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DETROIT

Building redundancy in an electrical systems that power 400V or 800V electric vehicles

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VICOR

The challenge: BEV's have a single source of power

A full Battery Electric Vehicle (BEV) derives its power from a single source, the high-voltage traction battery. An interruption of power from the traction battery is undesirable from the perspectives of owner convenience and safety.

To improve safety and reliability, redundancy needs to be included in the architecture at the very beginning of the project.

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Examples of redundancy & tradeoffs

N + 0

3kW

3kW converter 100% load

Load 3kW

N + 1

Capacity = 6kW

3kW converter 50% load

3kW converter 50% load

Load 3kW

2N + 1

Capacity = 4.5kW

1.5kW converter 33% load

1.5kW converter 33% load

1.5kW converter 33% load

Load 3kW

N + N

Capacity = 6kW

3kW converter 50% load

3kW converter 50% load

Load 3kW

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Adding redundancy in the source and power train improves safety and reliability

Redundancy provides power for three types of loads:

- ✓ Typical non-critical loads that can be turned off during an accident
- ✓ Steering and braking – always are on
- ✓ CAN bus and communication – always are on

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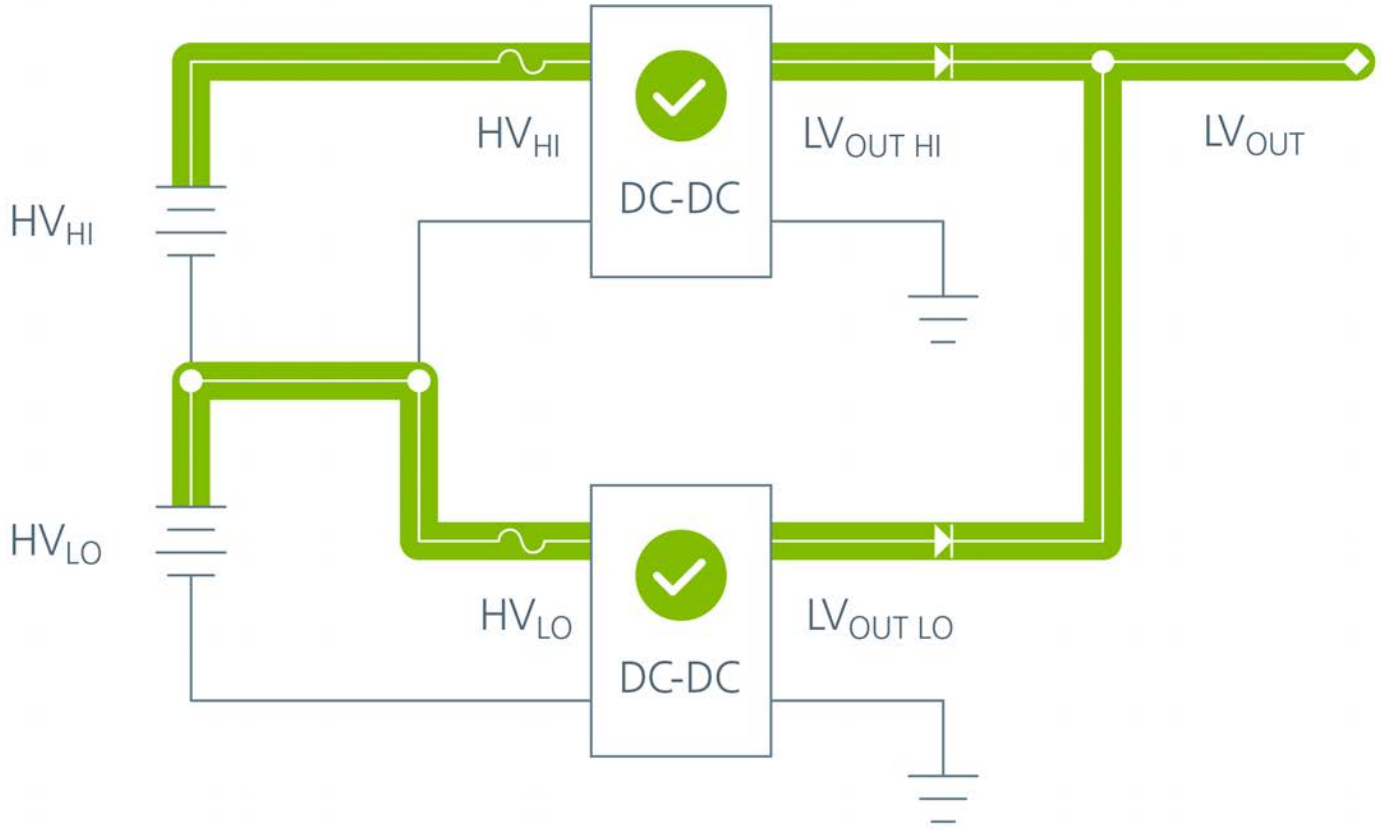
Redundancy using series stacked battery configuration



- The 800V battery could be split into two 400V batteries connected in series
- Each 400V battery uses a separate DC-DC converter
- This is referred to as a dual 400V series stacked system

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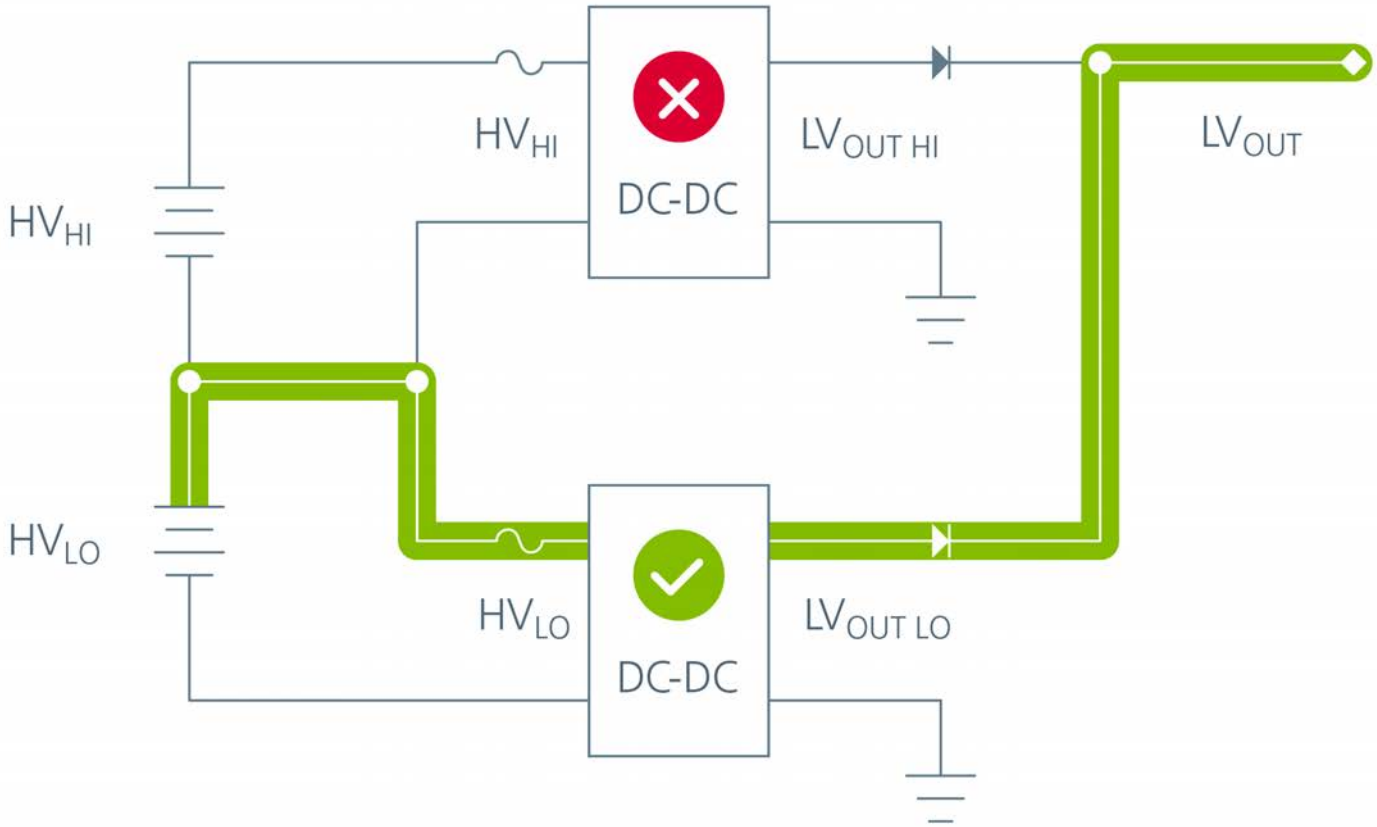
Redundancy using series stacked battery configuration



