WHITE PAPER

Meet MIL Specifications While Solving SWaP-C Challenges with 270V Input Applications

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Introduction

Defense applications with $270V_{DC}$ input must meet stringent EMI, environmental, and power related standards such as MIL-STD-461, MIL-STD-810, and MIL-STD-704. The design process is further complicated by SWaP-C requirements. Vicor's enhanced MIL-COTs products (including the 270V MFM™ filter and M-Grade VIA DCMs™) were built specifically to conform to these standards, simplifying the process of achieving compliance. The efficient packaging, high frequency Zero-Voltage Switching (ZVS) topology and flexible thermal management options deliver thermal and density benefits. They also have a small footprint and are lightweight for applications with demanding SWaP-C demands.

Standards Overview

Environmental Standards - MIL-STD-810

MIL-STD-810 [1] is the primary standard that addresses environmental conditions for defense and aerospace applications. This standard specifies test methods that replicate the effects of environments on the equipment. The latest revision of this standard MIL-STD-810G addresses numerous environmental conditions, including:

- Mechanical shock and vibration
- Humidity
- Acceleration
- Fungus
- Sand and Dust

The modular construction of the DCM (DC-DC Converter Module) and MFM (MIL-COTS Filter Module) is ideal for ruggedized DC-DC power systems used in compact enclosures, where these conditions can be severe. Modules provide improved reliability, and decreased the time needed for design and test, since Vicor has already proven the systems within the modules.

EMI Requirement: MIL-STD-461

MIL-STD-461 [2] addresses conducted emissions, conducted susceptibility, radiated emissions, and radiated susceptibility for electronics used in defense and aerospace applications (the latest version of the standard is G). At a high level, emission refers to the electromagnetic 'noise' a device generates as it impacts the source to which it is connected and susceptibility is the vulnerability of a system to incoming noise.

MIL-STD-461 covers four key aspects of electromagnetic interference:

- Conducted Emissions (CE) – what the power supply feeds back to the power grid
- Conducted Susceptibility (CS) – the effect that various noise and distortion elements in the power grid have on the power supply
- Radiated Emissions (RE) – the radiated noise generated by the power supply
- Radiated Susceptibility (RS) – is the supply performance disturbed by external voltage and magnetic fields

Typically, only CE and CS requirements apply to power converters, while RE and RS apply to the system as a whole. For COTS power supplies, the most problematic parts of MIL-STD-461 are CE101 and CE102, which are generally met by a combination of low-noise design and external filtering. The applicability of the various requirements to the end application types is outlined in Table 1.

CE101 is the test procedure that is used to verify that electromagnetic emissions from the equipment under test (EUT) do not exceed the specified requirements for power input leads, including returns, over the 30Hz to 10kHz range. It is required for power systems used in submarines, Army aircraft (including flight line) and Navy aircraft with anti-submarine warfare equipment.

CE102 verifies that electromagnetic emissions from the EUT do not exceed the specified requirements for power input leads including returns over the 10kHz to 10MHz range, and is required for a wide range of systems including: submarines, Army aircraft (including flight line), Navy aircraft, Air Force aircraft, space systems, ground Army, ground Navy, ground Air Force and surface ships.

The conducted susceptibility tests whether the EUT will continue to function properly if various parts of the system are injected with electrical or magnetic disturbances.

Table 1
EMI requirement applicability to platform

Equipment and subsystems installed in, on, or launched from the following platforms or installations	Requirement Applicability																	
	CE101	**CE102**	**CE106**	**CS101**	**CS103**	**CS104**	**CS105**	**CS106**	**CS109**	**CS114**	**CS115**	**CS116**	**RE101**	**RE102**	**RE103**	**RS101**	**RS103**	**RS105**
Surface Ships	A	A	L	A	S	S	S	A	L	A	S	A	A	A	L	A	A	L
Submarines	A	A	L	A	S	S	S	A	L	A	S	L	A	A	L	L	A	L
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S			A	A	A	A	A	L	A	A	L
Aircraft, Navy	L	A	L	A	S	S	S			A	A	A	L	A	L	L	A	L
Aircraft, Air Force		A	L	A	S	S	S			A	A	A		A	L		A	
Space Systems, Including Launch Vehicles		A	L	A	S	S	S			A	A	A		A	L		A	
Ground, Army		A	L	A	S	S	S			A	A	A		A	L	L	A	
Ground, Navy		A	L	A	S	S	S			A	A	A		A	L	A	A	L
Ground, Air Force		A	L	A	S	S	S			A	A	A		A	L		A	

Legend:

A: Applicable
L: Limited as specified in the individual sections of this standard
S: Procuring activity must specify in procurement documentation

Transient Immunity – MIL-STD-704

MIL-STD-704[3] refers to aircraft-based systems that describe the anticipated power quality of those systems, and the levels a device must meet or exceed in order to perform satisfactorily in the anticipated application. Generally, in regards to power supplies, MIL-STD-704 dictates the magnitude and duration of input transients that the unit under test will experience. In addition, the tests for MIL-STD-704 are actually dictated by the more exhaustive MIL-HDBK-704, which specifies various under- and overvoltage tests that devices should be subjected to. Below are excerpts from MIL-HDBK-704 that illustrate the various normal and abnormal tests for MIL-STD-704E and F (F is the most recent iteration of the standard).

