WHITE PAPER

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Radiation Hardness Assurance: VPT's Approach to NewSpace DC-DC Converter Reliability

The VSC Series: Balancing Affordability and Performance

Contents:

I. Introduction

In recent years, there has been an increasing trend toward the use of commercial off-the-shelf (COTS) electronics in space; the motivations are simple. Compared to their space-qualified counterparts, COTS components can dramatically reduce cost and lead-time. For example, a voltage reference qualified to MIL-PRF-38535 Class V may cost on the order of $400 each and have a lead time of several months. Meanwhile, the equivalent part can be ordered and received from a distributor in less than a week for $1 each. Furthermore, modern COTS electronics often offer increased integration and improved performance in smaller and lighter packaging, ultimately enabling smaller satellites with reduced launch cost.

On the other hand, neither cost nor schedule are improved if the COTS electronics fail a week after launch or even 1 or 2 years into a 3, 5, or 10 year mission. The space environment is extremely harsh, especially due to its natural radiation environment. Manufacturers of space-qualified electronics implement thorough radiation hardness assurance (RHA) plans to guarantee their parts will survive. They sacrifice cost and lead time to eliminate risk and bring a highly reliable solution to the market with guaranteed by design and radiation performance. COTS electronics are more affordable, but offer no radiation guarantees. Using COTS implies accepting risk.

At the interface between risk elimination and risk acceptance is a relatively new paradigm often termed NewSpace. NewSpace applications attempt to balance risk against cost and schedule. Manufacturers and designers offering products to this emerging market will succeed or fail based on how well they strike that balance and how well they communicate their risk mitigation strategies to their customers.

Given that radiation is a paramount risk factor, **it is crucial for anyone entering the NewSpace market to quickly develop a thorough and cost-effective RHA plan**. For those new to radiation-tolerant applications, this will be a daunting task and examples will be instructive. To this end**, this white paper summarizes key portions of VPT's RHA plan for its** [VSC Series of NewSpace DC-DC converters](). While the examples pull from the VSC Series, the ideas and methods are broadly applicable to other types of components and circuits. Section II provides a high-level overview of the RHA plan. Section III demonstrates our methods for radiation lot acceptance testing (RLAT). Sections IV and V share our approaches to module-level total-ionizing dose (TID) and single-event effect (SEE) testing, respectively.

II. RHA Plan Overview

The first step in developing the RHA plan is to understand the application's radiation environment and choose the specifications. The VSC Series targets short duration (≤ 5 years) low Earth orbit

(LEO) missions, which encompasses most NewSpace applications. After discussing cost considerations internally and risk mitigation concerns with customers, VPT ultimately elected to specify TID up to 30 krad(Si) and SEE testing up to 42 MeV-cm^2/mg for the power stage. After choosing the product radiation specifications, the next step is to determine how to properly verify the product can meet those specifications. VPT has tried-and-true methods for RHA verification of its MIL-PRF-38534 space-qualified DC-DC converters, which include both component and module-level radiation tests. Where practical, the same or similar methods are used to verify VSC Series RHA, however some deviations are necessary to achieve an appropriate risk-vs-cost balance. The following subsections give a brief description of the component sourcing and product verification methods adopted.

A. Component Selection and Sourcing

Traditional space-qualified components are sourced either directly from the component manufacturer or through a manufacturer-designated distributor who relays customer orders to the manufacturer. The good news is that the parts typically come with single lot date codes and lot traceability. The bad news is that the parts will more than likely not be stock items, leading to long lead times, and there will be substantial cost associated with the logistics of the lot tracing. This method immediately presents barriers to achieving NewSpace goals.

To mitigate these barriers, the VSC Series sources components from several distributors. Lot traceability is lost, but cost and availability are greatly improved. All semiconductors and integrated circuits are bought on reels, and component radiation screening is performed on samples from each reel.