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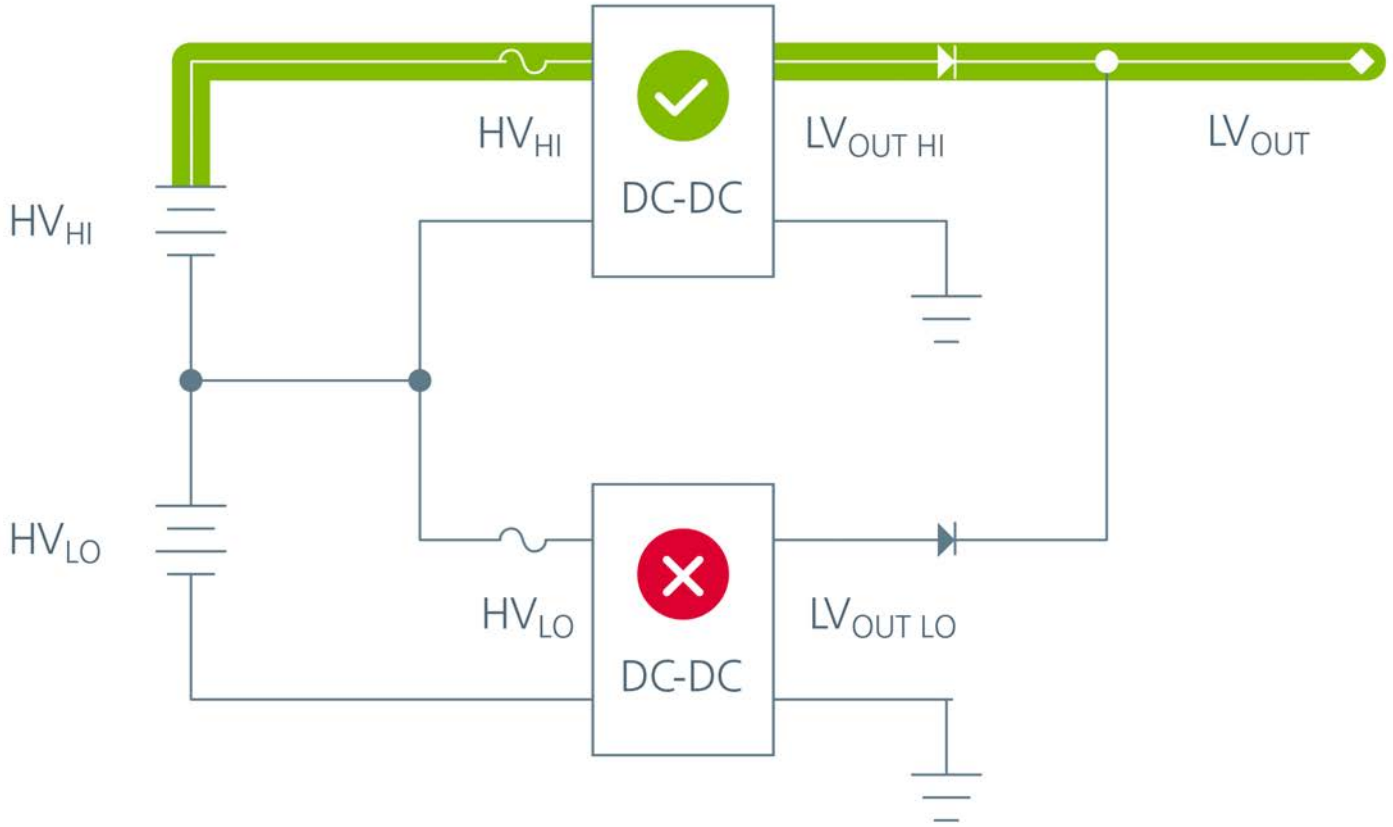

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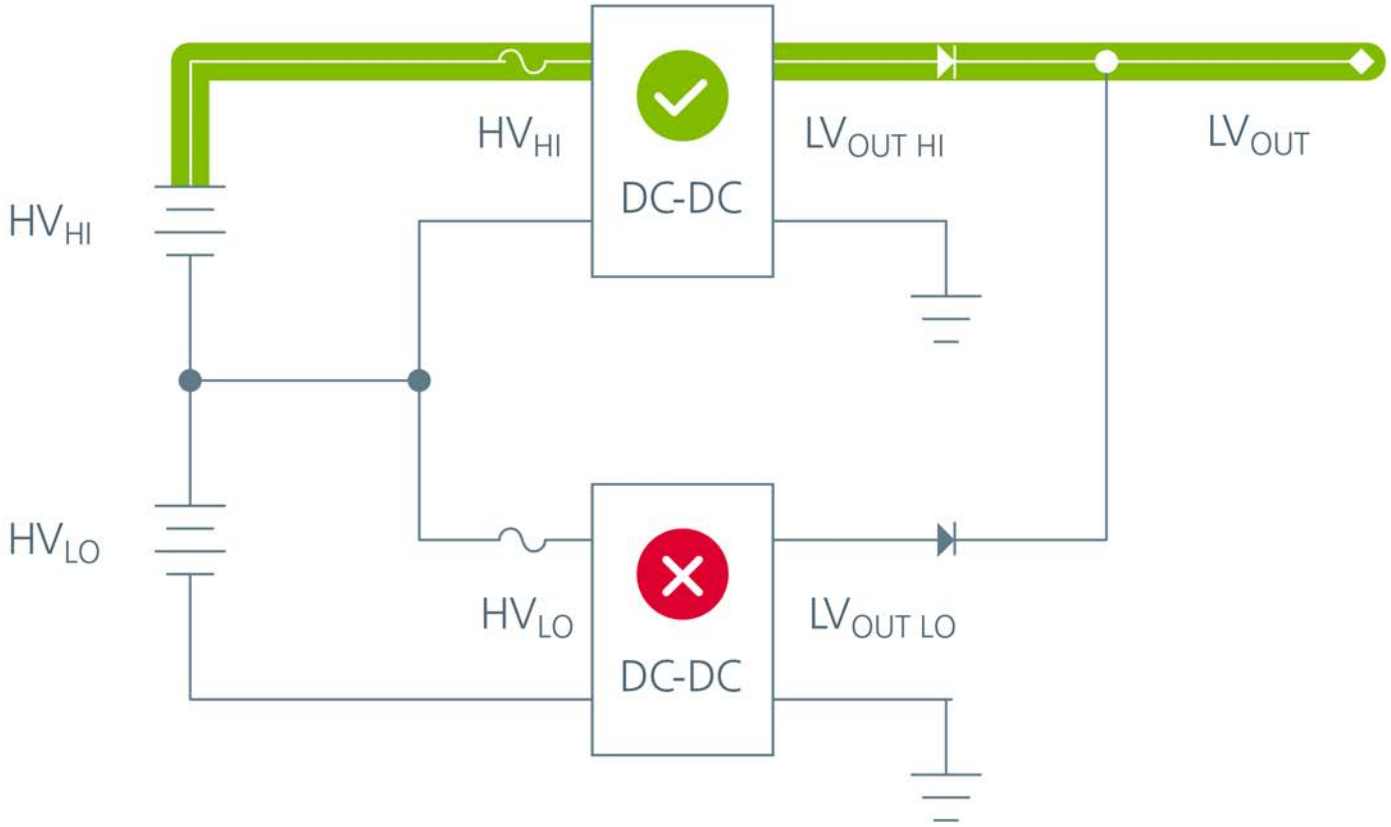

