NSREC Notes: Rad-Tolerant Power Devices, Reference Designs, And GaN-based Products Continue To Increase As Vendors Expand Space Portfolios

by David G. Morrison, Editor, How2Power.com

At the recent IEEE Nuclear & Space Radiation Effects Conference (NSREC 2024) which was held July 22-26 in Ottawa, Canada, a total of 54 companies and other organizations occupying 62 industrial exhibit booths highlighted the latest products and services for developers and users of rad-hard and rad-tolerant electronics for space and other applications. Among these were numerous power semiconductor and power converter companies showing their latest power transistors, ICs, modules and reference designs for LEO ("new space") as well as MEO and GEO satellites, and other spacecraft.

As was the case last year, power reference designs for advanced FPGAs and SoCs were on display or discussed by some vendors with extensive space-grade power IC portfolios. Meanwhile, these same vendors showed how their power IC portfolios continue to expand rapidly with many parts introduced and many new reference designs offered.

Several of the traditional suppliers of rad-hard power devices and converters continue to expand their rad-tolerant offerings for new space, and GaN devices are featured prominently among the new transistor and power stage offerings, as well as being featured in the latest power reference designs and dc-dc converter products. In addition, at least two first-time exhibitors were among those showing rad-tolerant power devices. This article offers highlights of various new and recently introduced power products featured in the NSREC exhibition.

Meanwhile in the conference itself, there were numerous papers this year on silicon carbide MOSFETs being researched for space applications, which may reflect a renewed interest in these devices.

Power Management And Telemetry Reference Design For Cutting-Edge SoC

At the Renesas booth, the company shared three demos relating to their power components for space. One demo was based on the company's power reference design for AMD's Versal Adaptive SoC, the XQRVE2302. AMD describes its Versal Adaptive SoCs as "adaptive compute acceleration platforms," which "combine scalar engines, adaptable engines, and intelligent engines with leading-edge memory and interfacing technologies to deliver powerful heterogeneous acceleration for any application." Or as Kiran Bernard, product line marketing for Intersil Space/Hi-Rel Products, Industrial Analog and Power Group, observed, an Adaptive SoC is "an FPGA with a lot of other functions."

The ISLVERSALDEMO3Z power management reference design, which was announced the week before NSREC (see Fig. 1), integrates key space-grade components for power management as required to power the AMD Versal AI Edge XQRVE2302 Adaptive SOC. Developed in collaboration with AMD, the ISLVERSALDEMO3Z reference design integrates key space-grade components for power management. It targets the cost-effective AI Edge with both rad-hard & rad-tolerant plastic solutions specifically designed to support a wide range of power rails for next-generation space avionics systems that demand tight voltage tolerances, high current, and efficient power conversion.

All of the devices in this reference design are produced in the company's rad-tolerant plastic flow. But some devices are also available in hermetic packaging in case the customer wants to implement a design for a GEO application.

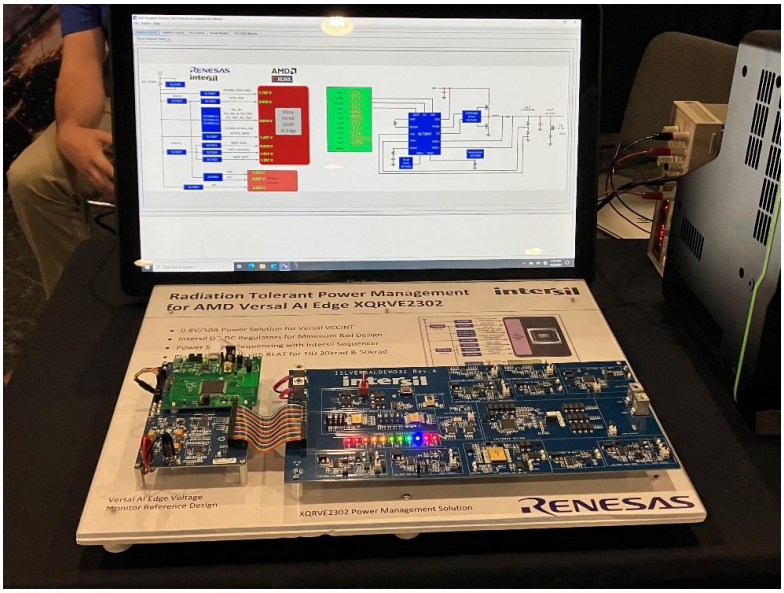

Fig. 1. Renesas' demo of the ISLVERSALDEMO3Z power management reference design for the AMD Versal AI Edge XQRVE2302 Adaptive SOC also incorporated a voltage monitor reference design for the SOC, which can be seen in the lower left corner of this display.

According to Bernard, the power highlight of this reference design is the ISL73849, which he described as the first PWM controller for space with a digital interface. This IC is scheduled for production release in the fourth quarter of 2024. Besides being a key element of the Versal Adaptive SoC power reference design, the ISL73849 was featured in its own demo at the Renesas booth (Fig. 2).

Renesas's demo of the ISLVERSALDEMO3Z reference design also included a voltage monitor reference design. This design represents the type of independent monitoring system that the customer would normally design and build using discrete components to implement cold sparing. According to Aaron Weittenhiller, product line marketing for the Hi Rel Product Group, this voltage monitoring reference design features a novel space-grade ADC with high-input impedance, which allows the design to be implemented with many fewer parts than would be required in a typical customer design.

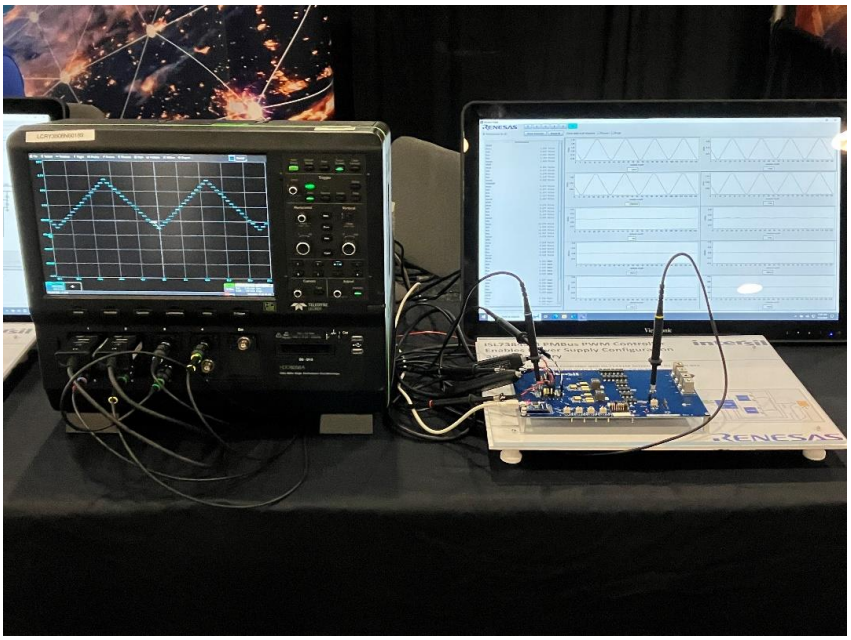

Fig. 2. A demo of the ISL73849 PMBus PWM controller reference design. A GUI is shown here reading the device's data via the PMBus.

