Metal Additive Manufacturing Applied to VITA 48.2
Conduction-Cooled Single Board Computers

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Abstract: Additive Manufacturing, and more specifically Metal Additive Manufacturing (or Metal 3D Printing), is changing the manufacturing industry by lifting some of the design constraints inherent to traditional processes. In this document, we will present a feasibility study of a Lattice Structure created by Metal AM applied to a standard ANSI/VITA 48.2 Conduction-cooled Single Board Computer Assembly. Using a technique for which TEN TECH LLC holds a USPTO Provisional Patent, a 40% weight reduction was achieved while maintaining dynamics and thermal performance.

Keywords: Additive Manufacturing, 3D Printing, VITA 48.2, Shock & Vibration, Thermal, Single Board Computer, VPX, OpenVPX, Lattice Structure, MIL-STD-810.

1. TEN TECH LLC: Defense Electronics Subject Matter Experts

TEN TECH LLC is an ITAR-registered Engineering Services Company based in Los Angeles, CA that provides Subject Matter Expertise in the areas of Modeling & Simulation.

Our core competency is in shock, vibration and thermal management of Embedded Defense Electronics systems such as Single Board Computers, RF & Microwave Components as well as complete rugged chassis and subsystems for Avionics, Flight Data Recorders, Guidance & Navigation, Radar Processing, Electronic Warfare and C4ISR applications.

In the course of a year, the engineers at TEN TECH LLC participate in the design and qualification of 20-25 such systems and subsystems for Sea, Air and Land applications. It is safe to say our understanding of ruggedized electronics in harsh military environment is substantial.
2. VITA 48.2 Single Board Computers

A Single Board Computer (SBC) is a complete computer, including CPU, memory, storage, I/O and GPU built on a single circuit card. For military applications, SBCs are ruggedized for harsh environments for shock, vibration and temperature among others, as described in standards such as MIL-STD-810.

Military SBCs follow certain design standards (ANSI/VITA) which define shape, size, electrical and mechanical interfaces. Every manufacturer’s SBC will mechanically fit into standard ruggedized chassis such as ATR Chassis. Examples of an ATR chassis, and SBCs can be seen on Figure 1.

![Figure 1: ATR Chassis & SBC Payloads](image1)

A ruggedized SBC’s main components consist of a circuit card with its connectors and components, sandwiched between a primary and secondary cover. These covers, made of machined aluminum, provide mechanical interface to the chassis via wedge-lock systems, flexural stiffness to avoid components vibration fatigue failure and heat sink functions to lower the components operating temperature. Figure 2 shows an assembled conduction-cooled SBC and its bare board.

![Figure 2: 6U Conduction-cooled SBC and SBC Bare Board](image2)

In the case of a VITA 48.2 conduction-cooled SBC, both primary and secondary covers, because of their “massive” nature, are perfect candidates for an Additive Manufacturing process, with the main goal to decrease mass while maintaining comparable performance structurally and thermally.
3. **Metal Additive Manufacturing**

Additive Manufacturing, or 3D Printing, is the process of creating parts layer-by-layer as opposed to removing material by CNC operations. Metal Additive Manufacturing is used in the production of critical aerospace components such as rocket engines or commercial aircraft structures, offering a clear advantage in terms of weight reduction. Aluminum and Titanium, among other metals, can be “printed” with high accuracy and repeatability into complex shapes, as seen on Figure 3.

![Figure 3: Metallic AM Part (front) & Legacy CNC Part (back)](image)

4. **Geodetic & Lattice structures**

A geodetic or lattice structure is a type of design that uses many closely spaced diagonal truss elements to provide structural integrity without the weight penalty of a massive construction.

Sir Barnes Wallis pioneered geodetic structures in aircraft design in the 1930s. The Vickers Wellington bomber had lattice structures that could take incredible damage without breaking, while providing weight savings of 40% or more. High assembly cost and complexity made it impractical for high volume production as required during wartime.

![Figure 4: Vickers Wellington Assembly Line](image)
With current Metal AM processes, fabricating lattice structures is now an easy and fast process that can be applied to many different types of structures as seen on Figure 5, bringing the same beneficial stiffness/weight ratio.

![Figure 5: Examples of Lattice Designs](image)

The object of our study will be to apply Lattice Structure designs to the SBC cover.

5. **Conduction-cooled SBC Primary Cover Design**

The Primary Cover of a conduction cooled SBC serves as a mechanical interface to the chassis as well as a stiffening structure and a cold plate. Thus, it contains important feature & functions:

- Machined Aluminum Construction for conduction to chassis walls
- Wedge-lock Mounting Tabs to tighten the SBC in place in chassis slot
- Mounting Screws to clamp the circuit board assembly
- Internal Protrusions in direct contact with hotter components

A representative 3D CAD model of a VITA 48.2 SBC, assembled and as an exploded view, can be seen on the figure below (Primary Cover Highlighted in Red):

![Figure 6: VITA 48.2 SBC CAD Assembly](image)
Some characteristics of the Primary Cover, such as wedge-lock interface location, through holes and component sink protrusions are unmovable. In fact, attempting to alter these would most likely have only negative effects. A CAD model of a representative Primary Cover is seen below:

![Figure 7: VITA 48.2 SBC Primary Cover](image1)

6. Lattice Core Primary Cover Design

The goal of our Lattice Core design will be to lower the weight of the cover, which in our case weights 2.25lb, while maintaining structural and thermal performance comparable to the standard design.

