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Rad Hard Processors And Power Converters Propel Intermediate Bus Architecture Into Space Applications

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As the performance requirements of space-based electronic systems increase, so do the demands on the power supplies for these systems. In the past, the data processing technology (CPUs, DSPs, FPGAs, etc.) used in space-borne applications lagged several generations behind the state-of-the-art commercial equivalents. That trend is now changing with space-qualified product offerings catching up to the current states of various technologies.

There is a direct correlation between the increase in processing power of today's devices and their demands on power systems. The increased device speeds and transistor density require operation at low voltage and high current, which is very demanding on a power supply and not compatible with efficient distribution. The age-old solution is to distribute power at high voltage and drop down to the required voltage as close as possible to the load.

For years, this has been the way high-performance data-processing systems have been powered in commercial as well as military terrestrial and airborne applications. An isolated converter provides an intermediate bus voltage for distribution to point-of-load converters (POLs)—typically high-efficiency buck converters—placed as close as possible to the low-voltage load.

Until very recently, this efficient POL-based distributed topology, also referred to as the intermediate bus architecture, was not available to space designers due to the extreme environmental requirements of these applications. While designers could apply distributed power schemes using space-grade, isolated dc-dc converters and EMI filter modules, they were limited to using linear regulators for voltage stepdown at the point-of-load. However, with the introduction of high-efficiency, high-power-density POLs qualified for space, the use of the intermediate bus architecture in space systems became feasible. This approach enables designers to better optimize their power distribution systems for efficiency, size and weight.

Optimal Architecture

When developing a power system for space-based applications, selecting the proper system architecture is critical to optimizing for efficiency, size and weight. Many military, aerospace and space systems attached to a 28-V dc power bus require an isolation boundary, so one of the traditional approaches for systems requiring multiple output voltages is to use an isolated dc-dc converter for each output voltage as shown in Fig. 1.

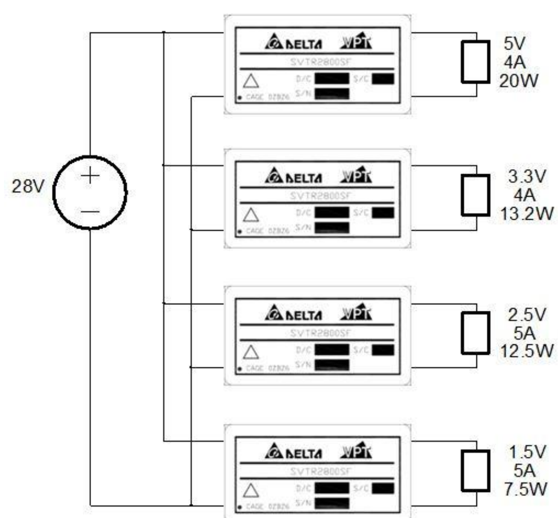

Fig. 1. Traditional power system using isolated dc-dc converters.

The disadvantages of this approach include increased size and weight due to the unnecessary complexity of repeating the isolation boundary in each converter. One method of reducing the power system size and weight is to use one isolated converter feeding several linear regulators to provide the lower output voltages. However, this approach results in poor system efficiency and the linear regulators may not be capable of providing the regulation required for more advanced DSPs and FPGAs.

A much better approach for systems with multiple low-voltage load requirements is to use one isolated converter to provide the critical isolation barrier, and then feed the power to multiple, high-efficiency, non-isolated point of load (POL) converters as shown in Fig. 2.

