An Expert Looks at the Issues

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Editor's Note: For this special reliability issue, Editorial Director Joseph C. Fjelstad interviewed Werner Engelmaier, an internationally-known expert in electronics packaging and interconnection technology. Prior to forming his own consulting firm, Engelmaier Associates, he was a Distinguished Member of Technical Staff at Bell Laboratories. He is the author of more than 125 technical publications about electronics packaging. Mr. Engelmaier earned mechanical engineering degrees from TGM in Vienna, Austria, the University of Southern California, Los Angeles, and from MIT.

Q. Reliability seems to mean different things to different people; as a reliability expert how do you define the term?

A. I define reliability as we first defined it in IPC-SM-785 Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments: "Reliability is the ability of a product to function as predicted for an expected period of time, without exceeding expected failure levels."

This definition requires implicitly that, first, the product design include "Design for Reliability" (DfR) procedures that assure the design is inherently capable of surviving the loading conditions the product may be subjected to during assembly, testing, transport, storage and end use; and, second, that the product be manufactured to consistent good quality.

If either the DfR or the manufacturing quality is inadequate, the product is likely to fail prematurely; because inadequate manufacturing quality leads to early failures (infant mortality) more often than poor design (early wearout), the emphasis has traditionally been centered on manufacturing quality.

Q. How does corporate thinking about reliability vary around the world? How has it changed over the years?

A. While many of the larger OEMs are now thinking about reliability, and some have instituted the required DfR procedures, other companies may bring in a consultant if one of their engineers suspects a possible reliability problem - but many still do nothing. Thus, unless somewhere along the design process a corporate employee suspects possible problems, nothing may get done in terms of DfR. The consequences may be field failures and litigation. The difference in this thinking is differentiated more by industry rather than geography.

Corporations pushing the technology envelope typically are more concerned with reliability than those using more pedestrian product technology. As a result, while the telecommunication industry on the whole is rather conscious of reliability aspects, military suppliers have been somewhat slower to adopt new technologies, SMT for example.

The automotive industry, with the exception of at least some Japanese manufacturers, is the least sophisticated in terms of reliability. Relatively little has been done to promote longterm reliability in the consumer products industry.

Q. Over the years you have been an early voice of caution as the electronics industry has transitioned from one technology to another, both in PC board manufacture and in component assembly. Which transitions do you feel have been most difficult?

A. The transition from plated-through-hole technology (PTH) to surface mount technology was clearly the most difficult. The key reason is that the connections are mechanically very robust with PTH technology. A component lead soldered into a copper-plated throughhole is very redundant. Thus, the packaging densities did not require much more than a 6-layer MLB, because the PTH hole diameters are adequate to accept component leads.

More over, even fully-fractured PTH solder connections will not show electrical discontinuities.

In contrast, SMT solder joints provide the sole mechanical, electrical and thermal connection of the components to the PC board (no redundancy). SMT enables packaging densities that, for some applications, require MLBs with upwards of 20 layers. In the absence of component leads, of course, PTH-via (PTV) diameters can shrink at the same time as the MLB thickness increases.

Consequently, the successful change from PTH to SMT required a total change in philosophy, a different way of thinking. It was, to coin an overused cliché, truly a paradigm shift.

Q. Area array packaging technologies, such as BGAs and CSPs, offer significant benefits in terms of board real estate savings and assembly yield, but solder spheres do not flex the way gullwing leads do. What can be done to improve solder ball reliability?

A. Appropriate DfR measures to reduce the cyclic loading of solder joints are best employed in combination for improved reliability margins. These measures are:

1) Reduction of component size, e.g., fine pitch and area arrays;
2) CTE tailoring of components and substrates, e.g., low CTE substrates for ceramic components and plastic components with Alloy 42 leadframes, as well as the use of Cu leadframes and soft die attach for components on FR-4 substrates;
3) Reduction of temperature swings, e.g., heat transfer measures, satellite rotation and independent heaters;
4) Increasing attachment compliancy, e.g., by increasing the solder joint height (high melt solder balls, solder columns) and compliant leads;
5) Reduction in strain concentrations, e.g., non-uniform solder joint cross-sections, solder-mask-defined soldering pads;
6) Elimination of the effect of the global expansion mismatch by mechanically coupling the component and the substrate with an appropriate underfill;
7) Avoidance of asymmetrical components with high power dissipation, which may significantly warp and subject solder joints to large tensile loads.

Q. Is rework a good idea from a reliability perspective?

A. With the adoption of the ANSI/IPC-J-STD-001, we have finally gone away from the previously required, but technically unnecessary, rework of cosmetic abnormalities. Thus, unnecessary rework should hardly ever occur any more. If rework is carried out appropriately, no significant negative reliability effects should result. But rework, as with any other manual process, is subject to operator error or inadequate operator training. This can result in fractured PTV copper barrels due to overheating, cold solder joints on adjacent components due to partial reflow and fractured solder joints due to thermal shock, warping, etc.

Q. There are pronounced differences in terms of reliability between different BGAs and CSPs. How might we resolve concern that low reliability products might infiltrate high reliability applications?

A. Pray a lot. These attitudes come from the false belief that achieving reliability is expensive. The implementation of DfR procedures in the early stages of design is not really associated with additional cost. On the contrary, in many cases the additional design attention can result in better designs that cost less to implement.

Q. Weibull curves are widely used to report IC packaging reliability data. What are the strengths and weaknesses of this reporting method?

A. Weibull statistical distributions are commonly used to represent wearout failures, because they linearize the failure data best. That is, after all, the purpose of the various statistical distributions. For those aspects of IC packaging that are subject to wearout mechanisms, Weibull curve representations are most appropriate.

Q. What role does finite element modeling play in reliability prediction and management?

A. In many cases involving complex designs, only finite element analysis (FEA)can offer an accurate indication of the loads to which solder joints are subjected. However, beware of "GIGO"—garbage in, garbage out (in the case of FEA), because of the involved cost and the pretty multicolored pictures, which are often accepted as gospel. In most cases, the material properties need to be measured, because "book" values are frequently wrong, e.g., the "book" value for the modulus of elasticity for copper is $18e^{6}$ psi, but plated copper measures from lOe^{6} to $12e^{6}$ psi.

Q. What are the critical reliability issues that lie ahead for the electronics industry?

A. As the industry pushes for ever-higher functionality, density and power dissipation (all, of course, at lower cost), we will reach the limits of materials and processes. These limitations will manifest themselves initially in narrower processing windows—and thus lower yields, which, if not recognized at this stage, may cause field failures. Thus, it becomes increasingly more important that threats to reliability be recognized and solutions found.

Werner Englemaier can be contacted at:

Englemaier Associates
7 Jasmine Run
Ormond Beach, FL 32174
Phone: (904) 437-8747
Email: engelmaier@aol.com