Density, Efficiency & Innovation in Airborne/Defense Power Supplies

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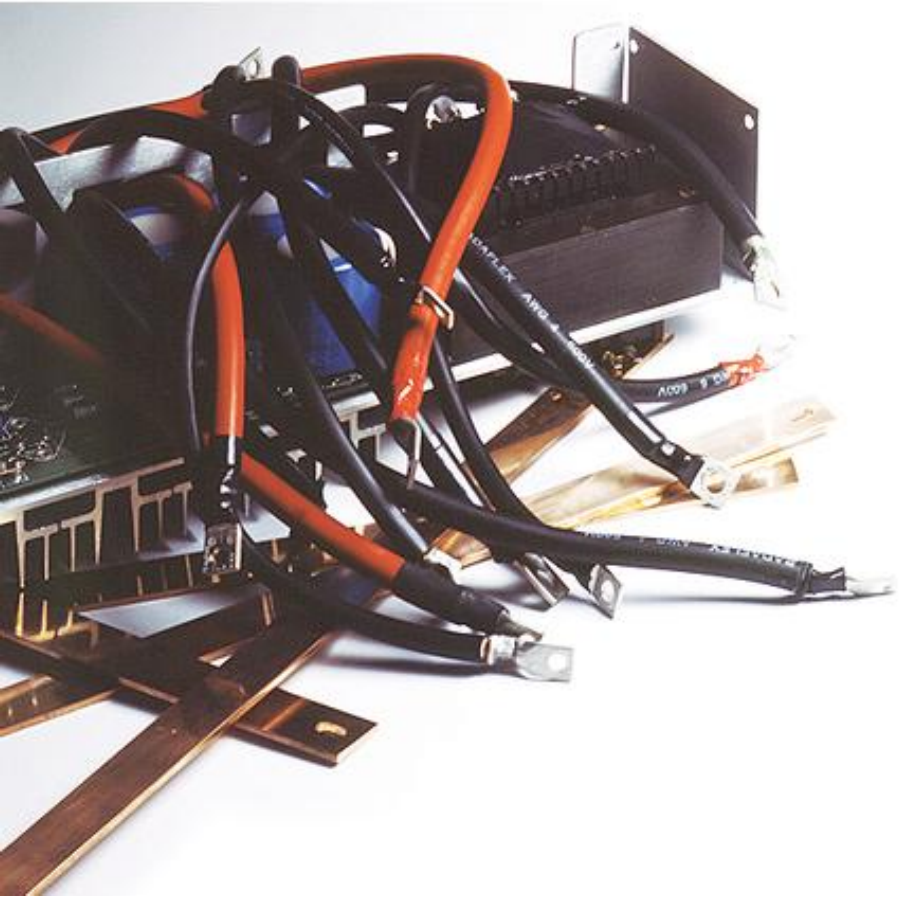


Power conversion needed to:

- Be closer to the point of load
- Meet an increasing number of load requirements (voltages, currents, controls)
- Be designed concurrently with the end equipment

Dawn of the Power Component Age

Power Components must be:

› Efficient

› Dense

› Flexible

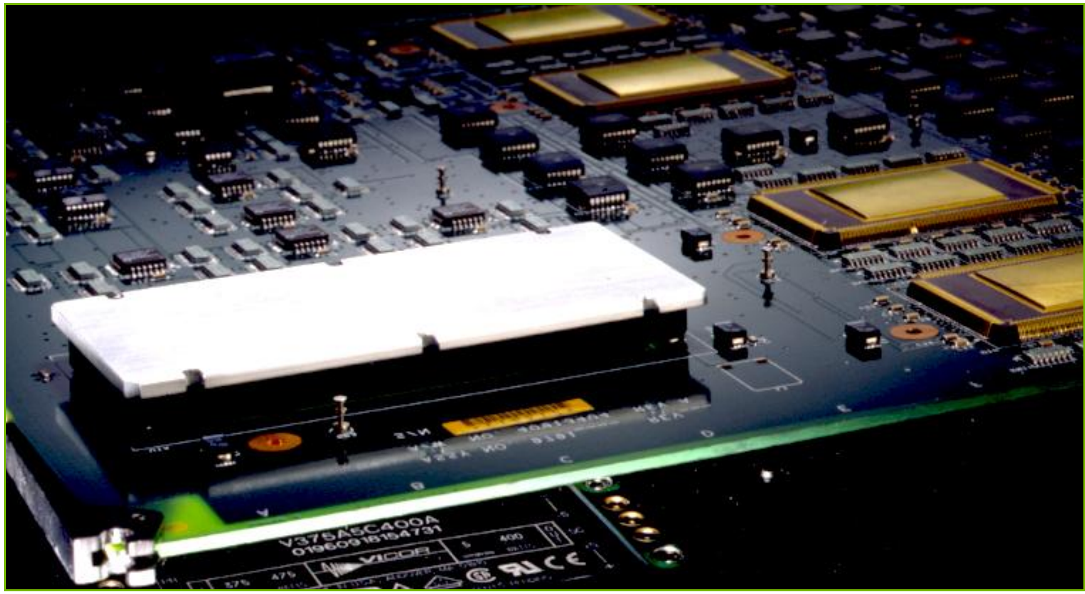
› Scalable

› Cost effective

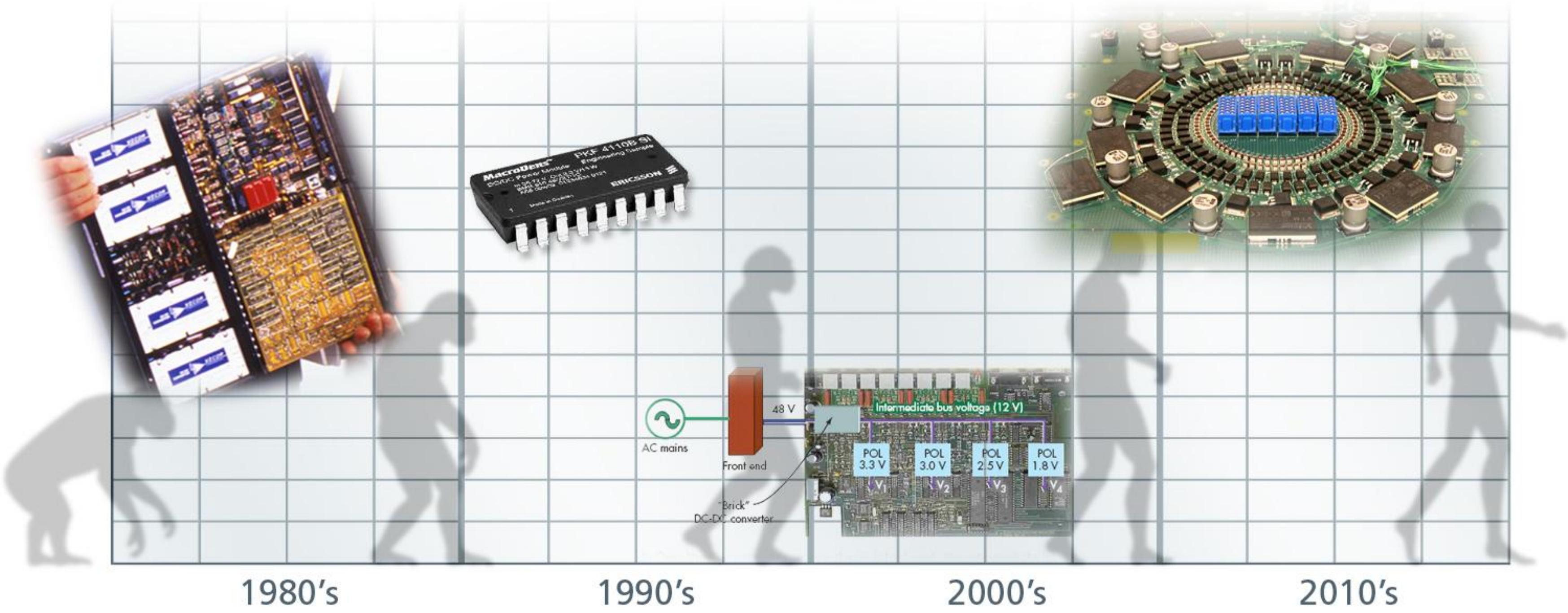
› Reliable

› Low Noise Generating

› High Noise Immunity



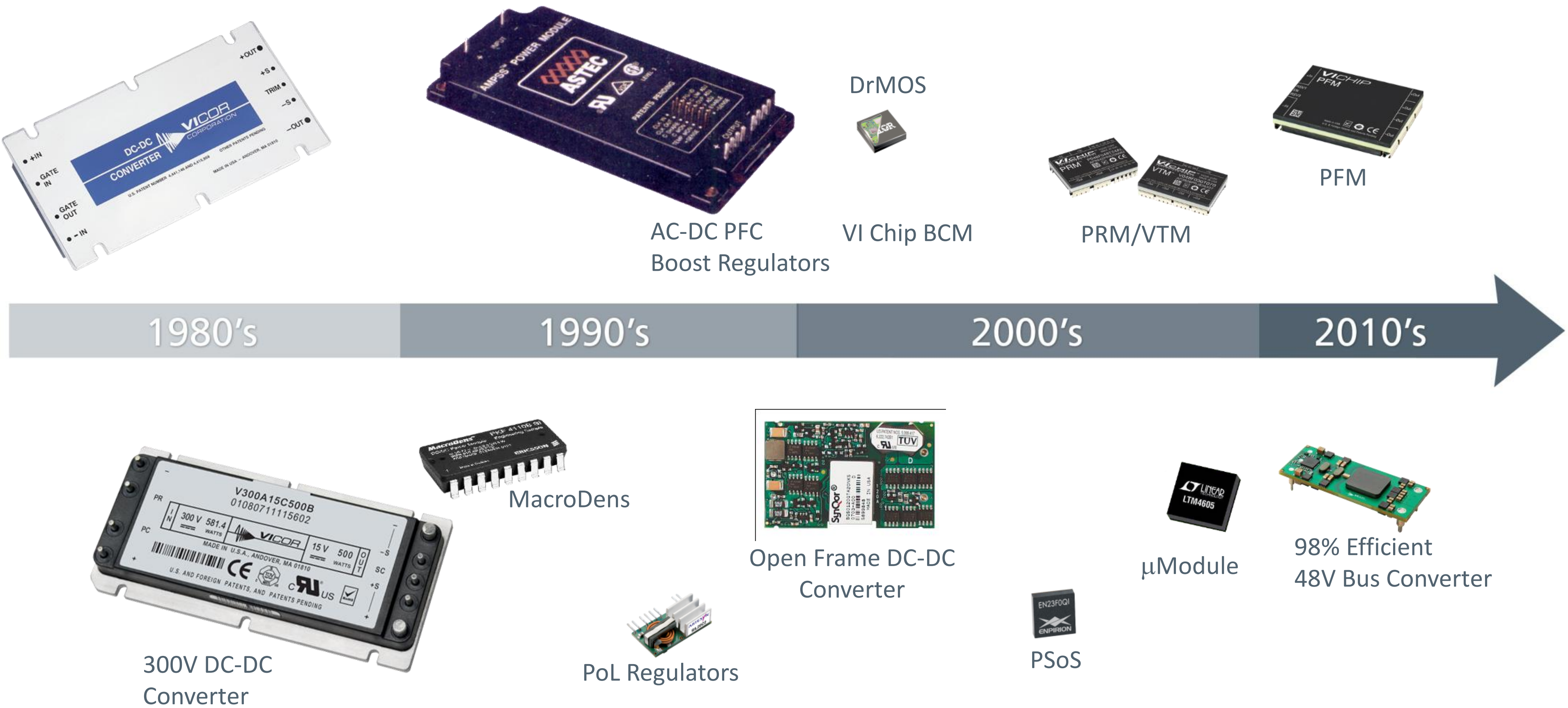
Evolution of Power Components within Power Systems



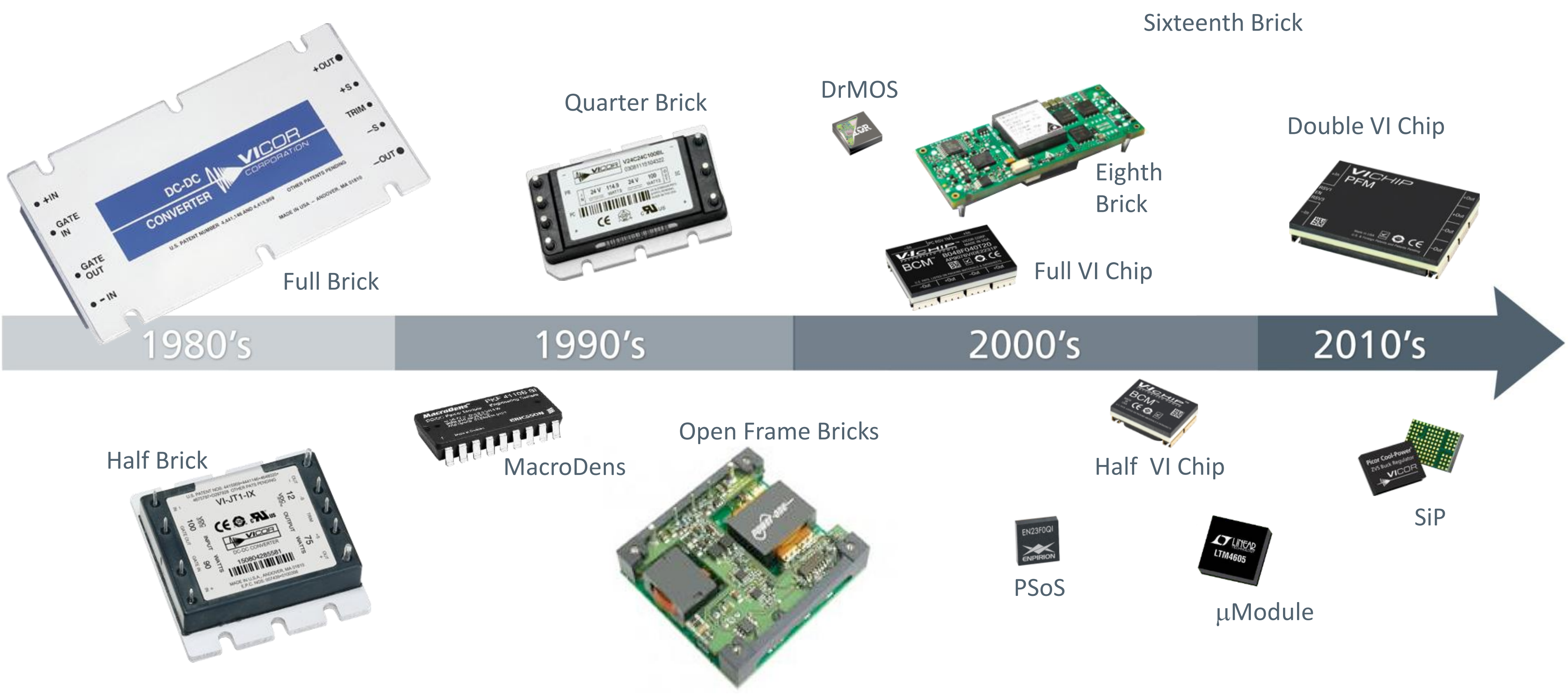
Progress in Power Component Functionality and Figures of Merit (FOM)

- Functionality
- Power density
- Efficiency
- Heat density
- Noise Generation
- Reliability
- Noise Immunity

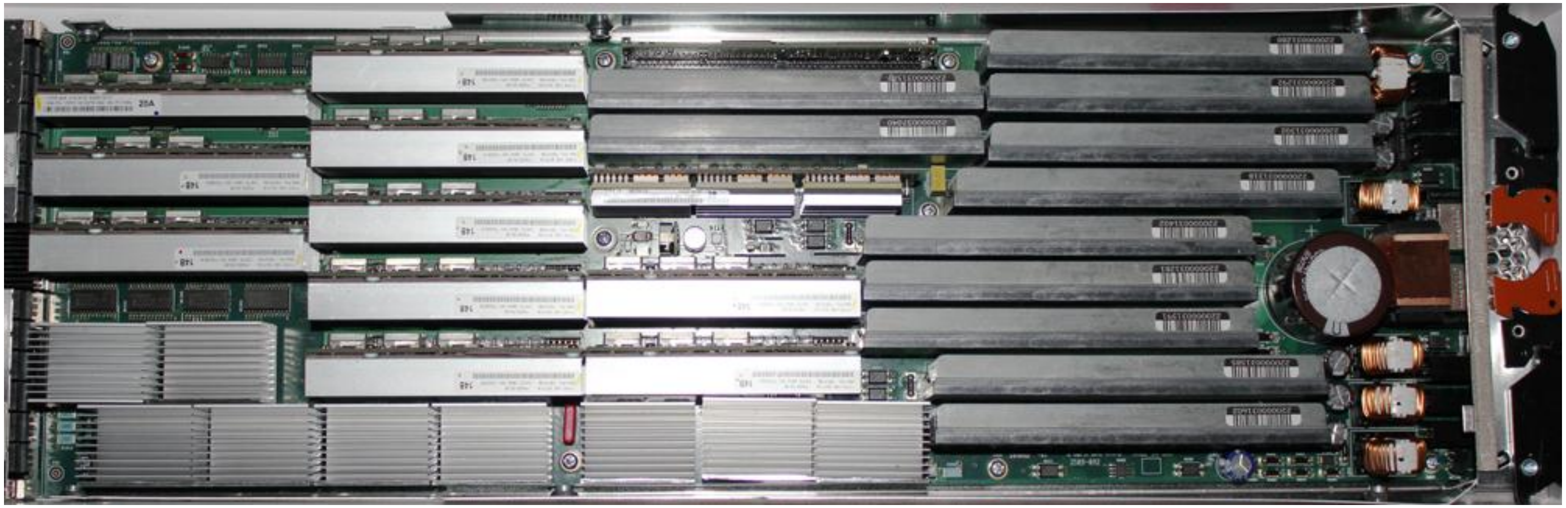
Evolving Power Component Functionality Over Time



Power Component Package Evolution



Power Components have evolved from early Bricks



Where do we go from here?

