VICOR

Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INNOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
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Vicor Key Technology

Peng Yuxin

Senior FAE, Vicor China

Vicor's Key Technology Drivers

Advanced Engines (Topologies)

- Enable high efficiency and superior power density
- Switching frequency > 1Mhz
- Maximize efficiency of power silicon
  - Cutting V•I requirements
  - Low Voltage Current Multipliers cut switching MOSFET VDrain-Source requirements:

Advanced Architectures (Factorized Power Architecture)

- Reducing distribution losses throughout the power chain
- Removing the inefficiency of multiple conversion or regulation stages in the power chain

A Packaging Strategy that supports high Power Density and > 1Mhz switching frequency

- Small, highly integrated power components with tightly controlled parasitic
- Planar magnetics
- Designed for flexible mounting and cooling options

Continuous Technology Advancements to Raise the Efficiency and Density Bars for the Industry

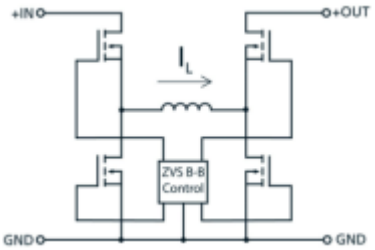
- Power loss cut by 25% every 2 years
- Power density increased by 25% every 2 years

Vicor Power Technology – Engines (Topologies)

ZVS Regulator

Non-isolated, DC-DC regulator

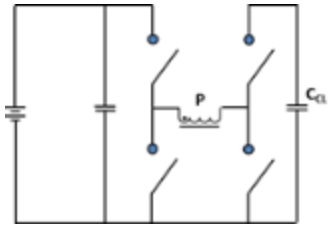
- Pre-Regulator Module (PRM)
- Cool-Power ZVS
  - Buck
  - Boost
  - Buck-Boost

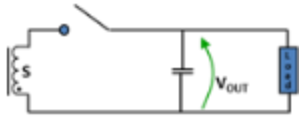


Double-Clamped ZVS (DC-ZVS)

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

- DC Converter Module (DCM)
- Cool-Power Converters
- Power Factor Module (PFM)

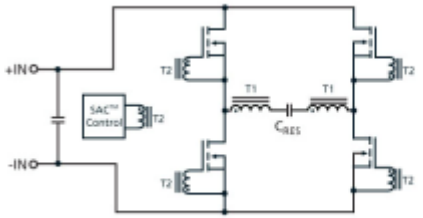


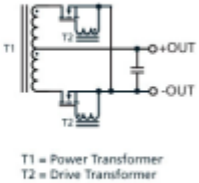


Sine Amplitude Converter (SAC)

Isolated, fixed-ratio, DC-DC transformer

- Bus Converter Module (BCM)
- Intermediate Bus Converter (IBC)
- Voltage Transformation Module (VTM)
  (current multiplier)





Addressing the Entire Power Chain with Comprehensive Portfolio

VIA
Vicor Integrated Adapter

ChiP
Converter Housed in Package

SiP
System in Package

SOURCE to PoL

Power Source to Point of Load

Benefits of using Power Component Design Methodology

Modular system building blocks enable solutions achieving:

› High density and efficiency

› Flexibility, scalability

› Fast time to market, cost effective

Markets and Applications

- Aircraft test equipment
- Reconnaissance / Targeting Systems
- Radio / Telemetry Systems
- Secure Communications Systems
- Ground Vehicles

- Wireless & Satellite Base Stations
- Broadcast Equipment
- Power Amplifiers
- Microwave Communication
- Remote Telemetry Communication

- Enterprise Servers
- Optical Switchers
- Data Storage Systems
- Network Servers
- Super Computers

- ATE
- Process Control
- Energy
- Lighting
- Transportation/ Railroad
- Factory Automation

- Electric / Hybrid Vehicles
- Commercial / Aftermarket

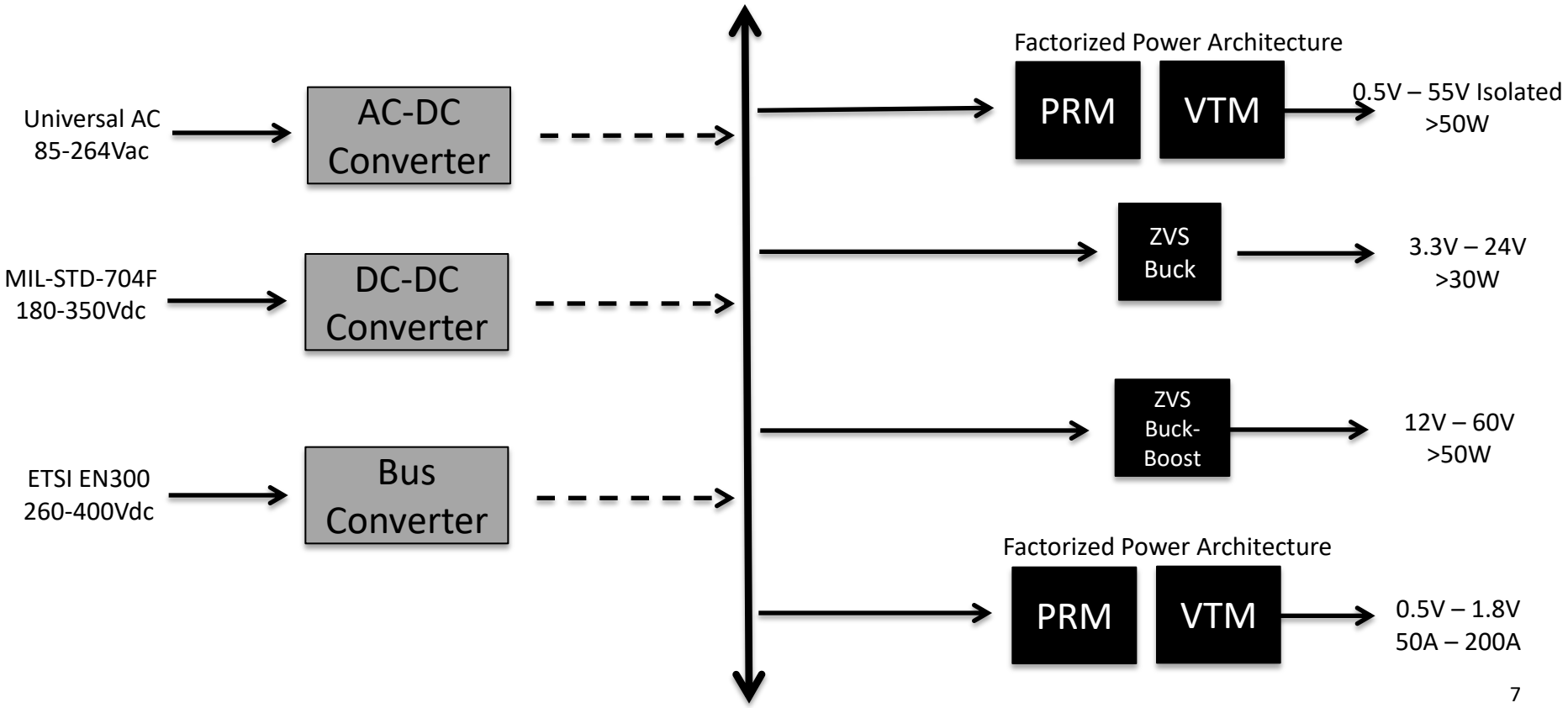
Power Component Methodology/Business Units

Front End

Vicor Power Systems (VPS) **48V, 28V, 24V…**

Point of Load

Vicor Power Components(VPC)

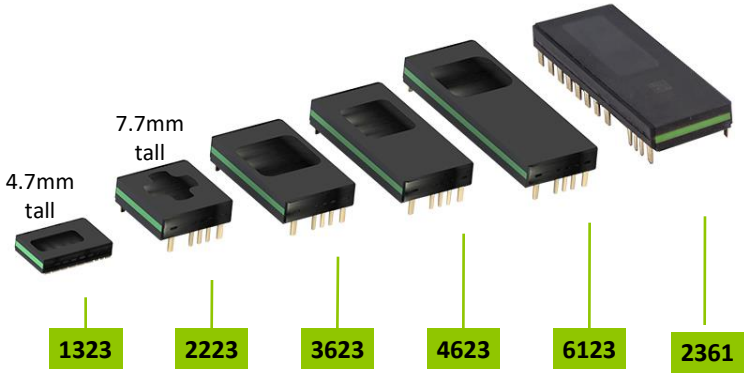


"ChiP" Power Component Platform

Converter housed in Package

(Package Nomenclature: expressed in mm)

ChiP power components are born out of a scalable power platform



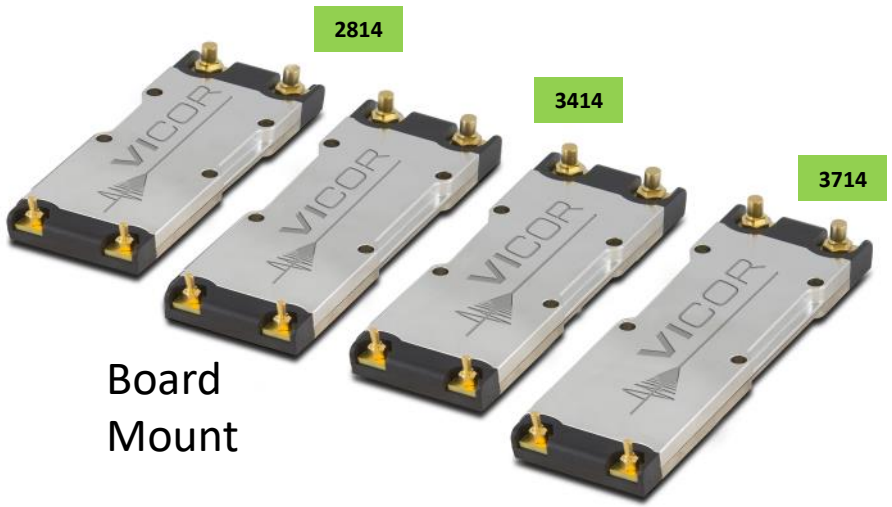
- **ChiP is Flexible** (topologies, applications)
  - AC-DC with PFC
  - DC-DC conversion (regulated, unregulated)
  - Buck, Boost, and Buck-Boost regulation
  - PoL current multiplication
- **ChiP is Scalable** (size, power)
  - From 4.7 mm thin
  - 0623 to 6123 and expanding
  - Up to 180 A, 430 V, 1.8 kW and rising
- **ChiP will be SMT/MSL4**
  - RTP 1H 2017
  - Release across other ChiP sizes.

