Advantages of Mercury’s Modified Off-The-Shelf (MOTS) Product Approach
Abstract

This white paper describes Mercury’s approach to building products for enhanced durability under extreme environmental conditions, including repeated temperature cycling over wide temperature ranges. Requirements and best practices have been accumulated over dozens of military and avionics programs resulting in a best-in-class set of design rules and manufacturing process call Modified Off-The-Shelf (MOTS). The baseline hooks for the MOTS process are built into each new Mercury ensemble boards and subsystem components so that customers can choose the enhanced durability options for any of those products without requiring a redesign or respin. The resulting MOTS-enhanced subsystems are designed to withstand extreme conditions, such as over 1000 wide temperature cycles.

Introduction

The defense electronics market encompasses a significant range of environments — from fixed installations with conditioned environments, to mobile deployment in extreme temperature environments, from under the sea to the edge of the atmosphere. Attempting to create a “one size fits all” approach to the full environmental spectrum makes little economic sense — less rugged and size/weight/power (SWaP) constrained environments would end up paying the rugged tax, and the more constrained deployments may not end up with the optimized solution they demand. For this reason, Mercury has broken its product line into various form factors — rack servers and ATCA-based architectures for less constrained environments, and OpenVPX (3U and 6U) for rugged optimization. Within the rugged OpenVPX solution space, the most demanding deployments require additional manufacturing and packaging technology and techniques to deliver the ruggedness, durability, and reliable long-term operation required in the harshest of environments. In response to this need, Mercury has developed a set of design requirements and manufacturing operations to provide extreme durability, resulting in Mercury’s Modified Off-The-Shelf (MOTS) service offering. Many DoD programs have already benefited from the application of MOTS to meet their durability requirements, and MOTS offerings can help future avionics programs meet their reliability-related safety requirements. Mercury’s ability to integrate requirements from system integrators, prime contractors, and government agencies, sourced across a wide breadth of program requirements and commercial best practices, results in a comprehensive solution that spans multiple disciplines and delivers the required level of long-term durability to meet program requirements.

This paper examines the various mechanical and electrical modifications that go into a MOTS design, and describes the benefits that result from the application of these cross-program requirements across multiple technology deployments.

MOTS Mechanical Attachment

One of the critical elements of a MOTS solution is the method of Ball Grid Array (BGA) mechanical attachment. Due to the application of regulations that limit lead content, most BGA manufacturers no longer offer their components with lead balls. The most critical failure that can result from these less rugged solder balls is cracking and opens as a result of repeated thermal cycling. Unfortunately, thermal cycling is a common occurrence in many deployed programs. Consider an aircraft sitting on a desert runway, called into service and rapidly transitioning from the ground to tens of thousands of feet in the air. This cycling occurs many times in the life of deployed electronics equipment such as radar or EO/IR processors. Using a non-eutectic solder under such conditions can result in cracks in the solder joints, as shown in Figure 1, and is simply not an option for these systems.

Figure 1: 84 Ball COTS SDRAM (lead-free): solder joint crack after 250 thermal cycles

To mitigate this concern, Mercury’s MOTS service chooses BGAs with eutectic tin-lead (Sn/Pb) solder spheres whenever commercially available. (Ceramic BGAs may have 90%Pb /10%Sn non-collapsing solder spheres). For BGAs available only with SAC solder spheres, Mercury sends the BGAs in question to an approved contractor for re-balling. As a result, the solder joints can withstand many hundreds of extreme temperature cycles, as shown in Figure 2. Any Land Grid Array (LGA) components (such as Intel Xeon EP or SP processors) are consistently converted to BGAs in all Mercury products, and only leaded solder is selected for this LGA conversion. Conversion of LGAs to BGAs also greatly improves tolerance to vibration by eliminating the socket.

Figure 2: 84 Ball MOTS SDRAM (tin-lead solder): solder joints after 750 thermal cycles
The number of components treated by Mercury’s MOTS service can range from 10-100 BGAs and LGAs per design, and from smaller pin count BGAs to large LGA devices with a pin count greater than 3000. For products with the MOTS service applied, this conversion is built in to MOTS design documents and processes, so that it proceeds without manual intervention should the service be flagged as applicable to a particular design.

