SAE INTERNATIONAL®

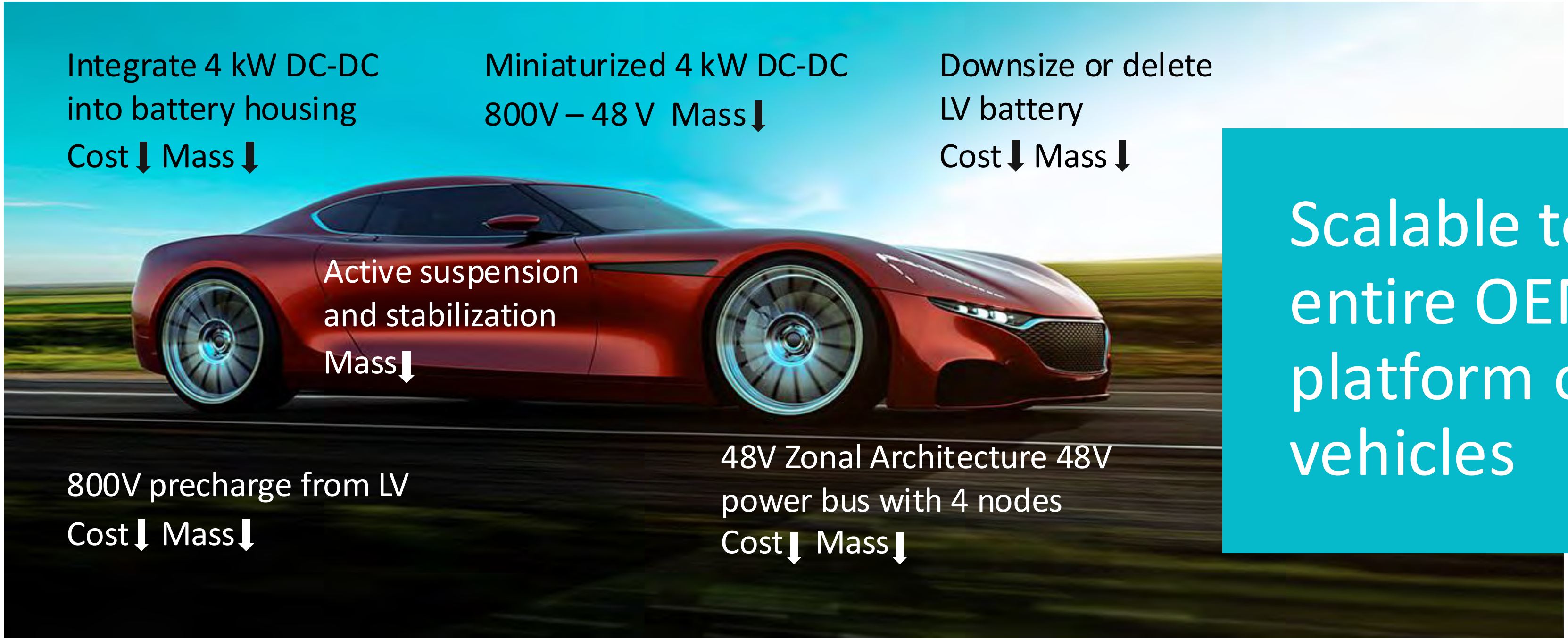
Mobility, Advanced™

Optimize High Voltage to SELV Performance While Eliminating 48V Battery and SuperCaps