“VIA” Power Component Platform

Vicor Integrated Adapter

(Package nomenclature: expressed in inches X 10)

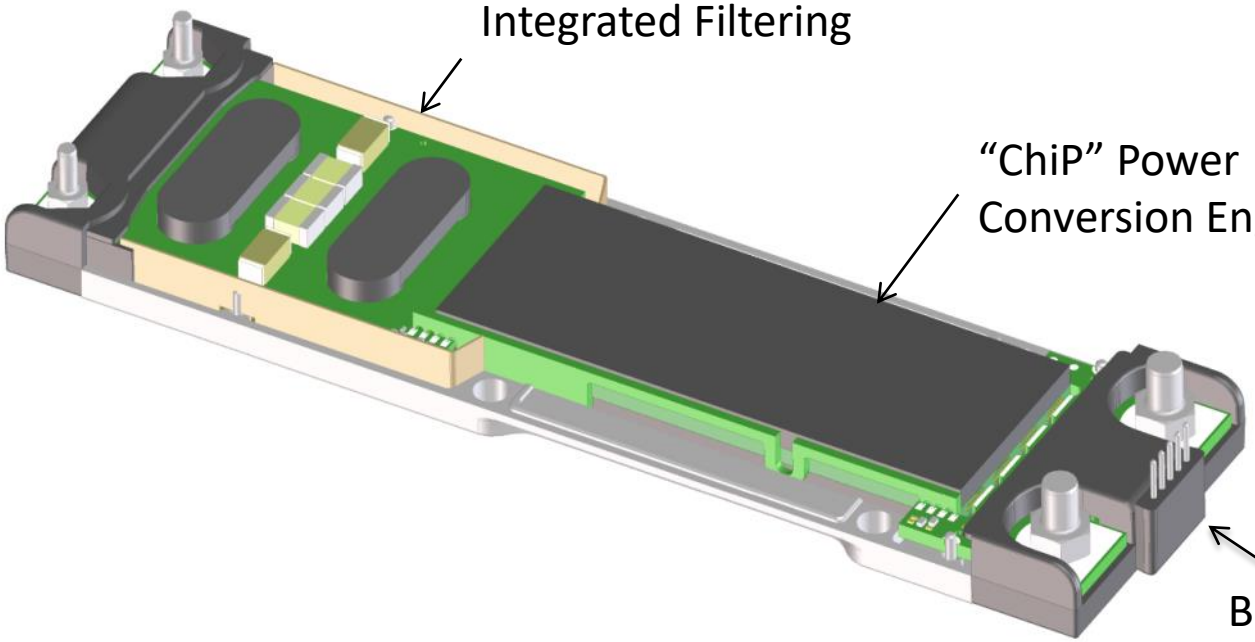
- Objective: Provide a thermally adept, flexible, dense, low cost, housing for Vicor front-end (FE) power conversion engines, including:
  - PFM, BCM, DCM and all future Front End ChiPs.
- Ease-of-Use: Build on Vicor’s heritage
- Solutions may include integrated EMI filtering, transient voltage suppression (TVS), inrush protection…with optional digital communication (PMBus).
- Available in Board-Mount or Chassis-Mount form-factors
- Focus on “Power Component Methodology”

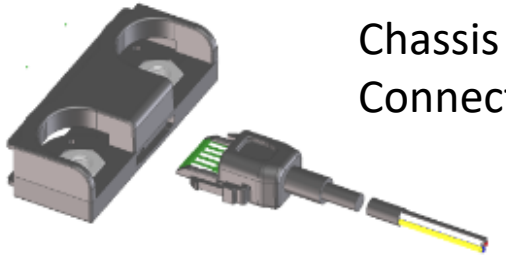


Board Mount

Chassis Mount

VIA Packaging





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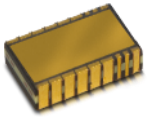
VPS product overview

DC Modules (DCM) in a ChiP package

- Isolated, regulated DC-DC converters
- Converter housed in Package (ChiP) power component platform
- VIN: 24, 28, 30, 48, 270, 275, 290 and 300 VDC nominal inputs
- VOUT: Predefined outputs from 3.3 to 48 VDC, regulated, isolated
- Power capability:
  - Up to 600 W – 4623 ChiP
  - Up to 320 W – 3623 ChiP
  - Up to 120 W – 2322 SM ChiP
- Over 93% efficient

4623 ChiP:
1.9 x 0.90 x 0.3in
47.9 x 22.8 x 7.3 mm

3623 ChiP:
1.5 x 0.90 x 0.3 in
38.7 x 22.8 x 7.3mm



2322 SM ChiP:
0.91 x 0.89 x 0.3 in
23.1 x 22.7 x 7.5 mm

Family	Input Voltage	Output Voltages	Max power	Package	Availability
Industrial HV	300 (180 – 420)	48, 28, 24, 12	600 W	4623 ChiP	NOW
Telecom/Datacom	48 (36 – 75)	48, 36, 28, 24, 15, 12, 5	320 W	3623 ChiP	NOW
Industrial LV	24 (18 – 36)	48, 36, 28, 24, 15, 12, 5	320 W	3623 ChiP	NOW
EV/HEV	290 (160 – 420)	13.8	600 W	4623 ChiP	NOW
MilCOTs 270	270 (160 – 420)	28, 24, 15, 12, 5, 3.3	500 W	4623 ChiP	NOW
MilCOTs 28	28 (16 – 50)	48, 28, 24, 15, 12, 5, 3.3	320 W	3623 ChiP	NOW
MilCOTs 30	30 (9-50)	48, 28, 24, 15, 12, 5, 3.3	160 W	3623 ChiP	NOW
Industrial 275	275 (120 – 420)	28, 24, 12,	375 W	4623 ChiP	NOW

DC Modules (DCM) in a VIA package

- **VIA Power Component Platform – a 'better brick'**
  - Isolated, regulated DC-DC converters
  - Easy to use, robust and reliable, thermally adept, integrated filtering
  - Chassis or PCB mounting options, secondary side controls, low profile
- **VIN: 28, 48, 270 and 300 VDC nominal inputs**
- **VOUT: Predefined outputs from 5 to 48 VDC, regulated, isolated**
- **Power capability:**
  - Up to 600 W – 3714 platform
  - Up to 320 W – 3414 platform
  - Up to 120 W (est.) – 2214 platform (1Q17)
- **Over 93% efficient**

3414 VIA:
3.38 x 1.40 x 0.37 in
85.9 x 35.6 x 9.4 mm

3714 VIA:
3.75 x 1.40 x 0.37 in
95.3 x 35.6 x 9.4 mm

Package/Input voltage	Output Voltage/Power					
	5 V	12 V	15 V	24 V	28 V	48 V
3714/300 Vin (200-420 V)		400 W		600 W	500 W	500 W
3714/270 Vin (160-420 V)	250 W	500 W	500 W	500 W	500 W	
3414/28 Vin (16-50 V)	180 W	320 W	320 W	320 W	320 W	320 W
3414/48 Vin (36-75 V)	160 W	320 W	320 W	320 W	320 W	320 W

- **Green – Currently Available, Blue – On development**

PFM & AIM :
Lowest profile AC-DC power system components.

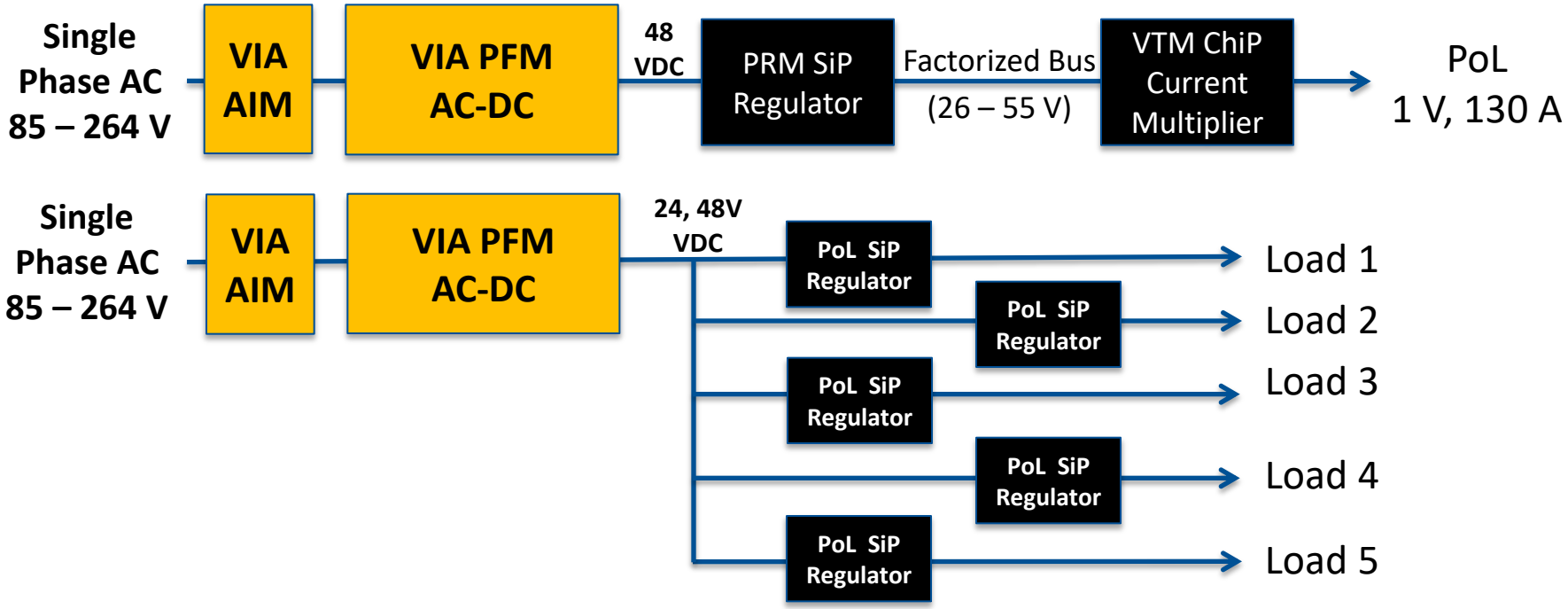
- **The PFM is an isolated, regulated converter in a VIA package**
  - Input : Rectified single phase AC
  - Output : regulated 24 or 48 Volts
  - Chassis or board mount, C & T grades
  - Available in 400 W now, 200 W version late 4Q16
  - No paralleling (no innate share ability)

- **The AIM is filtering & rectification in a VIA package**
  - Input : Single Phase AC
  - Output : Rectified single phase AC

- **The AIM + PFM meet required safety and conducted EMI standards**
  - Class B per EN55022
  - External TMOV required for EN61000-4-5 compliance for surge immunity

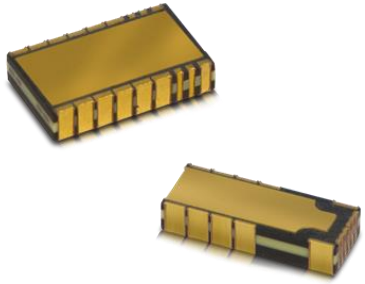
Product	Tested w/AIM ?	V_{OUT}	EN55022	Release to Production
PFM4914	NO	48	Class A	NOW
PFM4914	NO	24	Class A	NOW
AIM1714 & PFM4414	YES	48	Class B	NOW
AIM1714 & PFM4414	YES	24	Class B	NOW

Enabling the Vision: Power-dense, Modular AC to PoL Solutions



BCM Product Families

"Low Voltage" BCM/NBMs: V_{IN} = 36-60V	"High Voltage" BCMs: V_{IN} = 260–410V	"Ultra High Voltage " BCMs: V_{IN} = 400–800V
SMChiP versions mid 2017	*200 - 400V ChiP/VIA RTP 4Q16* *SM ChiP in mid2017*	*VIA RTP 1Q17, SMChiP follows*

