Baker Hughes

How to achieve full quality electronics inspection

Beyond optical and electrical testing with microfocus and nanofocus X-ray inspection

Executive summary

We often take safety for granted. However, every time an airplane lands safely, your car performs reliably or your cell phone works flawlessly, it is because manufacturing engineers obsessed about electronic component quality to ensure our collective safety.

Electronic components are growing exponentially in use around the world. They are essential elements in products that help us manage and navigate our lives every day: computers, cell phones, cars, airplanes, and remote controls. No matter where these parts are manufactured or how they are used, safety and quality must be ensured globally. As such, electronics manufacturing requires comprehensive quality inspection techniques to maintain public safety, regulatory compliance and sustain marketplace trust in electronics manufacturing brands.

Across a spectrum of products, such as semiconductors, printed circuit board assemblies' (PCBA's) and lithium-ion batteries (batteries), and a host of industries such as aviation, consumer electronics and automotive, specific quality needs may vary, but the core requirements are universal: to ensure public safety, manufacturers must inspect to complete component integrity—prior to end-use, when the consequences of failure can escalate significantly. That assurance requires inspection techniques that use high resolution on both visible and non-visible areas to provide comprehensive product quality assurance.

Current inspection techniques include destructive and non-destructive options. Destructive inspection can only test sample components versus every component and ultimately destroys the part. Non-destructive inspection can check every component and includes options such as optical inspection and electrical testing. While helpful, optical inspection and electrical testing are not enough for the thorough inspection required to prevent and mitigate electronic product failures. Next gen approaches such as nano- and microfocus X-ray solutions are available today and provide comprehensive quality inspection solutions for electronics while also ensuring IPC Class 1, 2 or 3 compliance. Thus, manufacturers can help to ensure parts are free of function-limiting voids, foreign materials and imperfections and provide high precision inspection at critical junctures, such as solder joints, to validate part integrity and full compliance while simultaneously maximizing production yield.

Sole reliance on optical inspections and electrical tests introduce unnecessary risk to public safety, manufacturing profit, brand reputation, and regulatory compliance, making them inadequate as stand-alone techniques for comprehensive inspection. Adoption of microfocus and nanofocus X-ray solutions help electronics manufacturers to boost safety, achieve regulatory compliance and create sustainable business models in the production of PCBA's, semiconductors and batteries.

These new inspection solutions are the way forward, helping us to achieve peace of mind knowing that safety grows in congruence with electronics usage and sophistication.

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Requirements for comprehensive electronics quality control

Let's start with the common ground. Across diverse industries such as aviation, consumer electronics and automotive, key electronic components, like printed circuit board assemblies (PCBA's), lithium-ion batteries (batteries), and semiconductors, are heavily utilized. These components enable operations of everyday utilities including airplanes, automobiles and cell phones. Thus, quality control for full compliance, assurance and public safety is essential.

Electronics: quality inspection requirements

Given the micro and precise nature of these often-intricate electronic components, quality inspection aligned to three characteristics is needed. While specific quality and compliance requirements may vary by part, end-use application and industry, the essential inspection capabilities to ensure holistic quality of electronics are universal. They are:

1. High resolution | 2. Inspection of non-visible areas (dimensional + structural integrity) | 3. Non-destructive testing

Today, however, many manufacturing quality tests rely primarily on optical inspection and electrical testing. While both techniques can identify some levels of defects, they are not sufficient for full inspection. Optical inspection and electrical testing are incapable of seeing and checking non-visible surfaces, such as hidden solder joints or bond wires, to reveal obscure defects. Thus, sole reliance on optical inspections and electrical tests introduces unnecessary risks to public safety, manufacturing profit, brand reputation, and regulatory compliance. As standalone techniques, they are inadequate for comprehensive quality inspection of PCBA's, batteries and semi-conductors.

Another inspection category, off-line destructive testing, does offer high resolution, but with many less-attractive trade-offs. Destructive testing cuts out a section of the component, embeds it into resin and uses a grinding machine to access a specific area of interest. After grinding, a high magnification microscope looks into the cross-section but does not analyze the entire component while also destroying the part. Thus, to level the playing field, let's focus on non-destructive inspection options.

Pros and cons of optical inspection and electrical testing

Optical inspection refers to visual inspection done manually—an often used technique—or automated optical inspection (AOI) done by a machine. Not surprisingly, machine vision or AOI is typically done at faster speeds and can be more accurate than manual inspection. Optical inspection is used to check for physical flaws such as scratches. Electrical testing assesses device functionality by sending electrical signals to a device to measure output signals vs. benchmark values.

