AVIONICS

COTS ATR System Enclosure Technology:

Considerations for the reliable and cost-effective deployment of VMEbus hardware in avionics applications

By Bob Amos

There is nothing new in the deployment of VMEbus-based system solutions into avionics applications. However, you could be excused for thinking, particularly in the defense arena, that it is the preserve of conduction-cooled technology.

While this certainly was the case, times have changed. Indeed, progressively over the past five years or so, commercial grade, forced-air, convection-cooled VME hardware has found its way into airborne environments hitherto considered for a number of reasons as too hostile.

Commercial pressures coupled with the wider choice of diversely functional and readily available-standard-grade VME boards have very much ensured this instinctive outcome. The same applies to other system ingredients such as mass storage devices, Ethernet hubs, and media converters etc.

There is nonetheless a somewhat less obvious but equally important factor, which has enabled defense contractors and OEMs alike to fully exploit this trend – system enclosure technology.

Naturally, the ability of a VME system's operating infrastructure (turnkey system enclosure) to be able to mitigate the inhospitable threats of moisture, humidity, high/low temperatures, shock, vibration, low pressure, conducted, and radiated Electro Magnetic Interference (EMI) is of paramount importance.

As challenging as these issues are to deal with from an enclosure solution supplier's perspective, other demanding defense nuances come into play, particularly within the avionics industry sector. These also have to be dealt with equally effectively.

Downsized defense equipment OEMs wishing to deploy their resources in their core areas of expertise will view a supplier with minimal enclosure flexibility and systems engineering ability as of limited use. Unquestionably, a holistic systems approach is essential.

This article touches on a number of key techniques developed by Mektron/Miltron Systems and combines them with interesting observations gleaned throughout the company's pioneering Air Transport Rack (ATR) enclosure years.

ATR enclosures and COTS semantics

Custom-off-the-shelf

The world's defense OEM market is very much program based and fuelled by a combination of demands, primarily the upgrading of aging equipment and the development of new equipment. In the ATR system enclosure context, the odds are stacked against finding an off-the-shelf solution.

Suffice it to say there is generally always a demand on the enclosure supplier for a degree of tailoring. This can amount to partial customization of a pre-existing standard enclosure or, quite frequently, total custom design.

The issues driving customization

Space and form factor

Usually there is a fixed space set aside for the equipment. In the case of an upgrade/retrofit program it is normally the area vacated by the old equipment. If it is a new aircraft it will still have predefined space allotted. In essence, it is generally accepted as commercially unattractive to redesign the fuselage of an aircraft just so that a standard off-the-shelf enclosure can be used.

Accordingly, the issue of available aircraft space coupled with the VME board form factor creates one of the most critical ATR enclosure/configuration considerations at the very outset for the enclosure customer and supplier. Figure 1 shows one of Mektron's custom enclosures.

Figure 1. Customized VME ATR enclosure

Tables 1a and 1b provide useful insight into configuration possibilities when using VME boards in ATR system enclosures conforming to the ARINC 404 specification. It is only theoretical however, insofar as it is not easy to account for unknown configuration nuances relating to power supply space/budget, thermal management convention, mass storage, I/O, and vibration/shock isolation requirements etc.

