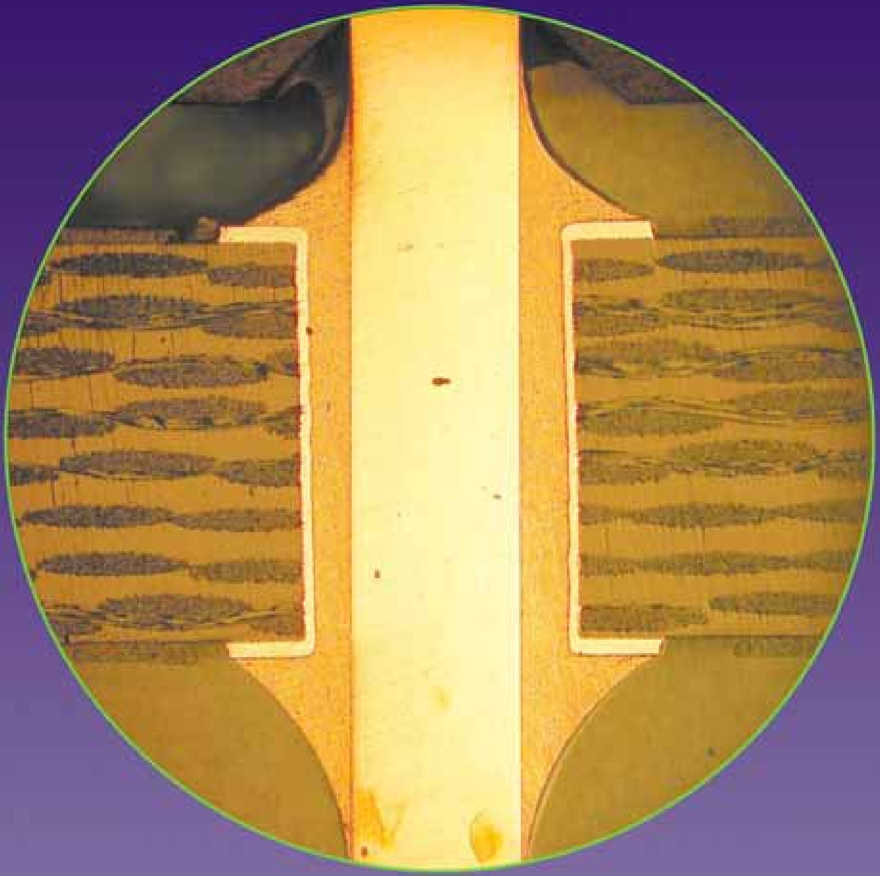
ASSURING RELIABLITY IN ELECTRONIC PRODUCTS UTILIZING LEAD-FREE NON-HAZARDOUS MATERIALS IN SOLDERING



WHITE PAPER

March 23, 2006

G.Cutler

TDI POWER

TABLE 1 PROPERTIES OF COMMON SOLDER ALLOY

Solder	Melting Temperature	Elongation	Wetting Time @ 250°C	Characteristics
Tin Lead SNPb	183°C	25%	<1 Sec.	Baseline eutectic alloy.
Tin Silver Copper SnAgCu	217°C	22%	3-4 Sec.	High surface tension, poor wetting. Ag provides greater strength but less ductility than Pb.
Tin Silver SnAg	221°C	24%	3-4 Sec.	Fatigue life is better than SnPb at 0-100° C but worse at -55 to 125° C. Very often used in plumbing applications.
Tin Silver Bismuth SnAgBi	210°C	16%	2-3 Sec.	Good wetting characteristics and low melting point from the addition of Bismuth-Bi. The alloy is mainly used in SMT applications. Thru-hole applications can result in fillet lifting.
Tin Bismuth SnBi	138°C	46%	<.7 Sec.	Lowest melting point from Bi additive. Low melting point precludes its use for applications where operating temp. is close to or exceeds 138° C. Consumer electronics applications.
Tin Copper SnCu	227°C	22%	5-8 Sec.	Thermal shock resistance of this alloy does not perform as well as SnAgCu and SnAg. Fatigue life of SnCu is .5-.7 times SnPb. With the addition of other elements such as Ni, Ag and Au, this can improve.
Tin Zinc Bismuth SnZnBi	195°C	16%	2-3 Sec.	Melting point slightly higher than SnPb, causing high oxidation rate limiting this alloy from wave solder and paste application.
Tin Copper and nickel SnCu+Ni	227°C	48%	2.5 - 3.5 Sec.	Small amount of nickel causes the alloy to exhibit fluidity comparable to tin-lead alloys. Other characteristics similar to SnCu.

