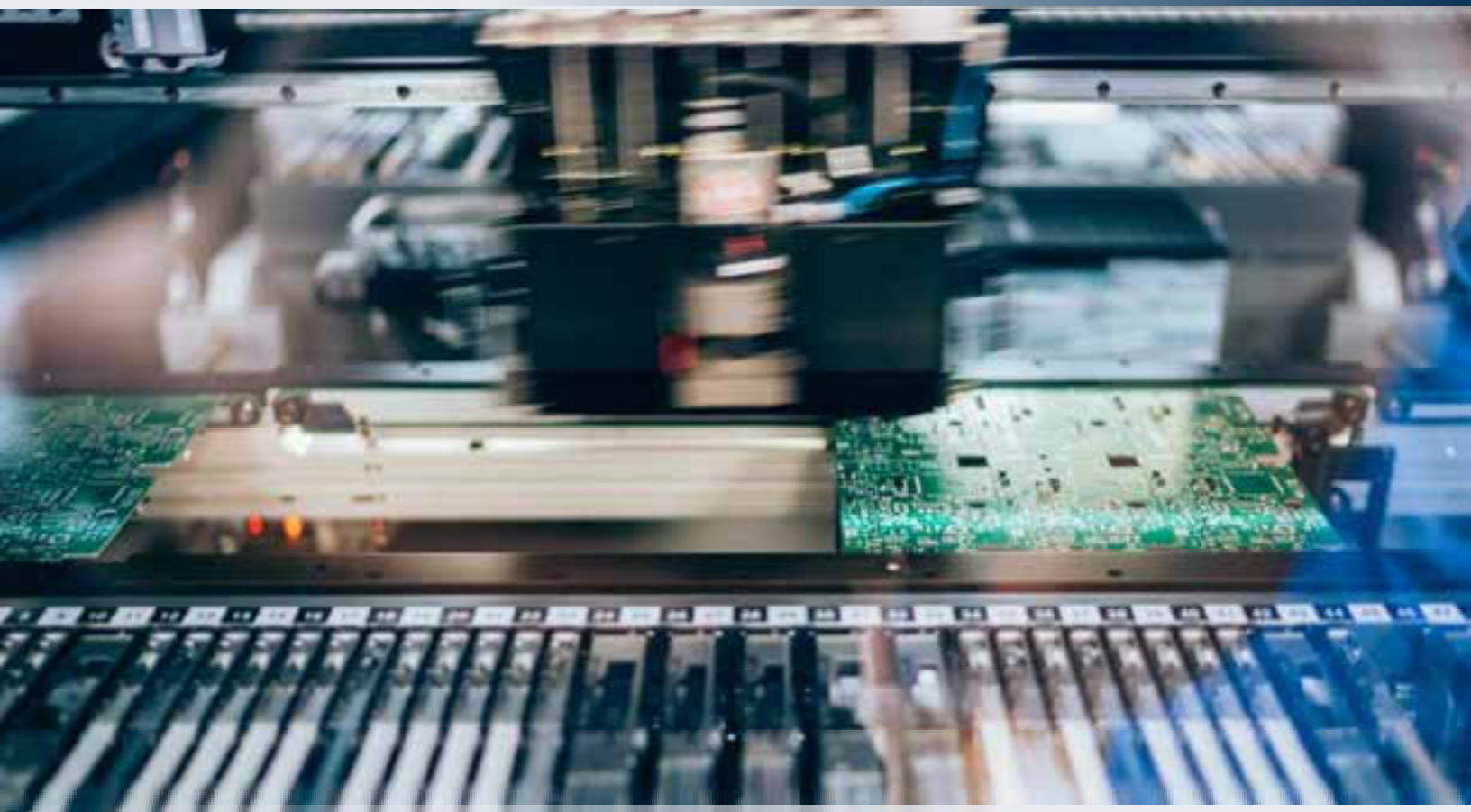




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TECHNICAL PAPER



HOW IPC-A-610 WORKMANSHIP CLASS AFFECTS RELIABILITY, INSPECTION, AND COST

A practical guide for engineers and sourcing teams evaluating an outsourced assembly partner.