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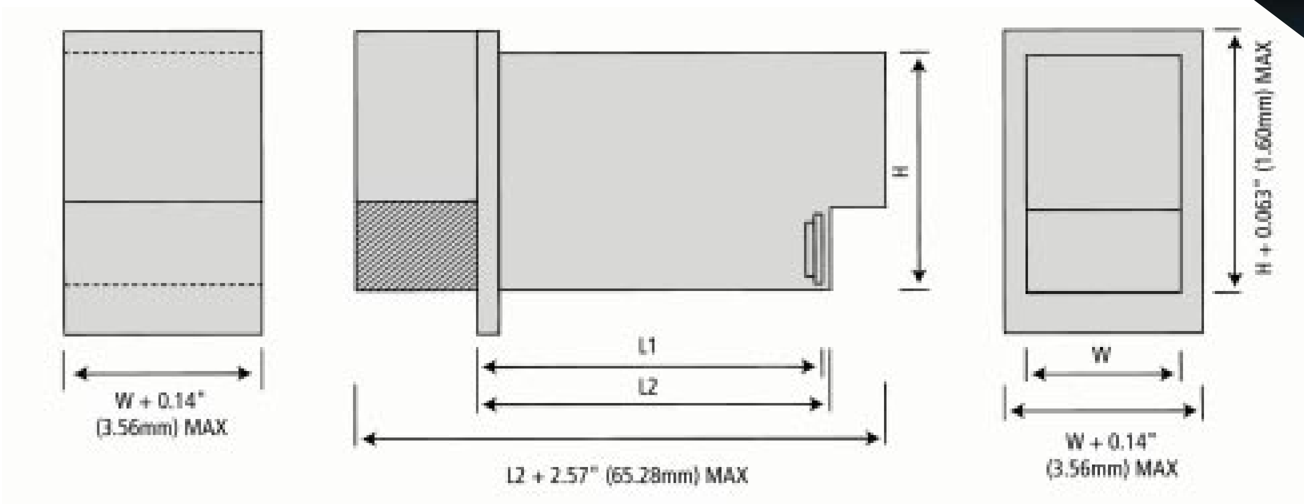

Table 1a: Standard ATR dimensions

ARINC SPECIFICATION 404A											VME BOARD CAPACITY			
											CONVECTION COOLED		CONDUCTION COOLED	
ATR Size	Approx Volume		Width (W)		Length (L1)		Length (L2) Max		Height (H) Max		Horizontal (Side) Board Load Max No. Slots	Vertical (Top) Board Load Max No. Slots	Horizontal (Side) Board Load Max No. Slots	Vertical (Top) Board Load Max No. Slots
	in^3	Litre	±.03in	±.76mm	±.04in	±1.0mm	in	mm	in	mm				
1/4 Short	215	3.52	2.25	57.15	12.52	318.0	12.62	320.5	7.62	193.5	n / a	1 slot	n / a	1 slot
1/4 Long	335	5.49	2.25	57.15	19.52	495.8	19.62	498.3	7.62	193.5	n / a	1 slot	n / a	1 slot
1/2 Short	470	7.70	4.88	123.95	12.52	318.0	12.62	320.5	7.62	193.5	n / a	5 slots	n / a	5 slots
1/2 Long	725	11.88	4.88	123.95	19.52	495.8	19.62	498.3	7.62	193.5	n / a	5 slots	n / a	5 slots
3/4 Short	720	11.80	7.50	190.50	12.52	318.0	12.62	320.5	7.62	193.5	n / a	8 slots	n / a	8 slots
3/4 Long	1120	18.36	7.50	190.50	19.52	495.8	19.52	493.8	7.62	193.5	n / a	8 slots	n / a	8 slots
1 Short	975	15.98	10.12	257.05	12.52	318.0	12.62	320.5	7.62	193.5	8 slots	12 slots	8 slots *	8 slots
1 Long	1510	24.75	10.12	257.05	19.52	495.8	19.62	498.3	7.62	193.5	8 slots	12 slots	8 slots *	15 slots
1 1/2	2295	37.62	15.38	390.65	19.52	495.8	19.62	498.3	7.62	193.5	8 slots	18 slots	8 slots *	n / a

Notes: 1. Requires 'Tall Box' height dimension up to 10.625in (296.88mm)
2. Where the maximum 'H' dimension shown is insufficient for equipment reasons, it is suggested that the 'Tall Box' maximum 'H' dimension of 10.625in (296.88mm) be adhered to as specified in ARINC characteristic 561 INS

* When utilizing 'Tall Box' maximum = 13 slots

Table 1b: Standard ATR dimensions

Vibration and Shock

There is an essential need for the enclosure to mitigate the various environmental threats discussed in the introduction. These will vary from platform to platform. For example, the vibration characteristic of a rotary wing aircraft is more onerous than that of a fixed wing aircraft. Moreover, vibration signatures will vary by aircraft type and the position within a given aircraft that the equipment is situated.

Therefore, any solution deployed to mitigate the unwanted affects of vibration has to be application specific. It is carefully selected against the aircraft's vibration signature, VME board hardware fragility factors, equipment mass, and center of gravity etc.

Commonly, vibration isolation is required for the majority of airborne 19-inch enclosure and ATR form factor applications using forced-air, convection-cooled commercial VME hardware.