In addition to those two demos, Renesas showed a demo for its ISL74420 quad clock fanout generator reference design (Fig. 3). This is the type of clock that could be could be used to synchronize switching of the voltage regulators to reduce EMI, enabling use of smaller EMI filters. However, the ISL74420 can also be configured to run the regulators out of phase to avoid drawing large currents from the input caps at the same time.

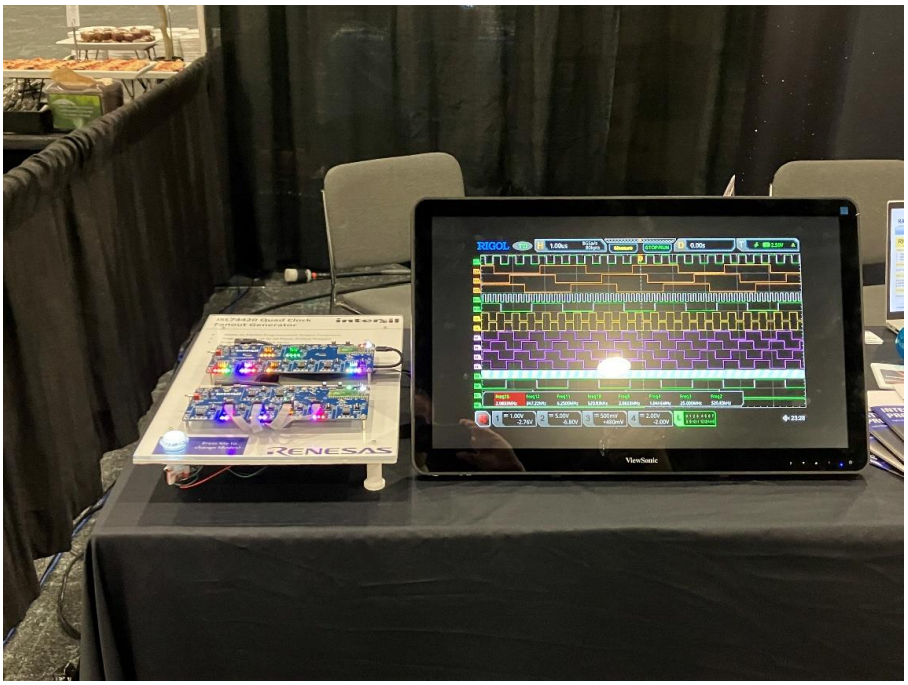

Fig. 3. The ISL74420 quad clock fanout generator. The demo shown here has the chip controlling 24 phases, which is beyond normal power management requirements, and mainly to showcase the chip's capacity.

In addition to developing the components associated with the above reference designs, Renesas has been developing the processes that will enable it to offer its rad-hard plastic ICs in compliance with the QML-P packaging standard. Bernard says Renesas is still working on their manufacturing flow. But they are also doing some things above and beyond the standard.

For example, the company performs 100% C-SAM—acoustic microscopy to check for mechanical defects on its rad-hard plastic components. "Others do this on a sample basis, we do it on 100% of parts shipped," said Bernard, who added that the company plans to announce QML-P parts at the end of the year.

For more information, see the ISLVERSALDEMO3Z announcement or contact Kiran Bernard.

An Expanding Portfolio Of Power ICs

At its booth, Texas Instruments showed a number of new power ICs and reference designs. One was the TPS73014-SP, a 14-V four-channel sequencer that performs power up and down with no SETs or SEFIs up to 75 MeV•cm^2/mg. Kurt Eckels, marketing, Space Power Products at Texas Instruments described this part as a very robust product, noting that it offers "market-leading small package size, accuracy and radiation performance."

In terms of size, the ceramic QML-V version of the TPS73014 measures only 6.4 mm x 7.9 mm versus 11.4 x 8.6 mm for a competing part, while the plastic QML-P and space-enhanced-plastic versions measure just 4.5 x 7.9 mm and are not yet available in plastic from competitors. With regard to accuracy, this sequencer specifies a trip point accuracy of better than 1% (Fig. 4).