Normal Voltage Transients

Overvoltage and undervoltage are voltage conditions that exceed the limits of normal operation as defined by MIL-STD-704 (See Table 2 and Table 3, which are excerpts from MIL-HDBK-704). With other solutions, protective devices are often needed to prevent damage to sensitive electronic circuitry. The DCM™ and MFM™ comply with many of these voltage ranges, eliminating the need for protective circuitry and resolving several issues for designers concerned with SWaP-C demands.

Table 2
Test conditions for MIL-STD-704E and F normal voltage transients

Test Condition	Steady State Voltage (V_{DC})	Time from Steady State Voltage to Voltage Transient Level (Miliseconds)	Voltage Transient Level (V_{DC})	Duration at Voltage Transient Level (Miliseconds)	Time from Voltage Transient Level to Steady State Voltage (Miliseconds)
Overvoltage Transients					
AA	$280V_{DC}$	< 1msec	$330V_{DC}$	20msec	< 1msec
BB	$280V_{DC}$	< 1msec	$330V_{DC}$	20msec	20msec
CC	$280V_{DC}$	< 1msec	$305V_{DC}$	30msec	< 1msec
DD	$280V_{DC}$	< 1msec	$305V_{DC}$	30msec	37.5msec
EE	$280V_{DC}$	< 1msec	$330V_{DC}$ (3 times)	10msec Every 0.5msec	< 1msec
FF	$250V_{DC}$	< 1msec	$330V_{DC}$	20msec	< 1msec
GG	$250V_{DC}$	< 1msec	$330V_{DC}$	20msec	33msec
HH	$250V_{DC}$	< 1msec	$305V_{DC}$	30msec	< 1msec
II	$250V_{DC}$	< 1msec	$305V_{DC}$	30msec	21msec
JJ	$250V_{DC}$	< 1msec	$330V_{DC}$ (3 times)	10msec Every 0.5msec	< 1msec
Undervoltage Transients					
KK	$280V_{DC}$	< 1msec	$200V_{DC}$	10msec	< 1msec
LL	$280V_{DC}$	< 1msec	$200V_{DC}$	10msec	49msec
MM	$280V_{DC}$	< 1msec	$200V_{DC}$ (3 times)	10msec Every 0.5msec	< 1msec
NN	$250V_{DC}$	< 1msec	$200V_{DC}$	10msec	< 1msec
OO	$250V_{DC}$	< 1msec	$200V_{DC}$	10msec	30msec
PP	$250V_{DC}$	< 1msec	$200V_{DC}$ (3 times)	10msec Every 0.5msec	< 1msec
Combined Transients					
QQ	$280V_{DC}$ then	< 1msec < 1msec	$200V_{DC}$ $330V_{DC}$	10msec 20msec	< 1msec 20msec
RR	$250V_{DC}$ then	< 1msec < 1msec	$200V_{DC}$ $330V_{DC}$	10msec 20msec	< 1msec 33msec

Abnormal Voltage Transients

Abnormal voltage transients (see Table 3) are voltage conditions that exceed the limits of abnormal operation as defined by MIL-STD-704. Like the normal overvoltage and undervoltage transients discussed above, protective devices are often needed in power supply circuits that don't use the DCM and MFM as a front-end circuit.

