Rad-Hard Power Converters Ride Intermediate Bus Into Space

by David G. Morrison, Editor, How2Power.com

Up until a few years ago, space applications such as satellites routinely employed distributed power architectures (DPAs) that were highly reliant on isolated dc-dc converters. But in recent years, power system designers working on space applications have taken a page from the telecom and computing worlds and begun turning to a refinement of the DPA known as the intermediate bus architecture (IBA.)

Although the main system bus voltages encountered in space applications may be different from telecom (28-V, 50-V, and 70-V to 100-V buses are common in space), the two-stage approach to power conversion is similar: An isolated dc-dc converter steps down the system bus to an intermediate voltage bus level. Then, non-isolated point-of-load buck regulators (POLs) step the intermediate bus voltage down to supply levels required by on-board circuitry.

The drive to adopt IBAs in space systems is driven largely by the increasing current demands of the loads, particularly power-hungry FPGAs like Xilinx's Vertex. Such chips make it less practical to rely only on isolated converters or to simply use LDOs to generate additional supply voltages at the point of load.

Although the IBA concept is similar to what's done in telecom/computing power systems, the power components that are developed to implement IBAs in space applications must be designed to withstand the environmental rigors of space. Therefore, the isolated dc-dc converters and non-isolated POLs must be designed for radiation hardness and be tested and qualified to various space standards. Another factor is thermal management as all power converters must be designed for conduction cooling. Typically, these power converters, which include both hybrid modules and monolithic devices are housed in hermetically sealed ceramic packages.

As a result of the special requirements associated with the design, manufacturing, test, and qualification of these converters for space, pricing for space-grade power converters is typically orders of magnitude above the cost of comparable commercial products.

At the 2012 IEEE Nuclear and Space Radiation Effects Conference (NSREC), held last month in Miami, suppliers of rad-hard dc-dc converters and POLs for space showed off their new and recently introduced products, many of which were developed to support IBAs. These products included the latest developments in monolithic regulators as well as the multi-chip hybrids plus various rad-hard components for power management.

Monolithic Point-of-Load Regulators (POLs)

At NSREC, **Texas Instruments** previewed the TPS50601-SP, the company's first POL for harsh environments. This member of the SWIFT family of monolithic regulators is a 6-A POL that accepts a 3-V to 6.3-V input (Fig. 1.)

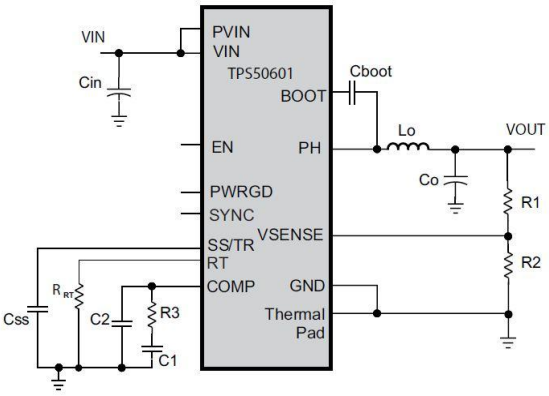

Fig. 1. Texas Instruments' TPS50601-SP monolithic point of load regulator is the company's first POL for harsh environments such as space.

A key feature of the TPS50601-SP known as dynamic bias improves transient response with low values of output capacitance. This enables a 10X reduction in output capacitance while maintaining the same transient response as that achieved without dynamic bias and the higher amount of capacitance (Fig. 2.) According to the company, a new feedback design enables the POL to achieve fast dynamic response without sacrificing efficiency (Fig. 3.)

Radiation hardness for the TPS50601-SP is specified as 100 kRad (Si), total ionizing dose (TID), with single event latchup immunity (SEL) and single event transient (SET) immunity each specified at LET ≤ 85 MeV•cm^2/mg. The device is also ELDRS free.

