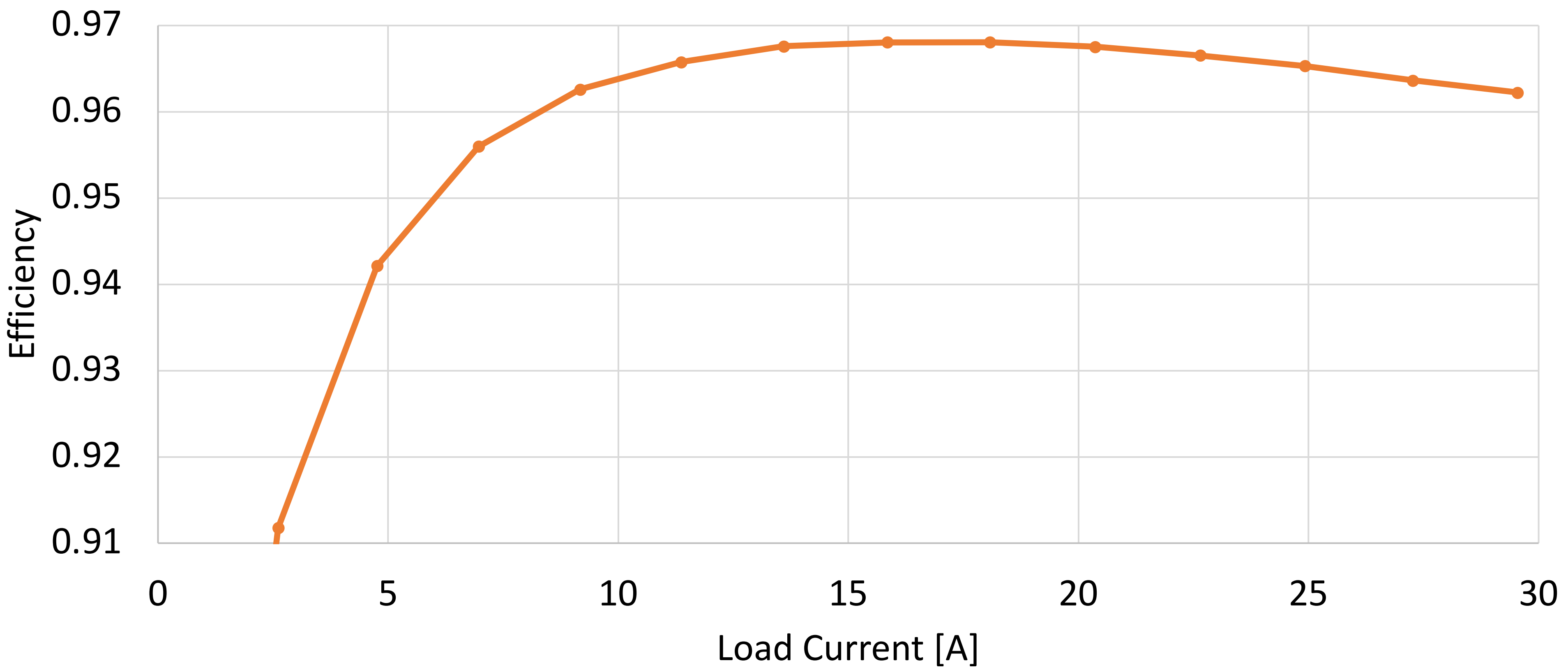
EPC9137 Buck Mode

48 V_{in}, 13.8 V_{out}, 250 kHz, 2.2 µH



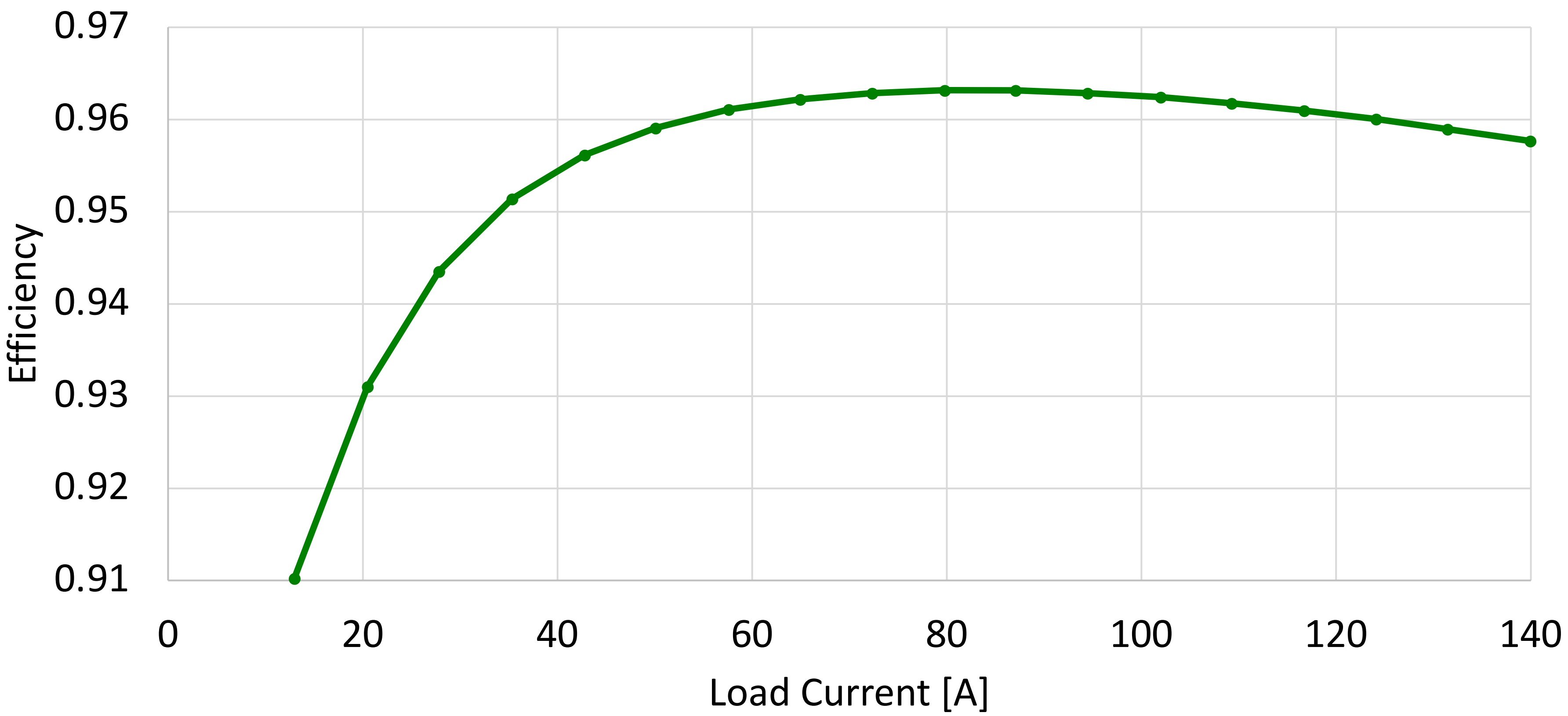
EPC9137 Boost Mode

13.8 V_{in}, 48 V_{out}, 250 kHz, 2.2 μH



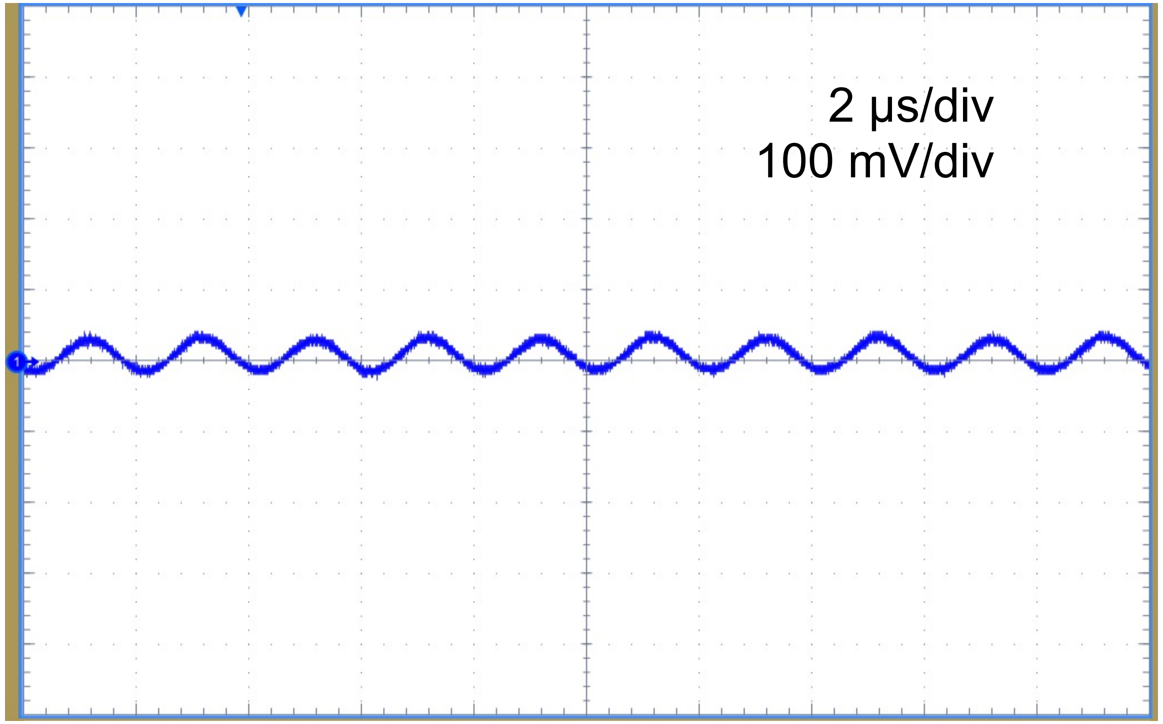
EPC9163C Buck Mode

48 V_{in}, 13.8 V_{out}, 500 kHz, 1 µH



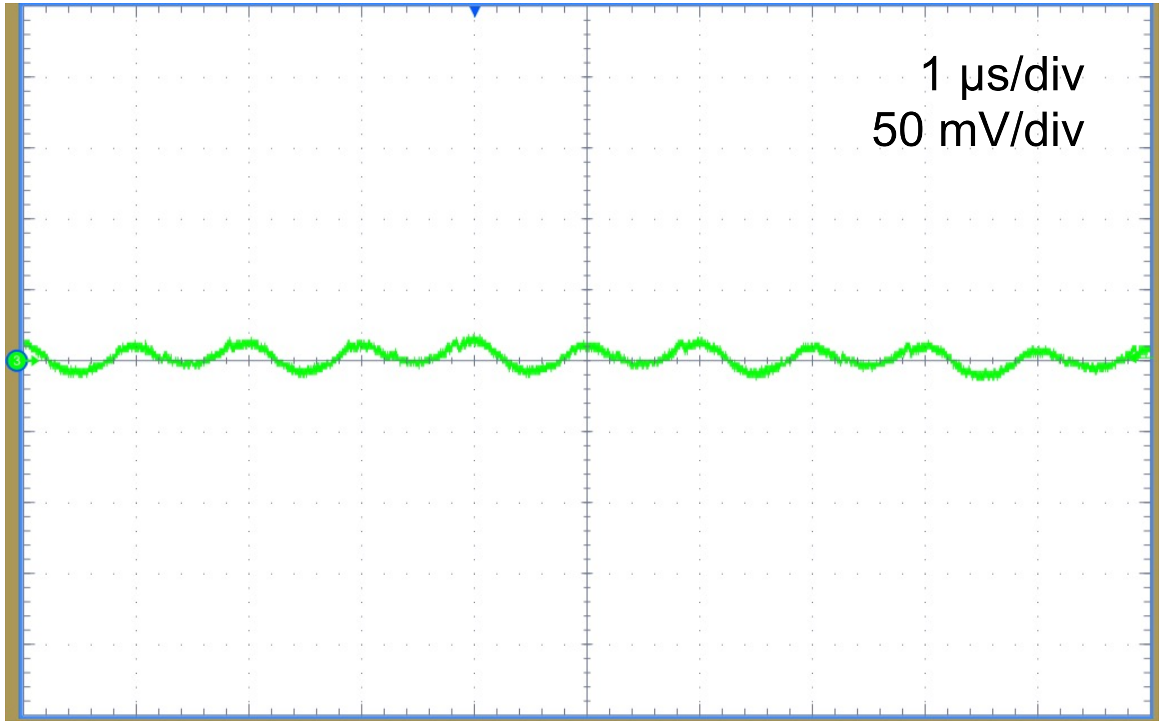
Output voltage ripple

EPC9137



48 V input, 12 V 30 A output (buck)

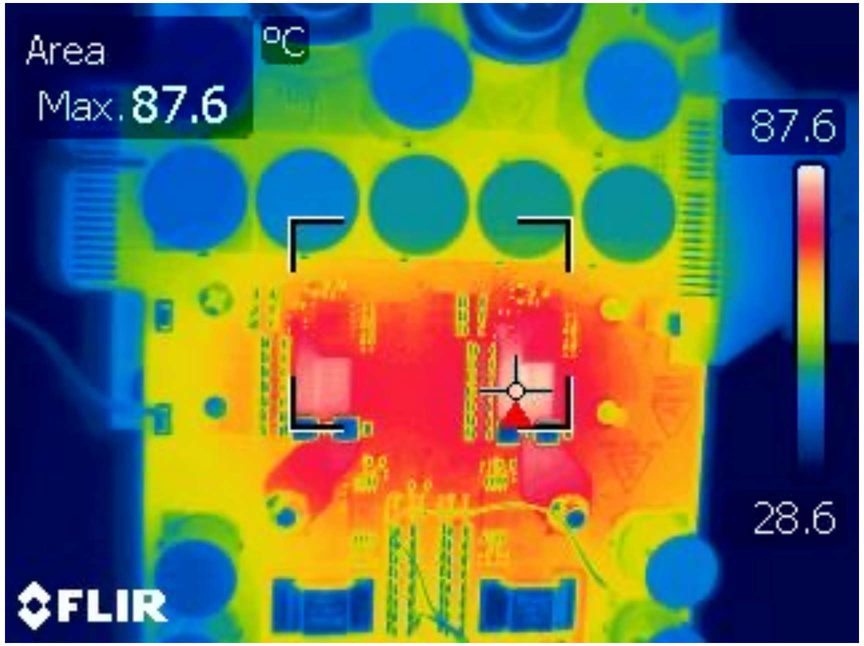
EPC9163C

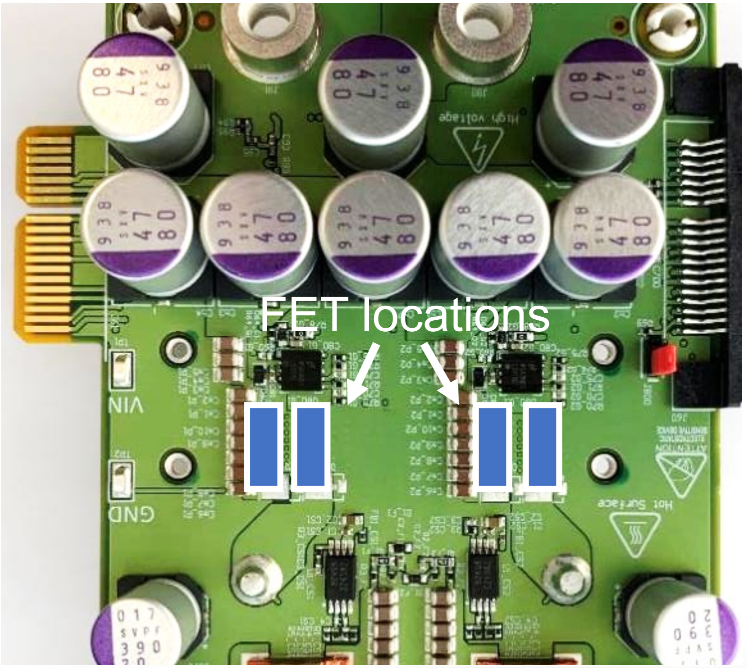