Source: Kester, Vitronics Soltec, NIST

EXECUTIVE SUMMARY

Tin/Lead - "solder" - has served as the primary bonding and conducting agent for electrical interconnection of wires and components in electronic and electrical equipment for decades. However, lead has been determined to be a hazardous substance and the use of tin/lead solders are being restricted by government laws and regulations such as the European Union's RoHS Directive (Restriction of Hazardous Substances).

Alternate solder alloys such as "Tin/Copper/Nickel" – "Tin/Copper" – "Tin/Copper/Silver", and "Tin/Silver" are available as potential replacements for Tin/Lead. Although the Tin/Lead solder technology has been well documented for it's reliability, durability, and maintainability, the Lead-Free solder alloys are not equivalent "drop in" replacements.

Several Lead-Free solder alloys are available as shown in Table 1. Each has advantages and potential problems. Their effectiveness under all potential operating conditions has yet to be established. Their process characteristics are more likely to result in solder deficiencies, component overstress and tin-whisker growth. When these compromising conditions are introduced into a severe operating environment the result can be premature product failure.

Accordingly, the RoHS Directive provides some exemptions to permit Tin/Lead in solder joints where reliability and long life are of critical importance (i.e telecommunications infrastructure, servers, security and data storage). Products, which utilize these exemptions are referred to as RoHS 5 compliant, whereas Lead-Free solder assemblies are referred to as RoHS 6 compliant.

As new Lead-Free solders and processes are implemented, due caution should be taken to assure that the process and procedures are meticulously correct.

THE PROBLEM:

The detailed procedure to create reliable Lead-Free solder assemblies is influenced by a significant number of variables including:

- Process time and processing temperature of the assembly
- The mass and size of the assembly including the printed circuit board (PCB) and mounted components
- Solder pot contaminants. Pots must be analyzed regularly for proper alloy composition and the absence of contaminants
- PCB type as defined by the Association Connecting Electronic Industry Standard IPC-610 (see footnote 1)
- The compatibility of alloys used on PCB, the electrical and electronic components and the manufacturing processes
- Length of time allowed for the solder to flow (wetting time)
- Continuous maintenance of the equipment used in the soldering process is an absolute requirement.

Tin/Lead and Lead-Free automated soldering processes are both influenced by these variables. However, Lead-Free processing tolerances are significantly less forgiving and challenging to control. The problem becomes more evident in "Low Volume" production of multiple products.

Figure 1 illustrates the allowable margins for error between Tin/Lead and typical Lead-Free solders and their relationship to component thresholds. As shown, a smaller margin of safety results when using higher temperature Lead-Free solders.

When selecting a Lead-Free solder, the following factors should be considered:

- Reasonable melting temperature not exceeding 227°C
- Low surface tension for better wettability/solderability
- Limit peak process temperature to maintain reasonable margins of safety
- Self-centering characteristics of SMT devices to the PCB land area
- Cosmetic appearance of the final assembly

---

[1] Type 1 Surface Mount Technology (SMT) topside; Type 2 SMT topside and bottomside; Type 3 SMT topside, bottomside and thru-hole devices.