Figure 1. Automated surface-mount assembly.

ABSTRACT

IPC-A-610 defines acceptance criteria for finished electronic assemblies across three product classes: Class 1 for general electronic products with limited performance requirements, Class 2 for dedicated service products requiring continued performance and extended life, Class 3 for high-performance products where continued operation is critical, and equipment downtime cannot be tolerated. While Class 1 establishes the baseline, this paper focuses on the more consequential distinction between Classes 2 and 3.

The distinction is often reduced to “tighter tolerances,” but the implications extend well beyond individual tolerance criteria. Class selection affects workmanship requirements, acceptance criteria, inspection rigor, process control, documentation, and ultimately manufacturing cost.

This paper examines where Class 2 and Class 3 requirements differ, and where they do not, and explains how those differences affect manufacturing, inspection, reliability expectations, and cost. Written for engineers and sourcing teams evaluating an outsourced electronics assembly partner, it also considers the applications and end markets typically associated with each class. The objective is to provide a practical basis for specifying the appropriate class from the outset, without adding unnecessary cost to commercial products or underspecifying electronic assemblies intended for high-reliability applications.

CLASS SELECTION IS A RELIABILITY DECISION

Every printed circuit board assembly is built to defined workmanship requirements, whether or not the purchase order clearly identifies them. If the required IPC-A-610 class is left unspecified, a contract manufacturer might simply assume that the commonly used Class 2 requirements apply. For most commercial and industrial hardware, Class 2 is appropriate. However, for products where failure or downtime carries serious consequences, leaving the class unspecified can create a significant risk.

Deliberate class selection is therefore an important engineering and sourcing decision. Establishing the acceptance criteria against which the assembly will be evaluated helps align manufacturing requirements with the product's intended use and reliability expectations.

The three classes reflect different performance requirements, service expectations, and consequences of failure:

- **Class 1, General Electronic Products**, applies to products where basic functionality is the primary requirement and extended service life is not a primary requirement.
- **Class 2, Dedicated Service Electronic Products**, applies where continued performance and extended life are required, uninterrupted service is desired but not critical, and the end-use environment would not normally cause failures.
- **Class 3, High Performance/Harsh Environment Electronic Products**, applies where continued performance or performance on demand is critical, equipment downtime cannot be tolerated, and the equipment may need to function in unusually harsh environments.

Importantly, the classes are not a ranking of the manufacturer's quality. They define the acceptance requirements appropriate to the product and its intended use. Selecting the appropriate class is ultimately a customer design and procurement responsibility, not a decision that should be left implicitly to the assembler.

IPC-A-610 & IPC-J-STD-001: TWO STANDARDS. ONE BUILD.

IPC-A-610 and IPC-J-STD-001 are closely related, but they serve different purposes.

IPC-A-610, Acceptability of Electronic Assemblies, is the global standard for evaluating the acceptability of electronic assemblies, covering everything from soldering and component placement to cleanliness and labeling. It provides observable criteria used to evaluate workmanship and quality for the specified class. It does not define the processes used to produce those end conditions.

IPC-J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies, goes deeper into how assemblies are manufactured and how manufacturing processes are controlled. It establishes materials, process, and acceptance requirements, and relies heavily on process-control methodology to achieve consistent manufacturing quality. Building to Class 3 therefore involves more than inspecting the finished assembly for tighter acceptance criteria; it requires controlled manufacturing and verification processes, supported by documented evidence of compliance.

Another distinction is equally important. Not every requirement engineers associate with Class 3 workmanship belongs to IPC-A-610. Bare-board requirements, including those for annular ring, breakout, and laminate integrity, are governed by IPC-A-600 for acceptance and IPC-6012 for performance. IPC-J-STD-001 references these standards as the fabrication and acceptability specifications underlying rigid printed circuit boards.