To comply with interface requirements and VITA 48.2 constraints, our design maintains all external features of a standard Primary Cover, but uses a hollow/lattice core as shown in the cross section below:

![Figure 8: Lattice Core Cover Cross Section](image2)

The tetrahedral pattern Lattice structure is defined using a proprietary algorithm we designed to evenly distribute lattice beams and allowing for density variations based on geometric curvature tolerance or stiffness requirement. The “face sheet” thickness is chosen to provide enough support and thermal mass to the structure. Thermal “sinks” for the main components as well as screw bosses are passing directly through the Lattice core and provide stiffness and/or thermal mass where needed.

*With this design, we can achieve close to 50% mass reduction: the new Primary Cover weighs in at 1.23lb, about 1lb weight saving.*
7. Comparative Performance Evaluation

With that design defined, we must compare its performance to the original design. Given the design change and inherent differences in material used, it is expected that the new cover will not perform as well as the original.

Stiffness, natural frequencies and thermal performance will be verified using Finite Element Analysis to assess if the impact of the lattice design will allow for a complete MIL-STD-810 qualification.

7.1. Vibration Performance Evaluation

Stiffness and natural frequencies will be evaluated by performing modal analysis of the covers, with boundary conditions simulating the installation in the chassis card slot with wedge-locks fully deployed. A typical SBC is designed to be stiff enough to avoid resonance with the vibration transferred to the chassis and its support shelf through the vehicle structure, requirement for minimum first natural frequency are typically applied to the SBC design, which can easily be extrapolated to requirements at the primary cover level. Figure 9 shows the 3D Finite Element Model and boundary condition location to perform the modal analysis.

![Figure 9: Primary Cover FEM & Boundary Conditions](image)

Modal analysis of both designs was conducted to 2000Hz (typical frequency range of airborne vibration). Both designs' first natural frequency is above 500Hz, necessary to avoid resonance coupling with other hardware. All frequencies within 2000Hz are quite similar, with a 5%-10% difference between frequencies between each design. Furthermore, the mode shapes for each natural frequency are very similar. An example of mode shapes can be seen on Figure 10.
Apart from the good correlation between the designs, the lattice core doesn’t seem to be causing any spurious resonance, a sign that both our face sheet thickness and lattice distribution and cross section are performing adequately.

The lattice design performs similarly to the original VITA 48.2 design, and possibly even improves on it given the slightly higher natural frequency values exhibited by the lattice design.

7.2. Thermal Performance Evaluation

The VITA 48.2 cover design acts as a heat sink for the SBC, conducting the heat away from the components into the chassis side walls.

For components with a particularly high power density, such as FPGA or GPU, extrusions protrude from the internal surface of the cover, creating a direct conduction path via Thermal Interface Material. Figure 11 highlights such extrusions.
Our lattice design maintained these protrusions, making sure the inner and outer face sheets were connected (see cross section Figure 8), expectations are that the thermal performance of the cover will not be dramatically worse, even though it is expected to be comparatively underperforming.

Both designs will be studied by Finite Element Analysis, simulating the ability of the cover to “expel” the heat dissipated by the components toward the outside of the cover.

The same FEM used for the modal analysis will be used. Heat loads are applied directly to the protrusions to represent the electronic components power dissipation while free convection boundary conditions are applied to the outside to simulate the SBC’s ambient environment, as described on Figure 10.

![Heat Loads & Boundary Conditions](image12.png)

**Figure 12: Thermal Loads & Boundary Conditions**

Comparative temperature distribution results can be seen on Figure 11.

![Comparative Thermal Analysis](image13.png)

**Figure 13: Comparative Thermal Analysis**

The lattice design performs slightly worse than the VITA 48.2 design: while the lattice design effectively dispatches the heat away from the components in a similar manner than the VITA 48.2 cover, it does so in a less “distributed manner”. This is caused by the lattice construction as can be seen on the cross section on Figure 14.
The effect of the lattice design on the temperature distribution creates a temperature rise of approximately 1°C per 50W of power dissipation, which we deem comparable to the original VITA 48.2 primary cover. Conversely, because of the more focused power dissipation, the overall minimum temperature of the SBC is lower for the lattice design.

*Overall, the lattice design performs in a similar fashion thermally to the standard VITA 48.2 cover.*

8. **Conclusions & Future Developments**

The proprietary lattice structure developed at TEN TECH LLC has been evaluated and proven by simulation to be performing similarly to or better than a standard VITA 48.2 cover, including:

- A 40% weight reduction over a standard VITA 48.2 design. A 1lb weight reduction per SBC could bring a 5lb-20lb overall system weight reduction,
- First natural frequency is high enough to avoid dynamics coupling with chassis and equipment,
- Natural Frequencies are comparable to the VITA 48.2 cover within MIL-STD-810 range of interest for sine and random vibration,
- Despite a slightly higher temperature concentration, the lattice cover allows sufficient dissipation of the components heat, thanks to the through-core protrusions

This Phase I study focused on the feasibility of an original lattice design, which was proven by simulation. Phase II study will focus on productization and prototyping, to allow for a repeatable and predictable product capable of advantageously take the place of a standard VITA 48.2 component.

Even it was applied to a 6U VITA 48.2 Primary Cover, the lattice core design can be easily applied to 3U payloads and even chassis substructures, essentially replacing massive machined aluminum plates with a much lighter lattice design.