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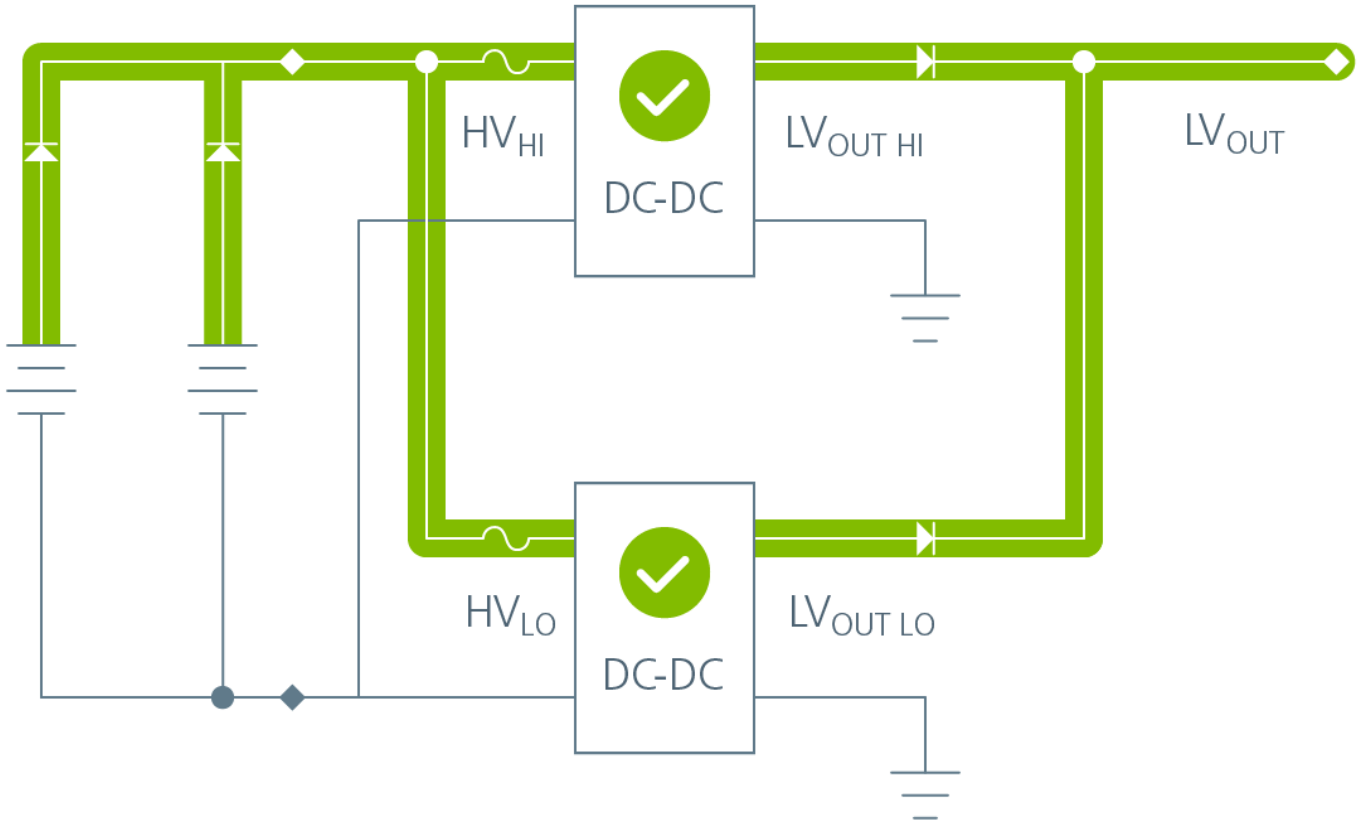

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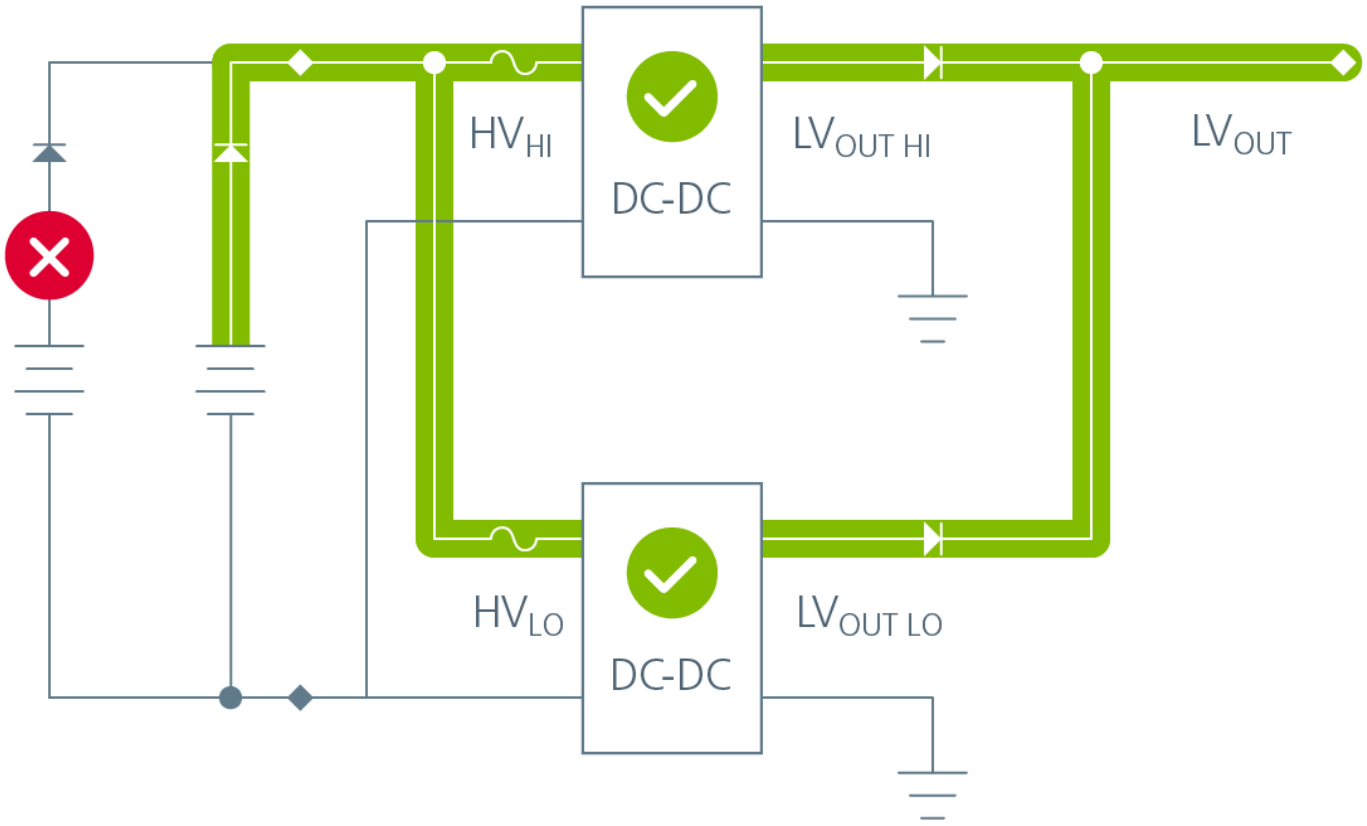
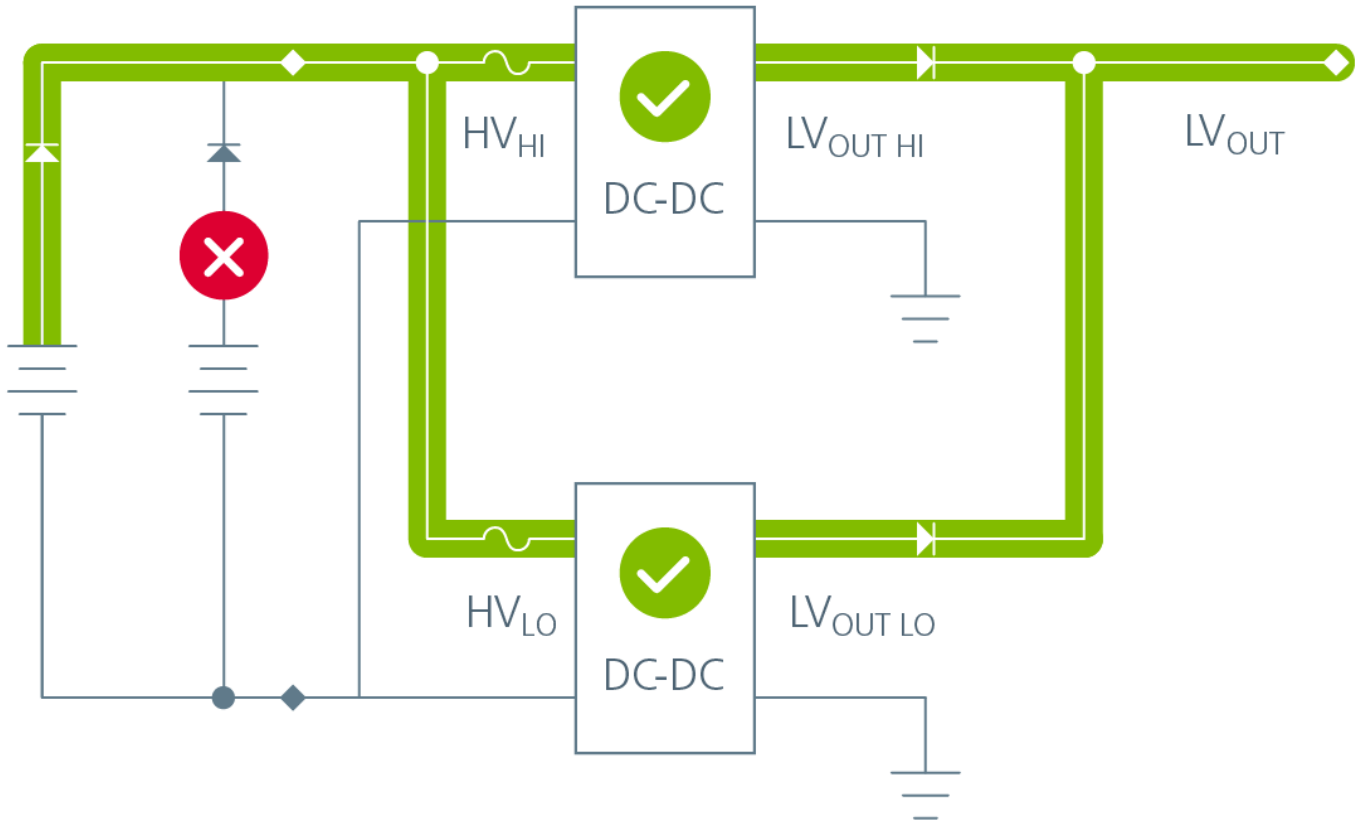
Redundancy using parallel battery configuration



- Two 800V batteries can be configured in parallel for redundancy.
- The **B**attery **M**anagement **S**ystem (BMS) will need to monitor and control the charging and discharging of the battery to prolong long usage.
- This is referred to as a dual 800V Parallel Battery Configuration.