48 V input, 14 V 23 A output (buck)

EPC9137 Thermal

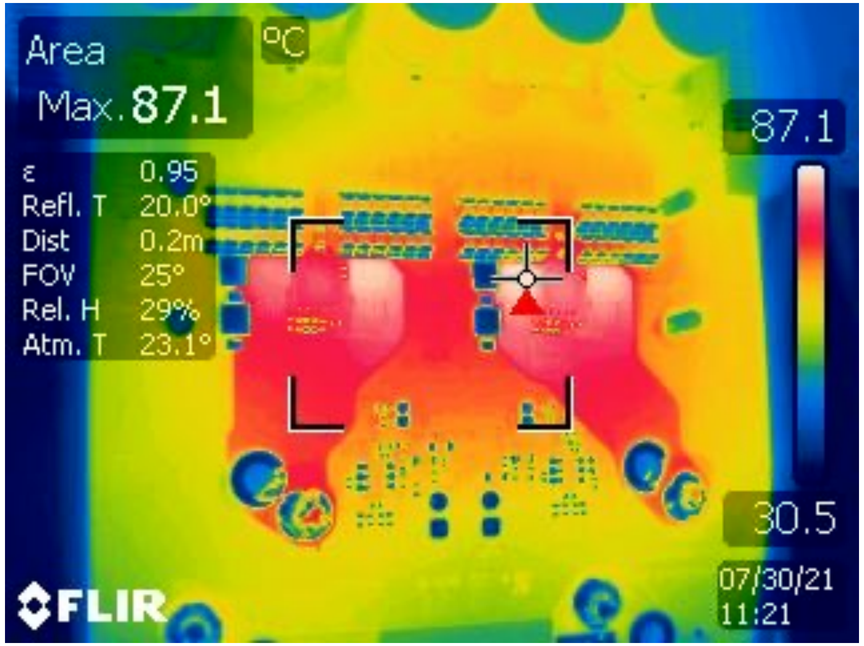
- 48 V input, 12 V output, 125 A, two phase
- With heatsink, high-performance TIM
- Airflow: max (2000 LFM)
- Measured at back side of PCB

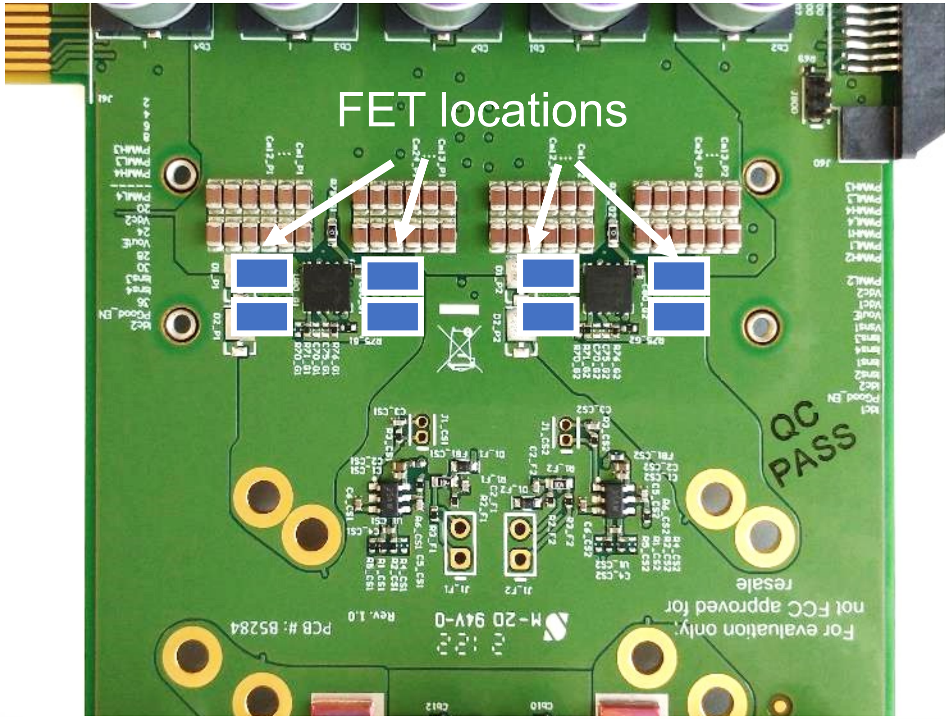




EPC9163C 2-phase thermal

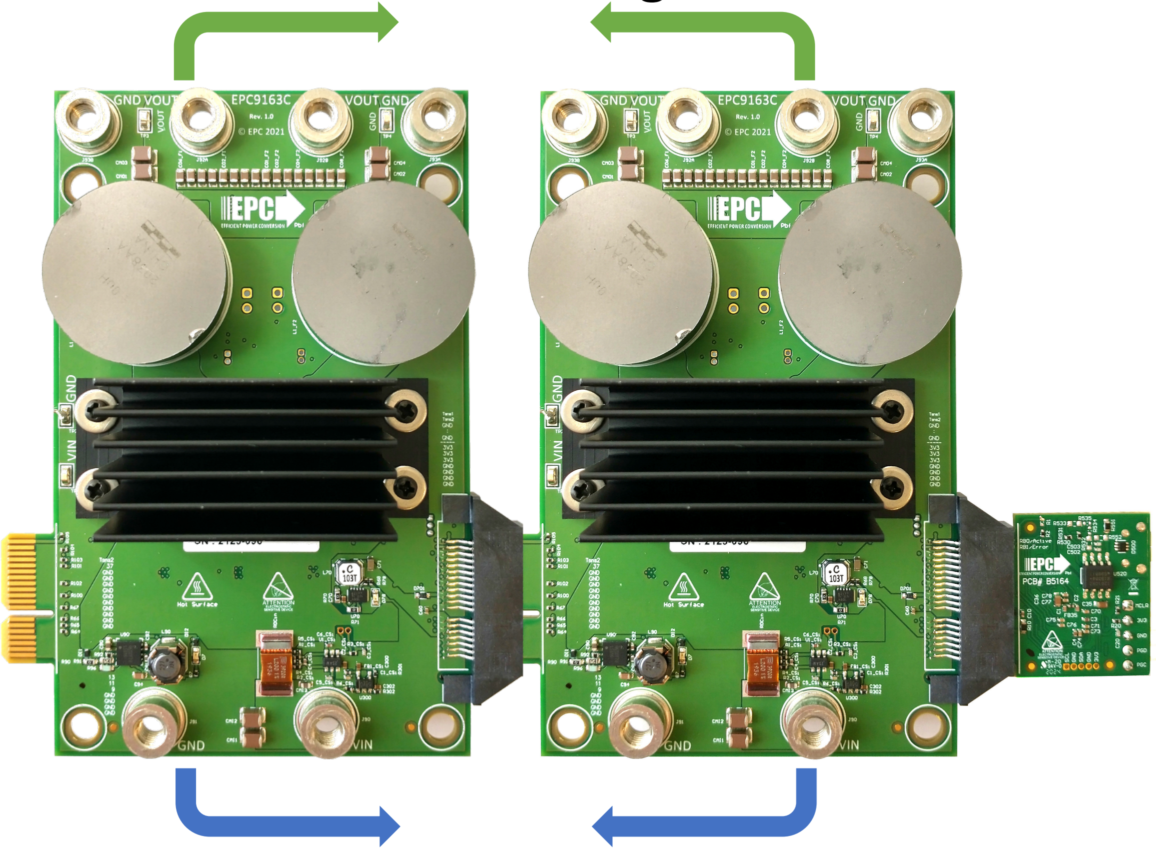
- 48 V input, 13.8 V output, 140 A, two phase
- With heatsink, high-performance TIM
- Airflow: max (2000 - 3000 LFM)
- Measured at back side of PCB