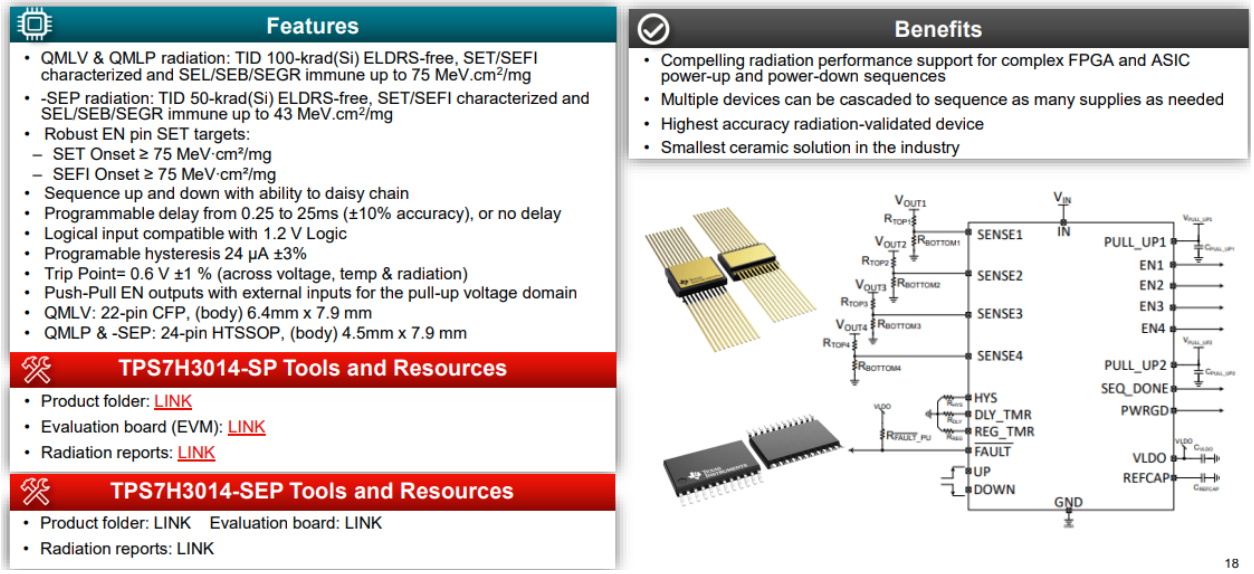

Fig 4. The TPS73014-SP 14-V four-channel sequencer is available in rad-hard QML-V and, in the near-future, QML-P and rad-tolerant -SEP versions.

The TPS73014 addresses sequencing requirements for a number of FPGAs on the market (see the table).

Table. Sequencers are needed for various space-grade FPGAs.

Brand	FPGA	Number of 4 channel sequencers	Comments
AMD (Xilinx)	Versal Core XQRVC1902	2-4	2 minimum, 4 for max flexibility
	Versal Edge XQRVE2302	1-2	
	RFSoC XQZU28DR or MPSoC XQZU9EG	2	
	Kintex Ultrascale XQRKU060	2	
Microsemi	RT PolarFire	1	
Texas Instruments	ADC12DJ500-SP, ADC12DJ5200-SEP	1	
	ADC12QJ1600-SP, ADC12QJ1600-SEP	1	
	AFE7950-SP	1	
	DAC39RF10-SP, DAC39RF10-SEP DAC39RFS10-SP, DAC39RFS10-SEP	1	

The TPS73014 was recently released with immediate availability of both flight parts and production/EM devices, all available now from TI.com

Another part on display at TI's booth was the TPS7H4011 14-V, 12-A rad-hard buck converter. This device can be paralleled for higher current with a multiphase output. It also has differential-mode current sensing. According to Eckles, this POL offers "market-leading power density while providing flexibility to interface to either 5-V or 12-V power systems." See Fig. 5.

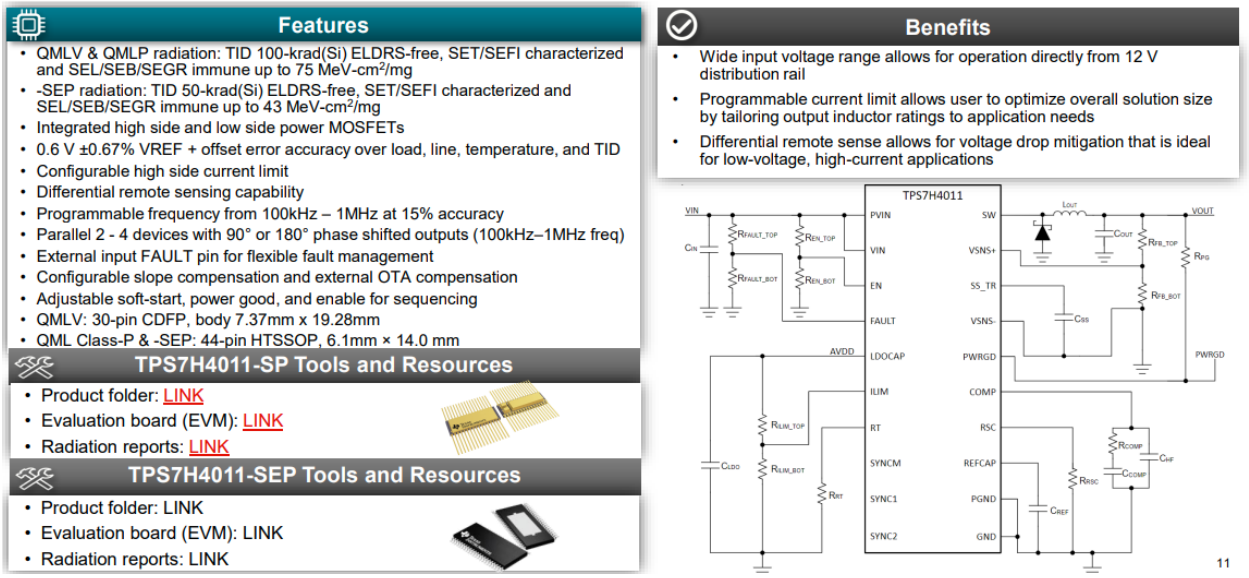

Fig. 5. The TPS7H4011-SP is a rad-hard 12-A current-mode-controlled POL converter currently offered in QML-V (hermetic) and QML-P (plastic) versions. The company also plans to introduce a rad-tolerant variant in space-enhanced plastic.

TI also showed its new TPS7H1121 14-V, 2-A LDO. This rad-hard linear regulator is said to be unique in offering features such as a programmable current limit, as well as configurable soft start, enable and open-drain power good. Other notable characteristics are its small size and radiation performance with both QML-V (hermetic) and QML-P (plastic) versions available (Fig. 6).

