TESTING TO ELIMINATE RELIABILITY DEFECTS FROM ELECTRONIC PACKAGES

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ABSTRACT

Electronic Packaging is a critical part of all electronic devices and can be a source of the reliability problems experienced by systems using those devices. In many cases, the packaging defects are intermittent in nature and difficult to detect. This paper describes a tester that has been used for 20 years on commercial products and has proven to be extremely effective in detecting these defects prior to component assembly. The LATEST™ (trademark of IBM) tester, invented by IBM Manufacturing Research, has been applied to defects in printed circuits, multilayer ceramic and flexible circuits. As packaging density increases, the use of this tester becomes critical because of the difficulty of producing "defect-free" product and the impact of defects on the reliability of the end-use product. This paper will cover the theory of the LATEST tester and the effectiveness of the test for printed circuits and flex products. It will also cover application methods and deployment. Comparisons to standard test systems will demonstrate the significant reliability improvement achieved with LATEST testing which makes its use imperative for mission critical applications.

INTRODUCTION

When the 3081 computers were introduced in 1980, they required a major increase in circuit board density through use of the Thermal Conduction Module (TCM) Printed Wiring Board (PWB) described by Seraphim. [1] The board had advanced features such as 3.6 mil (0.090 mm) lines, 4.0 mil (0.100 mm) blind laser vias, and 14 mil (0.350 mm) plated through holes with an aspect ratio of 15:1. Major process development was required to build this product, but the challenge of small features and increased densities of wiring left a residual defect level that could lead to open circuits in the customer's office and required an electrical test more effective than the standard opens tester. Figure 1 depicts some of the latent open defects that are field reliability problems. The IBM Manufacturing Research Laboratory in Yorktown, NY invented an electronic unit to detect potential opens. The unit was developed into a production tester and experiments were conducted to determine the critical circuit cross-sections that would fail during product use. This information was used to set the trigger points for the new tester.

LATEST Model 10 is the commercial version of this unit. Tests were then run on typical production defects in the TCM PWB that could be potential inspection escapes. They were tracked from core level through composite and then through field stress simulation to determine the effectiveness of LATEST and establish the set points required to eliminate customer problems.

This work was then extended to high density printed circuit cards and similar results were obtained; no escapes from the LATEST screen. Similarly, this test has been applied to complex double-sided flex product with copper circuitry, polyimide dielectric and plated vias. It has also been applied to Cables and has been used as a sorting mechanism to make pass / fail decisions on visual defects to allow the acceptance of those visual anomalies that met the reliability requirements of the product.

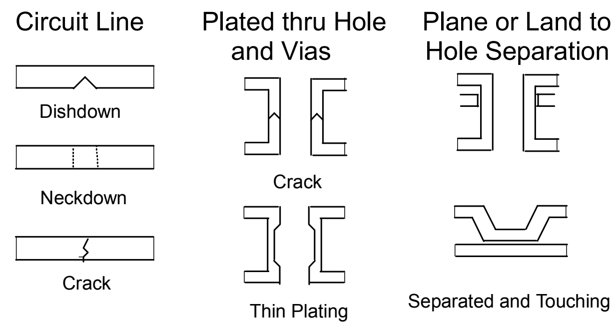

FIGURE 1 – LATENT OPEN SITUATIONS

. Because of the sensitivity of LATEST, it has proved extremely useful in reliability tests, product reliability monitoring, and evaluation of process changes. Reliability situations with potential opens can be assessed more effectively with LATEST. More than 50 units have been installed worldwide, demonstrating the high volume capability of LATEST. This paper will show the LATEST test theory and the data obtained on defects through stressing of printed circuits and flex circuits. The data will be compared to normal test methods to quantify the improvement in screening effectiveness. With a high screening effectiveness, many defects that are rejected by manual or automated optical inspection can be deemed acceptable by LATEST test and in many cases repair or scrapping of product is not required.

LATEST TESTER

During the process development phase of the 3.6 mil (0.090 mm) line product for the TCM PWB, it was determined that a line with a nominal cross-sectional area of 5 square mils (0.003125 sq. mm) could have a localized reduction down to 1 square mil (0.000625 sq. mm) and still be reliable during customer use. This criterion was derived through a series of flex tests and modeling. [2] A defect of this size has a localized resistance of 3 milliohms in a circuit net with a total resistance up to 5 ohms. The approach that met this requirement used a simultaneous application of AC and DC current. The localized heating at the defect creates a time-dependent resistance change which distorts the AC wave form. These distortions are revealed in the AC harmonics. The relevant harmonics are then converted to the electrical output of the LATEST tester. What is most interesting is that there are positive and negative outputs with a positive output typically showing a reduced cross-section circuit that heats up excessively in the localized defect area. A negative output can be obtained if the circuit includes a cracked line or cracked plated through hole and the application of current reduces the width of the crack and lowers the localized resistance. Fine tuning of the tester elements including calibration for known good lines with the desired resistance and calibration for known defects, yield the desired sensitivity. The tester was now ready to perform electrical tests and determine test effectiveness on actual product through downstream process stresses and field simulation stresses.