Expansion to Higher Power

12 V connect together

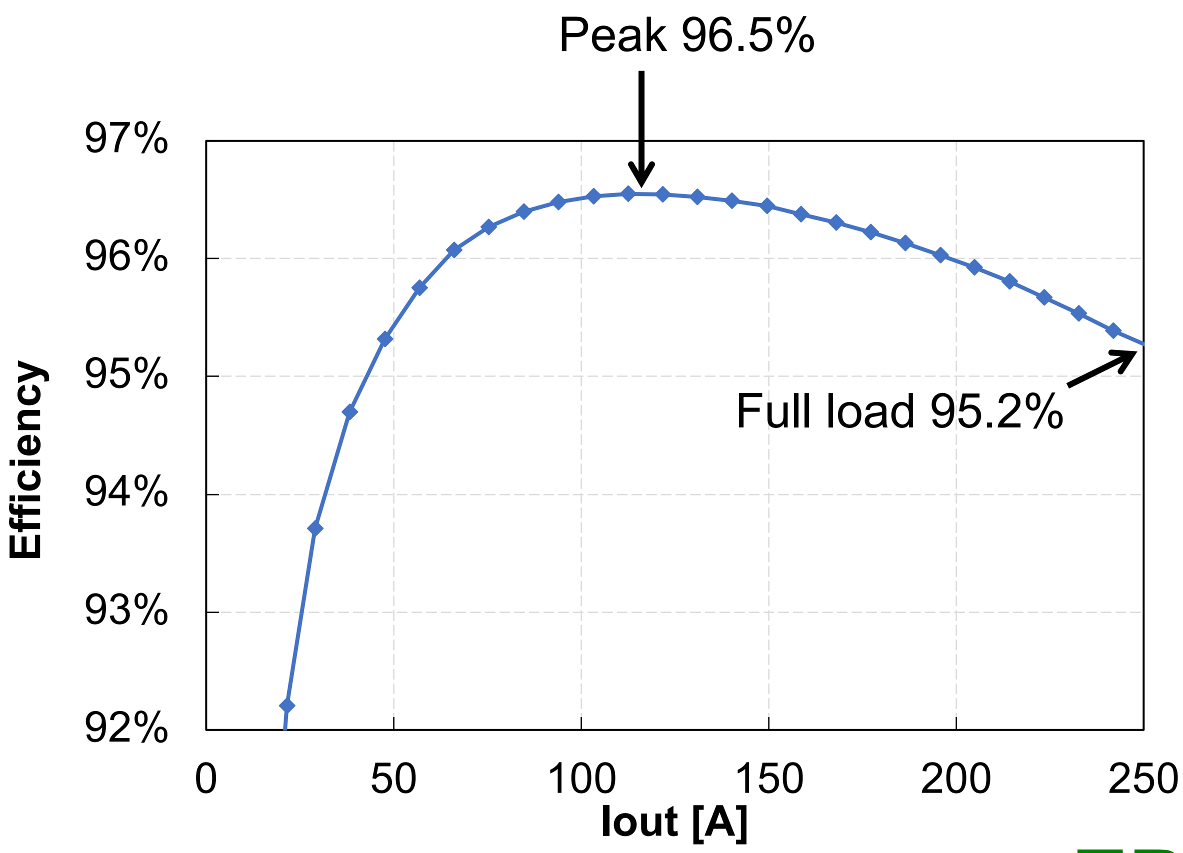


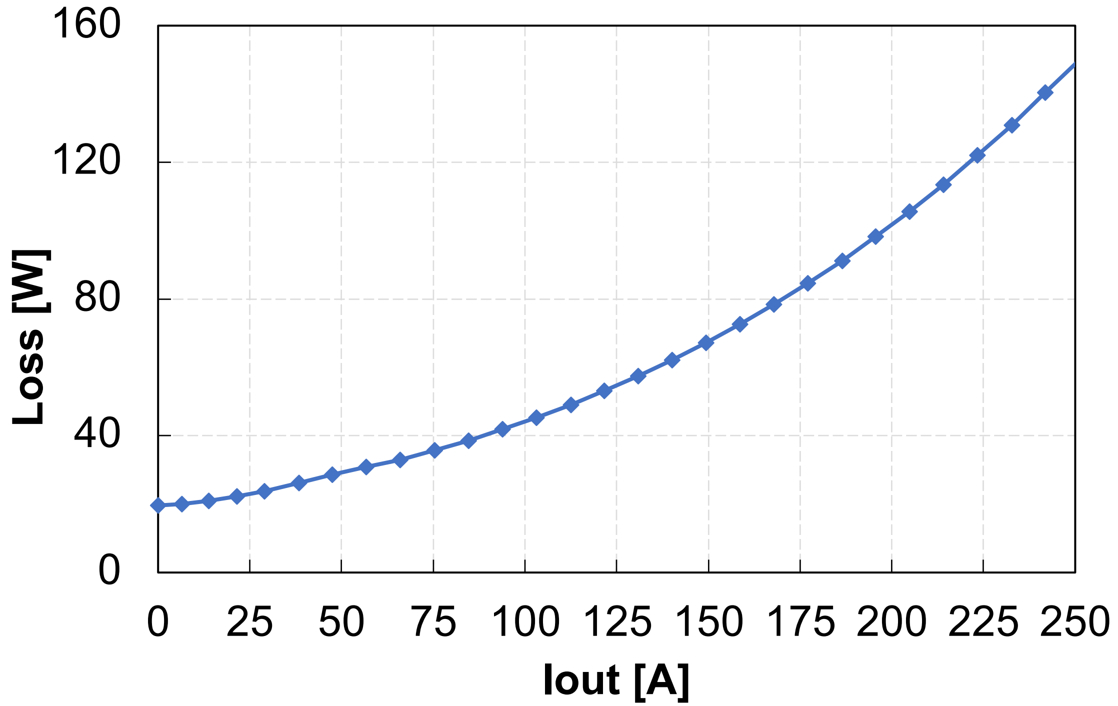
48 V connect together

- Additional board can be cascaded to form a 4-phase system
- Single controller – current mirror control

