Innovative approach for EV high-voltage-to-SELV conversion
電動汽車高壓到SELV轉換的創新方法

Jeff Chang 張仁程

Vicor Taiwan FAE

Innovative approach for EV high-voltage-to-SELV conversion

- EV Power HV Trend and Challenges
- Vicor EV Solution Advanced Topology and Package
- EV HV to SELV Innovation Solution
  - Bus Converter Module(BCM)
- Vicor 800V to 48V BCM6135 Performance
- EV System using Vicor Power Module

48V systems: vehicle level weight and cost savings

Scalable to entire OEM platform of vehicles

Two trends happening today

The design and architecture of 800V vehicles is complex

Consists of components such as high voltage batteries, motors, inverters, sensors, control devices, wiring, and auxiliary systems

The increased deployment of 48V systems and components

Challenges converting high voltage down to a safe (SELV) level:

- Efficiency
- Safety
- Creepage and clearance
- Higher cost materials with higher voltage
- Costs

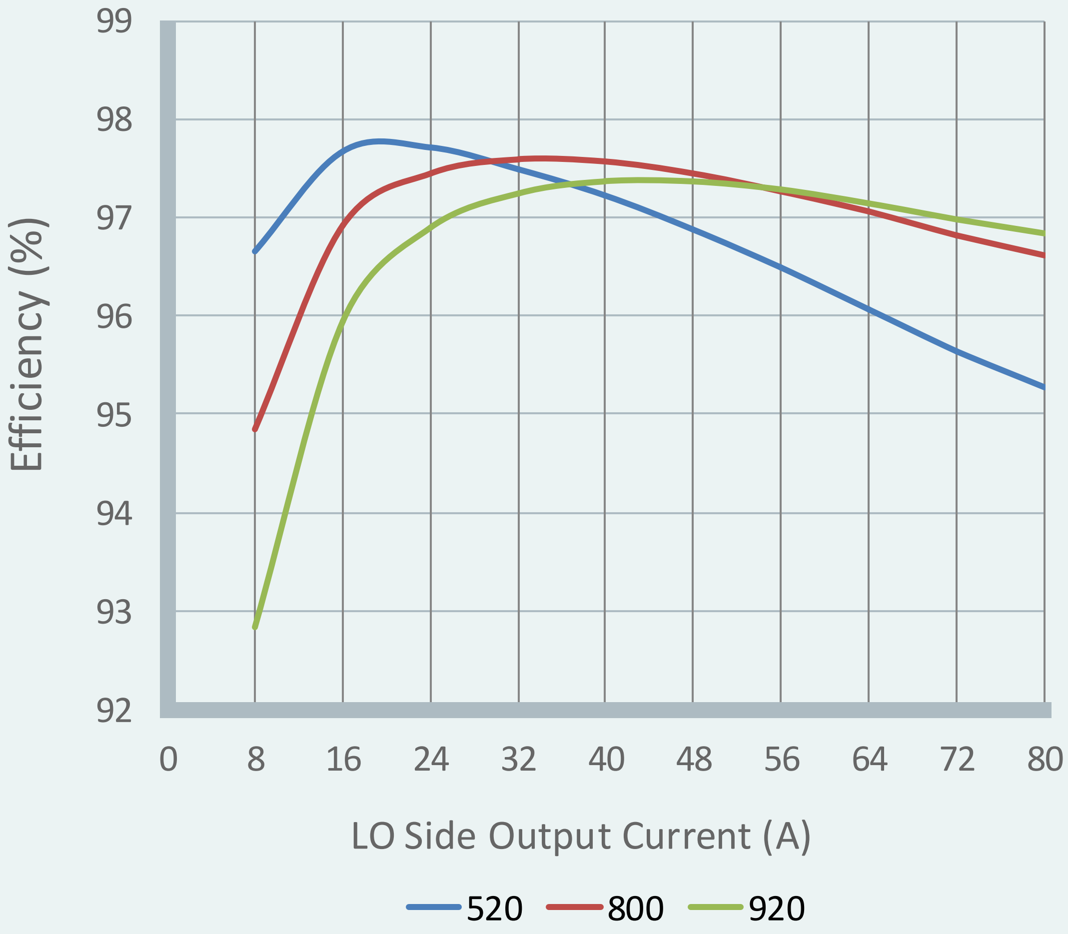
Today's challenges converting HV to SELV

- Efficiency
- Safety
- Creepage and clearance
- Peak power demands
- Package is large
- Thermal challenges
- Requires LV battery or supercap
- Transient response

Efficiency

- System targets between 95 – 97%
- Better efficiency usually means larger systems
- Vicor leverages a "system approach" for best packaging, control system, and powertrain to peak 98 – 99%

Bench measurement of efficiency at 25°C ambient



VICOR

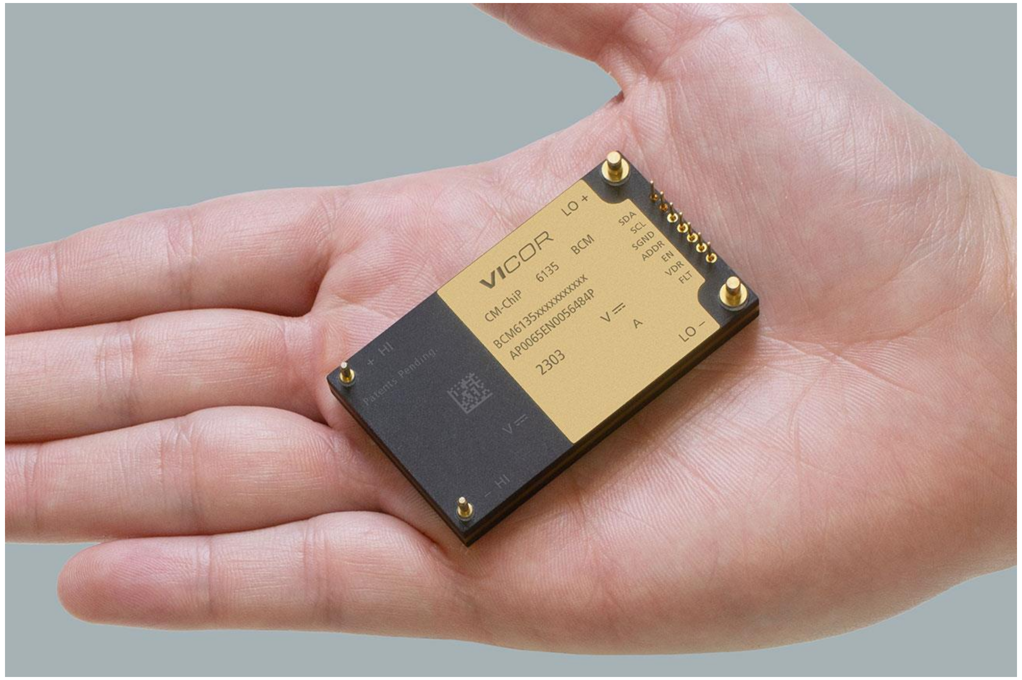
Safety

- Electric and hybrid vehicles (EHVs) use much higher voltages (up to 800V DC) than internal combustion engine (ICE) vehicles
  - Contact with voltages above 60V DC can stop a human heart!
- Higher voltage systems need more space to prevent overvoltage and arcing
- 800V conductors need more insulation than 400V
- 800V systems need advanced battery management for safe, efficient operation

Creepage and clearance

OEMs are driving aggressive requirements for higher voltage creepage and clearance, which impact system size:

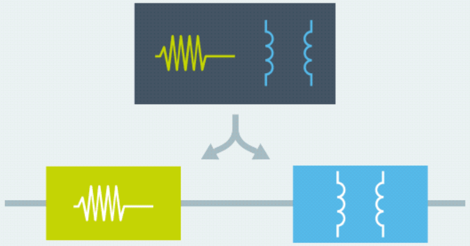
- **Safety Standards:** These distances are crucial for meeting safety standards and regulations
- **Reliability:** Proper spacing helps ensure the long-term reliability of components and systems
- **Preventing Electrical Breakdown:** Insufficient creepage and clearance can lead to arcing or electrical breakdown – causing malfunctions, fires, or even injuries



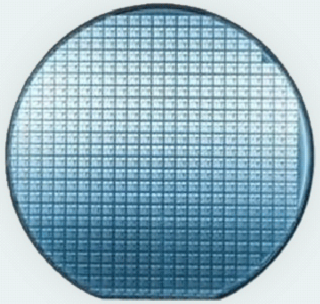
Vicor EV solution advanced topology and package

