Pulse

A TECHNITROL COMPANY

OPTIMIZING SOLDER JOINT RELIABILITY

for Surface Mount Magnetic Components

Pulse's Mechanical Design for Thermal Expansion and Optimal Lead Compliance Deliver Empirically-Measurable Solder Joint Reliability

The Situation

Suppliers of all types of electronic components need to constantly maintain a proactive awareness of the critical production issues faced by their customers and must continually improve their own design processes to support final product quality and reliability. A key production issue that is always at the forefront among electronics manufacturers is the achievement of consistently acceptable solder joint reliability.

The high temperatures associated with IR or Convection Reflow Solder processes are routinely sufficient enough to temporarily expand both the PCB and its various components, thereby setting the stage for either immediate or latent failure of the solder joints. Because the PCB and all of its separate components expand and contract according to their own specific Coefficients of Thermal Expansion (CTEs), there exists the potential for stress damage and/or completely open solder joints. The component and PCB have their own thermal mass, specific heat, and surface area and will have their own temperature profile during the solder reflow process. Any resulting temperature differential at the time the solder solidifies further complicates the analysis. While these differences in relative movement have little impact while the solder is liquid, the tendency of solder to solidify at a high temperature, while the PCB and its components are still cooling and contracting will cause stress.This means that the stress of subsequent movements must be absorbed by either the components or the solder joint. Failure to adequately predict and absorb these reflow-induced stresses can cause the newly formed solder joints to sustain internal damage and result in either latent or catastrophic failures.

The Challenge

With magnetic components, the stresses caused by differences in CTE can be even more dramatic and difficult to control than with semiconductor components. While the monolithic internal makeup of most semiconductors generally allows their CTE characteristics and expansion profiles to be somewhat predictable, the disparate materials, such as ferrite cores, copper wire, buffering compounds, molding compounds, etc., used in magnetics make them much harder to characterize. In addition the growing trend toward higher levels of integration, such as multiple channels or ports in a single package, continues to further complicate the challenge of characterizing the aggregate CTE profile of today's more sophisticated magnetic components.

For the system manufacturer, this higher level of unpredictability means that magnetic components represent a significant production risk for solder joint problems. If a high degree of relative movement occurs during the final stages of reflow cool down, after the solder has moved from its liquid state to plastic or solid, the magnetic components will have an increased risk for "dry-docking" failures during production and/or latent defects. This means increased cost of production rework or, worse yet, the warranty costs and loss of reputation from field failures during the temperature cycling of normal product operation.

The Solution

In order to meet required electrical and performance characteristics, most magnetic modules must contain a large amount of different materials, each with its own thermal resistance and CTE, as well as several plastics, each with its own glass transition temperature.

Therefore, in addition to designing the module to meet required electrical specifications, it is also incumbent on the magnetics supplier to coordinate all of the component's materials into a predictable composite CTE that is as close as possible to the PCB's CTE. At the same time, the magnetics supplier also must ensure that the components' external leads provide an optimal balance between structural strength and the compliance, or flexibility, required to absorb reflow-induced stresses.

Given the complex mechanical design issues required to ensure solder joint reliability for magnetic components, today's suppliers must proactively invest in the dedicated mechanical design resources, product verification testing procedures and on-going quality control needed to consistently deliver conforming products to their customers.

Designing for Thermal Expansion and Optimal Lead Compliance

As component sizes become larger the impacts of thermal expansion become significantly more critical. In addition to addressing the inevitable tradeoffs between functionality and complexity, designers also need to consider that thermal expansion becomes very difficult to manage in modules that exceed approximately one inch square. In addition, the basic structural design of the module greatly impacts the nature of its thermal expansion profile. For instance, modules that are built around an internal PCB tend to take on the CTE of the PCB, thereby making them generally easy to match with the CTE of the underlying system's PCB. Also, transfer-molded modules tend to have a lower overall CTE and higher glass transition temperatures than pour-filled components.

The key factor in relieving the solder joint stresses of relative movement is designing the package to provide appropriate lead compliance. In essence, the compliance (or flexibility) of the module's leads will act like a shock-absorbing spring to cushion the solder joint from the aggregate impacts of global and local movements. At the same time the package's leads must have adequate structural strength to support the module after assembly and prevent component damage or loss of coplanarity prior to assembly.