4-Phase Efficiency Results

48 V input, 12 V output, 250 kHz, 2.2 µH, 2000 LFM airflow

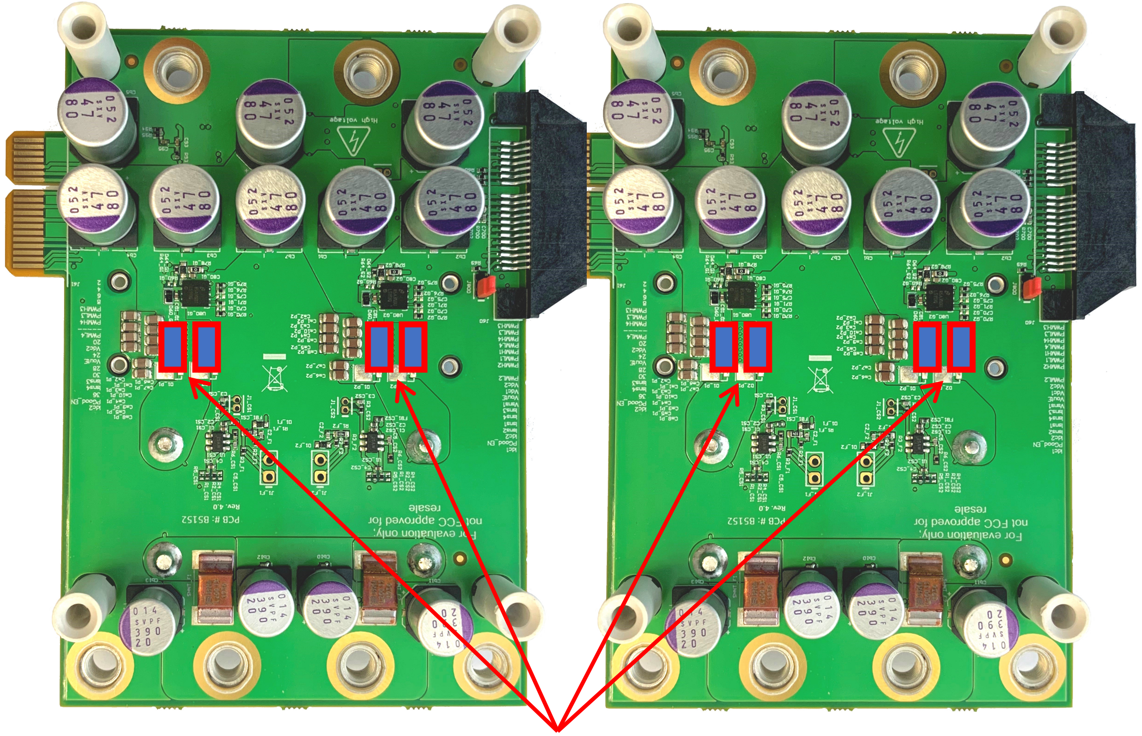




EPC9137

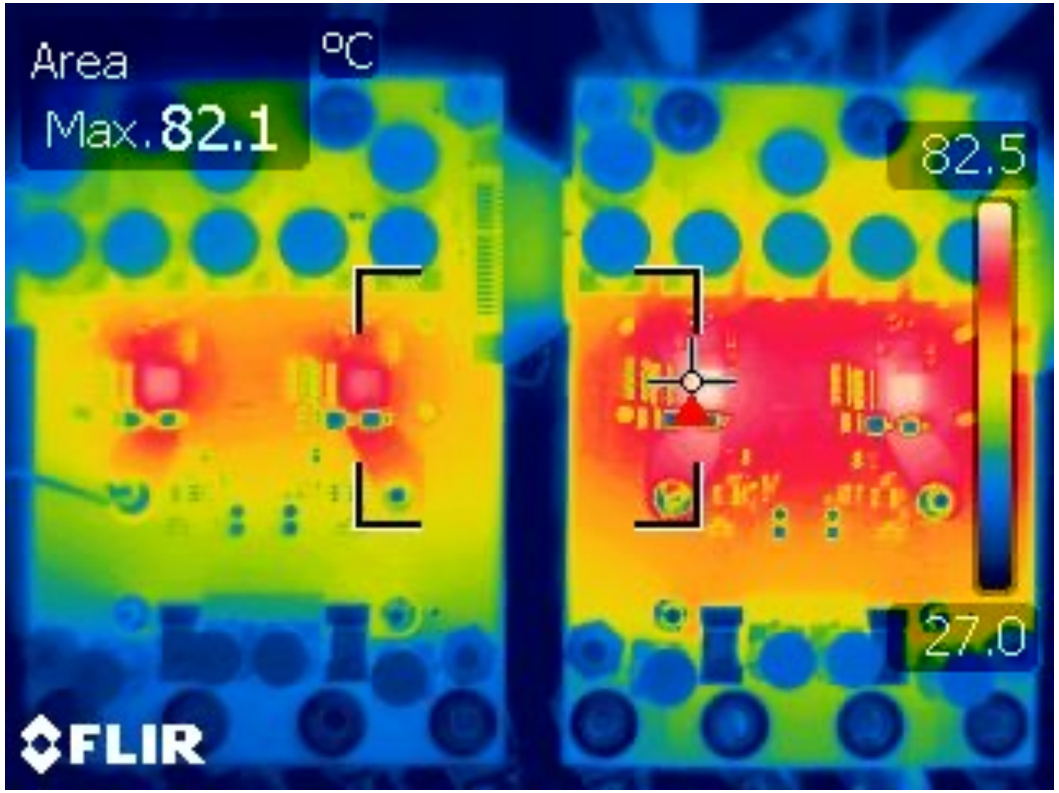
4-Phase Thermal Results

48 V input, 12 V 250 A output
250 kHz, 2.2 μH, 2000 LFM airflow



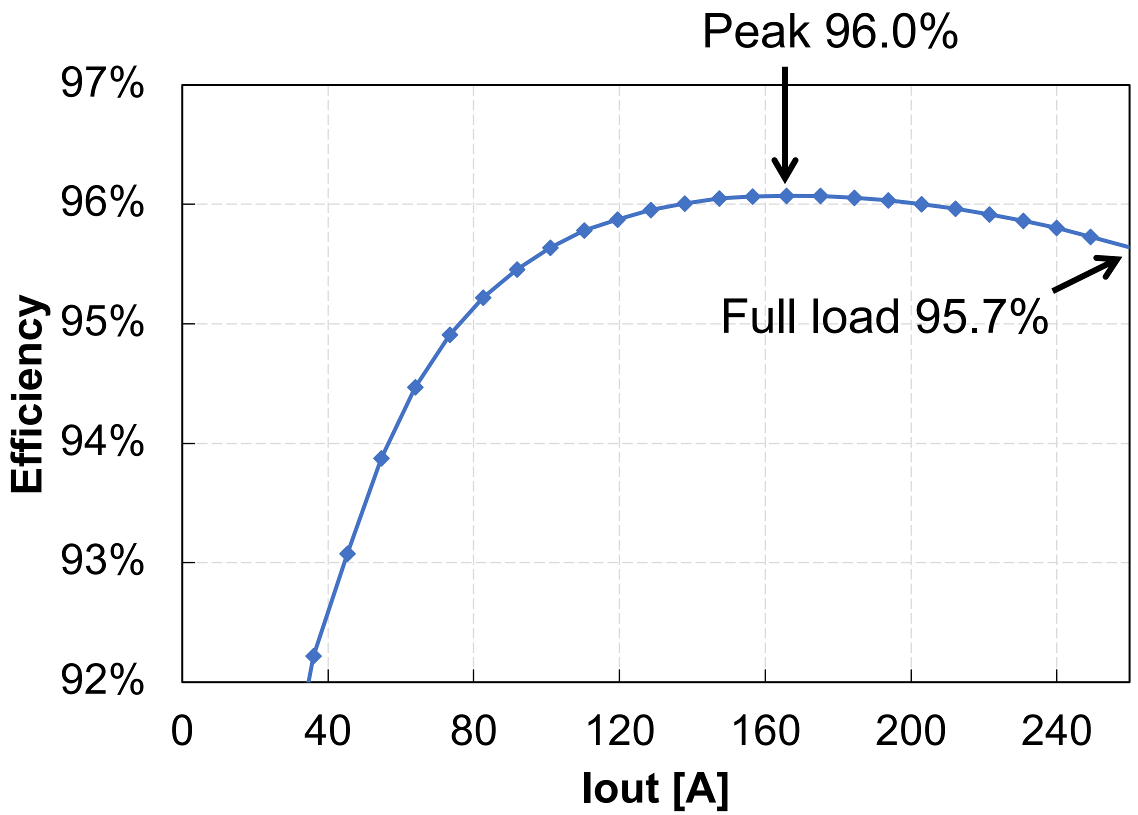
FET locations

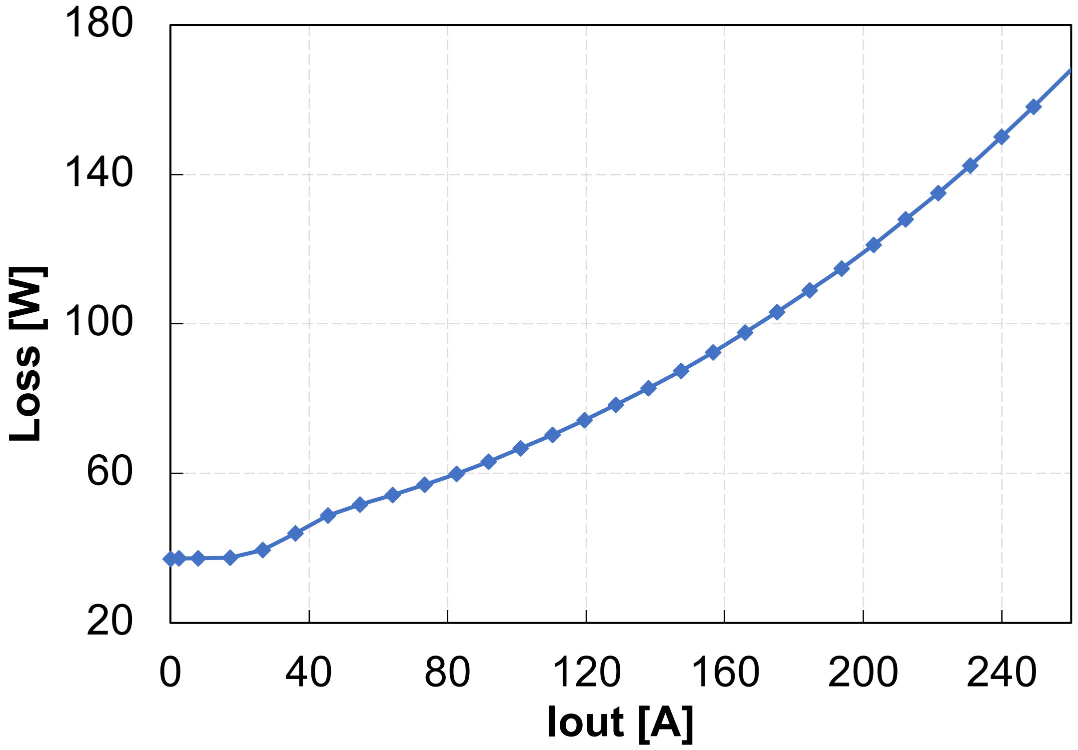
EPC9137



4-Phase Efficiency Results

48 V input, 14.3 V output, 500 kHz, 1 µH, 2000 LFM airflow

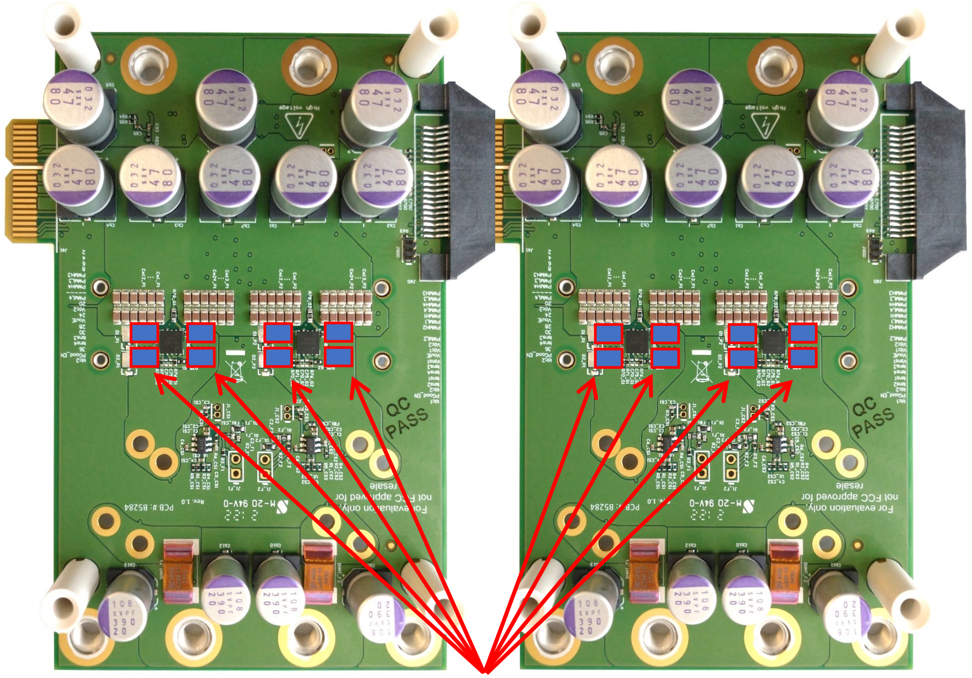




EPC9163C

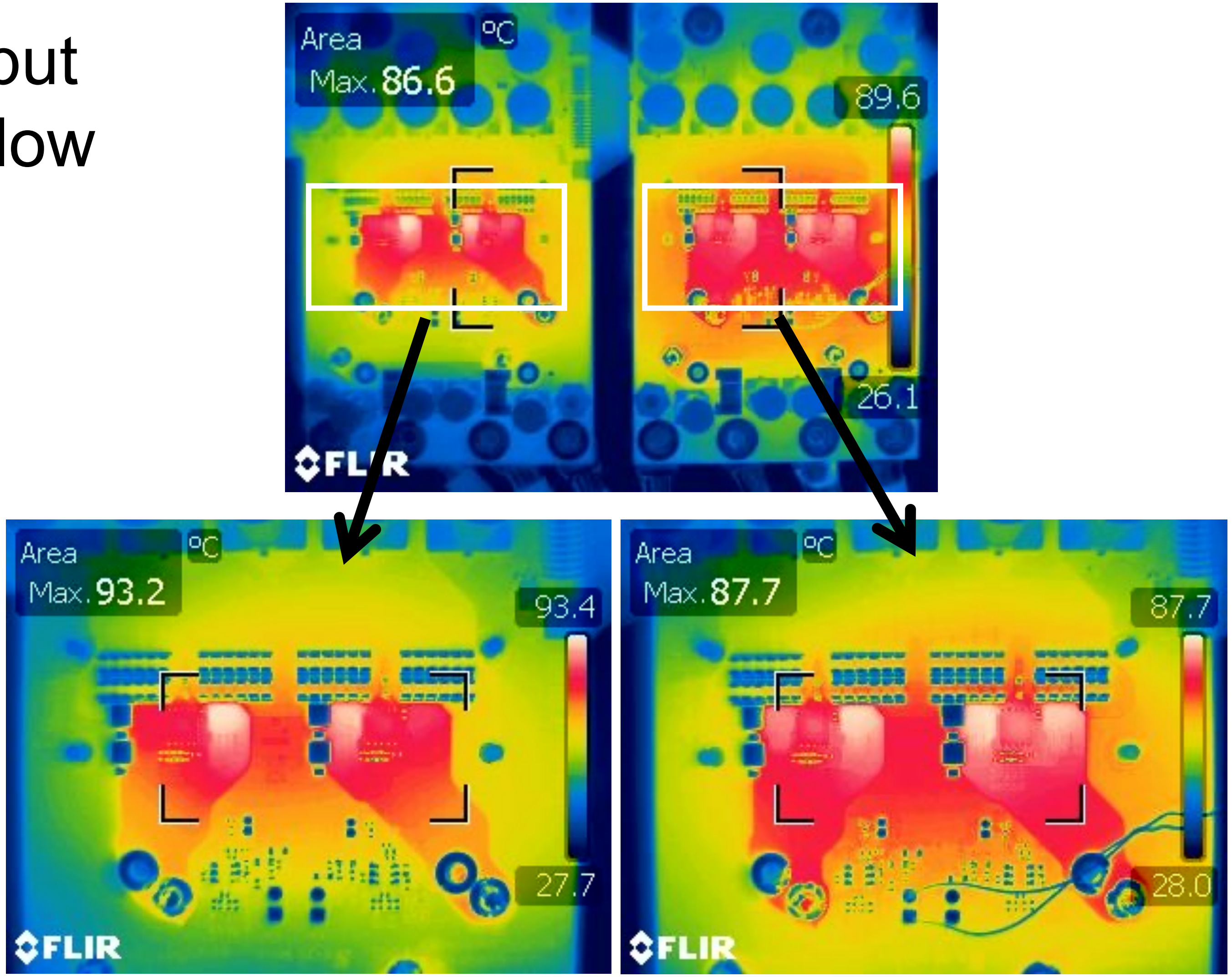
4-Phase Thermal Results

48 V input, 14.3 V 260 A output
500 kHz, 1 µH, 2000 LFM airflow



FET locations

EPC9163C



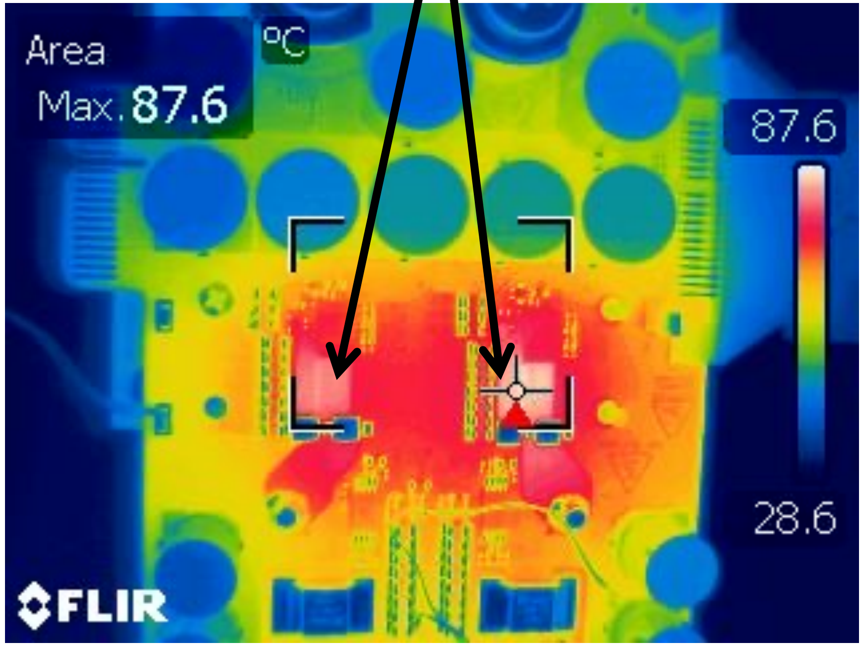
Controller Converter Performance

Testing Setup

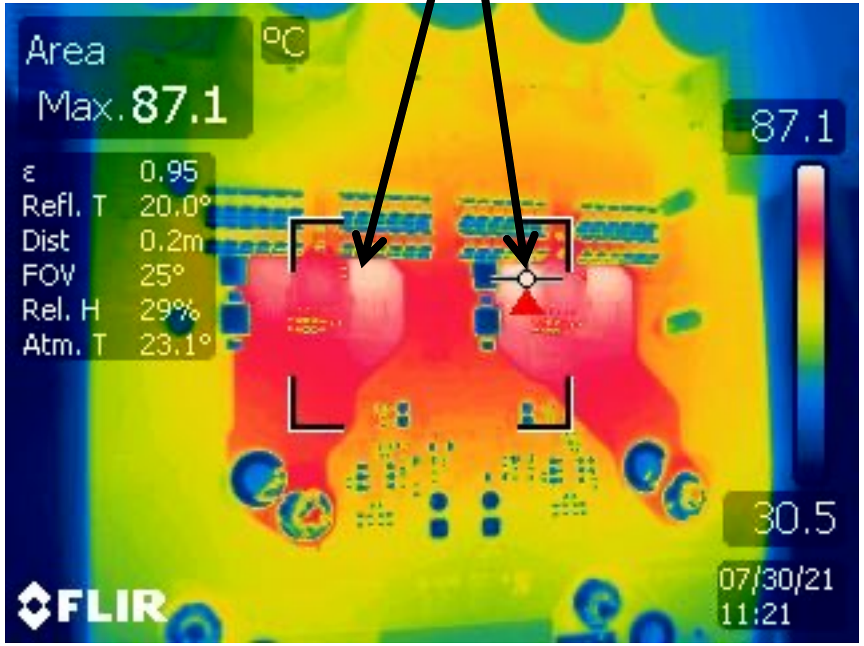
- Current balance (Thermal image)
- Transient response
- Start up
- 4-Phase configuration

Current Balance

- Use thermal image to verify current balance
- FET and inductor temperatures with 3°C of each other