Power Component Advances are Enabled by Package Technology

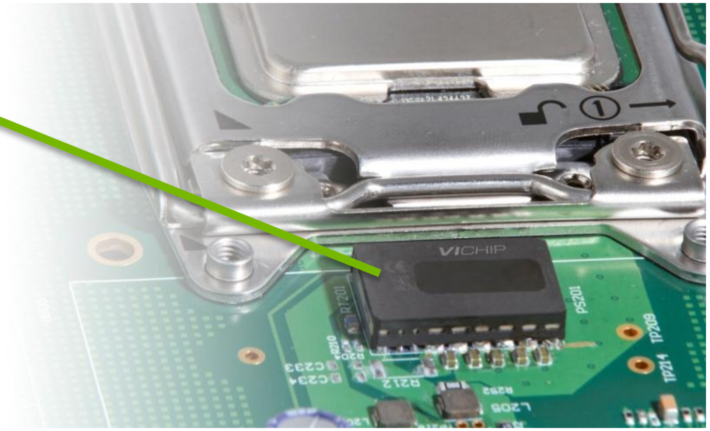
- Integrated magnetics
- Over-molding supports adept thermal management and safety insulation
- Chip-scale power semiconductors and ASICs
- High Density IC substrates
- SMD and Thru Hole package options
- Flexible mechanical mounting
- 3D thermal management

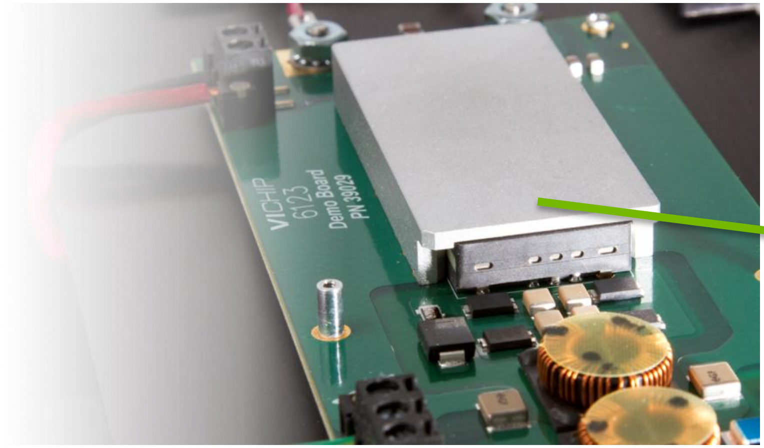
Introducing "ChiP" (Converter housed in Package) Technology

- Integrated magnetics panel over-molded above/below HDIC substrate
- ChiP sawn from panel to expose lateral interconnect terminals

1323 VTM Current Multiplier ChiP
24X , Up to 180 A, 96.5% peak 48V to 2V

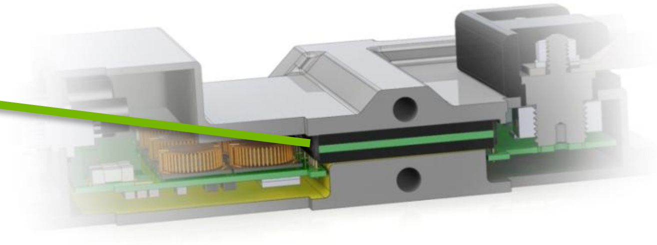
1323 VTM Current Multiplier ChiP
Supplying Processor from 48V Bus
(No PoL Bulk Capacitors)



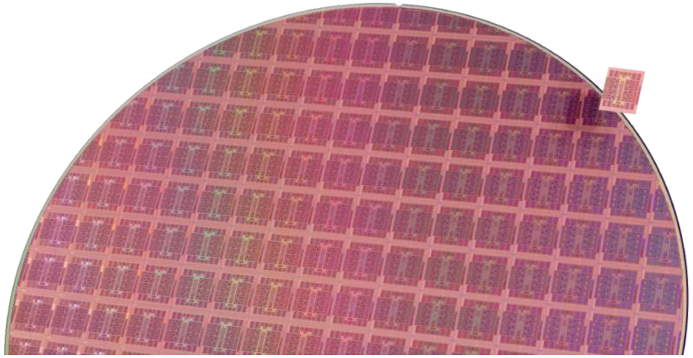


6123 PFM AC-DC ChiP
Up to 400 W at 48V or 24V

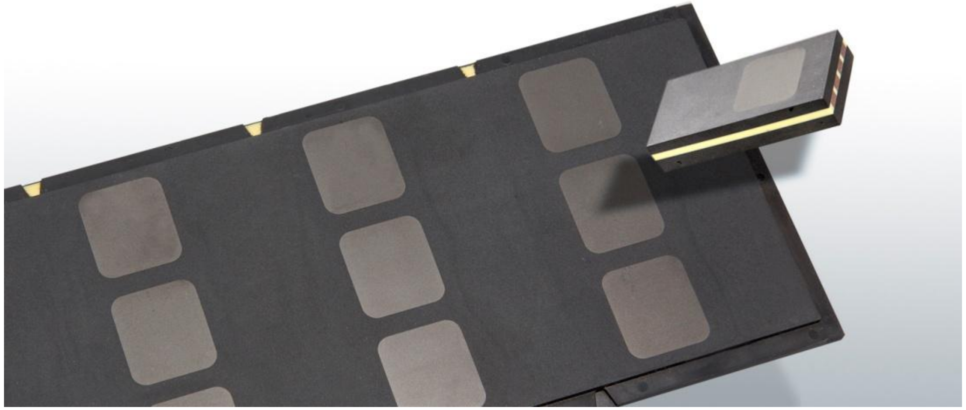
Liquid Cooled Automotive Power Module



4623 DCM DC-DC ChiP
180V to 420V Input
12V Output at up to 600W



Information Processors Are Sawn Out of Scalable Wafers

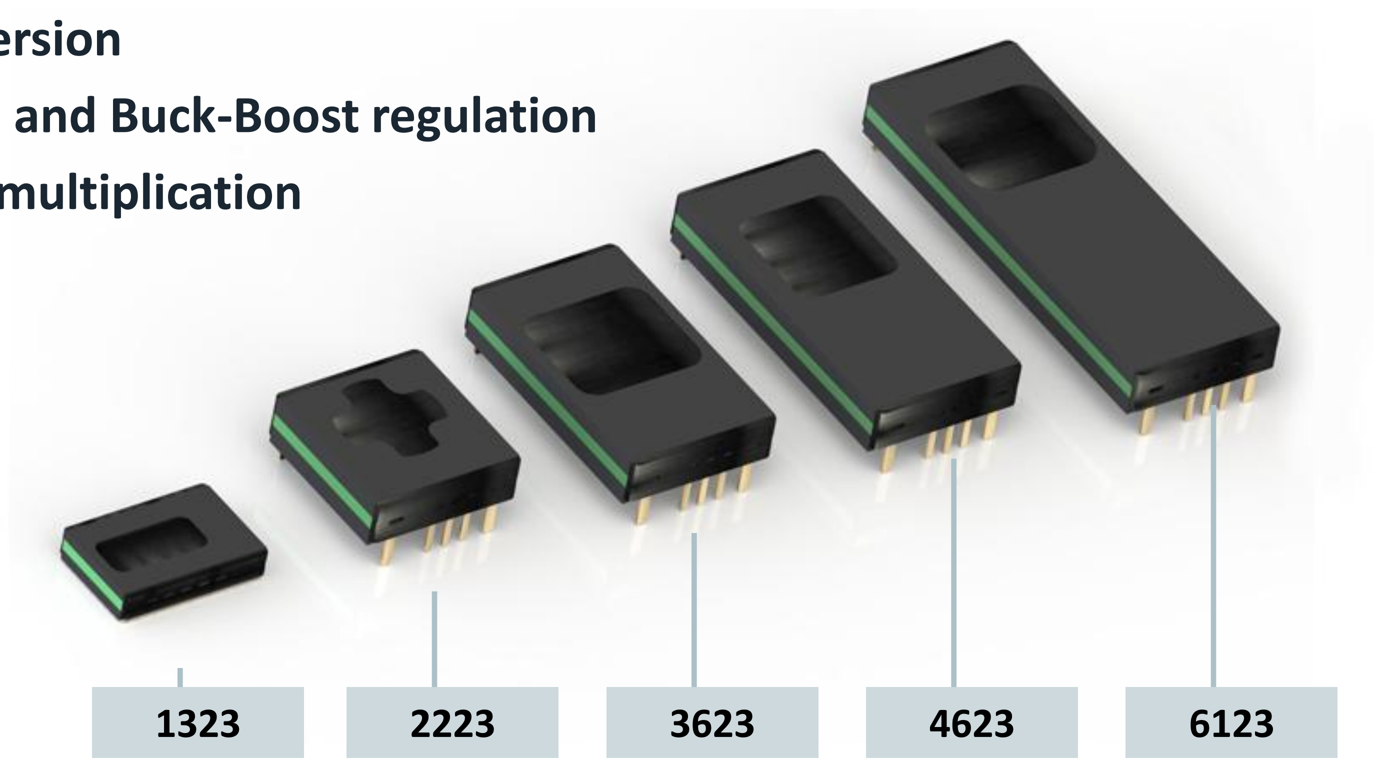


ChiP Power Components Are Sawn Out of Scalable Magnetic Panels

A Growing Lineup of ChiPs standardized packaging similar to semiconductor industry

ChiP Technology is Flexible

- AC-DC with PFC
- Isolated bus conversion
- DC-DC conversion
- Buck, Boost, and Buck-Boost regulation
- PoL current multiplication



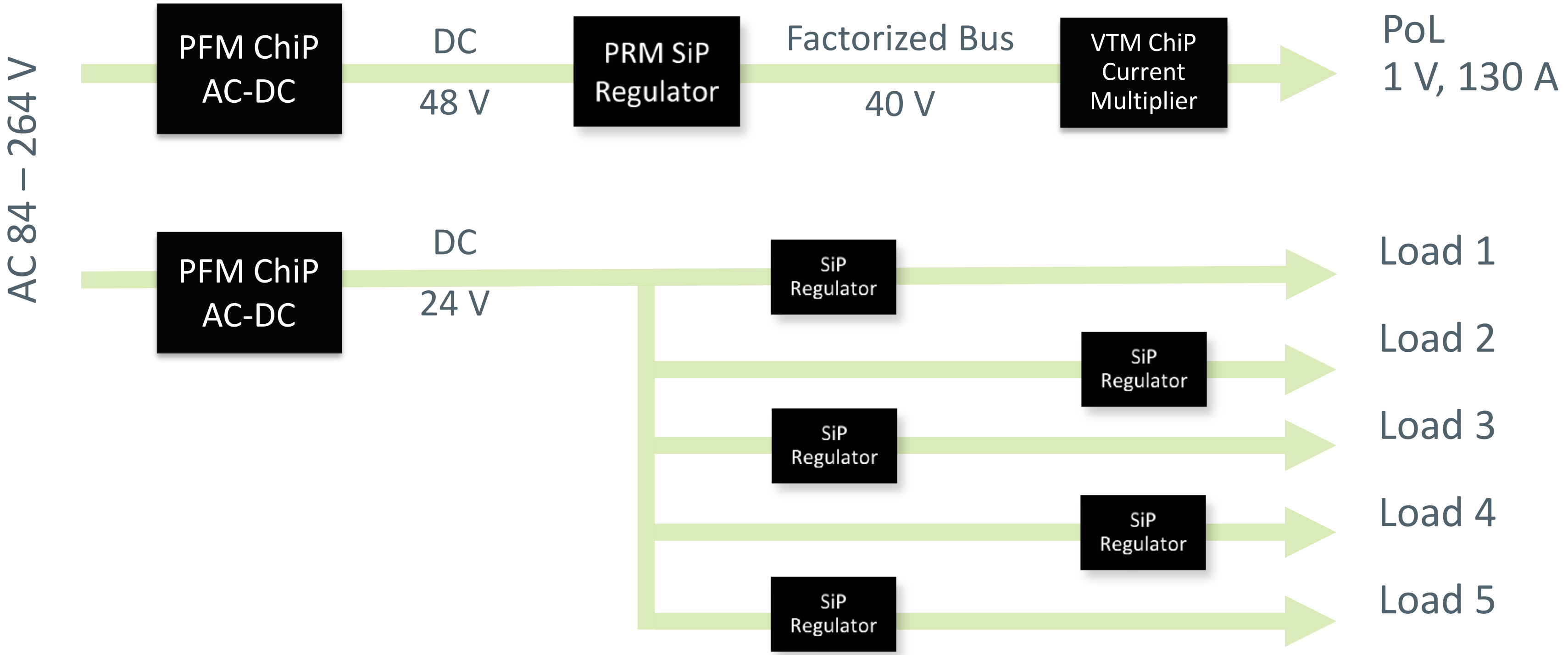
ChiP Technology is Scalable

- From 4.7 mm thin
- 0623 to 6123 and expanding
- Up to 180 A
- Up to 430 V and rising
- Up to 1.5 kW and rising

ChiP Technology Sets Higher Standards

- Up to 3 kW/in^3 power density
- Up to 850 W/in^2 area density
- Up to 98% efficiency

Architecting Power Systems with ChiPs and SiPs



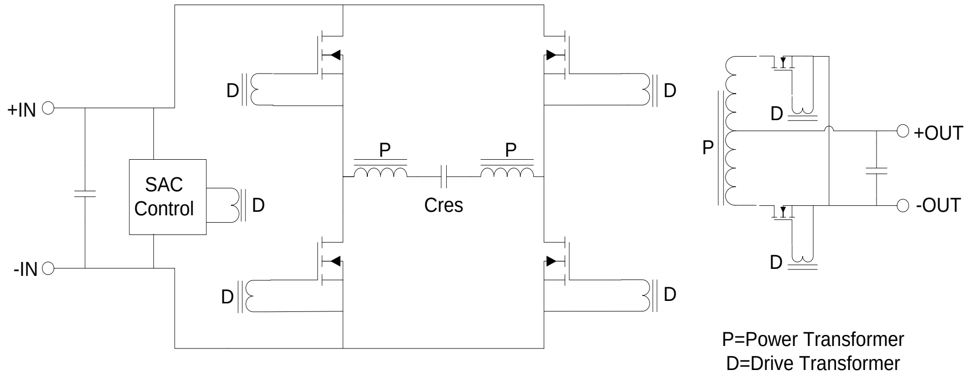
Advanced Topologies and Architectures

VI Chip Technology

- **Advanced Engines**
  - Enable high efficiency and superior power density
  - Switching frequency > 1Mhz
  - Maximize efficiency of power silicon
    - HV Adaptive Cell topologies cut V•I requirements
    - LV Current Multipliers cut Vds requirements
- **Advanced architecture (FPA) minimizes power distribution loss**
  - Dense, efficient energy storage at 48V
  - No Bulk Caps at the PoL
  - Highest current density at the PoL frees up precious real estate
- **Superior modular product line with high barriers to entry in an otherwise competitive and commoditized market**
  - Substantial IP portfolio covers architectures, topologies, internal components, control, etc…
    - From the AC or HV Bus to the PoL (LV, high current)
    - AC – DC and DC – DC
- **“Young” technology continues to raise the efficiency and density bars**
  - Power loss cut by 25% every 2 years
  - Power density increased by 25% every 2 years

VI Chip Engines : Sine Amplitude Converter (SAC)

- Proportional amplitude
- Fixed (resonant) frequency
- Inherently Bi-directional
- ZVS, ZCS (No switching loss)
- ~100% duty cycle down to < 0.5V
- Cycle-by-cycle transient response
  - Negligible intermediary energy storage
- 2X transient current capability
- Thermally (not power) limited
  - Higher efficiency → higher power
- Continuing opportunities
  - Efficiency
  - Density

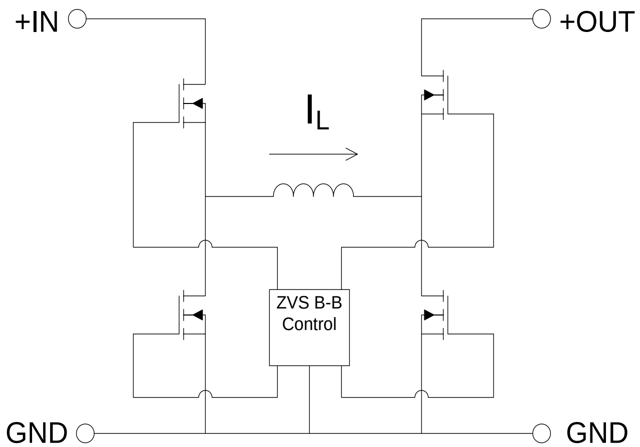


48V /1.5 V VTM Peak Efficiency and Current Density

Patents: 6,930,893; 7,145,786; 6,911,848; 6,934,166; etc.

VI Chip Engines : ZVS Buck-Boost (ZVS BB)

- ZVS Buck-Boost control architecture
- Negligible switching loss at high voltage and high frequency
- Voltage step-up OR step-down
- Universal engine cycle
- Small inductor
- Present 48V regulator efficiency: 97%
- Density: 1.4 kW/in^3
- Future HV (300V) capability



Patents: 6,788,033; 7,154,250; RE40,072; etc.