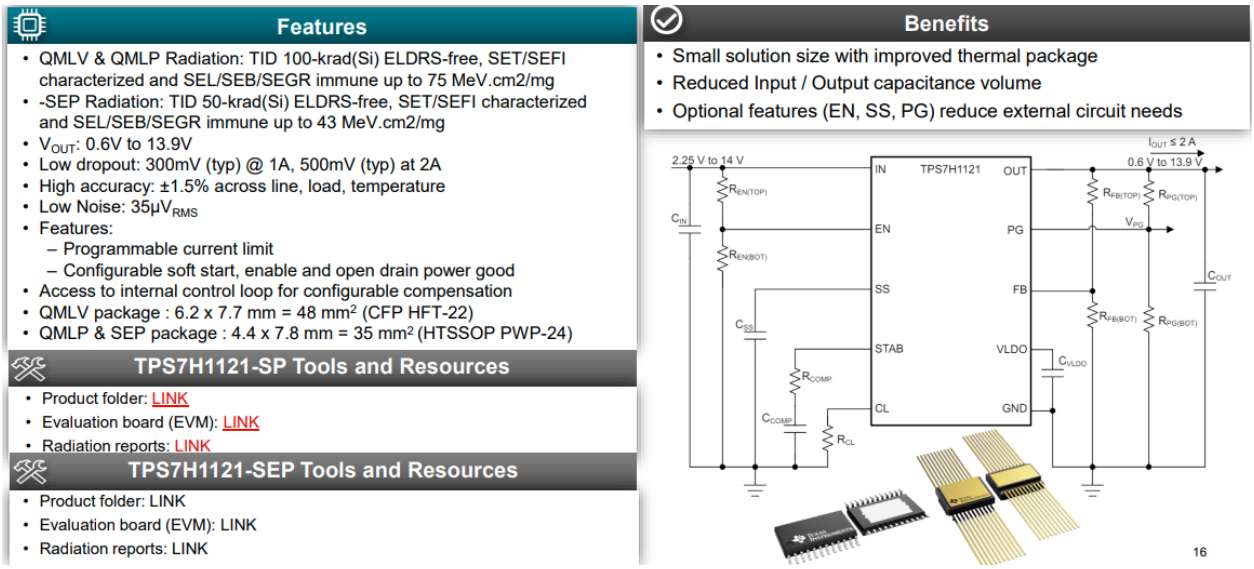

Fig. 6. The TPS7H1121 14-V, 2-A LDO features a programmable current limit.

With GaN FETs finding increasing use in space come requirements for suitable gate drivers. Eckles noted that TI now has a broad family of GaN half-bridge gate drivers capable of supporting voltages from 200 V down to 22 V for any mission type. These include the rad-hard TPS7H6003-SP, TPS7H6013-SP, TPS7H6023-SP_QML-V (hermetic) and the rad-tolerant TPS7H6005-SEP, TPS7H6015-SEP, and TPS7H6025-SEP space-enhanced plastic devices. The new 60-V and 22-V rated parts have helped to fill out this product family (Fig. 7).

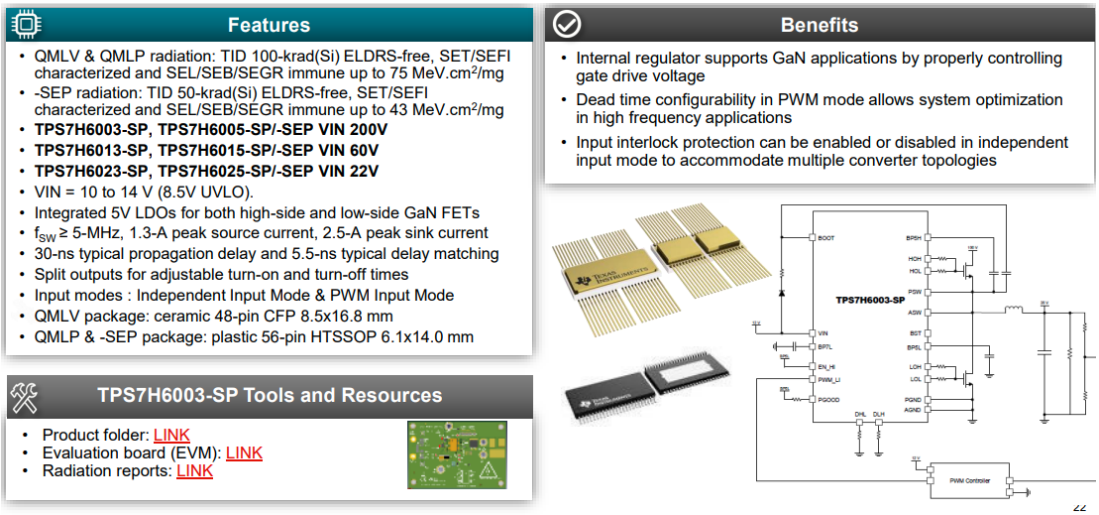

Fig. 7. The TPS7H6003-SP, TPS7H6013-SP, TPS7H6023-SP QML-V (hermetic) and the rad-tolerant TPS7H6005-SEP, TPS7H6015-SEP, TPS7H6025-SEP space-enhanced plastic devices are half-bridge gate drivers tailored to drive GaN FETs.

As reference designs are must-have collateral for power ICs, there will naturally be growth in this area as the chip portfolio for space grows. At the TI booth, the company highlighted several rad-hard reference designs for its PWM controllers including the

- PMP23193 140-W nonisolated, MOSFET-based synchronous buck converter with 50-V to 150-V input (100-V nom.) and 28-V output at 5 A. This design uses the TPS7H5001-SP controller together with an Infineon gate driver and MOSFETs.
- PMP23200 100-W isolated, GaN-based synchronous full bridge with 22-V to 36-V input (28-V nom.) and 5-V output at 20 A. This design also uses the TPS7H5001-SP controller and the TPS7H6015-SP GaN half-bridge gate driver.
- PMP23389 75-W nonisolated, GaN-based synchronous buck with 10-V to 14-V input (12-V nom.) and 5-V output at 15 A. Again, this design uses the TPS7H5001-SP controller and the TPS7H6015-SP GaN half-bridge gate driver. The associated reference kit also highlights an integrated overcurrent protection circuit.

In addition to the above designs, which are pictured in Figs. 8 through 10, the company has developed a new, nonisolated dual-phase buck converter design that converts 12 V to 0.8 V at 80 A. This design, which employs the TPS7H5001 controller and two TPS7H6023-SP half-bridge gate drivers, occupies a board area of just 4.5 in. x 3.0 in. This reference design is not published yet (Fig. 11).

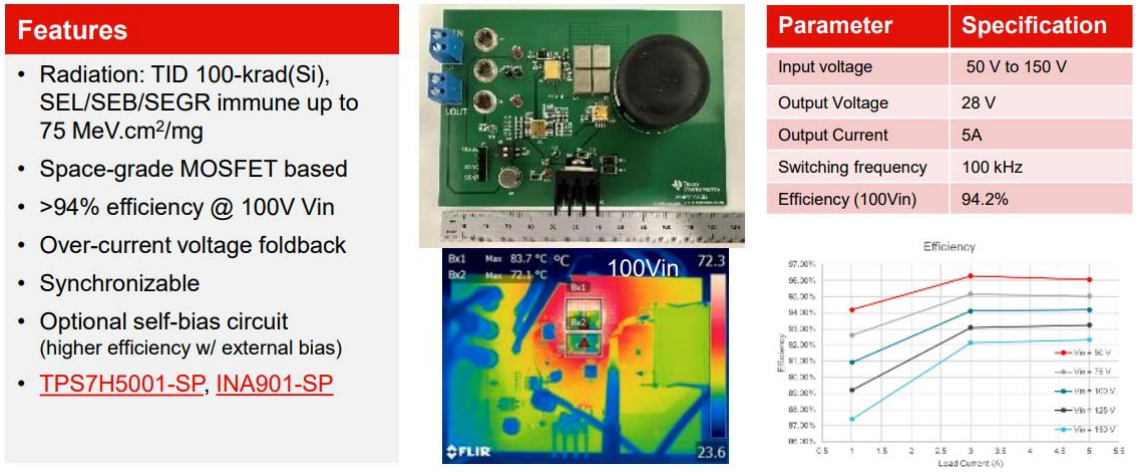

Fig. 8. The PMP23193 rad-hard high-voltage synchronous buck converter.

