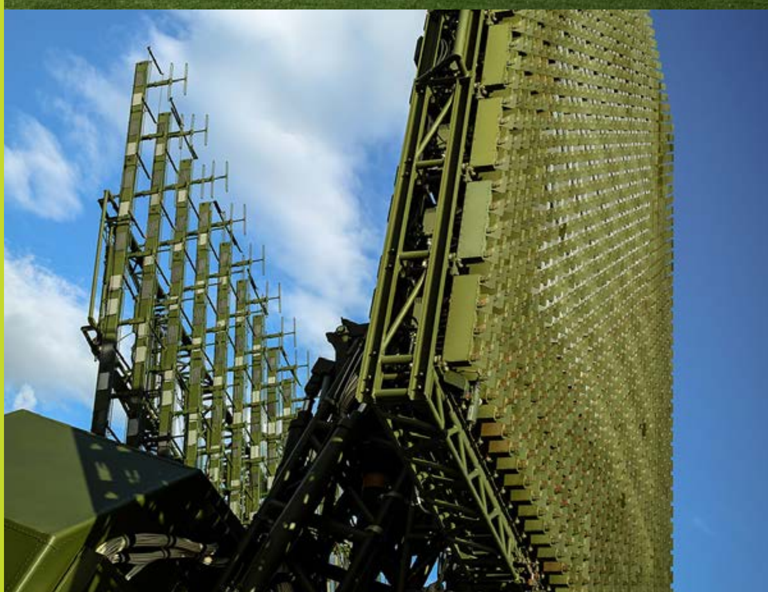





Aerospace, defense and satellite eBook

Innovative and reliable power solutions

for mission critical applications

VICOR

Contents

Aerospace/Defense and Space eBook Introduction

Driving innovation from decades of proven experience

Since 1981, Vicor has a long and successful heritage of serving customers in the aerospace/defense market and now the burgeoning commercial space market. Vicor has long supported key engagements in air, ground and shipboard power applications with high-performance MIL-COTS power modules that offer high density, efficiency and reliability using robust designs backed by 30-years of dedicated design and manufacturing excellence in the aerospace and defense industry.

> It is vitally important we continue to innovate to stay one step ahead of the rapidly growing number of sophisticated threats we need to protect against.

Staying ahead of today's evolving threats

We live in a rapidly changing world full of promise and possibilities. Along with that change comes the growing need to protect our interests at home and abroad from constantly evolving threats. Because of international access to new technologies these threats have become more sophisticated and lethal making it even more important that we stay one step ahead to thwart any attempts of hostility. Vicor power modules are making it possible for our armed forces to field new defense systems to help guard against these threats. From shipboard based phased array radar systems to high-energy laser directed energy weapons, used to neutralize drone swarms, Vicor has the power and reliability our armed forces need to keep us safe 24/7 365.

Case studies

Case study:

ASM missile capability

Adding air-to-surface (ASM) missile capability to an existing UAV platform

Customer's challenge

Adding air-to-surface (ASM) missile capability to an existing UAV platform requires the existing sensor suites remain in place and fully functional to preserve the multi-mission role of a UAV. And in some cases, the existing sensor data will also be utilized in support roles for this new addition to the platform. The challenges are to find a solution that will fit within a minimal mechanical footprint, add the least possible mass and utilize the limited power available – a classic size, weight, power reduction (SWaP) challenge.

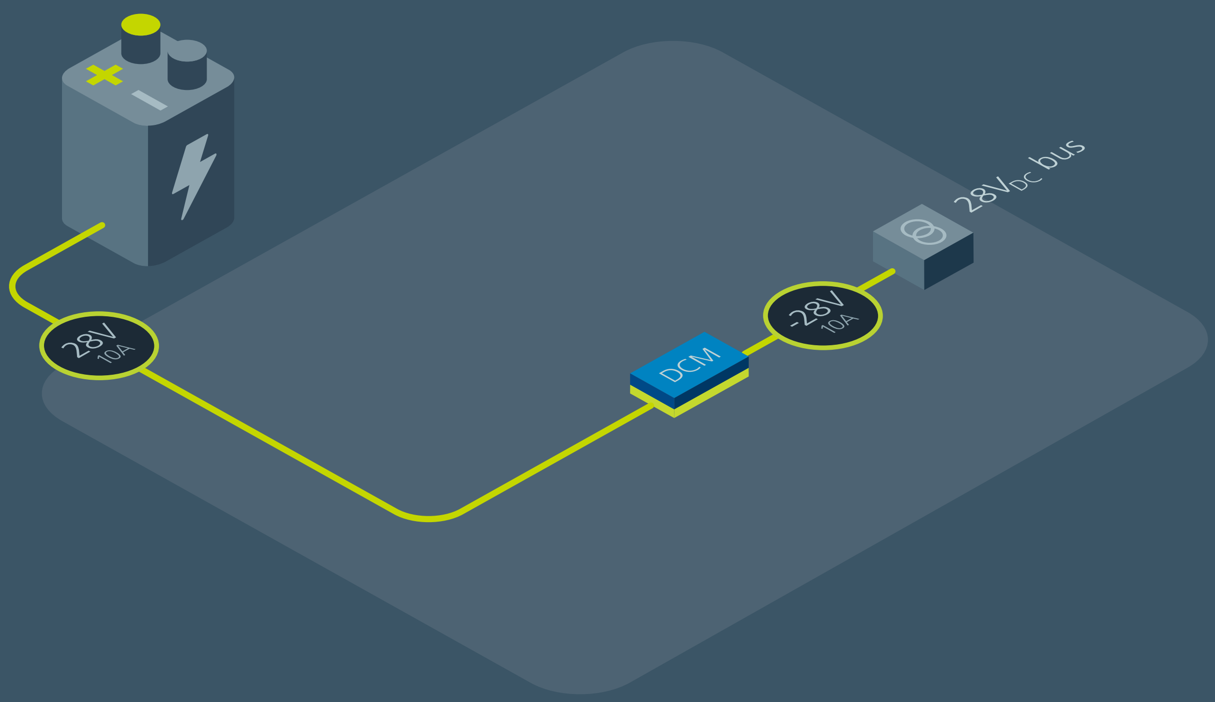
The Vicor solution

A 28V MIL-STD-704F input to –28V at 300W is converted using a DCM isolated, regulated DC converter. The thermal, mechanical and density benefits of Vicor ChiP packaging allow for cost-effective power solutions with previously unattainable system size and weight. Coupled with the high efficiency gained through zero voltage switching (ZVS) topology, these modules provide superior power system performance in a wide variety of environments. In this application, the Vicor DCM3623 provides the DC-DC conversion with a wide input range of 16V to 50V, peak efficiency of 93.6% and power density of 818W/in^3.

- Wide operational input range
- High power density enables small power footprint
- Reduces SWaP-C

Air-to-surface missile power delivery network

The PDN shown takes a 28V MIL-STD-704F input to –28V at 300W is converted using a DCM isolated, regulated DC converter. The low profile of the thermally efficient DCM enables a cooling solution utilizing an available cold wall, which along with the 818W/in3 DCM power density, further reduces the footprint of the PDN. The high efficiency of the DCM reduces the heat loss and improves reliability, while its high frequency helps reduce the size of the EMI solution.



DCM3623 DC-DC converter

Input: 24 – 110V

Output: 3.3 – 48V

Power: Up to 320W

Peak efficiency: 93.8%

36.4 x 22.8 x 7.3mm

vicorpower.com/dcm

Case study:

Portable digital radio

Vehicle-powered, portable digital radio

Customer's challenge

For this application, a new power solution is required to support a performance upgrade to an existing vehicle-mounted radio providing voice and data communications across the battlefield. Size, weight, and power are always critical parameters in vetronics applications, and in this case, the new peak RF output power requirement requires a well-regulated 48V at over 1kW, requiring an extremely dense power solution.

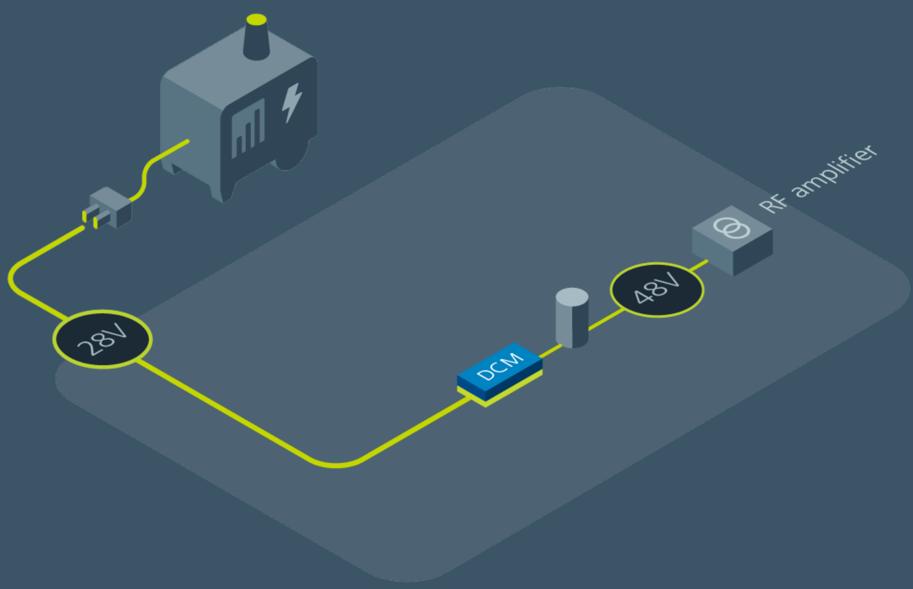
The Vicor solution

Today's sophisticated Vetronics systems are considered the digital hub of military vehicles. Vicor's power module solutions deliver the reliable power needed to enable the mission critical systems such as battlefield mobility, inter-vehicle communications and vehicle defense. Vicor's DCM3623 DC-DC converter module delivers regulated 48V (from a 28V supply) power to the charge the in-line capacitor for high peak power conditions.

- High power capability
- Reduced SWAP-C
- Improved reliability

Portable digital radio power delivery network

This PDN boosts the 28V bus to a regulated 48V with a MIL-COTS DCM3623 DC-DC converter module. The regulated 48V from the DCM charges a large capacitor required to deliver the high peak power required by the RF stage. The low profile (7.62mm) of the thermally adept DCM facilitates a cooling solution utilizing an available cold wall, which along with the 800W/in3 DCM power density, further reduces the footprint of the PDN. The high efficiency of the DCM reduces the waste heat and improves reliability, while its high frequency helps reduce the size of the EMI solution.



DCM3623 DC-DC converter

Input: 28V (16 – 50V)

Output: 48V

Power: Up to 320W

Peak efficiency: 93%

38.7 x 22.8 x 7.26mm

vicorpower.com/dcm

Case study:

Electronic countermeasure

Electronic countermeasure

Customer's challenge

The inclusion of airborne electronic attack capability to a long-duration UAV platform provides upgraded electronic warfare support in theater during engagements lead by older or slower aircraft that often rely on last-generation platforms. The challenge is to implement the smallest, lightest solution that is able to drive multiple high voltage sources to an isolated 270V with current sharing.

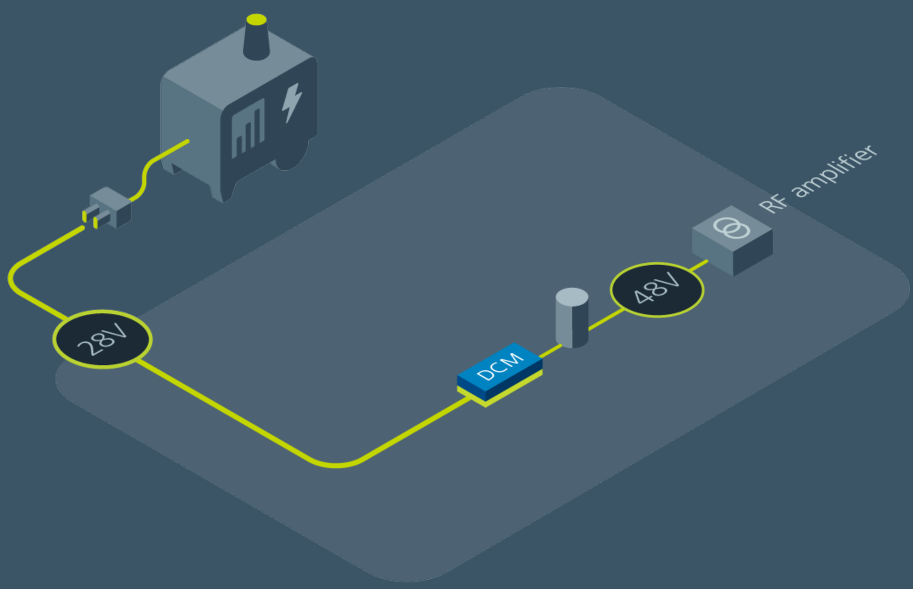
The Vicor solution

A stack of six BCM converter modules with the outputs all in series provide 4,242V_{DC} isolation and exceptional efficiency of 97.9%. As is typical in any UAV, the space made available is limited and of irregular shape. The Vicor modular approach allows for greater flexibility and scalability when designing a power delivery network. You can modify or update existing PDNs, that use Vicor modules, simply by replacing the module with the new desired power rating.