B. Total Ionizing Dose Tolerance Verification

The VSC Series of DC-DC converters is verified to perform to the TID level specified in the datasheet through a combination of component RLAT, generic performance data, worst-case analysis (WCA), and module level TID characterization. The fundamental verification approach is to use the semiconductor component radiation-induced parameter delta degradations in combination with aging and temperature-induced variations in WCA that shows the design will still meet performance specifications at the end-of-life (EOL). The radiation-induced parameter delta degradations are determined from the RLAT results with statistics applied or from the generic data for items that do not require RLAT (e.g. diodes).

As a final check on the behavior of the design and to validate the WCA, TID characterization is performed on samples of the VSC modules to at least the rated dose level at both high dose rate, HDR, and low dose rate, LDR. This test utilizes two samples built with RLAT-tested components for each dose rate, one of which is exposed in a biased condition while the other is unbiased during exposure. This test also confirms there are no synergistic effects at the circuit level. The module-level TID testing will be repeated on an annual basis.

C. Single Event Effect Tolerance Verification

The SEE verification is performed at the module level by testing the response of converters operating under heavy-ion irradiation. Module subassemblies are built using decapsulated semiconductor parts. The parts must be decapsulated to expose the die so heavy ions from the test sources can penetrate the die. While heavy ions and other energetic particles in space will easily go right through the plastic packaging, the heavy ions from the test sources used for the VSC SEE testing do not have the energy to penetrate the packaging.

VSC DC-DC converters are characterized for catastrophic events, including single event latch-up (SEL), burnout (SEB), and gate rupture (SEGR). They are also characterized for functional interrupts (SEFI). Single event transients (SET) on the output voltage may occur at levels below the maximum rating of the module and will be characterized for cross-section and magnitude for use by customers in their system analysis.

Each converter family (e.g. VSC5, VSC15, VSC30, etc.) will undergo SEE characterization under heavy-ion irradiation to include the following items:

- Cross-section and transient magnitude measurements for at least three different linear energy transfer (LET) levels.
- Transient characterization at various levels of external capacitance demonstrates the effectiveness of capacitance in decreasing the transient magnitude.
- Tests for operational upsets including non-destructive SEL and SEFI.
- Tests for destructive events including non-recoverable SEL, MOSFET/BJT burnout (SEB), and MOSFET gate rupture (SEGR).

For each VSC family, the SET testing is performed at nominal input voltage, and destructive testing is performed at maximum input voltage.

D. Qualification by Similarity

A VSC design family is defined as all converter designs having the same package dimensions, similar power rating, same topology, and having the same part number prefix; for example, VSC5 and VSC30 are each design families. For each of the VSC design families that have multiple output configurations and output voltages, the VSC level characterization must cover design extremes, and all other models in the family will be qualified by similarity. At a minimum, the following designs must be characterized for TID and SEE:

- One part type from the single output configuration and one part type from the dual output configuration.
- One part type with high voltage stress in the power stage and one part type with high current stress in the power stage.
- These requirements can be covered for example by testing a 5V single output converter (single output/high current stress) and a 15V dual (dual output/high voltage stress).

III. Radiation Lot Acceptance Testing (RLAT)

Every reel of every sensitive semiconductor component used in the VSC Series is sample tested for total-ionizing dose response. For most components, there will be 10 radiation samples with five of the samples biased during exposure and five unbiased. Control and spare samples are also provided. All sensitive components are tested to at least 40 krad(Si), and parameter degradations are tested and analyzed in 10 krad(Si) steps. Additional details of the RLAT testing are provided in subsections A – E below.

A. Bias Conditions

Radiation degradation of sensitive semiconductors will vary with the component bias conditions during exposure, with higher stress conditions typically leading to worse radiation test outcomes. Often, the worst-case bias conditions for the components in the converter will be far below the device ratings. For the VSC Series, the RLAT exposure bias conditions are generally set to actual circuit conditions rather than the device ratings. This approach provides more realistic degradation results and ensures the component under the test will meet the requirements of the specific circuit design.

