WHITE PAPER

Enhance product performance under extreme environmental conditions

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Durability Advantages of Mercury's Modified Off-The-Shelf (MOTS) Product Approach

This 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 called modified off-the-shelf (MOTS).

The defense electronics market encompasses a significant range of environments — touching every corner of the globe and the atmosphere's edge — from fixed installations with conditioned air environments, to mobile deployment in extreme temperature environments. Attempting to create a "one-size-fits-all" approach for the full environmental spectrum is impractical — operations with little concern regarding SWaP constraints or ruggedization pay for unnecessary features, whereas more constrained deployments may not receive the optimized solution they require.

For this reason, Mercury produces various form factors: rackmount servers and ATCA-based architectures for less-constrained environments, and OpenVPX (3U and 6U) for rugged deployment optimization. Within the rugged OpenVPX solution space, the most demanding durability requirements include the ability to withstand extreme temperature cycles, multiple patterns of shock and vibration, and resistance to fretting, corrosion, and tin whiskers that go beyond the baseline military standards.

In response to this need, Mercury has developed a modified off-the-shelf (MOTS) service offering that includes a set of baseline product design requirements and manufacturing operations to provide extreme durability. Each Mercury OpenVPX product uses a base design that includes built-in hooks for the MOTS process. This gives customers the freedom to select the appropriate durability options for their application without a required product redesign or re-spin. The resulting MOTS-enhanced products are able to withstand the most extreme conditions, including wide-ranging temperature cycles.

Many DoD programs have already benefited from the application of MOTS to meet their durability requirements. MOTS offerings also can help future programs meet their reliability-related requirements with significantly reduced technical and schedule risk. Mercury has managed a wide breadth of program requirements from a diverse set of customers: system integrators, prime contractors and government agencies. Applying learned best practices, Mercury's MOTS service is a comprehensive solution that spans multiple engineering and manufacturing disciplines to deliver long-term durability.

MOTS MECHANICAL ATTACHMENT AND SOLDER JOINT INTEGRITY

One of the critical elements of a MOTS solution is a ball grid array (BGA) mechanical attachment. Due to regulations that limit lead content, most BGA manufacturers no longer offer components with lead balls. Where lead solder forms a strong joint between different metals, less-rugged lead-free solder balls are rigid, fragile and do not bond well with other metals. They are prone to cracking from repeated thermal cycling that can result in critical failure. Unfortunately, thermal cycling is a common occurrence in many deployed programs. Consider an aircraft that has been sitting on a desert runway rapidly transitioning from the ground to tens of thousands of feet in the air.

The scope and rate of temperature change for a processing system housed in an unprotected pod under the wing of the aircraft would be extreme. 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 (see Figure 1) and is simply not a viable option for these systems.

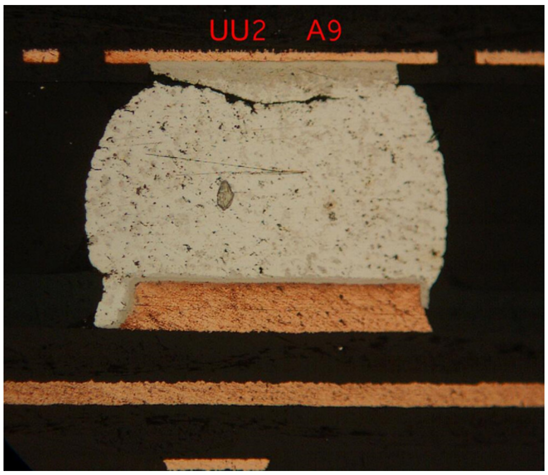

Figure 1: 84 Ball COTS SDRAM (lead-free): solder joint crack after 250 thermal cycles

To mitigate this concern, Mercury's MOTS service replaces lead-free BGAs with eutectic tin-lead (Sn/Pb) solder spheres on the product BOM 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 these BGAs 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® Scalable processors) are regularly converted to BGAs before use in 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.

The number of components treated by Mercury's MOTS service can range from 10–100 components per design, and from smaller pin count BGAs to large LGA devices with a pin count greater than 3000. For products designed for MOTS, this conversion is built-in to the manufacturing process so that it proceeds without manual intervention should the customer order the MOTS variant.

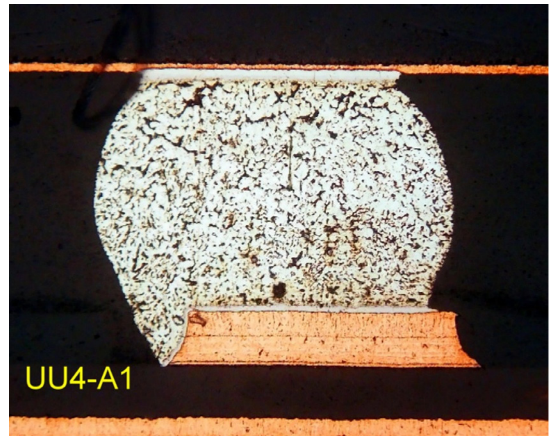

Figure 2: 84 Ball MOTS SDRAM (tin-lead solder): solder joints after 750 thermal cycles

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 latest socket in the Intel® Xeon® Scalable processor family, which is an LGA with 3647 contacts converted by Mercury to a BGA. The results are clear: structural underfill extends durability significantly. Components without underfilled BGA components failed before completing 1000 thermal cycles, while underfilled components remained stable well beyond 1000 cycles. Mercury supports a wide variety of underfill materials, selecting the appropriate material based on component material and construction, pad geometry, ball spacing and other module design parameters. Customers with specific underfill materials required can be accommodated in our manufacturing flow as well.