The two primary characteristics that most influence a lead's compliance are 1) its lateral dimensions (e.g. width & thickness) and 2) its overall length. In general, longer leads provide more compliance while greater lateral dimensions provide more rigidity. The proper design of lead compliance must take into account both the lead-stiffness and the overall expansion characteristics of the entire package.

Difficulties in Controlling for Multiple CTEs and Relative Movements And The Importance of Empirical Testing

Most solder joint failures in SMT magnetic packages can be attributed to mismatched thermal expansion that occurs both globally (between the package and the multilayered PCB), and locally (between the leads and the eutectic solder). An accurate estimate of the amount of solder strain can only be made after precise determination of the package's and PCB's CTEs, along with measurement of the lead stiffness. To predict production results, the profile for a specific magnetic component can then be compared to that of a package known to produce reliable results (such as a widely used semiconductor package).

Some manufacturers have tried to shortcut their mechanical design process by simply calculating the separate CTEs of the materials that comprise the magnetic component, such as the epoxy, the internal carrier, winding cores, etc. to obtain a "composite CTE". However, the internal complexity of today's magnetic components greatly limits the usefulness of such non-empirical assessment methods.

Such composite-CTE calculations generally reflect only the relative amounts of each material, while the overall expansion properties of the module itself are also greatly impacted by the shape, orientations and relative alignments of the various internal components. For instance, a module with several toroids mounted to an internal carrier will have a significantly different expansion profile if the carrier is square rather than rectangular, even though their calculated composite CTEs may be similar. Or, conversely modules with similarly shaped internal carriers may have significantly different expansion profiles if the toroids are laid out in different patterns.

Empirical Test Comparisons For Pulse's Magnetic Components vs. a Known-Reliable Semiconductor Component

As a continuing part of its mechanical design, Pulse has invested in detailed empirical testing of three of its primary SMT packages, including comparison of the test results to the characteristics of a known reliable semiconductor widely used in the communications industry (Texas Instrument's TI ALS244C - see page 10 for mechanical drawings). The basic test hypothesis was that solder strain can be estimated once the expansion coefficients of the package and the printed circuit card, and the lead stiffness are known. This solder stain can then be compared to a known-reliable semiconductor counterpart. The closer these parts match, the greater the predictability that the magnetic modules will provide both consistent initial results after reflow as well as long-term solder joint reliability.

In order to ensure impartial results and to take advantage of the most advanced testing techniques, all testing was carried out under contract by IBM Endicott Microelectronics Analytical Solutions at their state-of-the-art laboratories in Endicott, NY. Measurements were made using three complementary techniques:

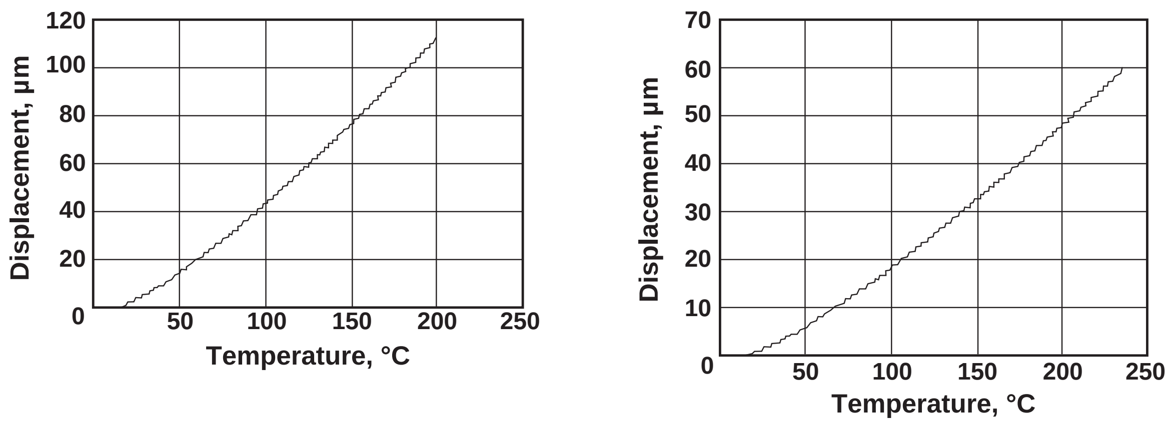
- Thermo-mechanical analysis (TMA)
- Moiré interferometry
- Micro-mechanical testing

The combined tests were designed to predict the amount of shear-stress that would occur at the solder joint, based upon the combination of empirically measured lead-stiffness and CTE.