Optical inspection and electrical testing, while not apt as stand-alone approaches, do offer specific niche benefits. In fact, many manufacturing applications can benefit from optical inspection and electrical testing at certain phases of the production process.

Pros

Cost effective.
Visual inspection is helpful for identifying and correcting obvious surface flaws—such as pits, blisters, voids and scratches—that can readily be seen by the human eye or detected by automated optical scans. When used at early stages of the production cycle, visual inspection can curb manufacturing loss, making it a cost effective approach.

Indicative.
Automated optical inspection techniques can create more standardization in testing and provide inspection of, for example, solder joints and solder volume, to partially assess the structural integrity of the component. Electrical testing is also a good "snapshot" indicator of a component's structural integrity as measured in terms of electrical performance.

Cons

Inconsistent.
Manual inspections are inherently inconsistent and thus do not provide a reliable, stand-alone inspection technique. Automated optical inspections can improve consistency, but do not provide a holistic analysis of the part due to limitations in what can be measured and assessed.

Incomplete.
As electronic devices become denser and more sophisticated, the presence of non-visible elements often increases. Any non-visible feature, such as multilayer solder joints, cannot be checked via optical inspection techniques, demonstrating why it is impossible to get a thorough quality assessment with optical inspection alone.

Imprecise.
Electrical testing does not provide visibility into voids, micro cracks or other micro or non-visible defects that can lead to medium or long-term product failures *(see example on the next page)*.

EXAMPLE

Electrical testing can confirm in-the-moment functionality of a part, such as a PCBA for an automobile. However, it cannot detect the presence of micro cracks, partial solder joints or voids that can limit part performance in the field. Thus, electrical testing may falsely deem a compromised component as fully functional. The result? Poor and often short-term component reliability in the final part. For example, the temperature cycles in a car span from -20 to 100 degrees Celsius. A compromised solder joint in a PCBA will not withstand these cycles, leading to a premature and unnecessary automotive failure of some type.

"Paradoxically, in electronics-based industries, large-scale safety is primarily determined by the integrity of a small part at micro and nano-levels of quality."

Next gen electronics quality inspection: Microfocus and nanofocus X-ray solutions

Describing the pros and cons of optical inspection and electrical testing shows us why they cannot provide a complete quality picture in electronics such as semiconductors, PCBA's and batteries. Specifically, the three critical capabilities needed—high resolution, non-visible area inspection and non-destructive testing—cannot be met with these two approaches. This deficiency introduces risks that span financial, legal and marketing areas, manifested as product recalls, in-marketing product failures, brand reputation damage and potential hazards to personal and public safety.

Mitigating these risks is not easy, but is essential. Inspection and analysis with high precision and reliability that includes 2-D and 3-D options to inspect non-visible areas while not destroying the part is a very tall order. In electronics manufacturing, however, it is needed to maintain safe and reliable operations while staying in compliance. Thus, for electronics manufacturers, adopting a comprehensive solution is of paramount importance.

This is where and why microfocus and nanofocus X-ray solutions are a welcome advancement and must-have solution for quality inspection of electronics. With these X-ray solutions, it is possible to inspect the hidden features of a component to uncover joint cracks, voids and partially connected elements or disconnections prior to end-use. Latent faults, only detectable via X-ray inspection, can prove just as dangerous during end-use as more obvious and visible flaws. It is the "normal" thermal, mechanical and electrical stresses during end-use that lead to failures, stemming from undetected electronic part defects. To achieve safe end-use operations, flaws must be detected much earlier in the component manufacturing process.

Consider these specific examples of X-ray inspections' efficacy in mitigating risks:

Lithium-ion batteries

There are an estimated **40 checks** that need to be performed to ensure safe and proper functionality of lithium-ion batteries. For example, detection of misaligned elements, a defect discoverable by X-ray inspection, can lead to a short circuit during final product usage. In a lithium-ion battery, a short circuit can cause it to ignite or explode. In cell phones, for example, 2018 global usage is estimated at over **5 billion** mobile phone users, thus safe battery operation has far-reaching and significant consequences.

PCBA's

Printed circuit boards have several attachment joints, many of which are non-visible. As such, X-ray inspection provides the much-needed analysis of these hidden joints. Specifically, X-ray provides inspection of surface mounting techniques that attach the circuit to the circuit board such as ball grid arrays (BGA's) and quad flat no lead. Defects revealed include voiding and different types of solder failures that lead to improper attachment and—if undetected—potential end-use failures such as head-in-pillow and non-wet open defects.