One 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 to maximize usable space. However, when designing a module where BGA underfill is required, proper spacing must be maintained. If a module design does not incorporate this requirement upfront, costly design changes and requalification efforts can add technical and schedule risk to a program. All of Mercury's OpenVPX module designs incorporate the necessary spacing to support underfill for all required BGAs, ensuring these risks never materialize and enabling MOTS services and techniques to be applied to any standard product without requiring a re-spin of the module design.

GOLD EMBRITTLEMENT

Gold plated components provide another challenge to 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 (see Figure 3). SMT RF connectors use thick gold (50 microinches) to avoid fretting and corrosion issues. When soldered to the PCB, gold can weaken a solder joint causing premature failure in a rugged environment. Other devices, such as gold-plated ceramic packages for crystal oscillators, can also have excessive gold at the solder interface.

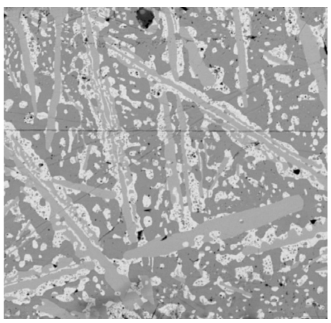

Figure 3: A solder joint showing the distribution of Sn-phase (dark gray), Pb-phase (light gray) and Au-Sn IMC (intermediate gray). [Ref. IFN 370_5, BSE SEM image, 1513X]. Hare, E. W. (2010). Gold Embrittlement of Solder Joints

To mitigate the risk of gold embrittlement in MOTS products, Mercury conducts an analysis to ensure that only 3% gold remains (by weight) after reflow. The gold plating thickness is empirically verified using X-ray fluorescence (XRF) instead of relying on calculations using the component's data sheet. Actual gold plating thickness has been measured at more than three times the vendor's specified thickness. The component leads' volume of gold and the tin-lead volume of the board pad is calculated, considering solder flux "burn off" and solder slumping, then the percentage of gold by weight on the component pad after reflow is also calculated. If the 3% limit is exceeded, the device is run through a solder dip and wick process to reduce the gold concentration prior to assembly to avoid 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 and were subsequently restricted or eliminated in the European Union (EU).

A key restricted material is lead (Pb). It was widely used in electronic solder on terminations of electronic parts and on printed wiring boards. While regulations may appear to affect only products for sale in the EU, many suppliers to the aerospace and electronics industry are changing their products to accommodate the consumer electronics market. Several states in the U.S. have enacted similar "green" laws and many Asian electronics manufacturers have recently announced completely "green" product lines.

The restriction on lead usage has initiated a transition by many component part and printed circuit board suppliers from using tin-lead (Sn-Pb) surface finishes to using 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. The interactions and exact physics behind tin whisker growth are not completely understood, leaving tin whiskers to remain a potential reliability hazard.

Mercury's MOTS approach provides overlapping mitigations to minimize tin whisker risk without degrading system performance or incurring unnecessary program costs or schedule delays. Specifically, 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.

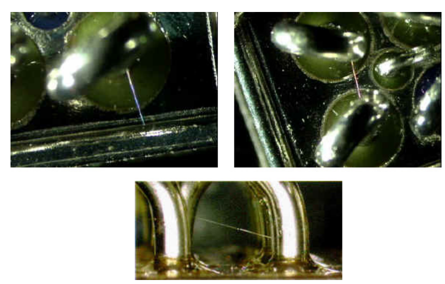

Figure 4: Tin whisker growing between pure tin-plated hook terminals of an electromagnetic relay similar to MIL-R-6106 (LDC 8913). Photo Courtesy of NASA Goddard Space Flight Center

One of the basic treatments performed on modules designed for rugged deployment is the application of conformal coating. Conformal coating provides moisture and abrasion protection and acts as a barrier against tin whisker growth.

Mercury supports multiple coating materials, from acrylic to urethane to parylene; however, the standard product is Mil-I-46058C and IPC-CC-830-compliant urethane. Experiments have demonstrated that tin whiskers can tent or project out of a thin layer of conformal coating but cannot repenetrate it. While this affords some protection against tin whisker growth, care must be paid to situations where minute space between contacts (less than 0.010") allows tin whiskers to grow even with a conformal coat in place. This tight space can prevent conformal coat material from fully encapsulating gull-wing leads, with the interior leg of the lead being exposed and unprotected. Mercury's MOTS products minimize the use of fine pitch components and, when required, tin-lead solder dip fine pitch lead-free devices.