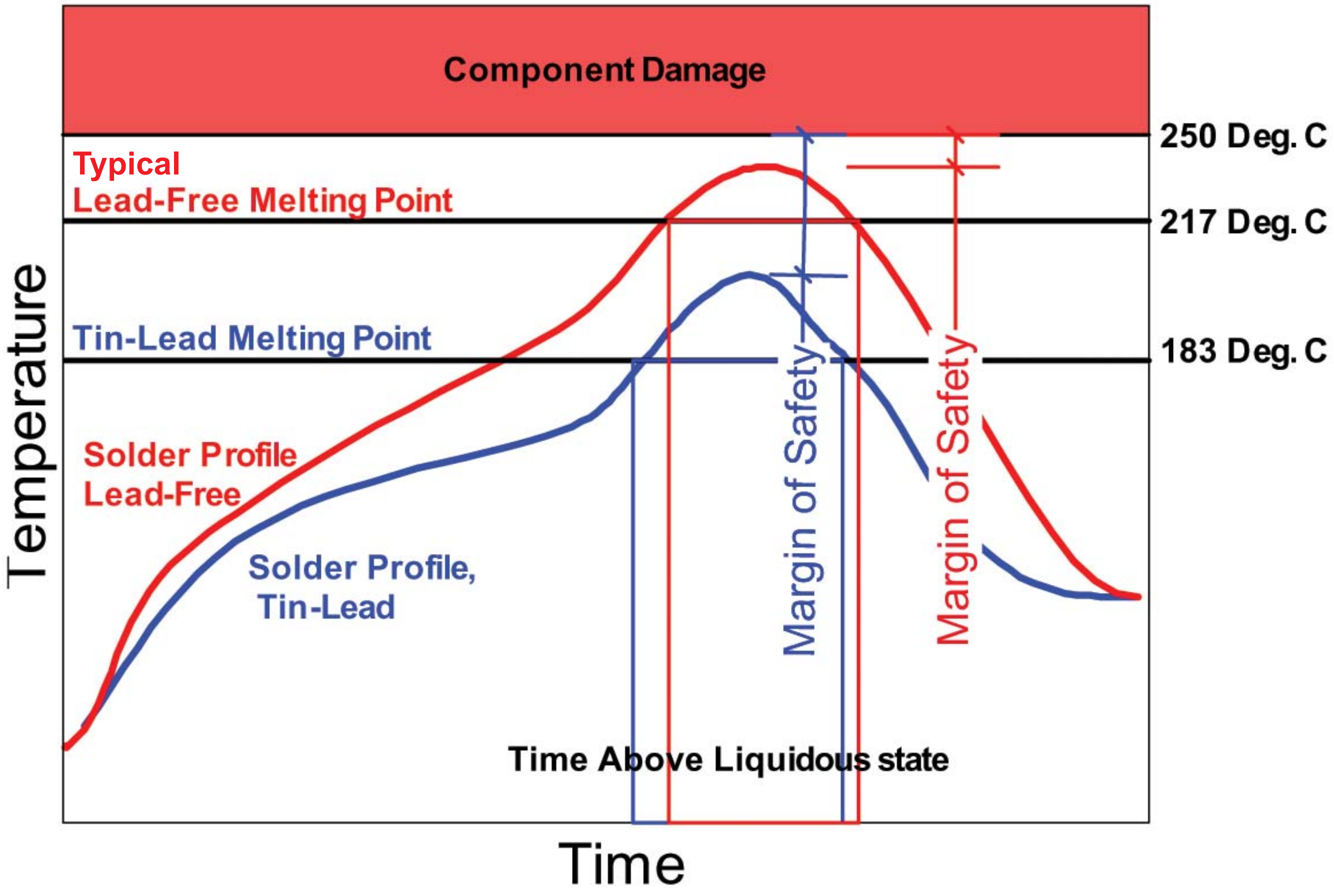


Figure 1: Solder Reflow profile for Tin/Lead and Lead-Free Solders

Many of the commonly used Lead-Free solder's have higher melting points (around 217°C) and good wetting/wicking is achieved at temperatures somewhat above 217°C for an extended period of time. However, higher temperatures may approach or exceed the component damage area. The maximum processing temperature should never exceed 250°C to maintain component safety.