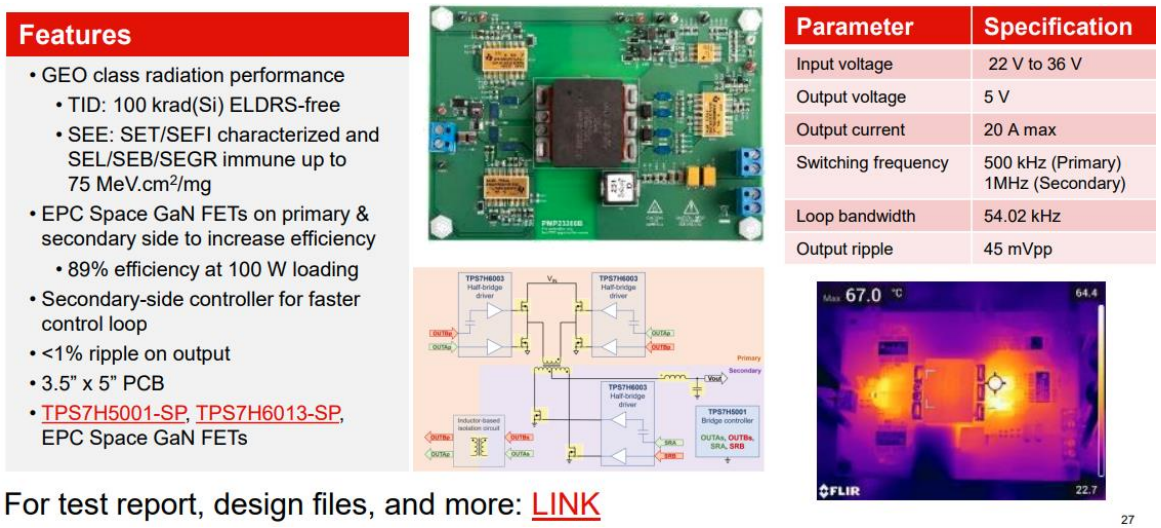

Fig. 9. The PMP23200 rad-hard hard-switched full bridge.

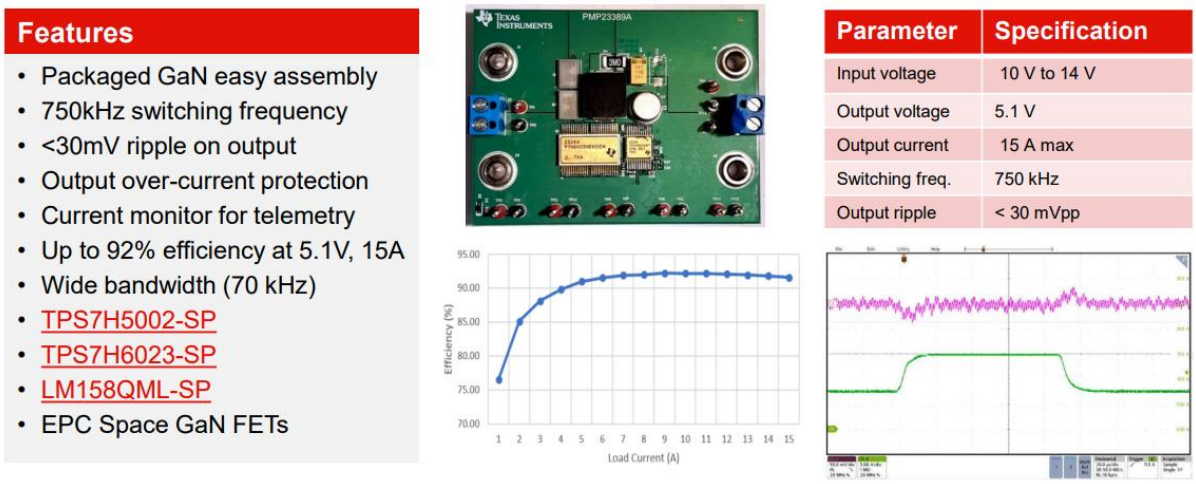

Fig. 10. The PMP23389 rad-hard 12-V to 5-V at 15-A synchronous buck converter.

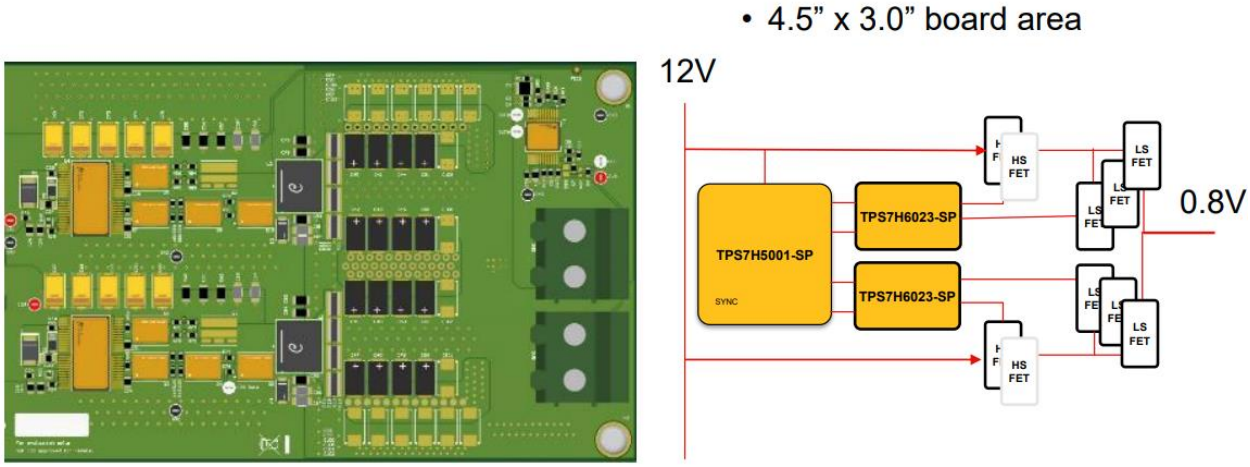

Fig. 11. Targeting core power supplies, this nonsiolated dual-phase buck reference design converts 12 V to 0.8 V at 80 A in a small pc-board area of 4.5 x 3.0 in.