Many of the company's rugged ATR system enclosures are fabricated from 3mm sheet aluminum and incorporate an internationally patented technique developed by Mektron/Miltron Systems referred to as "Crush-Fold" technology. This innovation has radically changed our approach to mechanical design and brings with it a number of distinct benefits over and above increased structural strength and rigidity, including excellent EMC integrity, minimal fastener count, clean-line aesthetics, and quicker assembly times.

ATR-style enclosures are particularly well suited to external isolation through its mounting tray/support structure (see Figure 2). However, it is not uncommon to hard mount a 19-inch or ATR-style enclosure and provide internal vibration/shock isolation to the equipment's most vulnerable components. Typically this would include the VME boards and any non-solid-state-based mass storage devices. Again, space constraints coupled with configuration and functional needs all play a part in determining the most effective and practical course of action. Figure 3 is a typical vibration response graph showing input vibration relative to attenuated output after isolation.

Figure 2. Typical ATR mounting tray with isolators fitted

Thermal management

The enclosure's thermal management system has to be compatible when fitted in its allocated space. For example it is not uncommon for an aircraft to provide its own pressurized or evacuating airflow to the equipment via a plenum or ducting arrangement. Therefore the enclosure's design generally has to fall in line with target application demands in this respect.

There are three basic techniques used by Mektron/Miltron in the provision of thermal management. A close understanding of the operational demands, configuration requirements, and commercial objectives is absolutely essential in determining the most suitable route to take.

Direct forced-air cooling is the most commonly used form of forced-air cooling, where ambient air is forced by fans over the heat dissipating electronic hardware. Ideally suited for the thermal management and effective deployment of convection-cooled commercial, industrial, or military grade hardware, providing that the ambient air is not laden with unfriendly or harmful contaminants such as moisture and salt fog.

Direct forced-air cooled ATR's can accommodate a number of thermal management options, including front to back evacuation/pressurized forced air (see Figure 4), or a combination of both to give a push-pull arrangement. Adaptations are sometimes required for externally generated ducted forced air delivered via a mounting tray/plenum assembly. This is more common with some ARINC 600 form factor implementations.

Indirect forced-air cooling is a technique for ATR and general applications, where the ambient air is isolated from the air circulating inside the enclosure. The heat dissipated within the enclosure is pumped out via an active or passive air-to-air heat exchanger. Suitable for the thermal management of commercial, industrial, or military-grade convection-cooled hardware in operating environments containing moisture laden or contaminated ambient air.

The laws of physics govern the suitability/feasibility of this method. In particular the following parameters are the key determining factors:

- Maximum heat load internal to the enclosure
- Maximum operating temperature of the active hardware
- Maximum ambient operating temperature environment

Conduction cooled enclosures are frequently used for very onerous defense applications. The heat generated within the enclosure is strategically conducted through to the outer surfaces and ambient air is then used to cool these surfaces. Certain applications may necessitate an external fan to move the ambient air over the enclosure's outer surfaces and maintain thermal integrity. Generally these enclosures are hermetically sealed.

Generally, conduction-cooled ATR enclosures do not lend themselves to cost-effective customization and scalability. Primarily this is due to conventional construction techniques, which can include wire erosion from a solid aluminum block, casting, or bolted/dipped braised machined sections.

To overcome these issues Mektron/Miltron Systems utilize a tried, tested, and much used technique based on its patented High