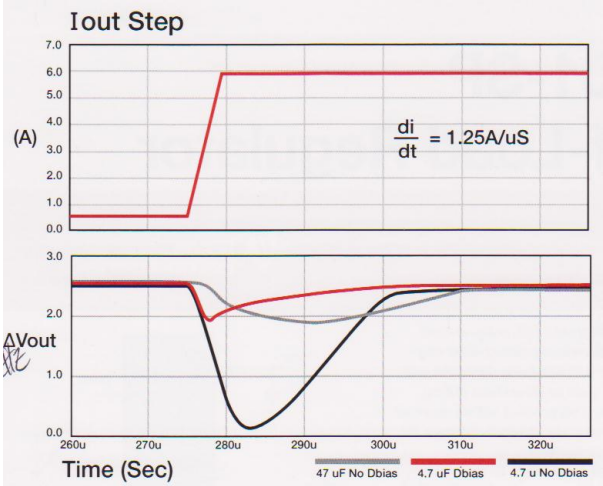

Fig. 2. The TPS50601-SP's fast dynamic response allows the use of a smaller output capacitor as shown here. The load-step response shown here was measured with 5-V input, 2.5-V output and a switching frequency of 100 kHz. Although this measurement was taken at a di/dt of 1.25 A/µs, this POL has been tested up to 20 A/µs.

In addition to the TPS50601-SP, which specifically targets space applications, a version of this POL for downhole applications is also planned, although that model will be derated to 3 A.

Housed in a 20-pin ceramic dual flat-pack package that measures 0.5 in. x 0.25 in., the TPS50601-SP will be qualified to QML Class V. Samples and evaluation modules are available now. The company plans to release the TPS50601-SP in the first half of 2013 with unit pricing expected to be $2500. For more details, see Texas Instruments' Space Products Guide.

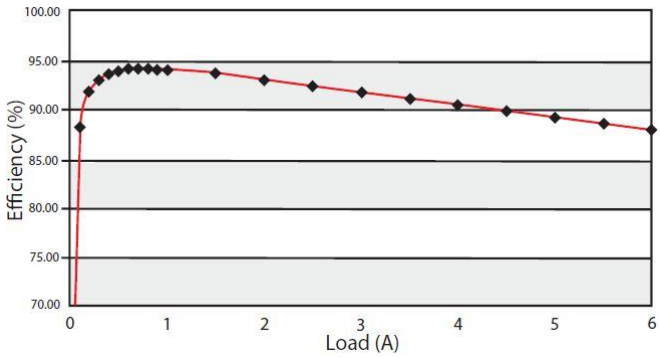

Fig. 3. The TPS50601-SP achieves 93% efficiency at 1-A output. (Inductance = 4.7 µH and switching frequency = 100 kHz.)

Meanwhile at their booth, **Intersil** presented a demo board employing their two new rad-hard POLs and one rad-hard LDO for space (Fig. 4.) The ISL70001 and ISL70002 are SEE immune monolithic synchronous buck regulators rated for 6 A and 12 A of output, respectively. Operating from a 3 to 5.5-V input, these POLs produce an externally adjustable output ranging from 0.8 V to ~85% of the input voltage. The output voltage tolerance on these POLs is 1% over line, load, and radiation.

Fig. 4. Intersil's rad hard FPGA power solutions reference design board, the VIRTEX5MEZPWREV1Z board, is optimized to power a Xilinx's Virtex-5 FPGA using rad hard components such as the ISL70001SRH and ISL70002SRH POLs and the ISL75051RH LDO.

When the newer of these two POLs, the ISL70002SEH, was introduced this past May, it was described as having "industry's highest output current," for a rad hard monolithic regulator. This regulator features high dose rate (HDR) and low dose rate (LDR) immunity. Its high level of integration eliminates the need for external components, reduces cost, board space, and provides the industry's highest reliability for space and harsh environment applications, according to the company. Additionally, the ISL70002's Class V compliant hermetic solution is said to meet the most-stringent satellite program requirements (Figs. 5 and 6.)

The ISL70002SEH features a maximum junction temperature of 150°C, allowing designers to take full advantage of the ISL70002's output power. It also offers synchronous rectification for optimum efficiency; especially at lower output voltages; is designed for complete single event immunity at LET = 86.4 MeV; and is SEL, SEB, SET, and SEFI hardened. Two ISL70002s can be paralleled to support output currents up to 19 A.