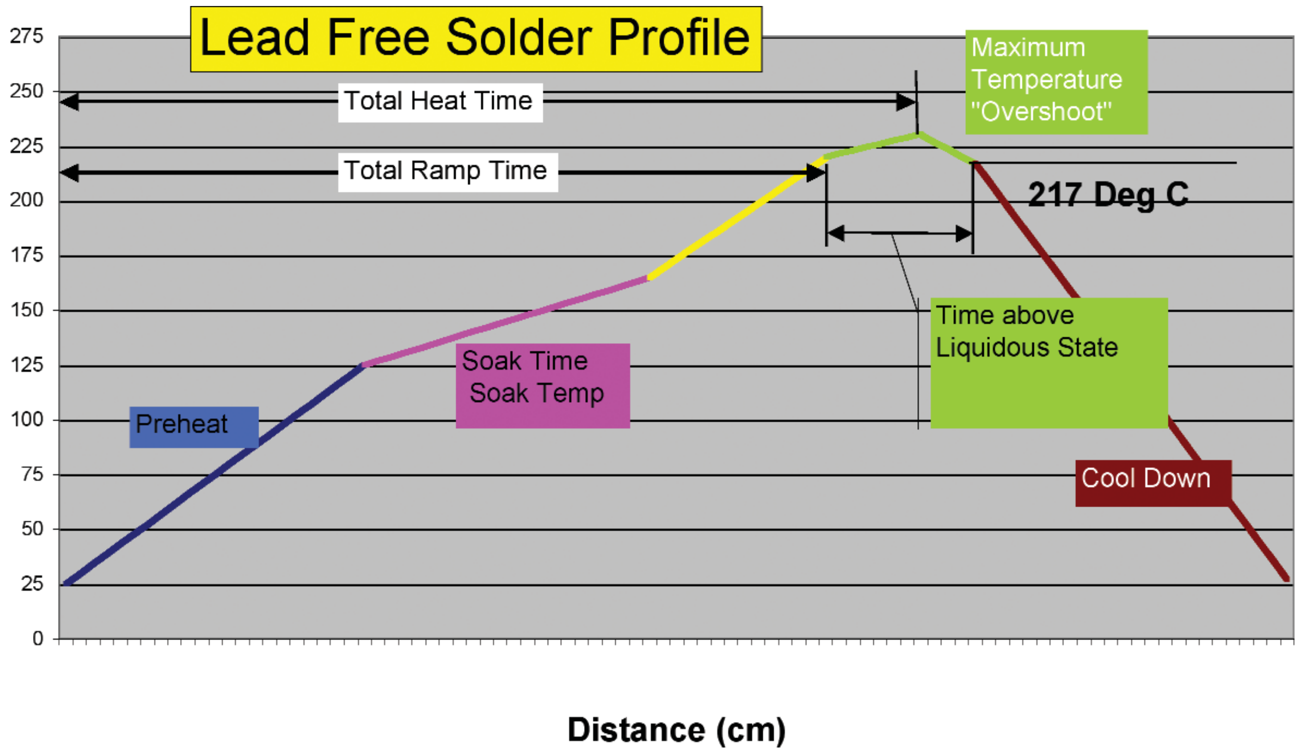


Figure 2. Critical Stages of a Typical Soldering Profile

The soldering profile of Lead-Free Type 1 SMT assemblies is relatively easy to control with modern surface mount processing equipment and current Lead Free solder alloys. However, Type 3 power assemblies' employ very involved electro-mechanical construction techniques utilizing SMT devices top and bottom, Thru-Hole components, large heatsinks, electrolytic capacitors and power magnetics. These assemblies are often processed through the soldering profile 2 or 3 times. Figure 2 illustrates the critical stages of a typical Lead-Free solder profile. The overall mass of these assemblies challenges the soldering profile through the Ramp/Soak stage and time above Liquidus state. "Hot spots" on the assembly can result, jeopardizing components or inversely "cold spots" may result at temperatures below 217ºC limiting proper solder wetting.

Higher process temperatures can also adversely affect both components and PCB's. Encapsulated epoxy packages on semiconductors and PCB's typically have a glass transition temperature (Tg) of 120-130°C. Once the Tg is exceeded, contaminants can penetrate the device or PCB. If then exposed to environmental application extremes premature failure may result.

In addition, plastic encapsulated semiconductors absorb moisture during storage, which may turn into steam during the soldering process, causing the package to delaminate, or in severe cases, explode. The MSL (Moisture Sensitivity Level) for most parts has dropped at least 1 or 2 points when re-characterized for the higher lead-free processing temperatures. In many cases the (larger) parts must be 'baked' within 24 hours before soldering to ensure reliability.

Industrial and other difficult environments may increase these stresses. Solder joint metal fatigue is also possible since weakened or substandard joints are more susceptible to thermal and physical stress.