The four pillars of power system innovation

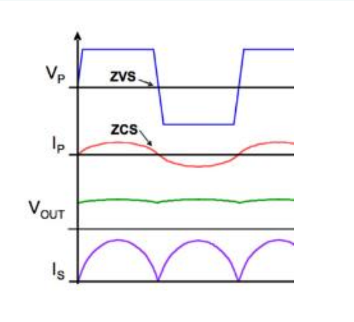
Innovative architectures

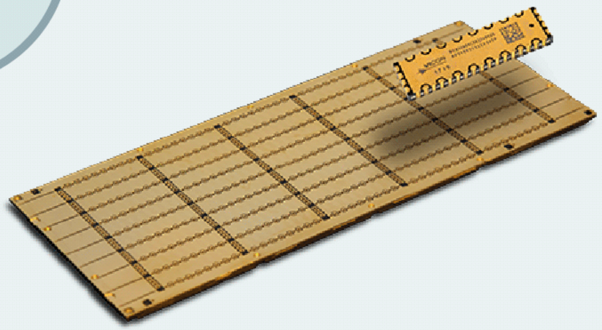


Unique control systems



Advanced topologies





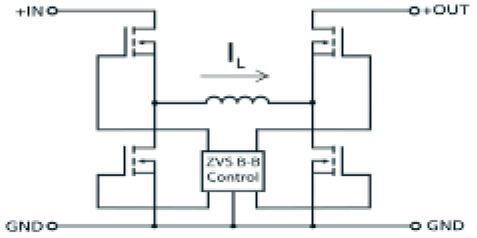
Proprietary components and packaging

Delivering high density, top efficiency, lighter weight, low noise

- Topologies
- High frequency switching
- Planar magnetics
- Semiconductor integration
- Modular, 3D packaging
  - Unmatched form factors
  - Superior thermal and EMI characteristics
  - Design flexibility

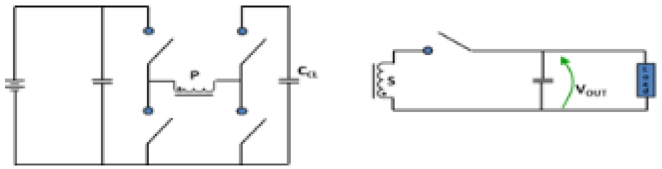
ZVS regulator

Non-isolated, DC-DC regulator



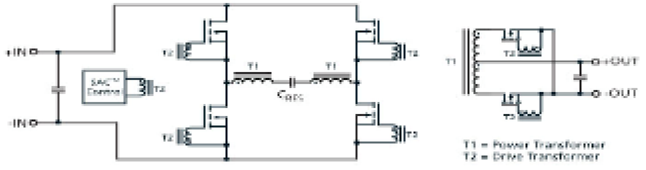
Double-clamped ZVS (DC-ZVS)

Isolated, regulated,
DC-DC or AC-DC converter



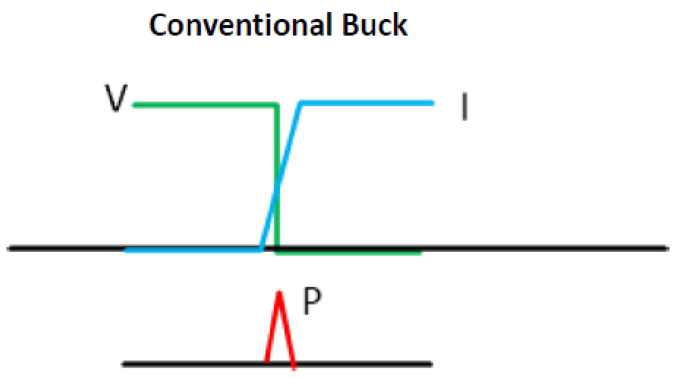
Sine amplitude converter (SAC)

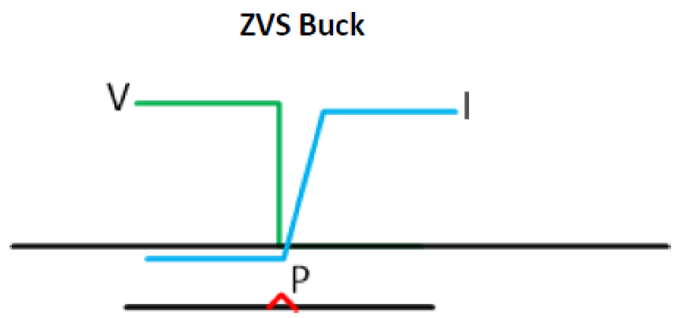
Isolated, fixed-ratio,
DC-DC transformer



What is zero-voltage switching?

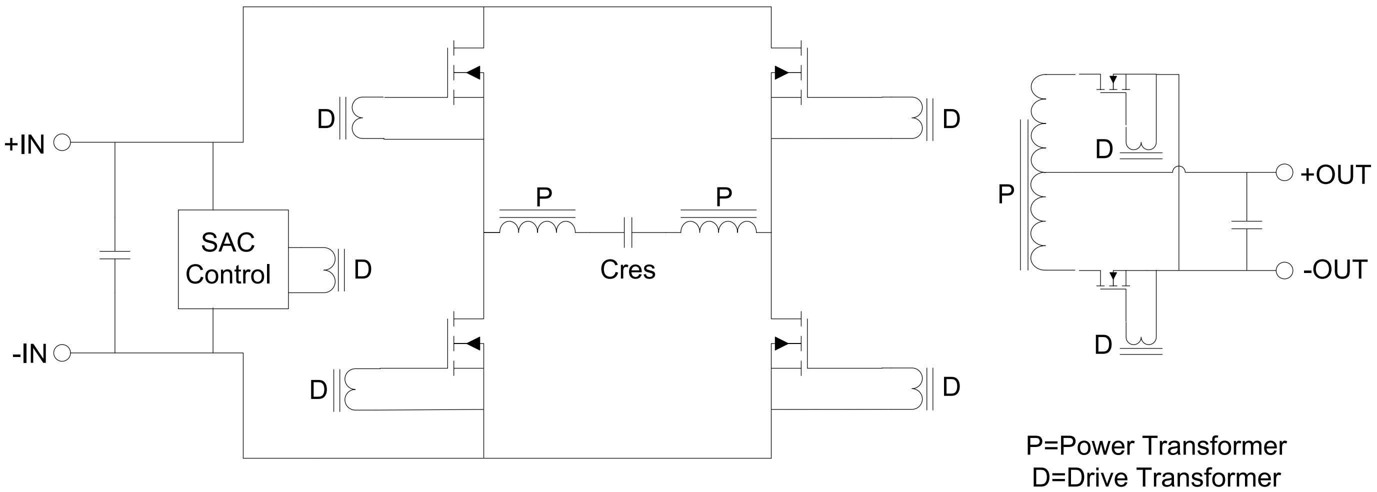
- Zero Voltage Switching is a technique where current is steered into a switch to equalize the voltage on either side before the switch is turned on
- This greatly reduces or eliminates switching losses
  - Enabling 4x (or more) increase in switching frequency, reducing the size of magnetics
  - Reducing the penalty of a large step down
- ZVS is used in all Vicor power modules

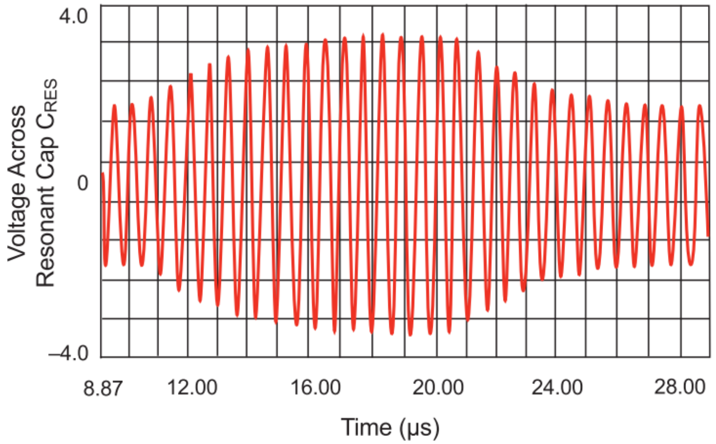




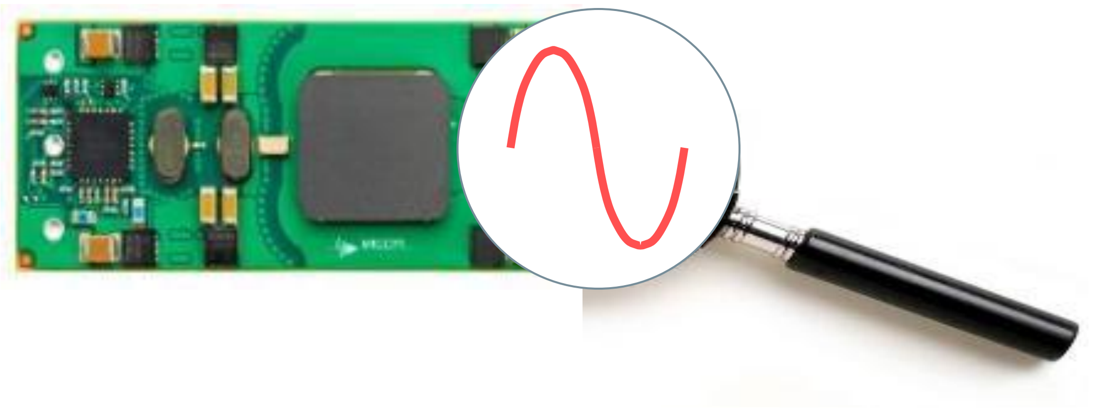
Vicor topology: sine amplitude converter (SAC)