A capable manufacturing partner therefore understands the entire standards stack. Importantly, Class 3 assembly requirements cannot compensate for a circuit board that fails to meet the underlying Class 3 board requirements.

WHERE CLASS 2 & CLASS 3 CRITERIA DIVERGE

The clearest way to understand the step from Class 2 to Class 3 is to examine where the acceptance criteria tighten, and where they remain the same.

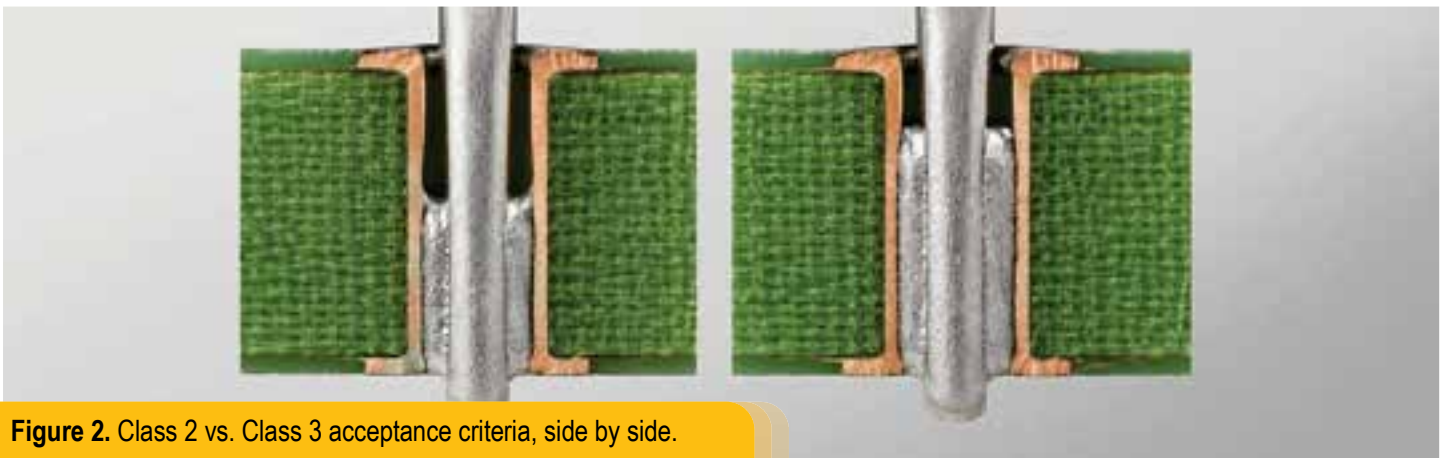


Figure 2. Class 2 vs. Class 3 acceptance criteria, side by side.

Plated through-hole soldering is a useful example. Minimum vertical solder fill for a supported hole is 75% for both Class 2 and Class 3. The distinction lies elsewhere in the connection criteria, including requirements for circumferential wetting of the lead, barrel and land. The lesson is important: Class 3 does not simply increase every numerical requirement. It selectively tightens criteria that affect connection integrity and reliability.

Surface-mount requirements show the same pattern. Depending on the component and termination type, Class 3 may impose tighter limits on characteristics such as joint width, joint length, overhang, and fillet geometry. A solder connection acceptable to Class 2 may therefore fail Class 3 even though both appear functionally sound.

Certain defects, by contrast, are unacceptable at every class. Solder bridging and tombstoning are defects across all three classes and therefore are not useful for distinguishing between them. Lead and wire requirements follow a similar principle: some criteria remain common across classes, while others become more restrictive as performance requirements increase.

Other important distinctions reside in the bare-board requirements. Characteristics such as annular ring, breakout, and laminate integrity are governed primarily by IPC-A-600 and IPC-6012 standards, rather than IPC-A-610. Class 3 imposes more stringent requirements in a number of these areas, reinforcing why assembly workmanship cannot be considered independently of bare-board quality.