Patrick Kowalyk
Vicor Automotive FAE for North America

VICOR

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

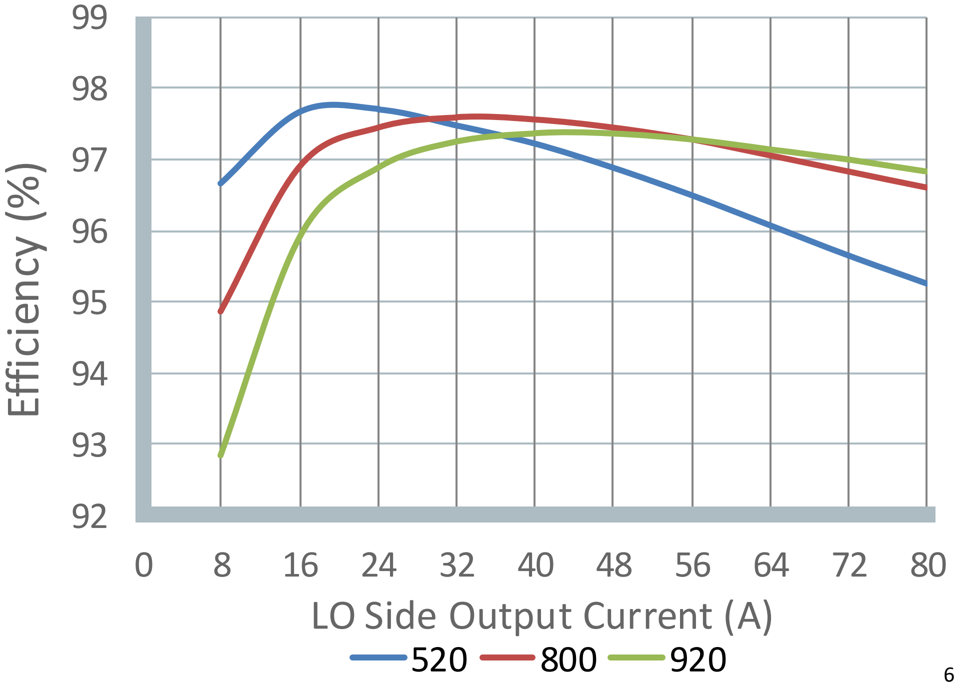
Today's challenges converting HV to SELV

- 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 and powertrain to peak 98 – 99%

Bench measurement of efficiency at 25°C ambient



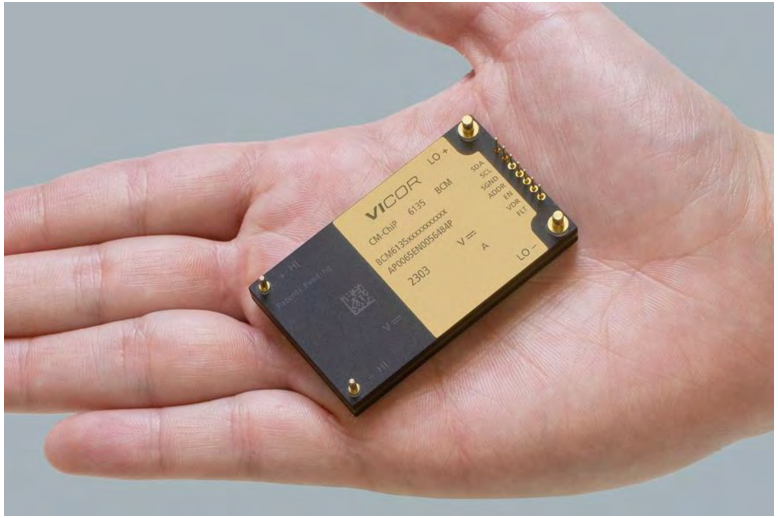
Safety

- 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, which pose safety risks
- 800V conductors need more insulation than 400V
- 800V systems need advanced battery management for safe, efficient operation