- Transformer based series resonant topology
- Fixed ratio DC-DC converter
  - Open loop control (non-regulated converter)
- Fixed switching frequency
  - Matching with the resonant frequency of the primary tank
- Zero Voltage Switching and Zero Current Switching
  - Very low switching losses





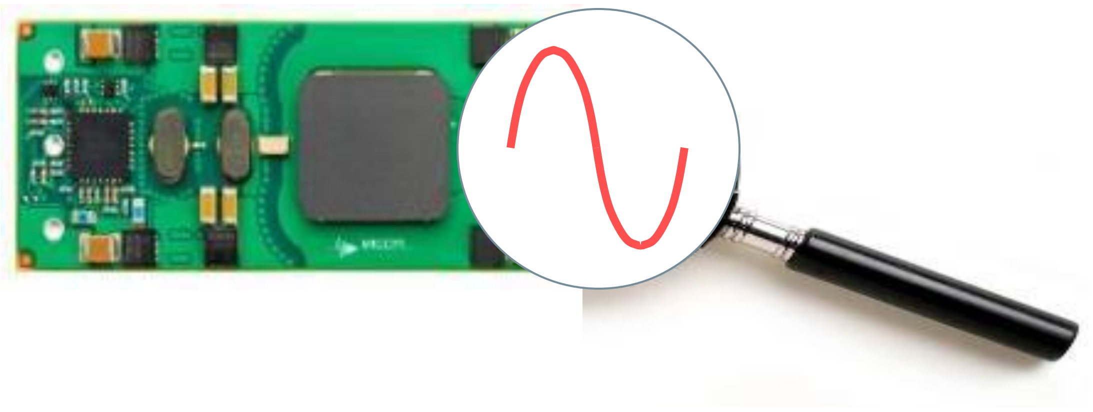
SAC topologies – always sinusoidal current



- Fast transient response
  - Resonant tank will naturally let current flow and output voltage settle within few switching cycles
- Reduced EMI
  - Very narrow spectrum
- Bidirectional
  - Power can be processed from input to output or vice versa across the entireconverter bandwidth
- Optimal filtering
  - No harmonics below switching frequency, and very few above

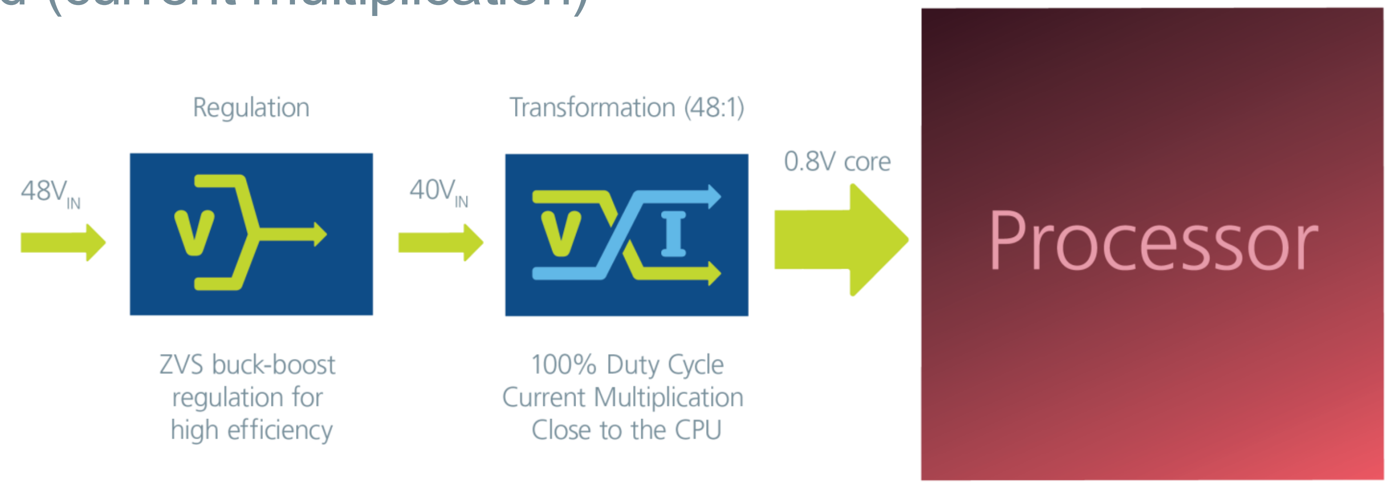
SAC topologies – always sinusoidal current

- Zero-voltage, zero-current switching
  - All transitions, every cycle
- Enables components with higher figure of merit
  - Reduced de-rating guidelines
- No switching losses
  - Switching frequency not limited by power switches’ losses
- Low peak to average current and voltage ratios
  - Most efficient use of silicon switches



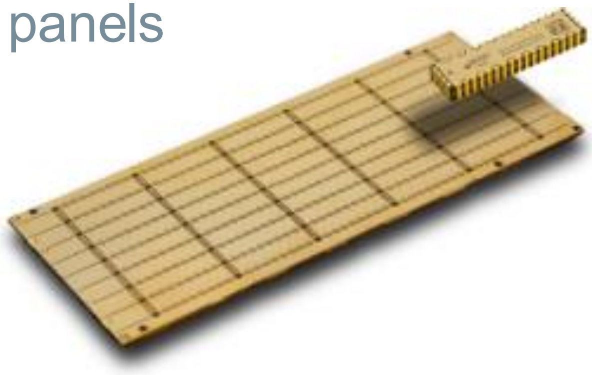
Vicor Factorized Power Architecture

- Regulation stage first
  - Keep input and output of regulator stage as close as possible to ideal (1:1)
- Transformation at the point of load (current multiplication)
  - Minimize impedance of current multiplier
- Soft switching topologies
  - Minimize noise
  - Enable High Switching frequency (1-3MHz)
  - Enable high-power density

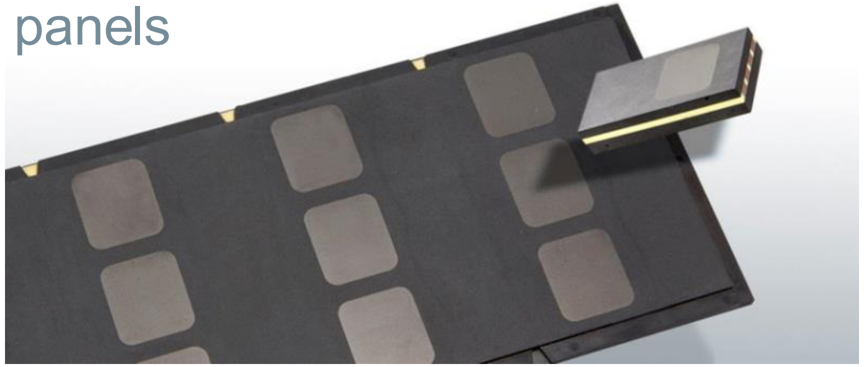


Vicor EV solution advanced package

SM-ChiP panels

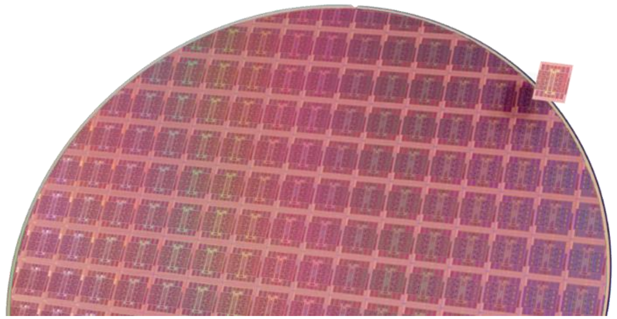


ChiP panels



IC-based controllers low component count, higher reliability

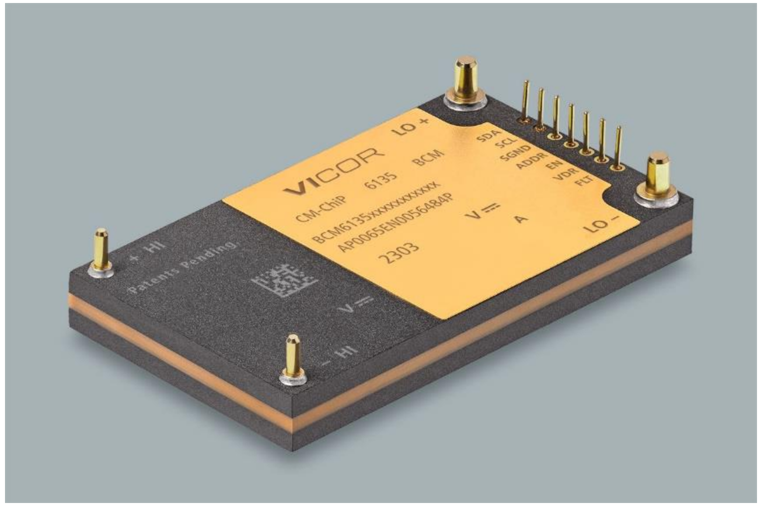
Semiconductor wafers



EV HV to SELV innovation solution: Bus Converter Module (BCM)

BCM topology – Sine Amplitude Conversion (SAC)