The broader point is that Class 3 is not simply Class 2 with every tolerance tightened. Some criteria become more stringent, some remain unchanged, and some defects are unacceptable at every class. Understanding exactly where those differences occur is essential when specifying, quoting, and manufacturing a Class 3 assembly.

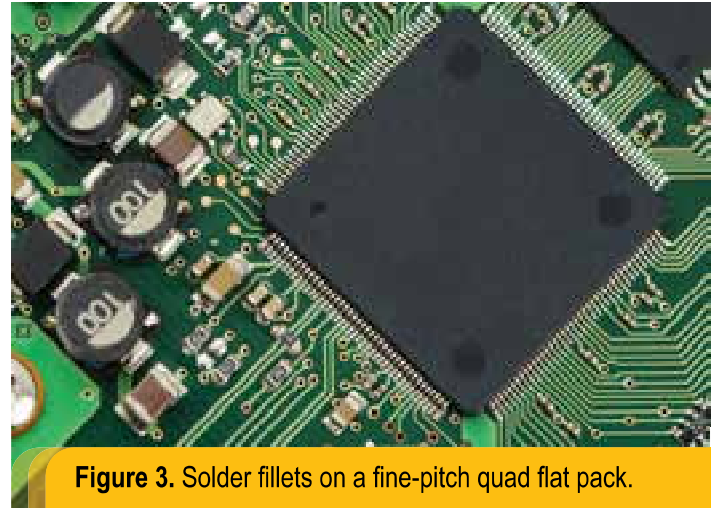


Figure 3. Solder fillets on a fine-pitch quad flat pack.

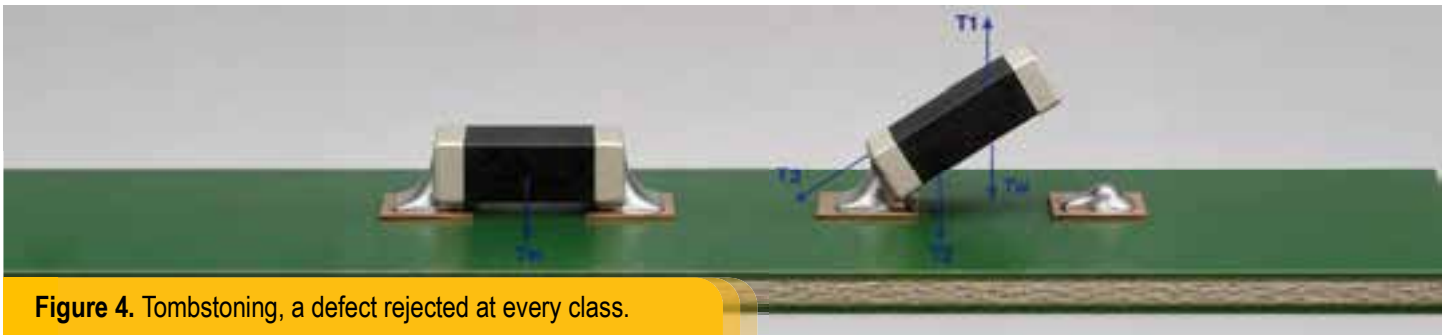


Figure 4. Tombstoning, a defect rejected at every class.

INSPECTION: GREATER RIGOR, GREATER ASSURANCE

Acceptance criteria set the bar. Inspection and process control determine how consistently those requirements are achieved and verified. This is where the operational demands of Class 3 become particularly important.

Class 2 production commonly employs statistical sampling, with a representative portion of the production lot inspected for acceptance. Class 3 production typically demands more extensive inspection and verification, with critical characteristics subject to greater scrutiny. The appropriate inspection method depends on the assembly, component types, contractual requirements, and characteristics being evaluated. Visual inspection and Automated Optical Inspection (AOI) can verify many observable workmanship conditions, while X-ray may be required to evaluate solder connections hidden beneath components such as area arrays and bottom-terminated devices. IPC-J-STD-001 also establishes requirements for evaluation methods, testing frequency, and process control.