Fig. 5. A 12-A synchronous buck regulator, Intersil's ISL70002SEH was introduced as having the industry's highest output current for a rad-hard monolithic regulator.

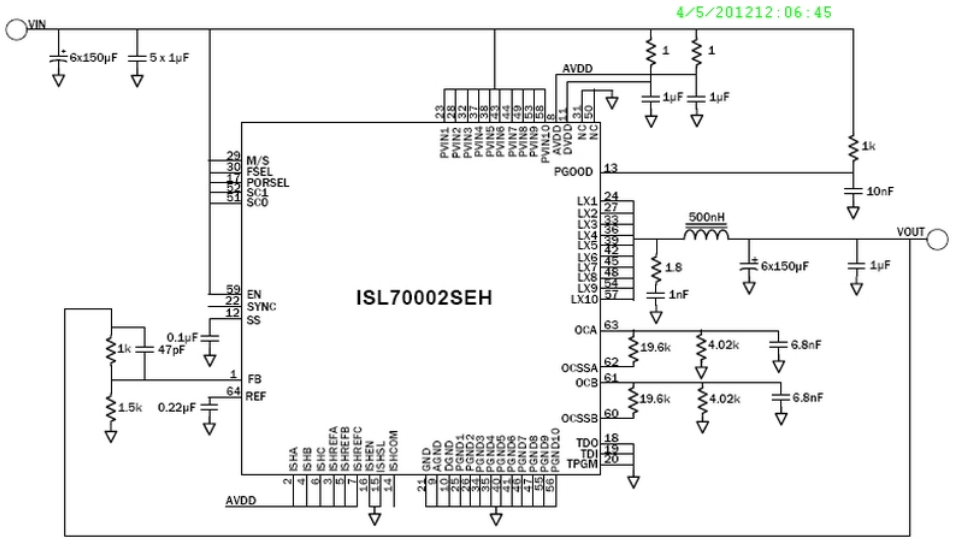

Fig. 6. An application circuit for the ISL70002 12-A monolithic POL.

The predecessor to the ISL70002, the 6-A ISL70001 regulator was introduced in 2009 as the industry's first SEE immune monolithic buck regulator. The introduction of the 70001 and 70002 has given designers monolithic alternatives to some of the hybrid regulators that were previously used in space.

The ISL70002SEH is currently available in a 64-lead ceramic quad flat pack package, with sample pricing starting at $602 each in 100-unit quantities. According to Phil Chesley, managing director of Intersil's High Reliability Products Group, the full flight-grade version of the ISL70002SEH is priced at approximately $2000 each. For more information, visit: http://www.intersil.com/products/ISL70002SEH.

Complementing the two POLs is Intersil's ISL75051SRH, a radiation-tolerant ultra-low dropout voltage regulator (LDO) that can operate over the full military temperature range of -55C to +125C. This 3-A SMD-approved LDO, which was introduced in February, is well suited for DSP, FPGA and microprocessor core power supplies, post-regulation of switch-mode power supplies and down-hole oil field drilling equipment.

The ISL75051SRH is immune to high-dose radiation up to 100 krads (Si), and to single-event effects without the need for additional diodes or filters. This LDO operates over an input voltage range of 2.2 V to 6.0 V and can provide output voltages of 0.8 V to 5.0 V. Dropout voltage is an ultra-low 65 mV at 1 A, and 225 mV at 3 A (Fig. 7.)

The ISL75051SRH is currently available in an 18-pin ceramic flat pack package, with samples available at $89.90 each. Quantity pricing is available upon request. For more details, see http://www.intersil.com/products/ISL75051SRH.

Fig. 7. Intersil's ISL75051SRH is a radiation-tolerant ultra-low dropout regulator.

Another exhibitor, **Peregrine Semiconductor**, discussed its new PE9915x family of rad-hard buck regulators with integrated switches. When these POLs were introduced in April, the company described them as the "industry's smallest space-grade monolithic non-isolated distributed power solution, replacing traditional multi-chip modules that power field programmable gate array (FPGA), digital signal processor, ASIC and SRAM power management designs."

