The Cluster Approach for In-Circuit and Functional Testing

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The cluster approach can improve testing efficiency and reduce broken pile for OEMs and EMS providers.

Test and inspection expenses limit original equipment manufacturers (OEMs) and electronics manufacturing services (EMS) providers in their operations. Combined with these expenses, OEMs continue to introduce new products at increasingly faster rates in response to market pressures. Numerous economic and manufacturing issues have forced OEMs to outsource their products, and many start-up OEM companies have found competing and introducing new products to market very difficult.

EMS providers are limited in choosing their OEM customers because of high design and maintenance costs for traditional testing, inspection, reworking and other quality support actions. According to one survey, testing and rework currently comprise 50 percent of all EMS operations.

Because in-circuit test (ICT) was originally developed to help functional testing isolate an integrated circuit's (IC) failures, ICT made sense for the previous generation of component packages. However, today's flip chips, ball grid arrays (BGAs), chip-scale packages (CSPs) and other high-density interconnect packages make the use of ICT less beneficial. In-circuit tests became less advantageous because of the inability to get the probe to the pad, the density of the product and the sheer increase in the number of testable nodes.

Ironically, all of the above expenses and efforts cover only production defects and deviations. In a traditional printed circuit board (PCB) process, manufacturers also need to continuously test and repair boards. Otherwise, the pile of broken cards (defective boards) gets out of control, and the product has to be scrapped. Both testing and reworking negatively affect the EMS provider's performance, and they are the least effective aspects of modern PCB technology.

Why ICT Versus Functional Test?

One way to compensate for the high cost of quality actions in the EMS industry is intensification of equipment, production flow and labor. However, if the equipment and production flow are intensified, more problems result with equipment and human reliability, increased maintenance costs and quality issues again.

Almost all quality support operations such as testing, troubleshooting, reworking and visual inspection contradict the mass product concept because of their individual nature, very limited productivity and reliability. Yet, all these operations are important in supporting new package technologies. For example, to support ceramic column grid arrays (CCGAs), special testing verification, rework and x-ray inspection shops on the production floor must be established. Despite their low reliability, these techniques currently provide the only way to handle broken pile.

Another way to decrease ICT expenses is unusual but could produce good results. Currently, all boards undergo ICT first and then functional test. Functional test is more powerful; after a functional test, a board is considered good. However, if functional test is conducted before ICT, then ICT maintenance expenses could be substantially decreased.

The functional test will detect a good board, and the board will not need ICT, which can be up to 50 percent of all product flow. Of course, both functional and ICT tests should be adapted to this new sequence. For example, functional testing should include some ICT features like power short identification, boundary scanning and filter failures.

However, using both approaches does not create a great future outlook for the EMS industry. When seeking any ICT replacement, managers usually consider flying probes, x-ray or automated visual inspections. Another alternative is the cluster approach, in which a simplified functional test replaces ICT. This solution might be very attractive for the EMS industry.

The Cluster Approach

A cluster is a group of objects with close properties that are all connected. One characteristic of a cluster is that its parts can be individually manipulated. Controlling the individual parts is much easier than manipulating the whole cluster.

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In fact, ICT was an attempt to divide functional testing into many smaller tests for each part of a PCB to make the test as complete as possible. ICT was a cluster approach in the test area.

Complete testing is very expensive and will cost even more as product complexity and performance requirements increase. Any further attempts to meet new component package requirements in PCB assembly will cause an exponential growth of testing, inspection and reworking expenses and time-to-market delays.

One way to reduce the gap between PCB and IC technologies is the multi-chip package (MCP) technology, which has recently been implemented in PCB assembly with CSPs. In a way, MCP is an ideal solution for PCB assembly. Nevertheless, this approach is still too expensive to solve the entire problem of transforming PCBs into one big package.

Another way to reduce the gap between IC and PCB technologies is the cluster approach in which the PCB is physically divided into several parts. Consider PCBs as clusters composed of different, small mini-boards. Technically, these clusters can be based on a frame with some regular PCB functions, or additional functions can be included such as chassis, interconnections between mini-boards, and connections with external devices and with other frames. Each frame will contain a certain amount of cells to hold the mini-boards. Each mini-board will carry several ICs or several passive components and will connect with the surrounding mini-boards through the frame-based cluster. Thus, the basic principle of the cluster approach is to produce many small built-up mini-boards that are assembled in one big final board.

In the cluster approach, each functionally whole unit (a cluster) is divided into several removable parts (mini-boards). In general, the cluster is a flat, plain unit that looks like a regular PCB. The number of mini-boards depends on the reliability of the entire technological chain and the board's complexity; the less reliable and higher the complexity, the greater the number of mini-boards.

At a first glance, the clustering approach resembles card-on-board technology. At today's high circuit speeds, the card-on-board interfaces exhibit high electrical capacitance, resulting in slower circuit speeds, signal reflections and other manufacturing problems. Instead, the cluster approach can solve some design and production issues in PCB assembly. A plain cluster has regular electrical properties as long as its frame is properly designed. The cluster approach allows a unit to be designed with fewer internal layers, which decreases design cost and time-to-market delays.

The cluster approach also resembles multi-chip packages. However, it is based on PCB assembly technology, not on IC technology. This approach allows new ICs with reprogrammable interconnections to be easily accepted. Therefore, IC manufacturers can support the cluster approach, and programmable mini-boards—interconnection ICs—will be possible.

