

AN ARGUMENT TO REDEFINE IPC CLASS DEFINITIONS FOR CLASS 1, 2, & 3 ELECTRONICS: IS IT TIME FOR A NEW CLASS?

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In the world of electronics manufacturing, the IPC standards provide critical guidance on the design, manufacturing, and testing of circuit assemblies. These standards are categorized into three primary classes [fig 1], Class 1, Class 2, and Class 3, based on the intended reliability and functionality of the end product. Class 1 covers products with the least stringent requirements, typically used for consumer electronics with short life spans and/or non-critical functions. Class 2 addresses products where performance and extended reliability are desirable but not mission-critical. Class 3, the highest tier, applies to products requiring consistent, high performance in demanding or harsh environments, such as aerospace or medical devices.

IPC Performance Classes for PCB			
Class	Description	Application	Examples
Class 1	General Electronic Products	For applications where aesthetic flaws are unimportant and the function of the completed printed board is the primary requirement.	Consumer products, computer peripherals etc
Class 2	Dedicated Service Electronic Products	For applications where uninterrupted service is desired but not crucial and extended life and high performance is expected. Minor aesthetic flaws permitted.	State of art commercial and business equipment, instruments, telecommunication equipment etc
Class 3	High Reliability Electronic Products	For applications where equipment failure or downtime cannot be tolerated and it must always operate and perform as per requirement.	Military applications, flight control systems, life support systems etc

Figure 1. IPC Performance Classes for PCB'S

While these classifications have served the industry well for decades, the landscape of electronics usage and expectations is changing. Even devices classified under IPC Class 1, historically considered lower quality with limited reliability requirements, are increasingly expected to perform in environments previously reserved for Class 2 or Class 3 products. This trend raises an important question: Should the IPC standards be redefined to reflect these evolving expectations, particularly regarding cleanliness and durability?

The Increasing Complexity of "Low-End" Electronics

Consumer expectations for electronics have drastically changed. Devices once considered disposable are now integral to everyday life. For instance, smart home devices, wearable health trackers, and IoT gadgets often fall under Class 1 due to cost constraints and limited life

span. However, these devices frequently operate in challenging environments, such as high humidity, temperature fluctuations, and exposure to contaminants. Despite being classified as Class 1, users expect these products to function reliably for extended periods.

Take the example of a fitness tracker worn during workouts and outdoor activities. While the IPC Class 1 designation may not mandate rigorous testing or cleaning standards, the product is exposed to sweat, dust, and moisture. Failure in such a device, while not catastrophic, can erode consumer trust and damage brand reputation. This demonstrates a gap in the current classification system: Class 1 electronics are not held to the same cleanliness or durability standards as Class 2 or 3 products, yet they are often expected to perform in similar environments.

The Role of Cleanliness in Reliability

One of the most critical aspects of electronic assembly reliability is cleanliness. Contaminants left on a circuit board after the reflow process can lead to failures through mechanisms such as electrochemical migration (dendritic growth and parasitic electrical leakage) [fig 2] or corrosion. IPC Class 1 does not require stringent cleaning standards because these products are assumed to have lower reliability requirements. However, as we've seen, the environments in which these devices are deployed often demand higher cleanliness levels.



Figure 2. Dendritic Growth

Courtesy Process Sciences

For example, a low-cost IoT sensor deployed in an industrial setting may be exposed to dust, chemicals, and humidity. If the assembly process does not include post-reflow cleaning, residues such as flux activators or ionic contaminants from board and component fabrication, assembly processes, and humans can compromise the device's performance. While the IPC Class 1 designation may allow for these residues, the user expects the sensor to function reliably despite its lower classification.

Harsh Environments and the Need for Redefinition

The traditional view of IPC Class 1 products as inherently disposable and lower-reliability is increasingly outdated. Modern electronics, regardless of classification, are often used in harsh environments. These environments expose devices to extreme temperatures, moisture, and contamination, all of which can lead to failure if appropriate manufacturing standards are not applied.