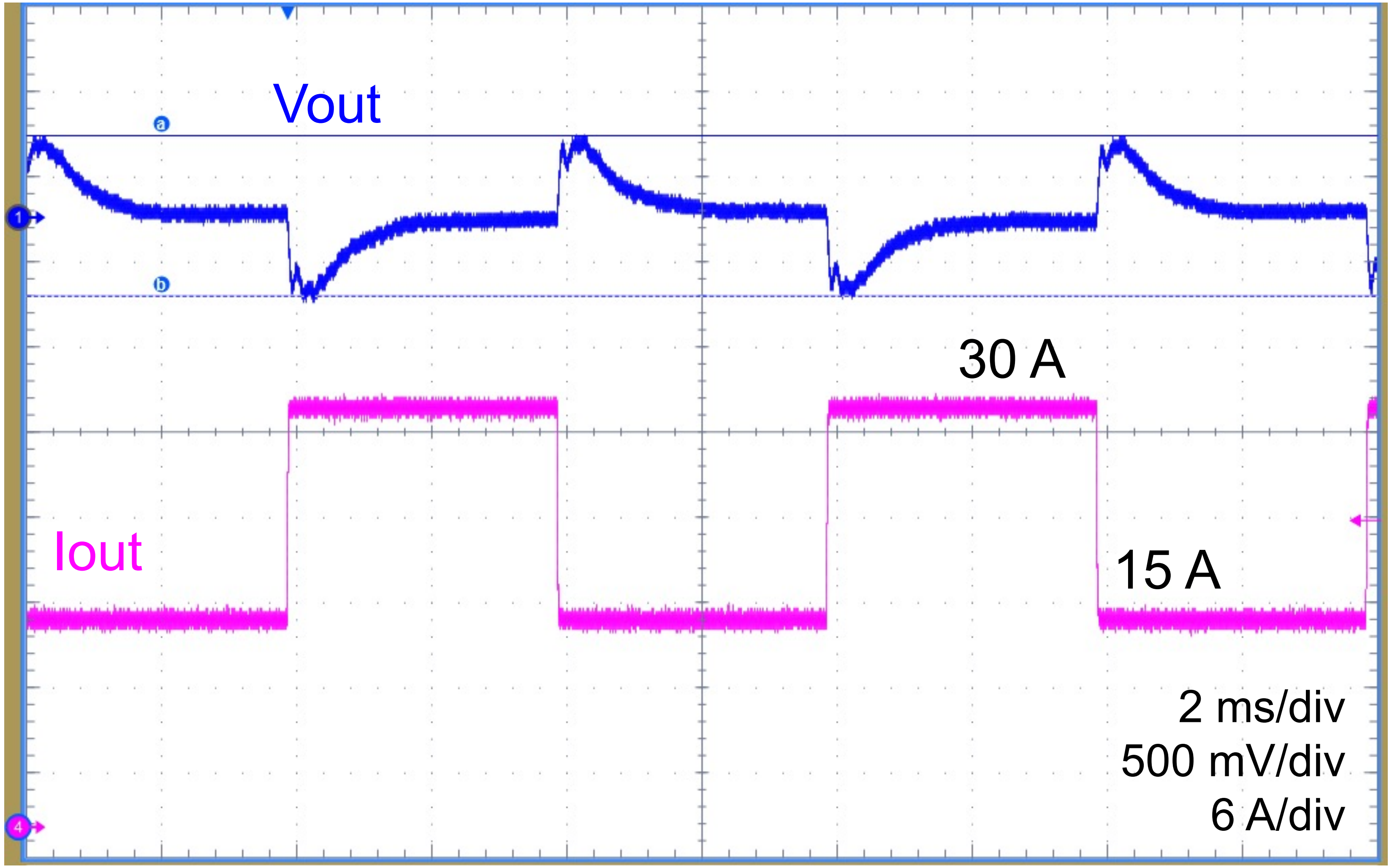


EPC9137



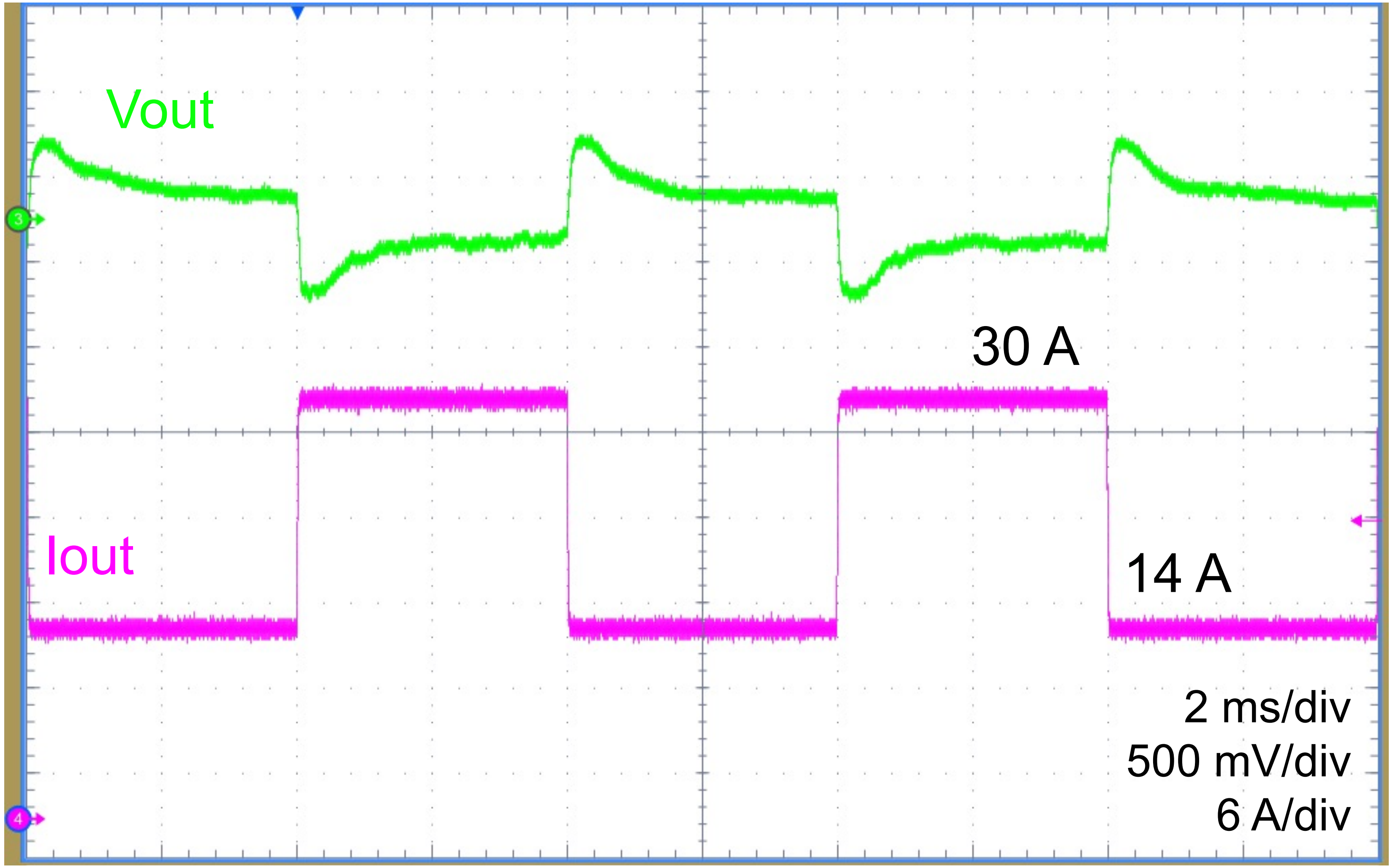
EPC9163

EPC9137 Load transient



48 V input, 12 V output (Buck)

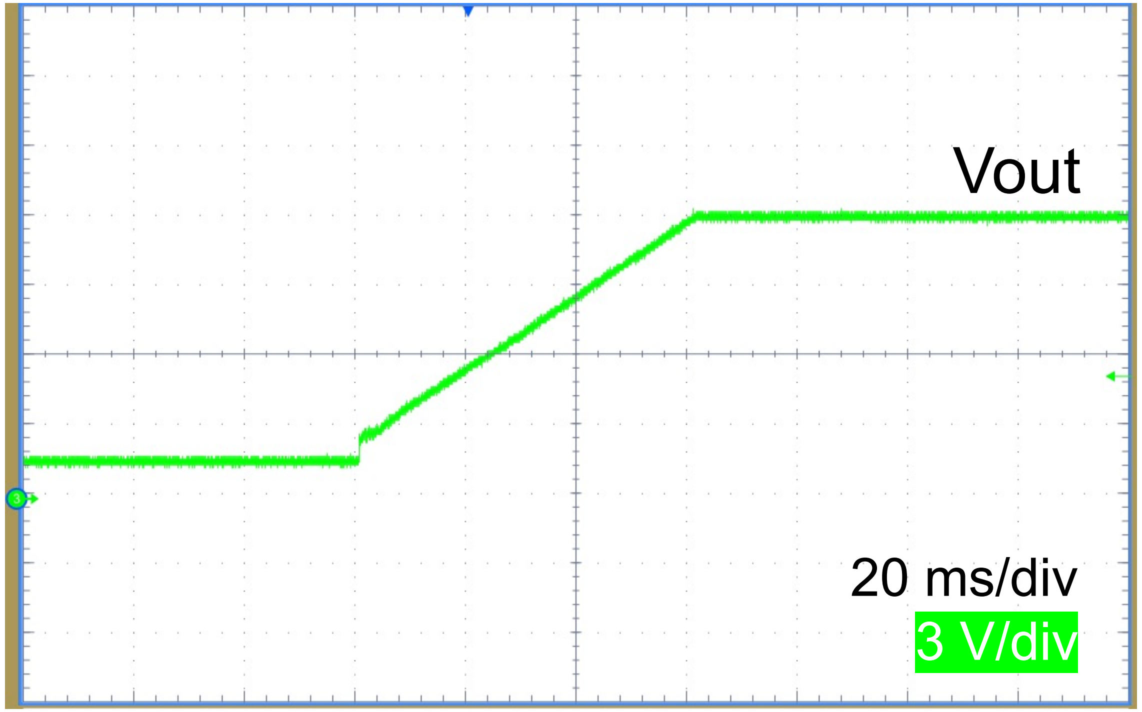
EPC9163C Load transient



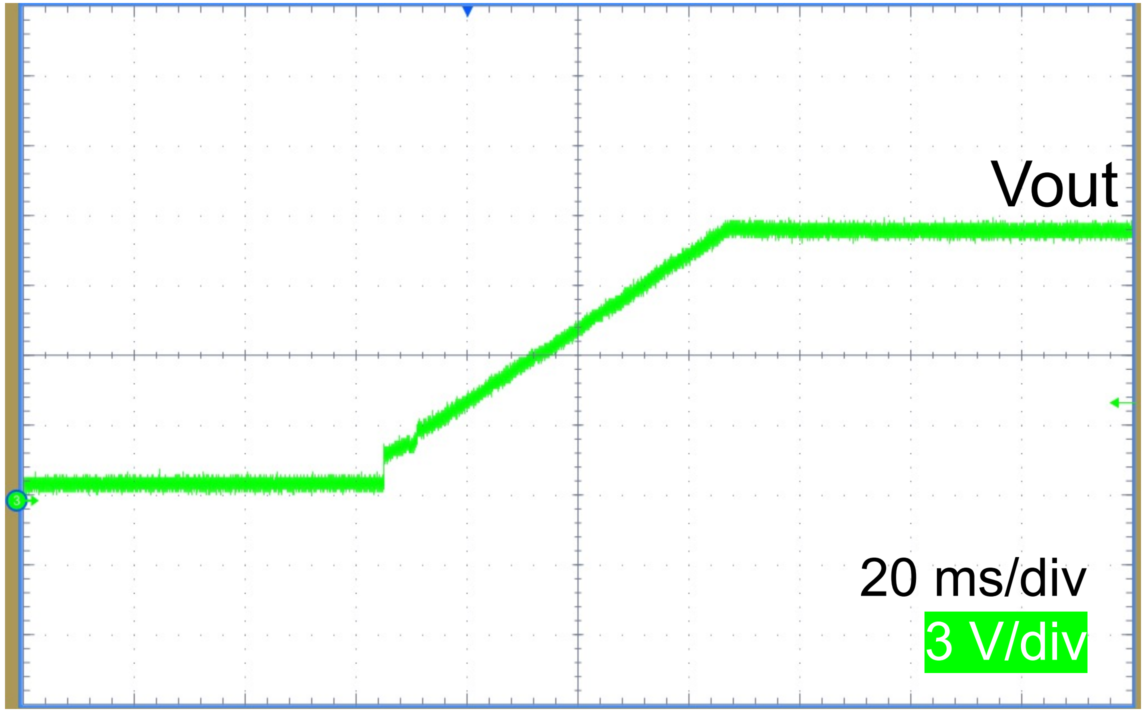
48 V input, 14 V output (Buck)

Start up

EPC9137



EPC9163C



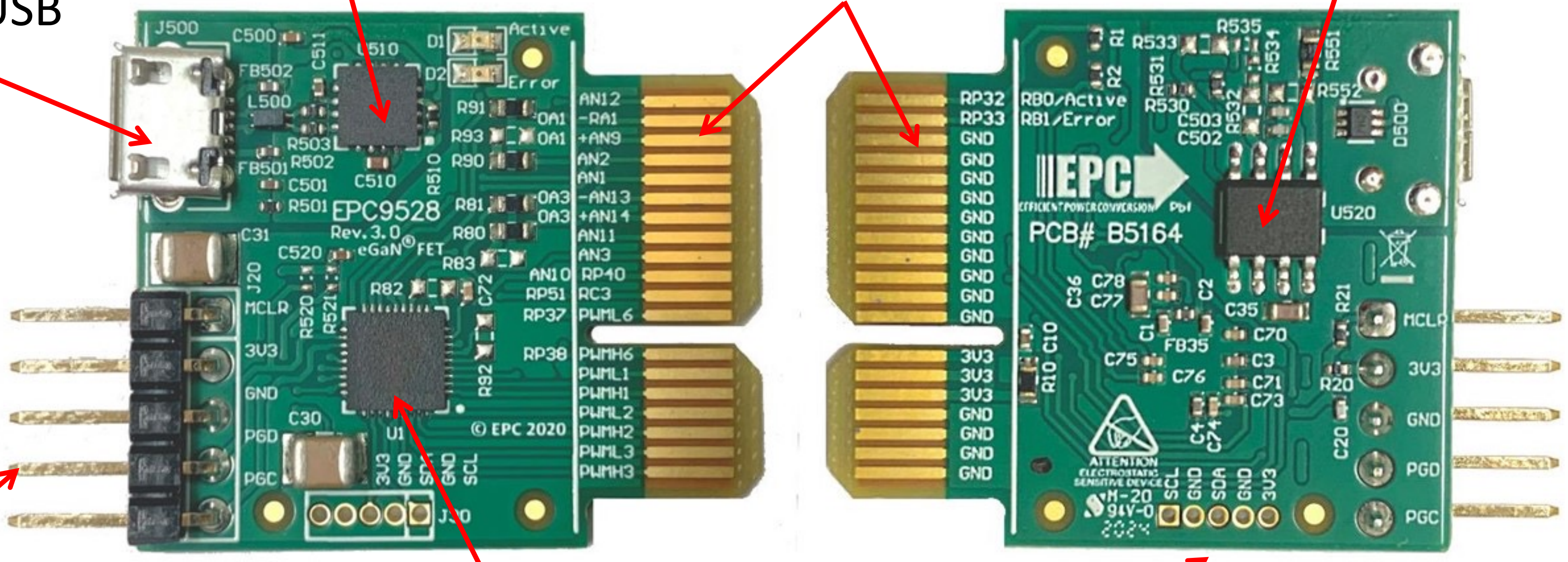
48 V input, 12 V output (Buck)