These POLs deliver continuous output currents of 2 A (PE99151), 6 A (PE99153), or 10 A (PE99155) at voltages ranging from 1.0 V to 3. 6 V, while operating from a 5-V nominal (4.6-V to 6.0-V) input (Fig. 8.) The integrated MOSFET switches lead to peak efficiencies at or above 93%.

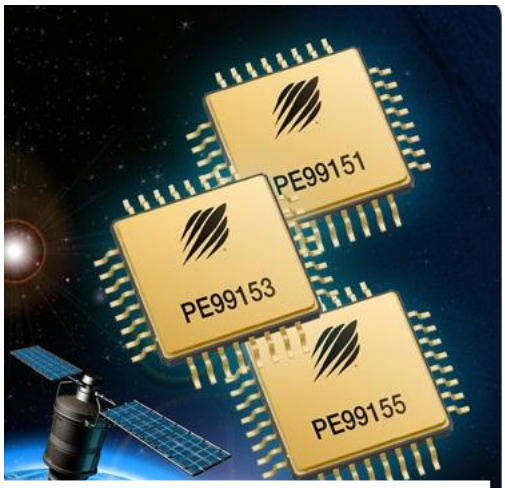

Fig. 8. Peregrine Semiconductor's PE9915x monolithic buck regulators convert a 5-V input to a 1.0-V to 3.6-V output at currents up to 2 A ('151), 6 A ('153) or 10 A ('155).

These regulators require few external components and allow very high switching frequency (adjustable from 100 kHz all the way up to 5 MHz), enabling designers to minimize the size and weight of external components. According to the company, these factors make it possible to achieve power densites >10 W/in^2. The wide range of switching frequencies also helps designers to limit the impact of RF spurs.

According to the vendor, the reduced bulk parasitics of the company's UltraCMOS process technology provides immunity to radiation-induced latchup. Radiation hardness is specified as a total ionizing dose of 100 Krad (Si) and the parts are guaranteed SEE immune to LET>90 MeV•cm^2/mg. Housed in 32-lead, ceramic QFPs.

For more information on the PE9915x, see http://www.psemi.com/articles/2012/2012_pr_4-18(POLBR).pdf.

Hybrid POLs and DC-DC Converters

International Rectifier previewed two POL products at NSREC. One was the GHP2815S single-output rad hard dc-dc converter. With its 120-W rating, this hybrid buck converter delivers three times the power output of the M3G series, a legacy dc-dc converter product with a proven flight heritage.

The GHP2815S, which has the same package outline as the M3G series converter (see Fig. 9), is currently being offered in only one version—a 15-V, 8-A output. (Input voltage ranges from 18 V to 40 V.) However, this model is intended to demonstrate the power capability of the converter and the company says it can tailor this part to generate other output voltages as desired.

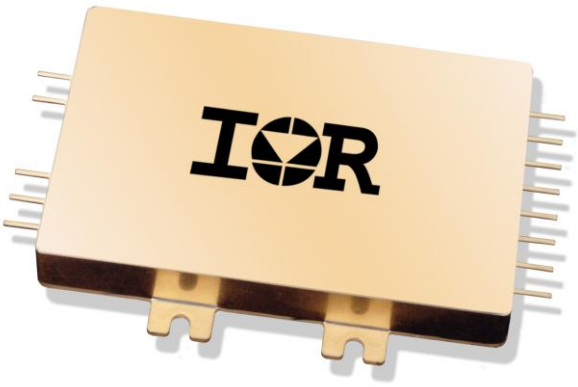

Fig. 9. The GHP2815S and the M3G series rad-hard dc-dc converters share a common package.

According to Tiva Bussarakons, technical marketing director for IR's HiRel Business Unit, the improvement in power output performance achieved by the GHP2815S can primarily be attributed to the development of an intermediate product, the GH series dc-dc converter.

"The GH series converters required lower output voltages than the older M3G series. So in developing the GH series, IR designers made the change from asynchronous to synchronous rectification, which naturally requires more complex control on the secondary side of the buck converter. To make room for the extra components needed for synchronous rectification, IR replaced a PWM controller built using discretes (as found in the M3G series) with a monolithic PWM controller," says Bussarakons. (The PWM controller die was sourced from another vendor.)