Classic	**ChiP**	**VIA**	**SM ChiP**
SMT	Through hole	Chassis & PCB Mount	SMT
			
• 120W to 325W (Platform released, complete)	• 800W to 1.75W (Platform released, in roll-out)	• 1.5kW to 2.4kW (Platform released, in roll-out)	• 200W to 6kW (Platform in Dev)

Original "Classic" BCM Power Component

- **Over 5M units sold since 2008**
- **Power: 120 to 325W**
- **Fixed Frequency Converter (+1.3MHz)**
- **Efficiency up to 96%**
- **Fixed Ratio Converter (Vout=Vin x K)**
  - Commercial BCMs:
    - Input Voltage: 38-55Vdc, 330-365Vdc, 360-400Vdc
    - Output Voltage: 1.19-55Vdc (48Vin), 10-13V, 44-50Vdc (350Vin, 380Vin)
    - Output Power: 120-325W
  - MIL COTS BCM:
    - Input Voltage: 240-330Vdc
    - Output Voltage: 30-41.3Vdc
    - Output Power: 235W
- **Full and ½ Size Classic SMD Package**
- **Usage:**
  - Can self-start and most commonly used as an Intermediate Bus Converter for downstream non-isolated PoL converters
  - Safety isolation between input source and output loads

Full VIC: 1.28" x 0.87" x 0.265"
½ VIC: 0.65" x 0.87" x 0.625"

BCM – "ChiP" Package

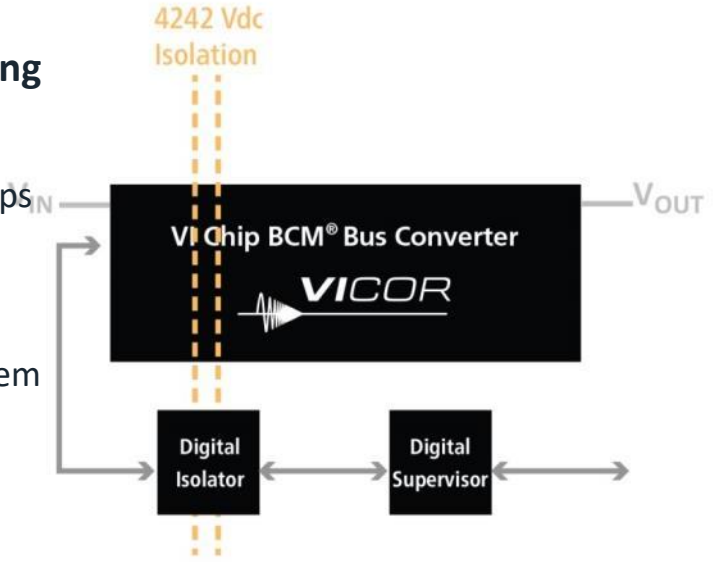
High Power and PMBus™ Digital Management Interface

Vicor's New BCM ChiPs sets new bar for power density

- **Input: 36-60V, 200-400V, 260-410V, 400-700V, 500-800V**
- **Power: Up to 2.4kW in a 2.2 in^2 footprint**
- **Power Density: Up to 3,600W/IN^3**

Digital telemetry to Vicor's ChiP BCMs

- **PMBus compatible management interface for real time monitoring and control**
  - PMBus chipset includes Vicor Digital Supervisor + Isolator companion chips + ChiP BCM
  - Available for ChiP BCMs
  - Provides secondary referenced control interface for real time power system telemetry



BCM – "VIA" Package

Themally Enhanced, Integrated Functionality

Vicor's New BCM VIA simplifies High Density Design

- Input: 36-60V, 200-400V, 260-410V, 400-700V, 500-800V
- Output: range available between 6V and 51V
- Power: Up to 2.4kW in a 2.2 in^2 footprint
- Efficiency: Up to 98%
- Power Density: Up to 1,200W/in^3

Unique VIA package Integrates Key Functions

- PMBus from secondary for real time monitoring and control
- Filtering to achieve required conducted emission
- Transient Voltage Suppression, Surge Protection
- PCB Mount and Chassis Mount options
- Rugged, Reliable, thermally adept metal housing eases thermal challenges

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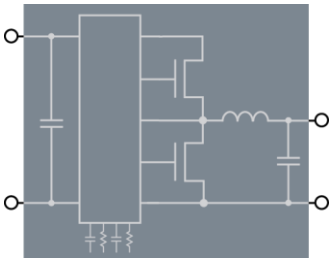
VPC product review

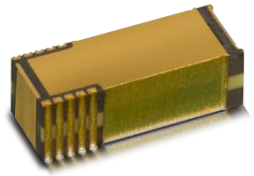
Cool-Power ZVS Buck Regulators

Portfolio for Full Scalability

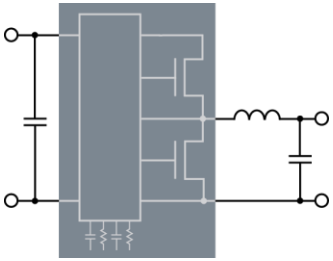


SM-ChiP Regulator Modules

- Complete module for highest density
- Surface mount
- Buck, Buck-Boost, Boost regulation
- Highest level of convenience and time to market
- V_{IN} 8 V to 60 V, output power from 100 W to 400 W (20 A max)



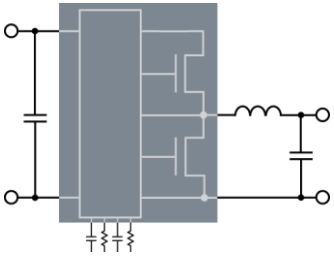
2308 SM-ChiP
(Roadmap: Q2, 2017)



SiP Regulator Modules (LGA/BGA)

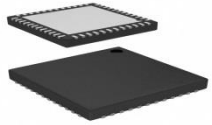
- Module with controller, FETs, and programming components
- Minimal input and output filtering required
- Full featured set capability including digital telemetry
- Buck, Buck-Boost, Boost regulation
- No parametric settings required
- V_{IN} 8 V to 60 V, 70 W to 250 W (22 A max w/ new FETs)

10 x 10mm SiP
10 x 14mm SiP



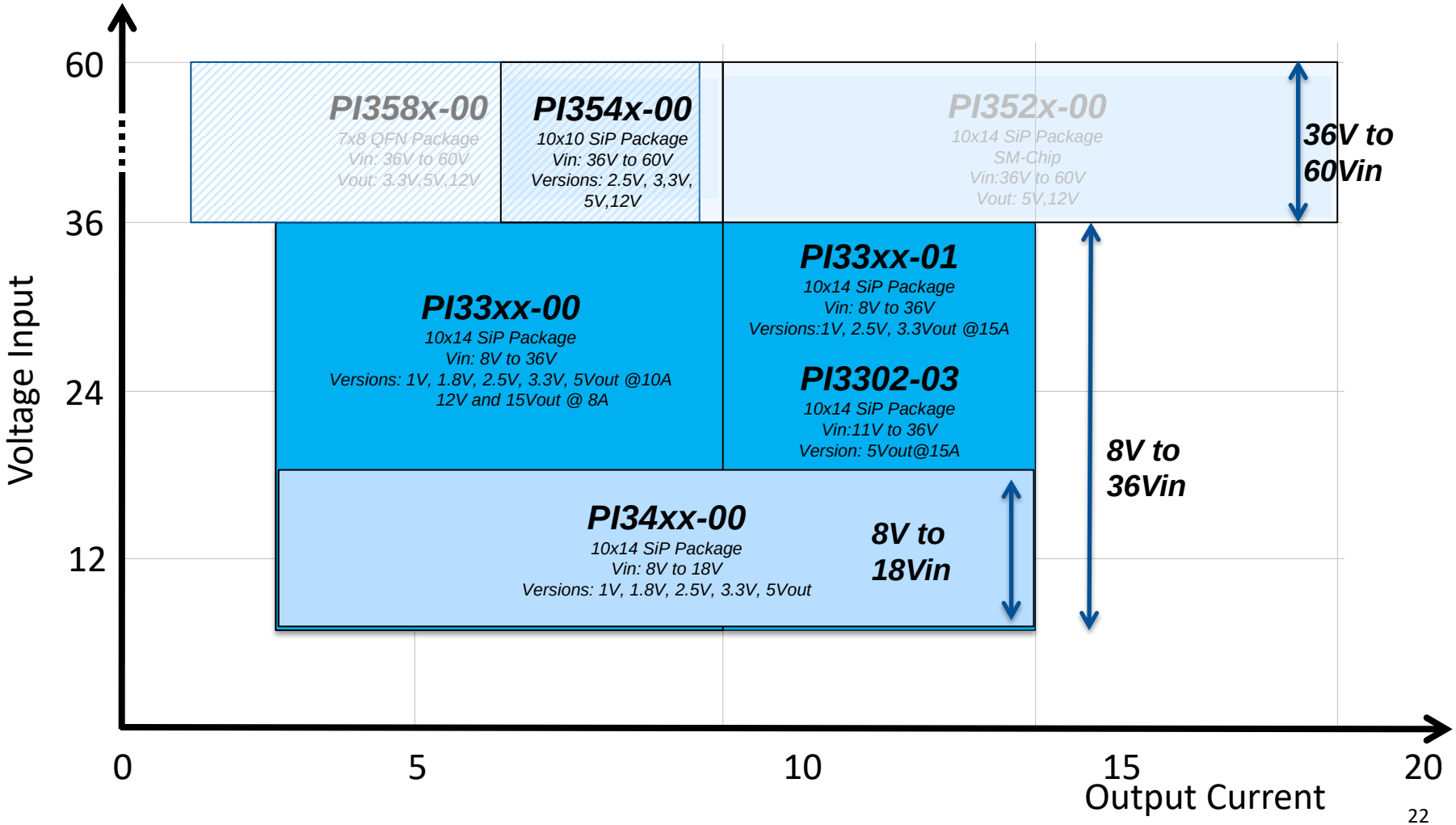
QFN Regulators

- Co-packaged controller and FETs
- Requires external programming components
- Buck regulation only
- V_{IN} 8 V to 60 V, up to 70 W (10 A max w/new FETs)



7 x 8mm QFN
(Roadmap: Q2, 2017)

Cool-Power ZVS Buck Regulators

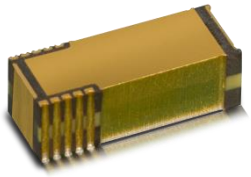


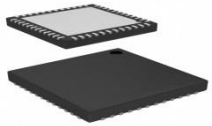
ZVS Buck Regulators

ZVS Buck →

Input Range	Output Voltages	Series/Package	Avail.	Rel.	Current / Power
8-36V	1V, 1.8V, 2.5V, 3.3V, 5V, 12V, 15V	PI33xx-xx / 10x14 SiP	**Now**	**Now**	Up to 15A
8-18V	1V, 1.8V, 2.5V, 3.3V, 5V	PI34xx-xx / 10x14 SiP	**Now**	**Now**	Up to 15A
36-60V	2.5V, 3.3V, 5V, 12V	PI354x-xx / 10x10 SiP	**Now**	**Now**	Up to 10A
36-60V	5V, 12V, 24V	PI352x-xx / 10x14 SiP			Up to 22A
36-60V	2.5V, 3.3V, 5V, 12V	PI358x-xx / 7x8 QFN			Up to 10A
36-60V	12V, 24V	PRMxxx / 2308 SM-ChiP*			150W-200W*