Redundancy using parallel battery configuration



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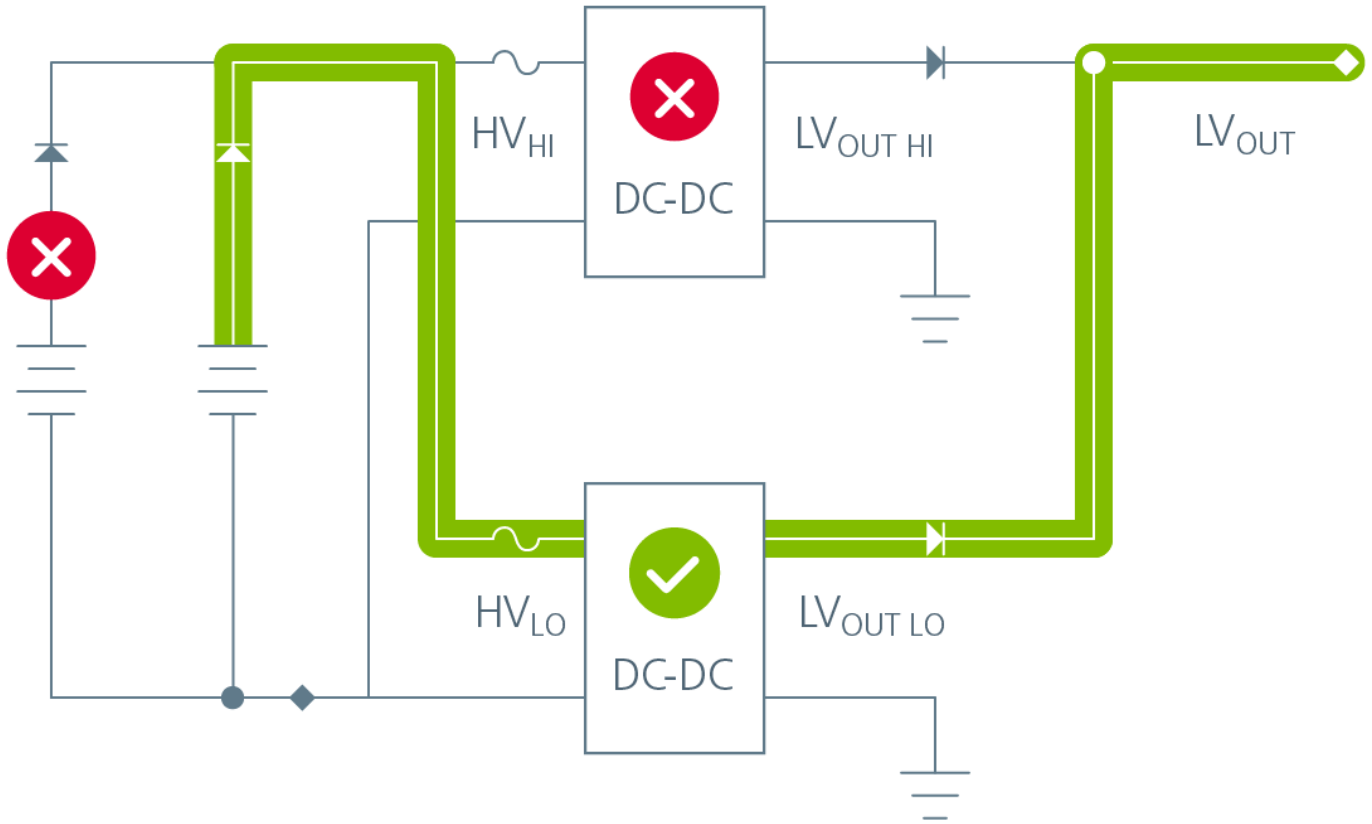
Redundancy using series stacked battery configuration



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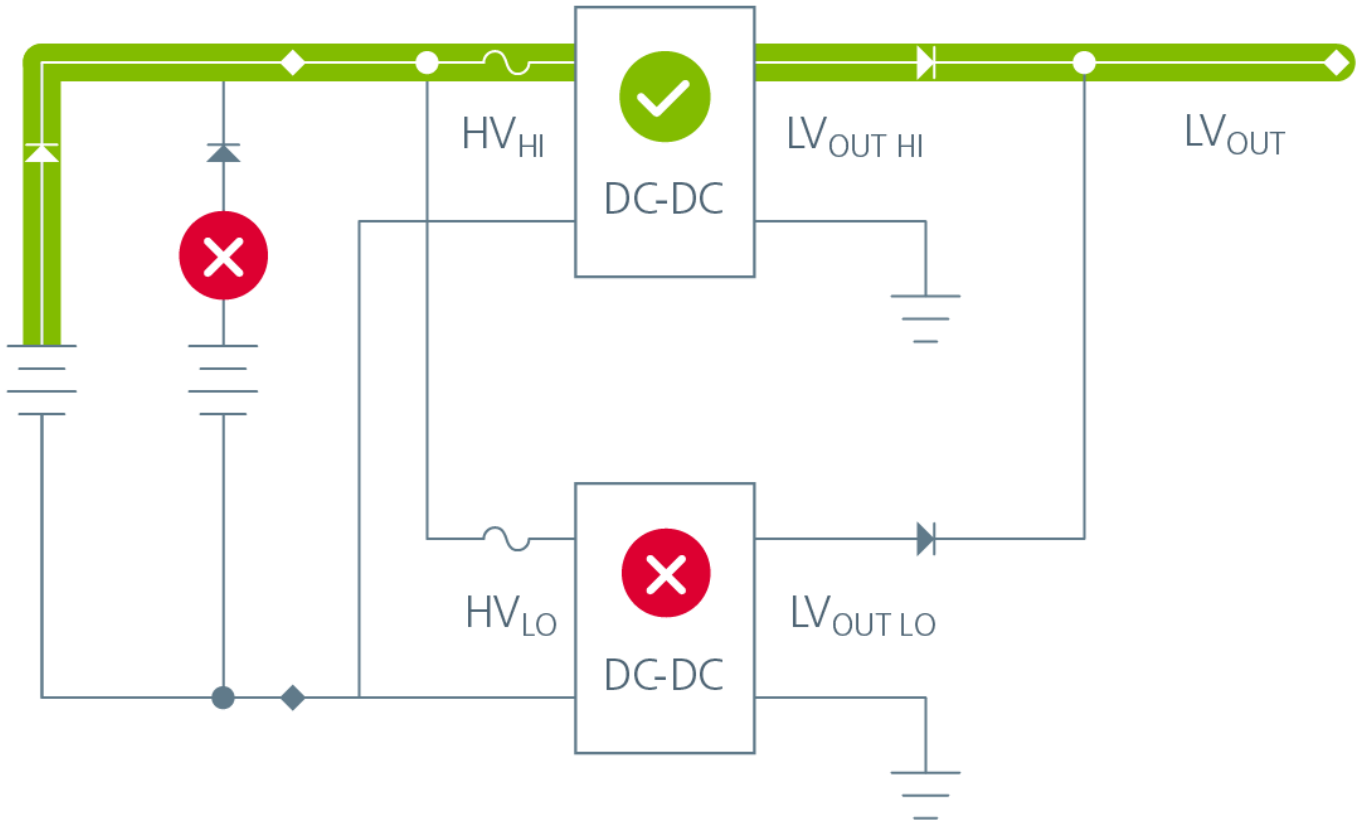
Redundancy using series stacked battery configuration