B. Dose Rates

Most component RLAT TID testing is performed at a high dose rate (HDR) of 50 – 300 rad(Si)/s per MIL-STD-883 Method 1019 Condition A. Exceptions apply where low dose rate sensitivity is observed (ELDRS). In these cases, a low dose rate (LDR) of 10 – 50 mrad(Si)/s is used, which is similar to the European Space Agency (ESA) dose rate specifications. The MIL-STD-883 LDR of ≤ 0.01 rad(Si)/s is NOT used here, because it is cost and lead time prohibitive. The dose rate during exposure must not vary by more than ± 10%.

C. Choosing Test Parameters and Establishing Limits

Rather than testing all device datasheet parameters, RLAT testing includes only those parameters that significantly affect the operation of the VSC converters. This approach significantly reduces test complexity and cost in alignment with NewSpace goals.

Component parameter RLAT delta degradation test limits are chosen based on two criteria:

- What do previous test results indicate about expected worst-case degradation?
- How much can the parameter shift before the WCA tells us the VSC converter will not pass its end-of-life specifications?

D. Evaluating Test Results

For each component tested, parameter data is measured at each TID radiation step. The delta degradation from pre-irradiation measurement to measurement at each step is calculated. All parameter degradation test data are applied with 0.99/90% statistics, meaning the worst-case test results are calculated with a standard normal distribution using a P = 99.00 percentile cutoff line as drawn on the corresponding C = 90% confidence probability density curve using Table 1 and the following formula:

$$X_R = X_{mean} \pm K_{TL} \bullet S_x \quad (1)$$

Where:

X_R = Radiation degradation limit

X_{mean} = Sample mean

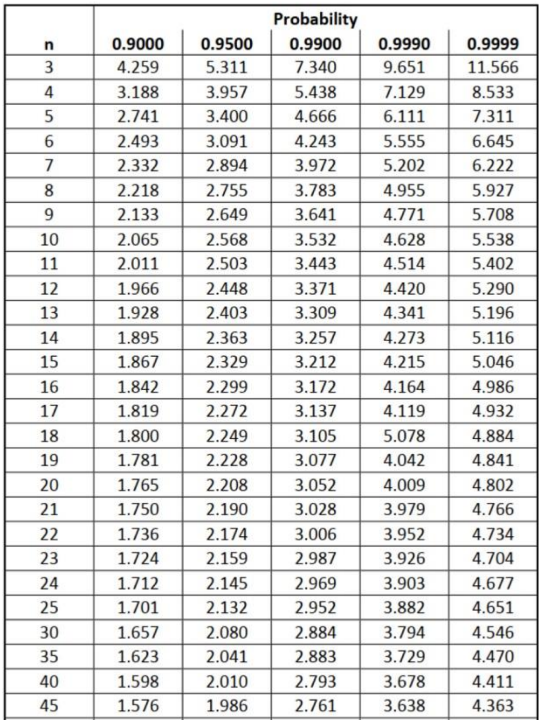
K_{TL} = Multiplying factor denoting the offset from the mean in units of sample sigma. This factor is a function of P, C, and n. The values for KTL are given in Table 1.

P = Percentage of total population exhibiting radiation degradation within the limit of X_R