Typical solder joint defects are illustrated in figures 3A - D:

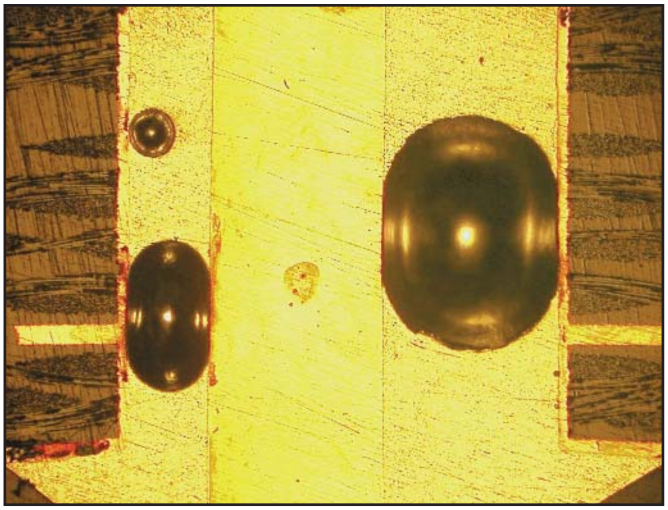


Figure 3A: Lack of Hole Fill, Voiding

Figure 3B: Poor Wetting

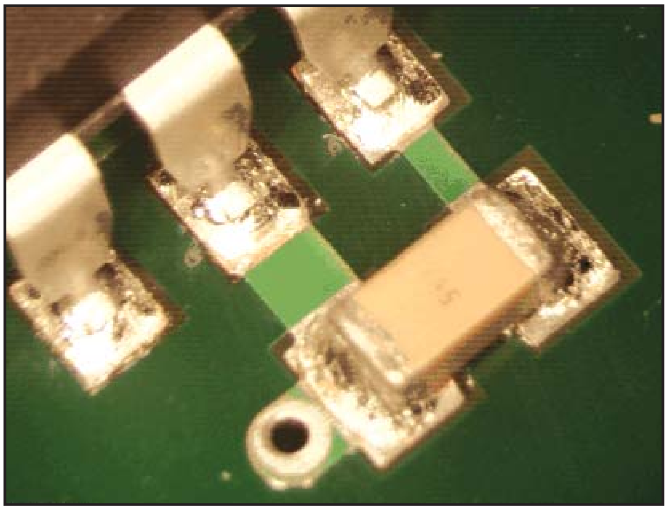


Figure 3C: Cold Solder

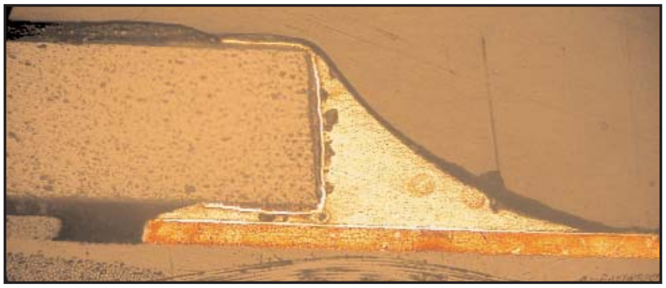


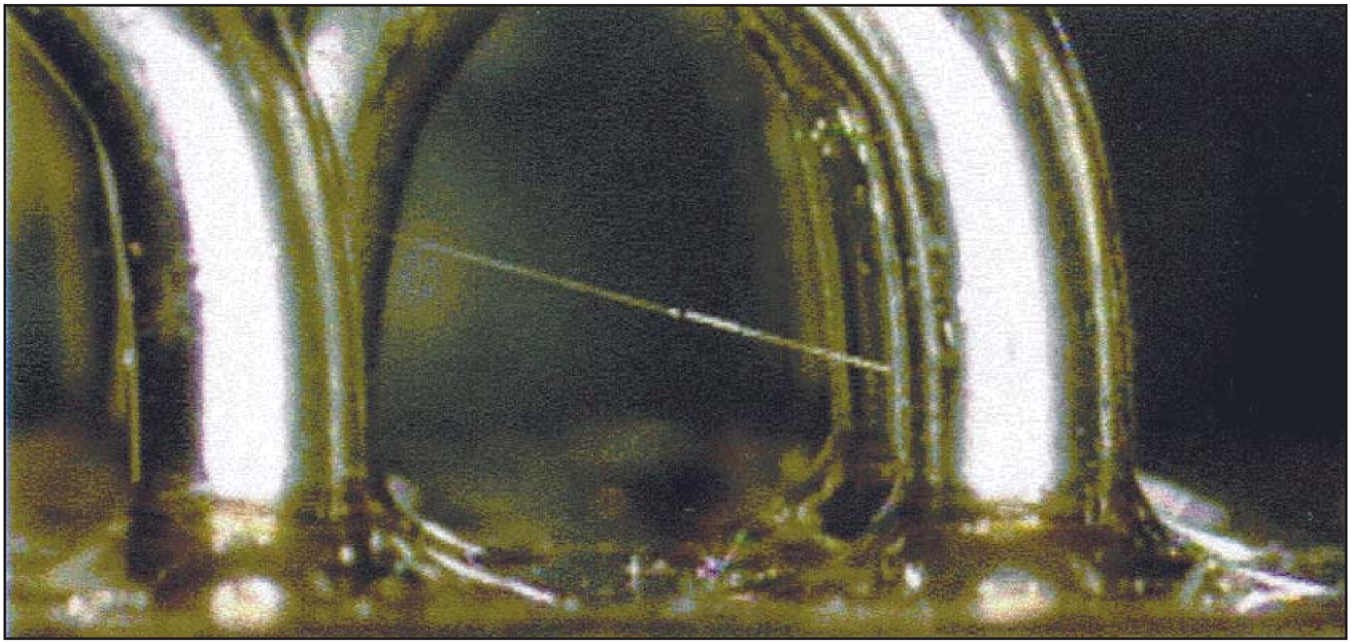
Figure 3D: Voids

Source: TDI

TIN WHISKERS

Tin-whiskers are conductive filaments that grow from tin surfaces. Over time, they can cause electrical shorts across conductors on printed circuit boards or components. The lead content of Tin/Lead solder has mitigated the creation of these Tin Whiskers. However, the new lead free alloys, which have high Tin content may accelerate Tin-Whisker growth which in turn causes shorts and equipment failures.

One effective method of slowing the growth of tin whiskers and insulating adjacent conductors on PC boards is conformal coating of printed circuit assemblies. However, this protection method may be limited in the long term since NASA has observed filaments growing through the conformal coating. Fig 4 shows a Tin Whisker bridging two adjacent conductors.



Courtesy of the NASA Electronic Parts and Packaging (NEPP) Program
http://nepp.nasa.gov/whisker/

Figure 4: Tin Whisker Growth

In 2002, Y. Zhang, Chen observed that tin diffuses into nickel at a greater rate than nickel into tin. He concluded that whisker creation could be mitigated by this inter-diffusion relationship between the nickel and tin. While the theory has merit, it has not been tested over time.

RECOMMENDED LEAD-FREE SOLDER ALLOYS AND PROCESSES FOR EVALUATION

Transistor Devices is currently using Lead Free solder alloys of tin, copper and nickel and conformal coatings to reduce the risk of Tin Whisker damage.

PRODUCT VERIFICATION:

Sophisticated production screening methods like HASS (Highly Accelerated Stress Screening) can detect and separate flawed parts or assemblies from an otherwise robust product. The thermal and mechanical extremes of HASS and HALT (Highly Accelerated Life Testing) may be introduced as part of the development and manufacturing process.

HALT defines the product design limits by cycling the product through a series of environmental stresses like vibration and temperature for the purpose of identifying the weakest link. Once identified the weak component is either upgraded or re-enforced therefore extending the design margins. Through several iterations the product can be made more robust and the safety margin limits are specifically defined. With this information a stringent manufacturing validation process is developed using a HASS discipline. HASS screening then subjects product to thermal and mechanical extremes that will stress all of the solder joints, validating 100% of the solder joints without destructive sampling.

The thermal extremes of HASS testing should not exceed operating limits by more than 15% to 20%. The product should be subjected to several hot-cold thermal cycles while the unit is fully functional. Random vibration may also be employed as part of the HASS process. Abnormalities are identified through statistical process control methods and conservative test acceptance limits. Corrective actions will result in continuous improvement.