Thermal expansion tests were performed using IBM's micro-mechanical 6-axis tester, capable of measuring movements to sub-micron levels. The sample packages were first prepared by polishing all sides to ensure smooth and parallel surfaces, and then they were placed between the jaws of the tester and subjected to a constant load of 32 gmf on the package body at the lead-frame level. While maintaining this uniform load, the chamber surrounding the sample was heated to 220°C at a heating rate of 0.25°C per second and the package's actual displacement expansion was measured to an accuracy of 0.1 microns.

See Figure 1, below, for a sample comparison of the expansion of Pulse E5007 module and TI ALS244C.

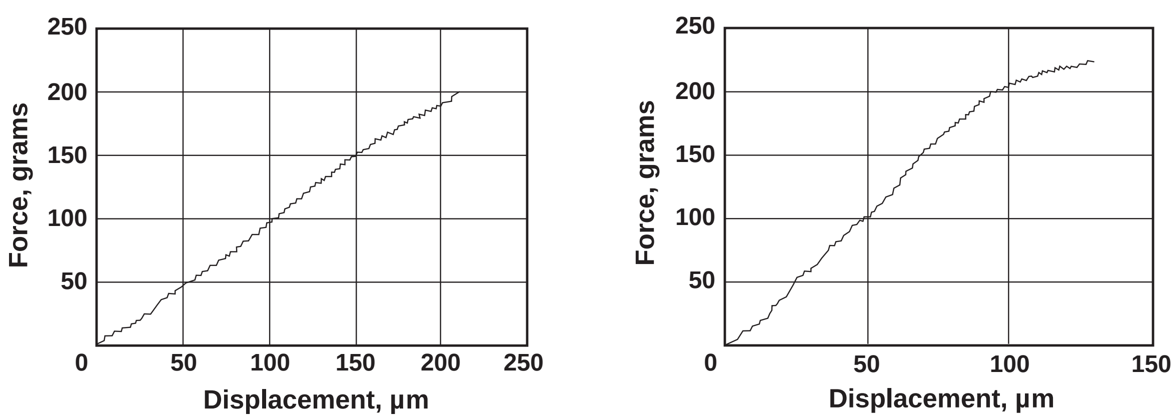
Figure 1: E5007 Module TI AL244C - CTE



Lead-stiffness was also measured on the IBM micro-mechanical tester. The package body was clamped in place and the leads deflected with a probe over a range of 200 µm. The lead-stiffness was calculated over the linear portion of the force deflection data, with stiffness measurements made in all 3 orthogonal directions.

See Figure 2, below, for sample comparison of lead-stiffness of Pulse PE-69037 module and TI ASL244C.