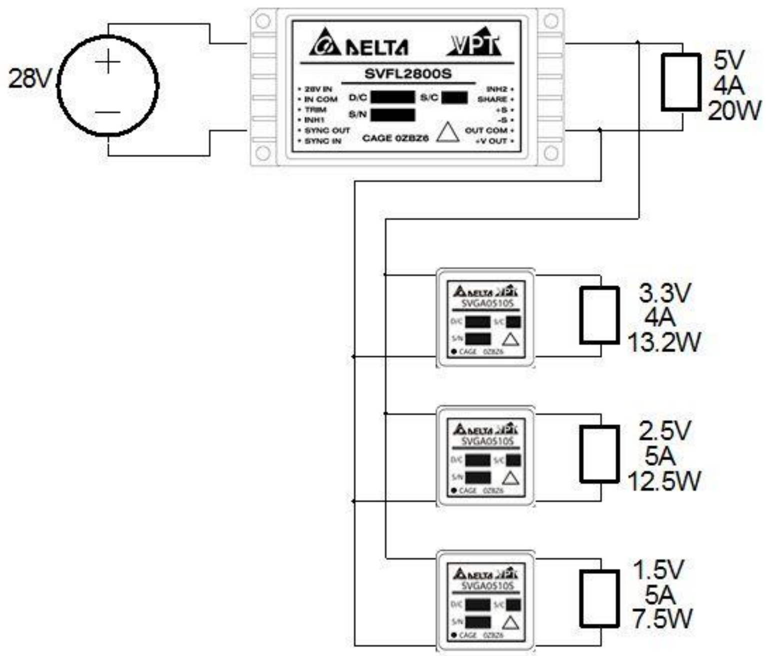

Fig. 2. Improved approach using space-qualified point-of-load converters.

This POL approach significantly improves many parameters over the traditional, multiple isolated converter approach including efficiency, size and weight. Whereas POL converters have been available for aerospace and defense applications for the past few years, now, POL converters are available qualified for the unique requirements of space with features including radiation hardening and resistance to single event effects.

Additional benefits of the POL converter approach include a reduced bill-of-material component count, system flexibility, and lower system cost. The VPT space-qualified POL converters' output voltages are programmed with a single external resistor. This ensures that one part number can be used for all of the different load-voltage requirements in the system, thereby simplifying the bill of materials.

The POLs' programmable output voltages also add greater system flexibility. For example, if a system voltage requirement changes during the design cycle, then the system change is limited to a single resistor value change. Finally, a simple POL converter cost is lower than the more-complex isolated converters, resulting in a lower overall power system cost—a critical factor for space systems.

Load Requirements

The POL-based distributed architecture allows the isolation boundary to be local to the input of the system board and the POL converters to be placed very close to their loads. Today's high-performance DSPs and FPGAs have power specifications that require very tight regulation on a low-voltage, high-current bus even during transients. This regulation cannot be achieved unless the converter is placed very close to the load, where it can minimize impedance between the source and load.

Placing the POL right next to the load provides extremely tight regulation during load-current transients. Because VPT POL converters are very light, small, and efficient, one can place the converters at any required location on the system board without requiring large heat sinks and reinforcing structures.

If the load ripple voltage requirements are tighter than what is specified in the POL converter datasheet, low ESR capacitors—placed between the converter output and the load—can reduce the ripple to the required levels. Bulk capacitance can also be placed at the input to the load to increase regulation performance during fast current transients. The VPT space-qualified POL converters are all rated to operate with up to 5000 μF of external capacitance on the output.

Input Requirements

The designer of a distributed power system must take into account the input requirements to the system as well as the intermediate bus between the isolated converter and the POLs. The input to the isolated converter must meet several requirements including conducted EMI emissions and susceptibility, which are governed by MIL-STD-461. The EMI performance requirement of the system can be met with the addition of an appropriately sized EMI filter module.

One important consideration for the intermediate bus between the isolated converter and the POLs is impedance interaction that can lead to instability.[1] This can be corrected by placing bulk capacitance on the intermediate bus.[2] There is no limit to the amount of capacitance that can be placed on the input of the POLs, but the design maximum capacitance for the isolated converter that feeds the intermediate bus should not be exceeded.

Environmental Requirements

The information covered so far in this article has been published many times over discussing the benefits of the POL converter-based distributed power system architecture. As mentioned in the introduction, the high-efficiency synchronous regulated POL converters were not available as off-the-shelf solutions for space power system designers until very recently. The reason for this delay in the availability of POL converters was the requirement to meet operational specifications in the natural radiation environment in space.[3,4]

The impact of the space radiation environment on the operation and reliability of microelectronics and power systems in particular can be simplified to two areas for this discussion: 1) total ionizing dose (TID) and displacement damage (DD), and 2) single event effects (SEE).

