Durability of COTS Modules in Tactical Fighter Environments

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The ability of Commercial Off the Shelf (COTS) electronic modules to meet the environmental requirements of tactical fighter jets has long been questioned, with the primary concerns being vibration and temperature cycling survivability. As a result, much of the electronics has been packaged using custom or pseudo-custom form factors. With the move to more open systems architectures, there is an opportunity to re-evaluate COTS modules to see how rugged they can be.

COTS comes in many sizes and varieties, from high volume consumer electronics to rugged modules specifically designed for harsh environments. We will focus on the latter end of the spectrum as most likely to be able to meet tactical fighter jet environments. It should be noted that most suppliers of rugged COTS modules offer several grades of ruggedness for their products, from lab-grade air-cooled versions, to base rugged conduction-cooled versions, up to highly rugged modules with enhancements to meet extended durability requirements (for example, high level/duration vibration, extended temperature cycling, etc.). Examples of these enhancements include connector changes for high vibration and BGA underfill materials for thermal cycling.

TABLE 1 Ruggedization Table

ENVIRONMENTAL CONDITION		AIR-COOLED (Note 4)			CONDUCTION-COOLED (Note 7)		
		Level 0	Level 50	Level 100	Level 100	Level 200	Level 300 (Note 6)
Temperature	Operating	0 to 5°C	+20 to 65°C	-40 to 71°C	-40 to 71°C	-40 to 85°C	-40 to 85°C
	Non-operating	-40 to 85°C	-40 to 85°C	-55 to 125°C	-55 to 125°C	-55 to 125°C	-55 to 125°C
Humidity, Non-operating (storage)		0 to 100%	0 to 100%	0 to 100%	0 to 100%	0 to 100%	0 to 100%
Vibration (Note 1)	Since	2g Peak 5-2000 Hz	2g Peak 5-2000 Hz	10g Peak 5-2000 Hz	10g Peak 5-2000 Hz	10g Peak 5-2000 Hz	10g Peak 5-2000 Hz
	Random	0.04 @ 5 Hz 0.04 @ 100 Hz 0.01 @ 2 kHz	0.04 @ 5 Hz 0.04 @ 100 Hz 0.01 @ 2 kHz	0.002 @ 5 Hz 0.04 @ 15 Hz 0.04 @ 2 kHz	0.005 @ 5 Hz 0.1 @ 15 Hz 0.1 @ 2 kHz	0.005 @ 5 Hz 0.1 @ 15 Hz 0.1 @ 2 kHz	0.005 @ 5 Hz 0.1 @ 15 Hz 0.1 @ 2 kHz
Shock (Note 3)		20g Peak	20g Peak	30g Peak	40g Peak	40g Peak	40g Peak
Altitude (Note 9)		-1,500 to 60,000 ft.	-1,500 to 60,000 ft.	-1,500 to 60,000 ft.	-1,500 to 60,000 ft.	-1,500 to 60,000 ft.	-1,500 to 60,000 ft.
Conformal Coat (Note 5)		No	Consult Factory	Yes	Yes	Yes	Yes
2 Level Maintenance Ready		-	-	-	No	No	Yes

Notes:

1. Sine vibration based on a sine sweep duration of 10 minutes per axis in each of three mutually perpendicular axes. May be displacement limited from 5 to 44 Hz, depending on specific test equipment.
2. Random vibration 60 minutes per axis, in each of three mutually perpendicular axes.
3. Three hits in each axis, both directions, 1/2 sine and terminal-peak saw tooth. Total 36 hits.
4. Consult the factory for air flow rate details.
5. Conformal coating type is manufacturing site-specific. Consult the factory for details.
6. This is a non-standard product. Consult factory for availability.
7. Temperature is measured at the card edge.
8. Assuming maximum pressure of 2.5" H2O.
9. Forced air cooled designs shall receive the same minimum mass airflow rate under these condition as required at sea level.