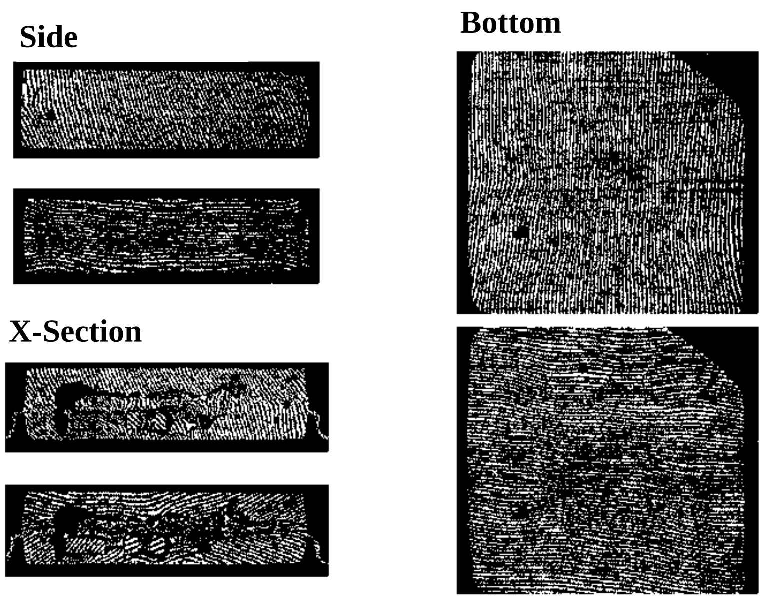
Figure 2: PE-69037 Module TI AL244C



To supplement the micro-mechanical tests and to normalize for any variations induced by sample geometry, cure-state or data-fitting, the expansion characteristics of sample packages were also measured using Moiré interferometry. For each sample package, the bottom surface, two sides and at least one cross-section were subjected to interferometric displacement measurements, over a temperature range from 20 to 90 °C. The actual in-plane displacements for each surface were measured against a phase grating with a spatial frequency of 2400 lines/mm. This technique has a sensitivity of 0.4 microns, which represents the differential displacement between adjacent fringes, with an accuracy of +0.5 ppm/°C.

Figure 3, below, shows an example of fringe patterns used to measure expansion of Pulse PE-69037.

Figure 3:



Finally, a sample of the molding compound from one of the packages was removed using a diamond saw and subjected to thermo-mechanical analysis (TMA) using a Perkin-Elmer analyzer. The CTE was calculated for ranges above and below the compound's glass-transition temperature (Tg) and the intersection of the two lines was used to estimate the glass-transition point at between 135 and 185°C.

Test Results and Observations

Table 1, below, provides a detailed comparison of CTE and lead-stiffness characteristics for the three Pulse packages and the TI ALS244C semiconductor package.

Table 1: The C.T.E. and stiffness of the Pulse packages

	C.T. E. ($T < T_8$)		C.T. E. ($T > T_8$)		K, N/m (lb_f/in)			Package Mech. *
	α_x	α_y	α_x	α_y	x	y	z	
Pulse PE-69037	17.5	17.5	20.0	19.7	11300 (64.5)	6950 (39.7)	22600 (129)	A
Pulse PE-68051	15.9	15.0	22.5	29.6	27800 (159)	16800 (95.9)	24500 (140)	B
Pulse E5007	20.7	18.8	33.1	31.3	39200 (224)	29400 (168)	42500 (243)	B
TI ALS244C	18.2	18.3	26.7	36.1	19900 (113)	41700 (238)	32700 (186)	C
Mold Compound	26.6	26.6	86.6	86.6	N/A	N/A	N/A	N/A

***NOTE:** See Mechanical Drawings on page 10.

As can be seen, the pattern of similar CTE and lead-compliance profiles for the Pulse components and the known-reliable TI semiconductor components can serve as a reasonable predictor of package performance during reflow. Because these profiles also track closely with the CTE for a typical PCB over the same temperature ranges, it can further be concluded that the reflow process will not result in the exertion of unacceptable stresses on the resultant solder joints.

According to the independent report, the sample-tested Pulse SMT magnetic packages empirically demonstrated CTE profiles "that are well matched to typical printed circuit boards." In addition, the packages' lead-stiffness and compliance profiles are "consistent with those required for such products." Finally, the report concluded that the "stresses produced by these packages after attachment to a typical printed circuit board are very low for typical pad sizes."

Summary

In the final analysis, the mechanical design of any component can be just as important as its electrical characteristics, especially when it comes to the efficient and reliable application of that component in a final PCB assembly. Because of the incorporation of a variety of different materials, magnetic components are particularly susceptible to uncontrolled CTE characteristics, which can negatively impact solder joint reliability.

Historically, Pulse has consistently led the way in the application of mechanical design disciplines to magnetic components. A prime example of this leadership is the company's early adoption and application of IPC guidelines for the design, testing and prediction of solder joint reliability, developed by AT&T Bell Labs (IPC-TP-787). Another specific example regarding lead-compliance is Pulse's 1993 patent for the Compliant Cantilever Surface Mount Lead, which combines lead-compliance and structural integrity for low-profile components. As this paper's independent test data demonstrates, Pulse continues to combine its leadership in product features and performance with a dedicated focus on solving the mechanical design issues that provide the foundation for reliable PCB production processes.

Every component Pulse designs is the result of a concurrent engineering effort, which combines inputs from our dedicated mechanical design section with the efforts of electrical engineering, process control, quality assurance resources that are ultimately required to produce a functional and reliable magnetics module. Rather than asking electrical engineers to double as part-time mechanical designers, Pulse has made the investment to build and maintain an independent internal group with in-depth mechanical expertise. In addition, the satisfaction of specific mechanical characteristics is required as part of every new component's Design and Verification Testing Plan.