C = Confidence level with which the population inference is made

n = Sample size

S_x = Sample standard deviation



	Probability				
n	0.9000	0.9500	0.9900	0.9990	0.9999
3	4.259	5.311	7.340	9.651	11.566
4	3.188	3.957	5.438	7.129	8.533
5	2.741	3.400	4.666	6.111	7.311
6	2.493	3.091	4.243	5.555	6.645
7	2.332	2.894	3.972	5.202	6.222
8	2.218	2.755	3.783	4.955	5.927
9	2.133	2.649	3.641	4.771	5.708
10	2.065	2.568	3.532	4.628	5.538
11	2.011	2.503	3.443	4.514	5.402
12	1.966	2.448	3.371	4.420	5.290
13	1.928	2.403	3.309	4.341	5.196
14	1.895	2.363	3.257	4.273	5.116
15	1.867	2.329	3.212	4.215	5.046
16	1.842	2.299	3.172	4.164	4.986
17	1.819	2.272	3.137	4.119	4.932
18	1.800	2.249	3.105	5.078	4.884
19	1.781	2.228	3.077	4.042	4.841
20	1.765	2.208	3.052	4.009	4.802
21	1.750	2.190	3.028	3.979	4.766
22	1.736	2.174	3.006	3.952	4.734
23	1.724	2.159	2.987	3.926	4.704
24	1.712	2.145	2.969	3.903	4.677
25	1.701	2.132	2.952	3.882	4.651
30	1.657	2.080	2.884	3.794	4.546
35	1.623	2.041	2.883	3.729	4.470
40	1.598	2.010	2.793	3.678	4.411
45	1.576	1.986	2.761	3.638	4.363

Table 1: One-Sided KTL Table for 90% Confidence Level

E. Approved TID Radiation Test Facilities

The radiation source used in TID tests shall be the uniform field of ^{60}Co gamma ray source. Radiation field uniformity in the volume where devices are irradiated shall be within ±10% as measured by the dosimetry system, unless otherwise specified. The intensity of the gamma ray field of the source shall be known with an uncertainty of no more than ±5%.

Any test labs used for TID testing must have an appropriate dosimetry system in place in accordance with Test Method 1019 from MIL-STD-883 and the ASTM standards and guidelines therein. Any new labs must be scheduled for audit of their dosimetry control system by VPT and/or DLA.

All instrumentation used for electrical measurements shall have the stability, accuracy, and resolution required to make accurate measurement of electrical parameters. Any instrument required to operate in a radiation environment shall be appropriately shielded. All instrumentation used must be calibrated and have a current record of the calibration.

VPT approved TID test facilities include:

- VPT Rad Incorporated, Chelmsford, MA
- Honeywell Radiation Effects Lab, Clearwater, FL
- Sandia National Laboratories, Albuquerque, NM

IV. Module Total Ionizing Dose Testing

The RHA approach for the VSC Series converters is based primarily on performing component-level RLAT. As further validation, converter modules from the Series are built from RLAT tested lots and subjected to characterization TID tests at HDR conditions (50 – 300 rad(Si)/s) and LDR conditions (10 – 50 mrad(Si)/s) to a total-dose of 30 krad(Si). This helps to validate the impact of the component parameter degradations on overall converter performance. TID testing includes single output and dual output versions, and both low (e.g. 5V) and high (e.g. 15V) output versions. For both HDR and LDR testing, VSC converters are exposed in both biased and unbiased conditions.

There are four key parameters that have been identified as significantly sensitive to TID irradiation: Inhibited Input Current, Output Voltage Regulation, Short-Circuit Current, and Efficiency. These converter parameters trace their sensitivity directly to the sensitivity of device parameters. Combined, the module TID test results indicate the following: MOSFET decreasing gate threshold and increasing leakage current; shifting of the op amp input offset voltage, input offset current, and input bias current; and degradation of the precision reference. Fig. 1 demonstrates the change in efficiency for the VSC5 single-output DC-DC converters under HDR and LDR TID irradiation *(see next page for Fig. 1).*