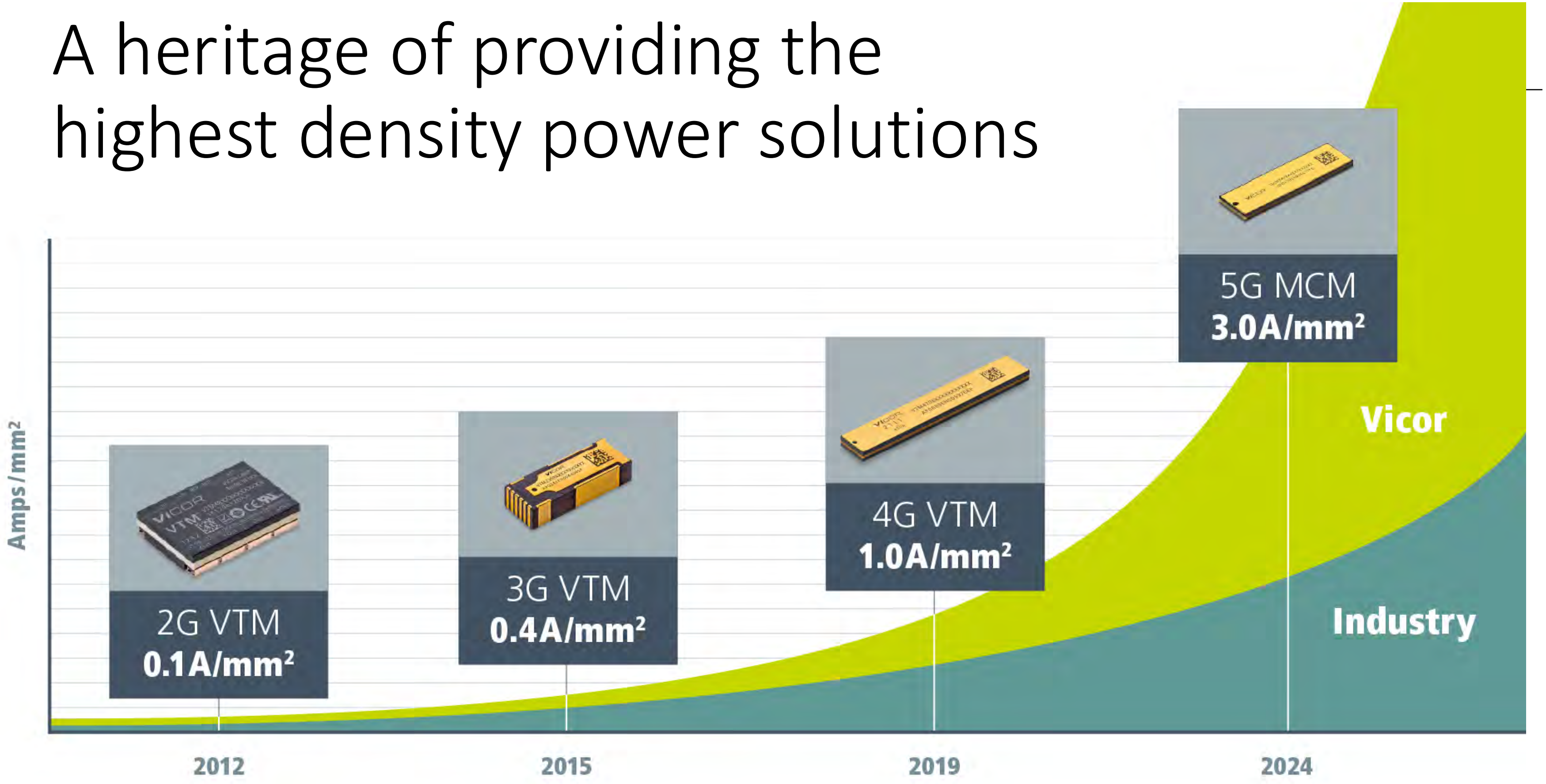
Creepage and clearance

OEMs are driving aggressive requirements for higher voltage creepage and clearance, driving increased 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



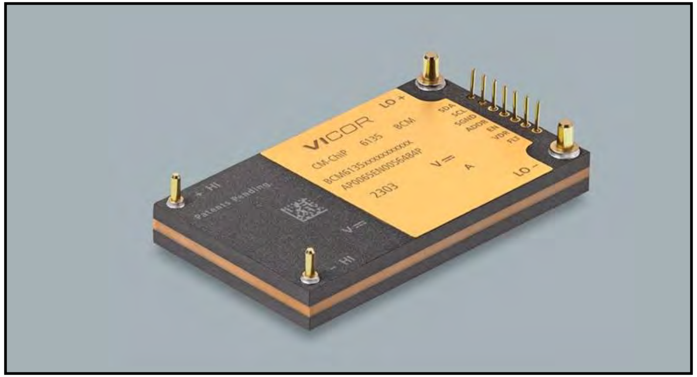
A heritage of providing the highest density power solutions



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

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

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 Min.	Typ.	Max.	Unit	Note / Test Condition
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 6cm^2 (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