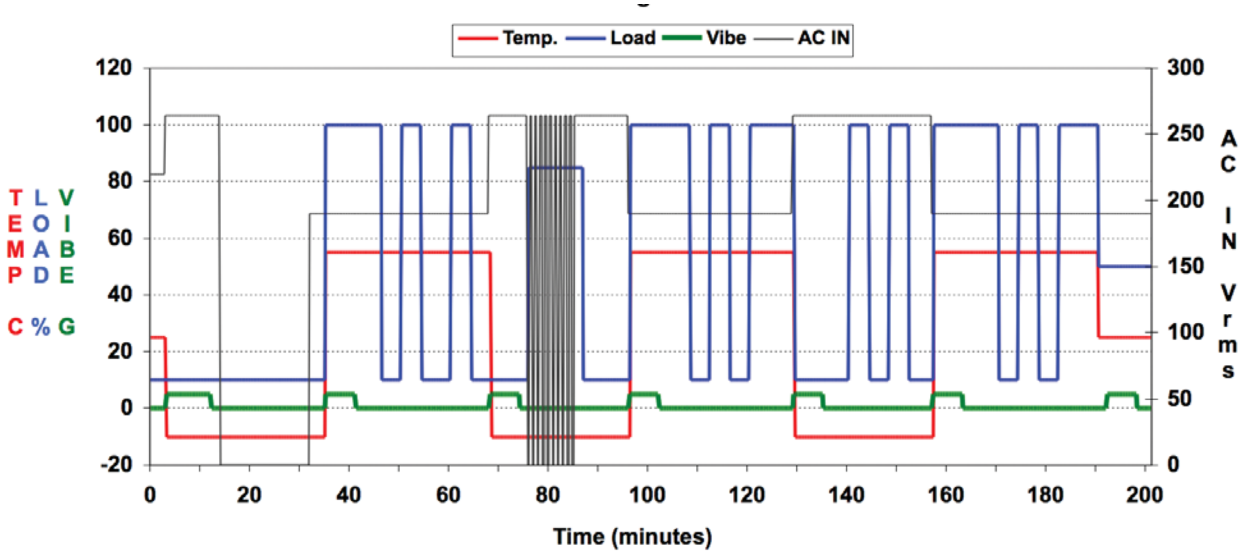


Figure 5: HASS Stress & Conditioning Profile

Traditional visual examination and burn-in does not provide the same level of confidence or guarantee the product will out-perform in the field.

Strong process controls or visual aids like color-coding of Lead Free assemblies, helps personnel identify proper material and processes (See Fig. 6).

Figure 6: Printed Circuit Assembly color coded "Red", signifying Lead Free and utilizing Tin-Copper-Nickel Alloy

Source: TDI

SUMMARY AND CONCLUSION:

Lead-free solders require a high degree of manufacturing control, sophisticated processing, stringent product validation methods and generous design margins. Transistor Devices employs several methods to achieve the highest level of confidence possible:

- Destructive and non-destructive process qualification methods such as process correlation through visual examination (AOI (Automated Optical Inspection) and human), X-ray and “Cross-Sectioning” of the solder joints.

- "Tin Whisker" mitigation like conformal coating, and Tin/Copper/Nickel solder alloys.

- 100% HASS (Highly Accelerated Stress Screen) testing to isolate substandard solder joints before shipment.

Only through these actions can we fully assure that the best possible solder joint is created. Even so, the long-term reliability data for lead free industrial grade electronics is currently inconclusive or unavailable. Until more data becomes available, from Lead Free consumer electronics, it remains prudent to continue with a proven tin-lead soldering process for “Mission Critical” applications.

GEORGE CUTLER

George Cutler is the Vice President of Quality for Transistor Devices, Inc. With over 20 years of experience, Mr. Cutler has held positions as Electro-Mechanical Designer, Industrial Engineer, Quality Assurance Manager and Operational Director for Asia. George has lead organizational teams to apply for the Malcolm Baldrige National Quality Award and won the New Jersey Governor's Award for Performance Excellence. George holds an Associate Degree in Mechanical Engineering from NJ's County College of Morris. He is a member of the American Society for Quality and has served on the Board of Examiners for the Governor's Award for Performance Excellence.

TDI
Transistor Devices

For more information,
please contact :

Norman Wolf
VP of Corporate Sales
36 Newburgh Road
Hackettstown, NJ, 07840
Office 908.850.5088
Fax 908.850.5731
Mobile 908.256.6204
norman_wolf@tdipower.com