Bussarakons adds that when it came time to develop the GHP2815S, it was natural to reuse the monolithic controller from the GH series. "However, since this new product was not being developed with low output voltage in mind, synchronous rectification was not needed. Therefore, returning to asynchronous rectification freed up space inside the converter for larger magnetics and filter components, enabling the GHP2815S to go to much higher output power than the M3G series," says Bussarakons.

Fig. 10 suggests the parts reduction achieved in going from a discretely designed PWM controller in the M3G series converter (top block diagram) to the monolithic controller used in the GH series and ultimately the GHP2815S converter (bottom block diagram).

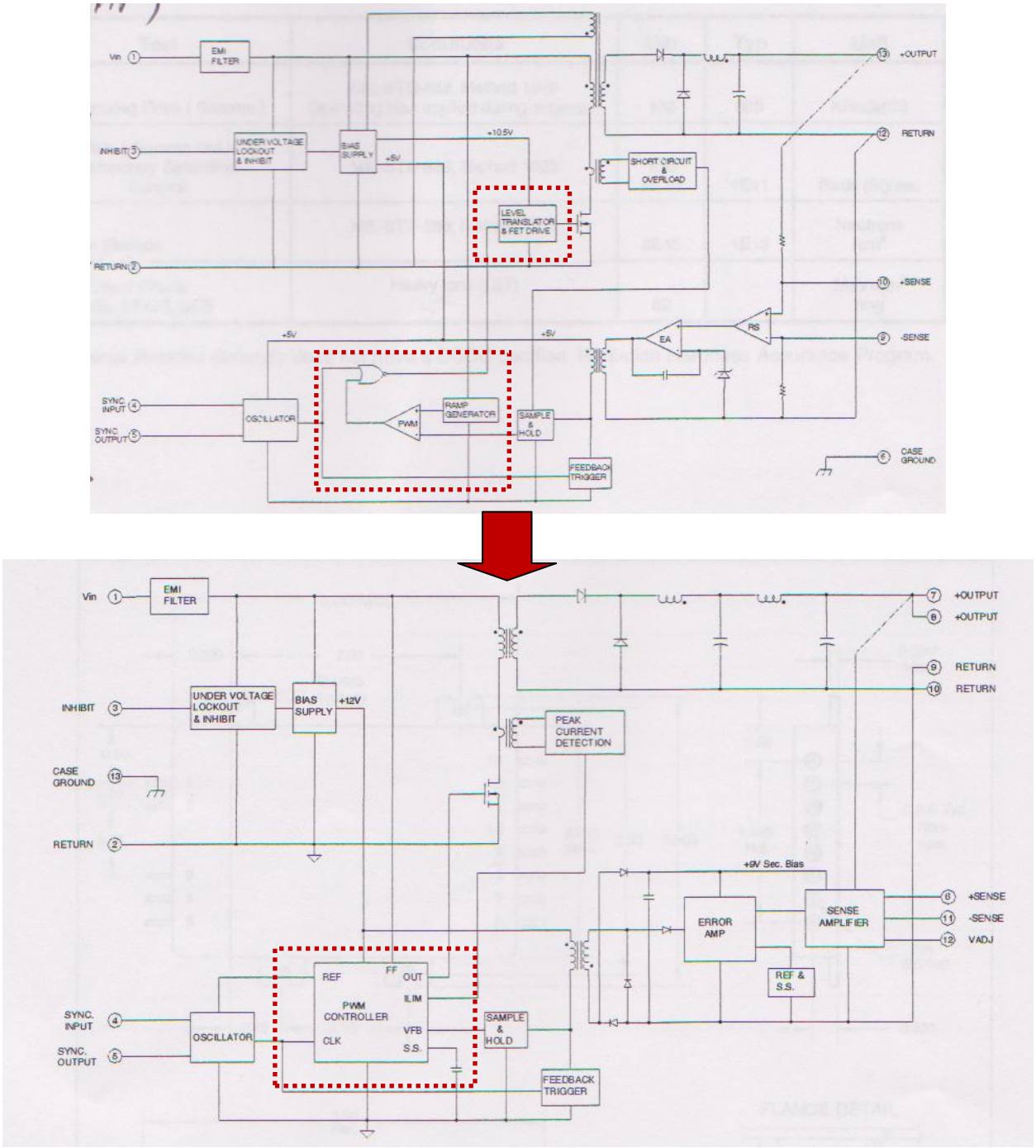

Fig. 10. A reduction in components was achieved by replacing the discretely designed PWM controller in the M3G series converter (top block diagram) with the monolithic controller in the GHP2815S (bottom block diagram). Functions associated with the PWM controller in each diagram are enclosed in dotted lines. The M3G series converter shown here is the 120-V input single-output model described later in this article.

The GHP2815S specifies a total ionizing doze of >100 KRad (Si) and is SEE hardened to a LET level of >83 MeV•cm^2/mg. Housed in a hermetically sealed package measuring 3.50 in. (l) x 2.50 in. (w) x 0.475 in. (h) including I/O pins and mounting tabs, the converter weighs less than 110 g. Other features of the GHP2815S include magnetically coupled feedback, efficiency up to 87%, undervoltage lockout, short circuit and overload protection, synchronization output and input, remote sense, and external inhibit. According to IR's Mike Sullivan, the GHP2815S is priced at $10,000 per unit in 25-piece quantities.

At NSREC, IR also previewed a new version of the M3G series. The new 40-W rated, single/dual output converters feature a 120-V input to accommodate the 120-V buses employed in the International Space Station and in the Orion program. Designed to operate over an input range of 90 V to 140 V, these converters are available in either single outputs of 3.3 V, 5 V, 12 V, or 15 V or dual outputs of ±5 V, ±12 V, or ±15 V.