For example:

Consumer Electronics in Outdoor Environments:

Devices like outdoor cameras and smart doorbells [fig 3] are subjected to rain, dust, and temperature fluctuations. Despite being consumer-grade products, they must withstand conditions akin to those expected for Class 3 devices.



Figure 3. Camera and Wi-Fi Equipped Doorbell

IoT Devices in Industrial Applications:

Many industrial IoT devices are classified as Class 1 due to cost constraints. However, these devices are deployed in challenging environments where reliability is critical to operational efficiency.

Automotive Applications:

Even low-cost electronics in vehicles must endure vibrations, temperature extremes, and exposure to moisture and chemicals. Failure of these components can lead to costly repairs and safety concerns.

Real-World Examples Highlighting the Need for Elevated Standards

The challenges of balancing cost-effective manufacturing with reliability and environmental tolerance are not hypothetical; they are echoed in high-profile failures and industry anecdotes. Two notable examples--Microsoft's Xbox "Red Ring of Death" failure and a professional amplifier manufacturer's shift to no-clean processes, illustrate the practical implications of insufficient cleanliness and the consequences of overlooking environmental challenges.

Microsoft's Xbox Failure: The Red Ring of Death

One of the most infamous product failures in modern electronics is Microsoft's Xbox 360 "Red Ring of Death" (RROD). The RROD [fig 4] became a symbol of frustration for millions of gamers and a financial nightmare for Microsoft. At the heart of the issue was condensation-induced electrochemical migration (ECM).



Figure 4. Microsoft Xbox RROD

When users powered off the Xbox 360, excessive cooling of a specific component caused condensation to form on the circuit assembly. This moisture provided the perfect environment for ionic residues left from the assembly process to cause electrochemical migration. In this failure mode, dendritic growth occurred, creating unintended conductive paths between traces. These paths resulted in electrical shorts, rendering the console inoperable.

The RROD led to a massive recall and repair campaign that reportedly cost Microsoft over \$1 billion [#1]. While the Xbox was not classified under IPC Class 3 standards, this failure exemplifies the importance of managing cleanliness and environmental factors, even in consumer-grade electronics. A more robust standard, accounting for environmental conditions and post-reflow cleanliness, might have mitigated this catastrophic failure.

The Professional Amplifier Manufacturer: "The Sound of Clean"

Another striking example comes from a major professional amplifier manufacturer [fig 5] in the music industry. This

company decided to switch from a traditional flux that required cleaning to a no-clean flux process, likely to reduce manufacturing costs and process complexity. However, the decision led to unintended consequences.



Figure 5. Professional Grade Amplifier

After implementing the no-clean process, customers began reporting a noticeable degradation in sound quality. Professional musicians and audiophiles, who demand pristine sound reproduction, found the amplifiers failed to meet their high standards. The manufacturer suspected that flux and other process residues left on the circuit assemblies were causing the issue, interfering with the performance of the amplifiers' sensitive electronics.

In an attempt to address the problem, the manufacturer reached out to us to clean their circuit assemblies. We proposed conducting a battery of cleanliness tests on the cleaned assemblies to quantitatively assess the improvement. However, the manufacturer declined formal testing, opting instead to rely on a unique and subjective method: a jam session.

During the jam session, they evaluated the sound quality produced by their amplifiers to determine if cleaning had resolved the issue. This informal test--dubbed "the sound of clean"--revealed a clear improvement in sound quality after cleaning. While unconventional, this anecdote underscores the critical role of cleanliness in ensuring reliability and performance, even in products that might not be categorized as high-reliability under IPC Class 3.

Lessons Learned from Real-World Failures

These examples demonstrate that cleanliness and environmental factors can have far-reaching impacts on product reliability and user satisfaction, even in devices that do not fall into IPC Class 3. They highlight key points:

1. **Unintended Environmental Conditions:** Devices may encounter unexpected environmental challenges, such as condensation in the Xbox example. This shows the importance of designing and manufacturing for resilience, in this case, proper thermal management, even in consumer

electronics.