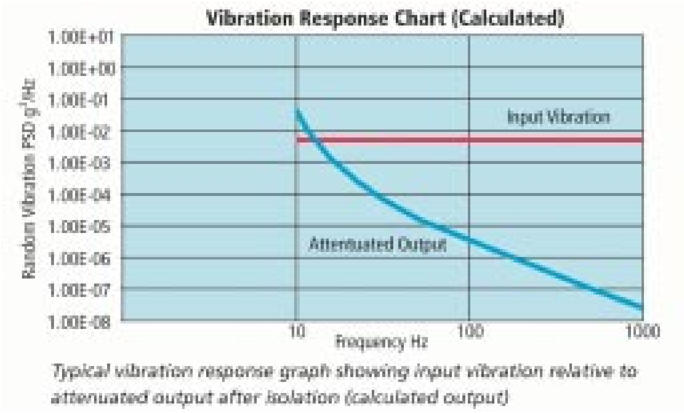

Figure 3. Vibration response

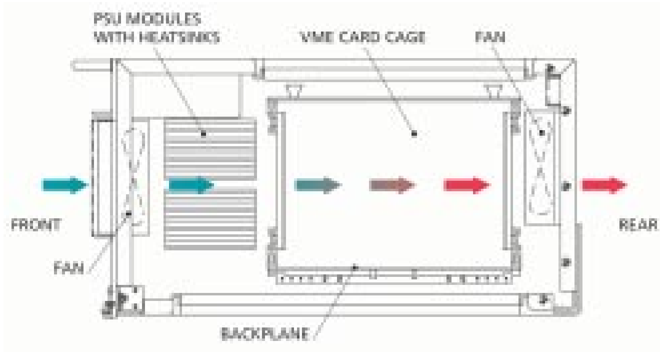

Figure 4. Airflow path for a typical direct forced-air cooled ATR enclosure

Integrity Frame technology (see Figure 5). This technique involves the use of a modular, high tensile strength skeletal frame, which is precision-machined from aluminum and consists of a number of lightweight interlocking sections that incorporate EMC and hermetic gasket channels (see Figure 6). The assembled frame is held together with locking dowel pins. Special outer panels with an aerodynamically profiled surface are then fixed to the frame. The net result is low mass, excellent thermal efficiency, inherently high levels of manufacturing flexibility, and reduced lead times.

Figure 5. Mektron's High Integrity Frame construction technique

High altitude/low pressure operation

Unless the equipment is intended for operating within the confines of a pressurized inhabited cabin environment or at relatively low altitudes, typically no greater than 10,000 feet, high altitude cooling fans are likely to be required.

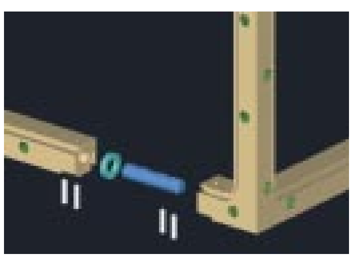

Figure 6. Interlocking sections

Some aerospace applications need fans to operate in an unpressurized environment up to altitudes of 50,000 feet or more.

ALTITUDE		AIR PRESSURE		TEMPERATURE	
Feet	Metres	mbar	PA	Deg C	Deg F
–820	–250	1,030	104,365	17	62
0	0	1,000	101,325	15	59
820	250	971	98,358	13	56
1,640	500	942	95,461	12	53
2,461	750	914	92,635	10	50
3,281	1,000	887	89,876	9	47
4,921	1,500	835	84,560	5	41
6,562	2,000	785	79,501	2	36
8,202	2,500	737	74,692	–1	30
9,843	3,000	692	70,121	–4	24
11,483	3,500	649	65,780	–8	18
13,123	4,000	609	61,660	–11	12
16,404	5,000	533	54,048	–17	1
19,685	6,000	466	47,218	–24	–11
22,966	7,000	406	41,105	–30	–23
26,247	8,000	352	35,652	–37	–34
29,528	9,000	304	30,801	–43	–46
32,808	10,000	262	26,500	–50	–58
49,213	15,000	120	12,112	–57	–70
65,617	20,000	55	5,529	–57	70
82,021	25,000	26	2,594	–52	–61
98,415	30,000	12	1,197	–47	–52
104,987	32,000	9	889	–45	–48

Table 2. Variation of atmospheric pressure and temperature with altitude

As altitude increases the air density decreases (see Table 2). This has two effects on a fan for which the choice of fan must compensate.

First, as air density decreases, the work that the fan has to do reduces. As a result, the speed of the fan will increase and generate additional heat from the motor. To compensate, high altitude fans are designed to ensure that adequate heat can be dissipated to cope with such operation.

Fans are essentially constant volumetric devices, so as air density decreases, the air mass flowing through a standard fan will decrease. Since most fan applications are used to provide cooling airflow, and cooling capacity is proportional to mass flow, this can cause a system problem. To deal with this, high altitude fans compensate for lower air densities by increasing their speed. Although they don't provide a constant mass flow, they approximate to it much more closely than a standard fan.