These converters specify a total ionizing dose >200 KRad (Si), but are typically usable up to >300 KRad (Si). And like the series described above, these 120-V input M3G series converters are SEE hardened to a LET level of >83 MeV•cm^2/mg. Housed in a hermetic package measuring 3 in. (l) x 2 in. (w) x 0.475 in. (h), the converters weighs less than 110 g. According to Sullivan, the 120-V input M3G-series converters are priced at $8,300 per unit in 25-piece quantities. To request more information on the GHP2815S and the 120-V input M3G-series converters, email tbussar1@irf.com. And for more information about the GH series mentioned above, see http://www.irf.com/whats-new/nr110630.html.

Fig. 11. Capable of delivering 15 A or up to 50 W output, the SVGA0515S achieves a power density of up to 160 W/in.[3.]

At their booth, **VPT** introduced its new POL designed for space, a 15-A member of the SVGA family known as the SVGA0515S. Like the previously introduced SVGA0510S, a 10-A POL, the SVGA0515S steps down a nominal 5-V input to a resistor programmable value in the range of 0.8 V to 3.4 V. In doing so, the POL achieves what the company describes as an "extreme accuracy" of 1.5%. Fabricated using hybrid thick film technology in a 100% hermetic package measuring 1.075 in. x 1.075 in. x 270 in. max., the SVGA0515S achieves up to 94% efficiency (Fig. 11.)

This device is qualified to MIL-PRF-38534 Class H and Class K. The company guarantees TID performance to 100 krads (Si) including ELDRS (enhanced low dose rate sensitivity), per VPT's DLA-approved RHA plan specified per MIL-PRF-38534, Appendix G, Level R. In addition, the regulator is SEE characterized to 85 MeV•cm^2/mg with no dropouts, shutdowns, latchup or burn out. Available off the shelf, the SVGA0515S is priced at $2,400 in OEM quantities. For more details including a datasheet, see the SVGA0515S product page.

Another exhibitor, **M.S. Kennedy** introduced the MSK 5060RH, a dual 10-A rad-hard synchronous rectified switching regulator with adjustable output. This POL can be configured to operate as two independent 10-A supplies or its outputs may be paralleled to create a 20-A supply. In the latter case, the regulators can be configured to switch in phase or phase shifted to reduce ripple (Fig. 12.)