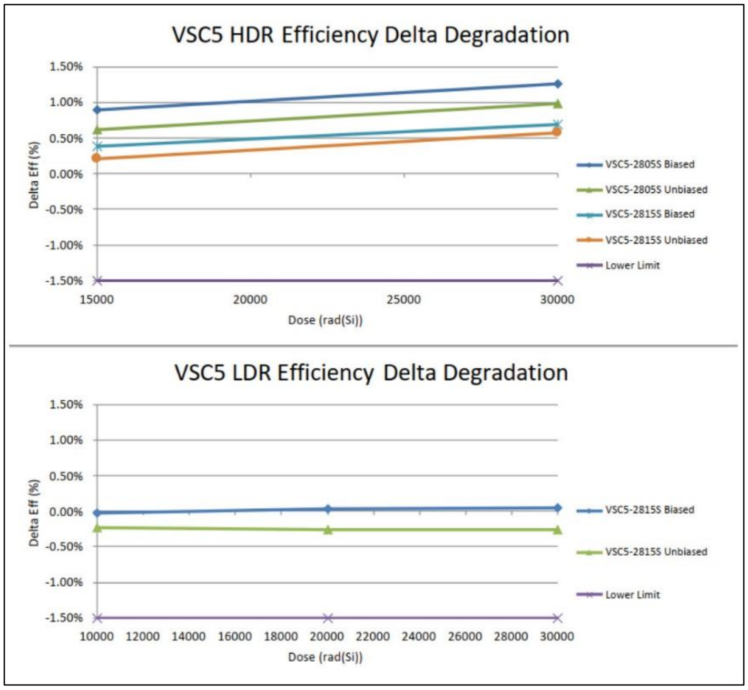


Fig. 1: VSC5-2800S Efficiency Delta Degradation vs TID.

V. Module Single-Event Effects Testing

The SEE response of the VSC converters is determined by testing converters built with RLAT tested components. For the VSC5 family of DC-DC converters, four module types are used to characterize the family. The VSC5-2805S (5V single output) and VSC5-2805D (±5V dual output) are used to characterize the SETs. VSC5-2815S (15V single output) and VSC5-2815D (±15V dual output) modules are used to test for catastrophic failure events (SEL, SEB, SEGR). This selection of converters covers the response of low and high output voltage designs, as well as the difference between single and dual output converter response.

All tests are performed at Texas A&M's Cyclotron Radiation Effects Facility (TAMU) with the following conditions:

- Testing is performed with the converter baseplate at 25°C in air for SET and SEB tests.
- All testing is performed at normal incidence to prevent shadowing and for the worst-case condition for the power MOSFET.
- The minimum range in silicon of any of the ions used in the testing was > 90 µm.

- Testing is performed at the nominal input voltage of 28V for transients and 40V for destructive failure events.
- Tests are run to a minimum fluence of $1x10^6$ ions/cm^2 for transient magnitude and cross-section measurements and to a minimum of $1x10^7$ ions/cm^2 for destructive event tests.
- Particle flux is maintained between 10^3 and 10^5 ions/cm^2/s.

Cross-sections are calculated as the number of upsets recorded during exposure divided by the fluence (typically ~$1x10^6$ ions/cm^2), giving a cross-section in units of cm^2. If no upsets were recorded during an exposure run, a 1 is used for the number of upsets as the upper limit.

SET results are tested with four different ions at TAMU with linear energy transfers (LETs) ranging from ~ 8 – 30 MeV-cm^2/mg. All SET tests are performed at both 10% and 100% load, and characterization runs are also performed with external capacitance ranging from 0 – 1000 µF. Testing over a wide range of operating conditions allows the customer to interpolate results and have an understanding of how the DC-DC converter will operate with their system conditions.

Destructive tests are performed at the highest LET, 48 MeV-cm^2/mg, with maximum input voltage and load current. This is the absolute worst possible operating condition, and no destructive SEB, SEGR, or SEL were observed.

VI. Conclusion: How to Best Balance Cost and Reliability

There are countless organizations entering the NewSpace market every year. The majority are relatively new to the space industry and are likely not fully aware of the necessary considerations and testing needed to successfully launch a program. **One of the pivotal questions facing this price-sensitive industry is how to provide radiation tolerance guarantees that customers can be confident in**? Given that radiation is a paramount risk factor, it is crucial for anyone entering the NewSpace market to **quickly develop a thorough and cost-effective RHA plan**.