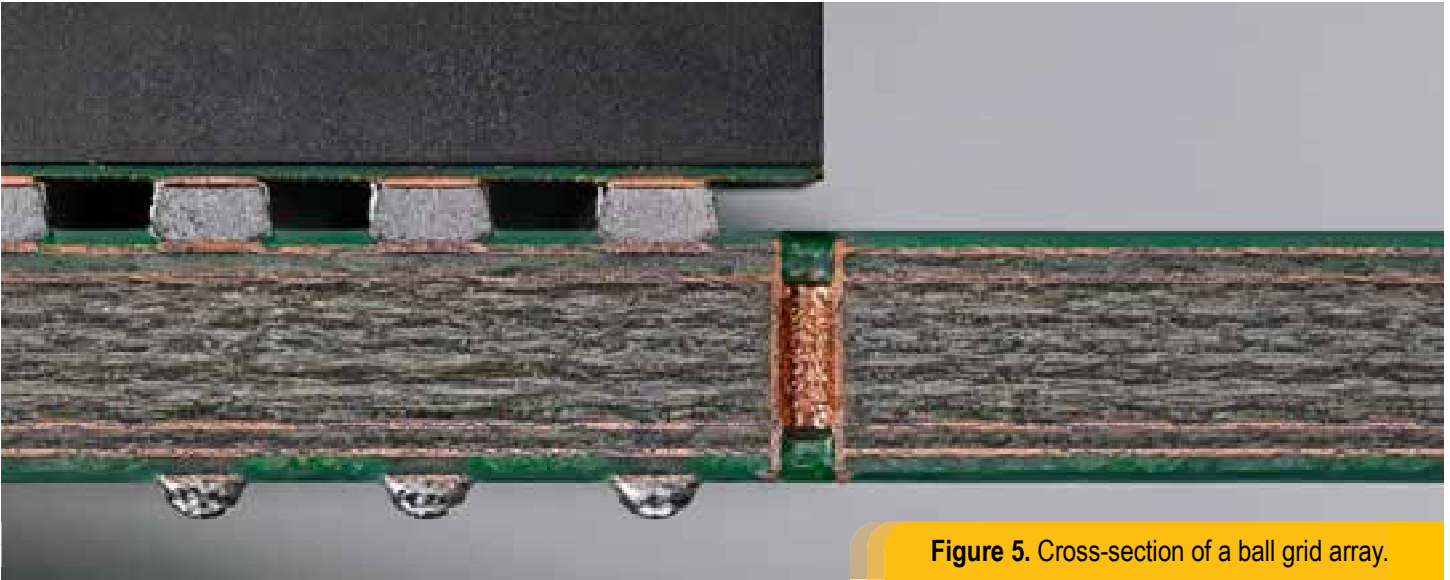


Figure 5. Cross-section of a ball grid array.

Rework requires similar discipline. Any reworked connection must still satisfy the applicable acceptance requirements, while the rework process itself must avoid introducing damage or compromising assembly integrity. Requirements for rework and repair also extend beyond IPC-A-610 and IPC-J-STD-001 to supporting standards such as IPC-7711/7721.

Behind inspection and rework is the larger process-control system. For high-performance Class 3 products, documented procedures, qualified processes, appropriately trained personnel, inspection records, and objective evidence of process control provide assurance that compliance is achieved consistently, not simply demonstrated on a handful of finished assemblies.

The distinction is fundamental: Class 3 reliability depends not only on what passes final inspection, but on the manufacturing controls used to build and verify the product.

WHY CLASS 3 COSTS MORE, IN PLAIN TERMS

None of this is free, and it is worth being direct about what drives the cost difference rather than treating it as a black box. Class 3 pricing reflects a stack of real manufacturing inputs. Tighter acceptance criteria can reduce process margins, increasing the potential for rework and scrap. More rigorous inspection and verification, including X-ray where appropriate, add skilled labor and equipment time. Greater documentation and traceability requirements add overhead throughout the build. Training, process qualification, and the controls required to consistently meet Class 3 requirements add further cost.