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Rugged COTS modules also come in different flavors, however modules designed and built to VITA standards have the benefit of a standards organization (and its associated large ecosystem) focused on the defense and aerospace market. Specifically, modules built to the new VPX standards (VITA 46, VITA 48 and VITA 65) offer several advantages for open systems architectures in tactical fighter jet environments:

- A large eco-system of modules that are interoperable with standardized mechanical and electrical interfaces.
- Many different types of products (e.g. single board computers (SBCs), DSPs, GPGPUs, memory, carrier cards, etc.) Available from traditional rugged COTS suppliers such as Curtiss-Wright. These suppliers have been providing rugged COTS modules into D&A programs, including tactical fighter jets, for decades.
- Sufficient I/O pin density on 3U module size for high functionality products. The 3U size is particularly attractive due to its low size, weight and power (SWaP) (attributes and high ruggedness (e.g. lower shock and vibration displacements due to the shorter span between wedgelocks).
- A high-speed, high density connector that has been thoroughly tested in harsh environments with successful results (for test report, see http://www.vita.com/Resources/Marketing%20Alliances/VPX/VITA46ContechTestReportrev1.4.pdf). This connector continues to be enhanced with more rugged features such as metal shells and new contact designs. For example, the new RT2-R backplane contact from TE has been shown to withstand 12 hours of 0.2 g^2/Hz random vibration on a 6U module, and is backwards compatible with current VPX modules.
- Optional optical and RF/coax connectors, standardized in VITA 66 and VITA 67.
- COTS module environmental requirements standardized in VITA 47. Customers can choose from several levels of environmental and durability performance to align with their specific platform/program requirements.

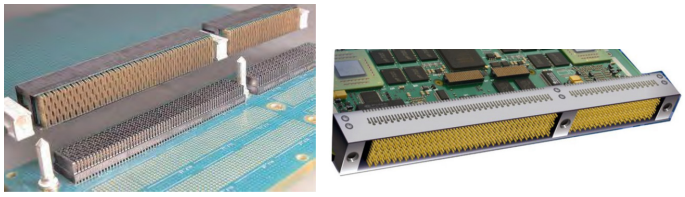

Figure 2: Examples of VPX connectors (VITA 46 TE MultiGig RT2)

As previously mentioned, VPX modules are offered in several grades of ruggedness. At the high end of the range, conduction-cooled modules offer a degree of durability consistent with requirements found in VITA 47, Environmental Class ECC4. VITA 47 (Environments, Design and Construction, Safety, and Quality for Plug-In Units standard) standardizes environmental requirements commonly met by standard modules from rugged COTS module providers.

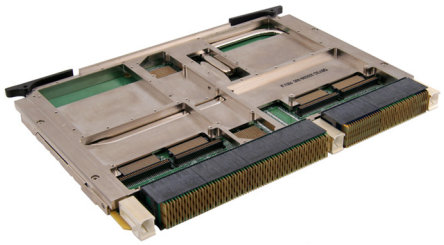

Figure 3: Rugged COTS 6U VPX module (with patented embedded heat pipe frame, two-level maintenance covers not shown)

Figure 4: Rugged COTS 3U VPX module

The table below lists most of the VITA 47 environmental and durability specifications for the ECC4 class, along with a comparison to Curtiss-Wright COTS module specifications.

TABLE 1 **VITA 47 environmental and durability specifications**

ENVIRONMENT		CURTISS-WRIGHT RUGGEDIZATION TABLE (L200)	ANSI/VITA 47 (ECC4)	COMMENT
Temperature	Operating	-40 to 85°C (card edge)	-40 to 85°C (card edge)	0.25°C/W thermal resistance (conservative) between card edge and chassis rail at sea level.
	Non-operating	-55 to 125°C	-55 to 105°C	Curtiss-Wright specification is more severe.
	Cycling	N/A[1]	500 cycles, -55 to 105°C	[1]Many CW products have been tested to various internal or customer/program-specific requirements, and qualification by similarity may be available.
Vibration	PSD level	0.1 g^2/Hz (15-2000 Hz)	0.1 g^2/Hz (100-1000 Hz), incr. 3dB/octave (5-100 Hz), decr. 6dB/octave (1-2 kHz)	Curtiss-Wright specification is more severe.
	Duration	1 hour/axis	1 hour/axis	
Shock, operating		40g, 11ms, half-sine and terminal sawtooth, all 3 axes	40g, 11ms, half-sine or terminal sawtooth, all 3 axes	Curtiss-Wright specification is more severe.
Humidity		0 to 100% non-condensing for operating, condensing for non-operating	0 to 95% (MIL-STD-810, Method 507, five 48-hour cycles)	Condensing humidity is more severe.
Altitude		-1,500 to 60,000 ft.	-1,500 to 60,000 ft.	
Rapid decompression		N/A[1]	From 8,000 to 60,000 ft.	[1]Many Curtiss-Wright products have been tested to various internal or customer/program-specific requirements, and qualification by similarity may be available.
Fungus resistance		N/A[1]	MIL-STD-810, Method 508	[1]Many Curtiss-Wright products have been tested to various internal or customer/program-specific requirements, and qualification by similarity may be available.
Corrosion resistance		N/A[1]	Salt fog & SO2 per ASTM G85, Annex A4	[1]Many Curtiss-Wright products have been tested to various internal or customer/program-specific requirements, and qualification by similarity may be available.
ESD (for 2LM LRMs)		L300 ruggedization level	15 kV air discharge (EN-61000-4-2)	VPX connector and covered module tested to VITA 47