COMPLEX PWB DISHDOWNS AND NECKDOWNS

A complex PWB is a high density printed circuit used to interconnect functional units through a connector system. The units it interconnects are either printed circuit card assemblies or in the case of this study, multi-chip modules. Dishdowns and neckdowns from TCM PWB production cores were intentionally made so that a large number could be tested. Circuit line reductions were all targeted to be close to the 1 square mil (0.000625 sq. mm) criteria so that the criteria and resultant test results could be critically examined. A total of 342 reductions were used in the study. Because defects at the limit of the tester sensitivity occur less than 2% of the time in production, the sample size of 342 actually represented the defect population that would have occurred in 17,000 parts. The LATEST sensitivity was set at 3 milliohms localized resistance at the core level and relaxed to 10 milliohms localized resistance at composite level because most stresses have already taken place through composite test. In this product, composite test is after a Tin-Bismuth solder reflow of 210C for 3 minutes.

Of the 342 core level defects that were tested with LATEST; 125 passed and 217 failed. At the composite level, all 125 parts that passed the LATEST at the core level were still satisfactory. Of the 217 LATEST fails at the core level, 9 became opens at composite test and 42 others failed the LATEST composite test which was set at a decreased sensitivity relative to the core level. The remaining 166 core level LATEST core defects stayed stable through the composite process and remained below the composite fail criteria. The population through composite test is noted in Table 1.

If LATEST was used to screen product at the core level, 217 core line reductions would have been discarded or repaired and 9 composite opens would have been avoided. At this point in the process, the decision is economic and the dollar values of cores vs. composites would enter into the decision.

TABLE 1 - TCM PWB YIELD AND RELIABILITY STUDY - NECKDOWNS/DISHDOWNS - CORE THROUGH COMPOSITE

	Number of Nets		
Test Level	LATEST Pass	LATEST Fail	Opens
Core	125	217	0
Composite	125 & 166†	42	9

†Failed Core LATEST Test but Passed Less Sensitive Composite LATEST Test

The composites were then subject to field simulation. Field simulation for this product is a thermal cycle test ranging from 0C to 100C for 250 cycles. A change in resistance of 100 milliohms during the test indicates an unstable net and is classified as a reliability failure. The 291 LATEST passes at the composite level test showed zero reliability fails. The 42 LATEST fails at composite level resulted in 12 reliability fails, all of the intermittent open variety. Table 2 summarizes this data.

TABLE 2 - TCM PWB YIELD AND RELIABILITY STUDY - NECKDOWNS/DISHDOWNS - COMPOSITE THROUGH FIELD SIMULATION

	Number of Nets		
Test Level	LATEST Pass	LATEST Fail	Opens
Composite	291	42	9
Reliability Stress	0	12	9

At the composite stage, with the standard shorts / opens test, 9 defects would have been discarded or repaired. With LATEST screen an additional 42 defects would have been scrapped or repaired. A total of 12 defects or 29% of the LATEST failed composites failed the reliability test and could have resulted in an intermittent open in the customer's office. Comparing the test efficiency of opens test alone vs. opens test combined with LATEST, the opens test discovered 9 out of the 21 critical defects for a test efficiency of 43% compared to 21 out of 21 or 100% test efficiency for LATEST. Because of the intermittent nature of these opens, they plague systems for many months until they become solid opens which can be detected by the system diagnostic tools. It was previously mentioned that this defect population would have been present in 17,000 parts and 12 field defects equates to 700 parts per million (ppm) per TCM PWB. With four to eight TCM PWBs per system, LATEST test with a 2 point probe tester at composite level was implemented for all mission critical TCM PWBs in high end systems. The 2 point probe approach was required because the matrix systems used in opens testers gives a LATEST signal due to contact resistance. With this test, a field reliability improvement of 2800 to 5600 ppm per system is achieved. One can multiply by the number of systems in the field to get the overall product improvement. In actual use over a 20 year time frame, several hundred thousand TCM PWBs have been shipped using the LATEST screen with zero field level opens, further verifying the very high effectiveness of the test.