$I_{D,pulse}$	30	A
E_{oss}@400V	3	µJ

Transient response

A battery delivers

250A/second

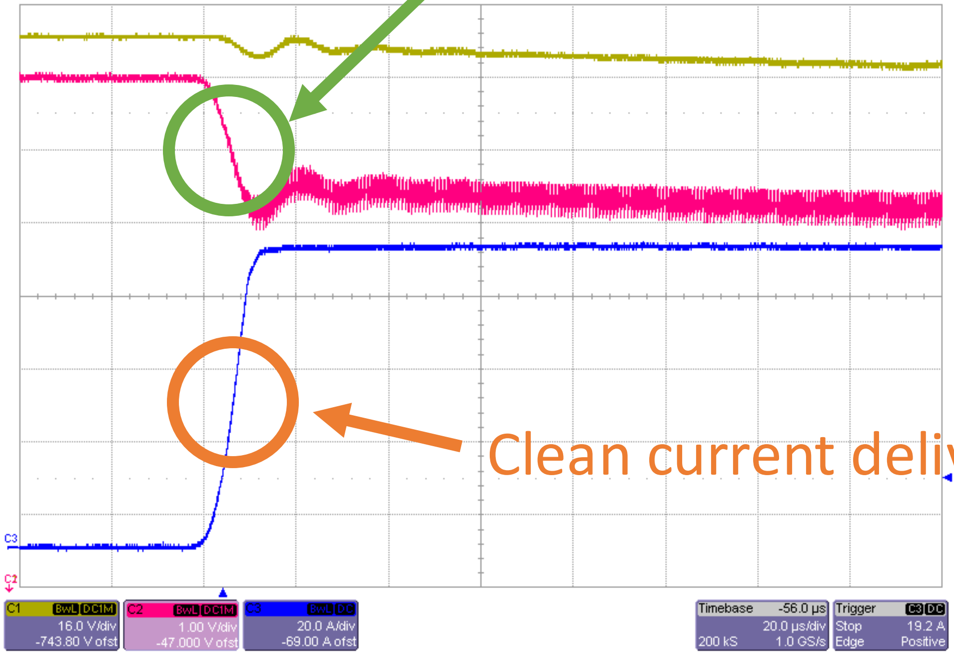
The BCM6135 delivers

8M A/second

Highest electrical performance

Load step transient

Vin and Vout follow each other by a K=1/16



Clean current delivery

V_{HI} = 800V

I_{LO} step from 0A – 80A

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

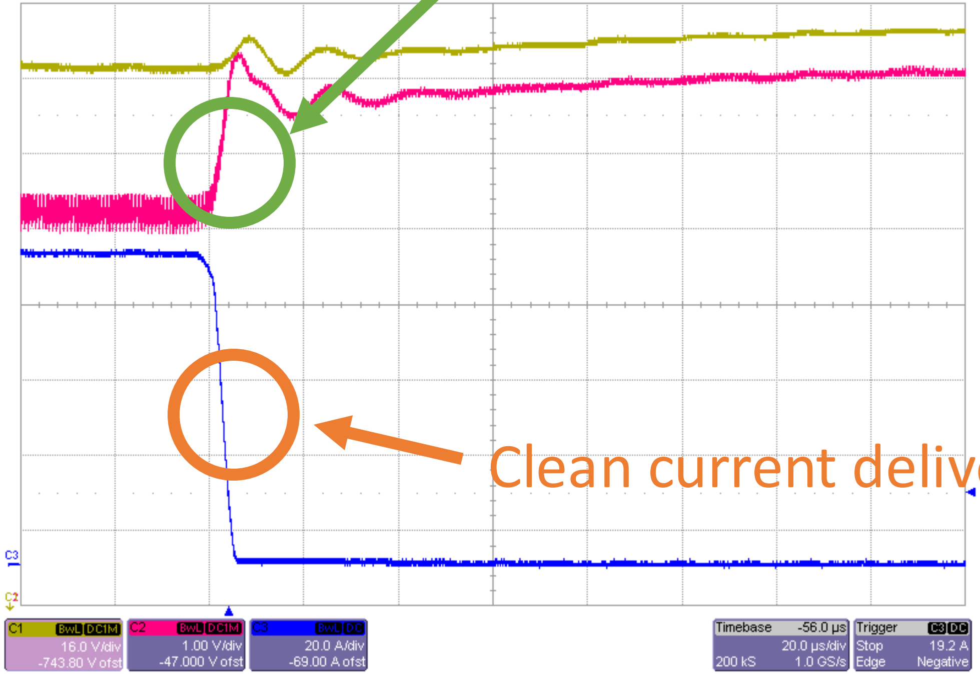
No C_{LO}

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

Timebase – 20µs/div.