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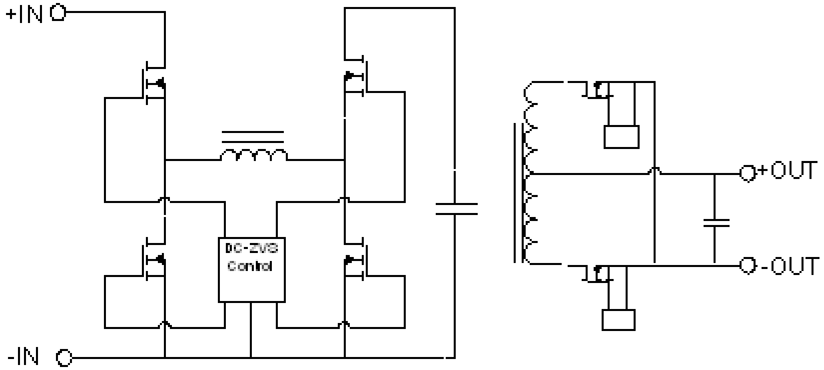
VI Chip Engines : DC-ZVS

- **Proprietary ZVS control architecture**
- **Negligible switching loss at high voltage and high frequency**
- **Wide input/output dynamic range**
- **Universal engine cycle**
- **Small transformer**
- **Initial 48V DC-DC efficiency: 94% at 850 W/in^3**
- **Initial 300V DC-DC efficiency: 94% at 850 W/in^3**

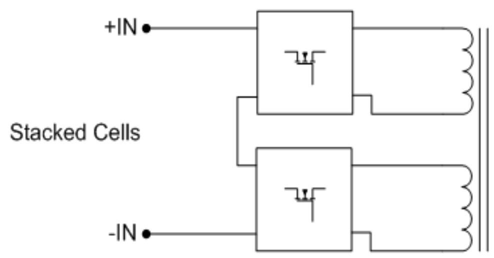


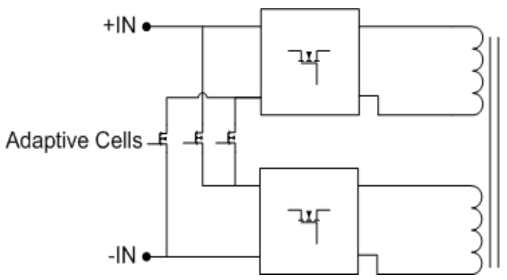
Patents: 7,561,446; etc.

Stacked Cells / Adaptively configured cells

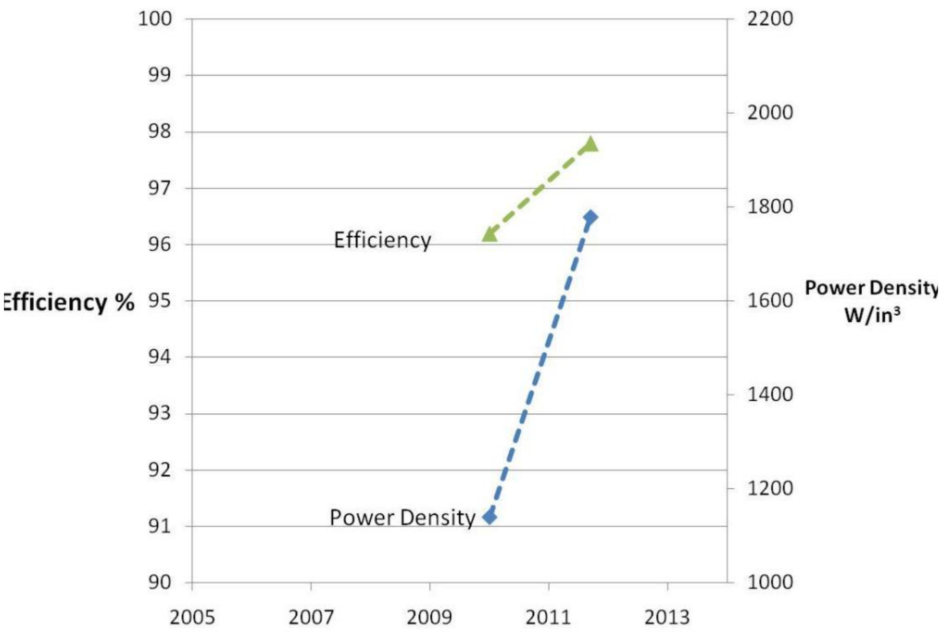
Stacked Cells

- Cut voltage withstand requirements of in/out FETs
- Enable high FOM, high frequency 250V FETs at HV (400V)
- High density Bus Converters
- High density DC-DC Converters
- Common transformer
- Scalable to HV (> 600 Vdc)





384-48V BCM Efficiency and Power Density



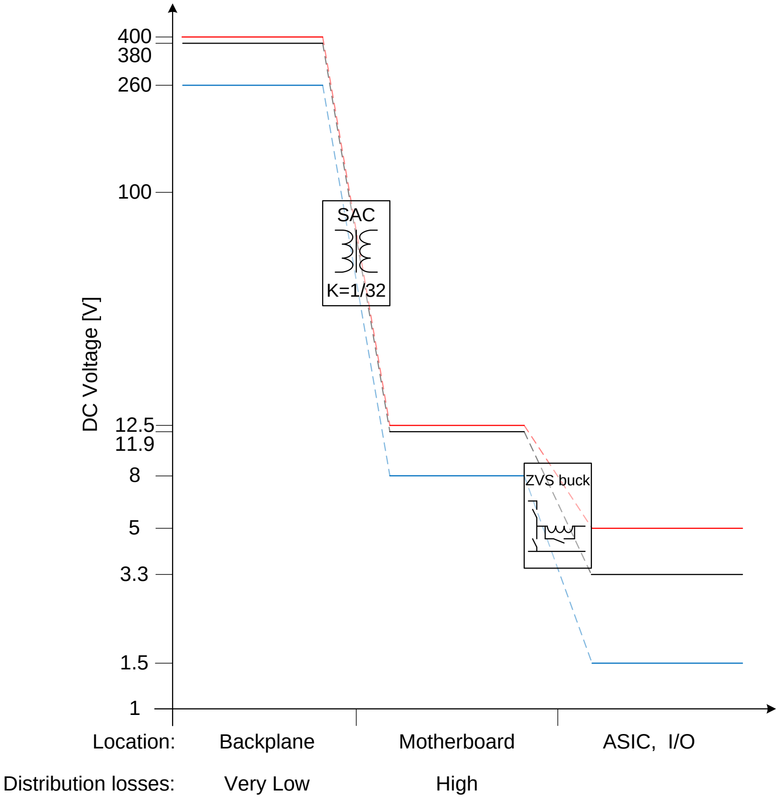
Adaptively Configured Cells

- Configuration switches carry DC current efficiently (< 0.1% loss)
- High frequency switches carry fractional V•I product
- Over 4:1 input voltage range capability

Patents: 7,170,764; 7,420,825; 7,212,419; 7,423,894; 7,782,639; etc. .

Example of an Efficient Architecture: Maximum Use of SAC

- Distribute high voltage throughout system
- Use SAC for voltage conversion and isolation
- Use ZVS-BB for "small step"
- Avoid duplicate regulation stages



Advanced Packaging

VI Chip Packages

- **Molded Package**
  - Molding provides
    - Electrical insulation (cemented joint)
    - Thermal conductivity
    - Planar thermal management
    - Protection of chip-scale silicon
- **1st generation VI Chip package:**
  - J – lead SMD interface
  - MSL 6, 245°C reflow → MSL 4, 245°C
  - Through – hole variant
  - All VI Chips RoHS 6/6
- **Available packages for “planar” VI Chips**
  - Full Size: 1.28” L x 0.87” W x 0.265” H; 1.11 in^2, 0.29 in^3
  - Half Size: 0.65” L x 0.87” W x 0.265” H; 0.57 in^2, 0.15 in^3
  - Double Size: 1.28” L x 1.69” W x 0.265” H; 2.16 in^2, 0.56 in^3

Patents: 7,361,844; 7,799,615; 5,945,130; 6,403,009; 6,710,257; 6,940,013;

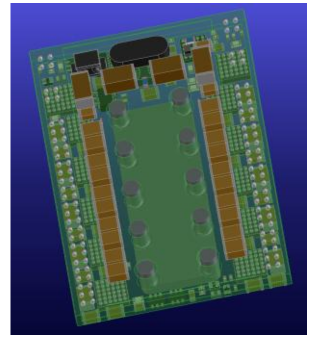
VI Chip Packages

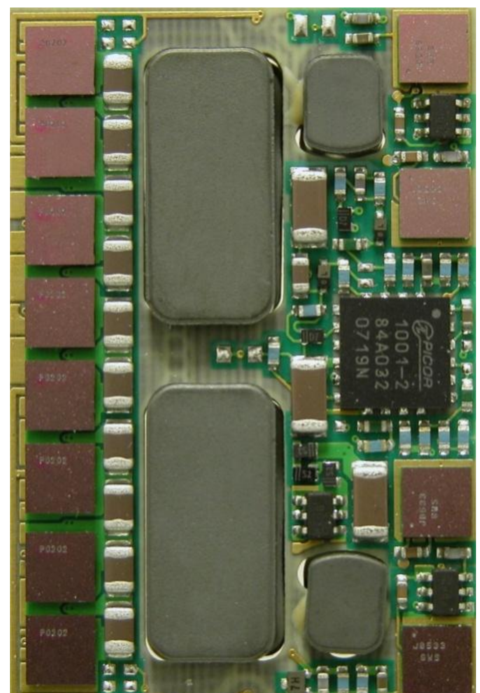
- **PCB substrate with SMT**
  - BGA FETs and controllers
  - Other SMT devices

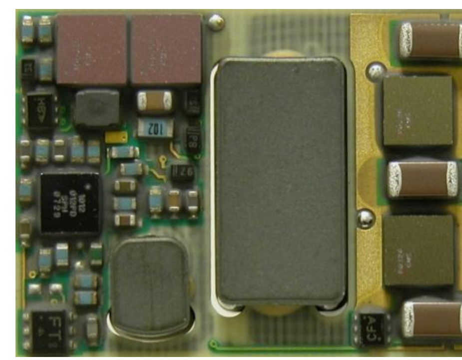
- **Unique planar magnetics**
  - Effective current multiplication
  - Low loss core structures minimize high frequency flux crowding

- **R_{OUT} : down to ~ 0.5mOhm**

- **L_{OUT} : down to ~ 100 pH**



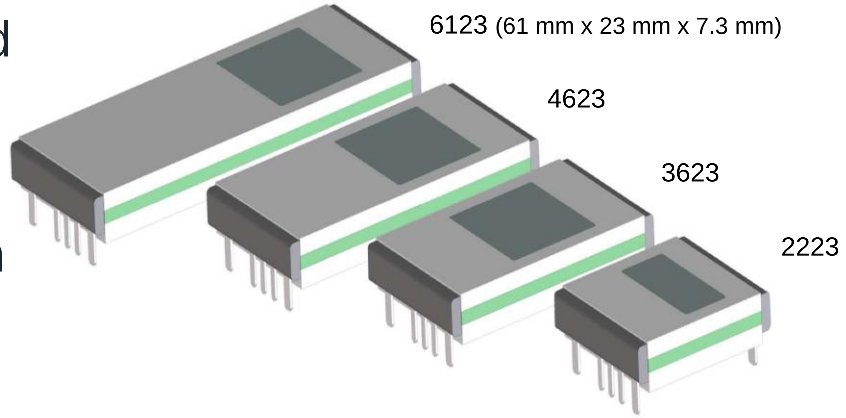




Patents: 7,038,917; 6,969,909; 7,166,898; 7,187,263; etc.

Roadmap: Next-Gen VI Chip Packaging

- **New packaging concept**
  - Complete array / panel of PCBs molded then cut into individual modules
  - Flexible packaging platform
    - *7.3mm height for first model, can be lower
  - Larger transformer cross-section = high efficiency and high power



- **AC-DC and DC-DC converters**
- **Example of products:**

Function	Input Voltage (range, V)	Output Voltage (nom, V)	Output Power (W)	Size	Notes
AC-DC	85-264	48	400	6123	PFM with filter, TVS, PFC
DC-DC	160-420	14.5	450	4623	DCM regulated
DC-DC	360-400	48	1,000	3623	BCM non-regulated

The Customer and Vicor

- **Vicor Technology offers significant benefits in:**
  - Weight (>60% reduction over conventional approach)
  - Efficiency (up to 98% in proven applications)
  - Scalability (10's of kW arrays built with ~0.5kW building blocks
  - Power Density (>50% reduction in size)
- **Optimized voltage transformer and regulator components offer further opportunities to optimize the architecture**
- **Capability of addressing up to 420 Vdc today; planned path towards higher input voltage development with existing topologies**
- **Vicor is now looking for partners who value the benefits provided by our technologies to help develop solutions.**

Cool-Power® Portfolio => Isolated and Non-isolated

Non-isolated DC-DC ZVS Buck Regulators

- PI33xx Series
- Wide input range (8V to 36V)
- Wide output range (1V to 19V)
- 8A, 10A, and 18A versions
- Parallel/Interleaving with up to six devices
- Optional I2C telemetry
- Packaged in LGA SIP 10x14x2.56mm

Isolated DC-DC ZVS Switching Converters

- PI31xx Series
- Wide Input 28 (16-50V), 48V (36-75V) and 24V (18-36V) versions
- 50W/60W isolated DC-DC conversion
- All magnetics internal to the package
- Complete isolated conversion solution with safety approvals
- Packaged in ½ VI Chip 16.5x22x6.7mm

Cool-Power® Isolated DC-DC ZVS Converters – PI3101 example

Challenge

- Delivering 60W isolated DC-DC conversion in a constrained space

Solution

- Cool-Power PSiP= Controller + Transformer + FETs
- Provides complete dc-dc isolated conversion within a 0.57in^2 area
- <50% of the area of conventional solutions
- Power Density: 105W/in^2 & 400W/in^3 (up to 3x the power density of conventional solutions)

PI3101 offers -

- Wide Range Input 48V (36-75V) with 100Vdc (non-operating, 100ms)
- 3.3V /18A Regulated Output (+/-3% over line / load / temperature) and trimmable to 2.5Vout
- Up to 87% Efficiency
- 2250V input isolation

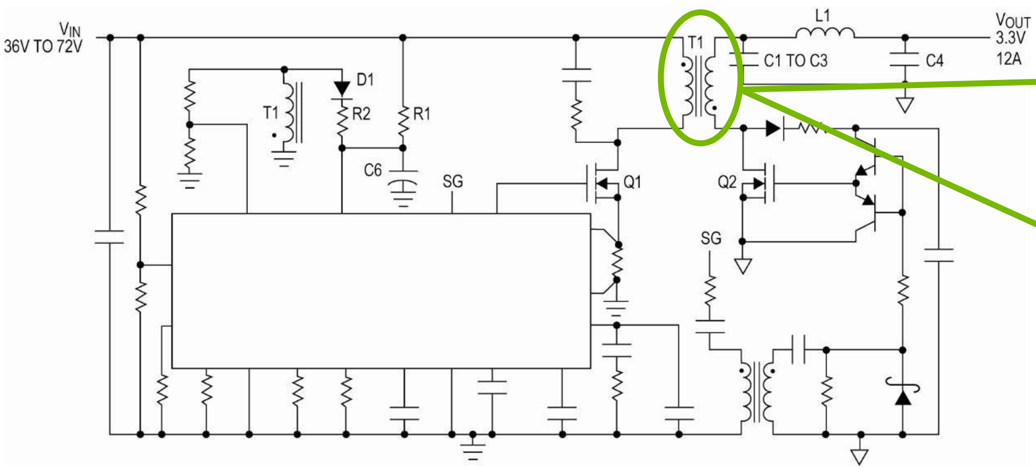
Technology Overview – A “Chip off the Old Brick”

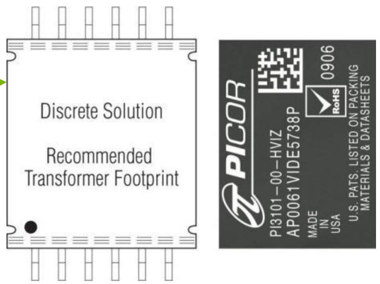
- Looks more like an IC than a power supply due to a number of innovative technical concepts
- Built on a patented Zero Voltage Switched Buck-Boost topology
- Implements state-of-the-art planar magnetics
- Proprietary control with advanced silicon integration in conjunction with proprietary gate drive techniques
- Enables switching frequencies in excess of 1MHz to become a reality.
- High Density surface-mount Power-System-in-Package (PSiP) packaging facilitates easy PCB layout optimization and implementation of various cooling techniques
- Proprietary sampled feedback control removes optical isolation and simplifies loop compensation
- Proprietary high performance MOSFET technology with best-in-class figure of merit attributes

Cool-Power®
Loaded with Innovative Technology

Cool-Power® Isolated DC-DC ZVS Switching Converters

Size comparison to standard controller IC with discretes

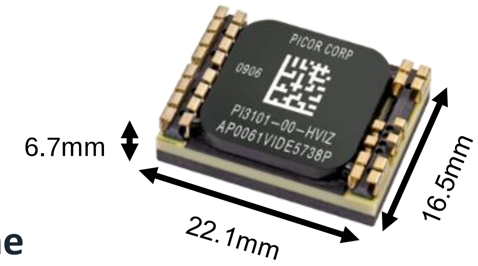




Size of recommended transformer for discrete design versus the PI3101 solution

Discrete designs:

- **Require a large "bag of parts"**
- **Lengthy design, safety, and reliability effort required**
- **Size of the recommended transformer can be as large as the PI3101 alone**