Although in this white paper we've reviewed the basics of our RHA plan for NewSpace products and how we're testing to ensure we best balance cost and reliability for our customers, this is not an easy feat. There is no standard. **For those new to radiation-tolerant applications, this will be a daunting task**.

Not only do we complete the above testing to qualify components for initial builds, but we also continually test SEE for destructive events and HDR to confirm that each converter is within the datasheet limits **on an annual basis.** These necessary processes alone may not be considered by those who are interested in designing, building, and manufacturing power supplies for NewSpace launch internally.

It is also worth noting that we receive accelerated component testing through connections with our subsidiary, VPT Rad.

VPT has over 30 years of experience designing, building, and testing DC-DC converters to meet a host of qualifications and specifications for leading organizations including NASA, Lockheed Martin, Honeywell, GE, and more. In fact, our NewSpace RHA plan is based on our DLA-approved RHA plan for our hermetic hybrid rad-hard DC-DC converter series. We combine our 30 years of industry experience in the Military Avionics and Space industries into this one plan in a cost effective manner to offer competitively priced, radiation tolerant DC-DC converters for NewSpace applications.

In summary, balancing cost and reliability in the NewSpace market requires strategic decision-making. If your team would like to design your own power supplies, consider the following:

- Does your team have expertise in TID and SEE testing?
- Is your team prepared to conduct annual tests to ensure components meet radiation tolerance specifications?
- Is your team willing to invest at least one year into developing and refining a Radiation Hardness Assurance plan?

By choosing a VPT VSC Series or complimentary DC-DC converter series, your team will save time, money, overall shorten your design cycle, and ultimately launch your program faster.

References

Author:

Brandon Witcher, VPT, Inc. Principal Design Engineer

Examples:

[1] VPT Radiation Hardness Assurance Plan, VPT internal document number RAD-001, Rev 3.0.

[2] Semiconductor Piecepart TID and Neutron Radiation Characterization and Lot Acceptance Test Procedure, VPT internal document number RAD-002, Rev 5.0.

[3] Hybrid Level TID Characterization Test Procedure, VPT internal document number RAD-003, Rev 5.0.

[4] Hybrid Level SEE Characterization Test Procedure, VPT internal document number RAD-003, Rev 3.0.

[5] VSC5-2800S/D Radiation Performance Report, VPT internal document number RADVSC5, Rev 2.0.

Contact Information

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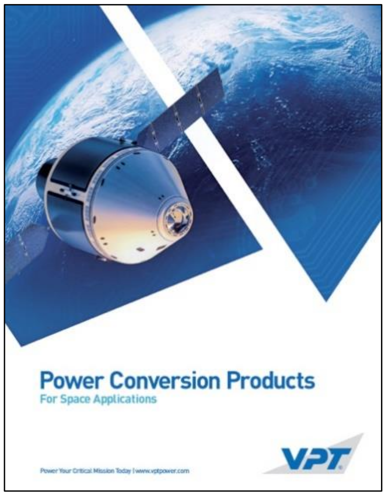
Additional Resources

Visit the VPT website for additional technical resources, including:

Product Catalogs



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Application Notes & White Papers

Military and Avionics Series Power

Save board space, weight, heat, and cost when you create an efficient power system using our isolated DC-DC converters plus our family of non-isolated, synchronous, buck regulated point-of-load DC-DC converters.

Compliances and Certifications:

- Products available qualified to MIL-PRF-38534 Class H and Class K
- MIL-PRF-38534 Class H and Class K certified manufacturing facility
- MIL-STD-704A input voltage requirements
- DO-160, ISO-9001
- MIL-STD-883 environmental screening
- MIL-STD-461 C-F when used with a VPT EMI filter
- DLA SMDs available for most modules

Note: Compliances and certifications vary by product series. Please see specific product datasheets for more information.