To continually improve new product designs, Pulse also proactively reaches out to customers to understand the parameters and requirements of their individual production processes. For instance, in today's competitive environment, some manufacturers may focus on improving throughput through conscious variations in their production methods, such as using rapid cool-down cycles after reflow solder process in order to expedite the next production operation. Obviously, such production variations can have significant impact on the thermal characteristics of the components and may impact the overall production results. While every Pulse component is mechanically designed to perform with adequate margins in standard production environments, Pulse also recognizes the need to help their customers meet their specific non-standard process requirements.

The extensive use of empirical testing, such as that described in this report, combined with a long history of mechanical design leadership and the use of dedicated mechanical design resources, provides Pulse with a unique position to address the full range of our customers' production-efficiency, quality and reliability objectives.

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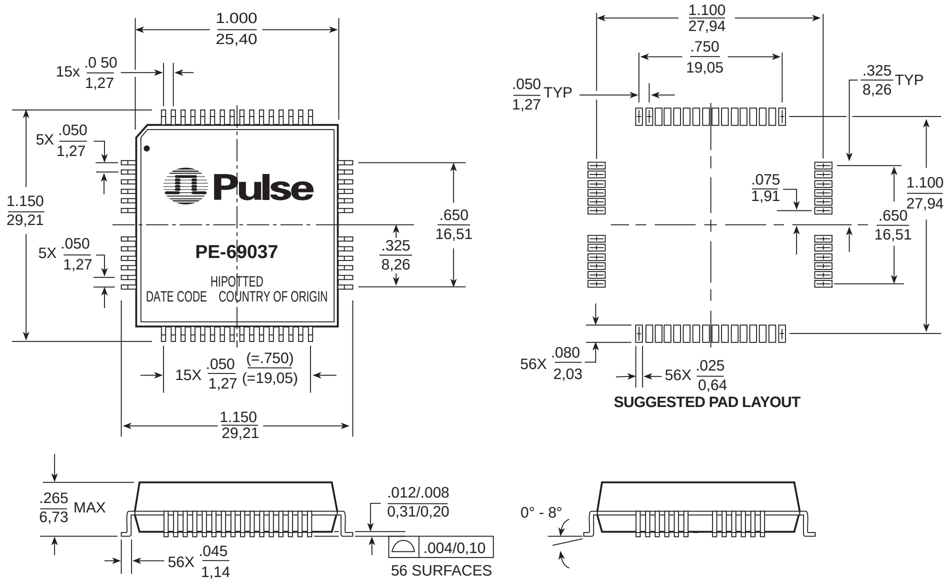
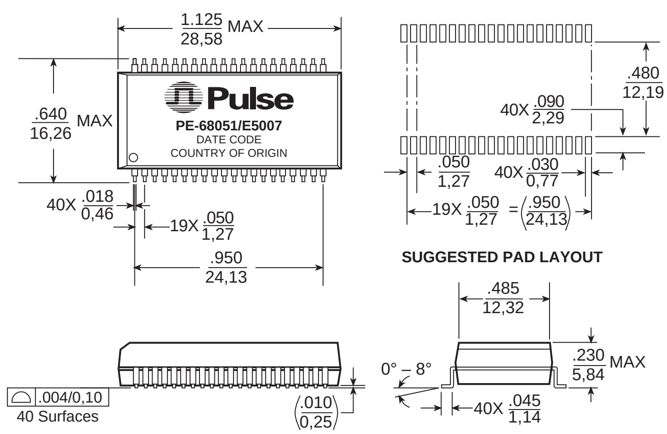
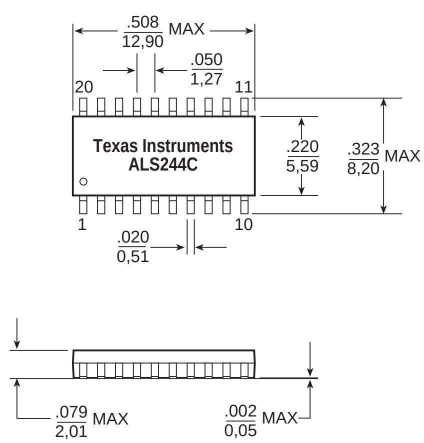
Mechanical Drawing A



Mechanical Drawing B



Mechanical Drawing C



Dimensions: Inches / mm

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