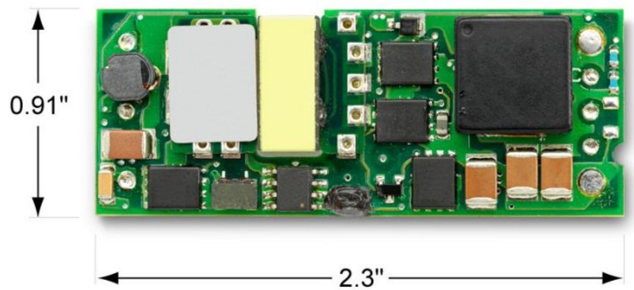


PI3101 Cool-Power® Scaled Size Comparison

Competitor A

2.1 in^2 and 34 W/in^2

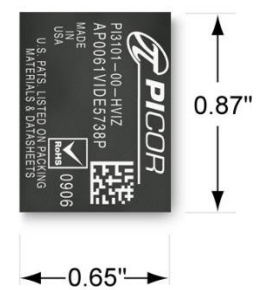
72 Watts



PI3101

0.57 in^2 and 105 W/in^2

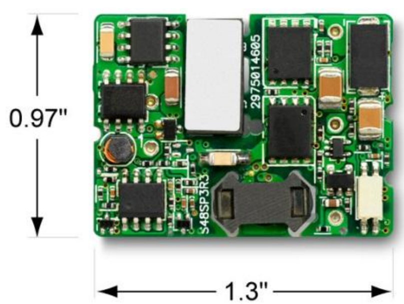
60 Watts



Competitor B

1.26 in^2 and 26 W/in^2

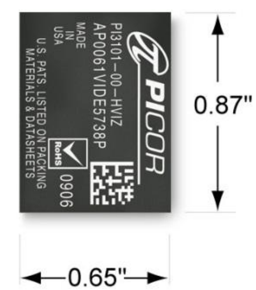
33 Watts



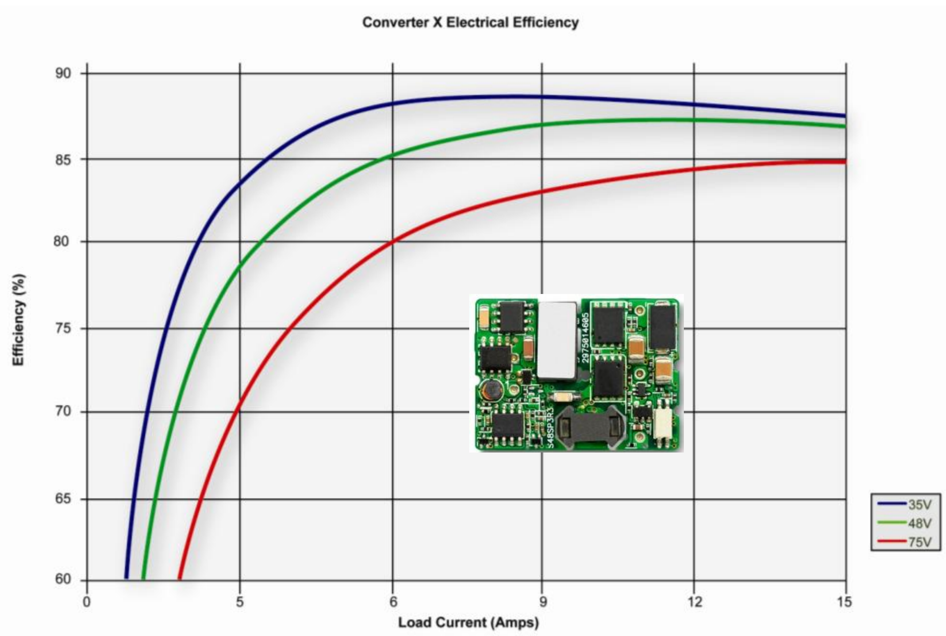
PI3101

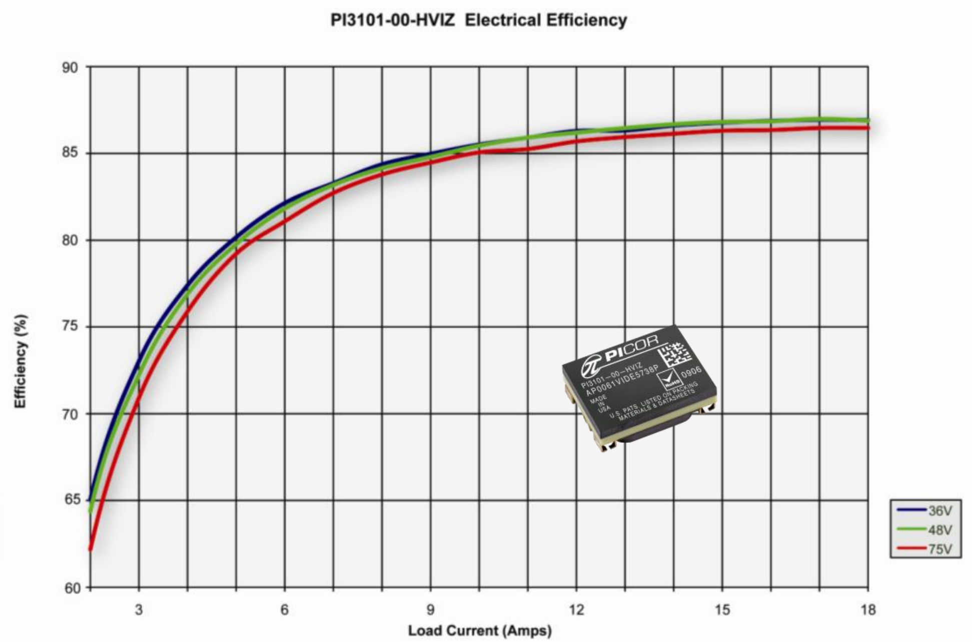
0.57 in^2 and 105 W/in^2

60 Watts



PI3101 Efficiency Comparison

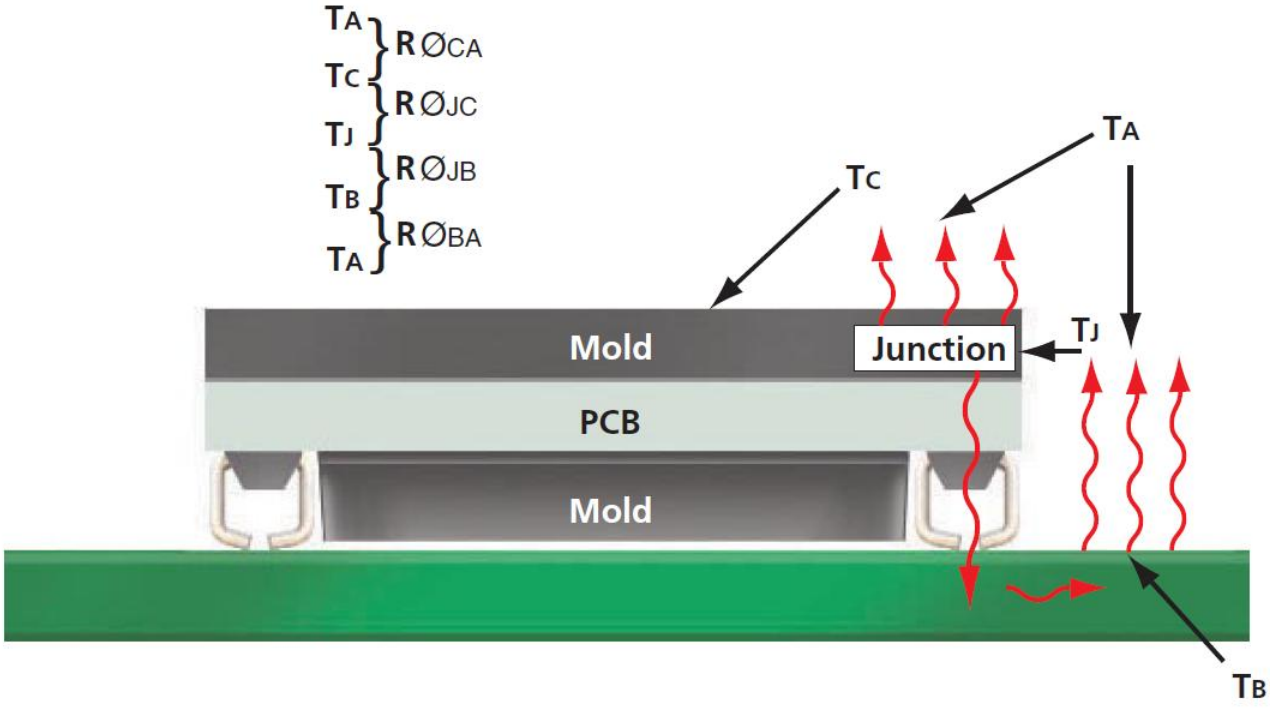




PI3101 Electrical Efficiency sets new standard in this ultra-small form factor, achieving similar performance as much larger solutions

Cool-Power® SiP Packaging Technology

- **Novel packaging provides many benefits**
  - Heat is transferred from the junction to the ambient environment through the mold compound, “J” Leads and the PCB.
  - The “J” leads offer extremely low DCR, parasitic inductance and excellent reflow characteristics.
  - The package design creates an exceptionally rugged mechanical platform.



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Cool-Power® ZVS Buck Regulators

<u>Non-isolated</u> DC-DC ZVS Buck Regulators

- PI33xx Series
- Wide input range (8V to 36V)
- Wide output range (1V to 19V)
- 8A, 10A, and 18A versions
- Parallel/Interleaving with up to six devices
- Optional I2C telemetry
- Packaged in LGA SIP 10x14x2.56mm
- **MIL-COTS version available**

Cool-Power	*Output Range*		Iout Max
	Set	*Range*	
PI3311-00-LGIZ	1.5V	1.00 to 1.75V	10A
PI3312-00-LGIZ	2.5V	1.87 to 3.23V	10A
PI3301-00-LGIZ	3.3V	2.24 to 4.18V	10A
PI3302-00-LGIZ	5.0V	3.30 to 6.61V	10A
PI3303-00-LGIZ	12V	4.0 to 15.65V	8A
PI3305-00-LGIZ	15V	5.0 to 19.65V	8A
Higher Current Versions			
PI3311-01-LGIZ	1.5V	1.00 to 1.75V	18A
PI3312-01-LGIZ	2.5V	1.87 to 3.23V	18A
PI3301-01-LGIZ	3.3V	2.24 to 4.18V	18A
I2C Interface Option			
PI3311-02-LGIZ	1.5V	1.00 to 1.75V	10A
PI3312-02-LGIZ	2.5V	1.87 to 3.23V	10A
PI3301-02-LGIZ	3.3V	2.24 to 4.18V	10A
PI3302-02-LGIZ	5.0V	3.30 to 6.61V	10A
PI3303-02-LGIZ	12V	4.0 to 15.65V	8A
PI3305-02-LGIZ	15V	5.0 to 19.65V	8A
PI3311-03-LGIZ	1.5V	1.00 to 1.75V	18A
PI3312-03-LGIZ	2.5V	1.87 to 3.23V	18A
PI3301-03-LGIZ	3.3V	2.24 to 4.18V	18A

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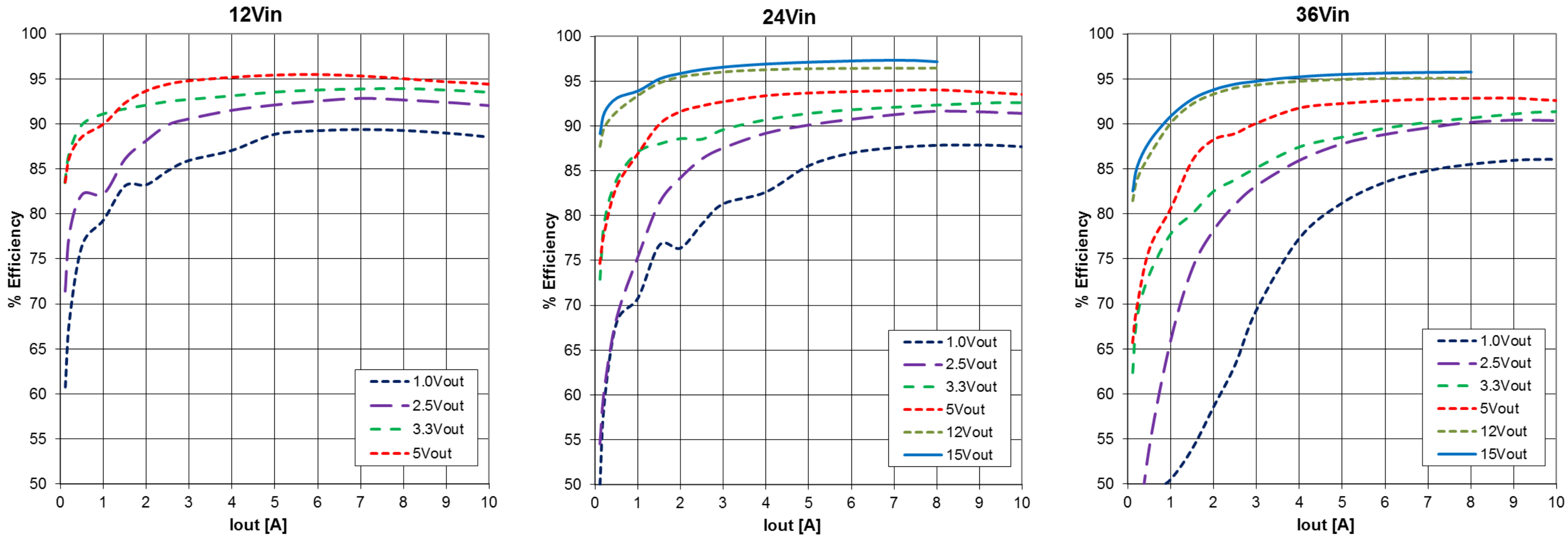
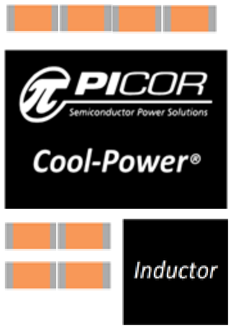
Cool-Power ZVS Buck PI33xx - High Efficiency

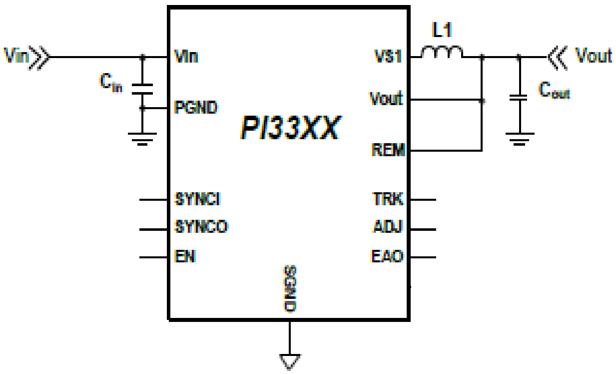


- High-efficiency performance at both light load and full load
- Enabled by the use of the Zero-Voltage-Switching, high performance control silicon and low impedance LGA SiP packaging

Cool-Power ZVS Buck - Simple to Use



Cool-Power Required Components



Cool-Power Schematic with required components

- Input/Output caps and a output inductor is all that is needed
- No additional setup required for basic operation
- Internal compensation
- No external resistor programming required
- Pin-for-pin packages allows for easy changes to high/lower current and voltage versions
- Additional features are present allowing for flexibility within different applications

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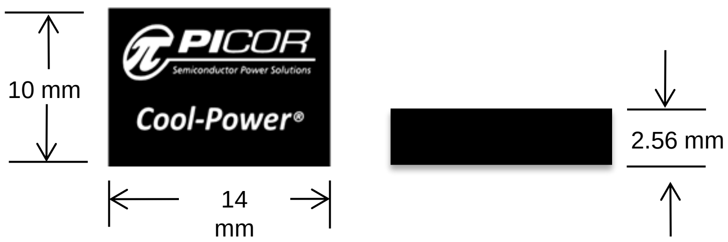
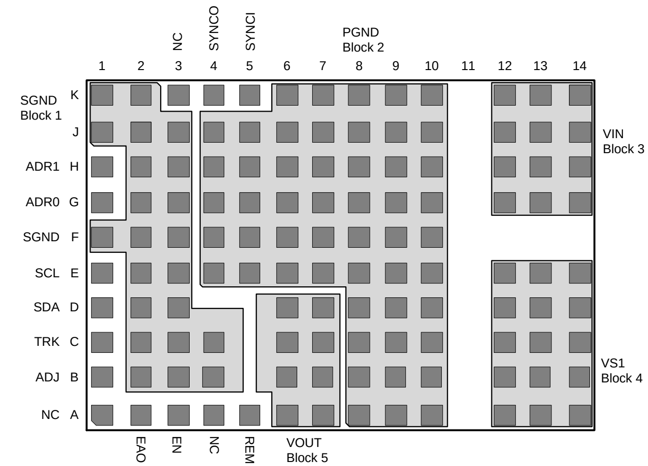
Cool-Power ZVS Buck - High Density



Cool-Power LGA SiP Package Profile

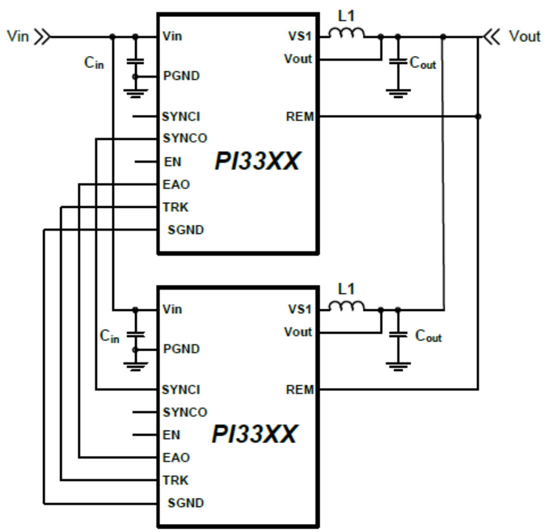


Cool-Power LGA SiP Package Pinout

- 10 x 14 x 2.56 mm Land Grid Array (LGA) System-in-Package (SiP)
- Low impedance interconnect design facilitates thermal management
- Up to 120W or 18A Iout capability
- All Cool-Power ZVS Bucks are pin-for-pin compatible allowing for added design flexibility