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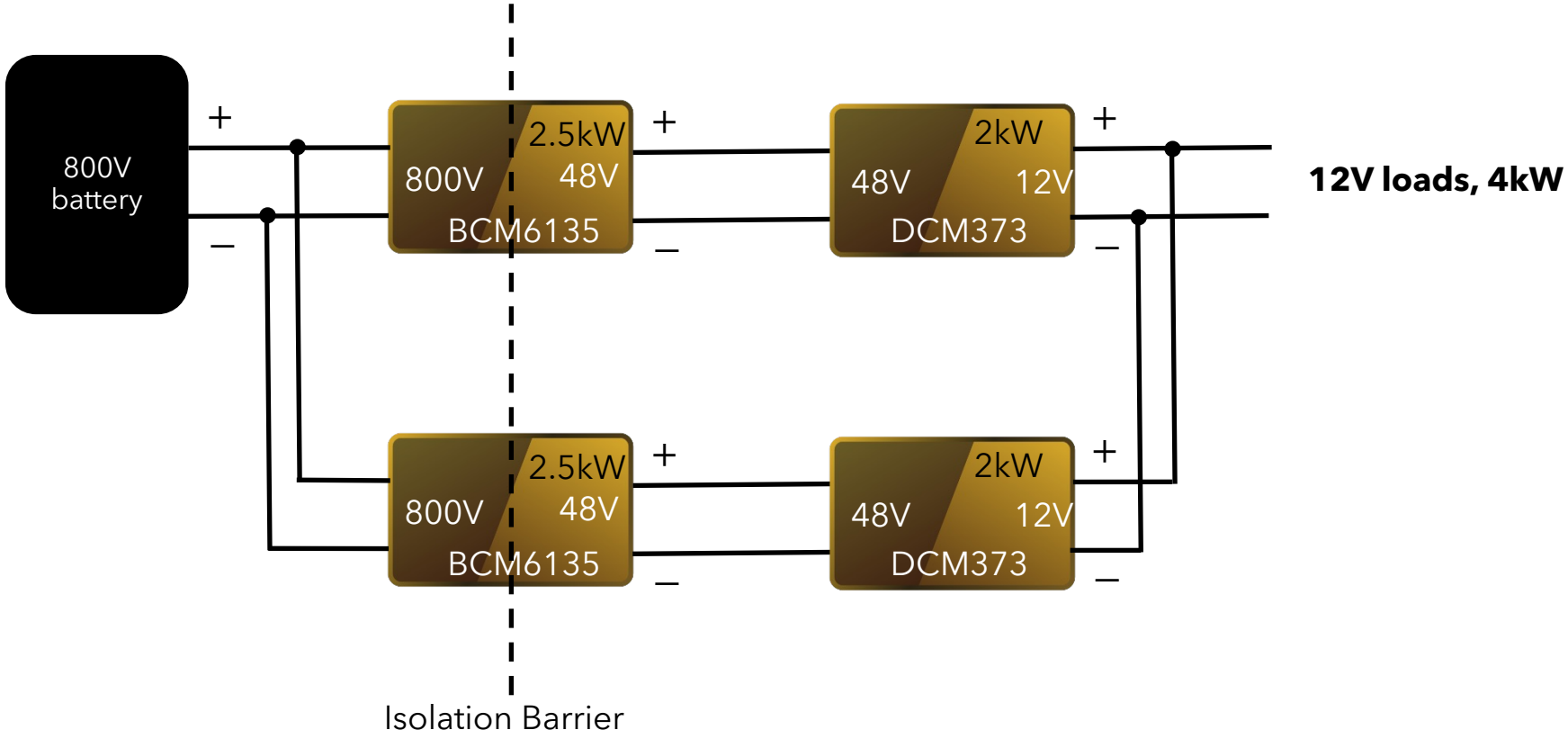
Block diagram of 800V to 12V @ 4kW



DC-DC architecture 800V to 12V @ 4kW

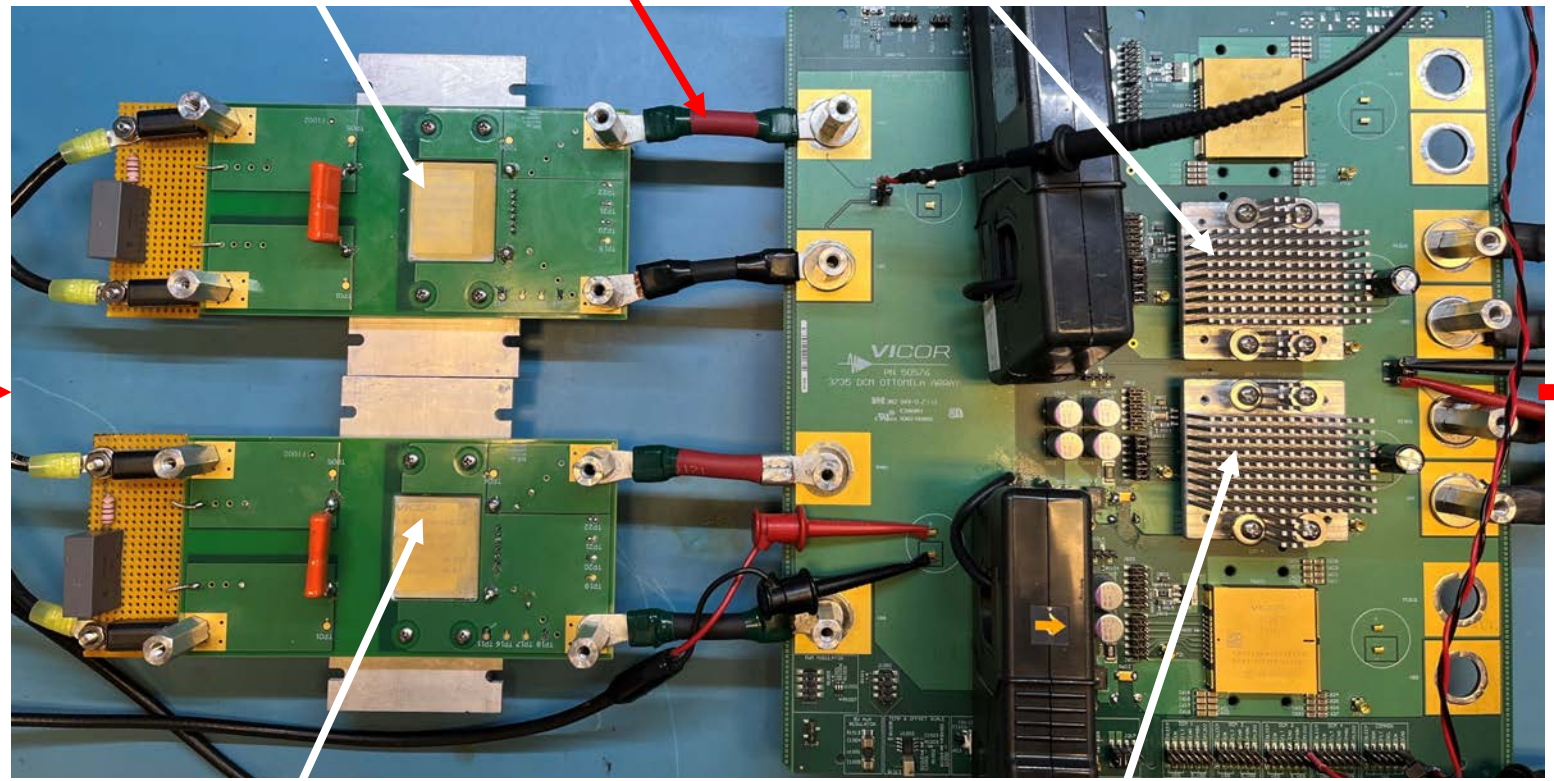
BCM6135 2500W
800V – 48V

48V

DCM3735 2000W
48V – 12V

HV Source

800V



13.5V @ 4kW or 300A

BCM6135 2500W
800V – 48V

DCM3735 2000W
48V – 12V

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How to parallel – properly!

- Regardless of the battery configuration, the outputs of the DC-DC converter should share during operation. A Vicor solution uses a DCM module for the output.
- The converters are isolated from the input and therefore the regulation portion performed by Vicor DCM can be paralleled for accurate load sharing and therefore redundancy.
- The DCM can also operate independently up to the rated current of a single DC module. Adding an Or'ing diode in the positive output leg will isolate the two or more converters.
- The DCM outputs can be paralleled for current sharing and redundancy. The Error Amplifier, Fault Pin and Enable Pin Circuitry in the DCM allows the current to be shared approximately fifty-fifty percent from 10% load to full load.

