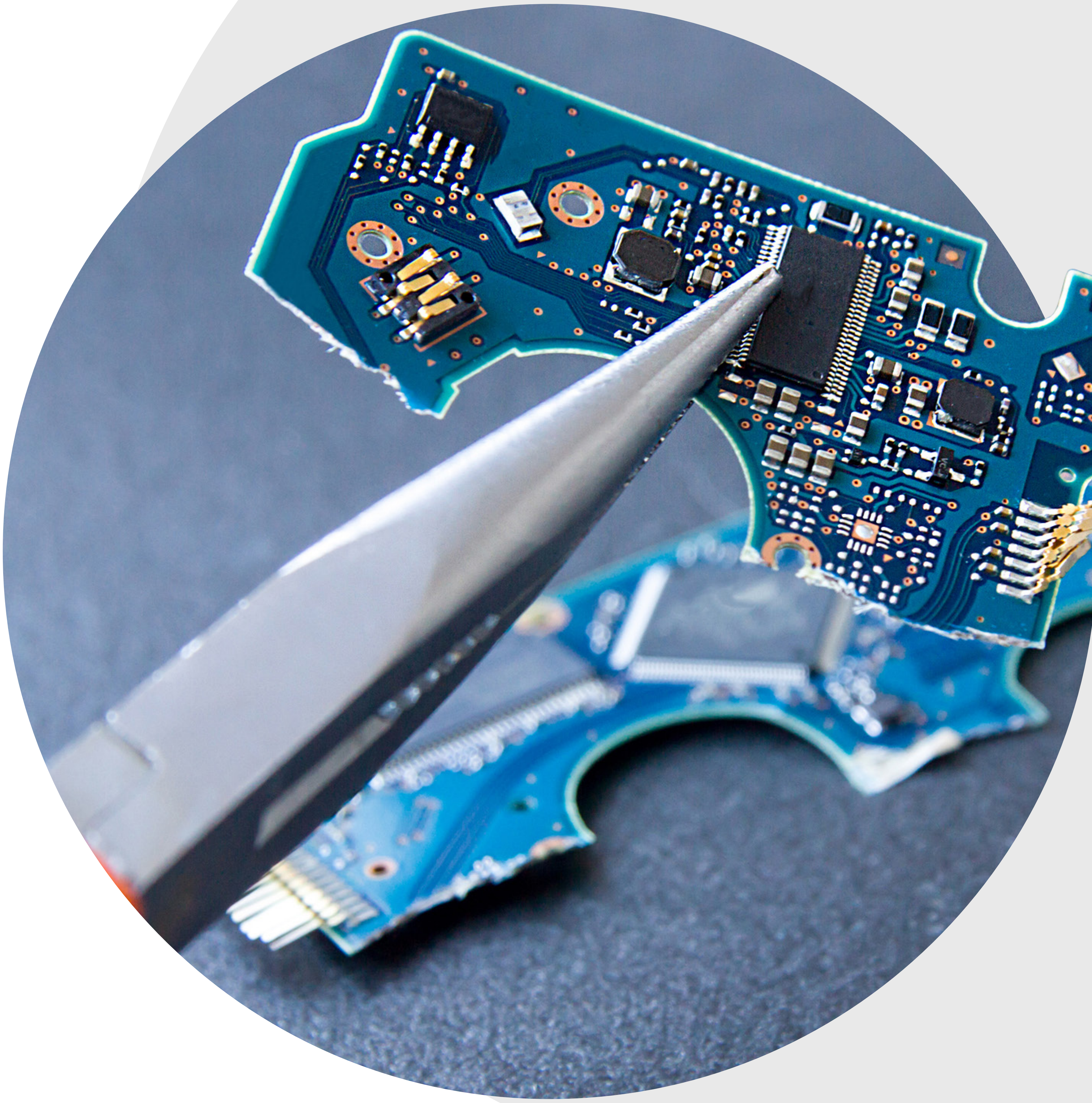

The High-Reliability PCBA Design and Test Challenge

Testing and Evaluation of High-Reliability PCBAs

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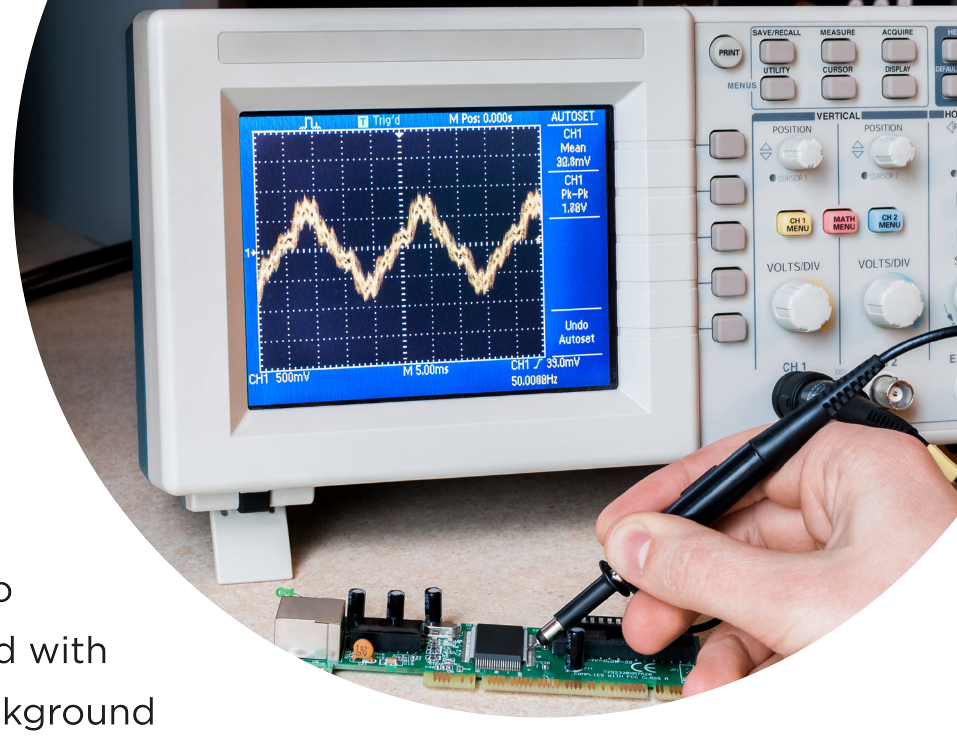
PCB Testing 101: Important Methods and Metrics



Manufacturers know that a lot will go into the PCB fabrication process in terms of quality control and PCB testing. There are many quality checks used to ensure a design will be manufacturable at scale and with high quality, but a lot of this can happen in the background without the designer realizing. Other important tests, like board bring-up and PCB functional testing, are generally the responsibility of a designer during prototyping, and these tests will get wrapped into manufacturing when producing at scale.

No matter what level of testing and inspection you need to perform, it's important to determine the basic test requirements your design must satisfy and communicate these to your manufacturer. If it's your first time transitioning from prototyping to high-volume production, read our list of PCB testing requirements so that you'll know what to expect.