Picor Cool-Power ZVS Buck - Flexibility

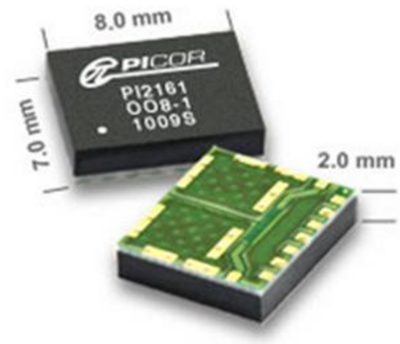
- Current source functionality for high load start-up
- Programmable soft-start & tracking
- Power-up into a pre-biased load
- Paralleling and single wire current sharing
- High efficiency light load operation
- Frequency sync, Interleaving up to 6 regulators
- I²C one time user programmable EN polarity and phase delay
- I²C Fault Telemetry (optional):
  - Over temperature protection
  - Fast current limit
  - Output voltage high
  - Input overvoltage
  - Input under-voltage
  - Controller VCC under-voltage
- I²C Vout margining tool (aids development work)
- -40 C to 125 C operating range



Cool-Power Parallel Operation with Current Sharing

39

Power Path Management



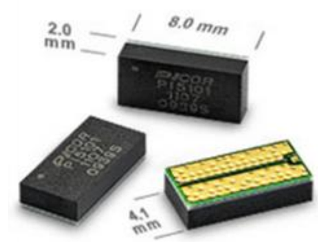
Cool-ORing®

›PI2007 and PI2127 lead the industry in response times

›SiPs lead the industry with lowest RDS(ON)

Cool-Switch®

›Beats competition in speed and efficiency



µRDS(on) FET™

›High-performance 5V, 360µΩ lateral N-Channel MOSFET

›Leads the industry in efficiency vs. size

Cool-Swap™

›MOSFET True-SOA™ protection via digital engine and Glitch-Catcher voltage suppression

›Only hot swap controller to perform digital emulation

VICOR

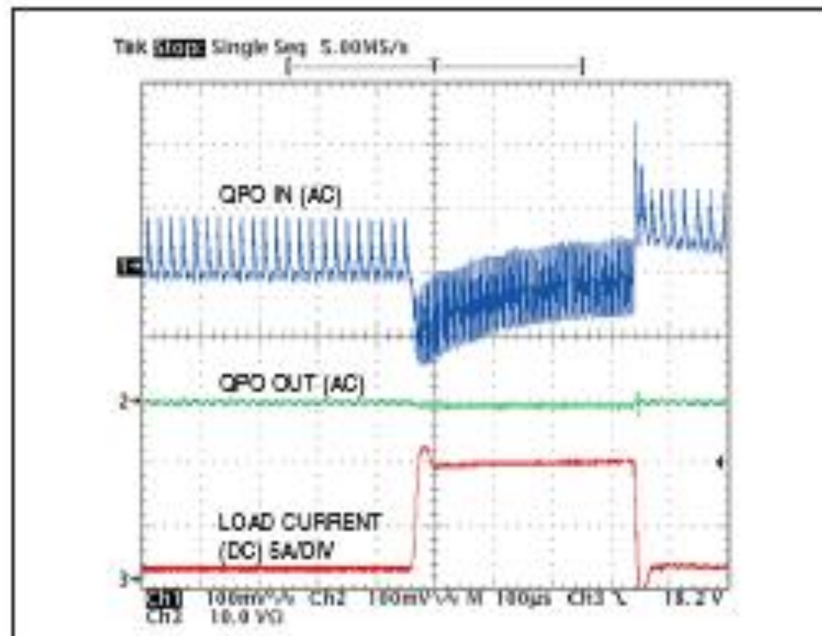
QuietPower®: QPI Active EMI Input Filters

- High density, active EMI filters
- Provides conducted common-mode (CM) and differential-mode (DM) attenuation from 150kHz to 30MHz (CISPR22 range)
- Optimized for applications that require EN55022 Class B limits
- 24V & 48V input voltages, 7 an 14A ratings
- MQPI-18 MIL-COTS version:
    - 28 V input, 7 A rating
    - Efficiency >99%
    - Also compatible with MIL PRM
    - MIL-STD-461F compliant* CE101, CE102, CS101, CS106, CS114, CS115, and CS116
    - 100 Vdc surge, 100 ms : 1500 Vdc hi-pot hold off to shield plane
    - -55 to +125C PCB temperature
    - Low profile LGA package - 12.9 x 25.3 x 5.0 mm w/Lid or 12.4 x 24.9 x 3.4 mm Open-frame SiP
    - Pb solder construction

VICOR

QuietPower®: QPO Active Output Ripple Attenuators

- Reduces power supply output ripple (to <10mVp-p) and noise (PARD) from 1kHz to 500kHz with proprietary active filtering circuit
- Ensures quiet point-of-load regulation, and works with most industry-standard converters
- Improves transient response of DC-DC converters, and can reduce output capacitance by a factor of 10



QPO Performance

ZVS - A Solution to Industry Demands

- **Increasing demand for higher efficiency, density, and power processing**
- **Demands require higher Vin/Vout and higher switching frequency performance**
- **The power semiconductor industry has enabled improvements with:**
  - **Silicon Integration**
  - **MOSFET Technology**
  - **Packaging**
- **These improvements are not keeping pace with industry demands**
  - ***Switching losses continue to hinder high performance***
- **Addressing the switching topology is the only way to dramatically reduce switching losses**

Picor Cool-Power Zero Voltage Switching Topology

- ***Reduces Q1 turn-on losses***

  Conventional regulator topologies incur high switching losses due to the simultaneous occurrence of high current and high voltage stress imposed on the MOSFET at the turn-on and turn-off transitions.

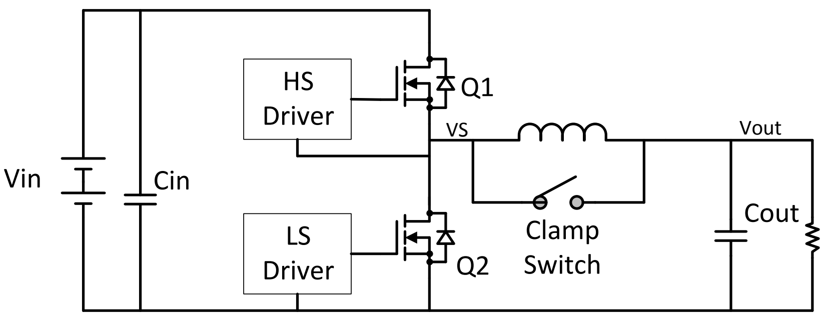
- ***Reduces Gate Drive Losses***

  Hard-switching topologies exhibit higher gate drive loss due to the Miller Charge dissipated within the gate drive circuitry.

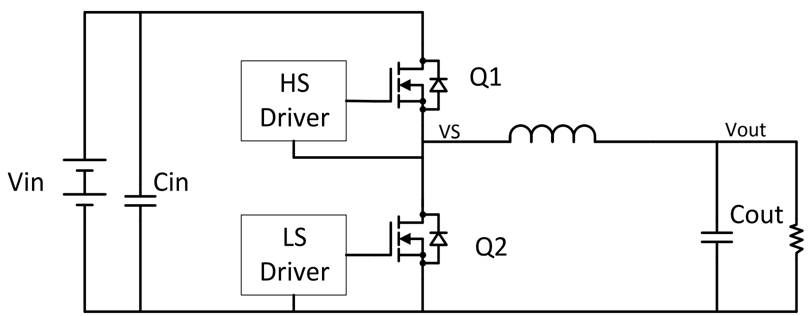
- ***Reduces Body Diode Conduction***

  High pulsating currents flow through the body diode of the low-side MOSFET as the high-side MOSFET gets turned on and off. The longer the body diode conducts, the higher the reverse-recovery losses and body diode conduction losses. Body diode conduction also causes disruptive overshoot and ringing.

ZVS-Buck



Conventional Buck



ZVS vs. Conventional Topology

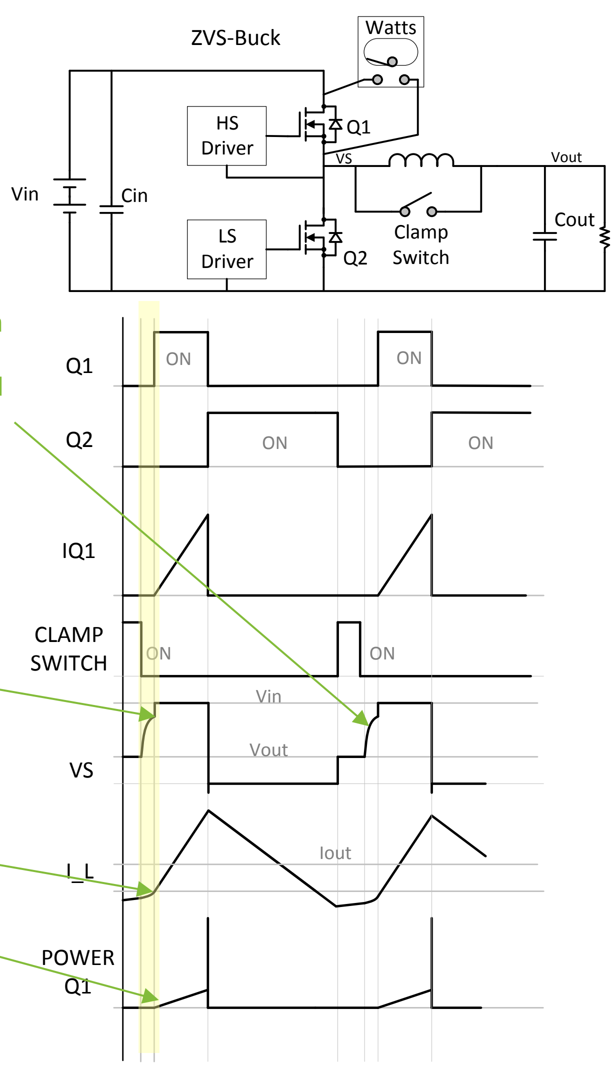
Resonant ZVS action virtually eliminates switching losses and removes Miller charge effect

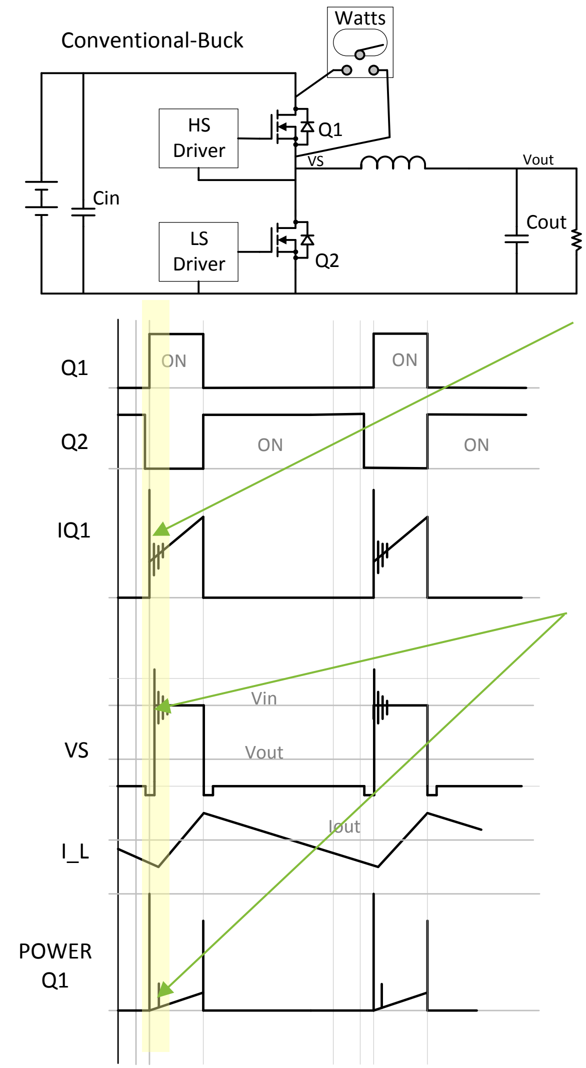
High-side turn on

Vds = (Vin-VS)

Zero-current turn on

Q1 loss is R_{DSon} dominant until turn-off





Very high-current turn on due to Q2 body diode looking like a short circuit for Trr (reverse recovery time)

Hard-switching transition and body diode reverse recovery expose Q1 to very high turn on losses. Energy stored in parasitic inductance causes VS to ring, increasing losses further. Increasing input voltage and/or frequency increases switching losses

Decreased Switching Losses Enable…

- Higher Switching frequency
  - Higher density (smaller passives)
  - Higher Performance

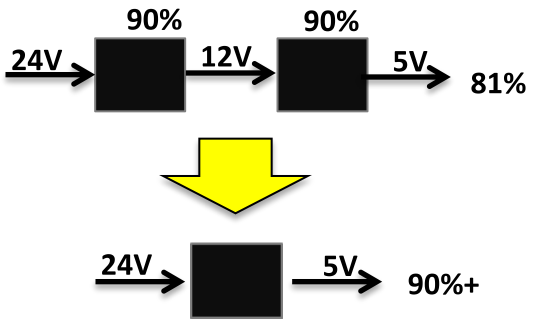
- Higher Input Voltages/ Higher Output Currents
  - Higher power density
  - Reduction of regulation stages
  - Line loss reduction

- Higher Efficiency
  - Higher power density
  - Lower thermal derating

VICOR

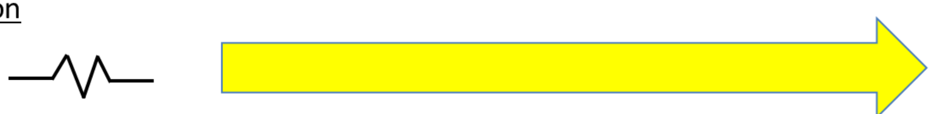
Benefits of High Vin Regulation

- **Regulation Stage Reduction**
  - High Vin operation can reduce the number of regulator stages
  - Increases in reliability, power density, efficiency



- **Line Loss Reduction**
  - Efficiency increases by routing a higher voltage across the PC board

12V Distribution



.025ohm loss in PC board trace
P = VI = I²R
P = 2,500*.025 = 62.5W
System efficiency of 600/662.5 = 90.5%

Total demand from all buck regulators
Voltage *= 12V*
Current *= 50A*
Power *= 600W*

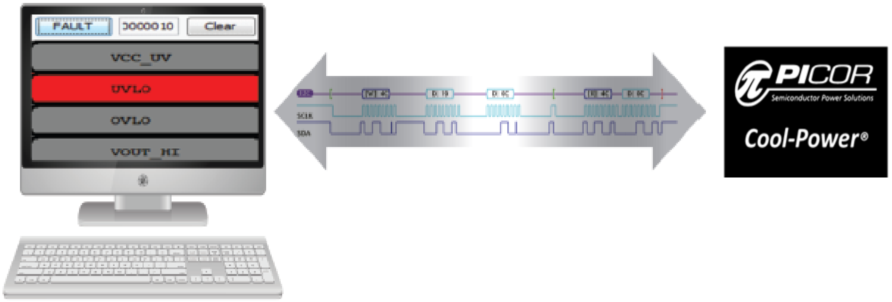
24V Distribution

.025ohm loss in PC board trace
P = VI = I²R
P = 625*.025 = 15.6.W
System efficiency of 600/615.6 = 97.4%

Total demand from all buck regulators
Voltage *= 24V*
Current *= 25A*
Power *= 600W*

Cool-Power ZVS Buck – I^{2}C Option Devices

- **Vout Margining Function**
- **Programmable**
  - *Enable and SYNCI pin polarity*
  - *Phase delay (for interleaving multiple regulators)*
- **Fault reporting**
  - *Over-temperature protection*
  - *Fast current limit*
  - *Output voltage high*
  - *Input overvoltage*
  - *Input undervoltage*
  - *Controller VCC undervoltage*



The Vicor Platforms…
DCM, BCM/VTM & PRM

DCM™ Isolated DC-DC Converters

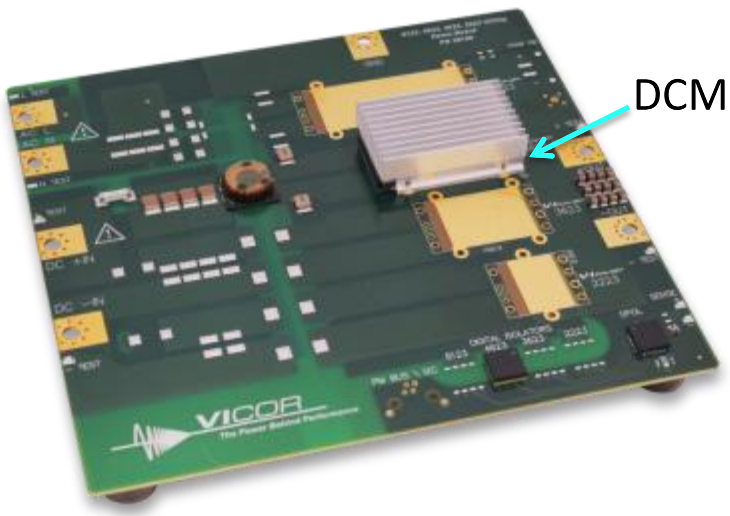
Isolated, regulated

High efficiency over wide input range

High power, low profile, light weight

Offered with either analog or digital control interface

ChiP package



High voltage automotive

- DC-DC Converter (DCM) in 4623 through-hole package
- VIN = 160-420V
- VOUT = 12.5-15V
- V_{OUT_RIPPLE} < 500mV
- 380-12V = 600W @ 93% efficiency
- Chip size: 1.94” x 0.9” x 0.29”
- Chip weight: 29.2g (1.03oz)