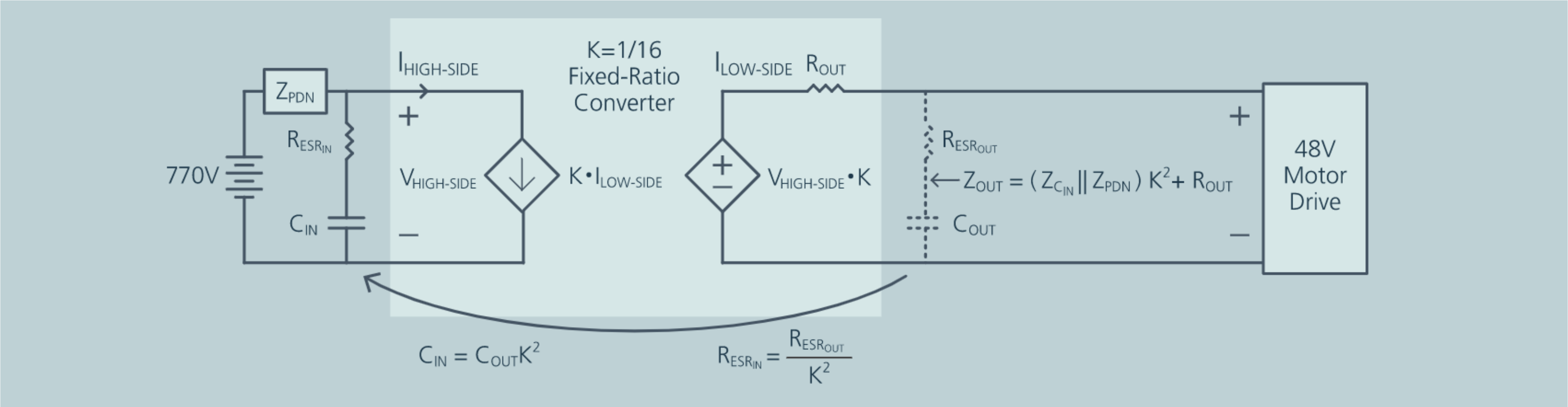
- Resonant topology
- Operates at resonant frequency, fixed gain
- Soft switching, constant frequency/duty
  - Low EMI profile
  - Switching losses minimized
- Enables higher switching frequencies and lower volume/weight
- Transformer design, resonant circuit design, low Q
- Vicor has intellectual property to optimize design



BCM6135

800V ←→ 48V @80A
61.3 x 35.4 x 7.3mm
58g

Impedance reflection reduces effective source impedance

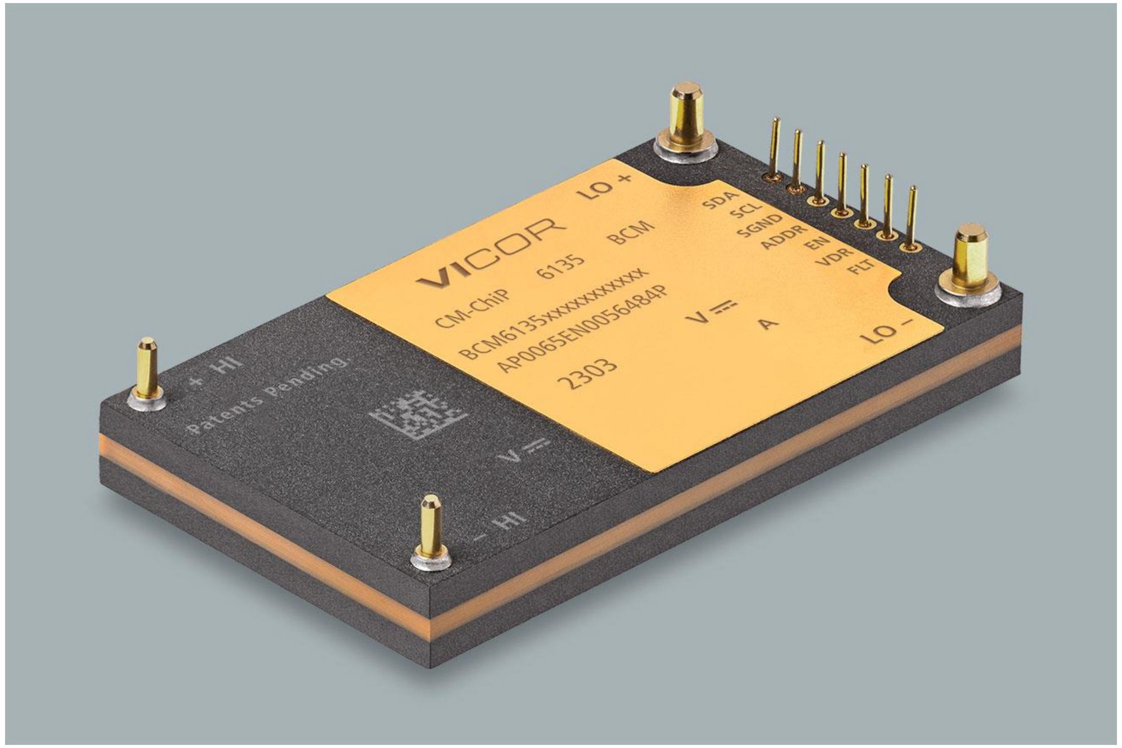


Impedance reflection reduces the effective source impedance by a factor of K2, thereby reducing the required capacitance

For these highly dynamic and powerful loads, reducing the resistive and inductive impedance improves both dynamic and static performance

Vicor 800V to 48V BCM6135 performance

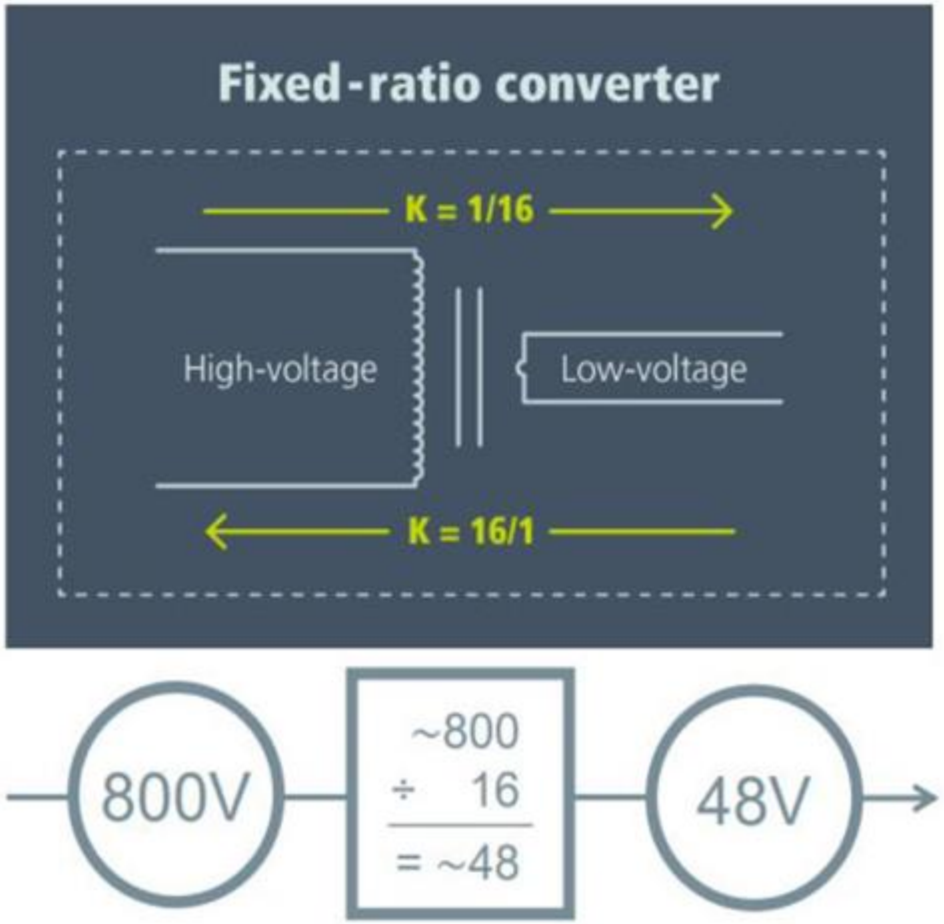
BCM6135 – 2500W, isolated, 800V <> 48V fixed- ratio converter



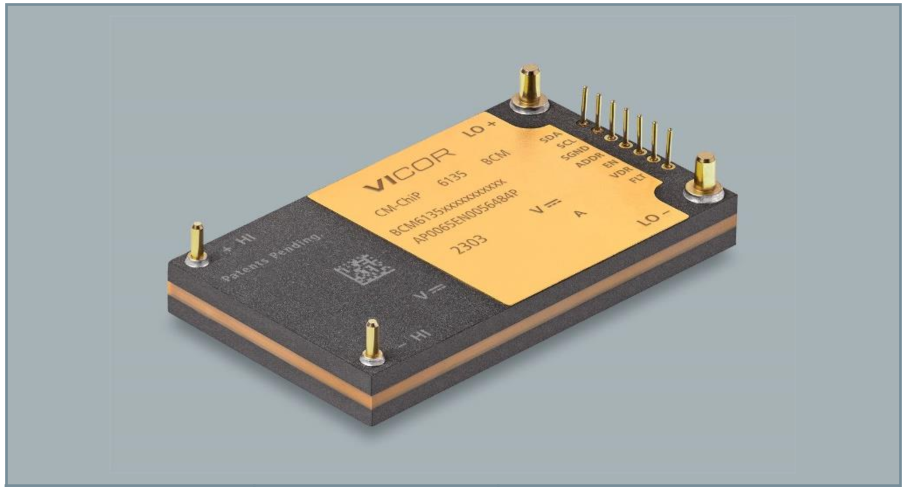
Input: 520 – 920V
Output: 32.5 – 57.5V
Current: 80A
Efficiency: Up to 97.3%
PMBus™ for telemetry and control
61.33 x 35.35 x 7.42mm