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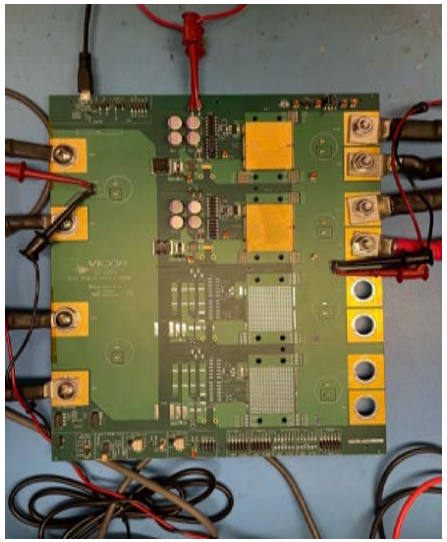
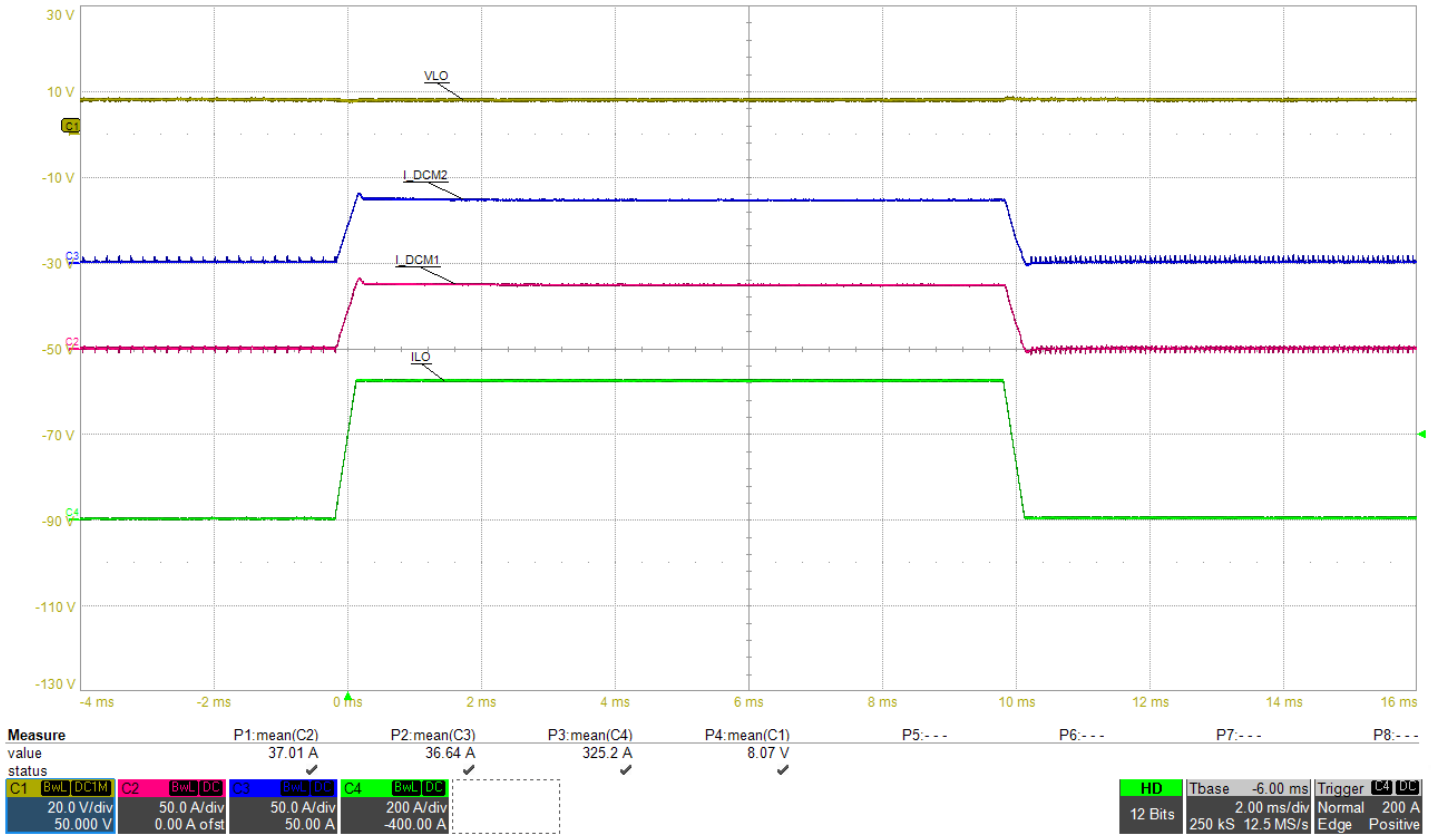
Low-voltage current sharing – regulated output



DCM3735 → 48V to 12V @ 320A

Two in parallel

Ch1 = V_{OUT} @ 20V/div
Ch2 = I_{OUT}_Upper @ 50A/div
Ch3 = I_{OUT}_Lower @ 50A/div
Ch4 = I_{OUT}_total @ 200A/div



DC modules running independently to single load

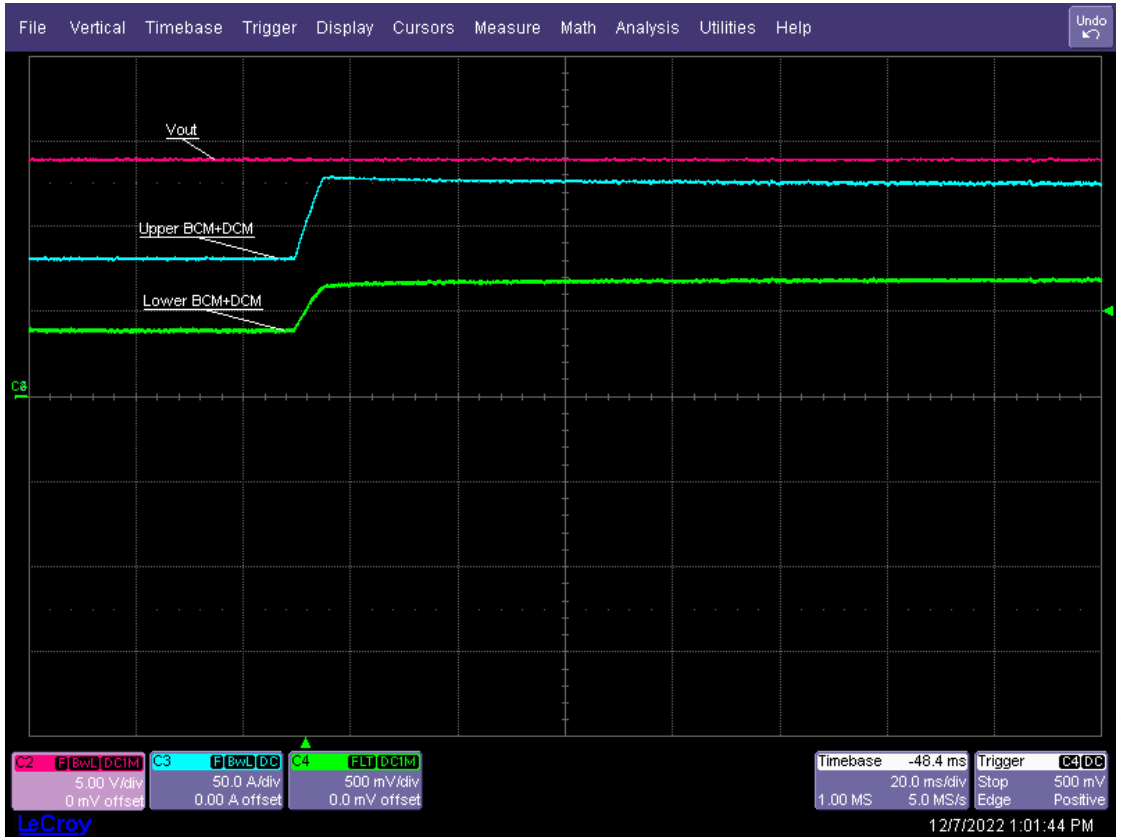
CH2 = V_{OUT} @ 5V/div
CH3 = I_UPPER @ 50A/div
CH4 = I_LOWER @ 50A/div

I_UPPER = 130A
I_LOWER = 70A

800V to
14V @ 4kW

V_{OUT} = 14V
I_{OUT} = 210A (total)

- ✓ Parallel (EAO) pin OPEN
- ✓ Fault pin OPEN
- ✓ Enable pin OPEN



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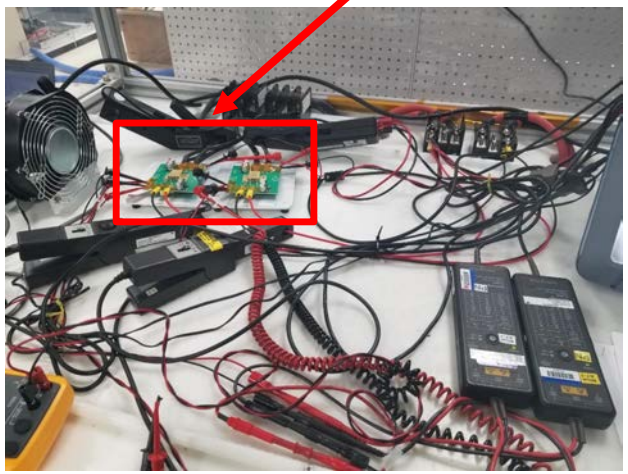
Low voltage current sharing during transient event