Total Ionizing Dose And Displacement Damage

TID and DD are combined in this discussion because they both result in a slow degradation of performance specifications of active devices (transistors, diodes, ICs, etc…) that eventually leads to system failure. As the energetic particles (electrons, protons, heavier ions, etc…) from the sun and other galactic sources interact with silicon devices, they generate electron-hole pairs and crystal lattice displacements.

The trapping of the generated charge carriers in the oxides of the semiconductor devices leads to charge buildup that affects such device parameters as transistor gain, device leakage, and minority carrier lifetime. The measure of the amount of energy absorbed in a device from ionizing particles is the total ionizing dose and is specified in units of rad(Si) or krad(Si). The unit specifies the material that is absorbing the dose, silicon in this case.

The crystal-lattice displacements are caused by non-ionizing energy loss or collisions of the energetic particles with atoms in the crystal structure of the devices. This also leads to degradation of device performance such as increased bulk resistance and decreased light transmission coefficients for optical devices. This effect is termed displacement damage, and is specified in units of particles/cm^2. DD performance is usually tested using neutrons and so DD performance level is generally specified in neutrons/cm^2.

The slow device-parameter degradations require that power converter components be selected to perform to the required TID and DD levels. In addition, for proper device selection, due to lot-to-lot variability of radiation performance, each lot of the semiconductor devices that are susceptible to degradation must undergo radiation lot acceptance testing (RLAT). In addition to the normal items (initial tolerance, temperature variation, aging) that are used to perform circuit worst-case analysis to ensure proper operation until the specified end of life, the degradations from TID and DD must also be taken into account.

One very important consideration for TID is a phenomenon termed enhanced low dose rate sensitivity (ELDRS) in which certain linear semiconductor devices can exhibit enhanced degradation when exposed at dose rates closer to those encountered on orbit.

Historically, ground-based testing has been performed at high dose rates to shorten test time, but this may not bound the response of some devices and may result in an overly optimistic TID rating of a device. Parts that are shown to exhibit ELDRS must be tested at a dose rate that is closer to that encountered on orbit. Therefore, designers must be aware of this issue and ensure that their component vendors take this into account when providing radiation hardness assured devices.

Single Event Effects

SEE are caused by the interaction of a single, highly energetic charged particle (typically a proton or a heavy ion) with an active device. As the particle transits through a semiconductor device, it deposits energy in the form of excess electron-hole pairs. The energy is deposited along the path of the particle, which is termed linear energy transfer (LET) and the units are given as MeV-cm^2/mg.

What follows is a charge collection of excess carriers, which results in a broad spectrum of circuit responses. These responses include minor transients that propagate to the outputs of devices, bit flips in digital devices resulting in corrupted memory locations or improper operation of sequential logic circuits, soft and hard latch-up events, power device burnout, and MOSFET gate rupture.[3,4] Testing for SEE is performed at particle accelerator facilities.

Several circuit responses from SEE can result in a POL converter design that will not be usable in a power system. Most of the modern PWM control integrated circuits (ICs) that are designed for POL applications contain digital logic to implement features such as predictive dead-time control. This digital logic is highly susceptible to SEE and—unless it is specifically designed for the environment through triplicate voting and redundancy schemes—the resulting upsets can cause continual converter-level upsets. These upsets can include large-magnitude transients at the output, shutdown/restart events, and MOSFET shoot through.

The ICs may also be susceptible to destructive latch-up. Any POL converter that is going to be used for space applications must be characterized for SEE response.

Regardless of how well a converter is designed for performance in a SEE environment, there will be transients on the output. The key is to make sure that the transients are well characterized and can be controlled to ensure that system operational requirements are met and the load-voltage limits are not exceeded.

Fig. 3 shows the response of an SVGA0510S 10-A space-qualified POL converter running at 3.3-V output under a beam of LET = 42 MeV-cm2/mg particles with no external capacitance on the left and with 880 µF of external capacitance on the right.