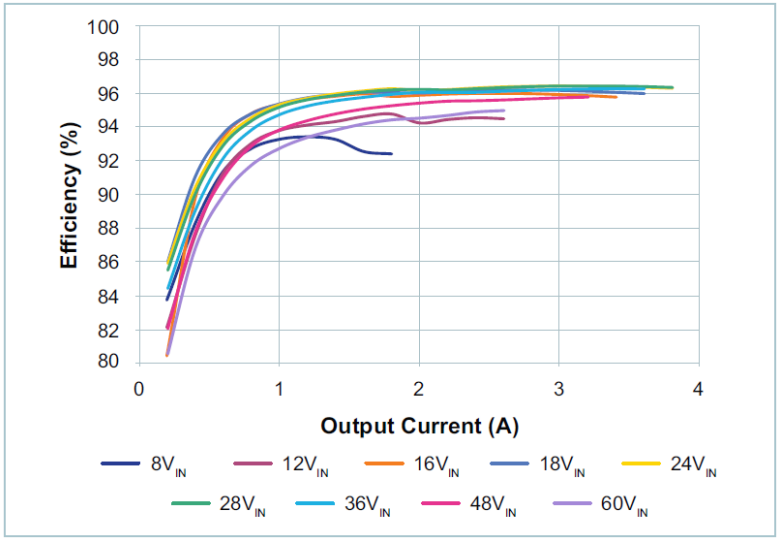
***2x, 4x Power versions planned in 2317, 3523 packages; samples and release in 2H 16**

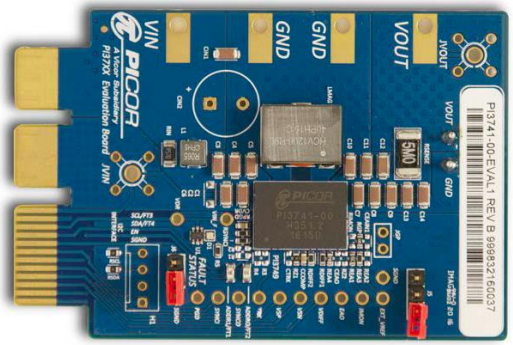


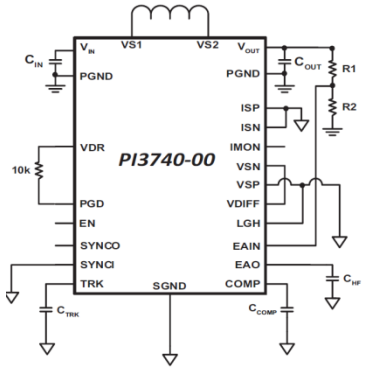


Wide Output Cool-Power ZVS Buck-Boost – PI3740

- Up to 96% efficiency
- 50–140W continuous output power
- Parallel capable with single wire current sharing
- External frequency synchronization / interleaving
- High Side Current Sense Amplifier
- General Purpose Amplifier
- Lighting / Constant Current Mode (LGH)
- Input Over / Undervoltage Lockout (OVLO / UVLO)
- Output Overvoltage Protection (OVP)
- Overtemperature Protection (OTP)
- Fast and slow current limits
- -40°C to 115°C operating range (T_J)
- Excellent light load efficiency







Minimal external components required.

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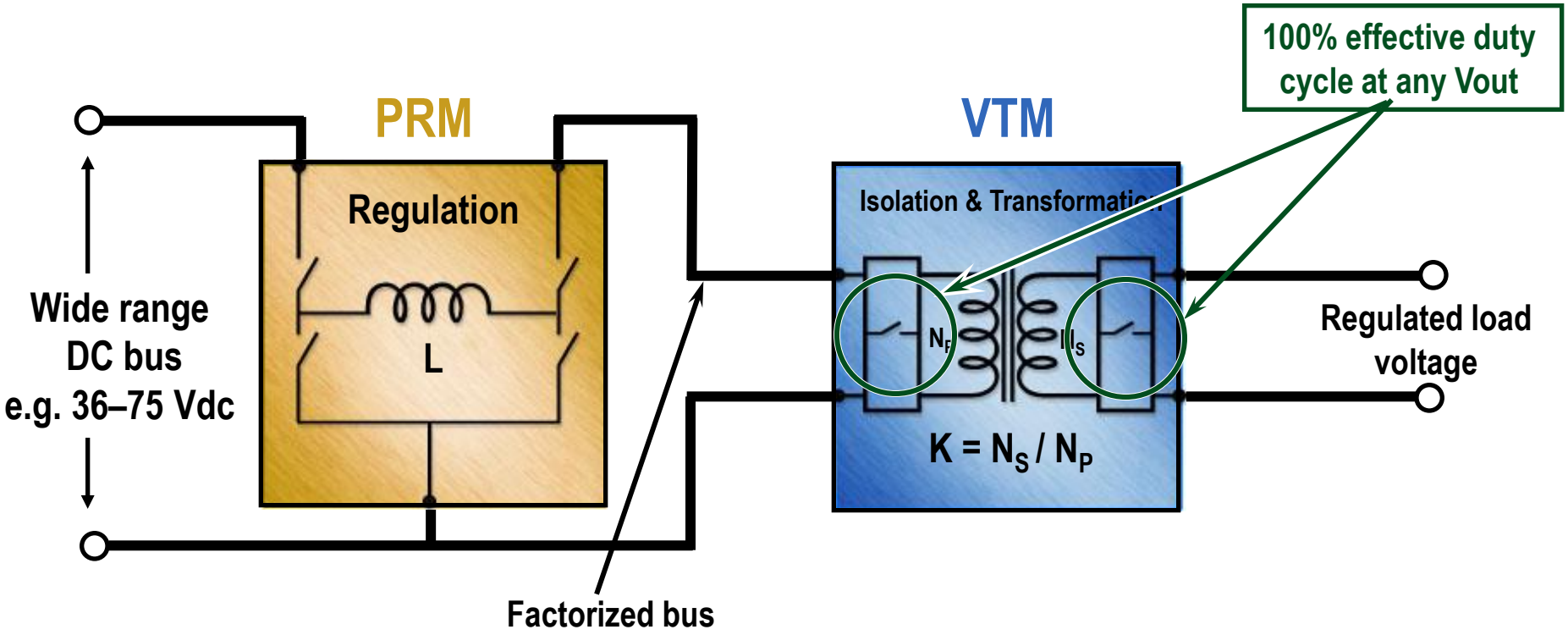
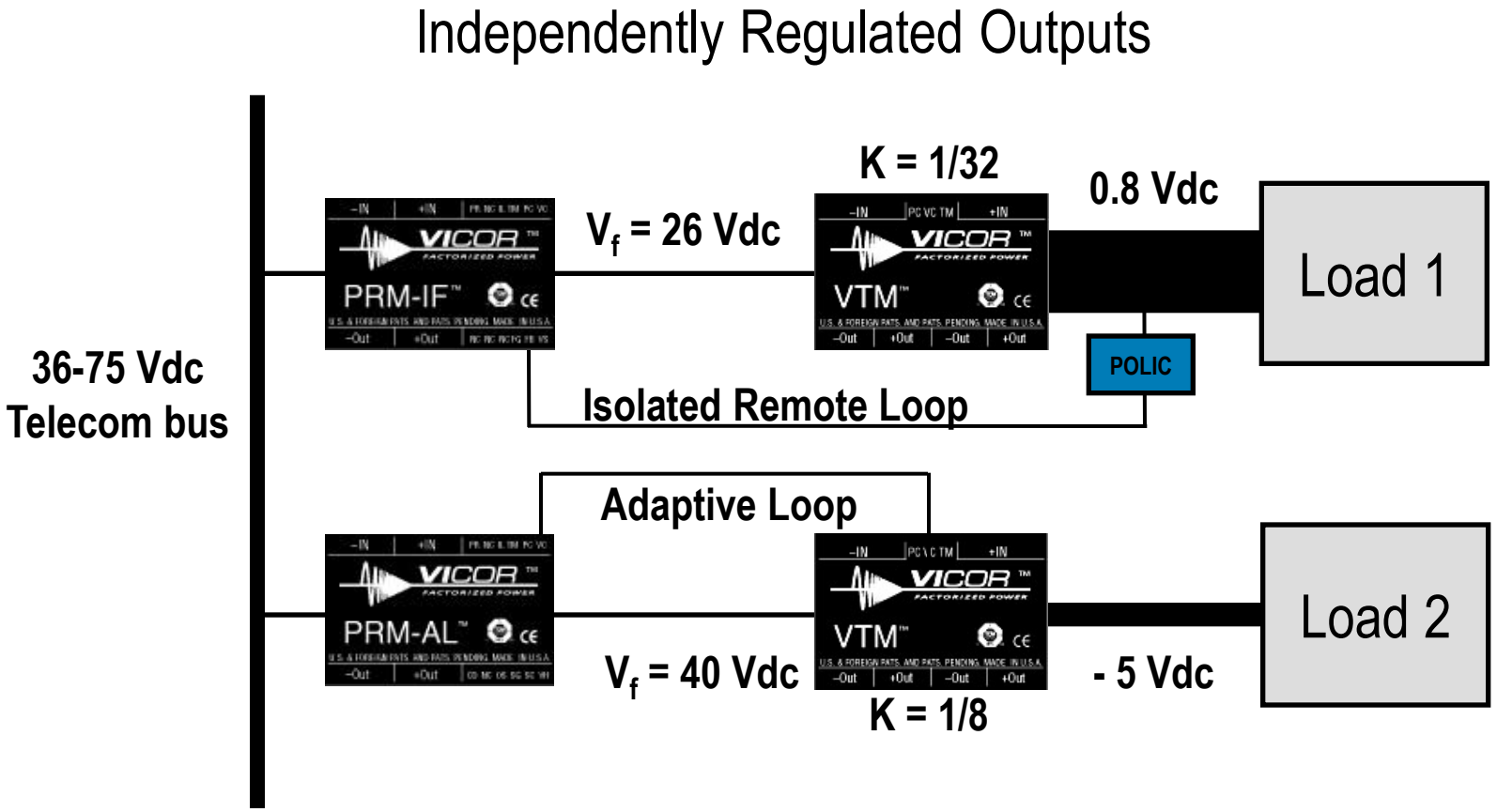
FPA Architecture

What is FPA?

Factorized Power Architecture 分比架构



How the FPA work?