Control

Controller Overview

EPC9528

EPC9528 Controller Card



Micro-USB

UART/USB interface

J10
Load Board Interface

USB isolator

J20
Programming
Connection

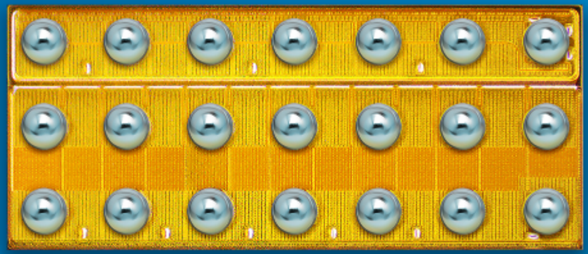
dsPIC33CK256MP503

J30
I^2C Port

EFFICIENT POWER CONVERSION

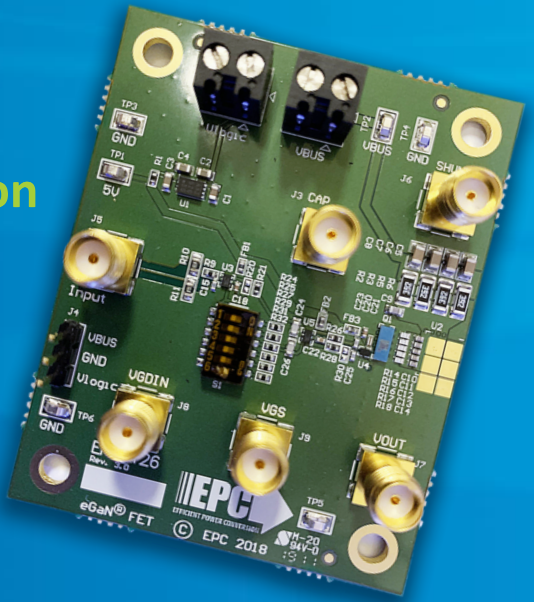
How To GaN Video Series

3rd Edition Textbook



eGaN® FETs and ICs

Evaluation Kits



epc-co.com

Microchip Solution On EPC9528 Controller Card

A Leading Provider of Smart, Connected and Secure Embedded Solutions

2021 Microchip 高效能電源技術線上研討會

Edward Lee

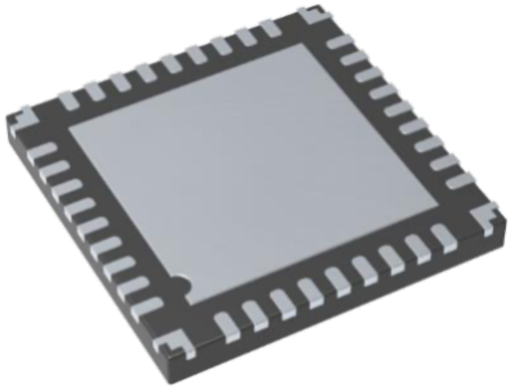
Dec. 2nd, 2021

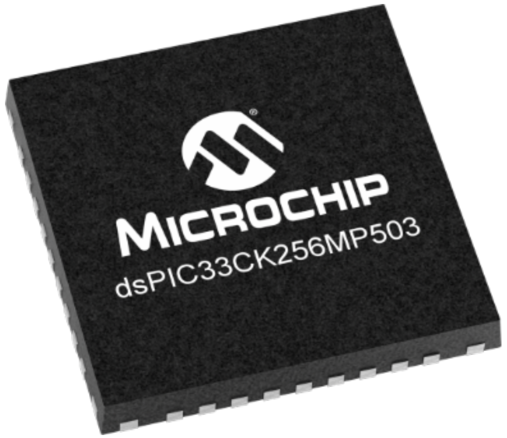
SMART | CONNECTED | SECURE

Controller Overview

EPC9528 Controller Card

- **Choice of controller dsPIC33CK256MP503-E/M5**
  - Small size at 5x5 mm
  - 250ps PWM resolution for precise PWM timing
  - Low power consumption
  - Built in Op-Amps for analog feedback circuit reduction
- **Controller used for**
  - Average current mode control
  - Voltage mode control
  - Over temperature protection
  - Startup
  - Phase current balancing
  - Operations monitoring
  - Communications





Behind the Scenes for Control

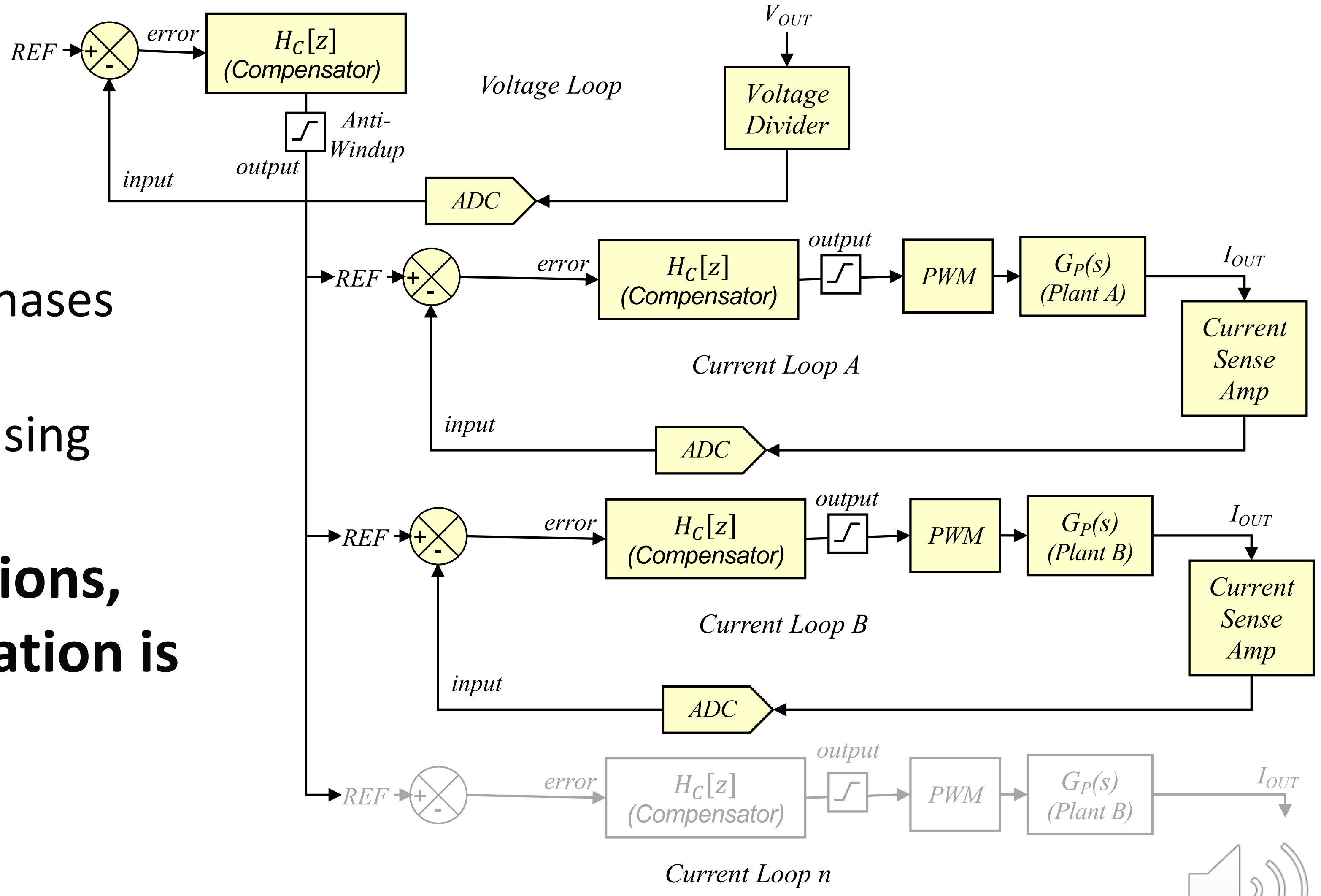
EPC9528 Controller Card

- **Tuning of Forward Buck/Reverse Boost Converter**
  - Loop measurement
  - Using PowerSmart™ to set up and tune the digital controller
- **Voltage loop auto gain for simple power reversal**
  - Constant current to constant voltage switchover
- **Various operating modes**
  - Both 48V and 12V low or high
  - 48V high 12V low, 12V high 48V low
- **Controllers**
  - Multiple current loop
  - Current mirror
- **Communications**
  - USB

Multiphase Controller Implementation

EPC9528 Controller Card

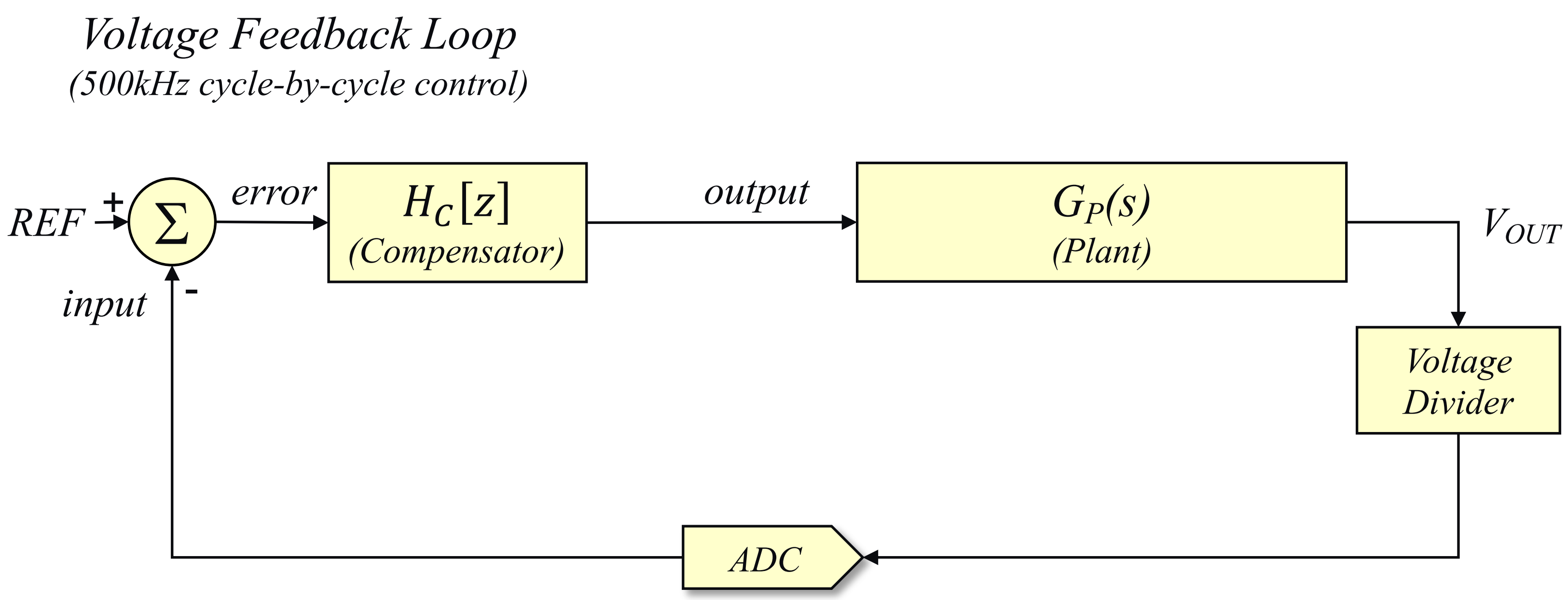
- **Multiphase converter controllers have limited scalability**
  - Max number of supported phases limited by CPU performance
  - Bandwidth drops with increasing number of phase controllers
- **To overcome these limitations, phase controller multiplication is used**