The point is not simply that Class 3 costs more. Its premium reflects the additional manufacturing discipline, verification, and process control required for products where continued high performance is critical. Where the consequences of failure are limited, Class 2 may provide the appropriate level of assurance. Where failure could have serious consequences, the additional rigor of Class 3 may justify the added cost.

MATCHING THE CLASS TO THE MISSION

The product's intended use, operating environment, and consequences of failure often settle the question. Aerospace and defense systems are common Class 3 applications where continued high performance, harsh operating conditions, and limited opportunities for repair can justify more stringent requirements. Life-supporting and other critical medical electronics may demand similarly high levels of manufacturing assurance, alongside applicable regulatory and product-specific requirements.

Class 3 may also be specified for high-reliability industrial, automotive, transportation, and power-electronics applications where thermal cycling, vibration, or extended service life place greater demands on interconnect reliability. Telecommunications, networking, and many commercial and industrial products are commonly built to Class 2, where continued performance and extended service life are required but uninterrupted service is not considered critical.

The objective is to match the class to the mission: avoid adding cost and manufacturing constraints where they provide little practical benefit, while specifying the additional rigor of Class 3 where performance requirements and the consequences of failure justify it.



Figure 6. High-reliability defense electronics.

CHOOSING A PARTNER THAT BUILDS TO THE CLASS

Workmanship class is only as meaningful as the manufacturing discipline behind it. A partner building to Class 3 should be able to demonstrate an appropriately trained workforce, documented and traceable processes, the inspection and verification capabilities required for the assembly, and a quality system capable of maintaining consistent process control.

Revco Products brings nearly 50 years of electronics manufacturing experience to those requirements, with full-service SMT and through-hole PCB assembly, an ISO 9001-certified quality system, ITAR registration, an IPC-trained workforce, and Design for Manufacturability review on every build. The same manufacturing operation that produces cost-effective Class 2 assemblies can meet Class 3 manufacturing requirements when the application demands it, allowing customers to match the class to the mission without changing manufacturing partners.

KEY TAKEAWAYS

- Class selection is a reliability decision. The appropriate IPC-A-610 class should be specified deliberately based on the product's intended use, operating environment, performance requirements, and consequences of failure, not left to assumption.
- Class 3 is not simply Class 2 with tighter tolerances. IPC-A-610 establishes acceptance criteria for the finished assembly, while IPC-J-STD-001 establishes requirements for materials, manufacturing processes, process control, and acceptance. Together, they define a more rigorous framework for high-performance electronics.
- Some criteria tighten at Class 3; others do not. Minimum vertical solder fill in a plated through hole, for example, is 75% for both Class 2 and Class 3, while other connection criteria become more stringent.
- Not every workmanship requirement belongs to IPC-A-610. Some defects, including solder bridging and tombstoning, are unacceptable regardless of class, while bare-board characteristics such as annular ring, breakout, and laminate integrity are governed primarily by the bare-board standards, IPC-A-600 and IPC-6012.
- Class 3 demands greater manufacturing and verification discipline. More rigorous process control, inspection, documentation, traceability, and objective evidence provide greater assurance that requirements are consistently achieved, not simply demonstrated through final inspection.
- The Class 3 premium reflects real manufacturing costs. Tighter acceptance criteria, more rigorous inspection and verification, documentation, training, process qualification, and process control add cost. That additional rigor may be justified where continued high performance is critical, or the consequences of failure are serious.
- Match the class to the mission. Class 3 is commonly associated with high-performance aerospace, defense, medical, industrial, automotive, transportation, and other demanding applications where failure could have serious consequences, while Class 2 is used for many commercial, telecommunications, industrial, and other products where continued performance and extended service life are required but uninterrupted service is not considered critical.



Revco Products Inc. is an experienced electronic manufacturing services (EMS) provider specializing in high-quality PCB assemblies. Since 1977, Revco has supported customers from prototyping through production with a focus on quality, reliability, responsive service, and cost-effective manufacturing solutions.