Table 3
Test conditions for MIL-STD-704E and F abnormal voltage transients

Test Condition	Steady State Voltage (V_{DC})	Time from Steady State Voltage to Voltage Transient Level (Miliseconds)	Voltage Transient Level (V_{DC})	Duration at Voltage Transient Level (Miliseconds)	Time from Voltage Transient Level to Steady State Voltage
Overvoltage Transients					
AA	$280V_{DC}$	< 1msec	$350V_{DC}$	50msec	< 1msec
BB	$280V_{DC}$	< 1msec	$350V_{DC}$	50msec	10msec
		then	$340V_{DC}$	decreasing	15msec
		then	$330V_{DC}$	decreasing	25msec
		then	$320V_{DC}$	decreasing	190msec
		then	$300V_{DC}$	decreasing	1.71sec
			$280V_{DC}$		
CC	$280V_{DC}$	< 1msec	$350V_{DC}$ (3 times)	50msec Every 0.5sec	< 1msec
DD	$250V_{DC}$	< 1msec	$350V_{DC}$	50msec	< 1msec
EE	$250V_{DC}$	< 1msec	$350V_{DC}$	50msec	10msec
		then	$340V_{DC}$	decreasing	15msec
		then	$330V_{DC}$	decreasing	25msec
		then	$320V_{DC}$	decreasing	190msec
		then	$300V_{DC}$	decreasing	6.7sec
		then	$250V_{DC}$		
FF	$250V_{DC}$	< 1msec	$350V_{DC}$ (3 times)	50msec Every 0.5sec	< 1msec
Undervoltage Transients					
GG	$280V_{DC}$	< 1msec	$180V_{DC}$	50msec	< 1msec
HH	$280V_{DC}$	< 1msec	$180V_{DC}$	50msec	10msec
		then	$190V_{DC}$	increasing	15msec
		then	$200V_{DC}$	increasing	25msec
		then	$210V_{DC}$	increasing	190msec
		then	$230V_{DC}$	increasing	6.7sec
		then	$280V_{DC}$		
II	$280V_{DC}$	< 1msec	$180V_{DC}$ (3 times)	50msec Every 0.5sec	< 1msec
JJ	$250V_{DC}$	< 1msec	$180V_{DC}$	50msec	< 1msec
KK	$250V_{DC}$	< 1msec	$180V_{DC}$	50msec	10msec
		then	$190V_{DC}$	increasing	15msec
		then	$200V_{DC}$	increasing	25msec
		then	$210V_{DC}$	increasing	190msec
		then	$230V_{DC}$	increasing	1.71sec
		then	$250V_{DC}$		
LL	$250V_{DC}$	< 1msec	$180V_{DC}$ (3 times)	50msec Every 0.5sec	< 1msec

Table 3 (Cont.)
MIL-STD-704 test conditions for transient voltages

Test Condition	Steady State Voltage (V_{DC})	Time from Steady State Voltage to Voltage Transient Level (Miliseconds)	Voltage Transient Level (V_{DC})	Duration at Voltage Transient Level (Miliseconds)	Time from Voltage Transient Level to Steady State Voltage
Combined Transient					
MM	280V_{DC}	< 1msec < 1msec	180V_{DC} 350V_{DC}	10msec 50msec	< 1msec 10msec
		then	340V_{DC}	decreasing	15msec
		then	330V_{DC}	decreasing	25msec
		then	320V_{DC}	decreasing	190msec
		then	300V_{DC}	decreasing	1.71sec
			280V_{DC}		
NN	250V_{DC}	< 1msec < 1msec	180V_{DC} 350V_{DC}	10msec 50msec	< 1msec 10msec
		then	340V_{DC}	decreasing	15msec
		then	330V_{DC}	decreasing	25msec
		then	320V_{DC}	decreasing	190msec
		then	300V_{DC}	decreasing	6.7sec
		then	250V_{DC}		

Note: Depending on the equipment under test and the application requirements, some or all of the tests may be required.

EMI Filtering

Note that the power system is more than just the DC-DC converters. The EMI filter is also part of the power system (See Figure 1). The input filtering deserves careful scrutiny during the system design review process. Ideally the filter or filter system will suppress HF/VHF/RF noise locally, dissipating much of the extraneous noise generated as a consequence of the power switching occurring inside the DCMs™. This prevents switching noise artifacts being transported from the DCMs' input port(s) back to the input power source, through the power bussing and its spreading to other parts of the system. Suppressing conducted noise eliminates spurious emissions that will otherwise end up being radiated. A good CE filter will prevent noise from cross-coupling into other sensitive circuits in the system. In the field of RF radar reception, noise is measured against a background of ambient energy very close to the thermodynamic minimum. There is a requirement in military system applications for conducted emissions not to exceed the template levels outlined in MIL-STD-461.

To assist system architects using the MIL-COTS DCM to realize a low emission power solution, Vicor has developed filters that are specifically designed to work with the VIA (Vicor Integrated Adapter) DCM, whereas an additional stage of filtering is required to work with ChiP (converter housed in package) DCMs when not packaged in the VIA. The filter is called out as HV MFM™ filter MFM1714xD2KD2F4yzz (see Figure 1). This module is compatible with 270V_{DC} inputs, which can range from 160 to 420V_{DC}. The M-Grade filter has an internal operating temperature range spanning -55 to +125°C. It meets MIL-STD-461E and MIL-STD-461F for CE101 and CE102 conducted emissions and CS101 for conducted susceptibility. In addition, when used with the 270V_{IN} DCMs, the solution will be compliant with the under- and overvoltage transients per MIL-STD-704F. Below is a comparison of the new HV MFM filter and 270V_{IN} M grade VIA DCM solution from Vicor when compared to a legacy solution, highlighting the benefits of applications requiring small size, reduced weight, higher power and lower cost.