Semiconductors

Defects that cause semiconductor failure, most notably when mechanical or thermal stress is applied during end use, must be identified earlier in manufacturing to mitigate risk. Starting with raw materials, X-ray inspection can detect silicone wafer cracks due to material impurities that ultimately lead to breakage in semiconductors. During manufacture, the presence of semiconductor voids, created by encapsulated air pockets or solder paste resin impurities, can be detected by X-ray inspection. Improper solder bonds or cracks are also revealed with X-ray.

Regulatory compliance for electronics

Ensuring our safety with specific requirements for compliance is an organization known as IPC or The Association Connecting Electronics Industries*. IPC is a trade organization that develops standards for electronics. IPC standards are global, widely used and its' worldwide offices span Europe, U.S., China and India.

The requirements: IPC Class 1, 2, 3 and 3A Compliance

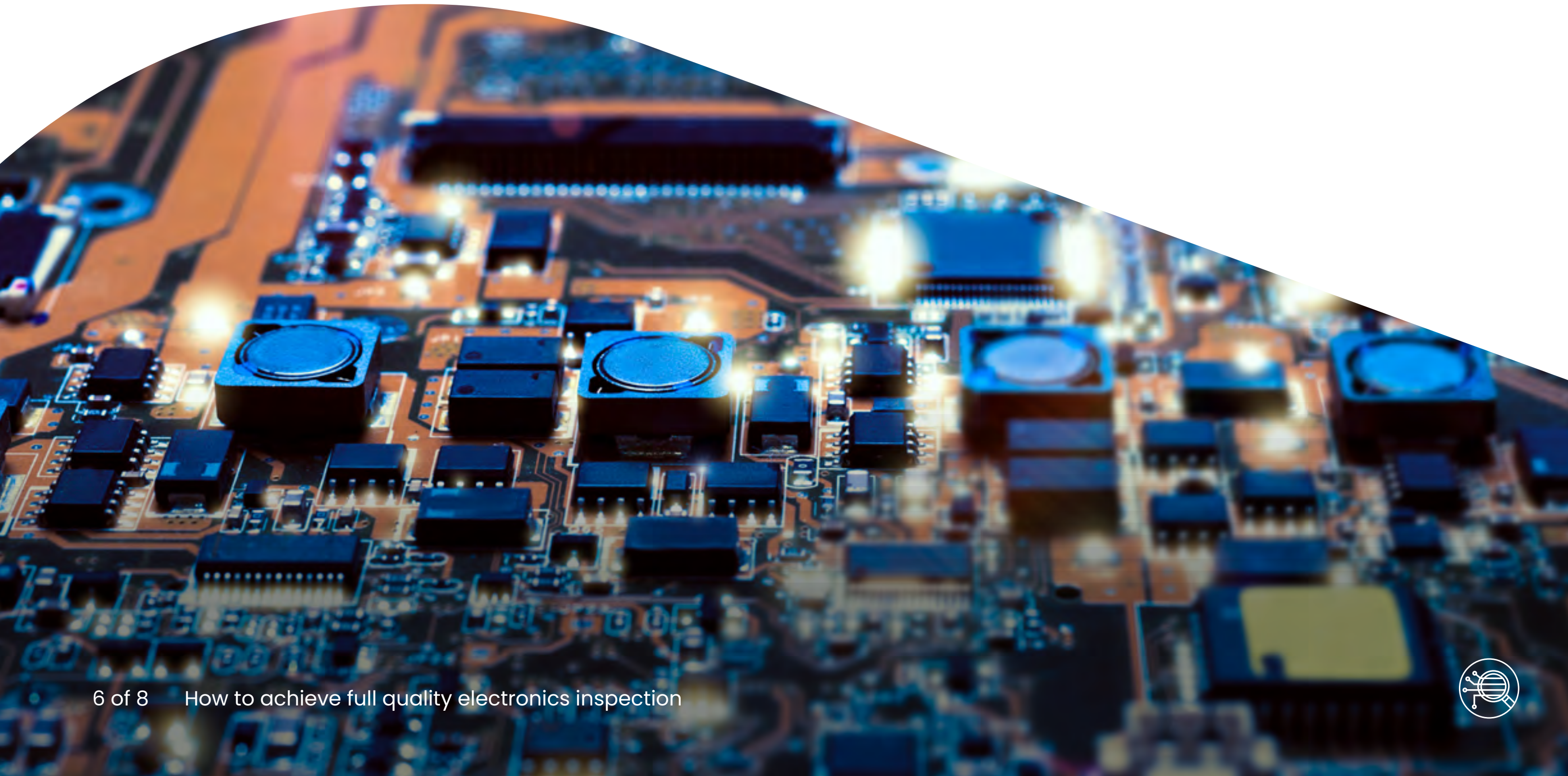
There are four IPC classifications with increasingly stringent requirements as described below. The classifications are globally recognized as standards that ensure safety and reliability and are often tied to "end-use industries" and thereby govern electronic components by end-use application. IPC classifications define the degree of inspection and the level of acceptance required for compliant inspection.