CIRCUIT CARD DEFECTS

The successful application of the LATEST technology in TCM PWBs naturally led to investigation of applicability in circuit cards that were less complex but also were single points of fail for a system and also mission critical. These cards housed surface mount and pin-in-hole components. A similar methodology was followed. Stress analysis indicated that the 1 square mil (0.000625 sq. mm) critical criteria used for TCM PWBs should also be applicable on cards and LATEST Model 10 could be applied.

The next phase of the card investigation was to determine the effectiveness of LATEST Model 10 compared to standard opens testing. A population of 4,246 cards (4 signal plane and 2 power plane) was tested initially with conventional shorts and opens testing in full panel form prior to protective coat and profiling. After profiling, the cards were tested with an opens tester and LATEST. Six cards were found to have open circuits at raw card test and 58 cards had 59 LATEST defects. The LATEST defects were then processed through card assembly simulation (wave solder), 5 shipping simulation cycles (-40C to 65C thermal cycles) and 1050 cycles from 0C to 70C to simulate field use. Through these stresses, 22 of the 59 LATEST fails deteriorated into opens or showed intermittent resistivity behavior and noted as Reliability Fails in Table 3. This represents a failure rate of 37% of the LATEST defects in customer use. Table 3 summarizes the data.

TABLE 3 - HISTORY OF 59 CIRCUIT CARD LATEST FAILS DURING CARD ASSEMBLY AND FIELD SIMULATION

	New Fails @ Test Level	
Test Level	Opens	Reliability Fails
After 2 Passes of Wave Solder 260°C/3.1 sec per pass	10	0
After 5 Cycles of -40°C to 65°C	2	5
After 1050 Cycles of 0°C to 70°C	1	4
Total	13	9

A more detailed breakdown of defect types vs. opens and reliability fails showed that the defect with the highest failure rate was dishdowns which are very difficult to detect even when using Automated Optical Inspection (AOI). Some AOI systems use the fluorescence of the laminate as a detection system and are totally blind to dishdowns. Other AOI systems depend upon reflection of the copper circuit lines and dishdowns can reflect enough light to look like a good line. Figure 2 shows a typical dishdown that escapes AOI and escapes opens test but is detected by LATEST. The shiny surface is the top layer of copper that is intact and the duller center area is the dishdown with a reduced circuit area.

FIGURE 2 - CIRCUIT DISHDOWN

In terms of test efficiency, as mentioned previously the raw cards test caught 6 out of 28 fails (22 defects that showed up after raw card test and 6 opens caught at raw card test) or 21% at the composite level because 22 defects showed up later. Looking at opens test efficiency at the card assembly test level, the opens tester caught 10 out of 22 defects or 45%. These numbers are not significantly different than the opens test efficiency noted in the TCM PWB study. In view of the effectiveness of LATEST and the low efficiency of normal opens testing, a 100% LATEST screen was implemented on a large number of mission critical cards using a 2 point probe test system similar to the system used for TCM PWBs. Although the 2 point probe test was much slower and more costly for volume production, the improved test efficiency eliminated fails on high value card assemblies with a net positive return for the more effective screen. A secondary benefit of this screen was immediate feedback on process defect levels and standard test escapes which significantly aided the defect improvement / detection activity. The third benefit was the ability to use this test to help evaluate the quality impact of follow-on process or design changes. Improvement in field reliability by adding the LATEST screen can be quantified as the avoidance of 12 field fails on 4,246 cards or 2800 ppm per card.

FLEX CIRCUIT VIAS

A study was performed on defective flex circuit vias to determine the test efficiency and potential for defective vias to escape to the field. This group of 50 flex cables was first tested with conventional functional tests after component assembly. The test was only sensitive to opens. Nineteen of the 50 assemblies failed the opens test which was an unusually high failure rate at the opens tester and gave a population of potentially defective product to pursue test efficiencies and field exposures. The 31 surviving parts were processed through the next level of assembly which included lamination temperatures of 150C and then tested with LATEST Model 10. Eight more assemblies were open and of the remaining 23, 3 that passed the opens test were defective according to the LATEST tester. Figure 3 shows one of the vias with a crack that was detected by LATEST.