Patents and Patents Pending

PRM and VTM introduction

› **PRM:** pre-regulator module

Non-isolated, regulated

ZVS buck boost topology

Up to 1MHz switching

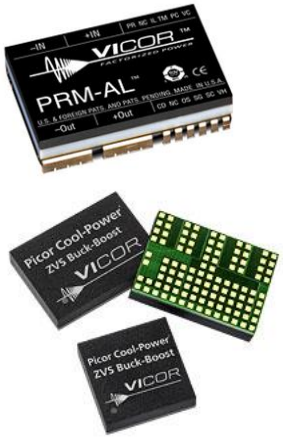
98% peak efficiency

Wide input range 36-75V

Wide output range 5~55V

Package:10X10,10X14 SiP

32X22, 16X22 Vichip



› **VTM:** Voltage transformation module

Fix turn ratio

SAC topology

Up to 2MHz switching

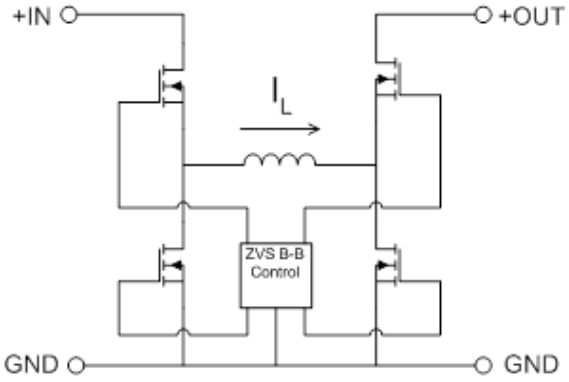
98% peak efficiency

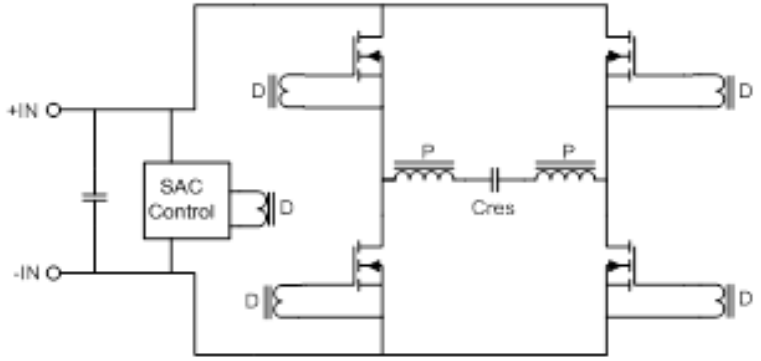
Output range 0~55V

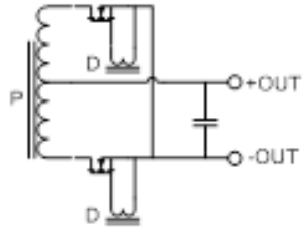
>100A

Package : 23X8, 23X16 ChiP

32X22, 16X22 Vichip



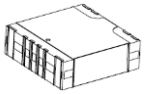




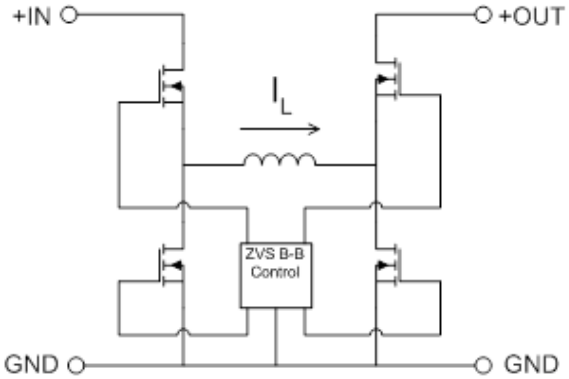
P=Power Transformer
D=Drive Transformer

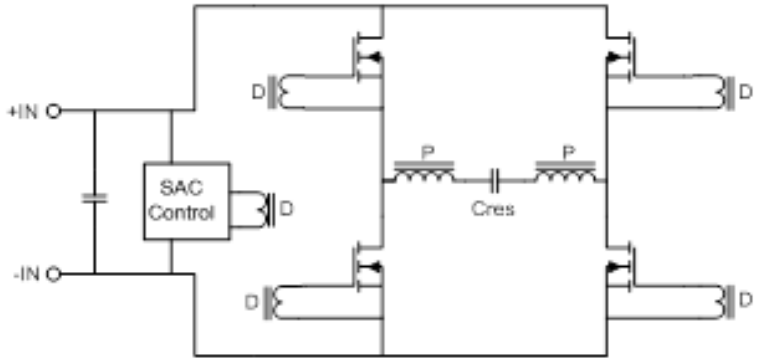
HV PRM & HV BCM introduction

- **PRM: pre-regulator module**
  - Non-isolated, regulated
  - ZVS buck boost topology
  - Up to 2MHz switching
  - 98~99% peak efficiency
  - Wide input range 160-410V
  - Wide output range 200~410V
  - Package: SM ChiP & ChiP

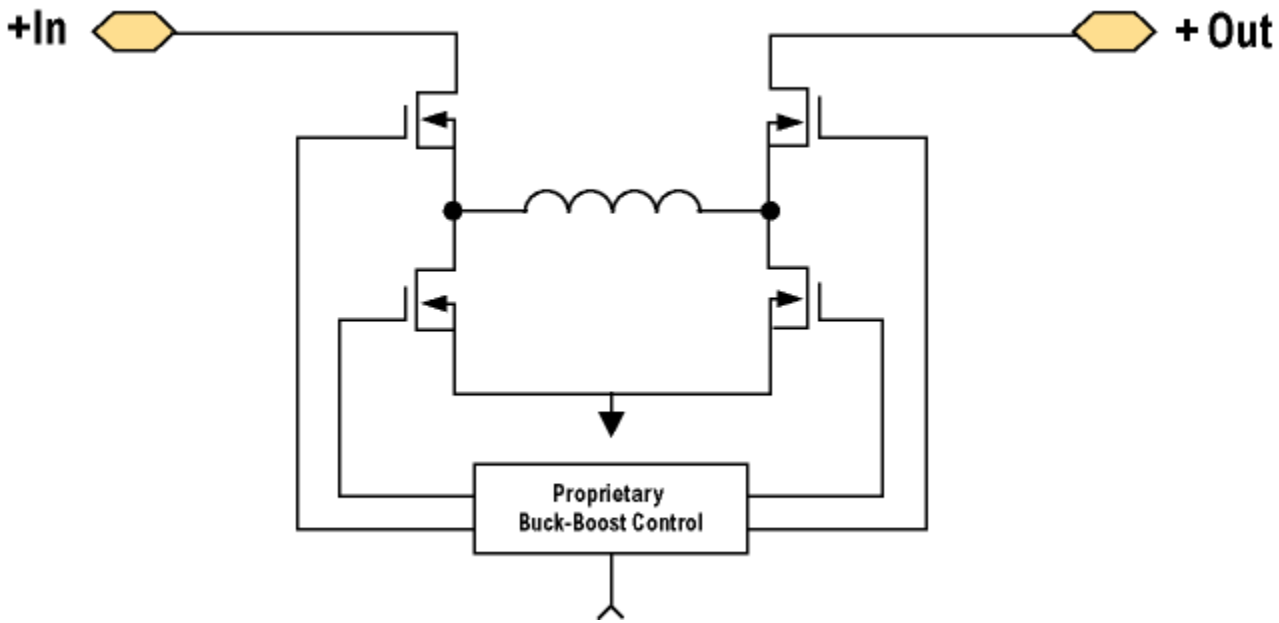


- **BCM: Voltage transformation module**
  - Fix turn ratio
  - SAC topology
  - Up to 2MHz switching
  - 98% peak efficiency
  - Output range 0~55V 1800W
  - Package : SM ChiP & ChiP