Although not shown at NSREC, TI is currently developing a power reference design for the Versal Edge XQRVE2302 ACAP/FPGA and the company is working with Alpha Data to build a complete FPGA single-board computer using that power design.

For more information on the devices mentioned here, see the following pages: TPS7H3014-SP TPS7H4011-SP, TPS7H1121-SP, TPS7H6003-SP, TPS7H6013-SP, TPS7H6023-SP, TPS7H6005-SEP, TPS7H6015-SEP, and TPS7H6025-SEP. For more on the reference designs, see the PMP23193, PMP23200 and PMP23389 pages. Or contact Kurt Eckles.

POLs, LDOs And A PWM Controller In Development

In the STMicroelectronics exhibit, Antonio Riviera, Space & High Rel, product unit senior manager in the AMG Group-GPA & RF Division, provided previews of several power ICs for space that the company currently has in development. One of these devices is a rad-tolerant point-of-load converter (POL) that was due for release in the weeks following NSREC with a datasheet becoming available on the website at that time.

According to Riviera, the LEOPOL1 will feature a 12-V input and 6-V, 6-A output with a "good SOA," making it a robust part. It will also be rugged with its radition specs, offering a 50-krad TID and a SEE rating of 43 MeV•cm^2/mg, but robust to 62 MeV•cm^2/mg. Naturally, this device is aimed at LEO applications.

However, Riviera adds that the company is also developing a rad-hard hermetic POL for GEO applications. The RH-POL, which is due out by the end of the year, will feature a TID of 100-krad TID.

In addition to these switching regulators, ST has a new ultra-low dropout LDO in development. This device will feature 1- to 2-A output, low quiescent current and a power-good pin. It will be released initially as a rad-tolerant plastic part for LEO in 2025 and then as a rad-hard part for GEO in 2026.

Meanwhile, to support higher power levels and architectures, STMicroelectronics plans to release a rad-hard PWM controller by the end of the year. They are still characterizing its features, says Riviera, but it will be compatible with GaN. He adds that the company is also working on a gate driver IC for GaN. That part is expected for a release in 2025 or 2026.

In terms of GaN power switches themselves, although the company has GaN power devices, it currently has no GaN parts for space. But, says Riviera, such parts are on the company's roadmap.

Although the parts described above were not shown at the ST booth, there was a display for the ICL-current limiter, which was introduced a couple of years ago (Fig. 12). According to Riviera, this device is seeing strong adoption as current limiting is becoming a "must have" function.

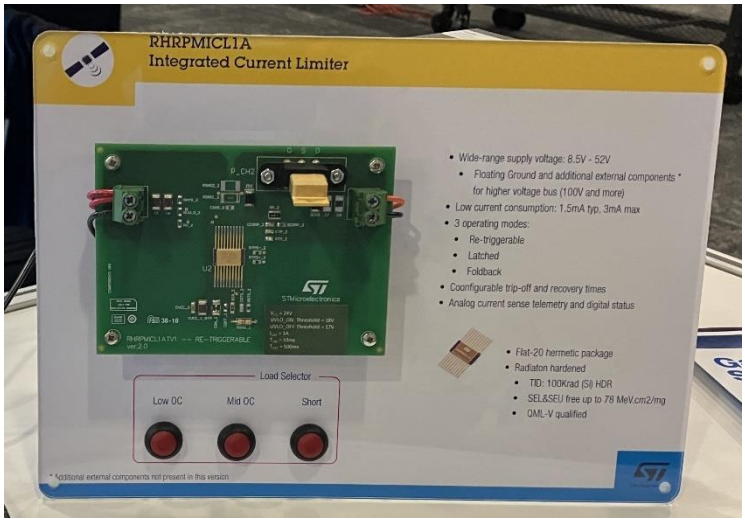

Fig. 12. The RHRPMICL1A rad-hard integrated current limiter works with an external p-channel MOSFET to protect a power supply (from 8.5 V to 52 V) from overcurrent faults.

For more information, see the website or contact Antonio Riviera.

Reaction Wheel Demo And Plastic-Packaged MOSFETs

At its booth, IR HiRel, an Infineon Technologies Company featured a demo of an inverted pendulum cube using the company's rad-hard MOSFETs and gate drivers. The demo contains three reaction wheels like those that would be used for altitude control stabilization in a satellite. Similar equipment could be used for inertial measurement units for determination of a spacecraft's motion and orientation.

In the demo, the reaction wheels spin at speeds in the correct proportion to keep the cube balanced on a corner as shown in the photo (Fig. 13) To see the demo in motion, click here. This demo features the IRHNJ9A7034 60-V n-channel R9 gen MOSFET and the RIC7S113 gate driver.

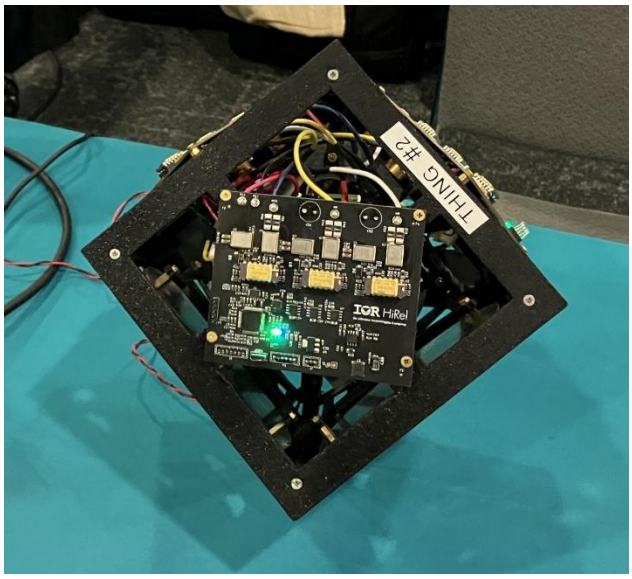

Fig. 13. This inverted pendulum cube demo, featuring the company's rad-hard gate drivers and MOSFETs, contained three reaction wheels whose controlled rotation kept the cube balanced on a corner.