Load step transient

Vin and Vout follow each other by a K=1/16



Clean current delivery

V_{HI} = 800V

I_{LO} step from 80A – 0A

$di_{LO}/dt \approx$ 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)

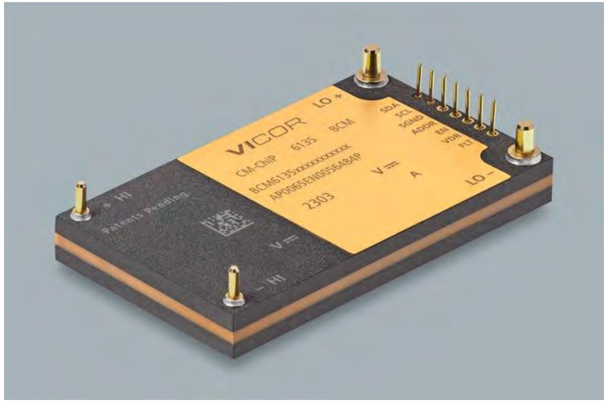
Timebase – 20µs/div.

There is a way to …

- 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

Example of Sine Amplitude Conversion (SAC)

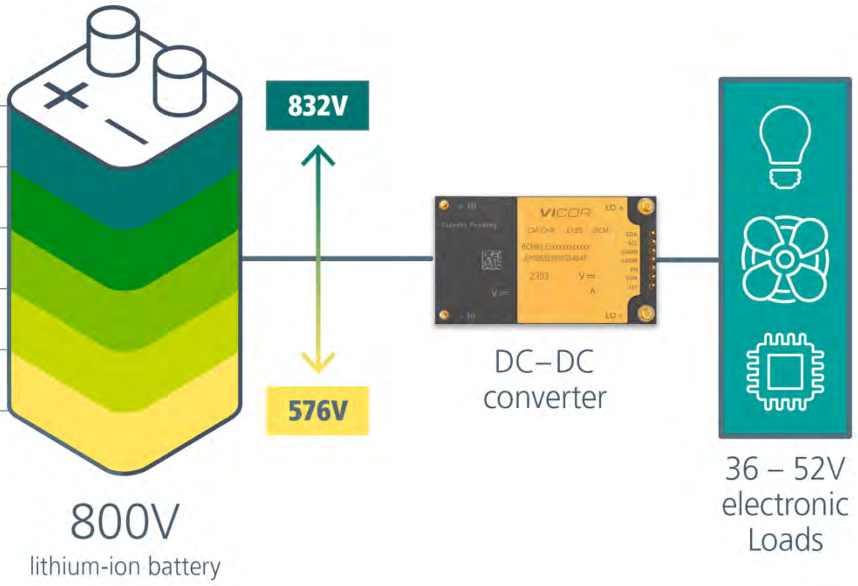
- Resonant topology
- Operates at resonant frequency, fixed gain
- Soft switching, constant frequency/duty
  - Low EMI profile
  - Switching losses minimized
- Enables higher switching frequencies and lower volume/weight
- Transformer design, resonant circuit design, low Q
- Vicor has intellectual property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