BCM6135 – sine amplitude conversion technology/topology

- Sine Amplitude Converter topology :
  - Zero Voltage Switching
  - Zero Current Switching
- Fixed Ratio Conversion:
  - Divide / multiply the voltage / current
- Extremely fast transient current capability
- Ideal transformer behavior
- No inductor usage
- Not dependent on internal energy storage
- Capacitance multiplication

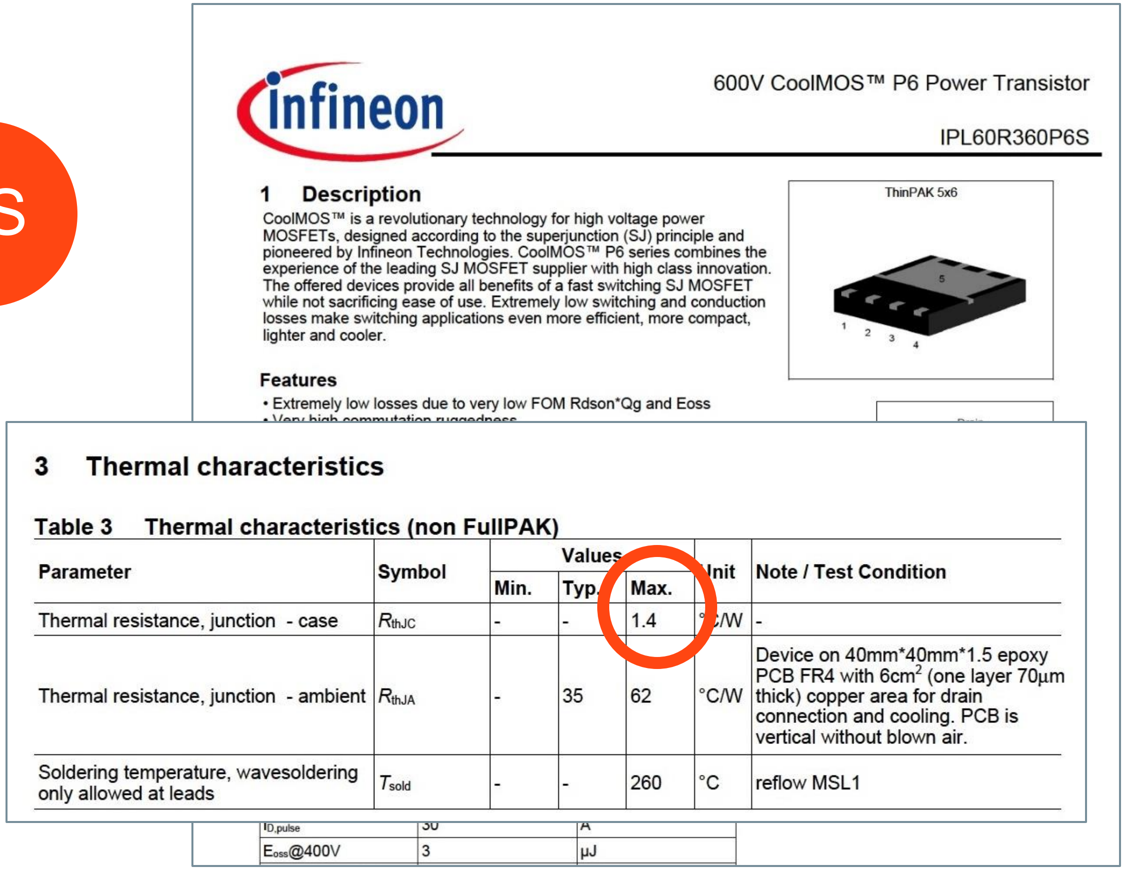


Thermal performance is equivalent to a FET



Symbol	Thermal impedance	Definition
$\Theta_{NON\text{-}PIN\_SIDE}$	1.4	From the hottest component inside the BCM to NON-PIN_SIDE
Θ_{PIN_SIDE}	1.4	From the hottest component inside the BCM to PIN_SIDE

VS



infineon

600V CoolMOS™ P6 Power Transistor

IPL60R360P6S

1 Description

CoolMOS™ is a revolutionary technology for high voltage power MOSFETs, designed according to the superjunction (SJ) principle and pioneered by Infineon Technologies. CoolMOS™ P6 series combines the experience of the leading SJ MOSFET supplier with high class innovation. The offered devices provide all benefits of a fast switching SJ MOSFET while not sacrificing ease of use. Extremely low switching and conduction losses make switching applications even more efficient, more compact, lighter and cooler.

ThinPAK 5x6

Features

- Extremely low losses due to very low FOM Rdson*Qg and Eoss

3 Thermal characteristics

Table 3 Thermal characteristics (non FullPAK)

Parameter	Symbol	Values			Unit	Note / Test Condition
		Min.	Typ.	Max.		
Thermal resistance, junction - case	R_{thJC}	-	-	1.4	°C/W	-
Thermal resistance, junction - ambient	R_{thJA}	-	35	62	°C/W	Device on 40mm*40mm*1.5 epoxy PCB FR4 with 6cm² (one layer 70µm thick) copper area for drain connection and cooling. PCB is vertical without blown air.
Soldering temperature, wavesoldering only allowed at leads	T_{sold}	-	-	260	°C	reflow MSL1