The Curtiss-Wright Ruggedization Table also includes a L300 category, which is intended for two-level maintenance (2LM) line replaceable modules (LRMs). The L300 category takes L200 standard product and adds covers and other protective measures for 2LM compatibility. Curtiss-Wright has extensive experience with modifying standard products for 2LM requirements, going back to VME products and now including VPX products.

There are, of course, a wide variety of environmental requirements from different D&A platforms, some of which cannot be met by VITA 47. In those cases, rugged COTS module providers offer enhanced ruggedness capabilities to meet the specific requirements. These enhancements are often transparent to the user, and stem from significant accumulated experience with harsh environment and high durability requirements. Examples include:

- Connector changes to meet shock or vibration levels/durations that are significantly beyond VITA 47. These include module/backplane connectors and module/mezzanine connectors.
  - For module/backplane connectors, the standard VPX connector (TE MultiGig RT2) has been tested up to 0.2 g^2/Hz random vibration with acceptable performance (note that a 6U test board was chosen to be a worse case, so stiffer modules like 3U would perform better). For vibration levels/durations significantly beyond this, the Amphenol VIPER® connector (VITA 60), Hypertronics KVPX® connector (VITA 63), and the new RT2-R contact design for the TE MultiGig RT2, are all available to be compared. The table below shows interoperability among these and the standard VPX connector. The VITA 72 study group has released comparison test results for the standard VPX, new RT2-R, and VITA 60 connectors, with the RT2-R performing the best under vibration.
- Solder joint reliability (SJR) enhancements such as BGA underfills to provide substantially better thermal cycling performance and/or vibration performance. Depending on the thermal cycling requirements, both a reworkable and non-reworkable underfill have been successfully used to increase performance at Curtiss-Wright, with the latter having achieved over 3000 cycles of -40 to 125°C (15 minute dwells) failure-free. Other enhancements used in the past include solder columns and S-leads, however these are more costly and require module metalwork modifications.
- Different conformal coatings for better protection against harsh environments like condensing humidity, salt fog/spray, and fluid contamination. Some of these coatings have the added benefit of improving solder joint reliability (up to 2X) and reducing tin whisker risk.
- Cooling improvements such as increased clamping force retainers to reduce thermal contact resistance at the conduction card edge to chassis rail interface. Typical standard retainers (i.e. 5-piece wedgelocks) provide between 200-300 lbs. clamping force (Curtiss-Wright tested), whereas new advanced designs offer up to 500 lbs. and beyond.

The above list is an example subset of the entire “toolkit” that can be deployed for high durability requirements. They also illustrate that COTS modules from rugged module providers can and do meet a wide variety of environmental and durability requirements, including requirements beyond VITA 47. In these extended cases, rugged module providers like Curtiss-Wright will make the necessary enhancements to standard products that were designed for VITA 47 requirements. Open discussions will allow for the best combination(s) of enhancements for either testing to specific requirements or comparison testing to determine life capabilities.

TABLE 2 **Interoperability Matrix**

BACKPLANE CONNECTOR	STD VPX (RT2)	V60 (VIPER)	V63 (KVPX)	NEW RT2-R (only required if full connector wipe used)
Std VPX (RT2)	✓			✓
V60 (VIPER)		✓		
V63 (KVPX)			✓	
New contact RT2-R	✓			✓

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