BCM6135
800V ←→ 48V @80A
61.3 x 35.4 x 7.3mm
58g

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

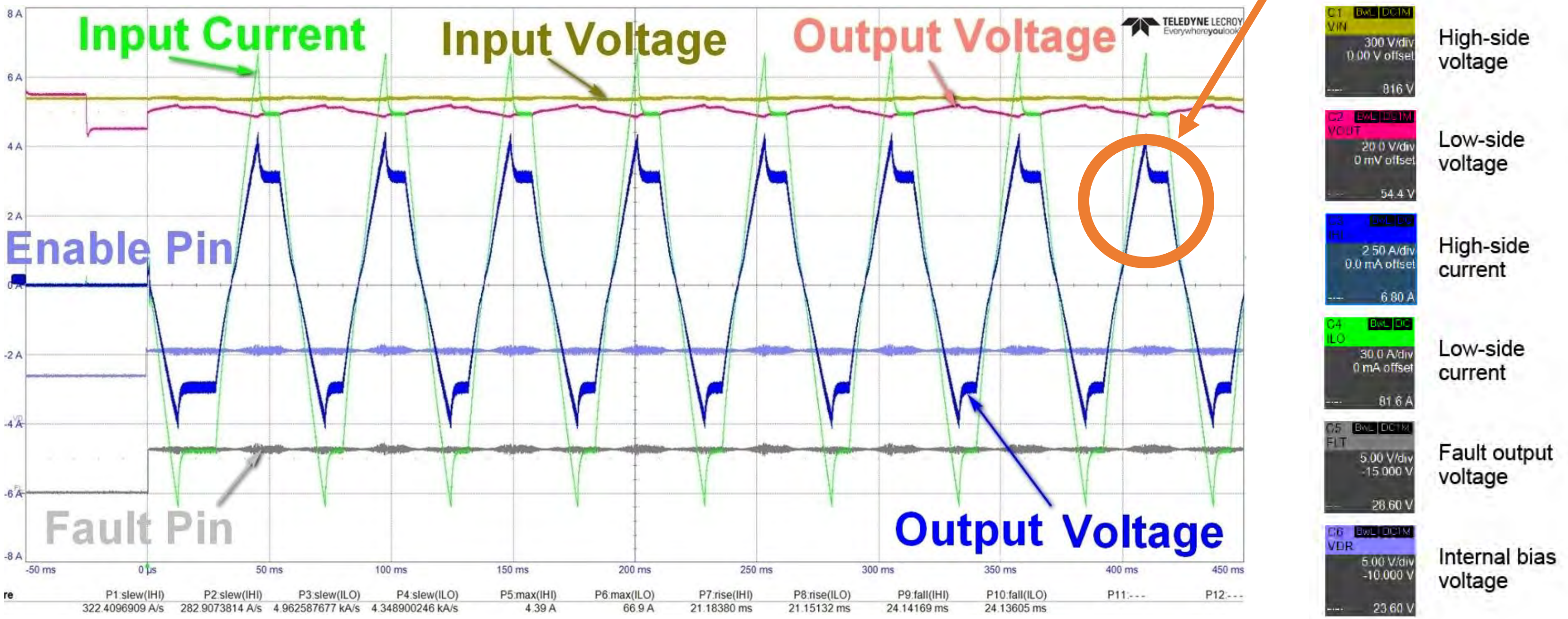


- Higher voltage > more power, less current losses, more energy storage
- Series and parallel combination of single Lithium-ion cells (example)
- HV range spans ca. 30% from HV max (+ voltage drop caused by current)
- Main loads:
  - Motor with traction inverter
  - HVAC
  - Auxiliary motors

