

Inspection and testing methods for PCBs: An overview

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Introduction

Within the broad and diverse array of PCB applications, one requirement is the same — PCBs are expected to function according to their design parameters with no errors or failures. In many applications, lives are at stake, so PCBs must perform flawlessly.

However, PCBs can be complex, with hundreds of components and thousands of solder connections. The PCB manufacturing industry and manufacturers of products that use PCBs have met this challenge

by instituting a variety of inspection and testing procedures to ensure the quality of their products. Inspection and testing pinpoint faulty boards for rework and provide process feedback that fuels continuous improvement.

To maximize final yield and ultimate device reliability, each PCB needs to be inspected and tested based on its specific design and performance

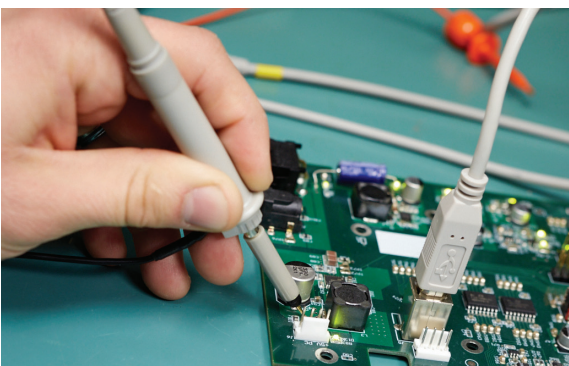
specifications. When a device OEM partners with a PCB manufacturer, the inspection and testing plan for the specific PCB is an important topic.

This paper will review PCB inspection and testing methods and note their advantages and disadvantages so the OEM team can determine the best process for a given PCB.

PCB inspection and test evolution

When circuit boards were fairly simple, with only a few components and solder connections, manual visual inspection (MVI) was sufficient for identifying placement errors and solder problems. This method of inspection has inherent drawbacks, though, because humans are not well suited for this type of repetitive task. Inspectors get bored or tired, defects are missed and faulty boards are not caught until later in the process when they are more costly to fix or even unfixable.

The next step in inspection systems was to limit the human error factor in the equation by automating the visual inspection process. Automated optical



inspection (AOI) is now a widely accepted inline process that can be used pre-reflow, post-reflow or both to check a variety of possible faults. Some pick-and-place machines have built-in AOI capabilities that allow them to check for faulty components and misalignment.

The advent of surface mount technology (SMT), which has brought smaller components, new chip packages, and the increased complexity of double-sided and even multilayer boards, has created difficulties for AOI systems. As board density increases, AOI systems have trouble reading all the solder joints involved. Also, new chip packages like ball grid arrays (BGAs) have connections underneath the package, making them invisible to AOI systems. X-ray inspection systems provide a solution since they can see

through a chip package to the solder underneath. They can also inspect multilayer, double-sided and densely populated boards. Automated X-ray inspection systems are referred to as AXI.

PCB testing is done once the board is completed. It often takes the form of in-circuit testing (ICT) and/or functional testing (FCT). In-circuit testing looks at the functioning of individual components after they are soldered in place. Functional testing provides a final go or no-go decision on finished PCBs.

Common PCB defects

Many things can go wrong on a PCB. Components may be misaligned. Solder connections may not be complete. Excess solder can bridge circuits and cause shorts. The chart (Figure 1, shown here) lists common PCB defects and characterizes them as structural or electrical. The different inspection and testing methods have varying levels of effectiveness with each type of defect.

Figure 1.¹ Industry data regarding the incidence rates of common PCB defects reveal the criticality of PCB inspection and, in particular, of solder paste deposition.

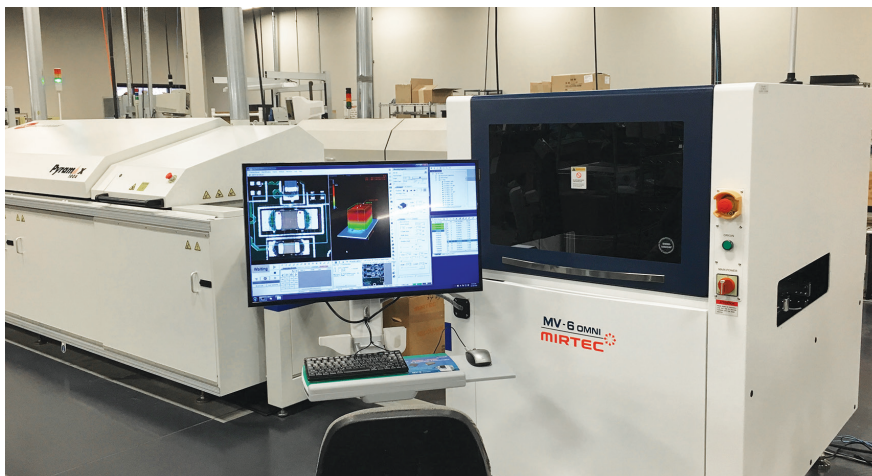
DEFECT	RATE	TYPE	SOLDER-RELATED
Open	25%	Structural	Yes
Insufficient	18%	Structural	Yes
Short	13%	Structural	Yes
Missing electrical component	12%	Structural	No
Misaligned	8%	Structural	Yes
Defective electrical component	8%	Electrical	No
Wrong component	5%	Electrical	No
Excess solder	3%	Structural	Yes
Missing non-electrical component	2%	Structural	Yes
Wrong orientation	2%	Electrical	No
Defective non-electrical component	2%	Structural	No

INSPECTION

Inspecting boards at various manufacturing stages allows for early detection of faults. (The earlier in the manufacturing process a defect is found, the less expensive it is to fix.) Defects can be corrected so yields at the testing stage improve. The most commonly used PCB inspection systems are automated optical inspection and automated X-ray inspection (AXI).