E_{oss}@400V	3	µJ

Transient response

A battery delivers

250A/second

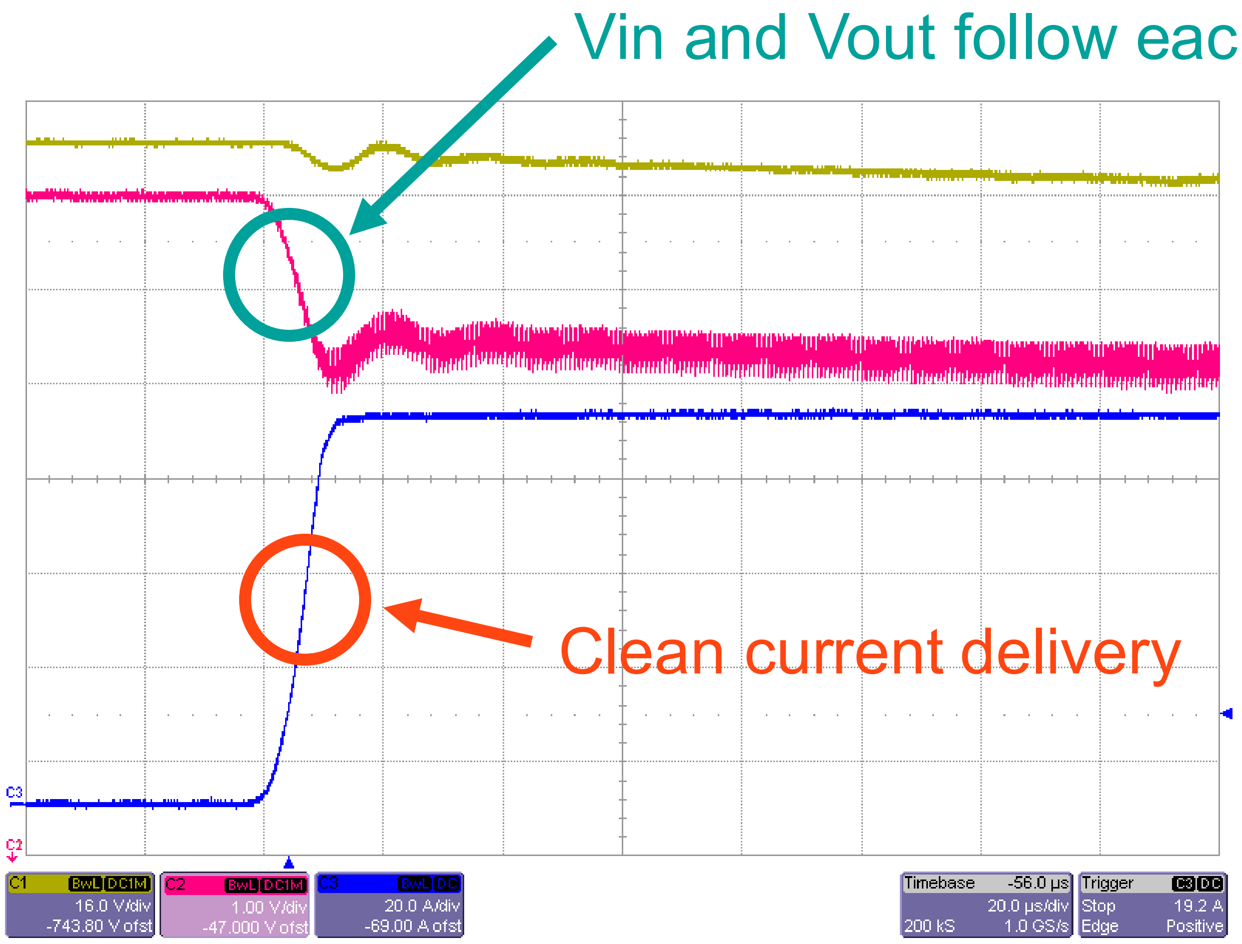
The BCM6135 delivers

8M A/second

Highest electrical performance

32,000 times faster

Load step transient for start-up



V_{HI} = 800V

I_{LO} step from 0A – 80A

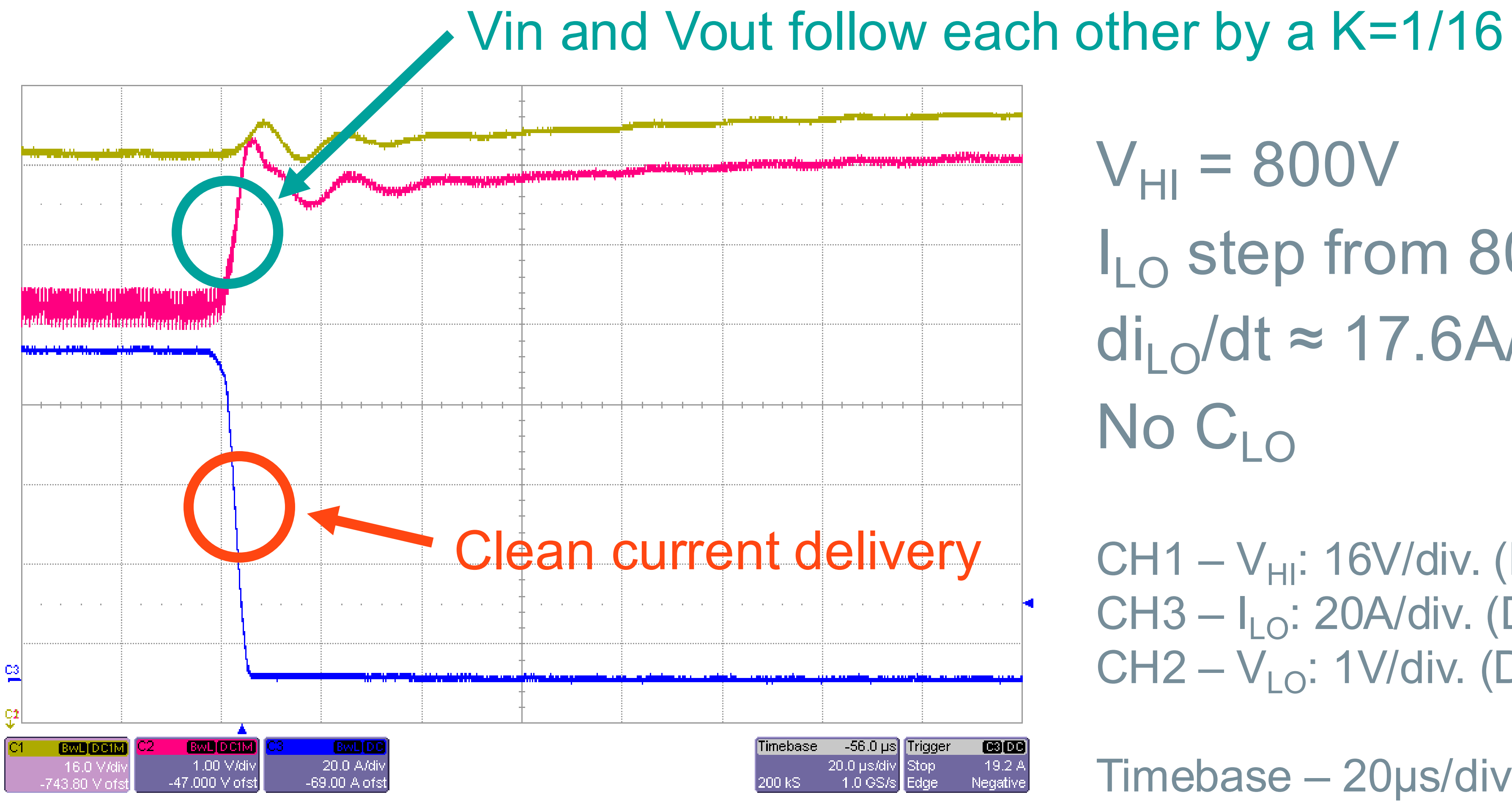
$di_{LO}/dt \approx$ 8.6A/µs (8.6MA/s)

No C_{LO}

CH1 – V_{HI}: 16V/div. (DC)
CH2 – V_{LO}: 1V/div. (DC)
CH3 – I_{LO}: 20A/div. (DC)

Timebase – 20µs/div.

Load step transient for shut-down



V_{HI} = 800V

I_{LO} step from 80A – 0A

di_{LO}/dt ≈ 17.6A/µs (17.6MA/s)

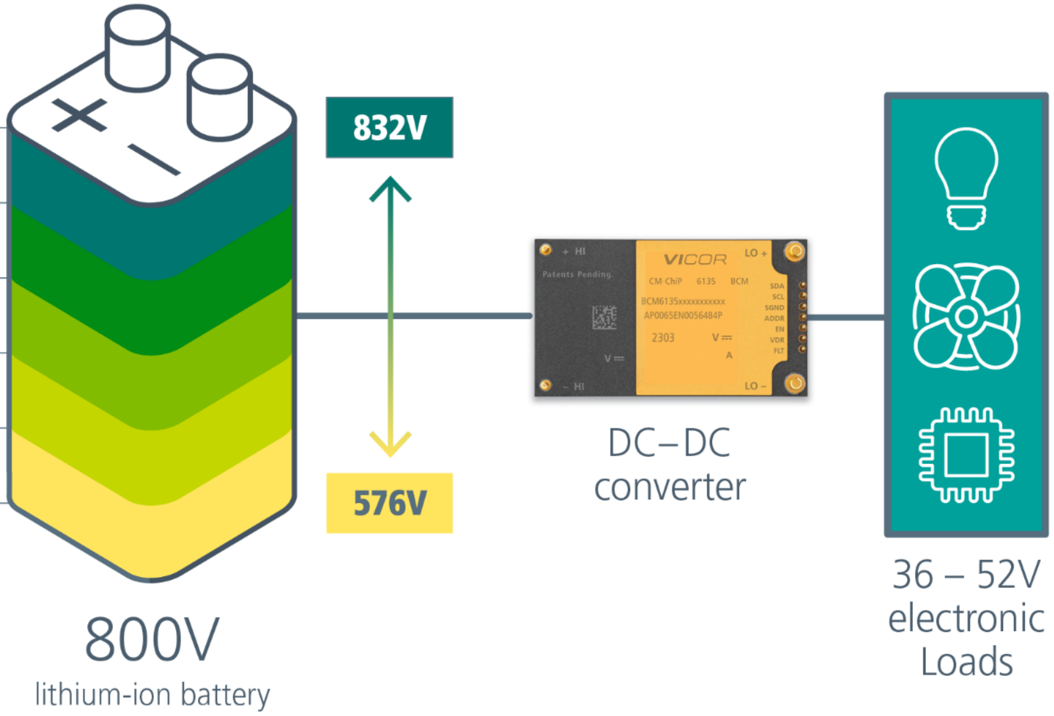
No C_{LO}

CH1 – V_{HI}: 16V/div. (DC)
CH3 – I_{LO}: 20A/div. (DC)
CH2 – V_{LO}: 1V/div. (DC)

Timebase – 20µs/div.