Features:

- 100% hermetic
- No optocouplers
- High efficiencies
- 28Vin nominal unless otherwise noted
- A host of circuit protection features
- Fault-tolerant magnetic feedback circuits
- Thick-film hybrid technology
- Available in industry standard output voltages including:
  - Single outputs: typically 3.3, 5, 5.2, 12, 15V
  - Dual outputs: typically ±5, ±12, ±15V
  - Triple outputs: typically 3.3/±12, 3.3/±15, 5/±12, 5/±15V

DC-DC CONVERTERS, ISOLATED

DV Series of DC-DC Converters: *Thick-film hybrid. -55 °C to +125 °C.*

Power Level (W)	Model Series	Outputs	DLA SMD #
1.5	DVCH2800S/D	Single and Dual	5962-09242, 5962-09243
6	DVSA2800S/D	Single and Dual	5962-03241, 5962-03242
12.5	DVSB2800D	Dual	5962-08207
12.5	DVGF+2800T	Triple	5962-08205
15	DVHV2800S/D	Single and Dual	5962-11226, 5962-11227
15	DVAB2800D	Dual	5962-14232
15	DVHF+2800T	Triple	5962-08206
20	DVHF2800S/D	Single and Dual	5962-03243, 5962-03244
25	DVWR2800T	Triple	5962-16203
30	DVTR2800T	Triple	5962-16202
40	DVTR2800S/D	Single and Dual	5962-11224, 5962-11225
50	DVHE2800S	Single	5962-15230
120	DVFL2800S/D	Single and Dual	5962-07243, 5962-07244

DV Series of DC-DC Converter with Integral EMI Filter: *-55 °C to +125 °C.*

Power Level (W)	Model Series	Outputs	DLA SMD #
10	DVEHF2800T	Triple	Contact VPT
40	DVETR2800S/D	Single and Dual	5962-15208, 5962-15209

POINT-OF-LOAD DC-DC CONVERTERS, NON-ISOLATED

DV Series of POL DC-DC Converters: *5Vin nominal. -55 °C to +125 °C.*

Power Level (W)	Model Series	Outputs	DLA SMD #
3	DVPL0503S	Single	5962-13243
5	DVPL0505S	Single	5962-09241
10	DVPL0510S	Single	5962-13219
20	DVPL0520S	Single	5962-13244

INRUSH CURRENT LIMITER

Control the Inrush Current: *-55 °C to +125 °C.*

Output Current (A)	Model Series	Outputs	DLA SMD #
11	DVCL28	Single	5962-13240

EMI FILTERS

Reduce Noise Even Further: *-55 °C to +125 °C.*

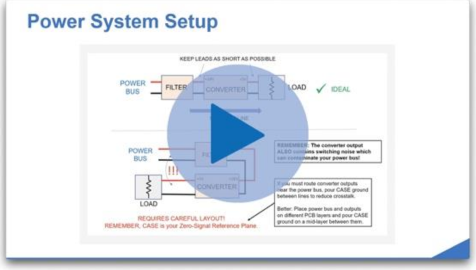
Output Current (A)	Model Series	Outputs	DLA SMD #
0.8	DVMSA28	Single	11016
1	DVMA28	Single	06004
2	DVMH28	Single	06005
2	DV704A	Single	Contact VPT
4	DVMC28	Single	06023
7	DVMD28	Single	06024
15	DVME28	Single	07004

THERMAL PADS

Ensure Low Thermal Resistance

Output Current (A)	Model Series	Outputs	DLA SMD #
N/A	TP-001 to 011	N/A	N/A

Technical Videos



Power System Setup

REMEMBER: The converter output ALSO contains switching noise which can contaminate your power bus!

If you must route converter outputs near the power bus, pour CASE ground between lines to reduce crosstalk.

Better: Place power bus and outputs on different PCB layers and pour CASE ground on a mid-layer between them.