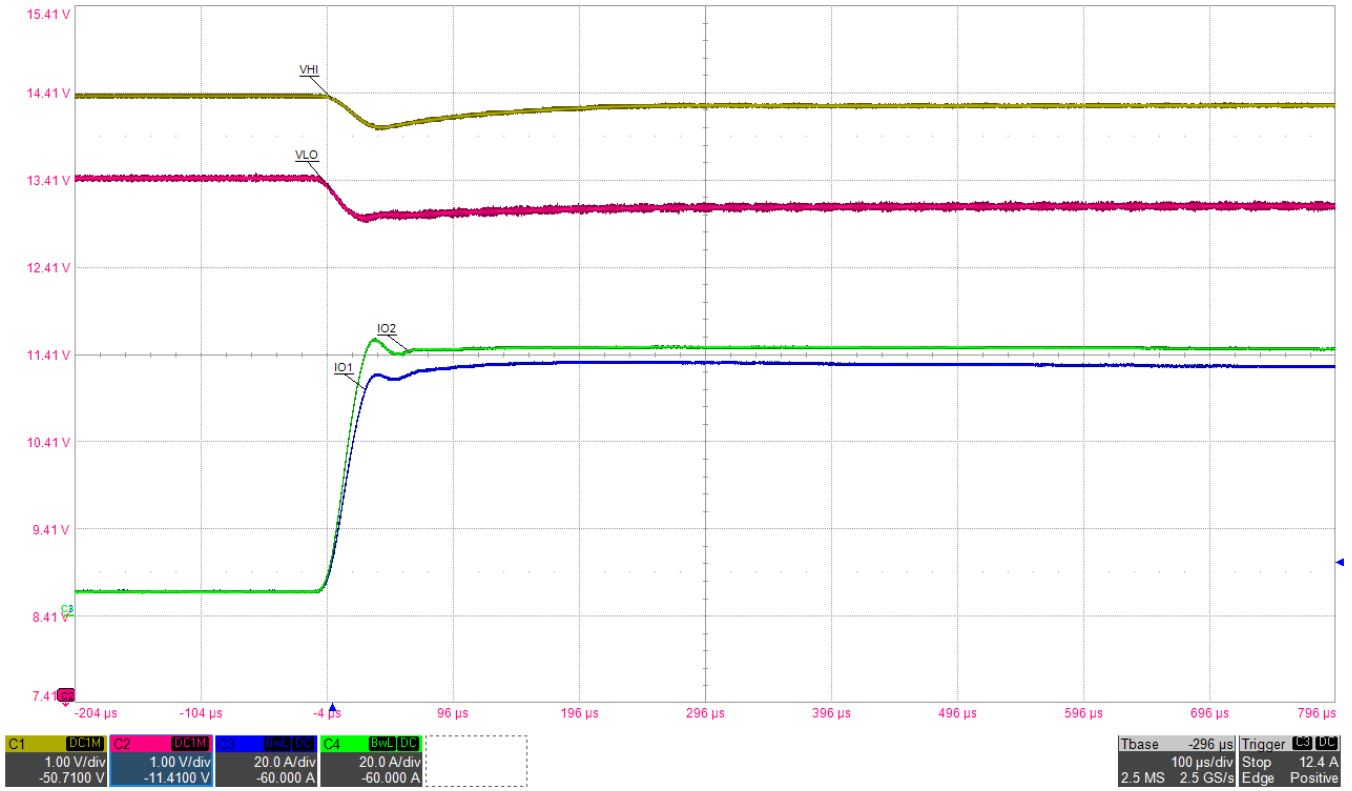
CH1 – V_{HI}: 1V/div (DC) V_{IN} or 48V
CH2 – V_{LO}: 1V/div (DC) V_{OUT} or 12V
CH3 – I_{O1}: 20A/div (DC)
CH4 – I_{O2}: 20A/div (DC)

Timebase – 100µs/div

2,000,000A/sec
2,000A/msec

48V to 12V
@ 1.6kW





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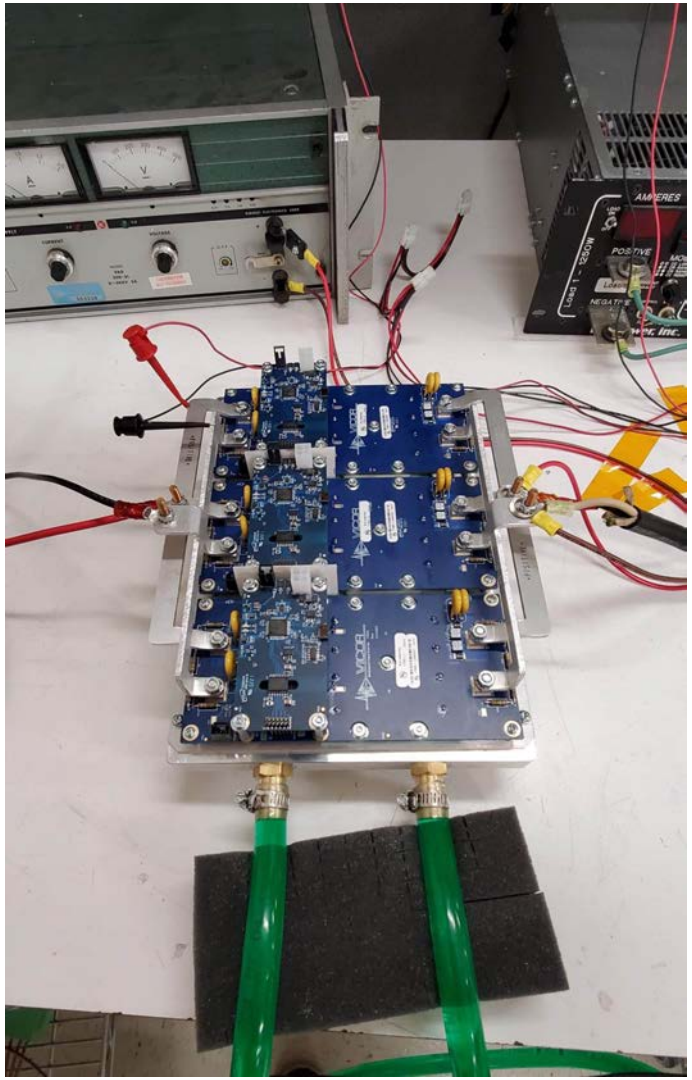
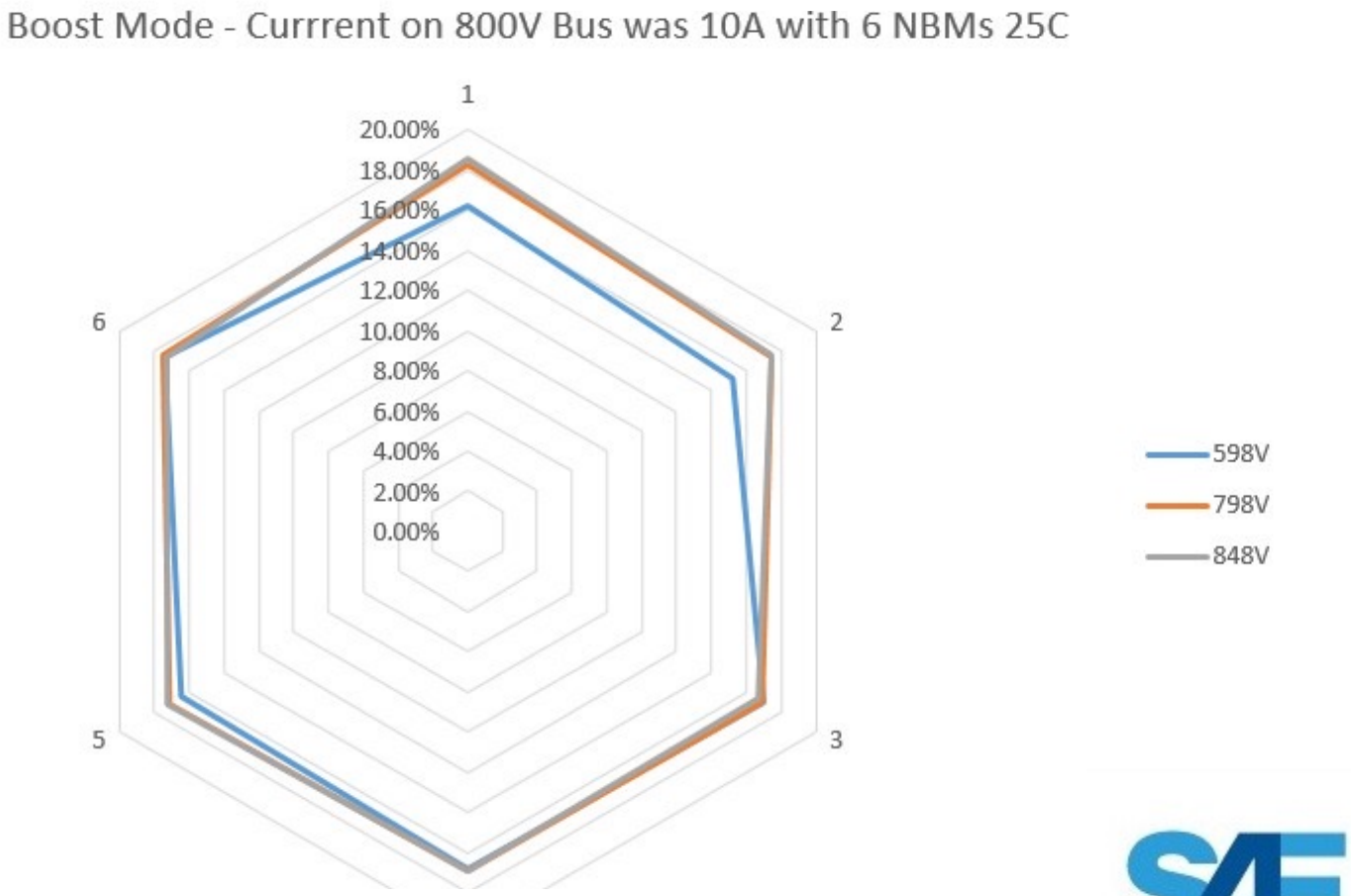
800V to 400V @ 40kW six in parallel – almost equal!