- Recuced SWaP-C
- Improved design flexibility and scalability
- Supports wide range of power inputs

Electronic counter measure power delivery network

This PDN boosts the 28V bus to a regulated 48V with a MIL-COTS DCM3623 DC-DC converter module. The regulated 48V from the DCM charges a large capacitor required to deliver the high peak power required by the RF stage. The low profile (7.62mm) of the thermally adept DCM facilitates a cooling solution utilizing an available cold wall, which along with the 800W/in3 DCM power density, further reduces the footprint of the PDN. The high efficiency of the DCM reduces the waste heat and improves reliability, while its high frequency helps reduce the size of the EMI solution.



DCM3623 DC-DC converter

Input: 28V (16 – 50V)

Output: 48V

Power: Up to 320W

Peak efficiency: 93%

38.7 x 22.8 x 7.26mm

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Case study:

Tethered vehicles

Tethered, aerial and underwater vehicles (UAV/UUV/ROV)

Customer's challenge

This class of unmanned vehicles is powered and controlled via a tether from a ground-based power source. High voltage levels of 500V to 800V allow for greater tether lengths, reduced I^2R losses and smaller and lighter cabling. These attributes enable the drone to fly higher, travel longer distances underwater, increase functionality and carry more payload. The power delivery network (PDN) inside the vehicle must be capable of down-converting the tether's high voltage power source with high efficiency, high power density and low weight in order to free up important payload space. Tethered drone applications typically require a 1 – 5kW ground power supply tethered to a rotor-wing UAV, or UUV, and offer unlimited run time and greater control.

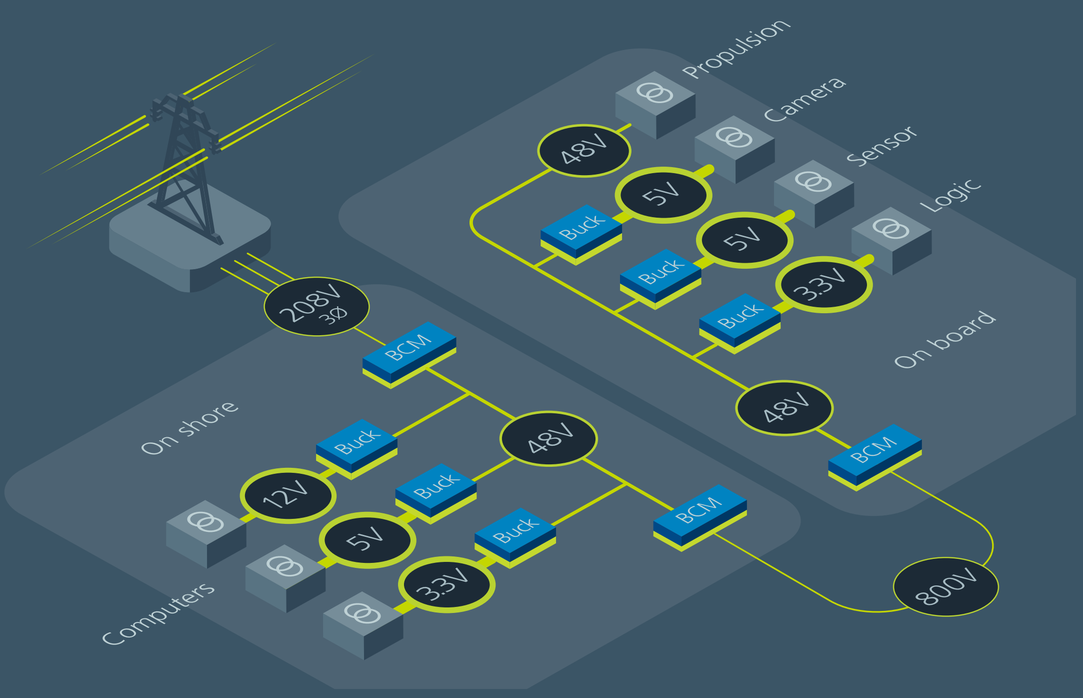
The Vicor solution

Using Vicor's high voltage, fixed ratio Bus Converter Modules (BCMs) and Zero Voltage Switching (ZVS) buck regulators the design engineer can create a power solution that optimizes the system for SWaP-C. One of the key benefits of using a Vicor solution is that you can use higher input voltages that create lower power losses which results in using a much lighter tether helping to reduce the load on the UAV/UUV helping to conserve energy and thereby extending the operational time in the air or under the water.

- Operate at higher voltages (lower losses)
- Manage a greater number of input and output voltages
- Higher density and better performance

Tethered UAV/UUV power deliver network

From the ground station, the BCM4414 isolates and steps down the rectified output from a single or three-phase AC supply to 48V. A second BCM4414 steps up the 48V to 800V for distribution across the tether. A third BCM4414 is used to step down the 800V to 48V onboard the vehicle. Downstream of the BCM4414, ZVS Buck Regulators offer board-level designers maximum power density and flexibility for high efficiency point-of-load DC-DC regulation. The integration of a high-performance Zero-Voltage Switching (ZVS) topology increases point-of-load performance, providing best-in-class power efficiency up to 98%.



MIL-COTS BCM® bus converter modules

- Input: 200 – 400V, 400 – 700V, 500 – 800V
- Output: 2.4 – 55.0V
- Current: Up to 35A
- Peak efficiency: Up to 98%
- As small as 2.5 x 0.9 x 0.3in

vicorpower.com/mil-cots bcm

MIL-COTS ZVS buck regulators

- Input: 12, 24 or 48V
- Output: 1 – 16V
- Current: Up to 22A
- Peak efficiency: 98%
- As small as 7 x 8 x 0.85mm

vicorpower.com/buck

Technical articles

White Paper by Ken Coffman and Salah Ben Doua

Delivering higher power density and low noise for New Space applications

VICOR

To reduce expensive communication traffic between satellites and the Earth, increased processing power is being hosted on satellite platforms. To meet the demands of additional onboard computation, signal- and data-processing hardware, system power and point-of-load (PoL) requirements must increase. Because hard-switched converters have drawbacks in size, efficiency and electromagnetic interference, system engineers and power supply designers are driven to consider more advanced power supply topologies.

Due to the physical size of modern ASICs, FPGAs, CPUs and GPUs—and their necessary cooling solutions—circuit board real estate around these big chips is precious. These chips require progressively lower voltages with increasing currents—hence the need for an optimized power delivery network (PDN).

Therefore, it is helpful to divide the PDN task into two sections: a regulation section that can be placed in a convenient location, and a power delivery section that benefits from being placed as close to the load as possible. This is a fundamental principle of the Vicor Factorized Power Architecture (FPA™).

Soft-switching topologies have distinct advantages over hard-switched converters by enabling high fundamental conversion frequencies with low harmonic noise.

Compared to a hard-switched, multi-phase topology…

1. A zero-voltage switching (ZVS) and zero-current switching (ZCS) topology, running at the highest practical frequency, is more space-efficient and dissipates less wasted power.
2. A zero-voltage switching (ZVS) and zero-current switching (ZCS) topology does not have the high-frequency, harmonic-series noise profile character.
3. With a >1MHz operating frequency, Vicor converters do not have troublesome 100-500kHz frequency content.
4. With low harmonic content and high fundamental conversion frequency, the noise-filter implementation is compact.

Vicor power modules operating at >1MHz help engineers create low common- and differential-mode (CM and DM) noise designs, particularly when component arrangements and device interconnects are properly considered.

As always, input and output filters are required and must be designed and placed properly, but the inherent nature of Vicor converters make this task easier.

Factorized Power: Delivering high current and low voltage efficiently

Top challenges for satellite power system designers:

1. Higher and higher load current requirements, from 10s of amps to 100s of amps.
2. Loads requiring faster transient response with tighter tolerance windows.
3. Requirements for lower PDN losses and impedances.
4. Expanding use of higher-voltage busses to reduce conductor sizes.

In addition to the advancing electrical requirements in space, radiation TID (total ionizing dose) and SEE (single-event effects) requirements are added. In some cases, the New Space philosophy of smaller, faster and cheaper space platforms and launches led to the adoption of rad-tolerant design methods as a cost-reduced substitute for radiation-hardening. This new approach is based on determining an acceptable level of performance and reliability based upon the specific mission, then developing boards and electronics based on size, weight and power consumption (SWaP) tradeoffs, as well as cost-effectiveness. This design strategy suits LEO and MEO satellite orbits inside the Van Allen radiation belt.

Optimizing for a high-current, high-density PDN calls for a new approach and a Factorized Power Architecture should be considered. The Vicor New Space FPA divides the PDN into three stages. Fixed ratio, non-regulated isolated DC-DC bus converters (BCM®), isolation and voltage transformation module (VTM™) convert voltages from one level to another. Pre regulation module (PRM™) regulators provide voltage regulation and control the converter output voltage to a target value when the input voltage and output load varies.

In the current generation of Vicor New Space converters, an unregulated first-stage BCM provides isolation from the spacecraft bus, a supply voltage for the downstream converters and voltage transformation to create an intermediate bus voltage compatible with the downstream converters. The current BCM design offers a 3:1 transformation ratio to convert $100V_{DC}$ to $33V_{DC}$, but other transform ratios are being studied and considered to support other bus voltages.

The second-stage PRM™ performs accurate output voltage regulation with a trimmable output voltage range of 13.4V – 35V.

The third stage VTM is the power delivery stage. It transforms the higher voltage from the PRM to the voltage required by the load. Currently, there are two transformation ratios: 8:1 and 32:1. VTMs are called current multipliers because the input to output current transformation is the inverse of the voltage transformation ratio. As an example, 6A injected into the 8:1 VTM results in a 48A output current.

Designing a low-noise Factorized Power Architecture for New Space

BCMs, PRMs and VTMs are the components that make FPA possible. The current generation of radiation-tolerant New Space BCMs, using patented Vicor Sine Amplitude Conversion (SAC™) topology, has an impressive peak efficiency of 96.9%.

Vicor PRMs use a patented ZVS buck-boost regulator control architecture to give high-efficiency step-up and step-down voltage regulation and soft start. Maximum efficiency is achieved when $V_{IN} \approx V_{OUT}$, with 97% peak being achieved with the latest PRMs.

VTM current multipliers are high-efficiency voltage transformation modules using a proprietary ZCS/ZVS Sine Amplitude Converters which transforms a nearly pure sinusoidal waveform with high spectral purity and common-mode symmetry. These characteristics mean it does not generate the harmonic content of a typical hard-switched PWM type converter and generates minimal noise. The control architecture locks the operating frequency to the powertrain resonant frequency, enabling up to 97% efficiency and minimizing output impedance by effectively canceling reactive components. This very low, non-inductive output impedance allows it to respond almost instantaneously to step changes in the load current.

The VTM responds to load changes regardless of magnitude in less than a microsecond. The VTM's high bandwidth obsoletes the need for large point-of-load capacitance. Even without external output capacitors, the output of a VTM exhibits a limited voltage perturbation in response to a sudden power surge. A minimal amount of external bypass capacitance (in the form of low equivalent series resistance/equivalent series inductance (ESR/ESL) ceramic capacitors) minimizes the output transient voltage overshoot.

Because the VTMs are nearly transparent without capacitive or inductive storage, bulk capacitance can be placed on the input voltage side—taking advantage of the squared voltage term along with the linear voltage transform ratio.

$$Ej = 1/2\ CV^2$$

Ej = Stored Energy in joules

C = Capacitance in farads

V = Voltage in volts

As an example, for equivalent energy storage with the Vicor VTM with an 8:1 transform ratio, 25µF of input capacitance at 28V acts very much like 1600µF of output capacitance at 3.3V (see Figure 1).

Because the VTMs are nearly transparent, the capacitance transfer ratio between input and output can help with pulsed loads. This transform means smaller values of capacitance (at the higher voltage) can be used to serve pulse-load requirements.

Vicor radiation-tolerant New Space VTMs have peak efficiencies of 94.7% for 8:1 transformation (3.3V at 50A) and 92.9% for higher-current 32:1 transformation with 0.8V at 150A capability.

Energy storage and dynamic response the FPA way

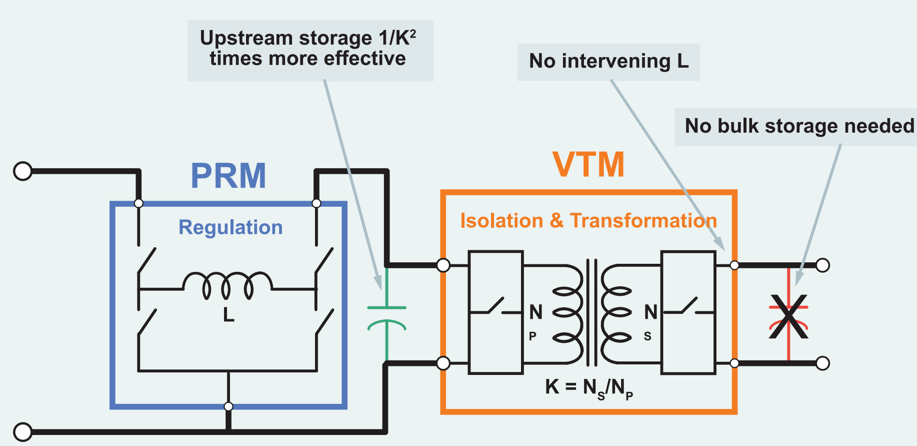


Figure 1: Diagram showing the more efficient and flexible Factorized Power Architecture (FPA) using Vicor PRM and VTM module products.