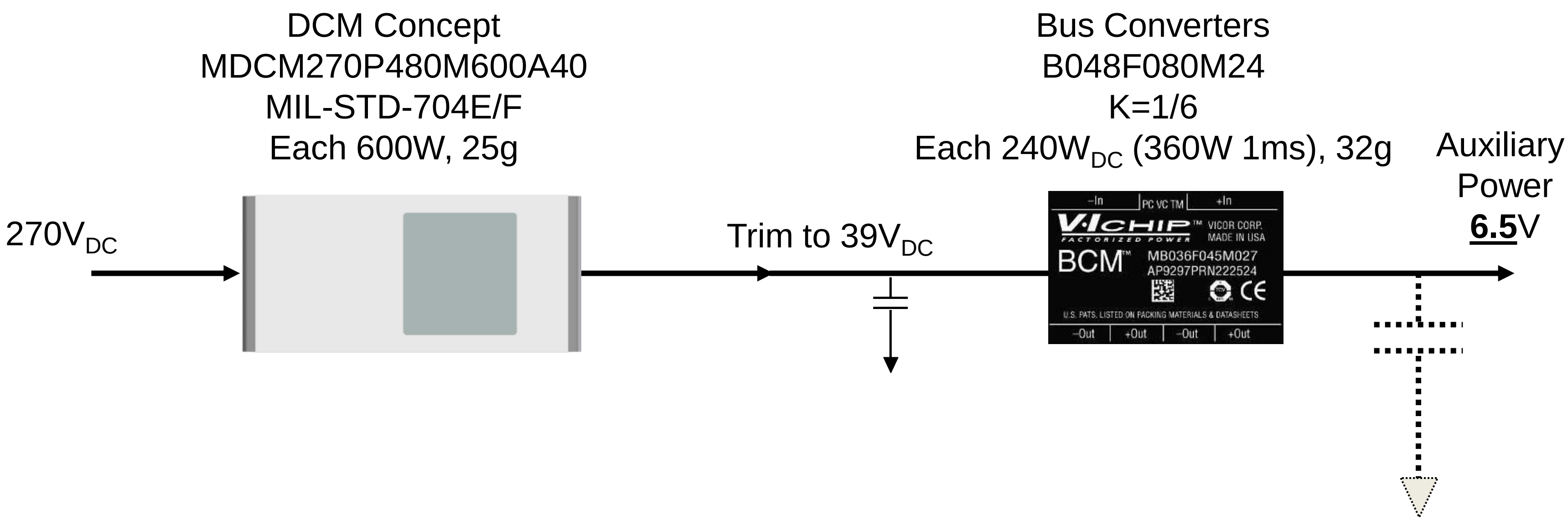
Defense Applications

- DC-DC Converter (DCM) in 3623 through-hole package
- VIN = 16-50V
- VOUT = 28V
- Power = 320W @ 92%
- Chip size: 1.58” x .9” x .29”

DCM 270V_{IN} to 24V_{OUT}

- **93% efficiency at Full Load**
- **600W**
- **4623 package**
- **RTP: 4Q13**
- **25KW requires ~ 42 DCM modules**
  - 74.4 in^2 (DCM area only)
  - 43 oz (DCM weight only)

270V to 6.5V DCM + BCM

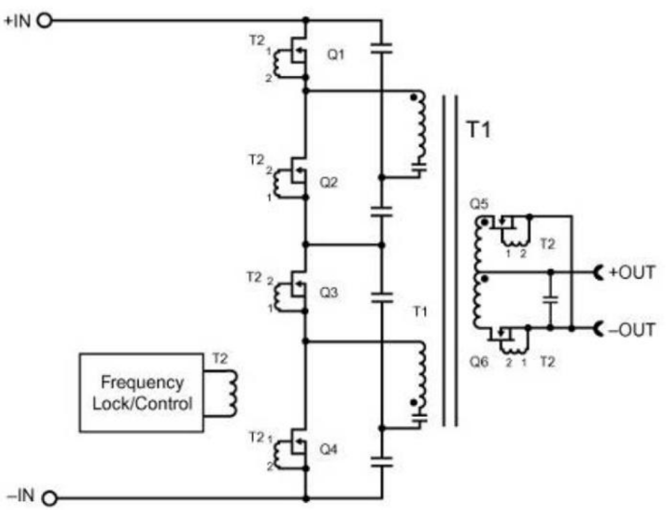


- MDCM270P480M600A40:
  - 270V$_{IN}$ (150-420V), 48V$_{OUT}$
  - 4623 package
  - 600W
- B048F080M24

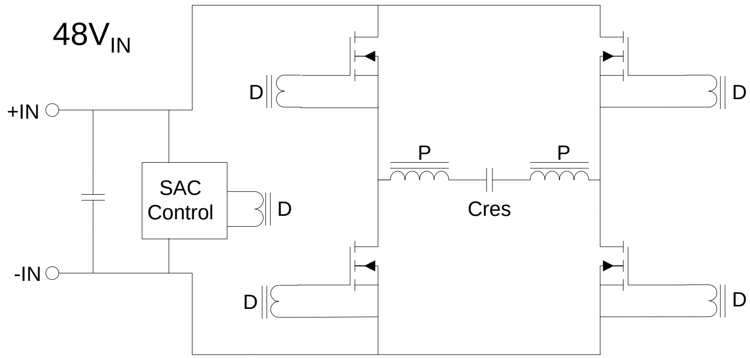
VTM, BCM: Sine Amplitude Converter (SAC)

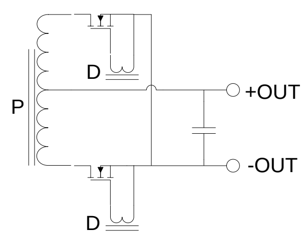
- **Fixed-ratio, DC-DC transformer**
  - Sine Amplitude proportional to load
  - “Voltage Transformer” or “Current Multiplier”
  - ZVS, ZCS (Low loss, low noise)
  - MHz switching
  - ~100% duty cycle down to < 1V
  - Cycle-by-cycle transient response
  - Negligible series impedance
  - 2x transient current capability
  - Thermally (not power) limited
- **Used in Vicor Bus Converter Modules (BCM) and Voltage Transformation Modules (VTM)**

270V, 350V, 380V$_{IN}$



48V$_{IN}$

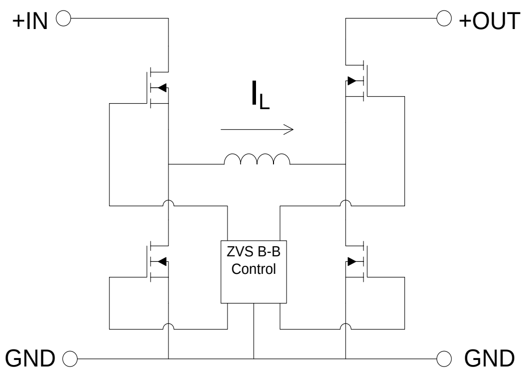




P=Power Transformer
D=Drive Transformer

PRM: ZVS Buck-Boost Regulator

- **Proprietary ZVS Buck-Boost control architecture**
- **Negligible switching loss at high voltage and high frequency**
- **Voltage step-up OR step-down**
- **Small inductor**
- **"Classic" VI Chip:**
  - Present 48V regulator efficiency: 97%
  - Density: 1.4 kW/in^3
- **"Next Generation" will have higher efficiency and significantly greater power density**



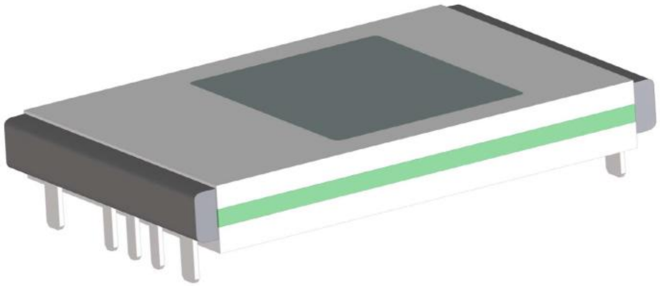
Patents: 6,788,033; 7,154,250; RE40,072; etc.

Next Generation PRM

First model:

$48V_{IN}$ $48V_{OUT}$ nominal

- V_{IN} 30V to 55V
- V_{OUT} 20V to 55V
- 3623 package: 1.58” x .9” x .29”
- 1000W maximum continuous output power
- 2500 W/in^3 power density
- 98% peak efficiency
- V_{OUT_RIPPLE}: <1% of V_{OUT}



Followed by:

- $28V_{IN}$ / $28V_{OUT}$
- 750W, 97.5% efficiency
- V_{OUT_RIPPLE}: <1% of V_{OUT}
- 3623 package

Application example: 270V to 24V with Current BCM, PRM

Bus Converters
MBCM270F450M270A00
K=1/6, MIL-STD-704E/F
Each 270W (350W <85°C)
96%

Regulators
PRM48BF480M500A00
Each 250W at $24V_{OUT}$
(trimmed from 500W at $48V_{OUT}$)
96%

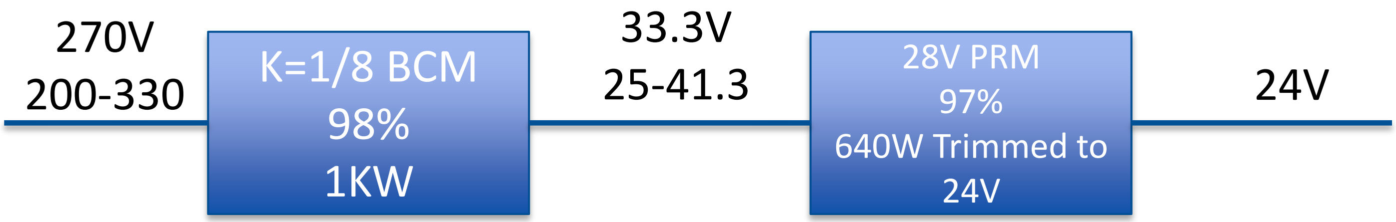
$270V_{DC}$ →

→ $45V_{DC}$ →

→ $24V_{DC}$

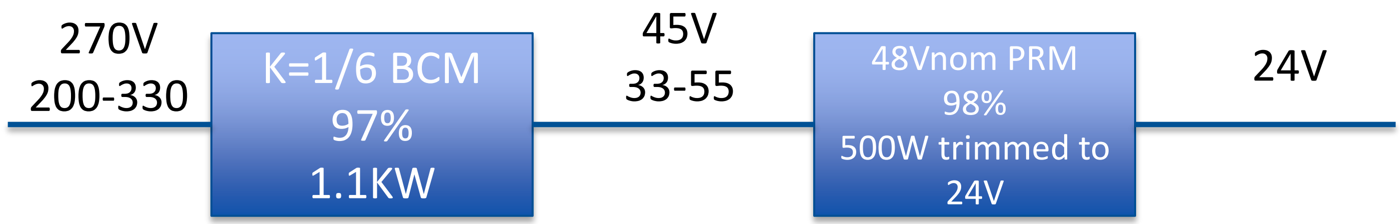
- **System efficiency ~92%**
- **Solution size for 25KW:**
  - 97 BCM + 100 PRM
  - 216 in^2 (modules only)
  - 104 oz (modules only)

270V to 24V: Next Generation K=1/8 BCM + 28V PRM



- **System efficiency ~95%**
- **Solution size for 25KW:**
  - 26 BCM (6123) + 40 PRM (3623)
  - 59.8in^2 + 56.9in^2 = 116.7in^2
- **K=1/8 BCM:**
  - 6123 package
  - 1KW, 98% peak efficiency
- **28V PRM**
  - 3623 package
  - 750W, 97.5% peak efficiency

270V to 24V: Next Generation K=1/6 BCM + 48V PRM



- **System efficiency ~95%**
- **Solution size for 25KW:**
  - 24 BCM (6123) + 50 PRM (3623)
  - 55.2in^2 + 71.1in^2 = 126.3in^2
- **K=1/6 BCM:**
  - 6123 package
  - 1KW, 98% peak efficiency
- **48V PRM**
  - 3623 package
  - 1KW, 97.5% peak efficiency

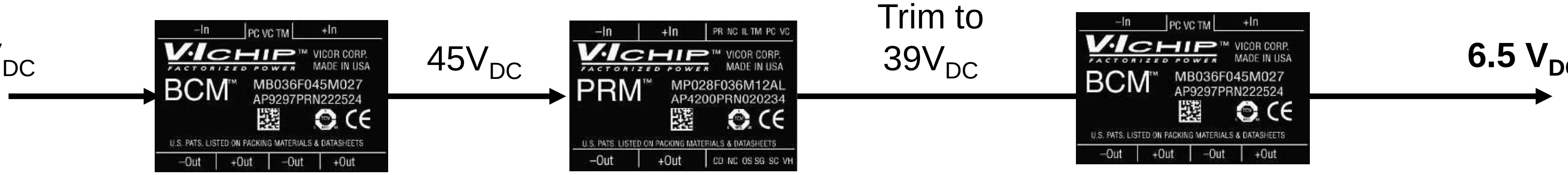
270V to 6.5V

Bus Converters
MBCM270F450M270A00
K=1/7
MIL-STD-704E/F
Each 270W (350W <85°C)

Regulators
PRM48BF480M500A00
Each 400W at 36V

Bus Converters
B048F080M24
K=1/6 Each 240W

270V$_{DC}$ → 45V$_{DC}$ → Trim to 39V$_{DC}$ → **6.5 V$_{DC}$**



270V$_{DC}$ (200V to 330V) to 24V$_{DC}$ @ 25KW Summary

	Units	Efficiency	Area (in^2)
Classic BCM + PRM	97 BCM + 100 PRM	92%	216
DCM	42 DCM	93%	74.4
PM: K=1/8 BCM + PRM	26 BCM + 40 PRM	95%	116.7
PM: K=1/6 BCM + PRM	24 BCM + 50 PRM	95%	126.3

VICOR

Vicor is Field Proven for Military Applications

Long heritage providing MIL-COTS solutions to customers worldwide
Power components and turn-key solutions
Made in USA

Partial Listing

F-15 Fighter Aircraft
F-16 Fighting Falcon Multi-Role Fighter Aircraft
F/A-18 Super Hornet Strike Attack Aircraft
F/A-22 Raptor Advanced Tactical Fighter Aircraft
F-35 Joint Strike Fighter
Eurofighter Typhoon Aircraft
Rafale Multi-Role Combat Fighter
Tornado Multi-Role Combat Fighter
B-1B Lancer Strategic Bomber
B-52 Stratofortress Long-Range Multi-Role Bomber
CH-53 Super Stallion Heavy-Lift Helicopter
AH-64 Apache Attack Helicopter
CH-47/MH-47 Chinook Heavy-Lift Helicopter
Black Hawk Multi-Mission Helicopter
AWACS Airborne Warning & Control System
E-2C Hawkeye Airborne Early Warning Aircraft
EA-6B Prowler Electronic Warfare Aircraft
Global Hawk High Altitude, Long Endurance Unmanned Reconnaissance Aircraft

Predator Unmanned Aerial Vehicle
JSTARS
Joint Surveillance & Target Attack Radar System
NIMROD MR4A Maritime Reconnaissance Aircraft
P-3C Orion Maritime Patrol & Anti-Submarine Warfare
T-50 Golden Eagle Jet Trainer & Light Attack Aircraft
C-130 Hercules Tactical Transport Aircraft
KC-135 Stratotanker Air-to-Air Refueling Aircraft
C-17 Globemaster Tactical Transport Aircraft
V-22 Osprey Medium-Lift, Multi-Mission, Tilt-Rotor Aircraft
Patriot Missile Air Defense System
THAAD Terminal High Altitude Area Defense Missile System
NASAMS Norwegian Surface-to-Air Missile System
MLRS Multiple Launch Rocket System
TOW Anti-Tank Missile
Tomahawk Cruise Missile
Harpoon Anti-Ship Missile

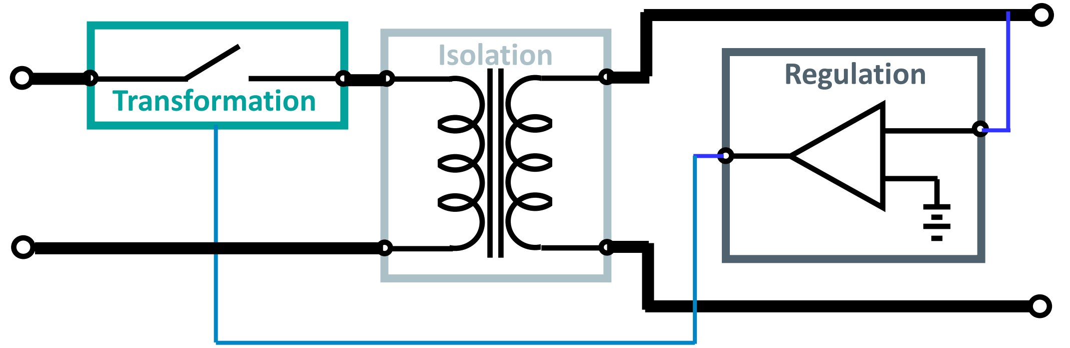
NSM Naval Strike Missile
TAURUS KEPD 350 Stand-off-Weapon
Sting Ray Lightweight Torpedo
Bradley M2/M3 Tracked Armored Fighting Vehicle
PUMA Tracked Infantry Fighting Vehicle
TETS Third Echelon Test System
Stryker 8-Wheel Drive Armored Combat Vehicle
Fire Finder Radar
Paladin 155mm Self-Propelled Howitzer
M1A1/M1A2 Abrams Main Battle Tank
CREW Counter Electronic Warfare
Blue Force Movement Tracking System
JTRS Joint Tactical Radio System
Falcon Tactical Radio
AEGIS Guided Missile Destroyer
DDG 1000 Zumwalt Class Destroyer
SSN Seawolf Class Attack Submarine
NSSN Virginia Class Attack Submarine
CEC Cooperative Engagement Capability
MCMV Hunt Class Mine Countermeasures Vehicle
NASA Space Shuttle
International Space Station