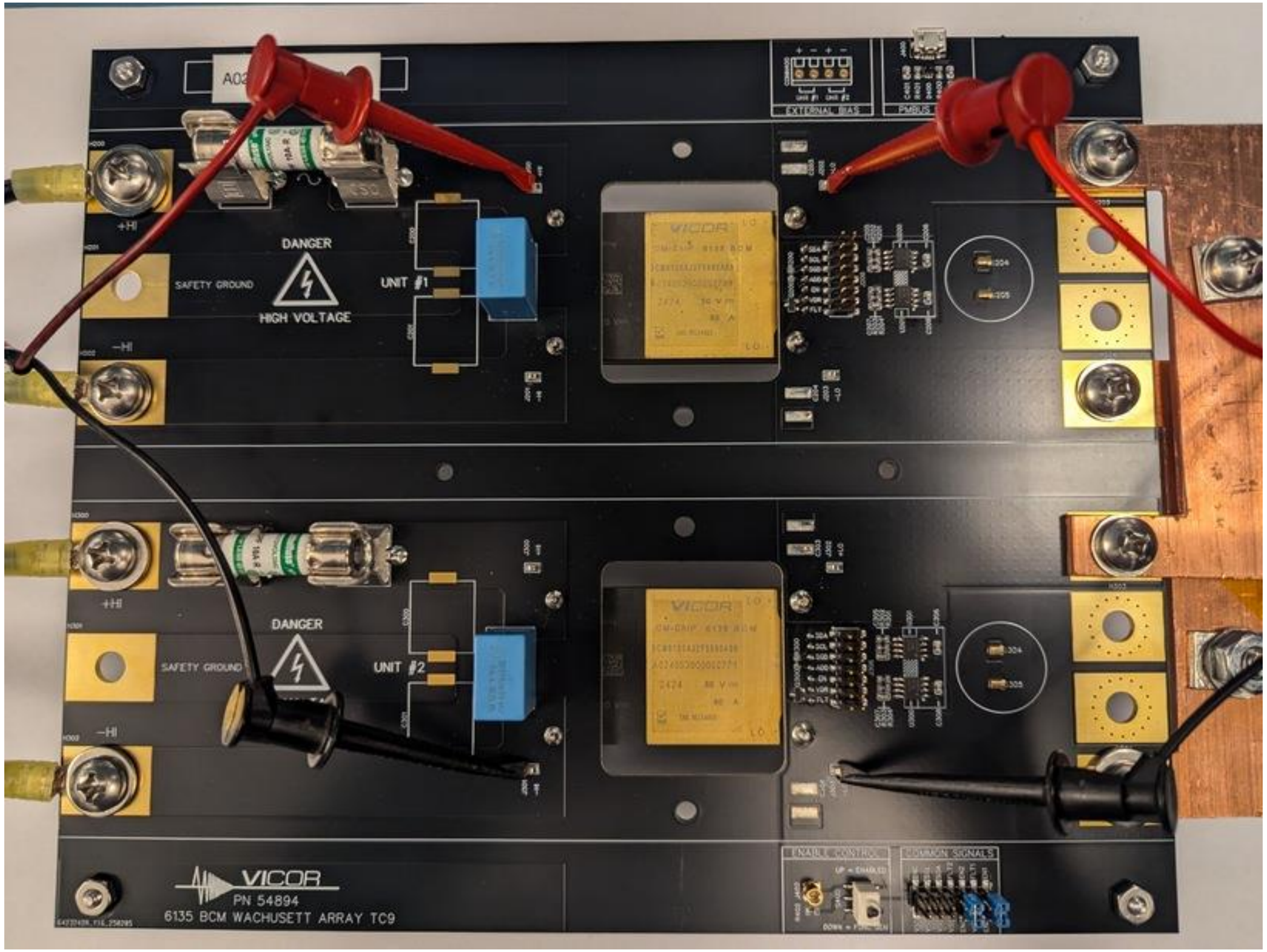
Power solution with Sine Amplitude Converter

State of charge	Voltage/cell
100%	4.2V
80%	4.0V
50%	3.7V
20%	3.4V
0%	3.0V



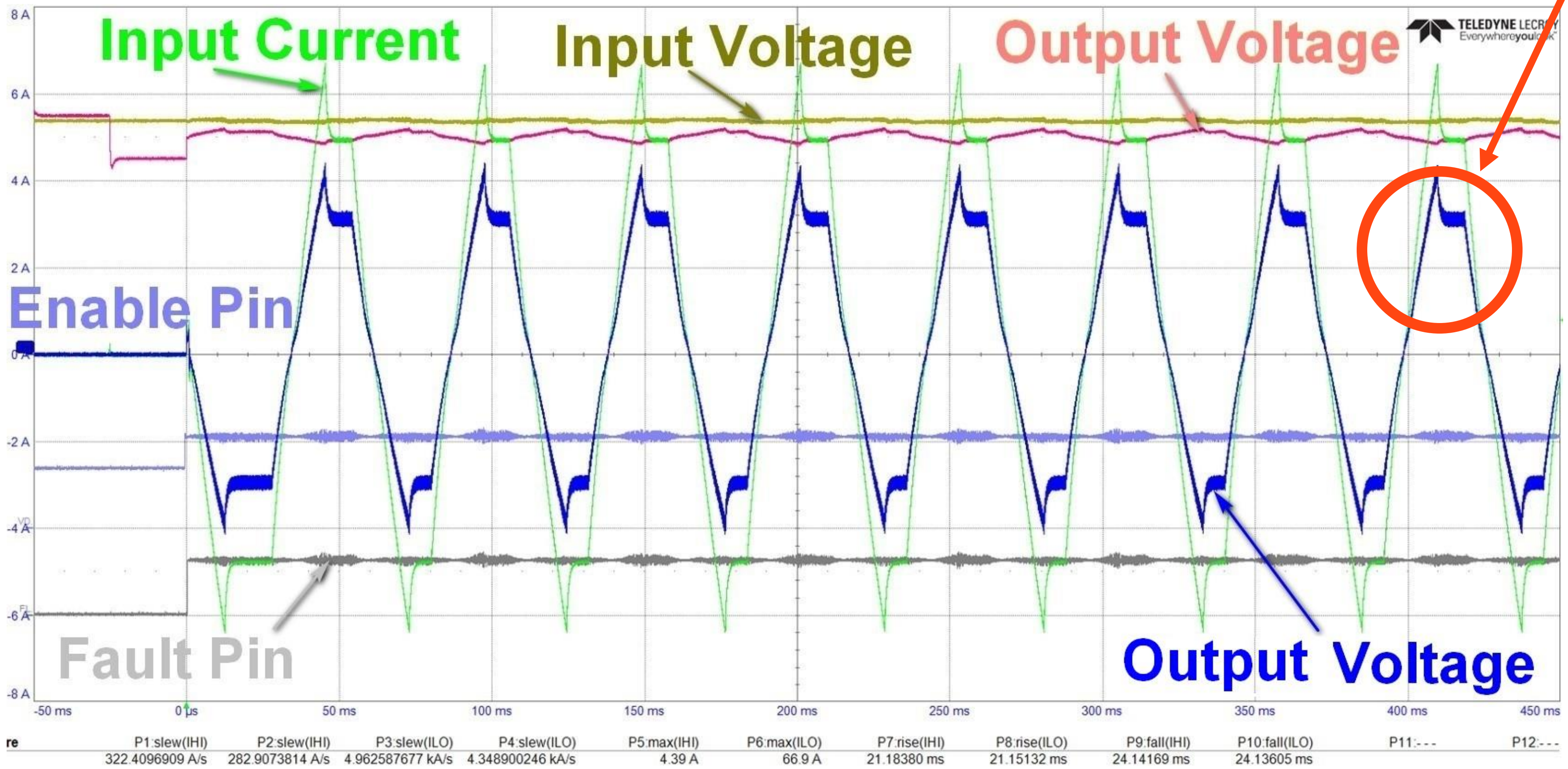
- Higher voltage > more power, less current losses, more energy storage
- Series and parallel combination of single Lithium-ion cells (example)
- HV range spans ca. 30% from HV max (+ voltage drop caused by current)
- Main loads:
  - Motor with traction inverter
  - HVAC
  - Auxiliary motors