The MSK 5060RH operates at a user-selectable switching frequency of 500 kHz or 1 MHz, synchronizable up to 5 MHz. As this article goes to press, radiation specs have not yet been published.

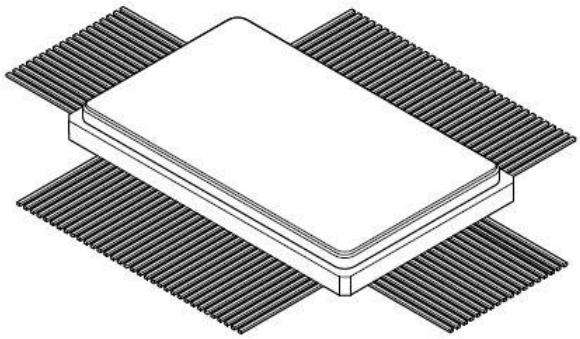

Fig. 12. M.S. Kennedy's MSK 5060RH dual synchronous POL can be configured to operate as two independent 10-A supplies or its outputs may be paralleled to create a single 20-A supply.

The MSK 5060RH is housed in a 106-pin hermetic flatpack package with straight or gull-wing leads. The package measures 1.06 in. (l) x 0.66 in. (w) x 0.15 (h) max., not including the leads. Pricing will be $4500 to $6000 each depending on volume and quality level (class H/K.) For more

information, see http://www.mskennedy.com or contact Bill Polinsky at w.polinsky@mskennedy.com.

Also seen at NSREC, the 3DPM0024-3 rad-hard POL from 3D plus. First introduced in 2010, this POL converts a 5-V input to an adjustable 1.225-V to 4-V output at up to 5.5 A. Rad hard specifications include an SEL/SEE LETth of 80 MeV•cm^2/mg and a TID of 50 krad (Si). Housed in a 14-pin gull wing SMD, the 3DPM0024-3 measures 26.5 mm x 25 mm x 10 mm and weighs 15 g.

Power Management Devices

In addition to the power converters, the NSREC exhibit included some new devices developed to carry out related supervisory, protection, and control functions.

Fig. 13. Aeroflex's UT04VS33P rad-hard voltage supervisor monitors up to four supply levels.

For example, **Aeroflex**, demonstrated its voltage supervisor family for high-rel applications. According to the company, this family includes the industry's first multi-channel rad-hard voltage supervisors. The family, which was introduced in June, consists of four products well suited for reducing the complexity and number of circuits required to monitor and sequence power supplies in systems using microprocessors, DSPs, ASICs and FPGAs used in high-rel environments (Fig. 13.)

The voltage supervisors (see table below) are available with 3.3-V and 5-V supplies over the full military temperature range of -55°C to +125°C , 300 krads (Si) and are single event latch-Up (SEL) immune to >110 MeV•cm^2/mg. The UT04VS33P and UT04VS50P four-channel voltage supervisors provide a cost-effective means for monitoring and sequencing up to four different voltage supplies. These devices significantly improve system reliability and accuracy over comparable systems that use separate ICs or discrete components, says Aeroflex.

The UT01VS50L and UT01VS50D single-channel voltage supervisors with watch dog timer can monitor a single supply, or may be combined with other four-channel or single-channel devices to monitor any number of supplies, providing flexibility in the design of power supply monitoring solutions.

"We are very excited to add voltage supervisors to our family of HiRel off-the-shelf standard products," says David Kerwin, director-Mixed Signal Products, Aeroflex Colorado Springs. "Aeroflex saw the need to supply voltage supervisors with a 3.3-V supply, since many systems no longer have a 5-V supply. Given that most micrprocessors, FPGAs, DSPs, and ASICs have multiple power supplies, with specific power-supply-sequencing requirements, we went one step further and added the capability to monitor four different voltage supplies in a single IC. The four VOUT pins can be used to control and sequence up to four different voltage regulators, including Aeroflex's series of voltage regulators. Customers can select pre-set voltage levels, or select any four arbitrary voltage levels using a resistor divider. Supply voltages as low as 0.6 V may be monitored, making the voltage supervisor family ideal for monitoring and sequencing of even the most advanced ASICs and FPGAs."