2. **Hidden Costs of Shortcuts:** Switching to a no-clean process without accounting for its impact on product performance can lead to unforeseen issues, as seen in the amplifier example. While the process was likely cheaper, it resulted in compromised product quality and the need for additional corrective actions.

3. **The Role of Cleanliness in Performance:** Both examples illustrate that cleanliness is not just about meeting arbitrary standards but directly affects functionality and reliability.

Implications for IPC Standards

These real-world cases support the argument for redefining IPC classifications or creating a new category. Devices historically categorized as lower-reliability (Class 1) or mid-reliability (Class 2) are increasingly exposed to environmental stresses or performance expectations typically associated with Class 3 products. The Xbox failure and the amplifier issue demonstrate that even minor residues can lead to significant performance degradation or outright failure in certain conditions.

By incorporating enhanced cleanliness and environmental tolerance requirements into IPC Class 1 or introducing a new "Class 1X," the electronics industry can address these challenges proactively. This would help manufacturers produce devices that align better with modern expectations and avoid costly failures, reputational damage, and excessive recalls.

Arguments for a New Classification

Introducing a new IPC classification could address the gap between the current standards and the evolving needs of the electronics industry. This new class, which we might call "Class 1X," could be designed for products that do not require the full rigor of Class 2 or 3 but must meet elevated standards for cleanliness and durability due to their operating environments.

Key Features of the Proposed Class 1X:

1. **Enhanced Cleanliness Requirements:** Mandate post-reflow cleaning to remove ionic contaminants and ensure long-term reliability in harsh environments.

2. **Environmental Tolerance Standards:** Specify minimum requirements for temperature, humidity, and contamination resistance.

3. **Testing Protocols:** Include reliability testing for common failure modes such as electrochemical migration and corrosion.

4. Cost-Effective Solutions: Balance enhanced standards with cost considerations to remain viable for lower-margin products.

Benefits of Redefining IPC Standards

Redefining IPC standards or introducing a new classification offers several benefits:

1. Improved Reliability Across All Classes: Ensuring that even low-cost products meet basic reliability standards will reduce failure rates and enhance user satisfaction.
2. Industry Alignment with Consumer Expectations: Manufacturers can better align their products with the performance expectations of modern consumers, protecting brand reputation and market share.
3. Reduced Environmental Impact: Extending the lifespan of electronics, even in the lower classes, can reduce electronic waste and promote sustainability.
4. Simplified Manufacturing Decisions: Clearer classifications will help manufacturers make informed decisions about design, materials, and processes.

Challenges to Implementation

While the case for redefining IPC standards is strong, there are challenges to consider:

1. Industry Resistance: Manufacturers may resist changes that increase costs or complexity, particularly for low-margin products.
2. Standardization Across Diverse Applications: Ensuring the new classification is applicable across the wide range of Class 1 devices could be challenging.

3. Cost Implications: Enhanced standards could increase production costs, which might be passed on to consumers.

The Path Forward

The IPC community must recognize the growing disconnect between traditional classifications and modern usage scenarios. Collaboration between industry stakeholders, including manufacturers, designers, and end users, will be essential to redefining the standards. Key steps could include:

- Conducting a comprehensive study to assess the performance of Class 1 products in harsh environments.
- Engaging with industry groups to build consensus on the need for new standards.
- Piloting the proposed Class 1X standards with a select group of manufacturers to refine the requirements.

Conclusion

The IPC Class definitions for electronics have long provided a reliable framework for manufacturing standards. However, the increasing complexity and environmental demands of even low-cost devices call for a reevaluation of these classifications. By redefining existing standards or introducing a new class, the industry can better align with modern expectations and ensure that all electronics, regardless of classification, meet the reliability needs of their users. It is time for the IPC community to take a proactive approach and embrace the evolution of standards to reflect the realities of today's electronics landscape.

References:

#1. Gregg Keizer "Xbox 360 'Red Ring of Death' costs Microsoft more than \$1B" COMPUTERWORLD, June 5, 2007 Accessed: January 4, 2025 [Online]. Available: <https://www.computerworld.com/article/1579132/xbox-360-red-ring-of-death-costs-microsoft-more-than-1b.html>