High altitude fans are specifically designed to run at rotation speeds of up to 23,000 RPM and incorporate high quality bearings, high quality grease (operating temp. –55°C to +100°C), and an additional grease reservoir. Metal housings and rotors are used to produce better thermal management from the fan to the surrounding fixings. Bearings are semi-sealed to prevent salt fog and moisture ingress.

These fans are designed in accordance with MIL-Q-23071 and are qualified and tested in accordance with MIL-STD-801. Power options include 28V DC, 115V AC, single- or three-phase, 50, 200, or 400 Hz, all compliant to MIL-STD-704.

Power supply

A specific power supply requirement will almost certainly exist. For example, it could be single or three-phase AC or 28V DC input. U.S. Military or British Defense Standards are likely to apply rules governing a number of input characteristics such as transients and surges.

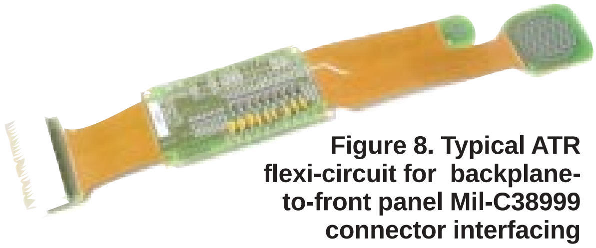

Figure 8. Typical ATR flexi-circuit for backplane-to-front panel Mil-C38999 connector interfacing

Backplanes and I/O

Due to an ATR system's high levels of compactness, considerable care needs to be paid to I/O signal interfacing. Quite frequently it requires a degree of innovation and careful planning to facilitate the unhindered routing of signals from the VME boards P0/P2 interfaces at the rear of the backplane to front panel connectors, while at the same time maintaining signal integrity and good EMC properties. Occasionally, "blind-mate," rear-panel-mounted, DPX-style connectors are used. This arrangement automatically engages with its reciprocal mating half connector when the ATR is offered up to its mounting tray. Flexi-circuits (see Figure 8) provide a good engineering solution for backplane to external I/O interface connectors.

It is not always financially viable to use flexi-circuits, particularly when only a very small number of systems are being produced. Therefore, and most commonly, discrete wiring is used (see Figure 9). The picture below helps illustrate the complexity and compactness issues when faced with a large number of wired interconnections – in this case well in excess of 600!

Special functional requirements

Certain functional requirements specific to the ATR system enclosure are invariably mandated. These could include accessibility of key components for maintenance and repair, such as power supplies, cooling fans, and air filters. Some applications demand operational access to shuttlized mass storage devices, usually through an EMC hatch on the top or front of the enclosure.

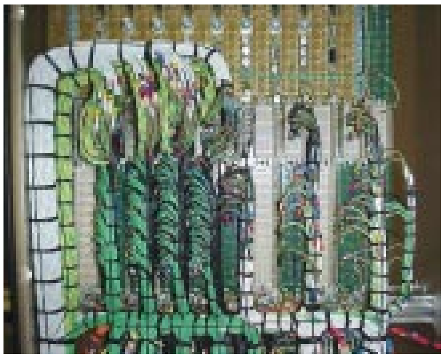

Figure 9. The complexities of discrete signal I/O wiring

Intelligent climatic control

A Climatic Controller Module has been developed by Mektron/Miltron Systems to enable the use of commercial electronic hardware, typically operating over the range of 0 to +50°C, in otherwise extreme temperature environments. This compact device has helped considerably with the deployment of COTS hardware in military and associated applications.

Qualification

With the inherent custom nature of VME ATR system enclosure solutions, coupled with very small production quantities – small meaning perhaps one or two units – how does a prime contractor gain the necessary confidence that everything is compliant to specification?

Almost always a contractor will have to demonstrate compliance all the way back up the chain. In adhering to tried and tested methods there can be an element of "read-across" from one job to another. Invariably though, a degree of formal qualification/confidence testing is normal. Interestingly, it is hardly ever just the turnkey system enclosure that is tested. Understandably, a compliant system enclosure on its own is of no use if damage is inflicted during shock/vibration or moisture attack when active hardware is installed. Similarly, EMC testing can become an irrelevance if it is not carried out on a representative system.

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