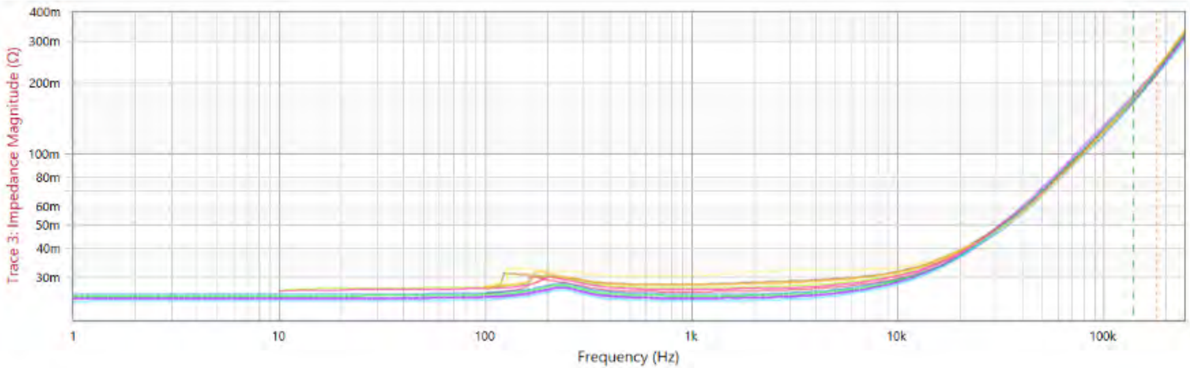
Example of SAC Implementation

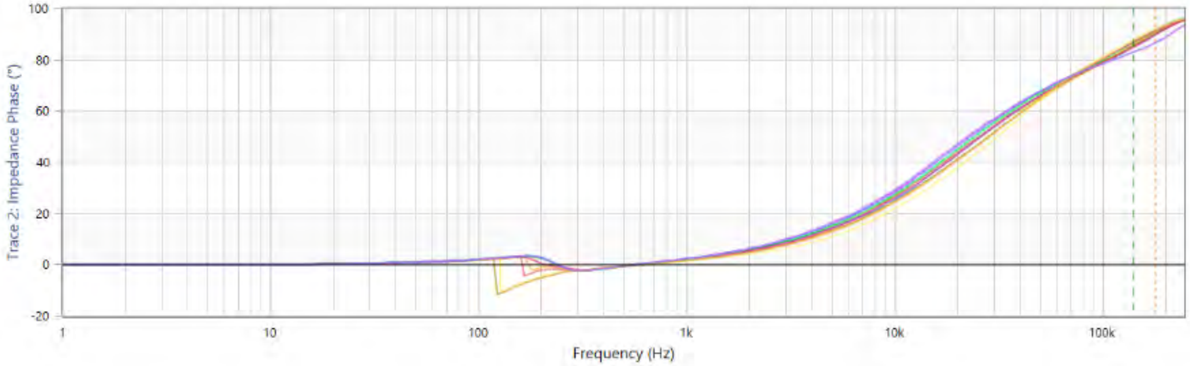
Zero delay in bidirectional operation

Zero delay

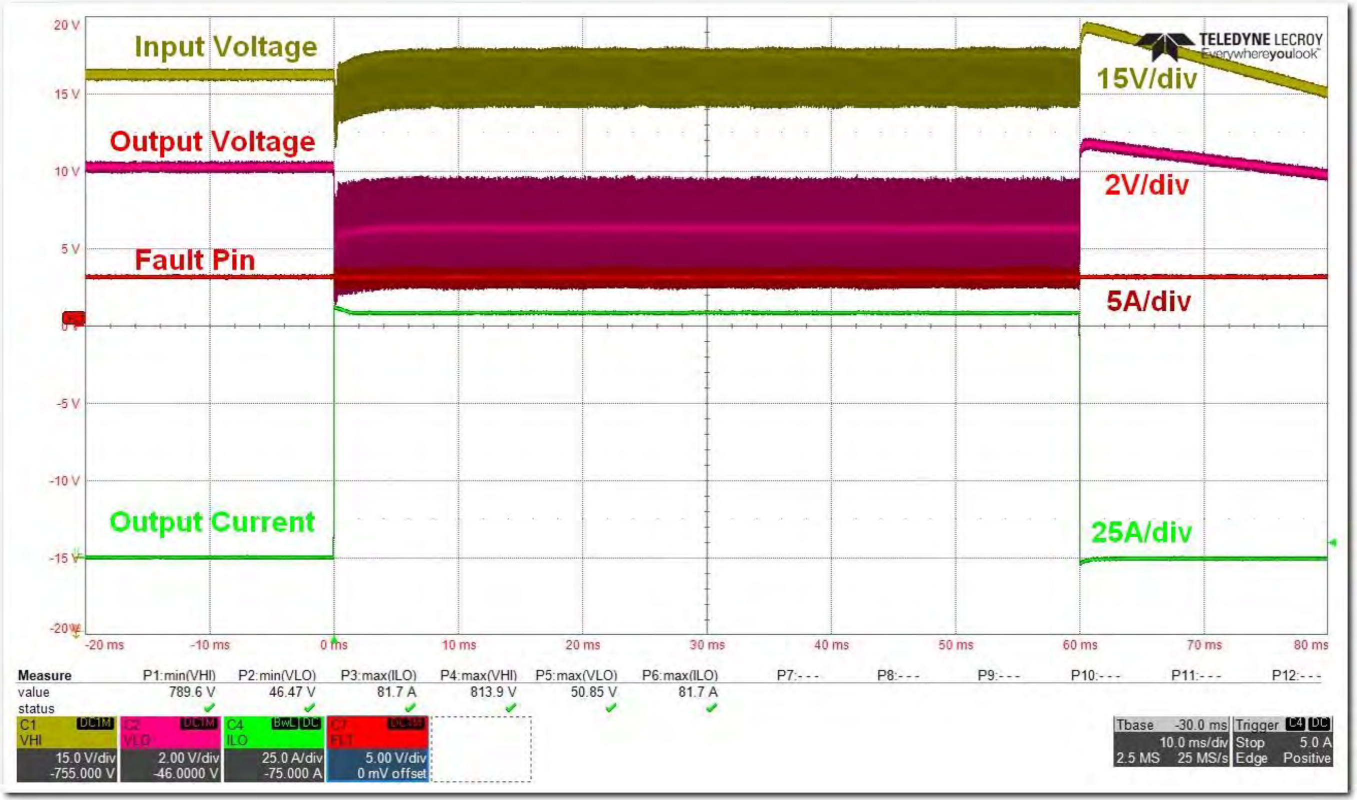


Free of parasitic C and l, which allows fast transient response



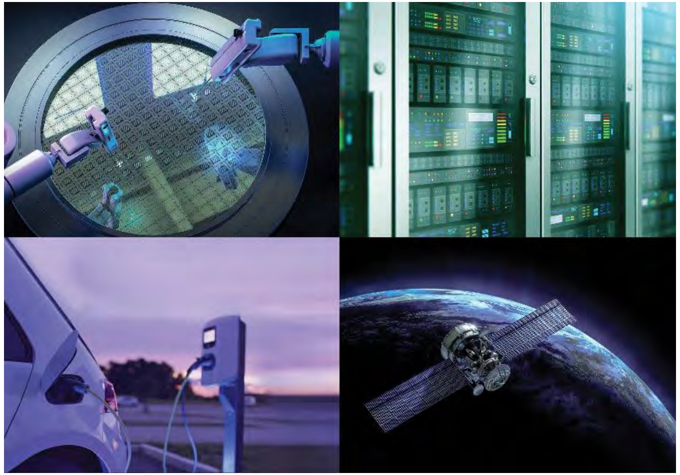


Peak current/power



Vicor snapshot

- Exclusively focused on power
- Approximately 10,000 customers, and just over 1,100 employees worldwide
- Over $1B+ invested in proprietary architectures, topologies, control systems and packaging
- Organized into four business segments: Automotive, Industrial, Aero/ Defense and High Performance Computing
- 43 Years in power solution business
- (NASDAQ: VICR) Andover, MA

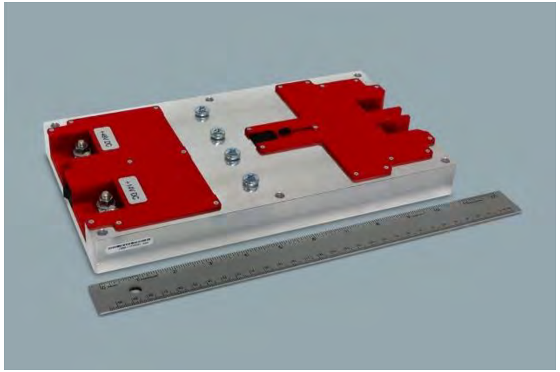


Join us in Suite 334 for refreshments and hardware examples

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

Contact Info

- Thank you
    - Patrick Kowalyk
    - Automotive FAE for North America
    - Vicor
    - 25 Frontage Road, Andover MA 01810
    - pkowalyk@vicorpower.com