Benefits of FPA

The Factorized Power Architecture (FPA™) enables power system density and high-current demands to keep pace with rapidly advancing CPU, GPU and ASIC technologies. Some key system design advantages include:

- Reduced PDN real estate consumption near the CPU/GPU by 50% or more
- Reduction by an order of magnitude in PDN and associated board losses
- Unfettered performance by placing the PRM in non-critical board edge areas
- Simplified CPU I/O routing
- Mitigated risk of placement near the processor's SerDes because of lower noise performance of the VTM

Overall peak efficiency for a power system—including the combination of a BCM, PRM and VTM — operating from an unregulated DC source and supplying a regulated, low-voltage DC output is 89% (for 100V:3.4V at 50A transformation) and 87.3% (for 100V:0.8V at 150A transformation). With higher efficiency comes lower total heat dissipation, an important consideration in a power system design for spacecraft where cooling mechanisms require additional mass and structure.

A summary of radiation tolerance parameters for the Vicor New Space power solution

A lot of work is required to create power modules that will survive useful periods in Low Earth orbits (LEO) and Medium Earth orbits (MEO).

In order to meet TID requirements, components must be carefully selected, screened for radiation performance and parameter variations are included in worst case analysis to assure performance.

In order to meet enhanced low dose rate sensitivity (ELDRS) requirements, only known-ELDRS-performance-rated components are used or the parts are tested at low-dose rates.

In order to meet single-event performance requirements extensive testing with accelerated charged particles has been performed. All parts that are used are tested and analyzed to survive up to a linear energy transfer of 35MeV-cm^2/mg. To mitigate for single event functional interrupts (SEFIs), dual-redundant internal powertrains with monitoring and power-cycling capability are implemented.

Vicor New Space radiation-tolerant power modules are survival-rated at 35MeV-cm^2/mg and TID rated at 50krad.

Worst case circuit analysis (WCCA) was performed on all circuits including statistical confidence limits (90% confidence with 99% probability) based on sample testing of the parts. Extreme value analysis (EVA), root-sums-squared (RSS) and Monte Carlo analysis methods were used where appropriate to evaluate the power module designs to ensure all parts will perform as expected.

Conclusion

In summary, Vicor technology has key advantages for New Space missions. To explore Vicor solutions in more detail, Vicor shares more information and radiation test data under NDA with select customers.

White paper by Matt Renola, Sr. Director Global Sales
Aerospace and Defense

The future of standardized defense platforms using MOSA, SOSA and VPX open architectures

Recent trends in the defense industry show there is a convergence towards standardizing electronic systems using open standards to increase interoperability, scalability, reliability, reduce system costs, and minimize the number of custom electronics designs that increase overhead and maintenance. In 2019, a DoD Tri Services memo was published calling for a MOSA (Modular Open Systems Approach) to be used to the maximum extent possible for future weapon system modifications and new start development programs. The memo, titled "Modular Open Systems Approaches for our Weapon Systems is a Warfighting Imperative," specifically cites the Sensor Open Systems Architecture (SOSA) Consortium, in addition to the Open Mission Systems/Universal Command and Control Interface (OMS/UCI), Future Airborne Capability Environment™ (FACE) and Vehicular Integration for C4ISR/EW Interoperability (VICTORY) standards, "as vital to our success."

What does all this alphabet soup really mean? Are MOSA, SOSA, FACE, VICTORY, and others just more attempts by the government to provide the same framework for oversight within different groups? In peeling back the onion, the outcome is obvious. The government is trying to provide some guidance with respect to the tri-services (Army, Navy, and Air Force) involved in key weapons development. This MOSA memorandum really announced that there was a need to insure interoperability and commonality across key hardware and software development.

For many years prior, each of the service branches in cooperation with industry and academia, have undertaken development efforts that have led to many of the working groups including the establishment of OMS/UCI, SOSA, FACE, and VICTORY. These working groups and their efforts have all contributed to the MOSA initiative and driving commonality across future design efforts. Modularity and flexibility from both a manufacturing and design standpoint enables users to address thermal management considerations and provides adaptability where standards may deviate. Often times customers are trying to move the goalposts and push the boundaries of capability and performance; with a modular approach internally, this flexibility can often be achieved by substitution of one part of another to allow for a quick-turn deliverable.

SOSA and VPX power management

VPX (VITA 46) and OpenVPX (VITA 65) are two popular standards that are being adopted rapidly with VITA 62 providing the guidelines for developing a power supply to support both VPX architecture requirements. The modular power supply standard includes provisions for redundancy, scalability, and energy storage for systems that may require hold-up. While VITA62 is intended to support VPX applications, system designers can implement the modular power supply in applications that are non-VPX.

The VITA 62 standard provides guidelines for mechanical packaging, electrical and mechanical interfaces and communication specifications that a power supply can incorporate. Most common off-the-shelf VITA 62 compliant power supplies are equipped with six outputs:

1. VS1 +12V,
2. VS2 3.3V,
3. VS3 5V,
4. AUX1 -12V,
5. AUX2 +3.3V and
6. AUX3 +12V.

Outputs VS1, VS2, and VS3 are intended to be high current or high-power outputs while the auxiliary outputs are for low power and signal circuitry. VITA 62 power supplies can have different combinations of outputs on VS1, VS2 and VS3 to support VPX applications.

SOSA specifies a power supply with fewer outputs than VITA 62 while heavily referencing VITA 62, VITA 46, VITA 48, VITA 65, and various MIL-STD standards for design guidelines and power and electromagnetic compliance (EMC).

SOSA aligned power supplies only have two outputs – VS1 12V and VAUX 3.3V. The VITA 62 standard also defines standard control logic both analog and digital for operating the power supply, which increases interoperability and reduces designer's burden for implementation.

Figure 1: Vicor VITA 62 and SOSA power supplies classified by input voltages.

Both SOSA aligned and VITA 62 power supplies can be equipped with two independent I^2C communication channels. An optional communication interface is defined in VITA 46.11 utilizing the intelligent power management interface (IPMI 2.0) commonly used in autonomous computer systems that provides management and control of the power supply.

Power supplies designed around VITA 62 and SOSA have multiple input AC and DC input options with a fixed number of outputs. The classes of power supplies offered by VICOR to support open architectures are categorized by their input voltage.

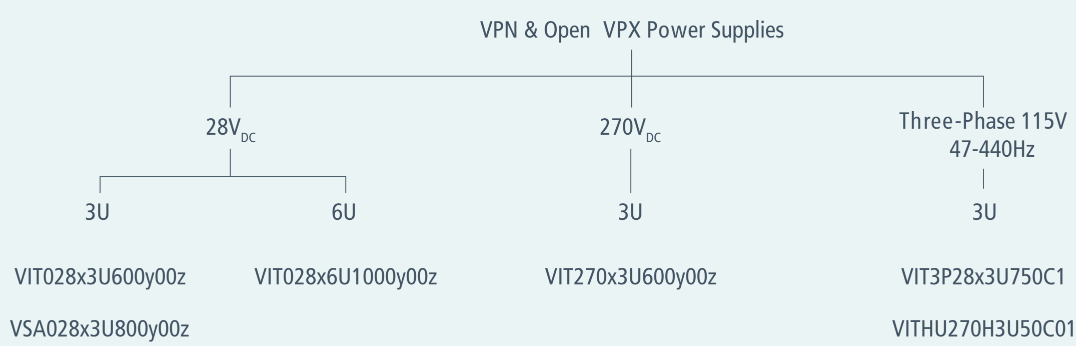


Figure 2: Vicor VITA 62 and SOSA power supplies classified by input voltages.

All power supplies defined by the VITA 62 and SOSA standards have at least two alignment key slots based on their input power characteristics. A 3U power supply with a 16V to 50V_{DC} input cannot be inserted into an application that requires 3U single-phase AC power when the system designer implements keying defined by Tables 4.3.2in VITA 62.0.

Deployment of any new power solution in a defense application requires meeting various environmental and electrical MIL-STD standard specifications before adoption. VITA 62 compliant power supplies can optionally meet EMC compliance defined in MIL-STDs 1275, 704, and 461, listed in Section 3.2 of VITA 62.0. Testing power supplies in systems can be a multi-month process requiring iterations to the design of the power supply, EMI filtering or system back plane to pass required EMC standards. VITA 62 and aligned power supplies stand out in the market by guaranteeing all power supply models comply with the standards listed in their data sheets and are verified at independent certified test labs.

Figure 3a shows a typical VPX power supply two-stage application where stage 1 is a Vicor front-end three-phase AC input module VIT3P28M3U750C coupled with a Vicor energy storage VITHU270H3U50C01 hold-up card to provide 50ms hold up at full power. The first stage provides a single 28V output and is connected to the second stage, a back-end Vicor VITA 62 VIT028T3U600C000 supply where the outputs are loaded at 600W in aggregate. Calibrated test lab EMI scans in Figure 3b show the entire system passing MIL-STD-461G CE102 EMI scans.

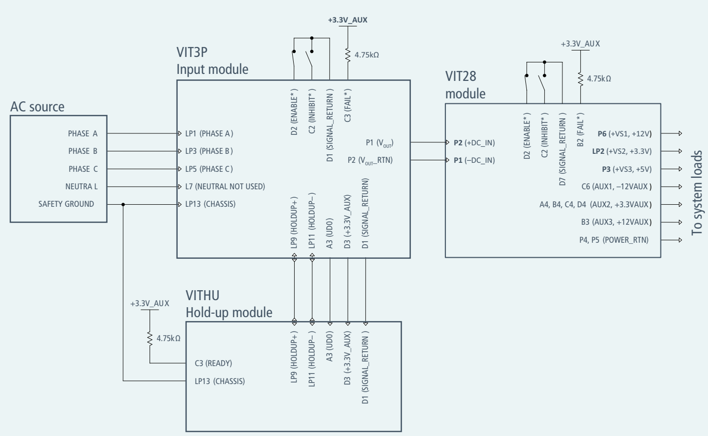


Figure 3a: Typical three-phase application.

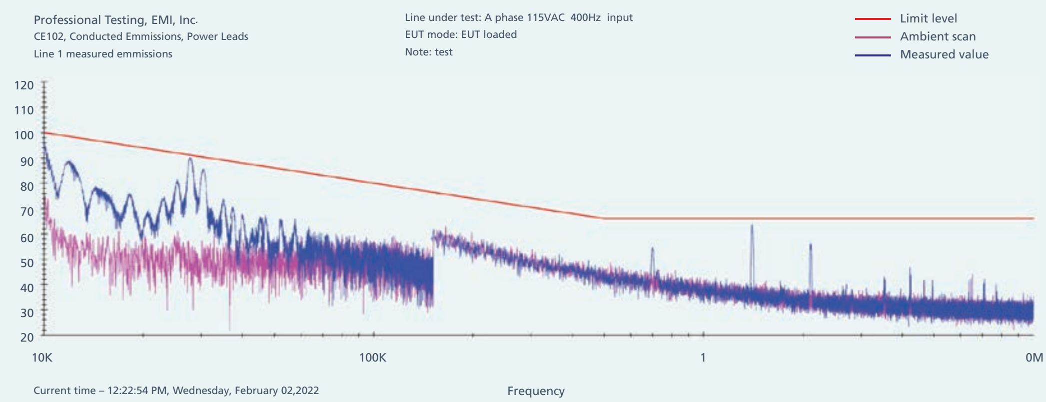


Figure 3b: MIL-STD-461G CE102 EMC Scan of a three-phase input line when the outputs of the VIT028x3U unit are loaded at 100%.

Scalability of power solutions is a cornerstone of open systems architecture standards. To this end, VITA 62 and SOSA standards provide recommendations for power supplies to be paralleled to combine the output capability of their main outputs. Design standards reserve contacts on the connector interface of the power supply to simplify paralleling power supplies and balance their output current sharing.

Paralleling can be taken a step further by unloading the burden of paralleling from the system architect by facilitating current sharing between supplies without the need for reserved contacts that are dedicated for power sharing between supplies. Conventional VPX power supplies require careful system design and special power supply part numbers to enable current sharing between supplies.

Current sharing between power supplies from Vicor have a proven wireless droop sharing algorithm. Figure 4 shows how the VS1 +12V output of a 6U power supply operating in paralleling mode. The output voltage varies with load current while still maintaining its voltage within the VITA 62 limits. The company's power supplies have been tested with as many as four units operating in parallel for current sharing.

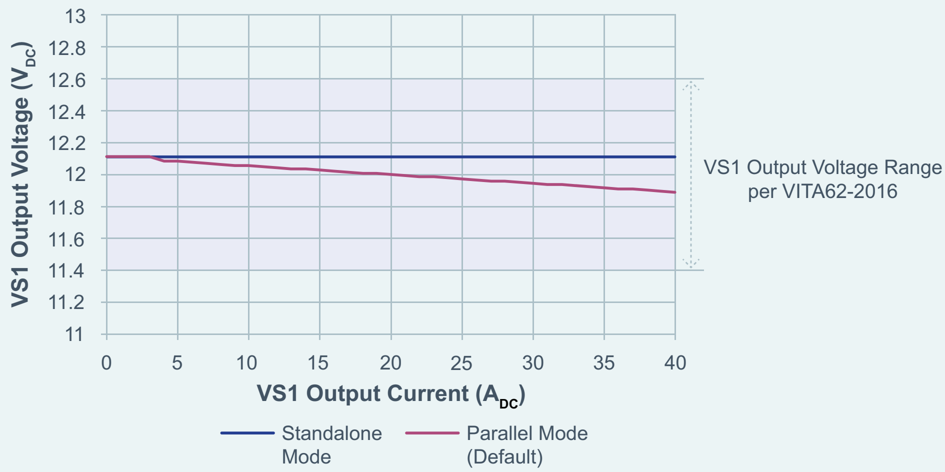


Figure 4: Output voltage variation in parallel and standalone modes.