Building the Control System

Basic Voltage Mode Control Implementation

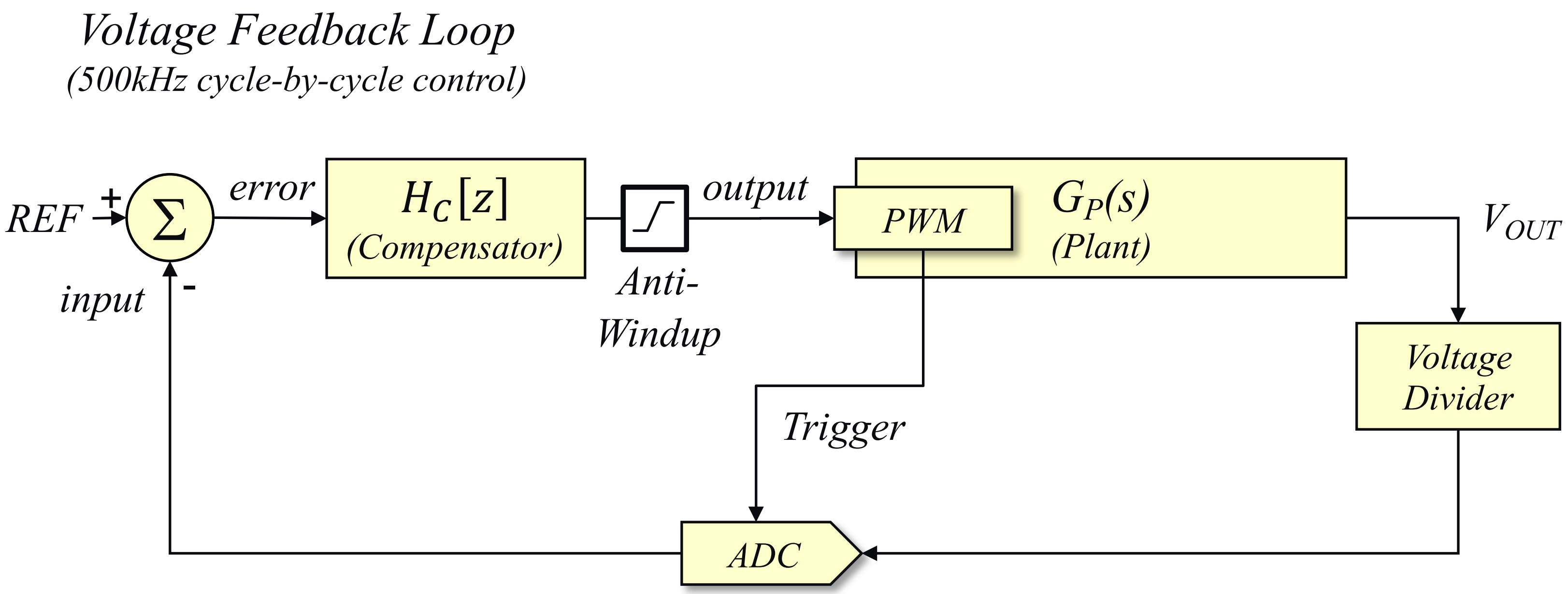
EPC9528 Controller Card



Building the Control System

Peripheral Interconnections

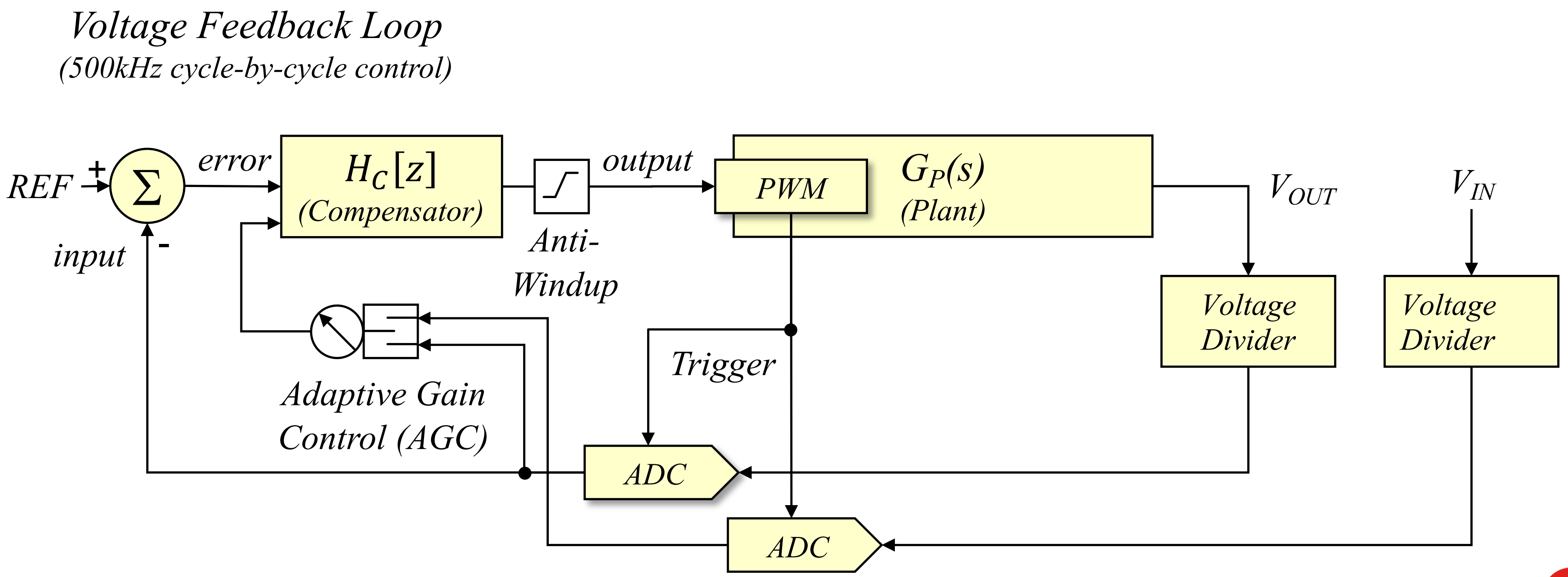
EPC9528 Controller Card



Building the Control System

Adaptive Gain Control Implementation

EPC EFFICIENT POWER CONVERSION
EPC9528 Controller Card

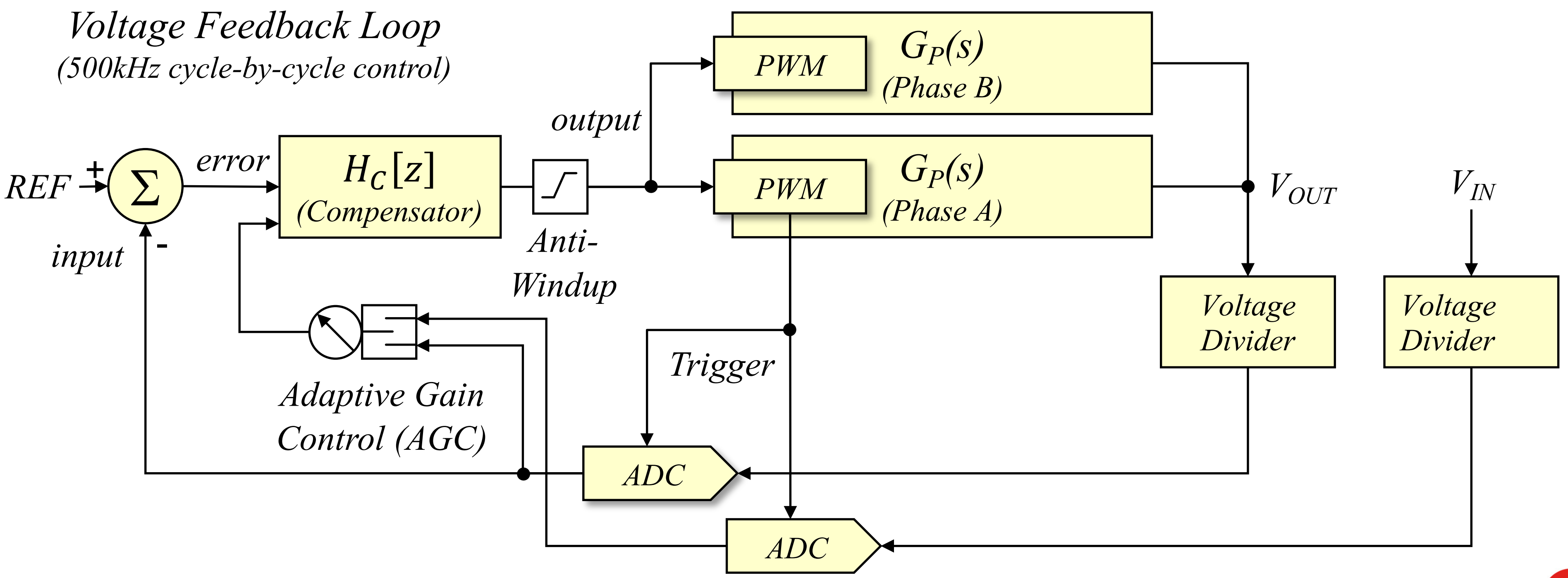


MICROCHIP

Building the Control System

PWM Mirroring with Phase Shift

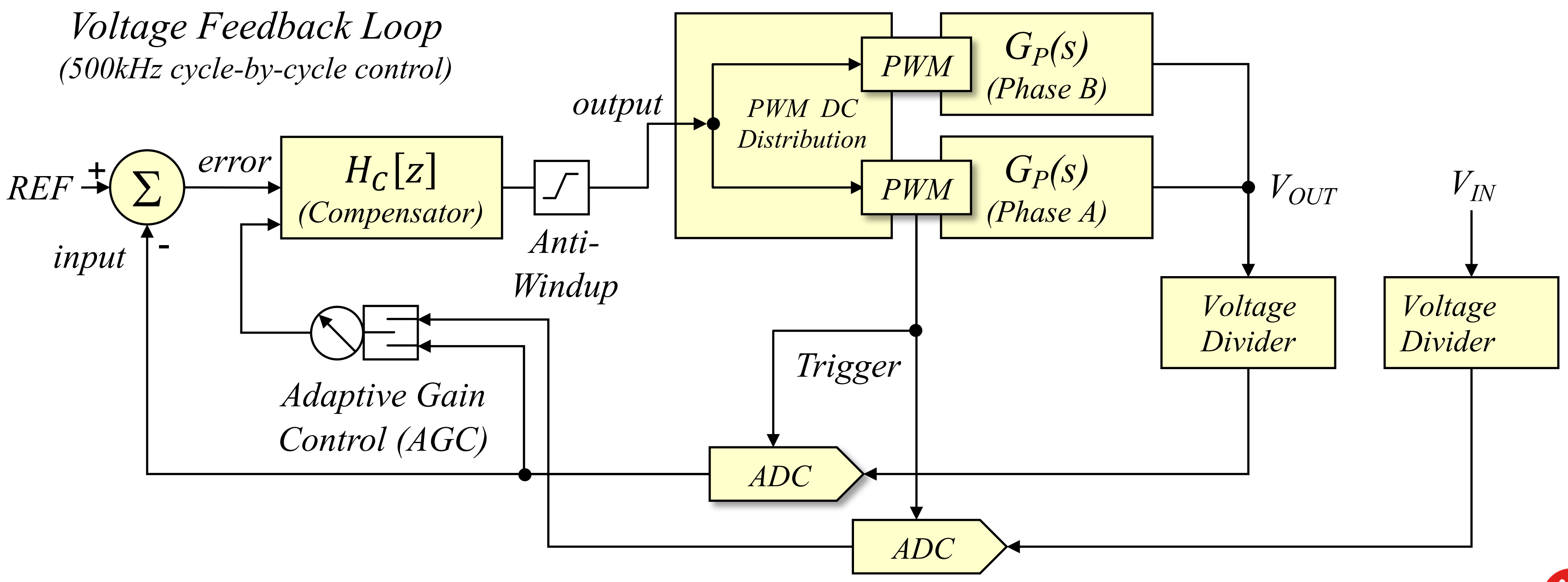
EPC9528 Controller Card



Building the Control System

PWM Duty Cycle Distribution

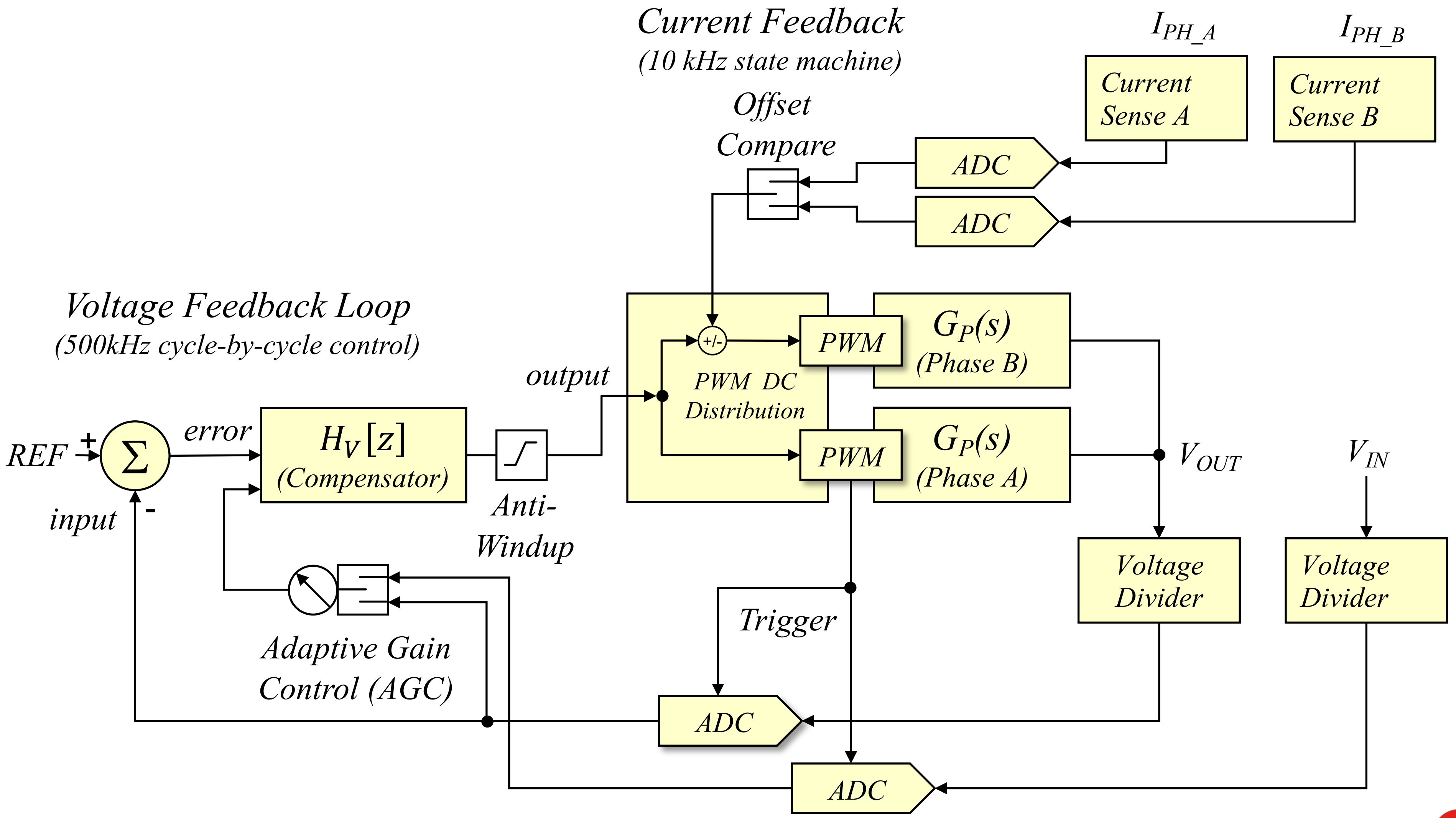
EPC9528 Controller Card



Building the Control System

Current Balancing

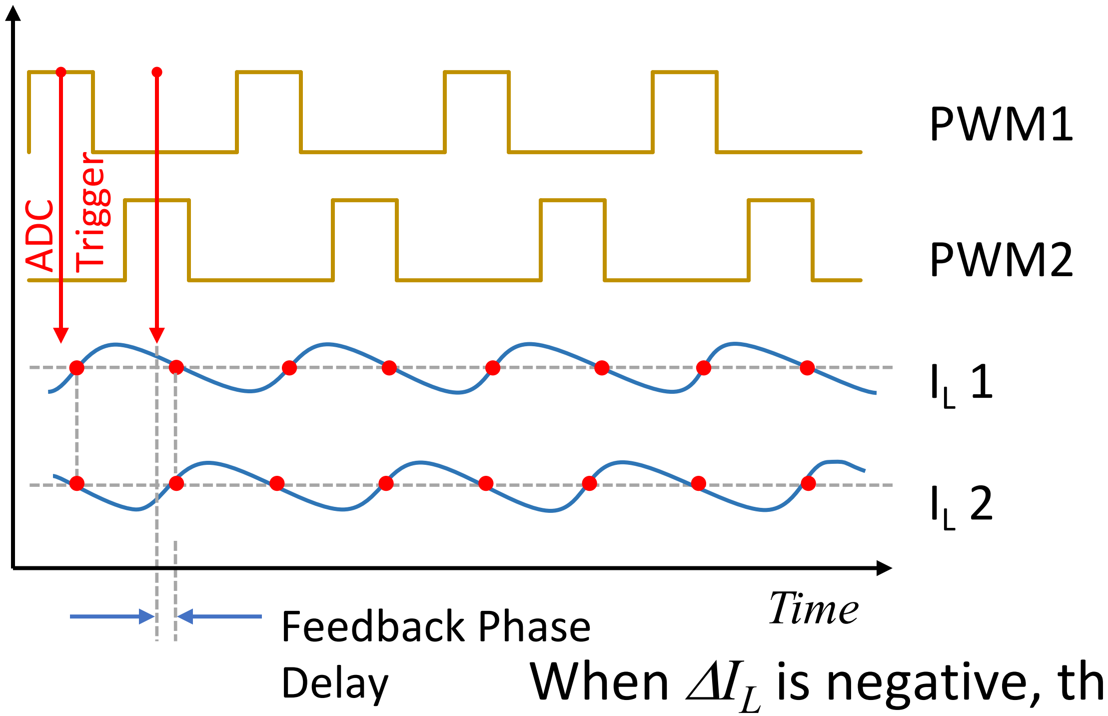
EPC9528 Controller Card

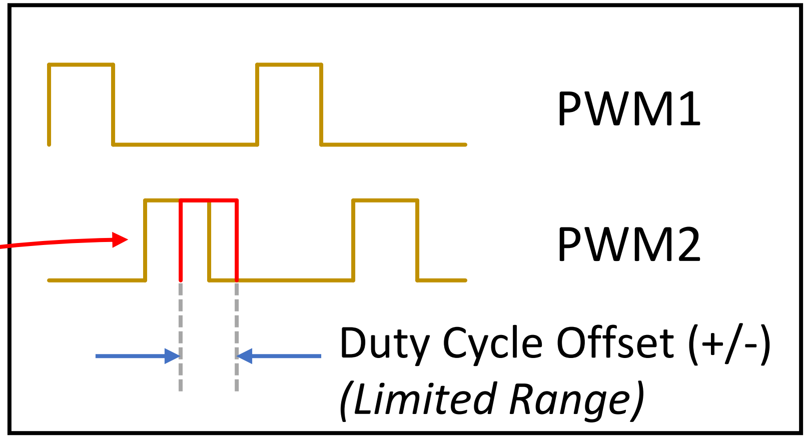


Current Balancing Implementation

EPC9528 Controller Card

Simple Bit Tracker Implementation





$$\Delta I_L = I_{L1} - I_{L2}$$

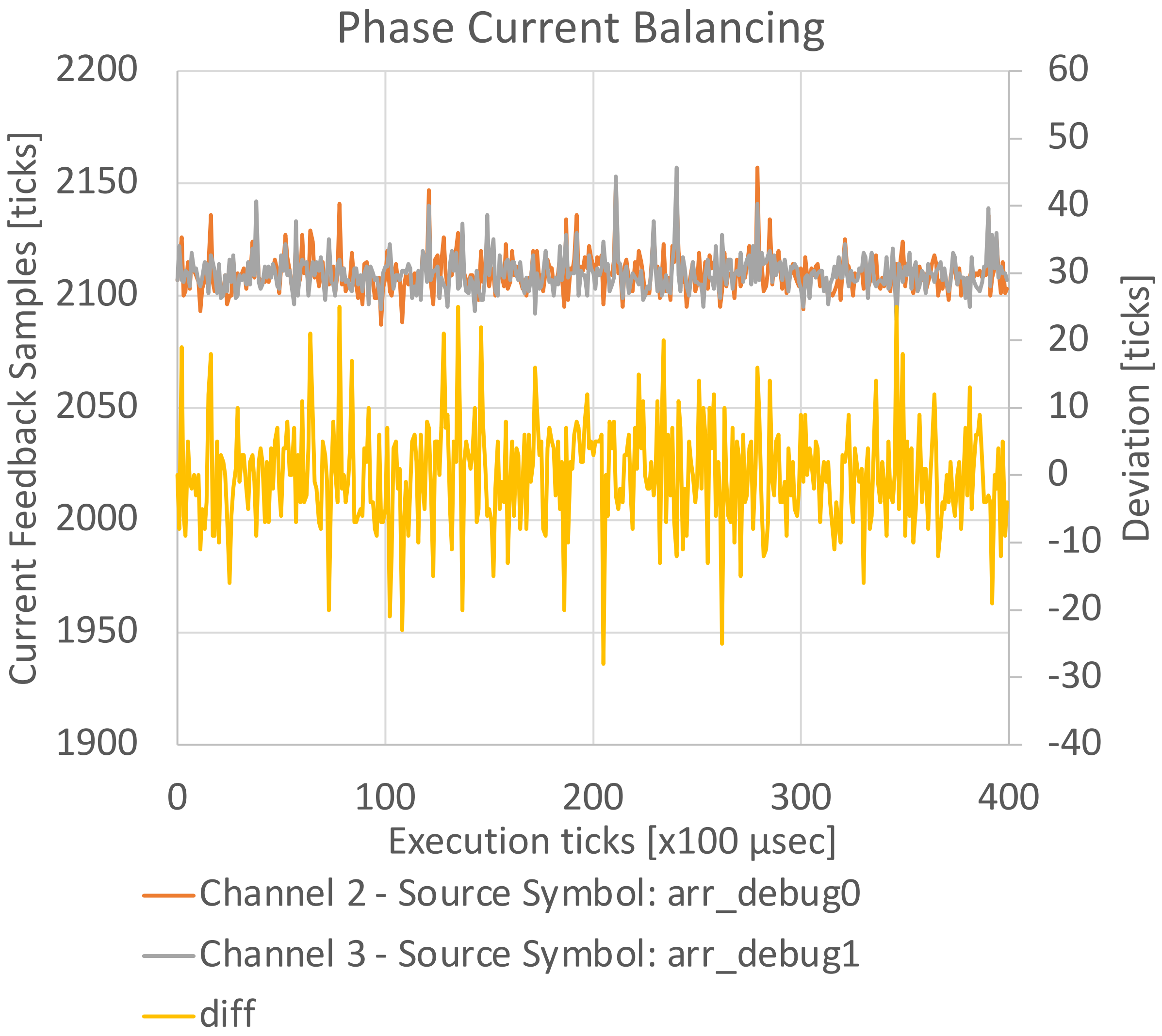