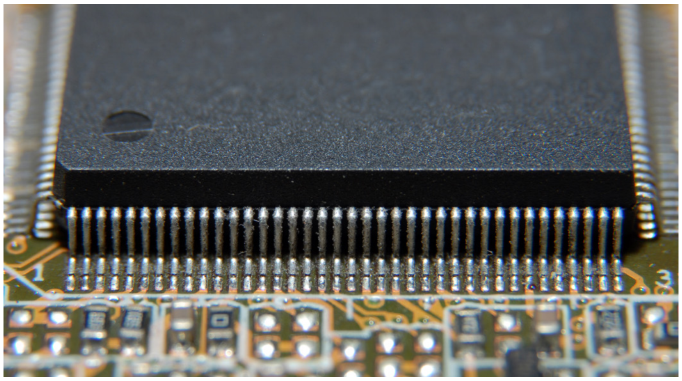

Figure 5: Fine pitch leads on components

Traditional mitigations may also not be applicable with press-fit connectors. Conformal coating is often unable to penetrate and cover exposed leads on these connectors due to the design of the connector itself. To resolve this issue, Mercury MOTS products apply underfill to these connectors to provide the same benefits of conformal coating.

DFN/QFN PACKAGES

While convenient for many applications, DFN/QFN packages present challenges when exposed long-term to highly rugged environments. Primarily, the low height of a soldered package is problematic. The very low-profile packages produce solder that is correspondingly reduced in height. With less solder to absorb movement from thermal expansion/contraction, the stress from the movement is almost entirely expressed as shear. The risk of long-term shearing to electronics integrity is too high; therefore, Mercury MOTS-compliant designs avoid these packages in favor of gull wing alternatives.

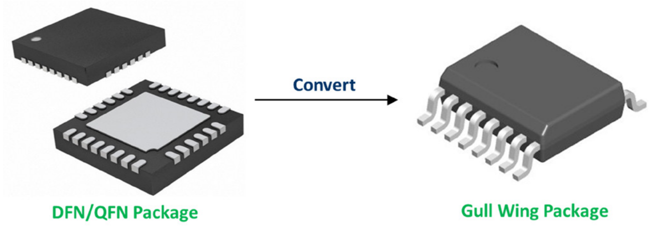

Figure 6: Convert DFN/QFN packages to gull wing packages

MANAGEMENT OF VENTED PACKAGES

Many large BGA flip-chip packages are vented – meaning there is an open vent from the inside to the outside of the package. This prevents issues when unwanted air or contaminants expand within the package, causing damage over time. Vented packages also carry challenges. To remove wash-down moisture from inside vented packages after conformal coating is applied, 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 mostly lead-free solder is used in the package. Some device manufacturers will produce a more rugged variant, using leaded solder inside. In these instances, Mercury re-scans the device to ensure no changes in height have occurred, as packages have often either grown or shrunk during the process changes.

LEVELS OF MOTS

The standard MOTS offering includes all the protections described above. MOTS+ is available for customers who need to reach beyond Level 2B to Level 2C tin whisker mitigation or require special test environments, special process controls, specific underfills or other custom features. In these cases, a customer-specific part number is generated and the required tests and/or processes are applied seamlessly to the product during manufacturing. The highest level of MOTS, MOTS Ultra, solder bumps QFN packages to avoid the joint fatigue issues for which they are prone.

MOTS AT MERCURY

Mercury has invested significantly to create a combination of design requirements and manufacturing processes that enhance durability of standard off-the-shelf products. A comprehensive solution that spans multiple disciplines and delivers long-term durability, Mercury's modified off-the-shelf (MOTS) design approach was developed from 40 years of experience meeting the requirements of system integrators, major prime contractors, and governmental agencies. As such, it represents the best and most complete set of requirements in the industry. All Mercury subsystems and module designs include baseline hooks for the MOTS enhancements to give customers a choice of durability options without requiring a product redesign.

This presents a significant risk reduction for programs in terms of both technical and schedule risks. A customized MOTS+ or MOTS Ultra service is available for customers requiring divergences from the standard MOTS approach.

Processing boards and systems that deliver the highest performance in the most extreme environments with long-term durability and significantly extended product lifecycles is why Mercury worked diligently to perfect the MOTS design approach. Combining product design considerations with enhanced manufacturing processes, Mercury's MOTS-enhanced products meet the broadest set of durability requirements in the industry.

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About Mercury

Mercury Systems (Nasdaq: MRCY) is a leading technology company serving the aerospace and defense industry, positioned at the intersection of high tech and defense. Headquartered in Andover, MA, we deliver solutions that power a broad range of aerospace and defense programs, optimized for mission success in some of the most challenging and demanding environments. We envision, create and deliver innovative technology solutions purpose-built to meet our customers' most-pressing high-tech needs.

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