If the system designer only requires a single power supply in their application, the power supply can be reconfigured through its I²C communication interface on the fly to disable droop sharing, thus achieving better than 1% output tolerance with under variable load (See standalone operation of VIT028x3U600y000).

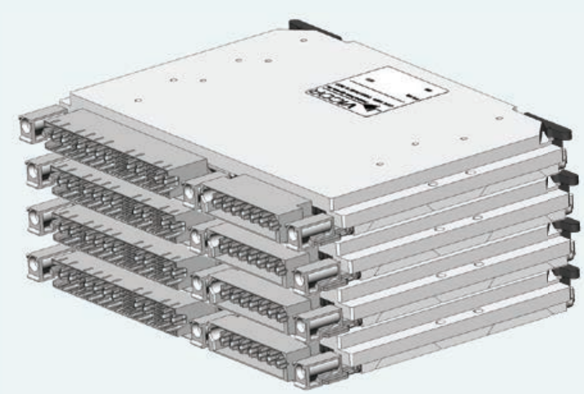


Figure 5: A stack of four VIT028x6U power supplies for system output power capability by 360% compared to a single unit.

I²C communication with SOSA-aligned and VITA 62 power supplies are defined by the VITA 46.11 standard. Conventionally, a 3U power supply supports four addresses, which are set by the application by pulling address pins to logic high or logic low. 6U power supplies support five addressing pins and a wider range of possible I²C address assignments. In a single VITA 62 power supply application, the system designer can now ignore (no connect) the I²C pins, and communicate with the single power supply on address 0x20.

Another advantage in deploying a modular power supply in an application is the ability to have fast start up times by default or customizable start up times and sequencing. In single-stage back-end power supply applications, the power supplies are capable of 200ms start up on all outputs for applications that require it.

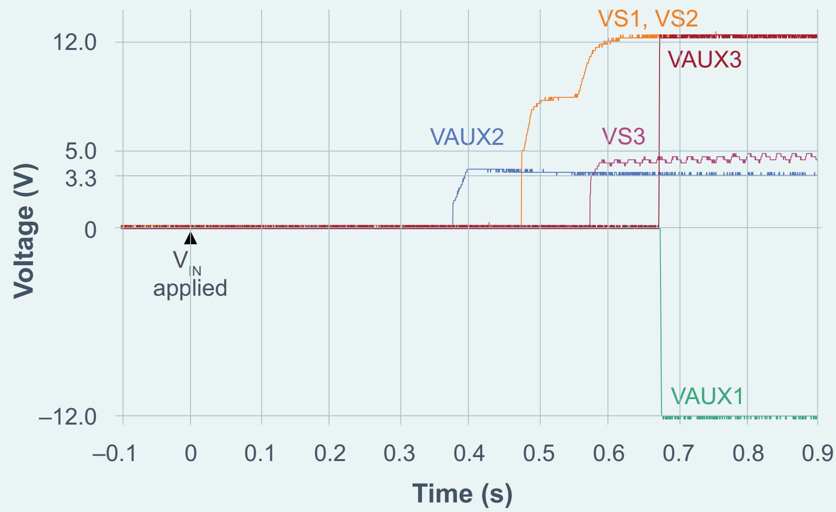


Figure 6: Default 200ms start up on all outputs.

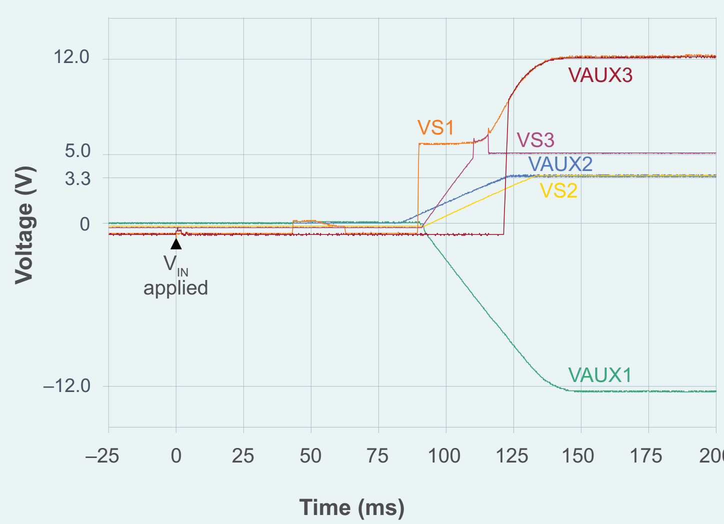


Figure 7: Custom sequenced start up set at factory for a 6U application.

VITA 62 and SOSA aligned power supplies are designed to be able modifiable at the factory to vary the output voltage as well have different output voltage combinations that are not part of the standard offering for a variety of applications. By using a modular approach internal to the packaging, the user can easily provide changes to output voltages or power levels in usually short order.

Article by Salah Ben Doua, Principle Applications Engineer and
Ken Coffman, Senior Field Applications Engineer

Radiation-tolerant power electronic systems are hard to design

Radiation-tolerant design requirements restrict the selection of components. The addition of performance monitors, safety protection mechanisms, power disconnects and reset circuitry must not exceed the efficiency, size and weight requirements of the final solution.

Electronic systems in space are exposed to many hazards. Among other things, without the Earth's protective magnetic field deflecting particles and our atmospheric blanket absorbing solar and cosmic rays, systems are exposed to greater levels of wave and particle radiation. Semiconductor devices are particularly vulnerable to particle radiation, which can lead to component or system faults or failures.

But even passives can be problematic because of issues such as outgassing. Thermal management is more challenging too because convection cooling does not work in space, so designers are limited to removal of heat through conduction to a radiating surface.

This article explores these issues as they relate specifically to the design of space power systems. The focus here is narrowed even further to those "new space" applications where "radiation tolerant" components and circuitry are required rather than the more robust "radiation hardened" devices and circuits. The radiation-tolerant requirement sets the bar lower in terms of a component or circuit's ability to withstand space radiation as reflected, for example, in a component's lower rating for total ionizing dose (TID). However, in exchange for this reduced degree of radiation robustness, component cost is also expected to be lower.

While semiconductor device selection is at the heart of developing radiation-tolerant power systems, it is just one of many design strategies that can be deployed at the component and circuit levels. This article discusses the basic strategies as well as the multiple benefits of soft switching in radiation-tolerant power systems.

Effects of particle radiation and other hazards

For our purposes, wave radiation includes rays and electromagnetic waves. Intuition about wave radiation is guided by what our senses can detect, i.e. visible light we experience with our eyes, infrared light we experience as heat and ultraviolet light we experience when it sunburns our skin.

Generally, wave radiation has properties similar to optics including reflection, absorption, refraction and diffusion. However, space (wave) radiation wavelengths extend above and below the visible light spectrum. Radiation below visibility includes microwaves and radio frequencies (RF). Radiation above visibility includes ultraviolet, X and gamma rays. In Figure 1, note the wavelengths and associated energies—which are key parameters for measuring radiation exposure.

Wave and particle radiation are not really two separate things, but the effects on electronic systems are different. Individual particles have very little mass, but can be accelerated to very high velocities. They can also carry charges—generally positive when negative-charge electrons are stripped from atomic orbits.

From particle radiation, we see physical damage, particularly to semiconductor crystal lattices—damage that is permanent and/or cumulative. We can see temporary upsets where electrons are dragged into depletion regions and make a nonconducting region conduct. We can also see permanent damage when positive ions replace doping atoms in a crystal matrix—sometimes making a semiconductor conduct when or where it shouldn't can also cause permanent damage via circuit malfunction.

There are many hazards in space. Much of radiation damage is cumulative, so the length of the mission is a factor. The intensity of radiation increases as the electronics exit the earth's system, so orbit or exposure to deep space are also factors.

An added factor in the vacuum of space is that the useful convection we use for terrestrial cooling does not work. Conduction works for spreading thermal energy, but eventually, excess heat must be radiated into cold space. A complicating factor is that surfaces exposed to the sun will get very hot, something like 250˚F (120˚C) while shaded surfaces will be very cold, around –238˚F (–150˚C). The thermal design of a satellite system is complex.

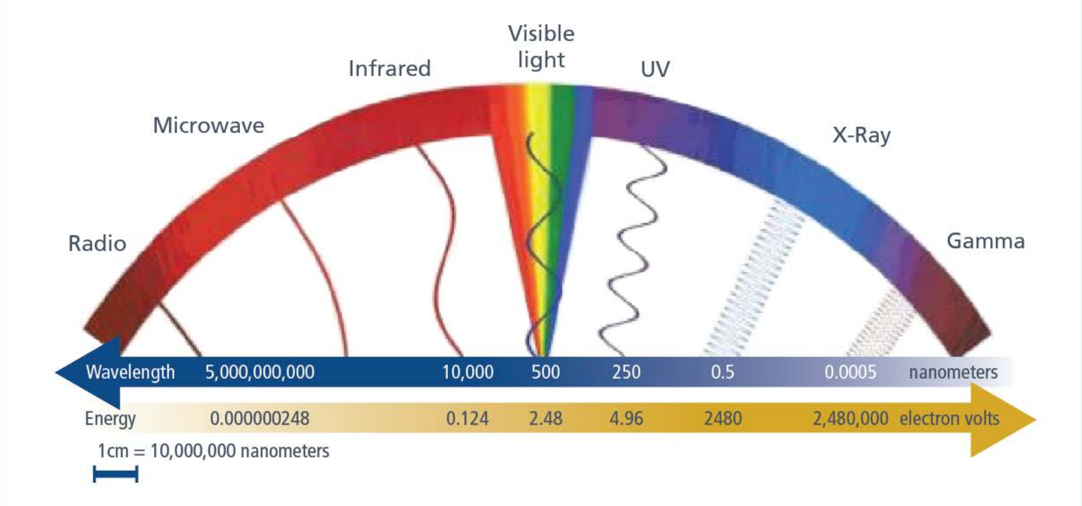


Figure 1: Radiation spectrum (illustration courtesy of Harvard University) [1].

Strategies for building robust rad-tolerant power electronics

Even in today's fast-paced new space business environment, costs to launch and to replace dead satellites are substantial, so care in design is important. We really want the highest reliability we can afford.

How is this done?

There is no one answer—solutions for creating robust space electronic systems are multifaceted.

- Components are selected for radiation tolerance. Some state-of-the-art semiconductor process nodes have improved radiation performance. Bipolar semiconductors can be selected for their displacement damage ratings. Wide-bandgap (GaN) FETs with inherent radiation tolerance can be selected. Some parts, like certain epoxies and aluminum electrolytic capacitors which outgas in a vacuum, are simply inappropriate for use in space environments.
- To account for lot-to-lot variations, a lot can be sample tested for radiation performance. If they pass, devices from this manufacturing run can be used with confidence.
- Physical redundancy. Multiple instances of systems can be implemented. If one fails, the system can be designed so another can take over. In some systems, there are three systems operating in parallel. If one disagrees with the other two, then its output can be ignored. Sometimes there are four redundant systems and one spare is swapped in if a system fails.
- Power MOSFETs can be derated so the inevitable VGS threshold degradation is accounted for and the device is still functional at the end of the mission life.
- Shielding can be used to protect sensitive electronics, but if the particle energy is high enough, cascading particles from the shield can add to the problem.
- Circuitry can be added to monitor performance, disconnect and restart misbehaving systems if a fault is recoverable.

Regardless of design strategies and power supply topologies, space electronic systems must be analyzed, simulated and tested for environmental and radiation performance.

Radiation-tolerant design requirements restrict the selection of components. The addition of performance monitors, safety protection mechanisms, power disconnects and reset circuitry must not exceed the efficiency, size and weight requirements of the final solution.

The impact of topology selection and switching mode

Balancing design tradeoffs by choosing an appropriate power system architecture is important. Topology and switching modes like soft switching (versus hard-switched power converters) can make a system less sensitive to parasitic effects like ringing—ringing that increases voltage stress on switching components.

As one example of the importance of topology selection in a new space design, the switching mode affects all the key specifications of power-conversion implementations including power density, efficiency, transient response, output ripple, electromagnetic interference (EMI) emissions and cost.

Dominant switching-loss terms are attributable to the turn-on behavior of a power train's high-side MOSFET via gate-charge requirements and drain-to-source capacitance. Switching losses increase with, and thus limit, switching frequency. Body-diode conduction losses detract further from power-conversion efficiency in hard-switched converters. Though GaN FETs do not have a physical body diode, they do have a reverse conduction mode clamping at several volts. This makes the GaN dead-time conduction period very challenging to manage.

In a synchronous, hard-switched buck topology, the high-side FET turns on when it has the maximum voltage across it (see Figure 2a) and it conducts its maximum current during the turn-on portion of the operating cycle. Power losses in the high-side switch, therefore, are at a maximum during the off-to-on transition. The larger the input voltage, the higher the power loss, so converters in high voltage-ratio applications (e.g., 28V to 3.3V) tend to deliver poorer efficiency than the same converters in circuits demanding lower conversion ratios (e.g., 5V to 2.5V).