Class 1.
Electronics with shorter life cycles and simpler end-use applications are held to IPC Class 1 requirements which have lower reliability standards. *Examples: remote controls, flashlights.*

Class 2.
Electronics with extended life cycles and mid-level end-use complexity requirements align to IPC Class 2 standards. In this class, reliability is needed, but is not critical. *Examples: computers, televisions and air conditioners.*

Class 3.
"Class 3 includes products where continued high performance or performance on-demand is critical, product downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the product must function when required," explains John Perry, Director of Printed Board Standards and Technology at IPC. *Examples: medical applications such as pacemakers or automotive and airplane components.*

Class 3A.
This is the highest and most stringent classification and is designated explicitly for space and military avionics.



Putting it all together: inspection solutions that optimize cost, speed and compliance requirements

To craft the ideal and appropriate electronics inspection solution, there are three primary determinants that drive selection:

- **Compliance requirements**
- **Inspection speed**
- **Cost**

Compliance requirements are the "first domino" criticality and it is mandatory to meet them. As such, compliance requirements determine the defect types and inspection levels required for proper quality inspection. For IPC Class 3 and 3A applications and their relevant end-use industries, this requires the highest quality inspection possible. These applications will leverage high resolution 3D CT (computed tomography) solutions combined with high resolution 2D inspection techniques.

In general, here is how the three determinants (compliance requirement, inspection speed, cost) align to aerospace and military applications, lithium-ion batteries and automotive and consumer electronics applications.

Across all industries and applications, companies must use higher or 'high enough' resolution to inspect non-visible areas and ensure full quality and public safety.

Aerospace and military applications

Regardless of electronic component type, in aerospace and military applications, full compliance must be ensured on each part as indicated by IPC Class 3A. In-use failure is not an option as the consequences are high. Thus, inspection speed is relatively low to help provide thorough inspection. Simultaneously, inspection solution costs—using the best of the best—are also high.

Compliance requirements	HIGH
Inspection speed	LOW
Cost	HIGH

Lithium-ion batteries

Lithium-ion battery applications typically require Class 2 or Class 3 compliance, depending on the end-use and its' criticality. End-use applications include areas such as cell phones, laptops and automobiles. Suppliers govern identification of the proper classification and then must meet proof and compliance requirements via specifications, reference documentation, drawings, and contracts.

Compliance requirements	MEDIUM-HIGH
Inspection speed	MEDIUM-HIGH
Cost	MEDIUM-HIGH

Automotive and consumer electronics

In automotive and consumer electronics applications, governed by IPC Classes 1, 2 and 3, there is more flexibility in selecting the type of quality inspection solutions. In general, automotive applications require mid-high tier quality levels and consumer electronics the same or slightly below. Thus, these applications utilize higher speed, lower cost quality inspection techniques which work within the compliance requirements and manufacturing yields needed for higher volume production.

Compliance requirements	LOW-HIGH
Inspection speed	MEDIUM-HIGH
Cost	LOW-MEDIUM

The next step to ensure full quality, inspection and compliance

Electronics manufacturing strives to maintain safe, reliable and profitable operations whilst ensuring compliance. Those goals can only be achieved when comprehensive quality is attained via inspection and measurement of electronic parts. For semiconductors, batteries and PCBA's, this means inspection of visible and non-visible areas with high precision. Optical, electrical and destructive inspection techniques can meet niche needs, but do not provide thorough quality assessments. Comprehensive quality mandates the use of micro and nanofocus X-ray technologies for the inspection of electronics. To risk not using this crucial technology and capability actually jeopardizes much, much more. Together, we can strive for zero failure and work to create a safer world that is proactive in achieving safety around the globe. This will give us peace of mind that our planes will land safely, our cars perform reliably and our cell phones operate effectively – each and every day.

For more information, feel free to contact us here: BakerHughesDS.com/contact

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