Automated optical inspection (AOI)

AOI is a visual inspection method for PCBs. In an AOI system, one or more still or video cameras scan the board. The board is lit by several sources from various angles, and the machine takes images so it can build a picture of the board. Then the system compares the captured images with what the board should look like (usually based on a “golden board” or design specifications).



AOI systems find problems like nodules, scratches and stains, as well as dimensional defects such as open circuits, shorts and thinning of the solder. They can also detect incorrect, missing and skewed components. They do all this in less time and with greater accuracy than human inspectors.

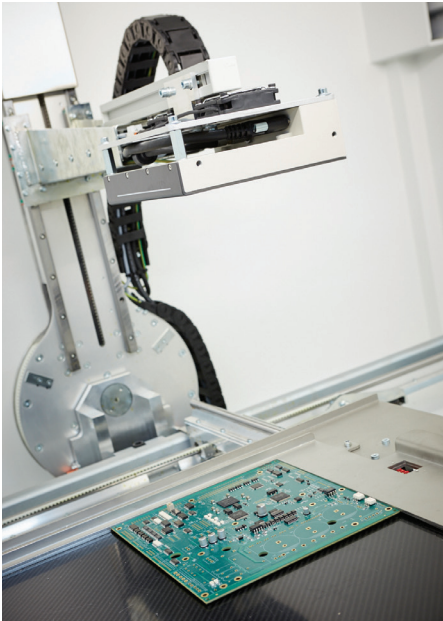
New 3-D AOI equipment can measure component height, a weakness of traditional 2-D machines. 2-D machines use multi-angled colored lighting and side-angle cameras to inspect height-sensitive devices, like BGAs and leaded components, but the results are not reliable. Using 3-D inspection allows a manufacturer to detect coplanarity on height-sensitive devices without difficulty, although shadowing may skew results for some board layouts.

Advantages²

- Well-known, accepted technology
- Detects many common PCB faults (See Figure 2.)
- Can be deployed inline at several points in the PCB manufacturing process

Disadvantages

- Limited to “line of sight,” i.e., unable to inspect hidden connections underneath BGAs and other packages
- Less effective inspecting densely loaded boards because some components and connections are hidden or shadowed



X-ray inspection/AXI³

Surface mount technology (SMT) has allowed for smaller components and PCBs that are very densely populated. Boards with more than 20,000 solder connections are not uncommon. The advent of SMT has also spawned new chip packages like BGAs and chip scale packages (CSPs) on which solder connections are not visible. These boards and chip packages cannot be inspected with the usual AOI equipment. X-ray inspection equipment, automated (AXI) or manual, can check the solder joints under components and show defects in solder joints that may not be visible with AOI.



Materials absorb X-rays proportional to their atomic weight. Materials made of heavier elements absorb more X-rays, while materials made of lighter elements are more transparent to X-rays. Solders are made of heavy elements, such as tin, bismuth, silver, indium and lead. Most other materials on a PCB (components, substrate, etc.) are made of lighter elements, like carbon, aluminum, oxygen, hydrogen, silicon, sodium and copper. In X-ray inspection, solder shows up extremely well, while most packages, the PCB board substrate, silicon integrated circuits (ICs) and component leads become barely visible.

Unlike visible light used in AOI, X-rays are not reflected. Instead, they pass through objects and can form an image of the other side. X-ray inspection systems can “see” through chips like BGAs for which the connections are underneath. With X-rays there is no shadowing so these systems can inspect very complex, densely packed boards.

X-ray inspection systems provide an internal view of the solder joints, detecting bubbles that would be unseen by AOI. Also, X-ray systems can see the heels of solder joints (hidden to AOI systems because they are masked by the leads).

Advantages

- Able to “see” through chip packages with connections underneath
- Can inspect densely packed boards
- Provide thorough inspection of solder joints

Disadvantages

- Newer technology may not be thoroughly understood
- Investment may only make sense in situations in which BGAs, CSPs and similar packages are used or in which board density is beyond AOI's capabilities

Figure 2. The chart below explains why multiple inspection and testing methods are required in order to ensure PCBA quality, board after board.

TESTING

After a PCB is manufactured, having passed all its inspections, it is ready for testing. While there are several test methods, in-circuit testing (ICT) and functional testing (FCT) are the most common.