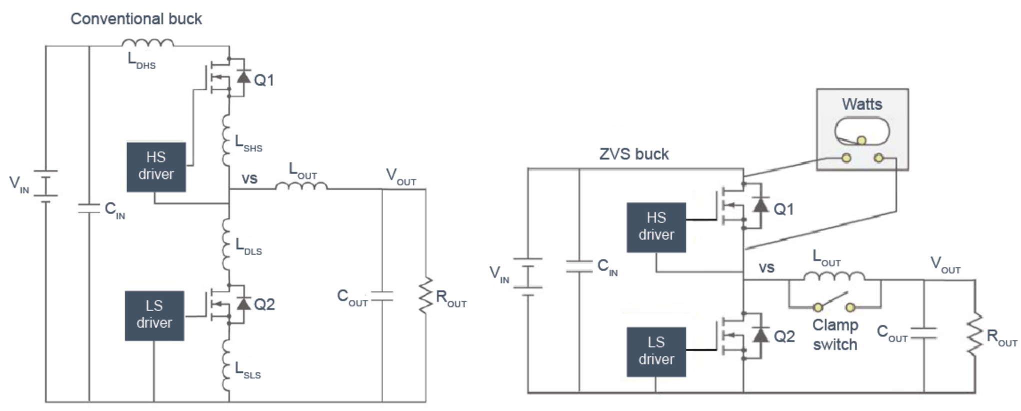


Figure 2: Conventional, hard-switched buck converter (a) versus zero-voltage switched (ZVS) buck converter. (Illustrations courtesy of Electronic Design, Stephen Oliver) [2].

The benefits of soft switching

The alternative, soft switching, significantly reduces these switching losses. Soft-switching techniques require more complex control circuits because the switch timing must be coordinated with the switched waveform.

One example of soft switching is the ZVS (zero-voltage switching) technique, which improves conversion efficiency across a range of power topologies. As the name suggests, ZVS switches the high-side FET on when the voltage across the switch is at or near zero (see Fig. 2b). This breaks the link between power losses and the voltage conversion ratio during the high-side FET's turn-on interval.

Operation of a clamp switch with the ZVS technique allows the converter to store a small amount of energy in the output inductor when both high-side and low-side switches are off. The converter uses this otherwise-wasted energy to discharge the high-side FET's output capacitance and charge the synchronous FET's output parasitic.

Taking the FET's output capacitance out of the switch's turn-on behavior desensitizes FET selection with regard to CGD and, consequently, allows designers to focus on on-state channel resistance instead of traditional figures of merit such as the product of channel resistance and gate capacitance.

This method of driving the high-side FET during turn-on avoids exciting the switch's parasitic inductance and capacitance, which tend to resonate, inducing large voltage spikes and ringing in hard-switched topologies (see Figure 3a). By eliminating the spikes and preventing the ringing (see Figure 3b), ZVS removes another power-loss term and eliminates a source of EMI emission.

Eliminating the voltage spikes from the switching behavior also allows designers to select lower-voltage FETs with lower RDS_{ON} improving the efficiency.

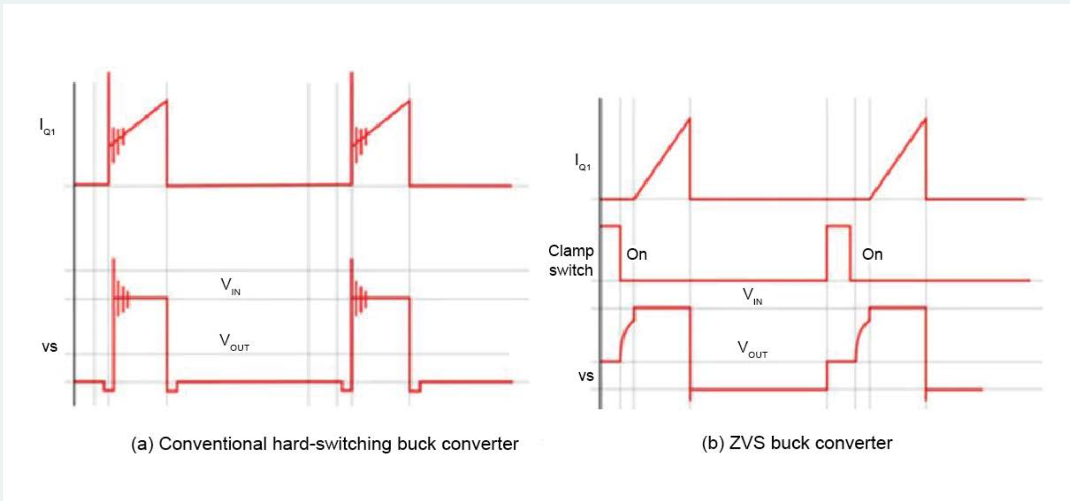


Figure 3: Hard-switching versus soft-switching waveforms (illustration courtesy of Electronic Design) [2].

Soft switching is extremely versatile. For example, Vicor uses soft-switching techniques in its radiation-tolerant power module solutions for powering high-performance communication ASICs (see Figure 4) dedicated to MEO and LEO satellite applications. The system modules use ZVS buck-boost topology for the PRM™ and ZVS and ZCS Sine Amplitude Converters (SACs) for both the BCM® and the VTM™.

The small size of the VTM allows it to be placed as close as possible to the ASIC. Optimizing the power distribution network (PDN) is very critical when dealing with high currents consumed by modern ASICs, FPGAs, CPUs and GPUs. Vicor modules combine soft-switching solutions, rad-tolerant active components and automotive-qualified passive components.

To mitigate the SEFI (single event function interrupt), all radiation-tolerant modules include completely redundant power trains operating in parallel. If one power train gets upset due to a single event, its protection circuits force a power-off-reset. During the reset interval, the redundant power train carries the full load and after the reset both power trains operate in parallel again.

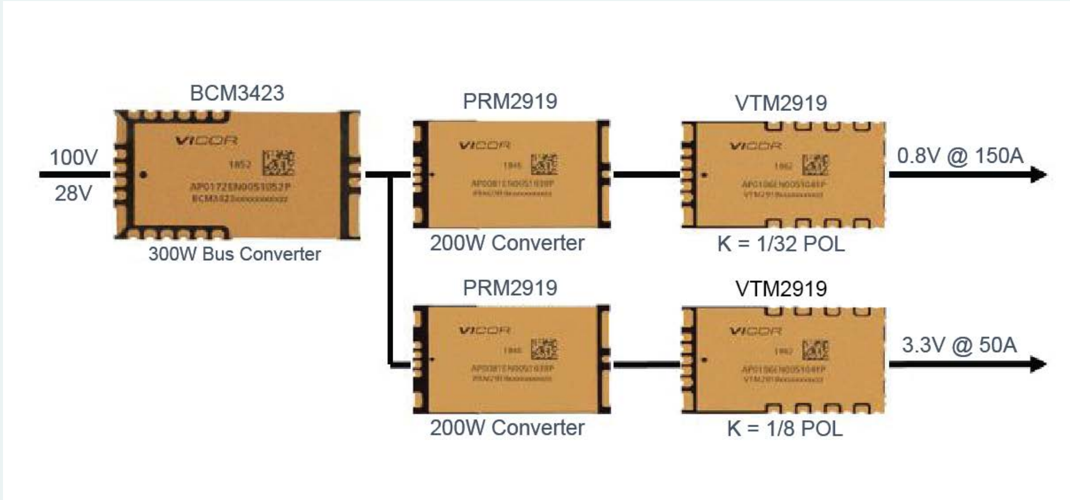


Figure 4: High-power resonant (ZVS and ZCS) topology modules.

Among many other factors, selecting a topology and switching mode are important factors when designing new space power converters.

But here's the bottom line: radiation-tolerant electronic systems are hard to design.

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1. Electromagnetic Radiation & Electromagnetic Spectrum, Chandra X-Ray Observatory website.
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About the Authors

Salah Ben Doua, Principle Applications Engineer, has 30 years of experience in the field of power design and has been supporting Vicor customers for over 20 years, providing expertise and advice in the development of DC-DC and AC-DC power systems in a multitude of areas, including aerospace and defense, industrial, rail, lighting and communications. Salah received a Ph.D. from the National Polytechnic Institute of Toulouse, specializing in power conversion.

Ken Coffman, Senior Field Applications Engineer, is assigned to Vicor's New Space Initiative. He is located in Phoenix, Arizona. You can email Ken at kcoffman@vicr.com.

Compact, high-density, high-efficiency DC-DCs for New Space applications

VICOR

More high-performance LEO processing requires next-generation power

Satellite operators are offering increasingly sophisticated on-board processing capabilities necessitating the use of the latest ultra-deep-submicron FPGAs and ASICs. These have demanding, low-voltage, high-current, power requirements and OEMs are being challenged to offer more functionality from smaller payloads and platforms. Cost and time-to-market are also key drivers!

Relatively, smaller satellites harvest less energy and with operators increasingly using faster and more on-board processing, there is a requirement that as much of the possible power budget is available for the payload. Traditional power-distribution architectures comprising an isolated DC-DC to step-down the external bus input, followed by localized POLs to produce the required load voltages, are becoming too inefficient because of large I^2R drops. To deliver the next generation of New Space missions, improvements are needed in conversion loss, power density, physical size and a transient response compatible with the switching speeds of the latest ultra-deep-submicron devices.

Instead of the conventional, intermediate power-distribution comprising an isolated DC-DC followed by buck bricks, Vicor Corporation's patented Factorized Power Architecture (FPA™) uses a modular approach to minimize I2R distribution losses, maximize efficiency and improve transient response.

The FPA comprises two stages: voltage regulation followed by transformation. First, a buck-boost topology is used to generate a 48V intermediate rail from an external source, which is significantly higher than the lower legacy buses typically input to POLs. For example, a 48V output bus requires four times less current than a 12V intermediate bus for the same power ($P = VI$) and PDN losses are the square of the current ($P = I^2R$), which reduces by sixteen. Placing a regulator first to produce 48V achieves the highest efficiency, allowing smaller satellites to avail of more of the harvested energy.

The second stage of the FPA uses a transformer to convert the 48V intermediate rail to the desired load voltage, e.g. 1V. The output is a fixed fraction of the input (K-factor) defined by the turns ratio. Stepping down the voltage increases the current by the same amount, e.g. a 1A input current would be multiplied to an output of 48A:

$$V_{IN} \cdot I_{IN} = (1/K \cdot V_{OUT}) \cdot (K \cdot I_{OUT})$$

A Pre-Regulation Module (PRM™) and a Voltage-Transformation Module (VTM™) current multiplier combine to realize the FPA, with each device fulfilling its specialized role to enable complete DC-DC conversion. The PRM generates a regulated 'factorized bus' from an unregulated input followed by the VTM, which transforms (steps down) the 48V to the desired load voltage.

The VTM's high bandwidth avoids the need for large point-of-load capacitance. Even without any external output capacitors, the output of a VTM exhibits a limited voltage perturbation in response to a sudden power surge. A minimal amount of external bypass capacitance (in the form of low ESR/ESL ceramic capacitors) is sufficient to eliminate any transient voltage overshoot. Without imposing the bandwidth limitations of an internal control loop struggling to maintain regulation, the VTM offers a unique capacitance-multiplication feature. For example, the effective, shunt output capacitance is 2304 times the input capacitance when a K factor of 1/48 is used, i.e. $C_{SEC} = C_{PRI} * K2$.

This means that significantly less decoupling is needed downstream of the VTM and only a small amount of capacitance at its input offers the same energy storage as the bulky tantalums typically added to the 1V output of a traditional buck brick as illustrated in Figure 1.

Low impedance is a key requirement for powering low-voltage, high current loads efficiently and the use of a VTM also reduces the effective resistance seen from the secondary side by K^2. This allows the VTM to be placed at the load, either laterally or vertically, resulting in a lower-loss PDN. The FPA's lower-current, higher-voltage intermediate bus means that the PRM can be located physically away from the VTM without impacting efficiency. This gives you more flexibility when deciding where to place the PRM, less worries about area congestion at the load and more freedom to size power planes for maximum current density. This floor-planning is very different to the traditional brick approach, which requires the isolated DC-DC and POLs to be close together to minimize I^2R distribution losses.

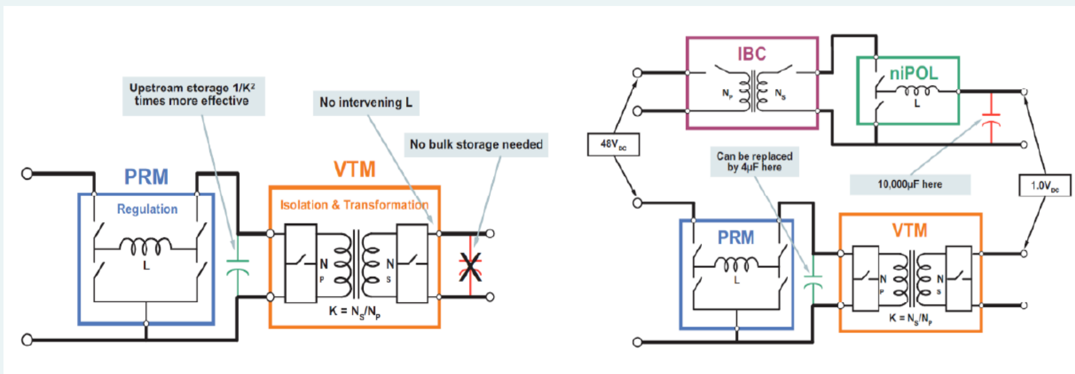

Figure 1: These diagrams show how the FPA compares to a traditional, intermediate architecture.