Table. Initial product offerings and availabilities for Aeroflex's voltage supervisors.

Part Number	Number of Monitored Supplies	Voltage Supervisor Supply Voltage	Prototypes	QML Q/Q+ Production
UT04VS33P	4	3.3 V	3Q12	1Q13
UT01VS50L (see note)	1	5 V	3Q12	1Q13
UT04VS50P	4	5 V	3Q12	1Q13
UT01VS50D (see note)	1	5 V	3Q12	1Q13

Note: The distinction between the two single-channel voltage supervisors is that the UT01VS50L offers a push-pull drain output, while the UT01VS50D offers an open-drain output.

The UT01VS50L and UT01VS50D are offered in 8-lead flatpacks while the UT04VS33P and UT04VS50P are in 28-lead flatpacks. All are Q and Q+ qualified and will be available to Standard Microcircuit Drawings. QML V accreditation will be available also. The UT04VS33P, QML Q, in lots of 100, is just $997, which is less than $250 per monitored power supply. For datasheets, call 1-800-645-8862 or see www.aeroflex.com/VoltSupv.

And at its booth at NSREC, **Modular Devices** featured its Model 3649 radiation hardened Bus Master Hybrid. Introduced about a year ago, this device is a 3-in-1 system-design solution that operates in conjunction with dc-dc converters. The Bus Master acts as an auto sequencer, inrush limiter and solid-state relay (Fig. 14.)

"The Bus Master implements functions commonly needed in a redundant satellite power system in a convenient hermetic assembly. It solves both the packaging function as well as the circuit implementation function," says Steven Summer, president of Modular Devices.

Summer elaborates on the device's usefulness saying, "The function of selecting one of two buses, and preventing the selected bus from back feeding the unselected bus typically requires four FETs, which are incorporated in the Bus Master. The function of limiting inrush current such as that caused by charging dc-dc converter input capacitors, generates a high peak power dissipation at a low duty cycle. This power dissipation is best absorbed and integrated by mounting the FET to a large thermal mass. This limits junction temperature rise on turn on."

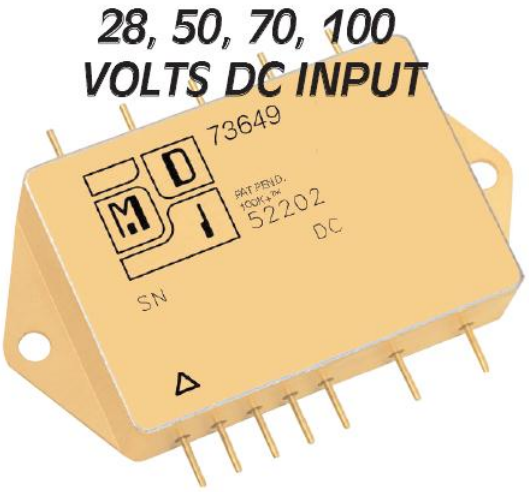

Fig. 14. Designed to operate in conjunction with dc-dc converters, Modular Devices' Model 3649 radiation hardened Bus Master Hybrid serves as an auto sequencer, inrush limiter and solid-state relay.

Summer also comments on the need for UVLO and interlock functions in the targeted applications. "The undervoltage lockout function is a feature that satellite power system designers often require," says Summer, adding, "The Bus Master also has an interlock function that inhibits the load (dc-dc converters) from turning on until all input capacitors are fully charged."

Intended to accommodate the various voltage buses encountered in satellite applications, the device is available with an input voltage of 28 V, 50 V, 70 V or 100 V dc and five different package configurations. The Bus Master is radiation hardened to >100 kRad (Si) for TID but operates beyond 200 kRad TID. It offers SEE immunity to a LET of >82 MeV•cm^2/mg. Furthermore, the units are proton resistant as they contain no optocouplers.

In quantities of 10 to 24 pieces, unit pricing for the Bus Master runs from approximately $3,400 for engineering grade units to $9,000 for space-grade units with pricing dependent on the grade level purchased. For more information, see http://www.mdipower.com/.