In-circuit testing⁴

In-circuit test equipment measures each component to check that it is correct and in place. During ICT an electrical probe tests a populated PCB, checking for shorts, opens,

resistance, capacitance and other factors to show if it was correctly made. ICT can be performed with a bed-of-nails test fixture or with a flying probe setup. A bed-of-nails tester is a test fixture with an array of small, spring-loaded pogo pins. Each pin makes contact with one node in the circuitry of the device under test (DUT). Contact is made with hundreds or even thousands of individual test points within the circuitry of the DUT when it's pressed against the pins.

A bed-of-nails fixture is costly to develop and difficult to change. These fixtures have difficulty testing densely populated boards. Another approach gets around some of the problems by using a roving or flying probe. A simple fixture holds the board, and the probes move around the board, making contact as required. Probe movements are controlled by software so any board updates can be accommodated with programming changes. In-circuit testing does not test the functionality of a board. ICT is based on the assumption that a PCB that has been designed and assembled correctly should work.

DEFECT TYPE	AXI	AOI	ICT
Soldering defects:			
Open circuits	Yes	Yes	Yes
Solder bridges	Yes	Yes	Yes
Solder shorts	Yes	Yes	Yes
Insufficient solder	Yes	Yes (not heel)	No
Solder void	Yes	No	No
Excess solder	Yes	Yes	No
Solder quality	Yes	No	No
Component defects:			
Lifted lead	Yes	Yes	Yes
Missing component	Yes	Yes	Yes
Misaligned/misplaced component	Yes	Yes	Yes
Incorrect component value	No	No	Yes
Faulty component	No	No	Yes
BGA and CSP defects:			
BGA shorts	Yes	No	Yes
BGA open circuit connections	Yes	No	Yes



Advantages⁵

- Finds defects such as solder shorts, missing components, wrong components and open connections
- Performs tests without power being applied to the DUT (avoids possible damage)

Disadvantages

- Requires costly test fixtures (bed of nails) or detailed programming (flying probe)
- Does not test continuity through connectors, so connector faults may not be identified

Functional testing⁶

To test a PCB's functionality, a functional tester interfaces to the PCB via its edge connector or a test-probe point. It then replicates the PCB's final electrical environment. For example, if a PCB is going into a slot inside of a computer, then functional testing will simulate the slot it's actually going to occupy (inputs, outputs, etc.).

Functional testers are often as unique as the products they test, although test equipment manufacturers are trying to standardize and modularize to keep costs in line. The overall tester system usually consists of a cabinet, an interface to the DUT, cabling to connect all of the instruments, a central processing unit and monitors. Hardware varies based on the DUT and the environment in which it will be used but generally includes instrumentation and power supplies.

The software is the operating system, the test executive and tool sets.

Functional testing is specific to the DUT so it requires investment of both money and time to ensure success.

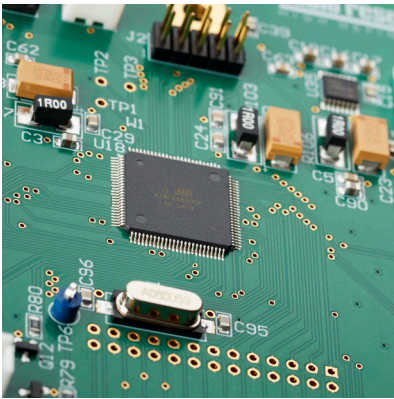
Functional testing is not a perfect solution. It involves a lot of variability, including how much of the PCB is going to be tested, what inputs or stimuli are needed, definition of desired results and delineation of testing parameters. Because of this variability, functional testing is very complex.

Advantages

- Identifies functional defects within a PCB
- Determines DUT power consumption during operation
- Uncovers problems with analog and digital circuitry

Disadvantages

- High cost
 - Programming requires a thorough understanding of the DUT and its working environment
 - Utilizes expensive high-speed instrumentation to characterize signals from the DUT
- Testing done through connectors can have reliability issues since connectors wear



Conclusion

Inspection and testing ensure high quality in the manufacturing of PCBs and electronic devices. Manual visual inspection has been replaced by AOI and AXI to catch errors in components, placement and soldering. In-circuit and functional testing can check a completed PCB's quality.

The program of inspection and testing is specific to each PCB, and decisions about that program are often made as early as the design process. Since device OEMs consider a PCB manufacturer's inspection and testing capabilities before establishing a partnership, the OEM's team needs an understanding of each method to help them identify the best partner.

Sources

¹ The Why, Where, What, How, and When of Automated X-ray Inspection, Agilent Technologies white paper, Glen Leinbach, Stig Oresjo, 2001

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⁴ ICT, In-Circuit Test Tutorial - notes and details about all the essentials of in-circuit testing, ICT and in-circuit test equipment for use for PCB, printed circuit board test, <http://www.radio-electronics.com/>, Ian Poole

⁵ In-Circuit vs. Functional Test, www.bloomy.com, Rob Putala, September 11, 2014

⁶ Functional Testing of PCBs, Assembly Magazine, Adam Cort, July 1, 2002

About Caltronics

Caltronics is more than a contract manufacturing company. We provide expert solutions in every facet of electronics design all the way to full production, and our systems are certified to ISO 9001:2008 for quality management.

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