Wibawa Chou, director of technical marketing and application engineering, stated that there is a reference design board for the RIC7S113 gate driver but a reference design for the cube demo itself is currently not available.

The company also used this exhibit to highlight its first rad-tolerant devices in plastic, which offer cost savings versus the company's rad-tolerant devices in hermetic packages. The new plastic-packaged devices, which currently include n-channel MOSFETs, were introduced in February 2024. The company is also developing rad-tolerant p-channel MOSFETs in plastic.

The products are SEE tolerant with a LET of 46 MeV*cm^2/mg and withstand a TID of 30 krad(Si). The product family offers four different n-channel MOSFETs based on the Infineon CoolMOS superjunction technology, making them well suited for fast switching applications. There are two voltage options, 60 V and 150 V, supporting the most common bus voltages used in LEO satellites, 28 V and 54 V. Max $R_{DS(ON)}$ values range from 15 mΩ to 60 mΩ at 25°C.

Offered in the surface-mount TO-263 and the through-hole TO-247, these MOSFETs are qualified to the AEC-Q101 automotive standard with an operating temperature of -40°C to 150°C. In accordance with the automotive qualification, they are built on high-volume automotive assembly lines.

Meanwhile the company is also developing n- and p-channel MOSFETs in the larger SupIR SMD. In addition to offering easier surface-mount assembly versus some existing packages, the SupIR SMD accommodates a high-current MOSFET die for higher current-handling capability, reduces thermal impedance and minimizes coefficient of thermal expansion (CTE) mismatch.

Perhaps more significantly, the company is working on 100-V rad-hard GaN with plans to release a part soon. As Infineon continues to bring the GaN Systems parts into its portfolio, there are likely to be more GaN devices

offered as rad hard. For more information, see the Rad tolerant MOSFETs page and the Space & satellite brushless DC motor controller page, or contact Wibawa Chou.

Rad-Hard GaN IC Power Stage, Low-Side GaN Gate Driver And Schottkys

Among various parts on display at its booth, GaN specialist EPC Space showcased its EPC7011L7SH, which it touts as the world's first rad-hard IC power stage. This 50-V, 6-A half bridge combines the company's eGaN FETs with integrated input logic interface, level shifting, bootstrap charging and gate-drive buffer circuits. The IC features a TID rating of 1000 krad and a SEE immunity for LET of 84 MeV/mg/cm^2 with V_{DD} up to 100% of rated voltage.

The company also highlighted the EPC7009L16SH, a rad-hard low-side eGaN gate driver IC, which the company launched in March 2024. The EPC7009L16SH integrates input logic interface, UVLO protection, a 10-V-to-5.25-V linear regulator and driver circuit within a space-efficient, hermetic 16-pin SMT package to create a high-speed driver that can switch at rates of up to 3.0 MHz. The TID is guaranteed to 1000 krad and a SEE immunity for LET at 84 MeV/mg/cm^2 with the IC's primary supply voltage at 100% of its maximum operating value (Fig. 14).

According to Bel Lazar, CEO of EPC Space, the company plans to introduce a rad-hard 20-V GaN FET designed for point-of-load converters, HEMTKYs (GaN FETs with an embedded Schottky diode) and rad-hard Schottkys this year. For more information on the EPC7011 see "GaN Power Stage IC Is Rad Hard") and for more on the EPC7009L16SH see the product page. Or contact the company.

Fig. 14. The EPC7011L7SH, a rad-hard GaN IC power stage, and the EPC7009L16SH, a rad-hard low-side eGaN gate driver IC, were featured at EPC Space's booth.

Rad-Tolerant Bipolar Transistors

A first-time exhibitor at NSREC, Zero-G Radiation Assurance, brought news of its rad-tolerant bipolar transistors. According to Dakai Chen, president and CEO, this is a new product line of radiation-qualified automotive-grade bipolar transistors (BJTs) intended to meet the SWaP goals of today's space flight missions. Housed in small-footprint plastic-encapsulated packages, these BJTs have been qualified to AEC-Q101 standards and feature a wide temperature rating (-55°C to 150°C) suitable for space environments.

Additionally, each lot has been qualified by Zero-G Radiation Assurance to a TID of 50 Krad, which meets many LEO and GEO mission requirements with margin to spare, said Chen. These are offered as low-cost alternatives to comparable rad-hard devices.

"Discrete BJTs are implemented in a wide range of applications. Their utilities include lower-frequency applications such as voltage regulation, power designs, error amplifiers, and higher-frequency applications such as RF amplifiers," said Chen. "Furthermore, in space or defense environments, the BJTs are robust against single-event latchup or other destructive single-event effects, which is the primary vulnerability for MOSFET devices and circuits. Longer term TID-induced gain degradation is a concern for BJTs, and that's where we focus our radiation qualification efforts. Our lot-level screening ensures that space system designers will know the end-of-life h_{FE} values for their models."

According to Chen, the U.S.-based Zero-G Radiation Assurance leveraged its expertise in radiation testing and in-depth understanding of BJT radiation susceptibility to develop and release this new family of products for space and military customers. At its booth, Zero-G offered a list of 16 released bipolar transistors ranging in V_{CE} voltage ratings from 40 to 150 V, plus 15 soon-to-be-released BJTs with V_{CE} ratings ranging from 40 V to 400 V. For more information see the website or contact Dakai Chen.

Rad-Tolerant And Rad-Hard DC-DC Converters

At its booth, VPT showed several of its dc-dc converter product lines. One was the VSC series of rad-tolerant converters, which feature 28-V input and a standard output. The series also includes input EMI filters.

The latest addition to this series was a 100-W single-output model, which was introduced in February. According to Ronaldo Maia, associate regional sales manager, a 100-W dual-output model is due out later this year. The next addition to this series will be a nonisolated, point-of-load converter (POL). This POL is close to being released, said Maia.

The company also showed its SGRBX line of configurable box solutions, which combine up to four GaN-based, PCB-style dc-dc converter modules (called slices in this series) in parallel to deliver up to 1600 V of output with up to 96% efficiency. The boxes also contain a built-in EMI filter. This is a rad-hard series with TID guaranteed to 100 krad (Si) including ELDRS, and SEE performance to 85 MeV/mg/cm^2. Since this was recently released, this was the first time this product was shown at NSREC.