Present space-grade, isolated DC-DCs and buck POLs are PWM-based devices with the output power proportional to the duty cycle of the switching frequency. These hard-switched converters use a square wave to drive an inductor or transformer with the MOSFET dissipating energy as it is turned on and off. A square wave contains lots of harmonics that must be filtered or they will conduct or radiate throughout the system. The VTM's topology uses a sinusoidal current in the primary winding, producing a cleaner output noise spectrum requiring less filtering. Existing space-qualified buck regulators and forward/flyback DC-DCs specify efficiencies in the range of 67 – 95% and 47 – 87% respectively.

Today, there are 12 suppliers of space-grade switching POLs offering almost 30 non-isolated converters. Input voltages range from 3 to 16V, load voltages and currents from 0.785 to 9.6V and 4 to 18A respectively, with switching frequencies from 100kHz to 1MHz. Previously, I described the theory of conversion for the buck topology, what criteria to consider when selecting space-qualified parts, and how to choose values for the inductor, input, and output capacitance.

There are seven vendors of space-qualified isolating DC-DCs offering over 30 families of parts generating single, double, or triple standard voltages, or in some cases, adjustable, regulated, stepped-down intermediate outputs. Power ratings range from 2.5 to 500W. Previously, I described the theory of conversion for the forward and flyback topologies.

To meet the power-distribution and low-voltage, high-current needs of future NewSpace constellations, Vicor is qualifying its novel, Sine Amplitude Converter (SAC™) topology for space applications. This patented, ZCS/ZVS technology offers higher efficiencies, larger power densities, and lower EMI emissions than existing space-grade DC-DCs. SAC is a transformer-based, series-resonant, forward architecture that operates at a fixed frequency equal to the resonance of a primary tank circuit as shown in Figure 2.

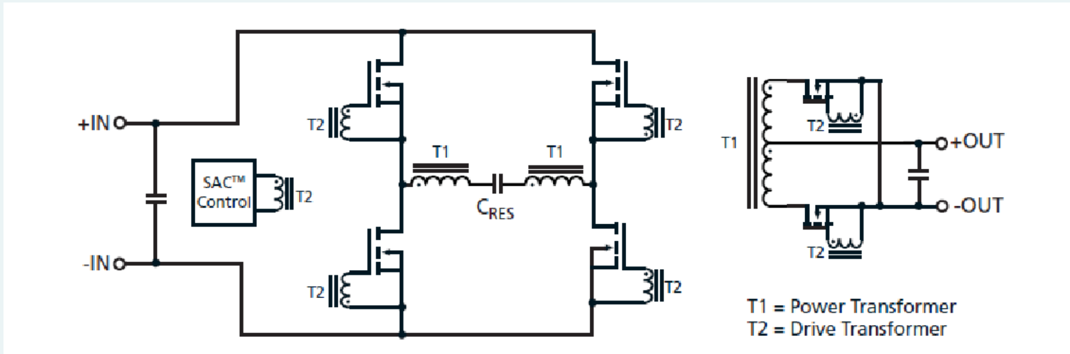

Figure 2: The full-bridge, SAC series-resonant topology offers advantages over existing space-grade DC-DCs.

The FETs in the primary side are locked to the natural resonant frequency of the series tank circuit and switch at zero-voltage crossing points, eliminating power dissipation and increasing efficiency. At resonance, the inductive and capacitive reactances cancel minimizing the output impedance, which becomes purely resistive reducing droop. The resulting very-low output impedance allows the VTM to respond almost instantaneously (< 1µs) to step changes in the load. The current flowing through the tank is a sinusoid that contributes less harmonic content, resulting in a cleaner output noise spectrum, requiring less filtering of the load voltage.

The SAC has a forward topology with the input energy passing to the output. The leakage inductance of the primary is minimized since it is not a critical storage element. The unique operation of the SAC forward topology enables a higher switching frequency and the use of smaller magnetics with lower intrinsic losses. The resulting increase in efficiency means less power is wasted during conversion, easing thermal management and allowing for more output current and a larger power density from a smaller package. Faster operation transfers energy to the output more often, improving the transient response to dynamic load changes to a few cycles.

Vicor is planning to bring to orbit a range of DC-DCs. Parts have already been de-risked and designed-in by Boeing for an O3b satellite offering space-based internet. Initially four rad-tolerant DC-DCs will be offered:

- A 300W, 9A, 849W/in^3, isolating, ZVS/ZCS, SAC bus converter module (BCM3423PA0A35C0S), which accepts a DC source from 94 to 105V and outputs a fixed load voltage 1/3 of the input, ranging from 31 to 35V. Its maximum ambient efficiency is specified at 94% in a package size of 33.5×23.1×7.4mm weighing 25.9g.

- A 200W, 7.7A, 797W/in^3, non-isolating ZVS buck-boost regulator, (PRM2919P36B35B0S), which accepts an input from 30 to 36V and outputs an adjustable load voltage from 13.4 to 35V. Its maximum ambient efficiency is specified at 96% in a package size of 29.2×19.0×7.4mm weighing 18.2g.
- A 200W, 50A, 1204W/in^3, isolating, ZVS/ZCS, SAC DC-DC (VTM2919P32G0450S), which accepts a line voltage from 16 to 32V and outputs a fixed load voltage of 1/8 of the input, ranging from 2 to 4V. Its maximum ambient efficiency is specified at 93% in a package size of 29.2×19.0×4.9mm weighing 11g.
- A 150W, 150A, 903W/in^3, isolating, ZVS/ZCS, SAC DC-DC (VTM2919P35K01A5S), which accepts a line voltage from 13.4 to 35V and outputs a fixed load voltage 1/32 of the input, ranging from 0.42 to 1.1V. Its maximum ambient efficiency is specified at 91% in a package size of 29.2×19.0×4.9mm weighing 13.3g.

The four DC-DCs have been designed using a redundant system architecture containing two identical parallel powertrains with fault tolerant control to meet single-event-effect (SEE) requirements. To reduce manufacturing costs, the parts have been packaged in a plated, epoxy-molded resin BGA with excellent thermal conductivity, branded as SM-ChiP™, compatible with standard surface-mount, pick-and-place, and reflow assembly processes (Figure 3). The DC-DCs are EAR99, specified from –40 to 125°C and offer various overvoltage, short-circuit current, undervoltage, and thermal protection features. The target total-dose is 50kRad (Si) with SEE and other reliability data to be released later this year. Data sheets are available and bespoke input/output options can also be ordered.

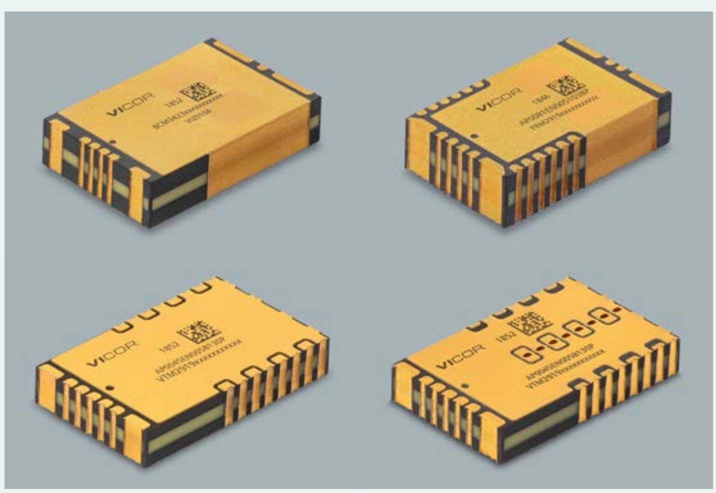

Figure 3: Vicor will offer these new BCM, PRM, and VTM rad-tolerant DC-DCs.

To highlight the superior densities offered by the new rad-tolerant DC-DCs, Figures 4 and 5 compare their relative sizes with existing space-grade switching POLs and isolated DC-DCs respectively. The power density of each converter in W/in^3, its efficiency in % and current density in A/in^2, have been annotated in blue, orange, and red respectively. A range of efficiencies are typically specified for different load conditions and the maximum values from each data sheet are displayed below.

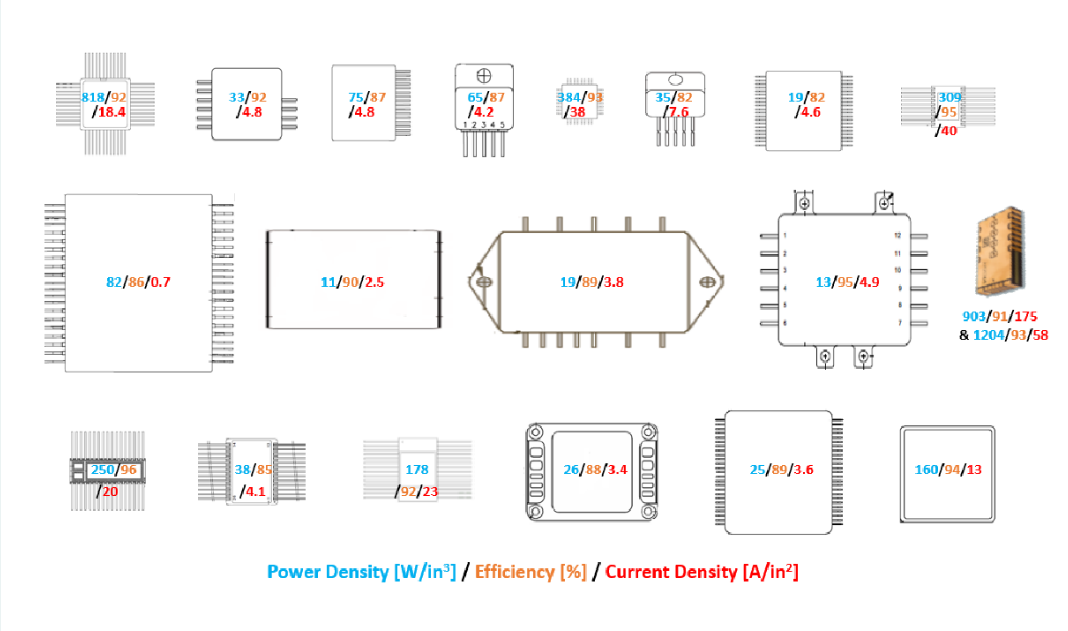

Figure 4: This diagram compares space-qualified switching POLs with the VTM2919 DC-DCs.

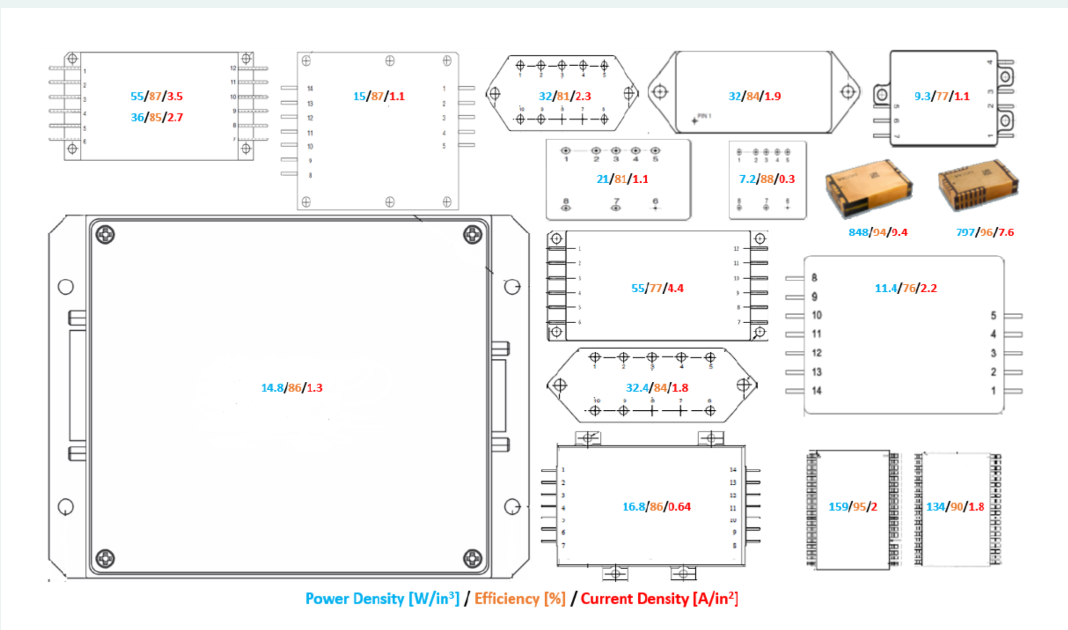

Figure 5: This diagram compares space-qualified isolated with the BCM and PRM DC-DCs.

The new, rad-tolerant, COTS SAC DC-DCs are an innovative and enabling technology for New Space applications. When compared with existing qualified converters, they deliver major increases in output power, density, and efficiency in a smaller volume and lighter form-factor. Regulated voltages are significantly cleaner with less bulk decoupling. Parts will have heritage from next year and evaluation boards are available to help you de-risk future mission needs.