PRM – ZVS Buck/Boost Engine

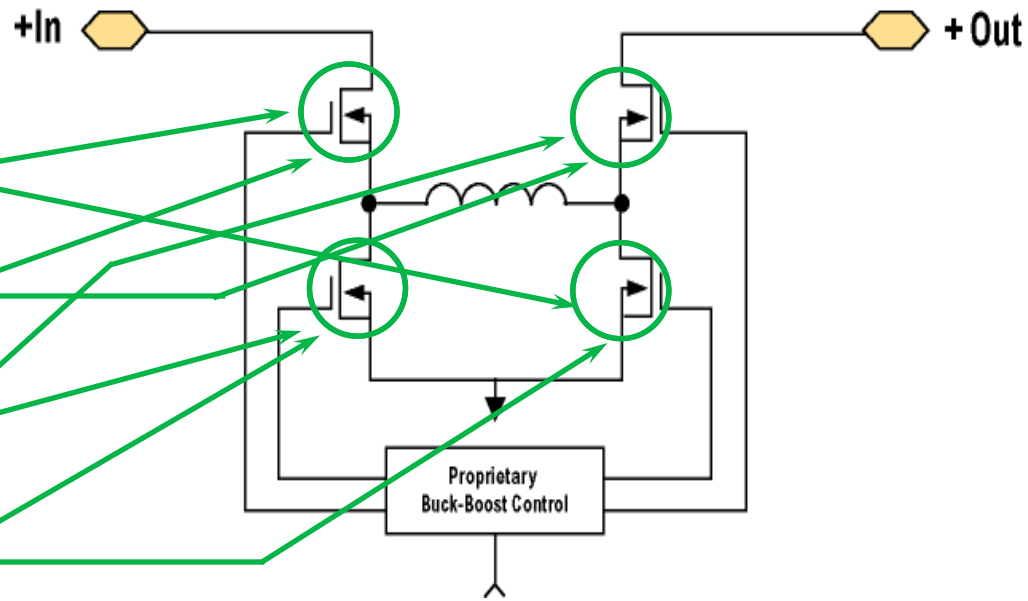


- ZVS buck-boost topology and control architecture
- High frequency operation

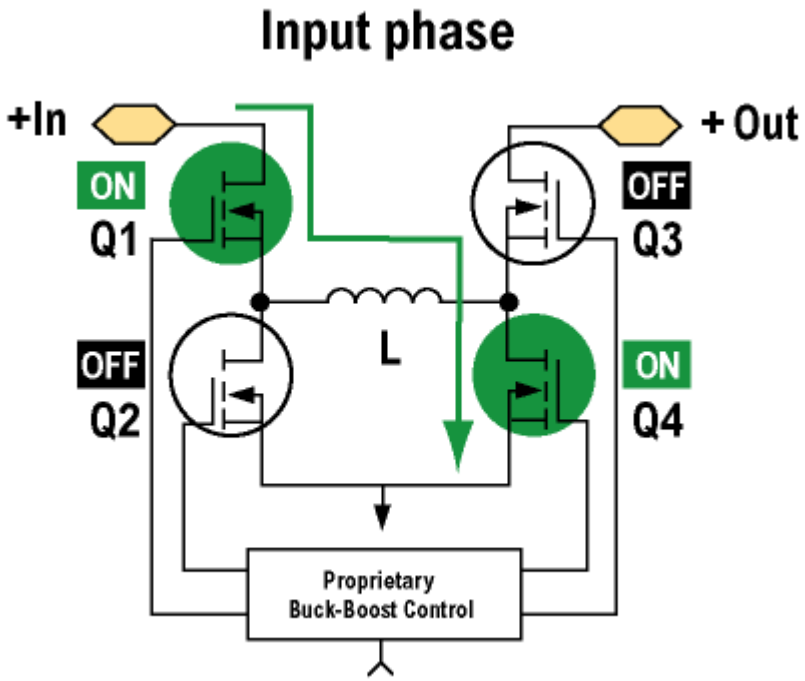
PRM Conduction Phases

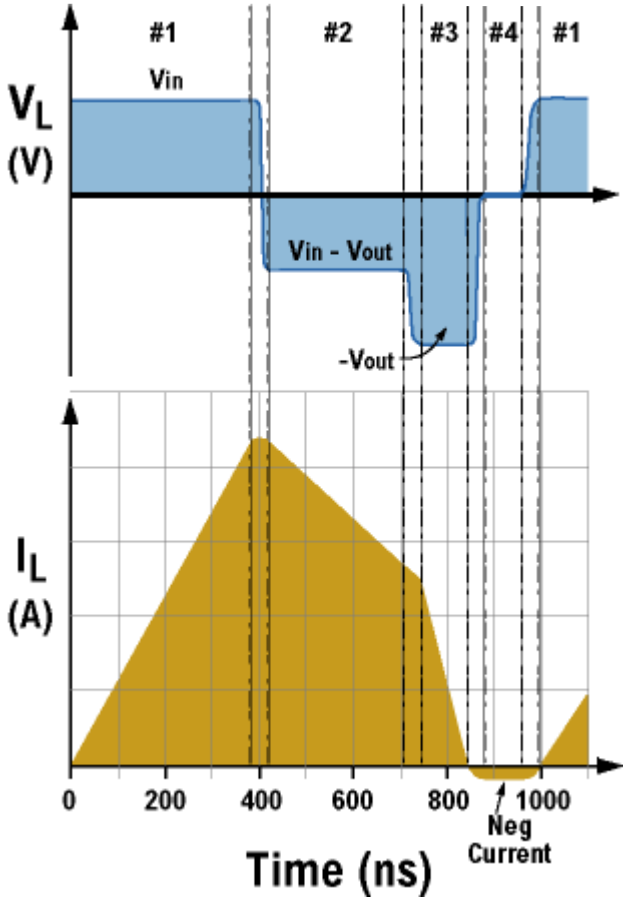
› **Power cycle comprises four conduction phases**

1. Input phase
2. Input-output phase
3. Free-wheeling phase
4. Clamp phase

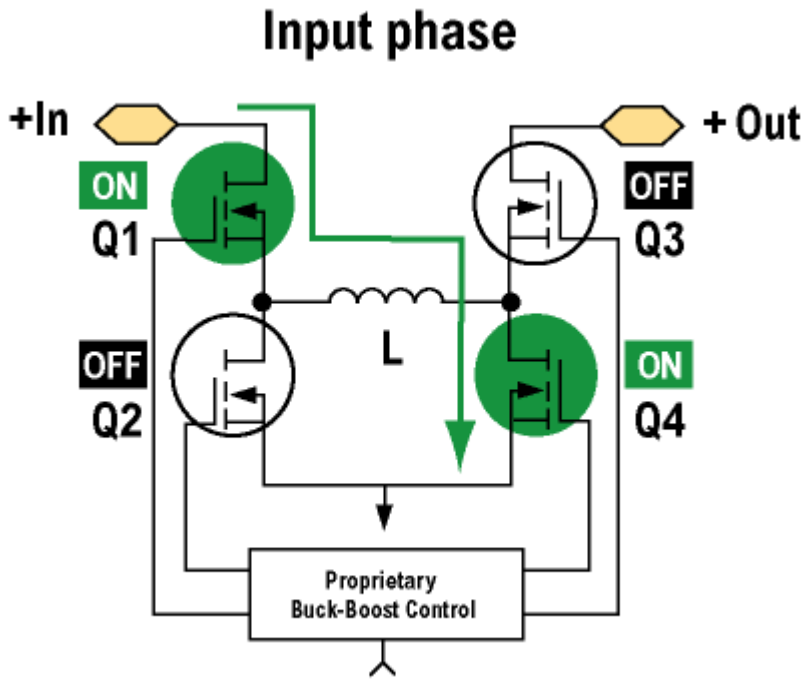


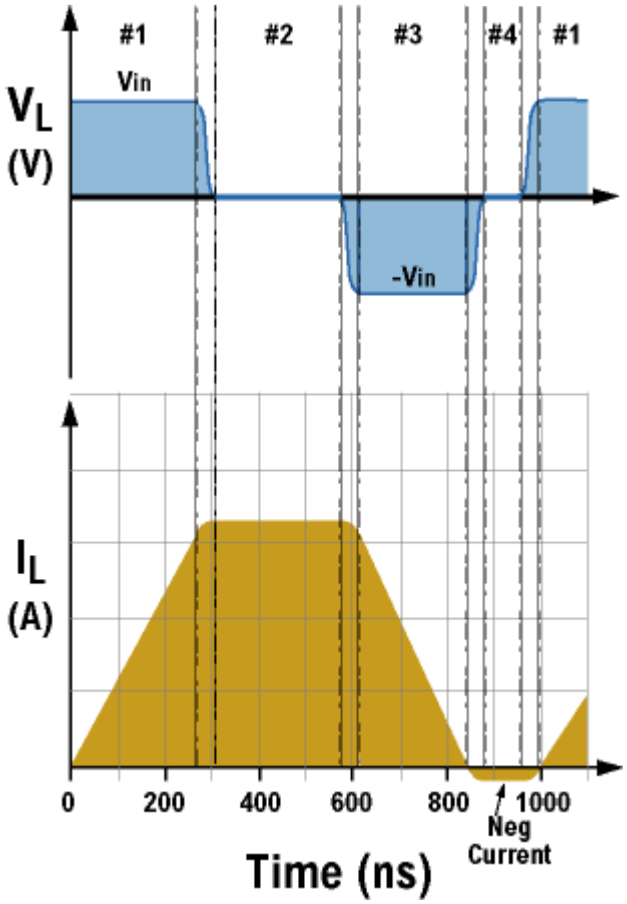
Vin<Vout


Input phase
+In
+ Out
ON
Q1
OFF
Q3
OFF
Q2
L
ON
Q4
Proprietary
Buck-Boost Control

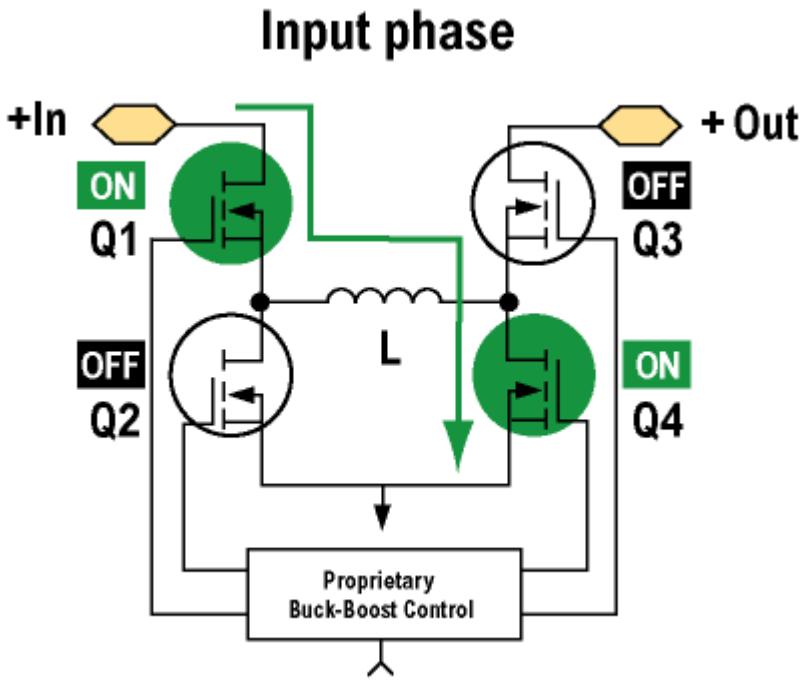

#1
#2
#3
#4
#1
Vin
VL
(V)
Vin - Vout
-Vout
IL
(A)
0
200
400
600
800
1000
Neg
Current
Time (ns)

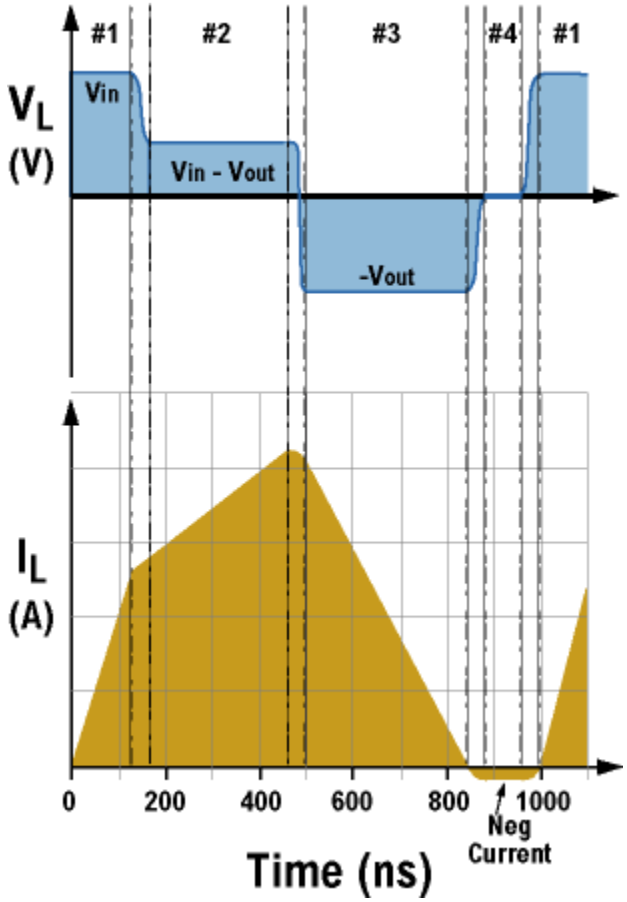
Vin ≅ Vout


Input phase
+In
+ Out
ON
Q1
OFF
Q3
OFF
Q2
L
ON
Q4
Proprietary
Buck-Boost Control


#1
#2
#3
#4
#1
Vin
VL
(V)
-Vin
IL
(A)
0
200
400
600
800
1000
Neg
Current
Time (ns)