Meanwhile in the SVPL series of rad-hard, hybrid-style POLs, which previously offered models with 9-A and 12-A output, the company recently added a 6-A model. For more information on the 100-W VSC series converters, see the VSC100-2800S DC-DC Converter page. For more on the SGRBX line, see "GaN Power Devices Enable Configurable, 1600-W DC-DC Solution For Space". Or contact Ronaldo Maia.

Rad-Tolerant Converters In PCB Or Hybrid Styles

At its booth, Crane Aerospace & Electronics was promoting its xMOR product family of rad-tolerant converters for LEO and "new space" applications, which currently include 120-W models. According to Simon Abel, director of Business Development, Strategic Sales, the company will fill out this product line by releasing 50-W, and then 15- and 30-W variants.

The xMOR family includes two PCB-style converters (Fig. 15) and two hybrid versions. Because the PCB-style converters are built with automated assembly—as opposed to hybrids which tend to require manual assembly—they offer lower cost. They also offer higher efficiency.

Prior to the release of the xMOR products, all of the company's power converters were hybrids. The xMOR line not only offers the choice of hybrid or PCB-style construction, it also features wider input range, the ability to parallel units for higher power, and output voltage trim. For more about the existing xMOR family see "120-W DC-DC Converter Family Addresses Deep Space, New Space, And Defense Requirements". Or contact Simon Abel.

Fig. 15. A member of the xMOR family, the rMOR is a rad-tolerant, 120-W PCB-style power converter for "new space" applications. It features a 15-V to 50-V input range and up to 92% efficiency.

DC-DC Converters To 400 W

Another vendor showing both styles of converters was Micross. In its booth, the company displayed its MIL-PRF-38534 class H and K qualified rad-hard hybrid dc-dc converters with power outputs ranging from 5 W to 120 W, and its rad-hard standard and custom PCB-style dc-dc converters with power outputs ranging 5 W to 400 W (Fig. 16). For more information, see the website or contact sales.

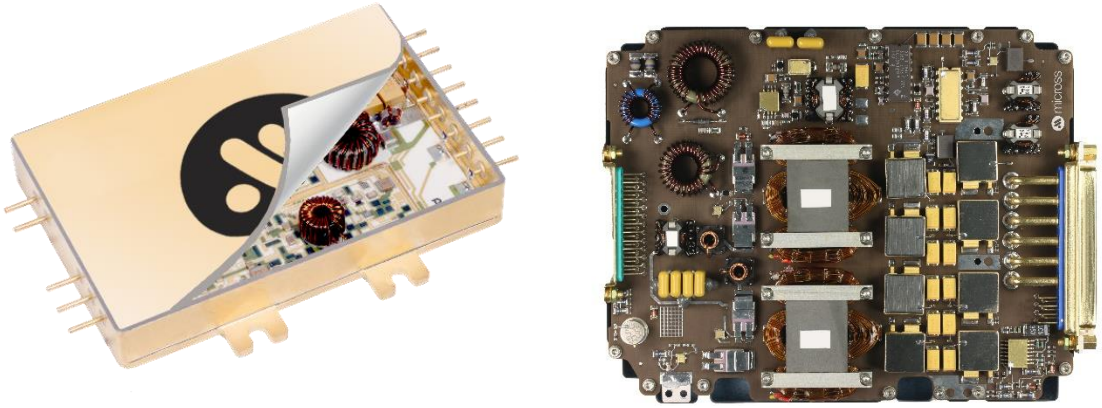

Fig. 16. The MIL-PRF-38534 class H and K qualified rad-hard hybrid dc-dc converters span power ranges from 5 W to 120 W, while the PCB-style converters extend this range to 400 W.

Rad-Tolerant Non-Hermetic Converters: A Flexible Platform

One more NSREC exhibitor featuring PCB-style converters (although they refer to them as non-hermetic or non-hybrid) was Microchip Technology. At their booth they showed the recently released radiation-tolerant LE50-28 family of isolated dc-dc converters, which is the newest addition to the company's existing rad-hardened SA50-120 and SA50-28 series, designed for new space. The new converters specify a TID of 50 krad and a SEE latch-up immunity of 37 MeV·cm^2/mg LET.

Amit Gole, product marketing manager, Integrated Power Solutions, noted that one of the advantages of the printed circuit card with standard-space-grade-SMT-component construction is that the converters can be reworked even if there's a failure in production. This alleviates concerns with lot jeopardy and potential risks with production schedules, leading to cost efficiency and high reliability. Also, the company can provide derivatives of this product and even full-custom solutions. So it's a highly flexible product platform.

For more information on the LE50-28 converters, see "Rad-Tolerant 50-W DC-DC Converters Address New Space Needs" or see the Space Applications page.

Rad-Tolerant Amplifiers For Position Control

Exhibiting at NSREC for the first time, Apex Microtechnology, a company specializing in precision power analog components, highlighted its PA07R 100-V, 5-A amplifier with low bias current and PA08R, a 300-V, 150-mA low-bias amplifier with programmable current limit. These are the company's first two rad-tolerant parts. Announced in April, these are class H components in hermetic, 8-pin TO-3 packages for use in applications such as fine-steering mirrors, position controls and actuators.

HelenAnn Brown, technical marketing manager at Apex Microtechnology, noted that the company, a subsidiary of Heico, collaborates with other Heico sister companies for testing and screening of its products, including up to 50-krad TID and 62.5 MeV·cm²/mg LET. According to Brown, these levels are "great for radiation tolerance."

For more information, see "Apex Microtechnology Announces New Line of Radiation Tolerant Analog Components" or contact HelenAnn Brown.

A GaN-Based Power Converter

While not showing any new power products, Frontgrade did display its GaN power converter and EMI filter from last year as well as its 8627 battery electronics unit, which is a popular product, says Jon Erb, communications specialist at Frontgrade (Fig. 17). For more information, see the website or contact Jon Erb.

Fig. 17. The Frontgrade single-stage dc-dc converter (shown on the left) is an efficient isolated stepdown regulator rated at 50 to 72 W. The Frontgrade Battery Electronics units like the 8627 (shown on the right) provide autonomous, dissipative, and continuous cell balancing to maximize available battery capacity.

For more information on rad-hard and rad-tolerant power semiconductors, ICs, converters and related products, see How2Power's Space Power section and see "News about rad hard dc-dc converter and related products".