Component Underfill

Another necessary ingredient for durability through thermal cycling is structural component underfill. Mercury has conducted extended thermal cycle testing on a wide variety of products, both with and without underfill. These products include the new Intel® Xeon® Processor Scalable Family (previously code named "Skylake-SP"), which is an LGA with 3647 contacts converted by Mercury to a BGA. The results are clear: structural underfill extends durability significantly, with non-under filled BGA components failing before 1000 thermal cycles, and underfilled components remaining stable well beyond 1000 cycles. Mercury supports a wide variety of underfill materials, and selects the appropriate material based on component material and construction, pad geometry, ball spacing, and other module design parameters.

A necessary consideration for underfill, beyond the choice of material, is the component spacing built-in to the module design. With module real estate at a premium, designers are naturally pressured to place components as close together as routing allows, maximizing usable space. However, when designing a module where BGA underfill is a known option, ensuring proper spacing to support the application of underfill to the placed BGA must be considered and implemented. If module design does not incorporate this requirement up-front, costly design changes and requalification efforts can result, which adds technical and schedule risk to any program. All of Mercury’s designs incorporate the necessary spacing to support underfill for all required BGAs on the module design, precisely to ensure that these technical and schedule risks never materialize for our customers. This enables MOTS services and techniques to be applied to any standard product without requiring a re-spin of the module design.

Mercury also offers the service to include a customer’s specific underfill via our MOTS+ customization service, which incorporates customer-specific requirements above and beyond Mercury’s standard MOTS configurations.

Gold Embrittlement

Gold plated components provide another unique challenge during the solder process. When soldered, gold can dissolve into the eutectic tin-lead solder and create brittle solder joints. This interaction is known as gold embrittlement. SMT RF connectors are a good example where thick gold (50 microinches) is used to avoid fretting and corrosion issues, but when soldered to the PCB, runs the risk of having a weak solder joint that can fail prematurely in a rugged environment. Other devices, such as gold plated ceramic packages for crystal oscillators, can also have excessive gold at the solder interface.

To mitigate the risk of gold embrittlement, when producing a MOTS variant of a product, Mercury conducts an analysis to ensure that only 3% gold remains (by weight) after reflow. The gold plating thickness is verified using X-Ray Fluorescence (XRF), rather than simply calculated from the component data sheet, as the actual gold plating thickness has been shown to be up to three times (or greater) in some cases than the vendor’s specified thickness. Both the volume of gold on the components leads and the tin-lead volume of the board pad is calculated, taking into account solder flux "burn off" and solder slumping, and the percentage of gold by weight on the component pad after reflow is calculated. When the 3% limit is exceeded, Mercury processes the devices through a solder dip and wick process to reduce the gold concentration prior to assembly, eliminating any chance of gold embrittlement.

Tin Whisker Mitigation

Due to a variety of potential health issues, many materials used in the production of electronic products have come under scrutiny. As a result, in 2002, The European Union (EU) enacted the following directives that restrict or eliminate the use of various substances in a variety of products produced after July 2006:

- 2002/95/EC Restriction of Hazardous Substances (RoHS)
- 2002/96/EC Waste Electrical and Electronic Equipment (WEEE)

One of the key restricted materials is lead (Pb), which is widely used in electronic solder, the terminations on electronic parts, and printed wiring boards. While these regulations may appear to affect only products for sale in the EU, many suppliers to the aerospace and high performance Industry in electronics are changing their products because their primary market is consumer electronics. Additionally, several states in the U.S.A. have enacted similar “green” laws, and many Asian electronics manufacturers have recently announced completely “green” product lines.

The restriction of lead use has generated a transition by many component part and printed circuit board suppliers from using-tin-lead (Sn-Pb) surface finishes to pure tin or other lead-free finishes. Lead-free tin finishes are susceptible to the spontaneous growth of crystal structures known as “tin whiskers”, which can cause electrical failures, ranging from parametric deviations to catastrophic short circuits. Though studied and reported for decades, the interactions and exact physics behind tin whisker growth is not completely understood, and tin whiskers remain a potential reliability hazard.