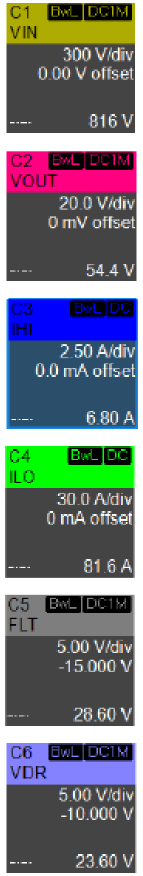
Example of SAC Implementation



Zero-delay bidirectional operation

Zero delay





High-side voltage

Low-side voltage

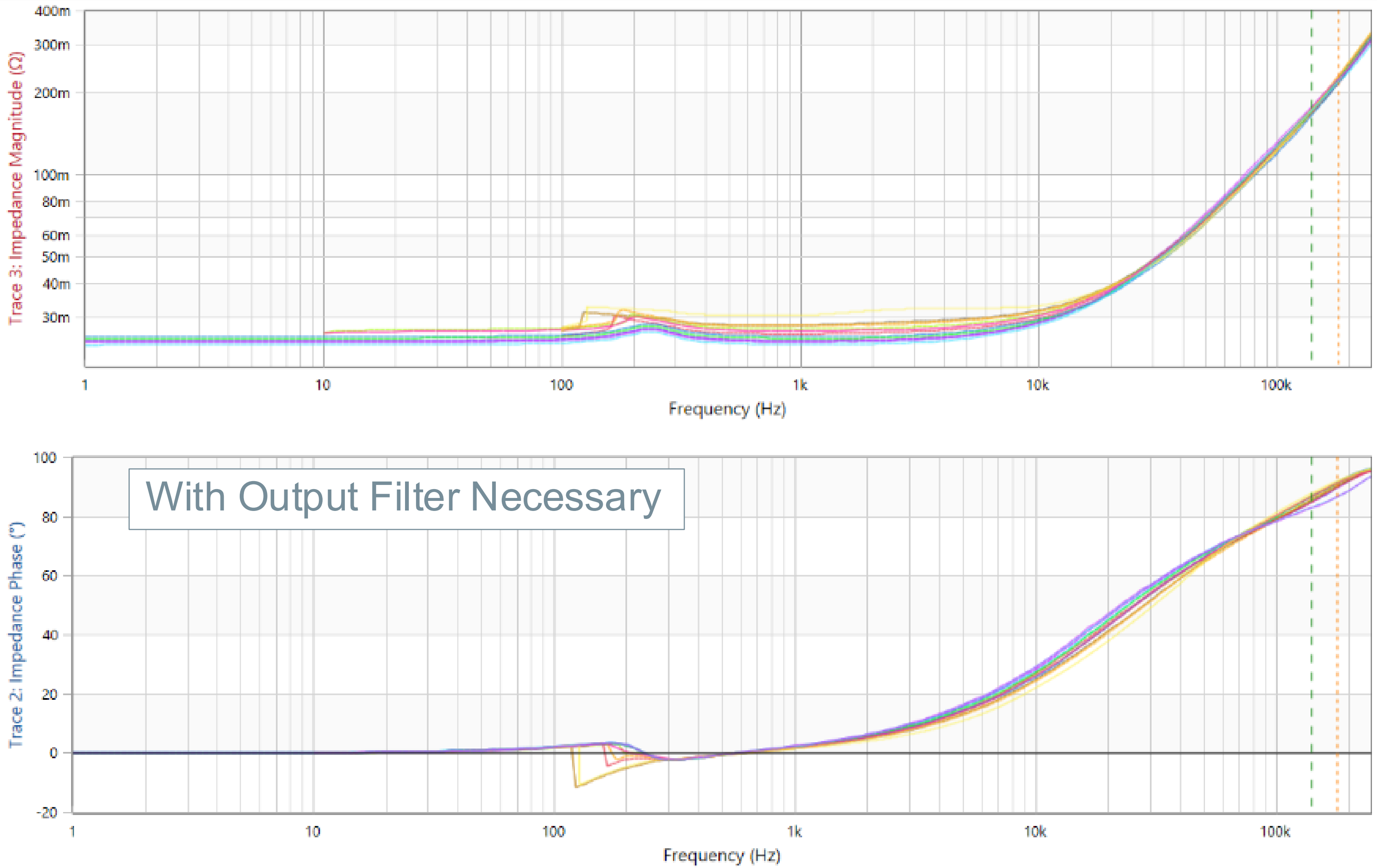
High-side current

Low-side current

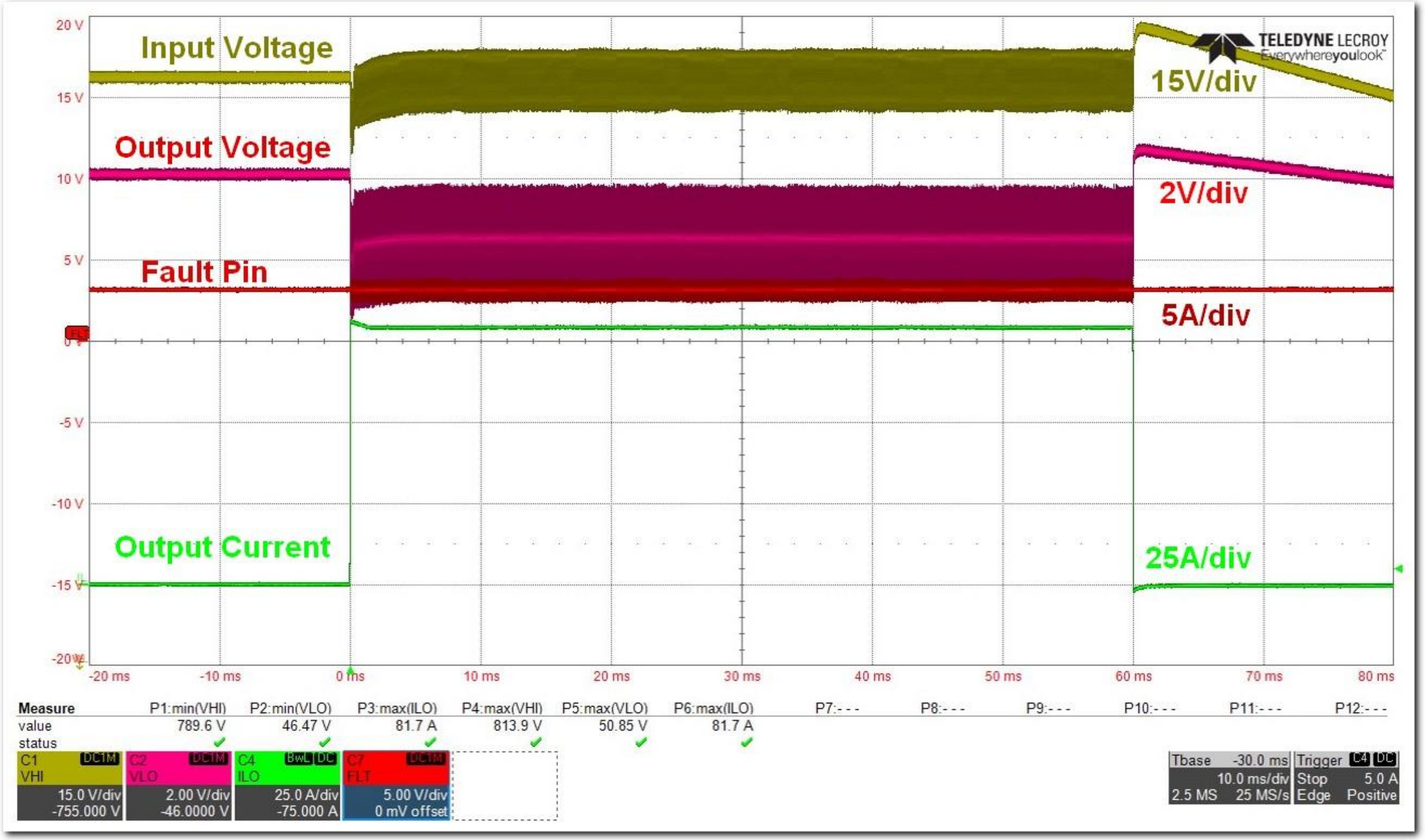
Fault output voltage

Internal bias voltage

Free of parasitic C and l, enables fast transient response



Peak current/power



Vicor BCM6135 performance summary

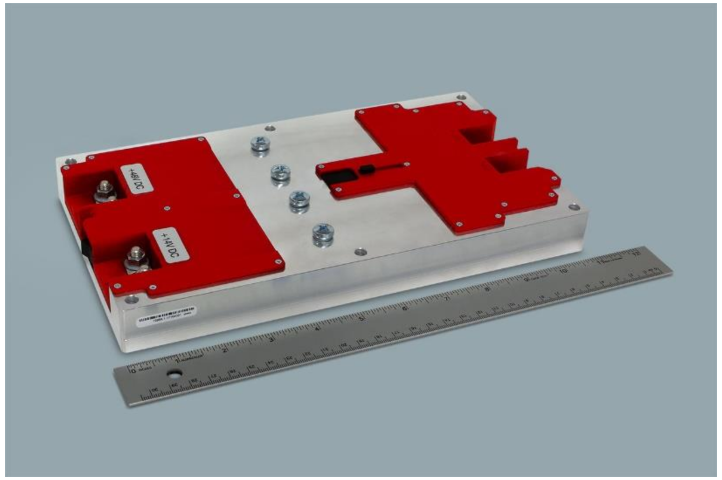
- Delete the 48V battery
- Delete the 48V supercaps
- Delete the low voltage DC-DC regulator
- Maximize the transient response
- Zero delay symmetrical regeneration
- Reduce cost, size, and weight
- Scale to the entire OEM platform of vehicles

EV system using Vicor power modules

Power modules

4kW 800 – 48V or 12V DC-DC

Systems using power modules



1.1L 4kW 800V-12V DC-DC

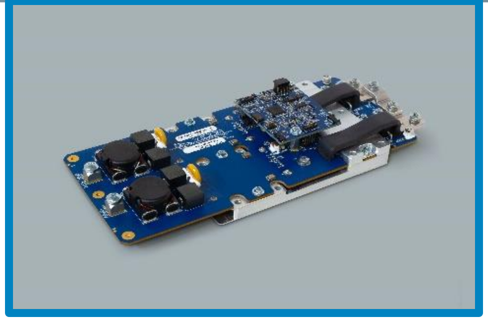
Power density: 3.6 Kw/L, 2.4 kW/kg

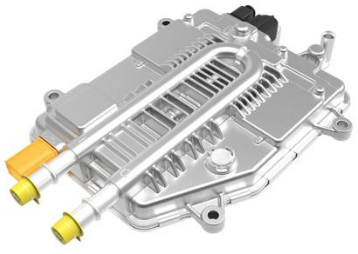
1.0L 150kW 800V-400V DC-DC

Power density: 150 Kw/L, >80 kW/kg

EV system using Vicor power modules – up to 3x improvement in power density

	Vicor Solution	Tesla Model X	Vitesco 4th Generation
Pout W (Output Power)	4000 @ 13.8V	2300 @ 12 V	3500 @ 14.5V
Output Current A	290	193	240
Weight kg	1.4	2.1	2.6
Volume L (w/o connectors)	1.1L	1.8L	2.5 L
Power Density kW/liter	3.63	1.3	1.34
Gravimetric Power Density kW/kg	2.85	1.1	1.5





Thank you