When ΔI_L is negative, the duty cycle of PWM2 is decremented with respect to PWM1 *by one tick despite the size of the difference* and incremented when positive.

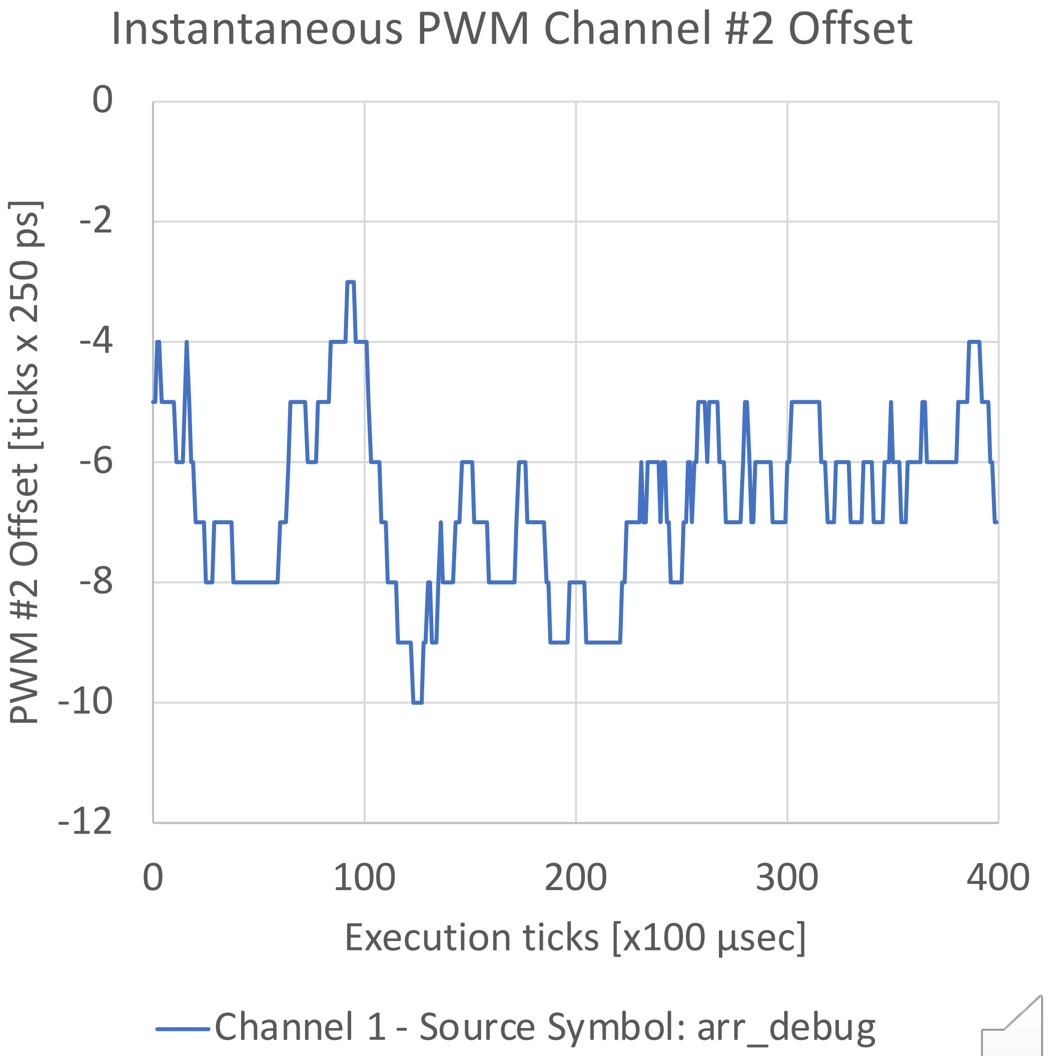
Offset adjustments are performed every 100 us (=10 kHz)

(adjustment in 250 ps increments/decrements)

Current Balancing Results

EPC9528 Controller Card

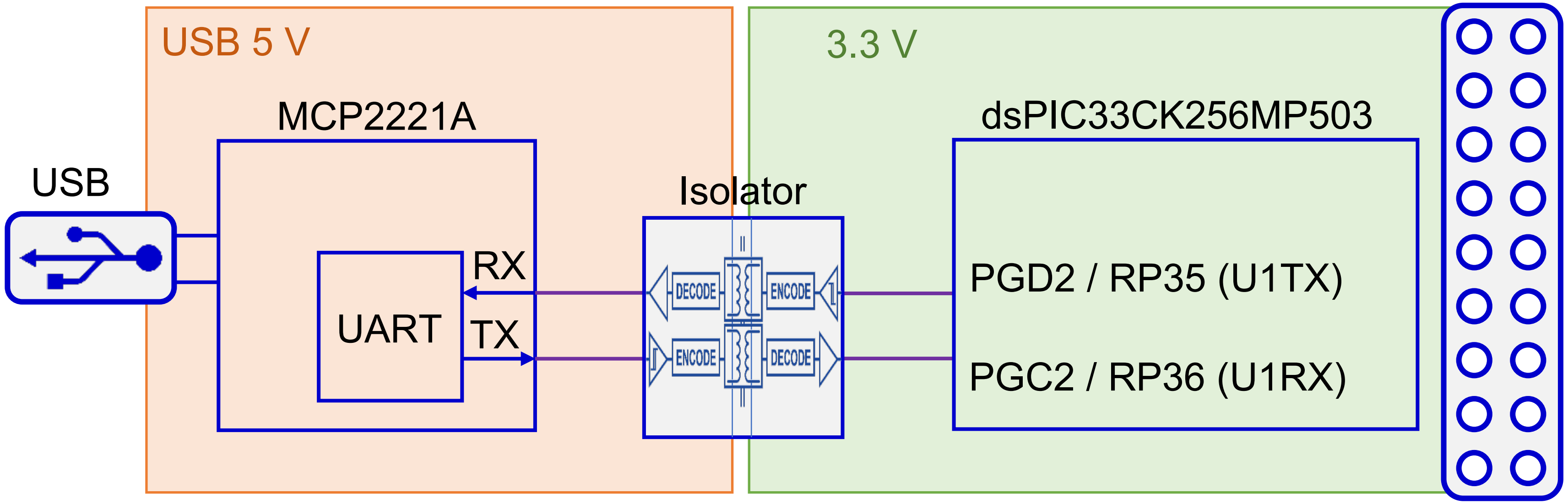




USB Communications

EPC9528 Controller Card

- **USB is isolated from power circuit**
- **Provides real-time communications**



Summary

- **EPC eGaN Devices Improve 48V – 12V Converters**
  - Higher efficiency, from 95+% to 97+%
  - Excellent thermal for air-cooled DCDC
  - 500 kHz for less phases and smaller, lower-cost, and lower-DCR inductor
  - Lower system cost & smaller size
  - More Reliable: AEC-Q101 devices tested at 100% Voltage
- **EPC GaN Experts Available to Support Design Questions**
  - Schematic, Layout Review & Thermal Simulation
- **Develop Multi-phase Converter Using dsPIC33C**
  - Adaptive Gain Control, Current Balancing, Communication and etc.
- **UART to USB with MCP2221A**

May The Power Be With You