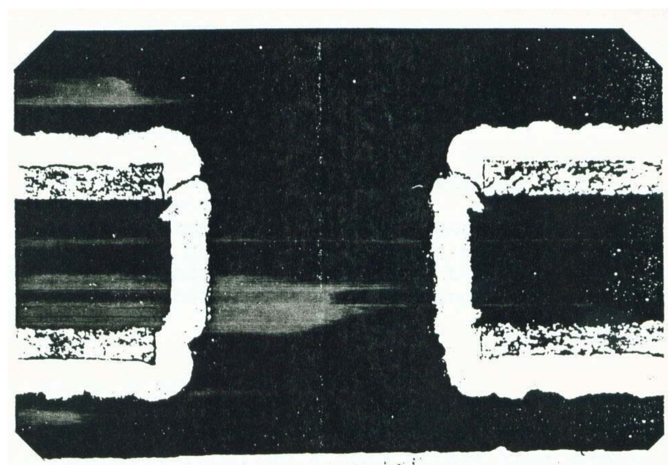

FIGURE 3 - FLEX CIRCUIT DEFECTIVE VIA

The next step was to go through field simulation and see if any of the LATEST fails became open circuits or had significant changes in resistance. Two of the three LATEST defective assemblies were open after the field simulation. The 20 assemblies that passed LATEST had no opens. Results of the assembly process and reliability testing are noted in Table 4. Examination of this data shows a total of 30 defective assemblies. Opens test efficiency after initial assembly test is 19/30 = 67%.

After purging the 19 opens at initial assembly, of the remaining 31 assemblies 11 are defective giving a final assembly opens test efficiency of 8/11 = 73%. LATEST test efficiency at final assembly is 11/11 = 100%. None of the parts which were non-defective using LATEST became defective with further use. The opens fails and LATEST fails were all defective vias. Reliability improvement for LATEST on this population was avoidance of 3 reliability fails on a population of 50 flex assemblies which equates to 60,000 ppm, much higher than the card example because it was a highly defective lot. A more normal flex assembly lot would be 2% defective in opens test vs. 38% for this lot and the reliability improvement would be about 3000 ppm per flex assembly.

TABLE 4 - HISTORY OF 50 FLEX CIRCUITS THROUGH FLEX ASSEMBLY AND RELIABILITY TESTS

Test Level	Opens	LATEST Fails
After Initial Assembly	19	Not tested
After Final Assembly	27	3
After 10 Cycles of -40°C to 65°C plus 449 Cycles of 0°C to 95°C	29	1

SUMMARY

The preceding technical data indicates situations where LATEST is effective for defect detection and the commonly used approaches have limited test efficiencies. Table 5 summarizes the efficiency of standard opens test vs. LATEST test for various latent open situations. Conventional approaches have efficiencies ranging from 21% to 73% and LATEST has shown 100% efficiency in all the test studies which was further reinforced by zero field fails for opens on LATEST screened product.

TABLE 5 - TEST EFFICIENCY FOR LATENT OPENS

	Test Efficiency (%)	
Latent Open Defect Type	Opens Test	LATEST
TCM PWB Circuit Lines	43	100
Circuit Card Composite Test	21	100
Circuit Card Assembly Test	45	100
Flex Vias Final Assembly	73	100

Table 6 shows the effectiveness of LATEST in terms of field reliability improvement. Since the type of reliability defects that are eliminated are of an intermittent nature the system impact in terms of field repair visits and customer interruption will be much greater than the numbers shown in Table 6. The numbers in Table 6 also reflect the type of products that were part of the experiments and the reliability improvement is a function of the inherent product defect level. As a general rule of thumb go back to Table 5 which indicates that on average the final opens testers are only catching half of the defects in the product. Therefore, if the yield at final opens test is 99.5% it has detected a 0.5% defect level and an additional 0.5% (5000 ppm) would be shipped to the field. If these defects are of a type that has been shown to be detectable with LATEST, e.g. circuit lines, they could be screened with LATEST which would eliminate those reliability fails. Final opens test yields and failure analysis of those defects can give a very good indicator of the need for additional latent defect testing.

TABLE 6 - RELIABILITY IMPROVEMENT USING LATEST

	Reliability Improvement (ppm)
TCM PWB	700
Circuit Card Assembly	2800
Flex Assembly	3000

CONCLUSIONS

Significant reliability improvement of electronic assemblies is available using the techniques described in this paper. A full deployment of LATEST as used at Endicott Interconnect Technologies (EI) consists of the following:

1. Screening of mission critical product using a 2 point probe tester with LATEST.
2. Failure analysis of LATEST fails detected by the tester to improve product and eliminate potential reliability defects at the source.
3. Manual probing of visually questionable circuit elements to accept or reject them.
4. Field failure analysis of intermittent opens to determine whether they are present in the Printed Wiring Board or elsewhere in the component or assembly.

LATEST is an extremely useful tool to enhance the total Quality System and produce the highest reliability product. Since the time of these studies, the speed and sensitivity of LATEST has been improved making it more cost effective to implement while preserving its extremely high sensitivity to detect potential reliability fails.

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