Figure 1
Block Diagram of a circuit with a DCM and an MFM Input Filter. MFM DCM Filter is a DC front-end module that provides EMI filtering and transient protection for the DCM

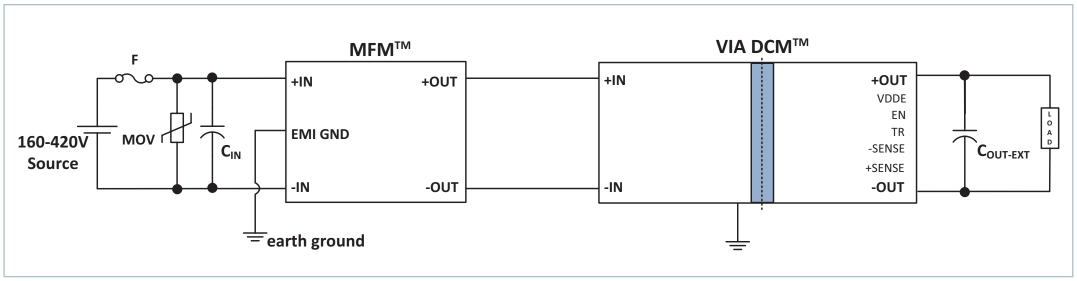

Figure 2 shows the VIA DCM™ and MFM™. Note that the MFM and DCM are sized and configured so the wiring from the MFM outputs to the DCM inputs can be easily implemented straight across.

Figure 2
A DCM and MFM, showing their relative sizes in VIA (non-through-hole) packages

The DCM is available as a ChiP DCM and VIA DCM (see Figure 3). The VIA DCM is a module that includes the DCM, a heat sink, input and output filtering and other circuitry. The DCM in the ChiP package requires that the user provide the external circuitry.

Figure 3
MIL COTS DCM DC-DC Converter Modules

Note: 28V input versions of VIA DCM and MFM are also available: [AN:022 MIL EMI and Transient Solutions]

The best package for a given application depends on a number of factors, which are summarized in Table 4. Depending on the specific requirements of the system, either the ChiP DCM™ or VIA DCM may be the best solution. Since both solutions have the DCM at their core, both solutions offer ZVS topology and efficient thermal management, so either one is a good solution for systems with challenging SWaP-C demands.

Table 4
Comparison of ChiP DCM vs. VIA DCM Package

Parameters	**ChiP DC-DC Converter Component**	**VIA Full DC-DC Solution The Better Brick**
Efficiency	Up to 93%	
Power Density	Up to 1,244W/in^3 (76W/cm^3)	Up to 458W/in^3 (19W/cm^3)
Output Voltage Regulation Accuracy	Up to ±5%	±0.5%
Filtering	External	Integrated EMI and transient filter, MIL-STD-461 compliance with external filter
Thermal Management	External thermal mangement may be required	Integrated heat sink
Operating Temperature Range	**T-Grade:** –40 to +125°C **M-Grade:** –55 to +125°C	**C-Grade:** –20 to +100°C **T-Grade:** –40 to +100°C **M-Grade:** –55 to +100°C (available soon)
Paralleling	Up to eight ChiP DCMs	Up to four VIA DCMs using external Digital Supervisor (available soon)
Mounting Options	Thru hole (PCB mount)	Thru hole (PCB mount) or chassis mount options
Integrated Output Voltage Sense	See App Note AN:035	Yes
Trim	Up to –40/+10% of normal output voltage	

Conclusion

The primary test specifications for EMI and voltage transients in a MIL-COTS system are MIL-STD-461 and MIL-STD-704. The primary environmental standard is MIL-STD-810. Vicor MFM™ and DCM products have been designed with these specifications in mind, simplifying the implementation of a compliant power system that conforms to stringent SWaP-C demands.

References

1. MIL-STD-810G, Department of Defense Test Method Standard Environmental Engineering Considerations and Laboratory Tests
2. MIL-STD-461G, Department of Defense Interface Standard Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
3. MIL-STD-704E, Department of Defense Interface Standard Aircraft Electric Power Characteristics
4. 270 to 28 VIA DCM datasheet (w/M-Grade):
5. HV MFM data sheet
6. AN:029 Single DCM™ as an Isolated, Regulated DC-DC Converter
7. ChiP Thermal Management White Paper