Vin > Vout

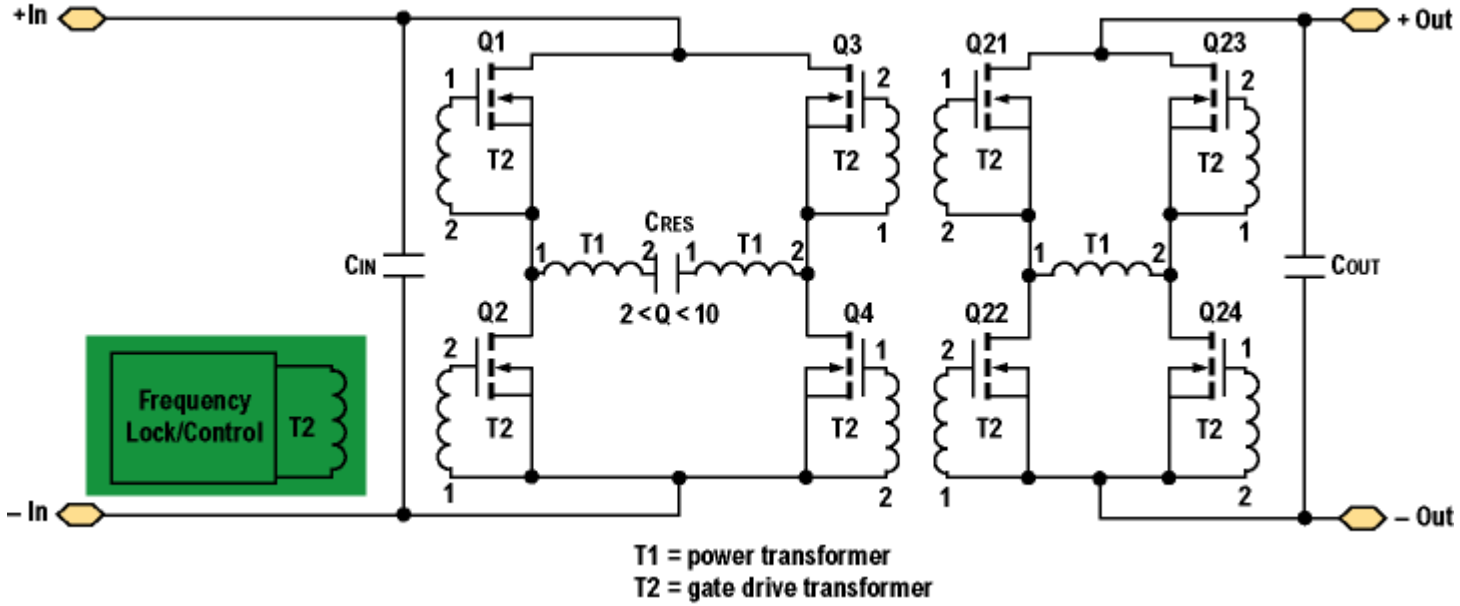

Input phase
+In
+ Out
ON
Q1
OFF
Q3
OFF
Q2
L
ON
Q4
Proprietary
Buck-Boost Control


#1
#2
#3
#4
#1
V_L
(V)
Vin
Vin - Vout
-Vout
I_L
(A)
0
200
400
600
800
1000
Neg
Current
Time (ns)

What is SAC

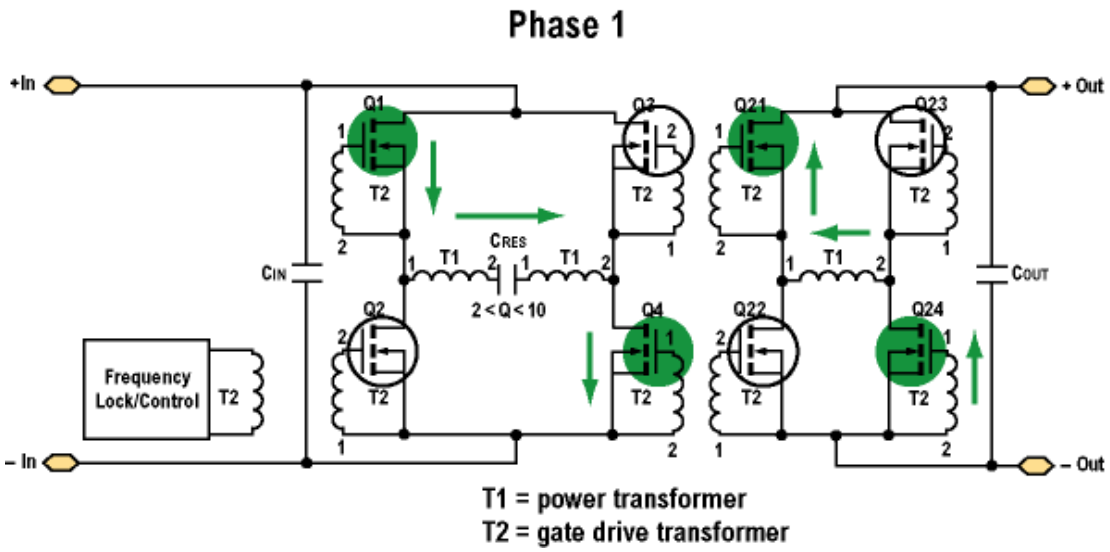
- Sine Amplitude Converter (SAC)
- Achieve ZVS and ZCS.
- Input voltage: 0-800 V (up to 2:1 input range)
- Output voltage: 0-55 V
- Transformation ratio (K): 1:1-48:1
- Output current or power: up to 160 A or 2.4KW
- Conversion efficiency: up to 98%
- Conversion frequency: up to 4 MHz, fixed
- VTM, LVBCM, HVBCM,UHVBCM,NBM and IBC are all use SAC.

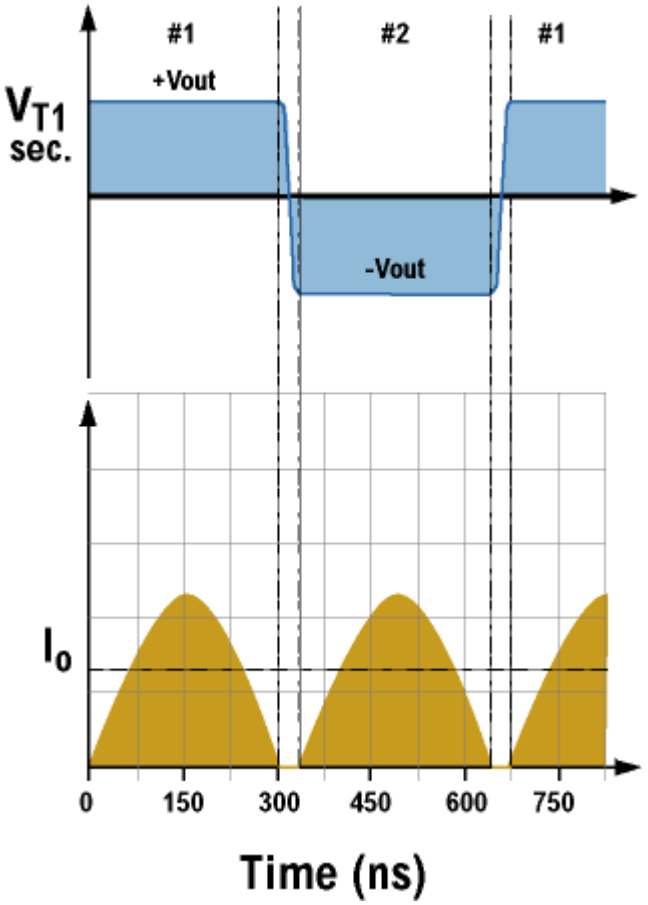
VTM / BCM SAC Control



- The controller locks to the natural frequency of the Low Q oscillator and turns all switches ON and OFF under ZCS/ZVS conditions
- Conduction states result in a 100% effective duty cycle
- Control circuitry recycles the gate drive energy from each pair of switches
- Control Servo locks to Sine Amplitude Converter resonant frequency and phase, compensating for power train parametric variabilities
- Soft start, inrush control and Adaptive Loop Compensation of Rout

VTM Operation Phases



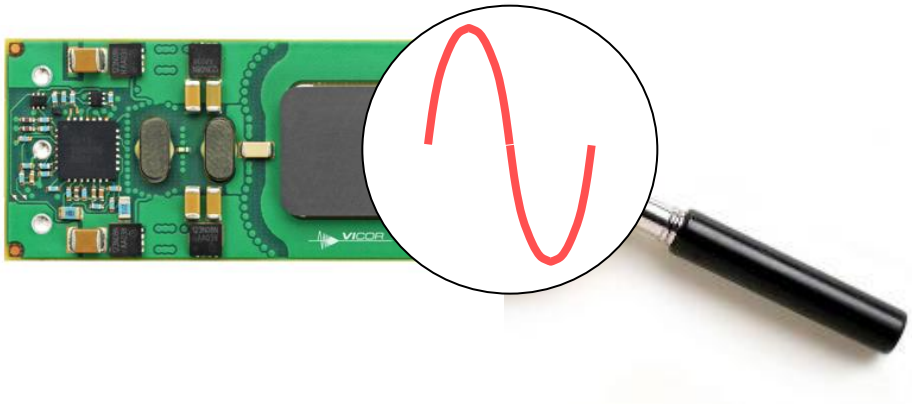


Always Sinusoidal Current

Zero Voltage, Zero Current Switching:
All transitions, every cycle

Optimal Filtering:
No harmonics below switching frequency, and very few above

Enables Components with Higher Figure of Merit:
Reduced de-rating guidelines



Reduced EMI:
Very narrow spectrum

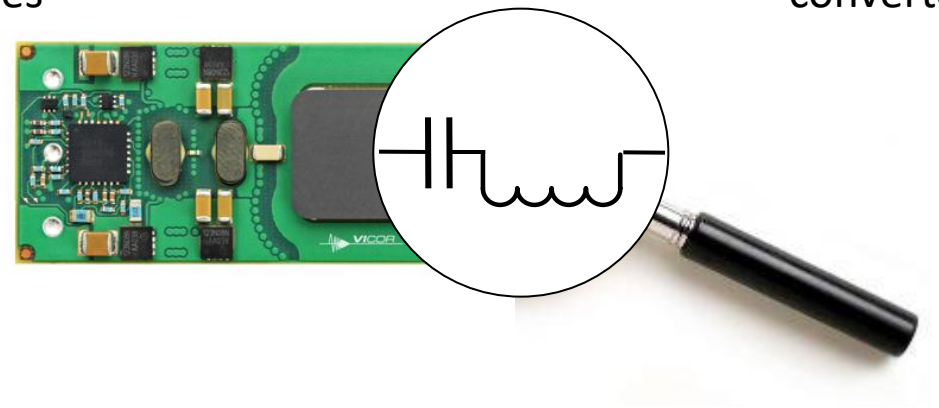
No Switching Losses:
Switching frequency not limited by power switches ‘losses

Low Peak to Average Current and Voltage Ratios:
Most efficient use of silicon switches

Converter Switching AT Resonant Frequency

Fast Transient Response:
Resonant tank will naturally let current flow and output voltage settle within few switching cycles

Bidirectional:
Power can be processed from input to output or vice versa across the entire converter bandwidth



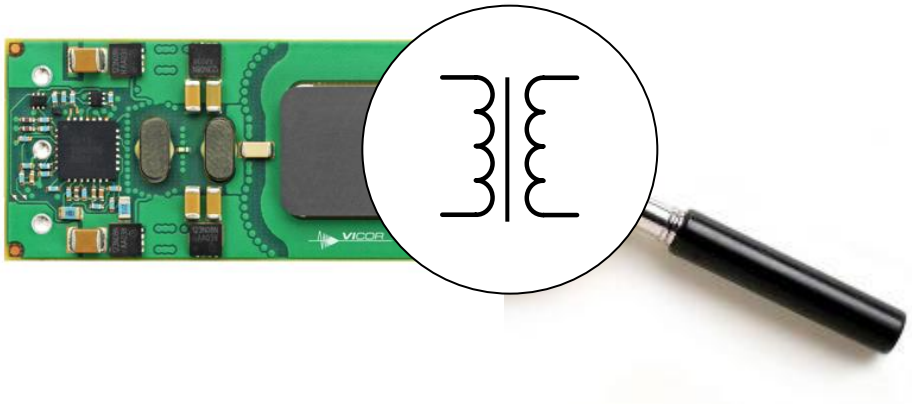
Low-resistive Output Characteristic:
Typical output voltage droop is only few percentage points of the no load output voltage