Cluster Approach Example

In the real world, the PCB assembly defect rate (D) without recovering can range from 20 percent to 60 percent depending on the board's complexity.

For very complex, big boards like net routers and switch buses, this defect rate can be 70 percent or higher. In this case, one out of every two boards, on average, must be looped back for inspection, testing, troubleshooting and reworking. Obviously, more revenue is generated with a smaller defect rate.

To demonstrate the cluster approach, several equations are used. The defect rate (D), defect production flow (DP) and production flow (P) can be expressed in the following equation: $DP = D \times P$. The products that are packed and shipped (revenue, R) are related to the other three variables as follows:

$$R = P - DP = P - (D \times P) = P \times (1 - D)$$

If the cluster consists of one board, then the cluster degree (C) equals 1. The more clusters, the higher the cluster degree; for example, a cluster of five mini-boards would have a cluster degree of 5. Assuming equal defect distribution across the PCB, the above equations become:

$$DP = (D \times P)/C$$

$$R = P \times (1 - D/C)$$

So, if the cluster is only one board (C=1) and the defect rate is 70 percent (D=0.7), the revenue will be only 30 percent. However, if a product contains 10 mini-boards (C=10), defect production decreases by 10 times and revenue increases from 30 percent to 93 percent without any technology improvements.

However, clustering cannot solve the problem of poor technology. For example, the difference between defect rates of 30 percent (reasonable) and 70 percent (poor) results in clustering degrees of C=3 and C=7 to reach the same 90 percent of revenue. In other words, poor technology requires too much clustering to increase performance (revenue).

Benefits and Costs

When considering the plusses and minuses associated with the cluster approach, several factors become apparent. First, a frame design must be created for the cluster, which must be robust and technological. This task is not a greater challenge than creating modern multilayered printed wiring boards (PWBs).

Second, many additional interconnections between the mini-boards and the frame in a cluster can present problems for reliability and electrical performance. This issue is primarily resolved by socket design for such components as EEPROMs and SIMMs. Creating such a big "socket" in PWB technology might be a big challenge for the industry.

Overall, the benefits of using the cluster approach include:

- In-circuit testing, reworking, traditional troubleshooting and visual inspecting will not be needed.
- Ramping up or closing a product line can be done in days or hours, instead of weeks and months.
- Many design and process issues can be fixed on the fly.

- The troubleshooting process will be fully "automated."
- The broken pile will be reduced to almost zero.
- Mini-board complexity will decrease.
- Transitions from traditional soldering to other technologies will be easy.
- Logistics will be simplified and warehouse inventory will be reduced.
- Design for manufacturing and testing will be simplified.
- Yields will be increased by aggregating manufacturing components.

Another indirect benefit includes increased surface-mount and flow solder process reliability by making homogeneous product flows. All of these benefits outweigh many possible problems caused by cluster approach implementation.

Troubleshooting and ICT will not be needed anymore because the following simplified procedure (much more acceptable for the mass production) can replace a regular process of revenue extraction.

In the cluster approach, troubleshooting is just a sequential dividing of a cluster in half several times until a failed module is found. Each time, while applying a functional test, the cluster is divided if it fails. Then both clusters are complemented with good parts and tested again. If one of the new clusters passes and another one fails, then the failed cluster contains a failed mini-board. The initially failed part of the cluster is divided again, and this procedure is repeated several times until the failed mini-module is found.

The best part of this troubleshooting procedure is that two automatically separated flows will result: ready to be shipped clusters and failed parts. As mentioned, separated ideal production and information flows result. Additional efforts for troubleshooting and fixing the whole cluster are no longer needed, as occurs now in PCB assembly.

Another benefit of this troubleshooting process is that it enables current automated equipment, including placement machines and automated testers, to assemble these clusters. Therefore, unreliable human factors such as electrostatic discharge can be eliminated across the whole technological chain.

However, one problem is not solved with the cluster approach: mini-board failures will happen more or less often in a traditional soldering process. However, they do not need to be fixed because a module is no longer the final product. The only task is to analyze all those mini-boards and find the causes of the failures. Once the failure analysis is separated from the commercial product flow, reliable results occur and the technology can be effectively improved.

In the framework of traditional soldering technology, the cluster approach will improve process quality and performance. Transition processes in modern soldering technology play a major role in creating defects and process deviations. A transition process often forces changes in technological parameters including a board's complexity and components and vendor's variety. The cluster approach can reduce these factors and make a product flow more homogeneous. Therefore, it reduces those transition factors, defects and process deviations.

Conclusion

One solution to reduce costs during testing is to have a process that does not generate any defects. This perfect process has not yet been developed. However, some industry professionals believe this perfect process can be achieved by using sophisticated management tools such as statistical process control and by employing very dedicated people in manufacturing and quality control.

Another very powerful method is the cluster approach, which can totally change the design, production, service, testing and inspection strategies in the EMS industry. The new PCB prospects with low pre- and post-production technological costs will attract many more OEMs and expand the outsourcing EMS market. The cluster approach is not perfect yet, but it is closer to being the ideal solution for current technology. ■

Acknowledgments
Special thanks to Tracy Vaught of SI Diamond Technology for her help with the article.

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