Mercury’s MOTS approach is designed to provide overlapping mitigations, based on the superset of recommendations from our customers. The goal is to minimize the tin whisker risk without degrading system performance, without incurring any unnecessary program costs or schedule delays. In specific terms, Mercury complies with the Government Electronics and Information Technology Association (GEIA) GEIA-STD-0005-2, Level 2B: Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems.

One of the basic treatments performed on modules designed for rugged deployment is the application of conformal coat. Conformal coat provides protection from moisture and abrasion and acts as a barrier against tin whisker growth. Mercury supports multiple coating materials, from acrylic to Parylene, but the default for our standard product is Mil-I-46605C and IPC-CC-830 compliant urethane. Experiments have demonstrated that in rare circumstances tin whiskers can tent or even project out of a thin layer of conformal coat, but cannot re-penetrate the coating. While this affords some protection against tin whisker growth,
care must be paid to situations where space between contacts is too small (less than 0.010 inches) as in Figure 3, and tin whiskers may bridge the gap even with conformal coat in place. In most cases however, the tight spaces can prevent conformal coat material from fully encapsulating gull-wing leads, with the interior leg of the lead being exposed and unprotected. For this reason, Mercury’s MOTS products minimize the use of fine pitch components, and when required, tin-lead solder dip fine pitch lead-free devices. To prevent tenting and provide a better adhesion surface, Mercury is investing in the capability to RF Plasma process PCB assemblies prior to conformal coating.

DFN/QFN packages

DFN/QFN packages, while convenient for many applications, bring challenges when dealing with highly rugged environments with long-term exposure. Primarily, the low height of the package when soldered is problematic. These packages are very low profile, and the solder is correspondingly reduced in height. Because there is less solder available to absorb movement resulting from thermal expansion/contraction, the stress of this expansion is almost entirely expressed as shear. The risk of long-term shearing to the integrity of the electronics is too high, and so Mercury MOTS compliant designs avoid these packages in favor of gull wing alternatives.

Management of Vented Packages

Many large BGA flip-chip packages are vented — that is, there is an open vent from the inside of the package to the outside. This prevents issues when unwanted air or contaminants expand within the package, causing damage over time. Vented packages, however, carry their own challenges. Moisture from wash downs should not remain inside vented packages after conformal coat, so a significant and measured baking cycle is required prior to coating.

As with BGA solder, die attach (when not wire bond) is preferred to be accomplished with leaded solder — but in many cases, lead-free solder is used internal to the package as well. Some device manufacturers will produce a more rugged variant with leaded solder used inside as well. In these cases, however, Mercury will re-scan the device to ensure that height changes have not resulted, as in many cases the packages have been seen to grow or shrink when process changes internal to the package have occurred.

Conclusion

Mercury has invested significantly to create a combination of design requirements and manufacturing processes that can be applied to standard off-the-shelf product lines to enhance durability. This Modified Off-The-Shelf (MOTS) approach is based on our extensive experience with the requirements from system integrators, major prime contractors, and government agencies when Mercury delivers subsystems — and as such, represents the best and most complete set of requirements in the industry. To ensure that these enhancements can be applied regardless of product selection, Mercury implements the baseline module design in a manner that allows the application of the MOTS process to deliver these enhancements without the need for a module redesign. This is a significant risk reduction for programs, both in terms of technical risk and schedule risk. Should a particular customer or program require divergences or enhancements from Mercury’s baseline MOTS approach, a customized MOTS+ service can easily be applied to meet that customer’s needs.

Mercury’s goal is to produce processing product lines that deliver the highest performance in the most rugged of environments. Mercury’s MOTS service is designed to ensure the long-term durability of these products in these environments. Through the combination of product design considerations, and enhanced manufacturing processes, products with the MOTS services applied meet the broadest set of durability requirements across the industry.