Factorized Power Architecture®

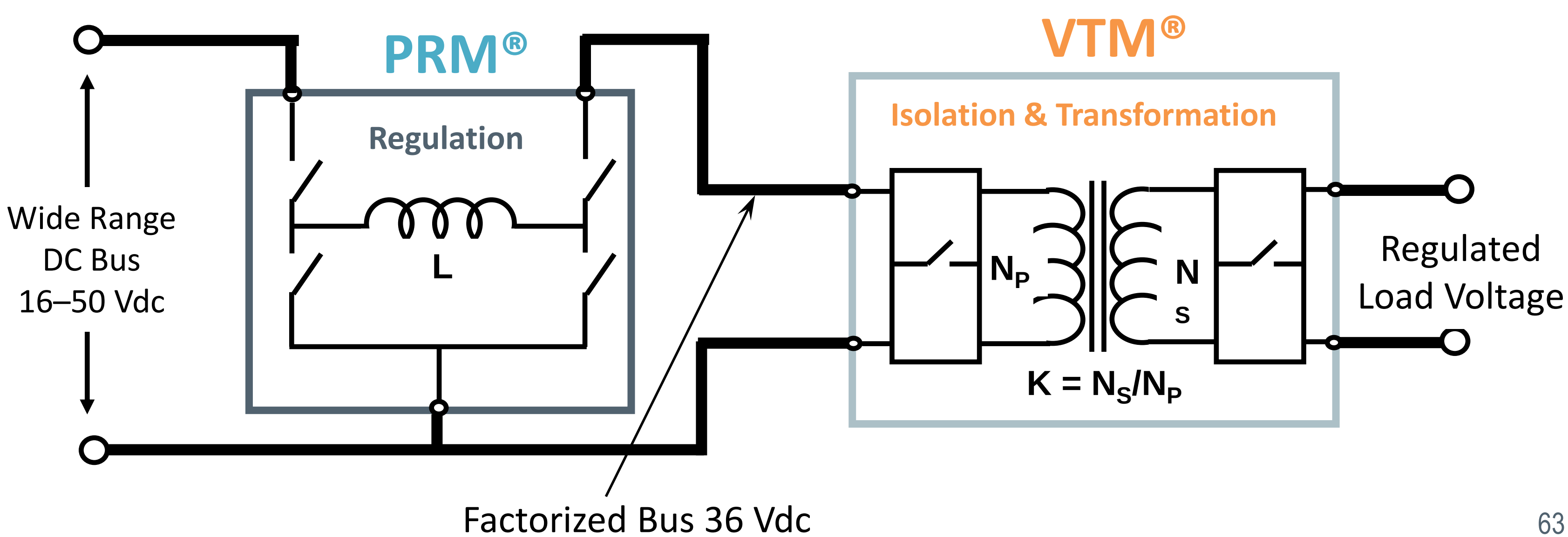
- **Separation of power conversion stages: regulation and voltage transformation**
  - Reduces distribution losses in a system
  - Reduces duplicated functions in the DC-DC conversion path
  - Reduces power dissipation at the point-of-load while increasing total system efficiency

DC-DC “Brick” Converter and Factorized Power

Traditional
DC-DC Converter



Factorized Power Architecture®



MIL-COTS High Voltage Bus Converter (HV BCM®)

- **Isolated voltage transformation**
- **Sine Amplitude Converter™ (SAC™)**
  - ZVS/ZCS, >1 MHz switching frequency
- **HV equivalent of VTM® Current Multiplier**
  - stand alone operation
  - Start-up & Inrush protection
- **Input: 270 Vdc nominal**
  - 200/240 - 330 Vin range
  - MIL-STD-704E/F
- **Two versions**
  - 270-to-33 V (MBCM270F338M235A00)
    - Power: 235 W
    - Efficiency: >95%
  - 270-to-45 V (MBCM270F450M270A00)
    - Power: 350 W
    - Efficiency: >95%
- **High Power Density**
- **Parallelable for higher power**

270 -to-33 V example

VICOR

MIL-COTS VI BRICK® PRM, VTM, and BCM

- **Simple “brick style” mounting and thermal management**
- **100°C baseplate operation**
- **Compliant to MIL-STD-810 for shock and vibration**
- **Compatible with Vicor MIL-COTS VI Chip/VI BRICK input filters**
  - MIL-STD-1275A/B/D, MIL-STD-704A, and DO-160E transient protection
  - MIL-STD-461E EMI compliance

1.91 x 1.09 x 0.37 in.
(48,6 x 27,7 x 9,5 mm)

Applications

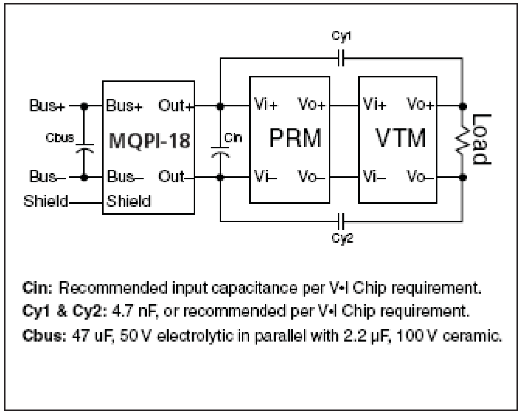
- Ground vehicle
- Airborne

VICHIP

QuietPower®: QPI Active EMI Input Filters

- **28 V input, compatible with MIL-COTS PRM**
  - MIL-STD-461E compliant: CE101, CE102, CS101, CS114, C5115, and CS116
- **1,500 Vdc hi-pot hold off to shield plane**
- **7 A rating**
- **Efficiency: > 99%**
- **Low profile LGA package**
- **-50°C to 100°C operation (PCB Temp.)**
- **Pb solder construction**

12.9 x 25.3 x 5 mm
Weight = 2.4 Grams



Cin: Recommended input capacitance per V•I Chip requirement.
Cy1 & Cy2: 4.7 nF, or recommended per V•I Chip requirement.
Cbus: 47 uF, 50 V electrolytic in parallel with 2.2 µF, 100 V ceramic.

Figure 1 – MQPI-18 Typical application schematic

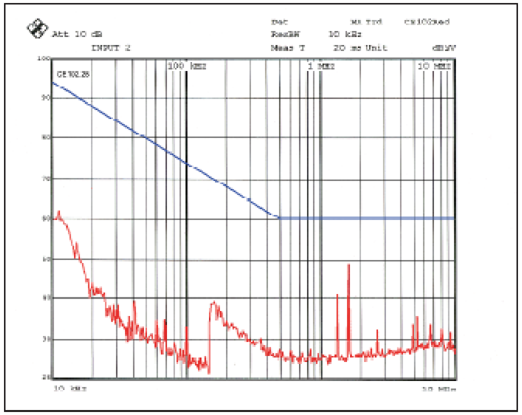


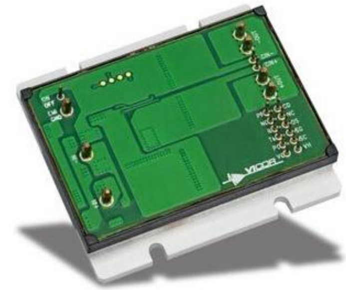
Figure 2 – MIL-STD-461, CE102 compliance with MQPI-18 using 28 V input MIL PRM and 12 V output MIL VTM

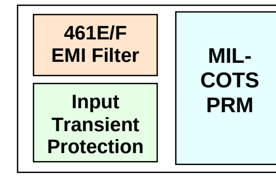
Applications

- **Military mobile and fixed communications**
- **Radar and targeting**
- **Missile and launch systems**
- **Airborne flight management systems**

28 V MIL-COTS VI BRICK Filter Product

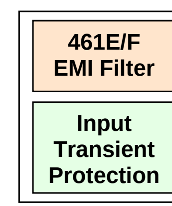
- **VI BRICK based filter integrated with or in addition to the MIL-COTS 28V PRM providing EMI and transient filtering**
- **Integrated Filter and PRM Regulator**
  - Dual VI Chip package
  - 8 A maximum input
  - 120 W max power
  - 16.5-50 Vin range (13.9-50 V after start-up)
  - 26 to 50 Vout (factorized bus)
- **Stand-alone Filter**
  - Single VI Chip package
  - 8 A maximum input
  - 16.5-50 Vin range (13.5-50 V after start-up)
  - Use with MIL-COTS VI BRICKS or VI Chips





MIL-COTS Filter w/Integrated PRM

2.19 x 1.91 x 0.37 in
(55,7 x 48,6 x 9,5 mm)



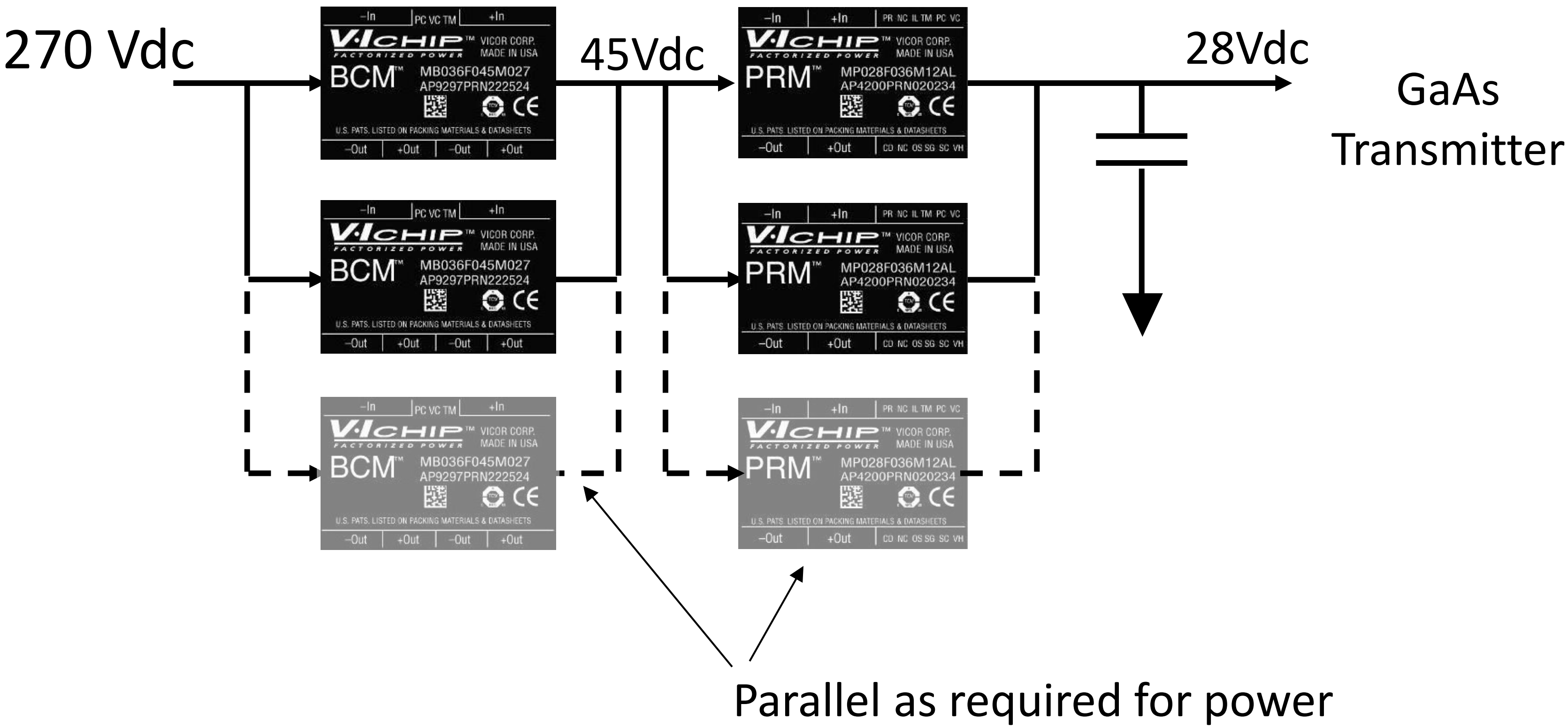
MIL-COTS Filter

1.91 x 1.09 x 0.37 in
(48,6 x 27,7 x 9,5 mm)

Airborne Radar Application

Bus Converters
MBCM270F450M270A00
K=1/6, MIL-STD-704E/F
Each 270W (350W <85°C)
96%

Regulators
PRM48BF480M400A00
Each 233W at 28V_{OUT}
(trimmed from 400W at 48V_{OUT})



VICOR

Pulsed Power Loads – GaN example

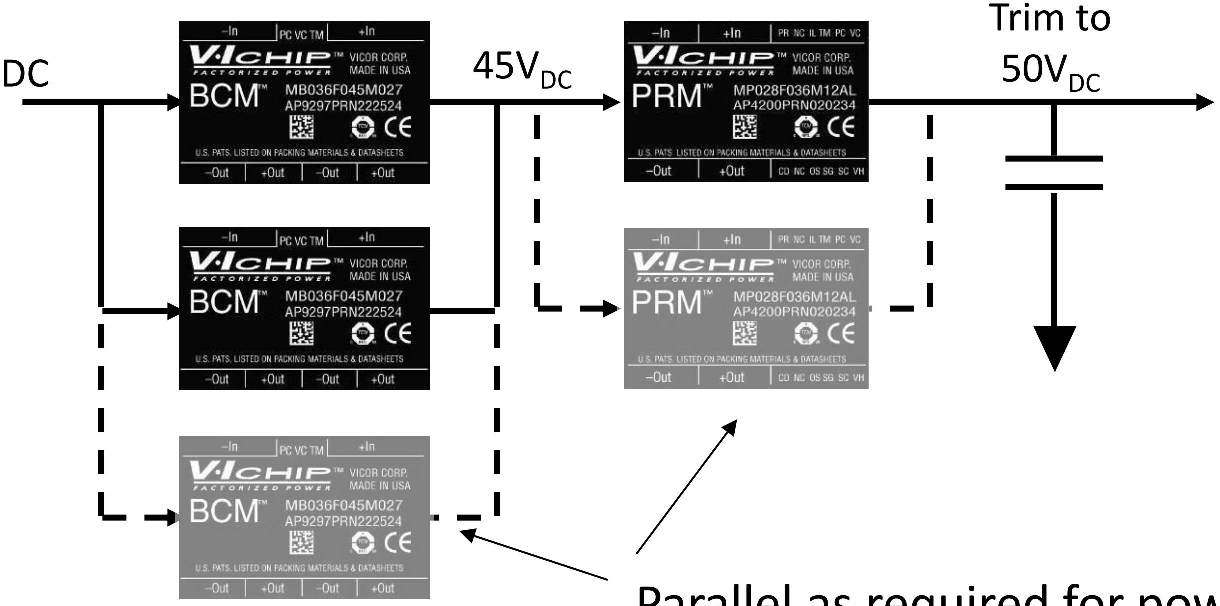
Bus Converters
MBCM270F450M270A00
K=1/6
MIL-STD-704E/F
Each 270W (350W < 85°C)