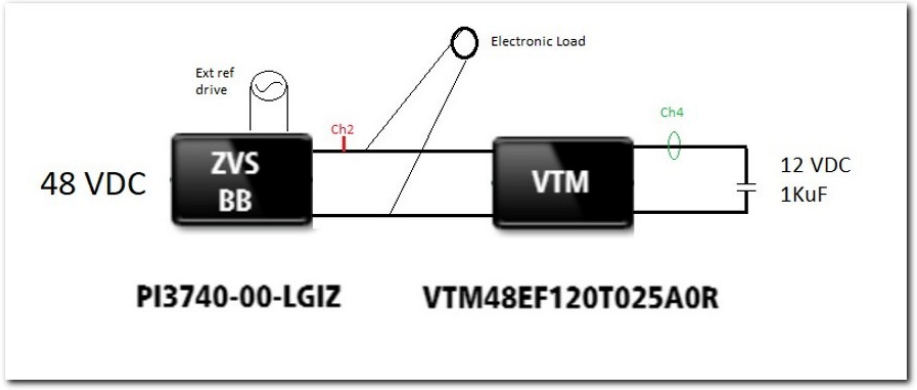


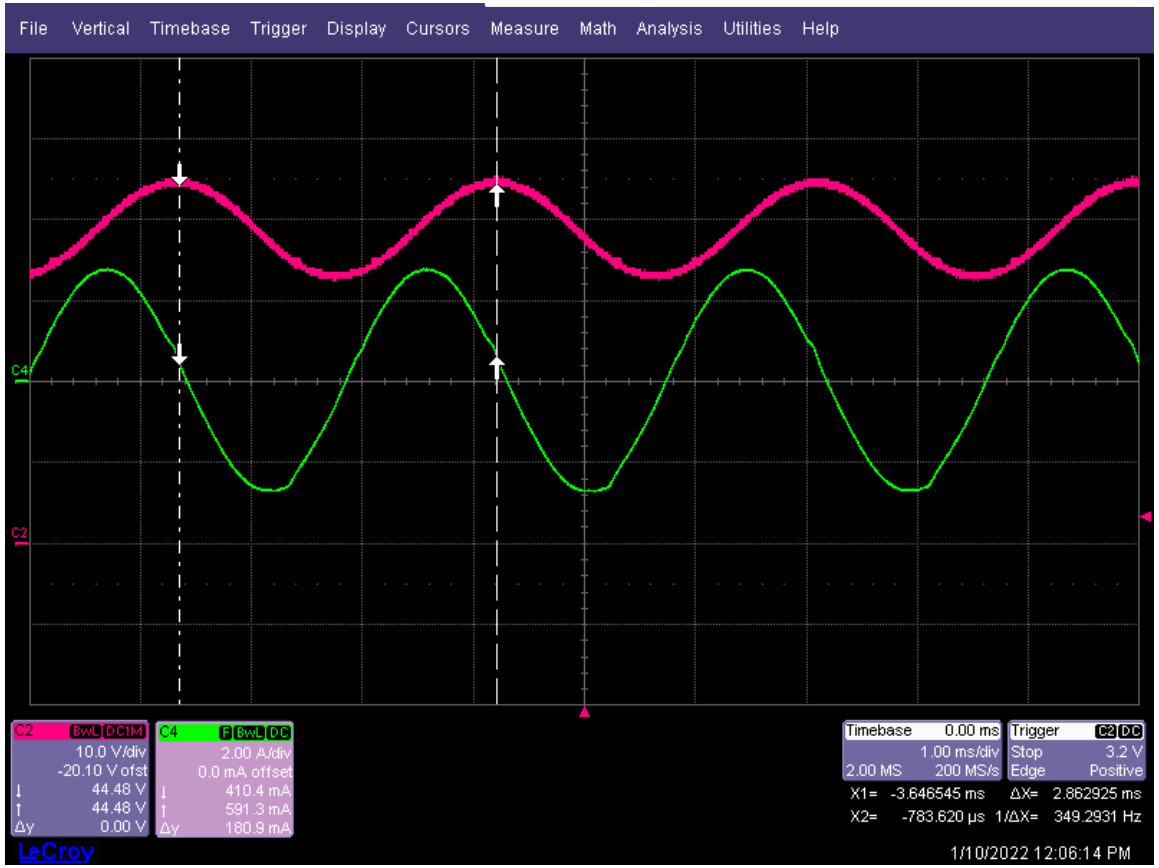
Bi-directionality of sine-amplitude converter

Switching at 349Hz (Cannot go higher because of lab test equipment limitations, not the Vicor Product).

I_{OUT} = 1.4A

Ch2 = PI3740 V_{OUT}
Ch4 = Capacitor current





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Bi-directionality of sine-amplitude converter – no delay

- ✓ Vicor technology enables design of redundant power systems due to the excellent current sharing characteristics of our DCM modules
- ✓ The scalability of Vicor technology supports many options for achieving redundancy

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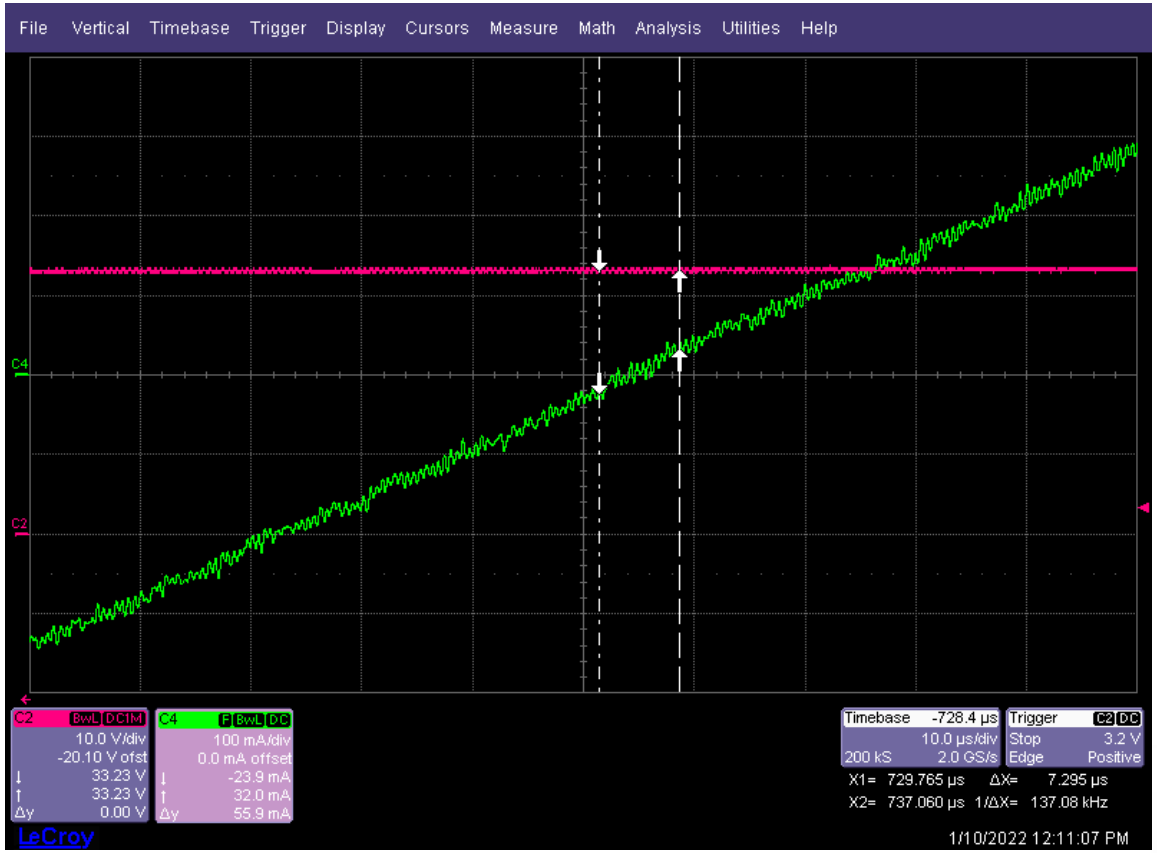

Patrick Kowalyk - author

- Thank you
- Vicor Corporation
- Patrick is the lead Automotive Principal Field Applications Engineer, helping power engineers architect new Automotive power delivery systems. He has a BS in Electrical Engineering from the Illinois Institute of Technology.
- pkowalyk@vicorpower.com or 630-551-5502