The FPA is a major advance to reduce the I^2R distribution losses handicapping existing intermediate power architectures. A low-current, factorized bus allows much more freedom to place the BCM® and PRM away from the typically-congested load area.

A modular, 100V PDN solution now exists offering SWaP benefits to supply the latest, ultra-deep-submicron, space-grade semiconductors. The VTMs provide high-performing ratiometric DC-DCs and when combined with a PRM, enable a complete closed-loop FPA exploiting the efficiency advantages of a high-voltage factorized bus (Figure 6).

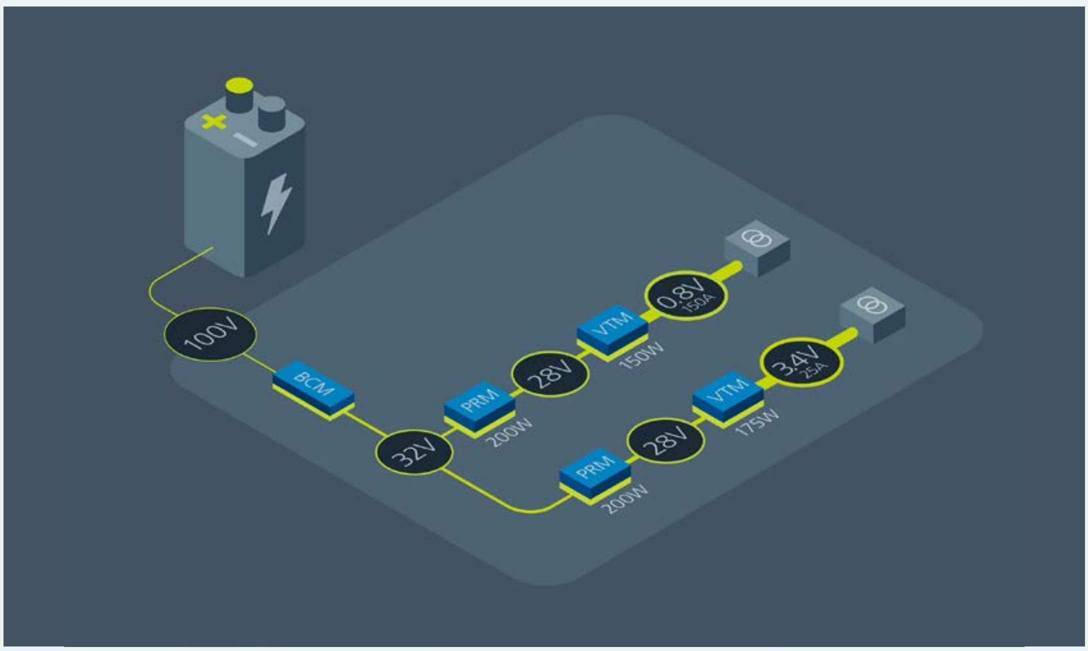

Figure 6: A modular 100V power-distribution solution now exists for spacecraft avionics.

This article was originally published by EDN.

Vicor power modules boost satellite internet constellations

VICOR

The Vicor product line is well suited for serving New Space. Reliability, high current and high density are important power requirements that are instrumental in powering New Space

Vicor Corp. has recently announced that its radiation-fault-tolerant DC-DC converter power modules will be used in Boeing-manufactured O3b mPOWER satellites. The O3b mPOWER ecosystem is a constellation of satellites in medium earth orbit (MEO) that SES will use for delivering global connectivity services to customers around the world.

A shifting focus to LEO and MEO satellites

There are basically three major types of satellites: GEO, MEO and LEO. Geostationary earth orbit (GEO) satellites require fully radiation-hardened components, and therefore are very expensive. Each satellite can cost up to $500 million, and has to last 15 – 20 years to make it worthwhile. The main advantage of GEO orbits is that at a height of 35,000 kilometers it is possible to cover a very wide geographical area with as few as three satellites.

Medium earth orbit (MEO), is between 5,000km and 12,000km in altitude, requires a constellation of 10 to 20 satellites to achieve a global coverage. Since this orbit is inside the Van Allen belt which protects the Earth, electronics providers have the leeway to use radiation-tolerant COTS solutions.

Low earth orbit (LEO) usually includes a constellation of hundreds or even thousands of satellites for stable global coverage, which makes it the growth segment of this market going forward. With LEO, there is even more leeway to use radiation-tolerant products, while mission requirements are somewhere in the 3-to-5-year range.

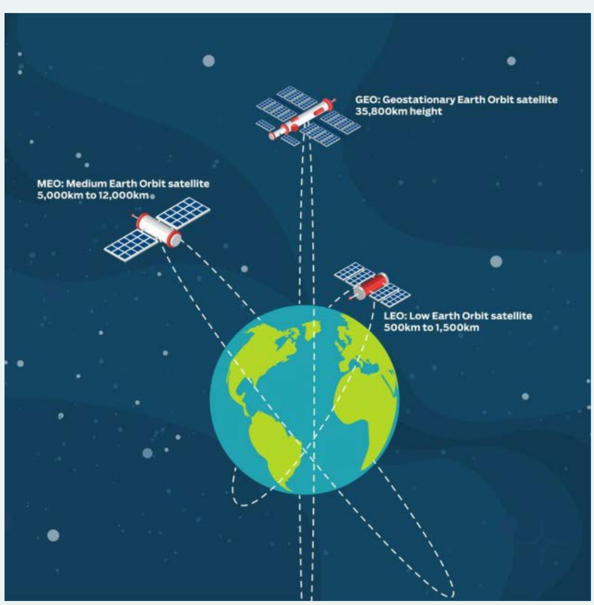

Figure 1: GEO, MEO, and LEO basics.

More satellites earmarked for New Space

"Low Earth Orbit missions are typically part of what we call New Space or Space 2.0. This market has lower cost compared to deeper space orbits, and are largely focused on increasing the internet bandwidth while at the same time reducing latency," said Rob Russell, vice president of satellite business development at Vicor.

Low transmission latency and high throughput are essential requirements for applications like 5G, live TV, military communications and financial trading. As many of us have experienced, satellite television transmissions are subject to a delay (latency) of a few seconds compared to terrestrial or cable transmissions. While this delay can be annoying during sports events, for example, the consequences can be far worse when affecting military communications on a battlefield.

Latency issues are also very important in financial trading since even a delay of one millisecond can make the difference between a profitable operation and one with losses. In high-frequency trading, a huge number of financial transactions are performed with a profit which can be as low as few cents for each operation, and therefore reduction in latency is a big deal. The same considerations apply to the roll-out of 5G technology, where huge use of bandwidth and extremely low latency are mandatory for telecom, IoT, and other next-generation services, such as autonomous vehicles.

Besides high bandwidth and low latency, another advantage of LEO applications is the coverage, as multiple overlapping ranges can achieve total earth coverage.

"Bringing broadband to places where they can't get it is a huge plus. One of the main goals of O3b, which stands for other three billion, is to bring broadband internet to the many people in the world for whom it is otherwise unavailable today," said Russell.

In order to get full coverage in LEO applications, hundreds or even thousands of satellites are needed versus as few as three for GEO. That means high-volume commercial parts are needed to reduce the overall cost. Instead of using fully radiation-hardened devices, which are expensive and are always two-, three-, or even more generations behind, modern ASICs, FPGAs, and custom chips are required. Those devices need modern power solutions with high density, high current, low cost and high efficiency, while maintaining some degree of radiation tolerance.

"Once a satellite is in orbit, the only power you have available is derived from solar panels. Because of the finite power available, you need high efficiency in all elements of your power chain. Vicor high-efficiency, high-density and high-current solutions really play well into this new space model," said Russell.

Vicor rad-tolerant power solutions

Today, larger satellites use a 100V power bus, which is what the current Vicor solution handles. As shown in the figure at right, the 100V that comes out of the batteries (charged by solar panels) is split to provide the two rails (0.8V at 150A max and 3.3V at 50A max) needed to power the ASICs.

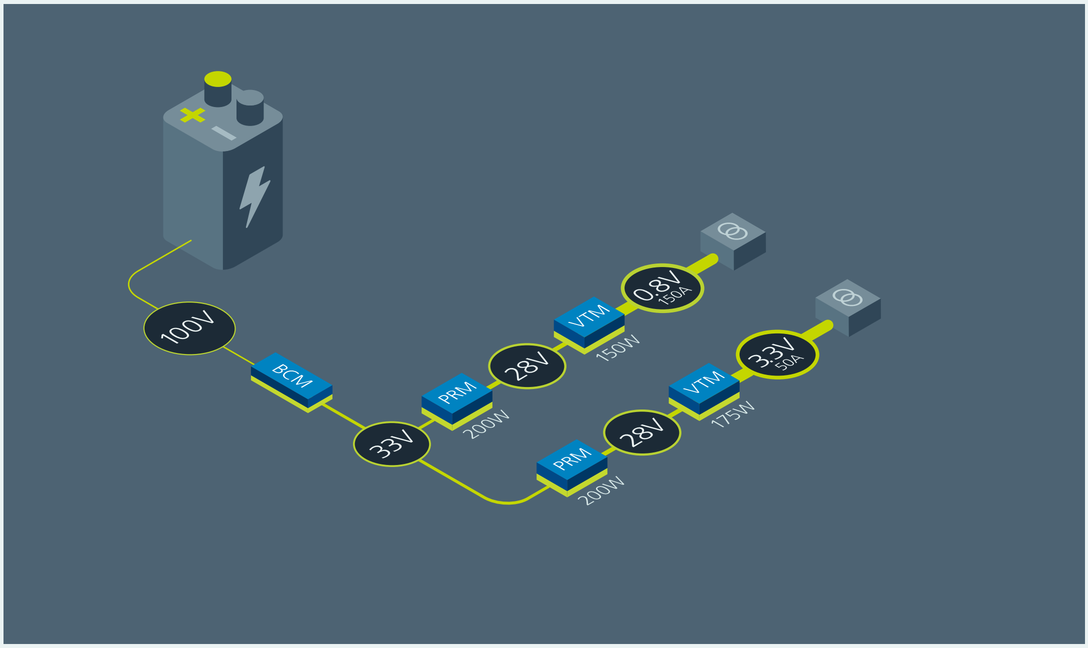

Figure 2: Vicor rad-tolerant factorized power (FPA) solution.

The BCM® isolated bus converter has a three-to-one conversion ratio (or K factor), since it takes 100V in input and reduces it to a voltage more suitable and efficient to be regulated. The 28V secondary bus drives the VTM™ current multipliers, which are also ratiometric devices (1/32 and 1/8, respectively) and further reduce the output voltage to the required values.

"Our basic solution is ideal for LEO and MEO satellites using 100V buses. Our modular approach offers tremendous design flexibility enabling designers to change the bus voltage or change the rail voltage relatively easily," said Russell.

Innovative designs, careful component selection, and extensive component and system testing assure total ionizing dose (TID) radiation tolerance and single-event effect mitigation suitable for LEO and MEO missions.

Single-event effects are electronic events caused by a single highly energetic particle. For this type of testing, devices under test (DUTs) are bombarded with high-energy particles to simulate what they will find in space. Total ionizing dose effects, instead, refer to the damage caused on electronic devices by long-term radiation exposure. This is a sort of cumulative effect, and corresponds to the radiation provided by the sun. In this case, a radiation exposure over time proves that DUTs are robust enough to withstand the maximum radiation level required for that type of mission.

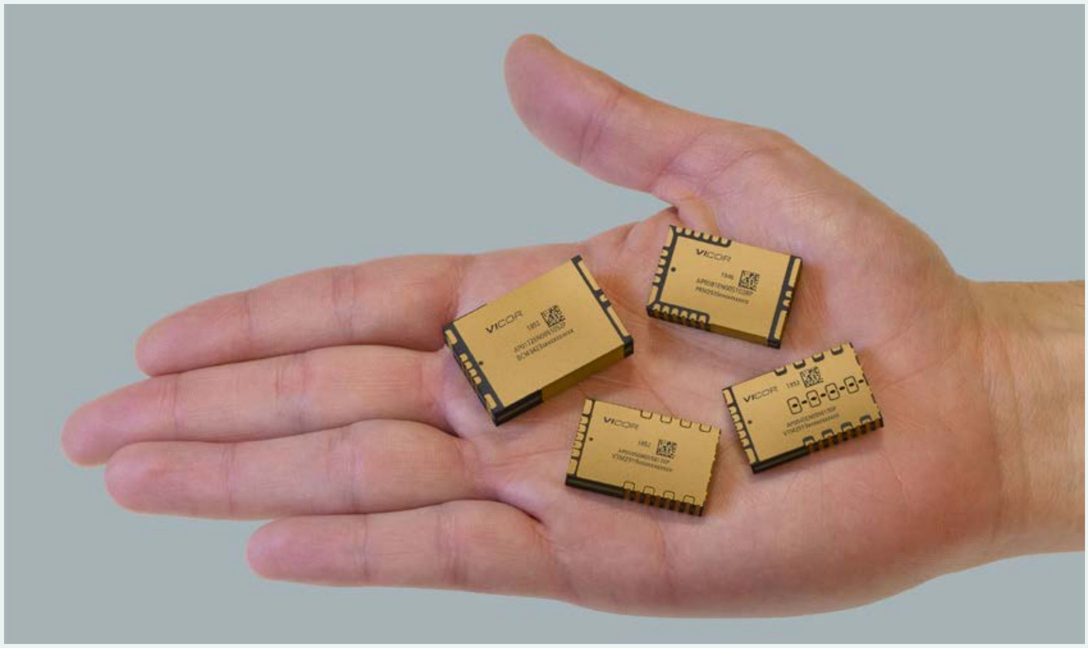

Figure 2: Vicor rad-tolerant factorized power (FPA) solution.