Regulators
PRM48BF480M400A00
Each 400W

270V_{DC}

45V_{DC}

Trim to
50V_{DC}



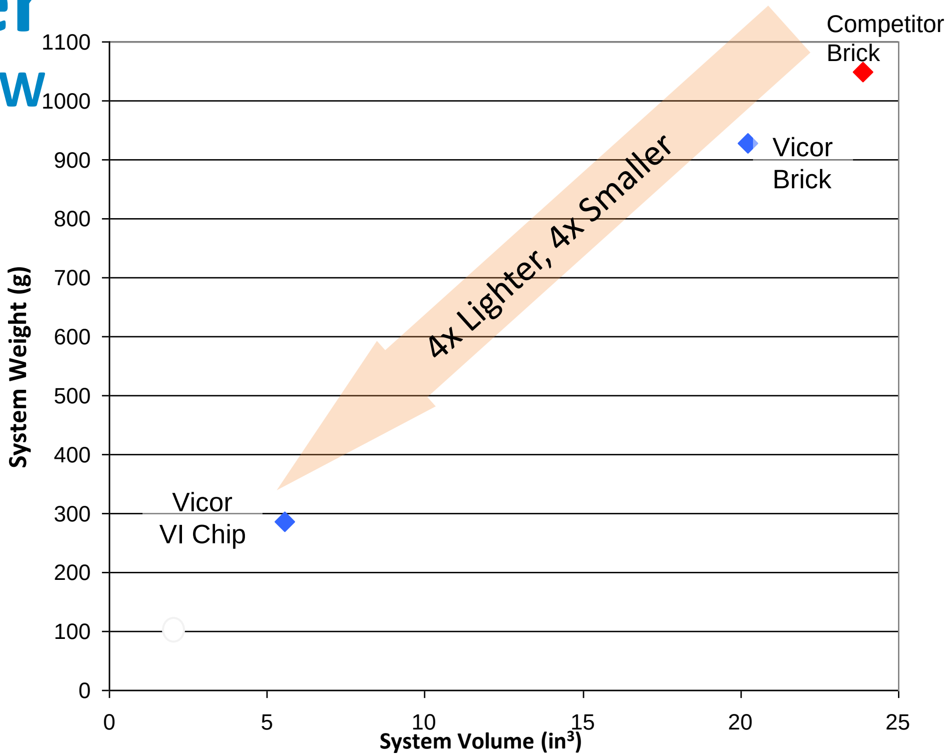
GaN
Transmitter

Parallel as required for power

Size, Weight and Power

270 V (MIL-STD 704D) to 28 V bus, 2400 W

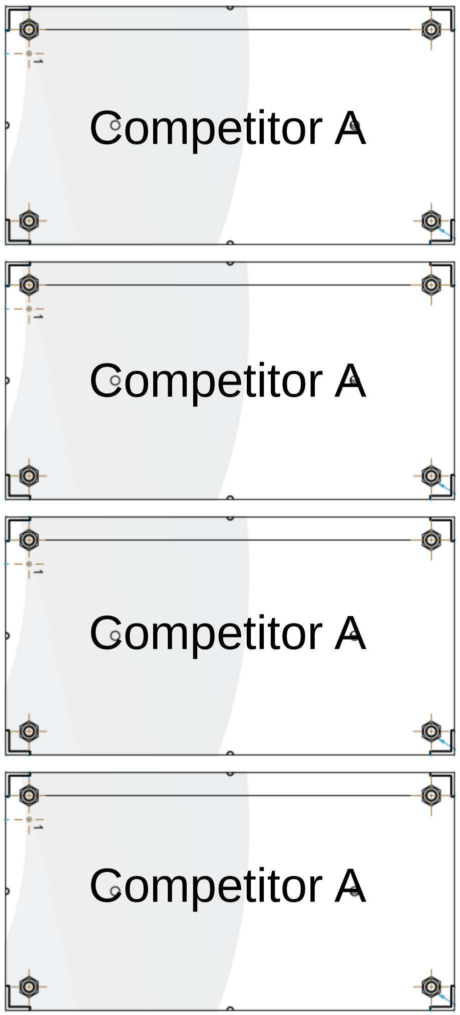
- **System:**
  - Vin = 270 V
  - Vout = 28 V
  - Pout = 2,400 W
- **Chart size and weight for power components only (no heat sinks, fans, etc.)**
- **Heat sink size / weight value derived from loss calculation**
- **This is not the optimal solution:**
  - Additional savings possible depending on amplifier voltage and bulk capacitor requirements



Solution	Partnumber	Package	Part Qty	Efficiency (%)	Volume Each (in^2)	Weight Each (g)	Area Total (in^2)	Volume Total (in^3)	Weight Total (g)	Heatsink Size / Weight
Competitor A	MCOTS-C-270-28-FT	Full Brick	4	91.0%	6.0	262	47	24	1048	Nominal
Vicor Brick	V375A28M600Bxx	Full Brick	4	88.0%	5.1	232	40	20	928	+33%
VI Chip	MBCM270F450M270A00, PRM48BF480M400A00	VI Chip	19	92.5%*	0.3	15	21	6	285	-17%

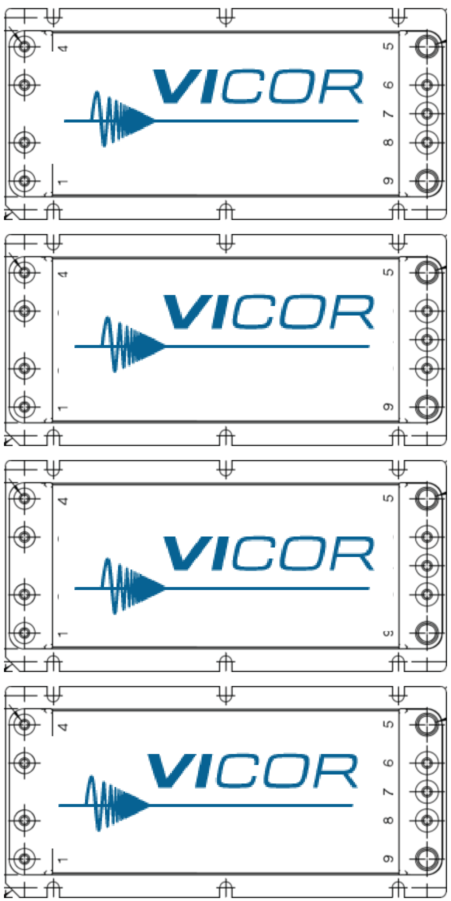
2400W Component Area (270 Vin, 28 Vout)

47 in^2 (1048g)



VERSUS

40 in^2 (928g)



VERSUS

21 in^2 (285g)

Space-saving Powertrain – and no 'Bulk Caps'

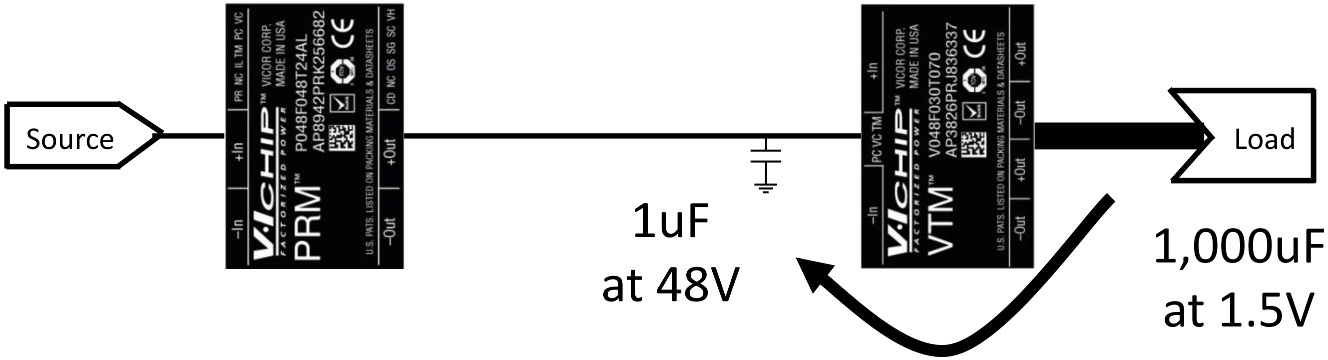
Direct 48V-to-load conversion with 2 VI Chips

Move PRM away from load

- Increased space on motherboard / near load
- Reduced power dissipation at load

Eliminate bulk capacitance

- VTM has very low output impedance (<1mOhm from DC to 1MHz)
- PoL bulk capacitors replaced by 48V ceramic capacitor
- Save space and cost

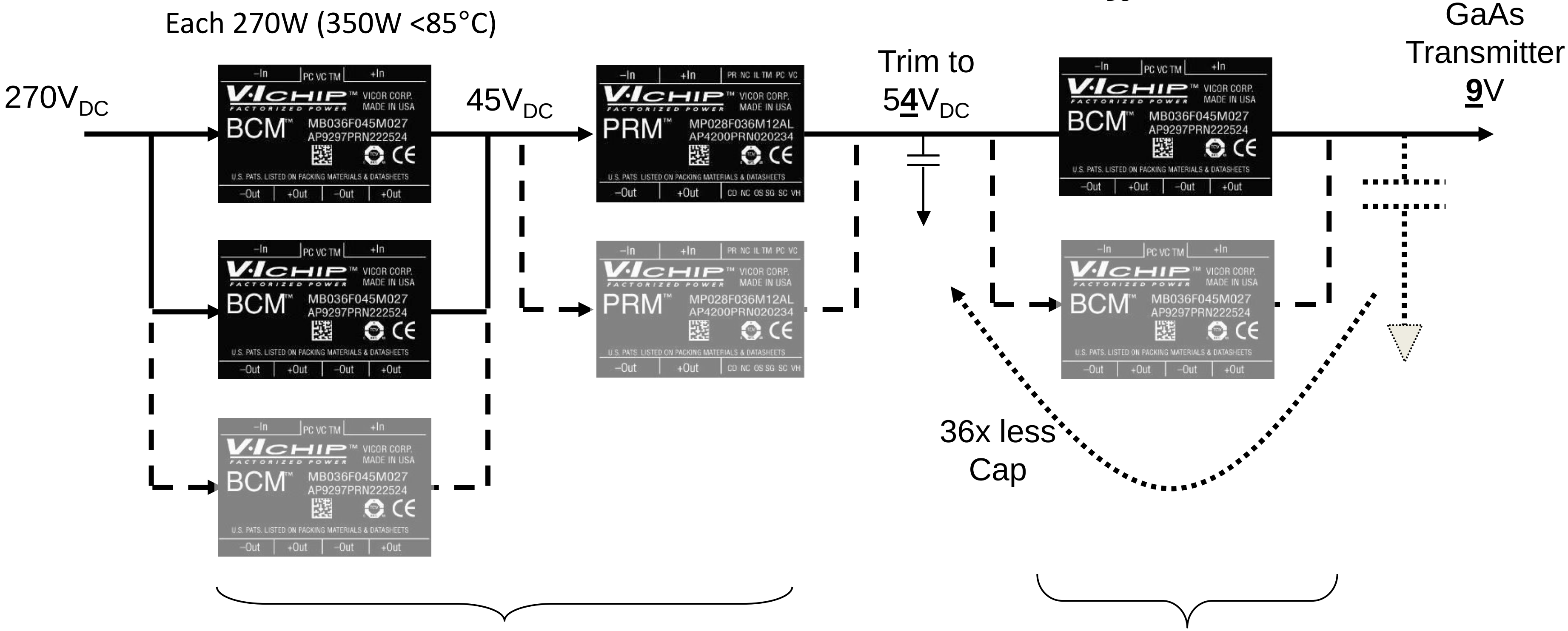


Pulsed Power Loads – GaAs example

Bus Converters
MBCM270F450M270A00
K=1/6
MIL-STD-704E/F
Each 270W (350W <85°C)

Regulators
PRM48BF480M400A00
Each 400W

Bus Converters
B048F080M24
K=1/6
Each 240W$_{DC}$, 360W 1ms pulse



Parallel BCMs and PRMs for ***average*** power
('trickle-charge' cap bank)

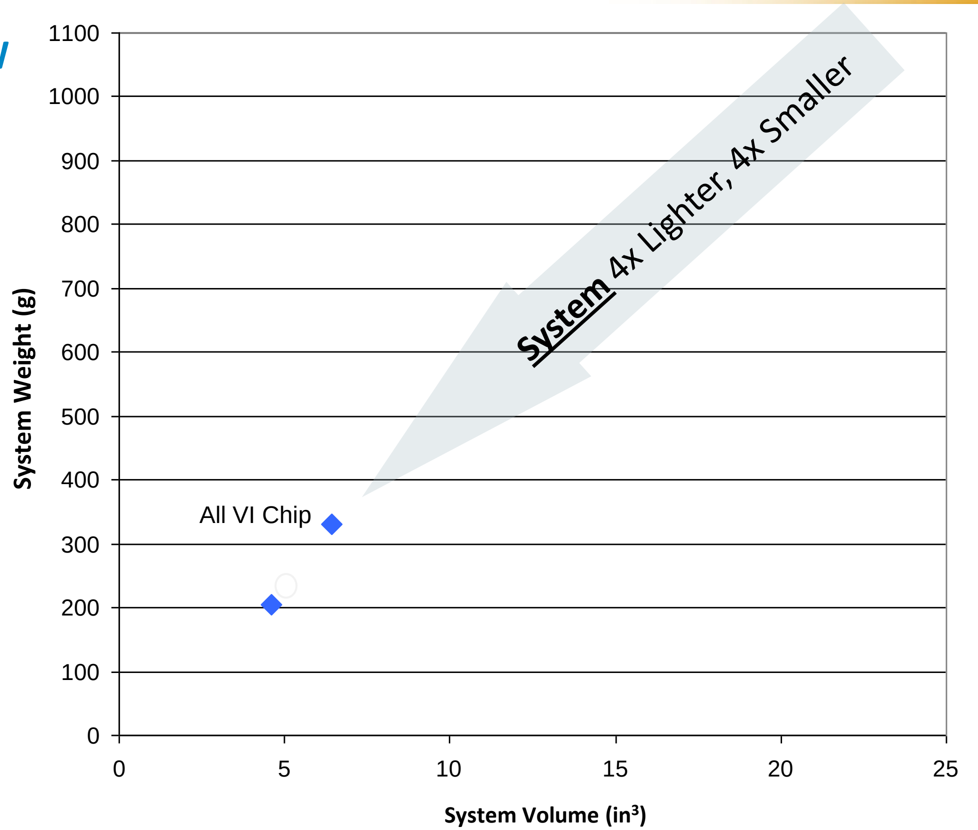
Parallel ***fewer*** BCMs for ***pulse*** power
(BCMs have pulsed 150% over-power rating)

SWaP including path to 9V

270V (MIL-STD 704D) to 9V Transmitter, 2400W

- **System:**
  - V_{IN} = 270V
  - V_{OUT} = **9V**
  - P_{OUT} = 2,400W
- **Chart size and weight for power components only (*no heatsinks, fans, etc.*)**
- ***270V-9V efficiency >89%***
- ***Bulk capacitance reduced***
  - *By 36x in μF*
  - *By >5x in weight / volume*

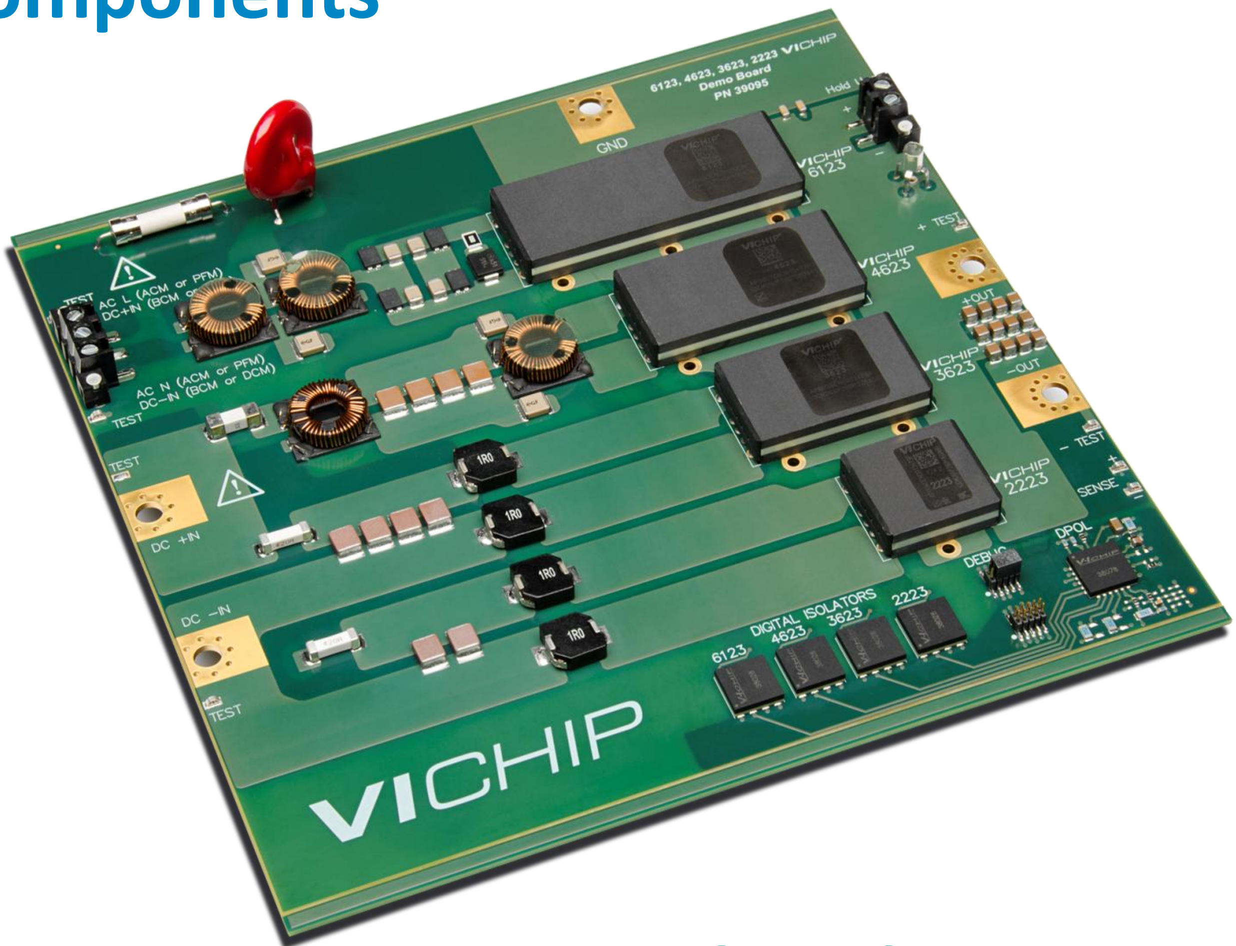
    accounting for different capacitor technology (e.g., 15V vs. at 10V)



Solution	Partnumber	Package	Part Qty	Efficiency (%)	Volume Each (in²)	Weight Each (g)	Area Total (in²)	Volume Total (in³)	Weight Total (g)	Bulk Cap Size / Weight
VI Chip	MBCM270F450M270A00, PRM48BF480M400A00, B048F060T240	VI Chip Full Chip	22	89.4%	0.3	15	24	6	330	-80%

ChiP Power Components

- Efficient
- Dense
- Flexible
- Scalable
- Cost-effective



Thank You