Negligible Energy Storage:
No need to store energy in magnetic components or bulk capacitance

Transformer Based

Broadband AC Characteristic:
Flat gain up to 2/3 of the switching frequency

Open Loop, not PWM Based:
Not affected by narrow pulse and regulation issues

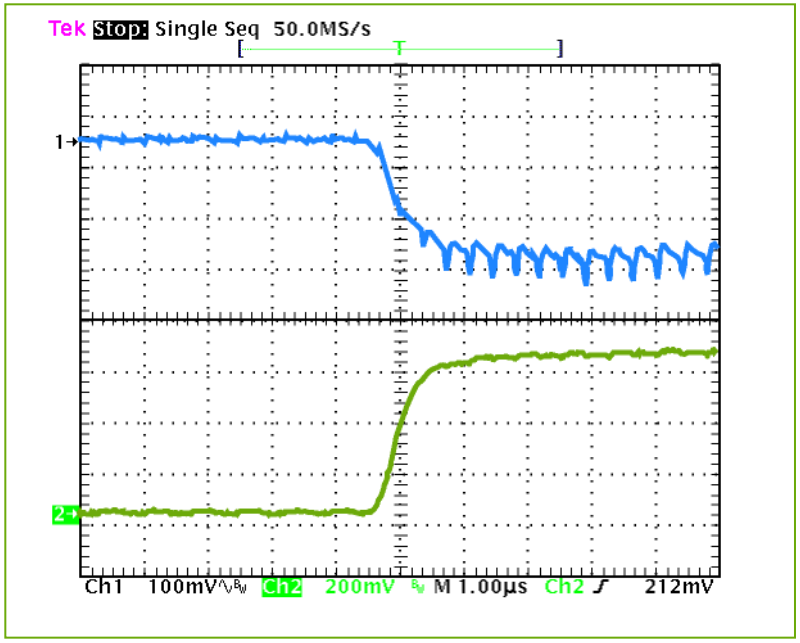


Capacitance Multiplication:
Primary capacitance is effectively applied to the load on the secondary multiplied by the square of the transformer ratio (K^2)

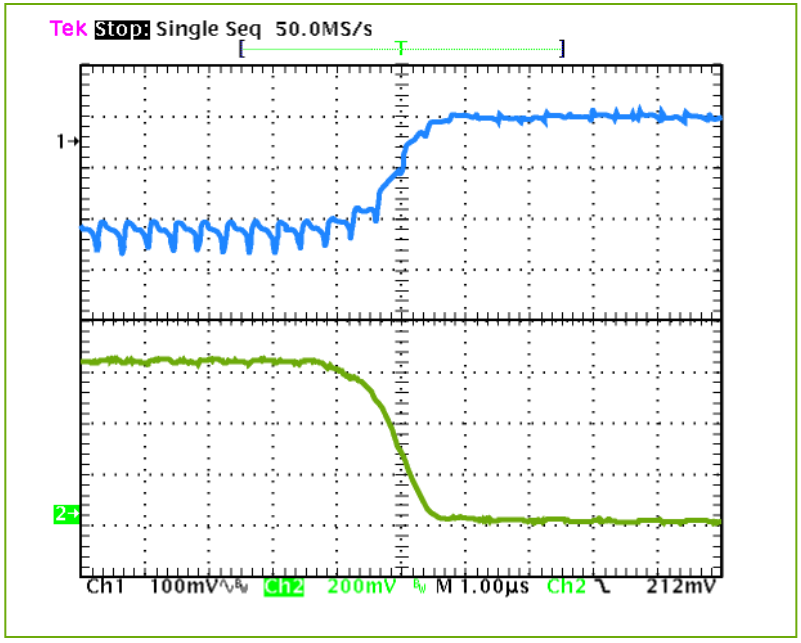
Extreme High Frequency Output Voltage Ripple:
Center tap output

Dynamic Response

K = 1/32 VTM @ Vout = 1 V



0 – 100 A load step with 100 µF input capacitance and NO output capacitance



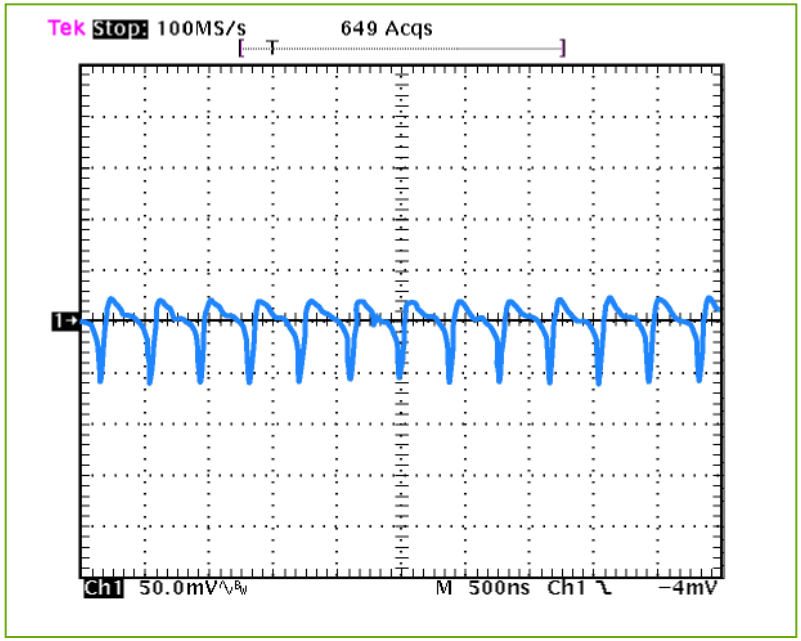
100 – 0 A load step with 100 µF input capacitance and NO output capacitance

SAC: Lowest Noise

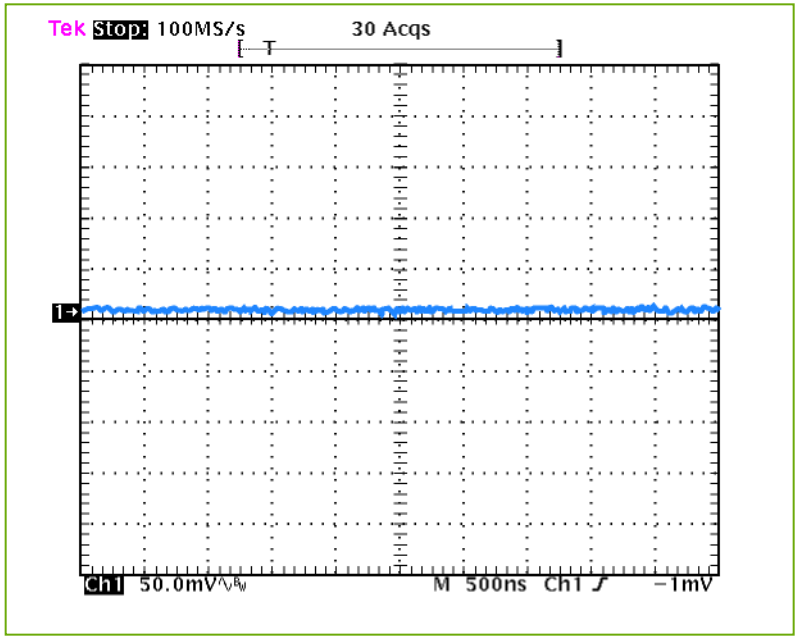
- **ZCS/ZVS**
  - Order of magnitude reduction in *dI/dt*
  - Significant reduction in *dV/dt*
- **Symmetric power train**
  - Cancellation of common-mode noise
- **High fixed switching frequency (up to 4 MHz)**
  - Easy to filter

Output Noise

K = 1/32 VTM @ 1.0 V & 100 A



Output voltage ripple @ 100 A
with NO bypass capacitance



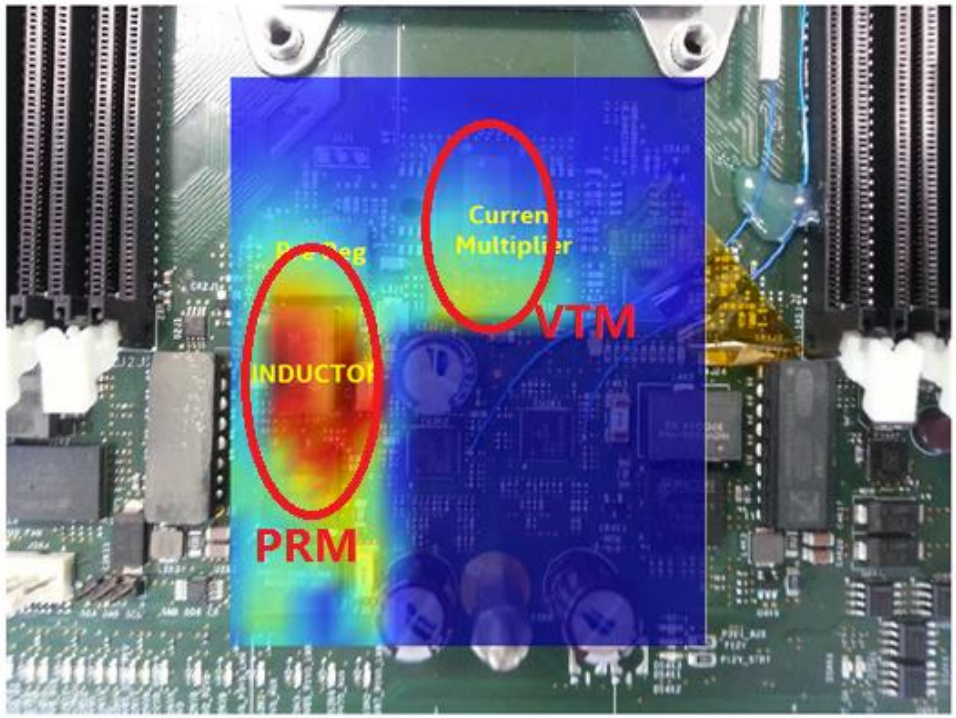
Output voltage ripple @ 100 A
with 200 µF ceramic bypass capacitance and
20 nH distribution inductance

Output noise comparison with multi-phase hard switching

› **Very good for signal integrity, easy for layout, small area for keep out.**

Total Noise

48V Mayan



12V Mayan

Twostage benefits

- **Very fast transient response**

  SAC high frequency, no energy storage.

- **Very high efficiency and density**

  ZVS,ZCS makes the loss very small.

- **Very flexible**

  The BCM output can be parallel or series stack.

- **Very good for deep system integration**

  Vicor is only the part of powertrain in the system.

VICOR

Modular Solutions for Your Power System

COMPONENTS • POWER • EASE-OF-USE • PERFORMAN
INNOVATION • EFFICIENCY • EXPERTISE • CONFIGURA
ME • VOLUME • RELIABILITY • FLEXIBILITY • LONGEVI
MWORK • PROVEN • DENSITY • QUALIFIED • COMPE
SOLUTIONS • INTEGRATION • SUPPORT • OPPORTUNI

Thank You