Looking at potential product line expansion, Russell says that, along with the 100V bus voltage, the 28V bus is one of the most prevalent solutions, while 50V and 70V buses will be required for some specific applications. Different K factors for the VTMs likely will be provided, and solutions optimized for lower power will probably be required as well. Some of the currently available technology, particularly the BCMs, might be modified to support bidirectional flow of power, improving the efficiency of the battery charge/recharge process, and reducing the amount of space taken up.

According to Vicor, the product line is well suited to serving New Space. Reliability, high current and high density are important power requirements that are instrumental in powering New Space.

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FAQs

By Matt Renola, Sr. Director Global Sales Aerospace and Defense

Aerospace and defense power FAQs

Gain some valuable technical insight into Vicor Power solutions by reviewing these frequently asked questions taken from actual customer engagements

Driving innovation from decades of proven experience

Since it's inception in 1981, Vicor has a long heritage of serving customers in the aerospace and defense markets. Vicor has long supported key engagements in air, ground and shipboard power applications. Vicor high-performance MIL-COTS power modules offer high density and efficiency with reliable and robust designs backed by 30-years of dedicated excellence in the aerospace and defense industry. Using that knowledge base we have compiled a list of commonly asked questions we feel will provide some guidance and insights along your power design journey.

Can you specify some of the programs that Vicor has provided mission critical power to?

- F-15 Fighter Aircraft
- F-16 Fig
- Eurofighter Typhoon Aircraft
- Rafale Multi-Role Combat Fighter
- 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
- 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
- Patriot Missile Air Defense 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
- 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
- Air and Missile Defense Radar- AMDR SPY-6
- TACAN Tactical air navigation system
- RSS Radar Sensor Systems
- LSRS Littoral Surveillance Radar System
- AIM-9X Sidewinder Air Intercept Missile
- JAGM AGM-179 Joint Air-to-Ground Missile
- JASSM AGM-158 Joint Air-to Surface Standoff Missile
- MQ-1 Predator Pilot & Sensor Shelter
- MX-15 EO/IR Air Surveillance and reconnaissance

- TAURUS KEPD 350 Stand-off-Weapon
- Sting Ray Lightweight Torpedo
- Bradley M2/M3 Tracked Armored
- V-22 Osprey Medium-Lift, Multi-Mission, Tilt-Rotor Aircraft
- Global Hawk High Altitude, Long Endurance Unmanned Reconnaissance Aircraft
- M982 Excalibur extended range guided artillery shell
- U-2S/TU-2S Reconnaissance and Surveillance Aircraft
- FAB-T Family of Advanced Beyond Line of Sight Terminals
- THAAD Terminal High Altitude Area Defense Missile System
- Honeywell (Allied Signal) Boeing 737 power distribution panel
- VIPER/T – Third Echelon Test System USMC

Challenges of meeting power requirements in military ground vehicles?

Military ground vehicles present various challenges when designing and meeting power requirements. Power supplies need to withstand shock and vibe requirements associated with rough terrain. Dust, humidity or sandy conditions are also present in these types of applications. Cranking voltages during vehicle start-up pull a tremendous amount of current and lower input voltage ranges. This all needs to be accounted for when deciding if your critical electronic equipment needs to ride through start up. Vicor has a long history in supporting military ground vehicle designs and can direct you to a host of standard products that meet Mil-STD-1275 requirements. MIL-STD-1275 power supply standards outline all the requirements that an engineer needs to account for when designing his/her power supply. Military vehicles distribute a nominal $28V_{DC}$ bus voltage for opportuning electronic systems. According to MIL-STD-1275, ground vehicle power supplies must be able to handle transient spikes of up to +/– $250V_{DC}$ for 50 micro seconds for 1msec. Vehicle surge requirements of up to $100V_{DC}$ for 50msec must be met without affecting the regulated output.

How does Vicor help engineers meet these military ground vehicle requirements?

The Vicor 28V DCM™ DC-DC Converter Modules have input ranges from 9 – $50V_{DC}$ in order to address low cranking voltage and surges of up to $50V_{DC}$ without affecting output regulation to your critical electronic needs. Vicor also provides MFM™ DCM filters for meeting MIL-STD-1275A/B/D/E requirements. These DC front-end modules provide EMI filtering and transient protection when used in conjunction with the Vicor 28V nominal input voltage VIA™ or ChiP™ modules.

I’m looking for a turnkey power solution as I don’t have experience in board mounted design. How can Vicor help me with that?

Vicor has design centers in North America that support build to spec or build to print system designs. These entities can customize solutions based on your statement of work (SOW). Having the Vicor highly engineered components already designed allows for quick response to provide full turn-key solutions. Vicor has many years of experience and has the design engineers and applications expertise to assist you with designing your mission critical needs.

Does Vicor have test capabilities internal?

Every module undergoes extensive post-production environmental stress screening (ESS) before shipment to verify compliance with Vicor high-quality and performance standards and to eliminate early life failures. To ensure the most effective routine for precipitating module failures, Vicor continually evaluates its ESS program and makes appropriate changes as new data becomes available or as product improvements occur. After burn-in and temperature cycling, each module undergoes final electrical testing over the specified temperature range.

I have a very wide input voltage requirement for a defense application. Is it possible to use multiple converters to handle this requirement?

When a single wide-input-range DC-DC converter results in unacceptable performance and cost, a combination of two or more DC-DC converters with overlapping input voltage ranges may be an effective alternative. Combinations of DC-DC converters with narrower but complementary input voltage ranges will typically operate at higher efficiencies and higher power densities allowing the total design to be smaller, more efficient and less costly than a single-converter solution. In applications that require ultra-wide-voltage input ranges, using a single DC-DC converter often forces a power system designer to accept significant reductions in available power, power density and system efficiency, while increasing overall system cost. Leveraging the efficiency, power density, ease-of-use and wide variety of Vicor DCM DC-DC converters, it is possible to create a smaller, more efficient and potentially less costly solutions for military applications.

What are the considerations for meeting MIL810 standards with Vicor modules?

One example of advanced packaging that improves power processing and delivery performance is the Converter housed in Package™ (ChiP™) technology from Vicor. ChiP-based devices exploit symmetrical configurations placing dissipative devices on both sides of a central PCB. A thermally conductive encapsulant transfers heat to both the top and bottom surfaces effectively doubling the cooling surface area relative to the device's PCB footprint. The module's encapsulant allows the module to meet shock and vibration standards.

When mounting to module to a pcb the designer has to consider the module a part of a system. The system typically uses standoffs and other mechanics to meet shock and vibration standards.

For what specific applications are your products best suited?

Because our products are compact and designed with thermally-adept packaging, most are ideally suited for many MIL applications, including surveillance, communications, radar and pulsed load. Vicor has a range of $270V_{DC}$, $28V_{DC}$ and $48V_{DC}$ input products. A power module design approach easily addresses challenges presented by load capacity, placement and user functionality requirements. To support easy power design development, Vicor offers an online tool, the Power System Designer, to aid in selecting the appropriate product(s) to optimize your power delivery network.

If design engineers want to test Vicor solutions they have developed, is there any simulation or assistance that you offer?

Yes, we offer valuable tools online for simulations and assistance using thermal management and component calculators. In addition, we are offer demo boards and our applications engineers are available to assist with design reviews.

What is the difference between your traditional brick power supplies and your new advanced power module products?

So, as significant an advance as brick packaging technologies were, and while the brick form factors still play a role in terms of simplicity, the industry has grown to need even more dense power management devices beyond what can be accomplished with purely single-sided cooling.

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How easy is it to upgrade to the new advanced power modules from bricks?

Vicor has established a power module capability spanning product design, manufacturing, simulation and selection tools. This capability allows Vicor to enable power systems designers to quickly and easily deploy high-performance power delivery networks (PDNs), from the power source to the point-of-load (PoL) for end systems extending across many different industries such as (defense and aerospace, LED lighting, etc.).

This modular power component approach signifies a new standard within the power industry, addressing the increasing power needs of modern, high-performance end systems with a methodology that also provides other power system benefits such as reduced power system footprint, high efficiency and faster time to market.

Are there any design limitations using the newer power modules?

Power delivery networks are rapidly changing within many end systems across many industries today. The power requirements for these different systems vary widely from each other and require a wide portfolio of modules to enable the maximum flexibility for a modular power component methodology to be employed. The range of modular power solutions Vicor provides include:

- AC-DC and DC-DC modules
- Power levels from 50W to over 50kW
- Currents from a few amps to 1,000A+
- Voltages from sub 1V to over 1,000V
- Isolated and non-isolated converters and regulators

- Regulated and fixed-ratio converters
- Board-mount, chassis-mount and surface-mount power module packages

In addition to the above, there are also different control features such as telemetry, compensation and programmability, plus any industry/safety certifications that can be required.

Does Vicor have products that support open architecture platforms like VITA, VPX and SOSA?

Leveraging the benefits of our DC-DC converter technology and modular building blocks, Vicor offers a range of standard and modified-standard VPX power systems for use in compact enclosures and space-constrained airborne and vehicle environments where temperature, shock and vibration conditions can be severe. There are 3U and 6U models available which are compliant to the VITA 62 standard, along with SOSA aligned models. The current products are available 3-phase AC in, $270V_{IN}$, and $28V_{IN}$, and are capable of providing one to six user-configurable outputs, with voltages from $2V_{DC}$ to $48V_{DC}$. Standard features such as wide output trimming / programming, current limiting, remote sense, reverse polarity protection, logic enable / disable are available. Products meet relevant standards, including MIL-STD-810F environments, MIL-STD-461E EMI, MIL-STD-1275A B and D, MIL-STD-704D/E/F transient compliance and MIL-STD-1399A, shock and vibration in conformance with MIL-STD-901D.

About the Author

Matt Renola is Senior Director, Global Business Development – Aerospace, Defense and Satellite Business Unit at Vicor. Matt has been with Vicor for 15 years and has been responsible for managing the Vicor sales teams and global accounts in all of Vicor main vertical markets. He has over 30 years of technical sales and marketing experience and has also worked for major OEMs: Artesyn Technologies, Emerson Network Power and Vishay Intertechnology. He has an undergraduate degree from Boston College and an MSE from the University of Pennsylvania.

Glossary of terms

Space/Satellite glossary of terms

Learn the language of the stars with this handy space and satellite glossary of terms

VICOR

Aerospace and defense glossary of power terms

A comprehensive list of commonly used aerospace and defense terminology

VICOR

Tools

Tools

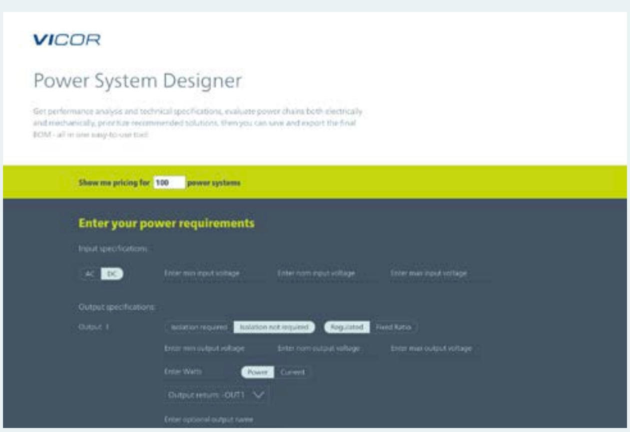
This section outlines Vicor tools that provide novice and experienced engineers a digital workspace where they can design and test power module solutions to best fit their application needs.

Power System Designer

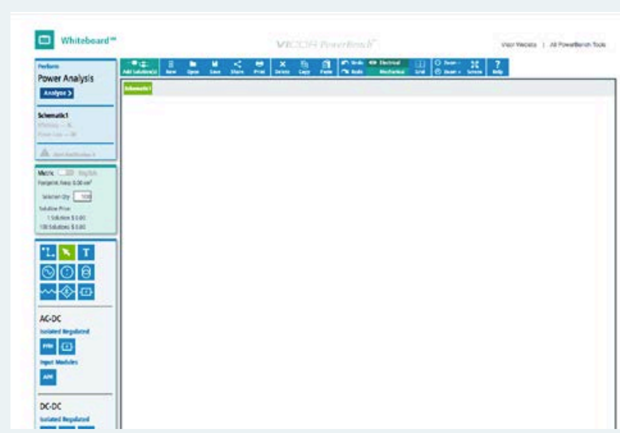
- The Power System Designer is a user-friendly software which both novice and experienced system designers can utilize to architect end-to-end power delivery networks. This tool harnesses Vicor's Power Component Design Methodology to produce optimized solutions without time consuming trial and error. The Power System Designer also provides a service which is up to 75% faster than traditional methods and allows users to export the final BOM.

Whiteboard

- Whiteboard is an online tool with an easy-to-use workspace where users can analyze and optimize the performance of different power chains. Users are able to find the best solution for their application needs using Vicor's high density, high efficiency power modules. In addition, users can set operating conditions for each component of the power design and get loss analysis for individual components and the system overall.



Power System Designer



Whiteboard