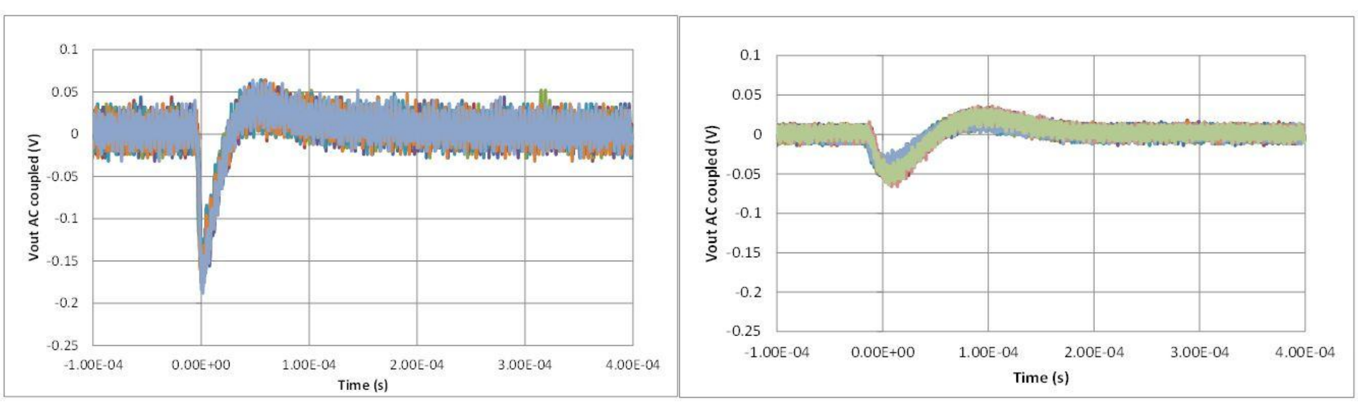

Fig. 3. SEE transient waveforms for the SVGA0510S POL converter with 0 µF (left graph) and 880 µF (right graph) of external capacitance.

With no external capacitance, the positive part of the transient is less than 1.5% of nominal and the negative part of the transient is less than 6%. With the addition of external capacitance, the transient is reduced to less than 1.5% for both the positive and negative portions of the transient. Power system designers must know what level of transients can be expected due to SEE to ensure that the load-voltage limits are not exceeded.

The power devices used in dc-dc converters are typically MOSFETs, which can be susceptible to hard failure modes in a SEE environment including single-event burnout (SEB) and single-event gate rupture (SEGR). These hard failure modes can be mitigated by heavily derating the drain voltage applied to the MOSFETs.

As previously mentioned, the power system efficiency can be improved by distributing power at a higher voltage, but a tradeoff must be made to reduce the risk of a device failure from SEB or SEGR. For example, a 12-V intermediate bus would provide higher system efficiency than a 5-V system, but the 12-V input POL converters may be at higher risk for SEE-induced failures.

Conclusion

The key to creating an efficient low-voltage distributed power system for space-based applications is implementing a proper architecture using space-qualified isolated dc-dc converters and POLs. These converters must be able to withstand the radiation environment specified for the mission. Converters that are qualified and screened to Class K of MIL-PRF-38534 add a significant level of reliability to a system design.

Designing a low-voltage distributed power system with off-the-shelf qualified modules will save your space-power system significant time, cost, and weight while increasing reliability and flexibility. Companies such as VPT offer an extensive range of isolated and non-isolated dc-dc converters and EMI filters that are built for rugged duty and qualified to MIL-PRF-38534 Class H and Class K level as defined in MIL-STD-883 including radiation hardness assurance to meet the demanding environments in space.

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About The Author

Leonard G. Leslie, Jr. received the B.S. degree from Virginia Tech in 2001 and M.S. degree from the Center for Power Electronics Systems (CPES), Virginia Tech 2002. He is currently the manager of Space Product Engineering at VPT Inc. in Blacksburg, Va. Leonard has combined his experience in the Navy Nuclear Power Program and power electronics design to develop and validate custom and standard radiation-hardened dc-dc converter solutions to support the space industry.

For further reading on the development of power converters and systems for space applications, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category, and select "Radiation" in the Extreme Environments category. Also see "Military and Aerospace" in the Application category.