PCB Testing During Manufacturing

There are several PCB testing procedures performed during fabrication and assembly. These aim to assess bare PCB quality and yield, and to ensure a design has passed through assembly without defects. In addition, electrical testing will be performed during manufacturing/ assembly and compared with the design netlist.

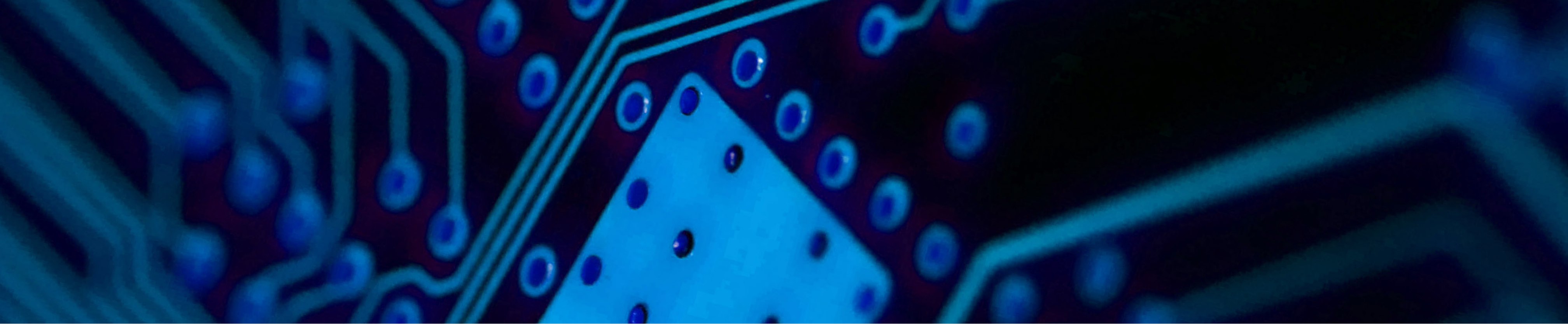
For prototype designs, testing doesn't end with manufacturing. Once the boards are received, the design team should put everything through board bring-up testing and functional testing before finalizing the design. Once you scale to thousands or millions of boards, some of these measurements may need to be automated to ensure high throughput and quality.

Mechanical PCB Testing and Inspection

There is a minimum set of mechanical tests and inspections that are performed during manufacturing to verify the bare board fabrication process and to ensure the board will be reliably assembled:

Test	What is Inspected	Criteria
Visual and X-ray inspection	Aims to identify any debris, delamination, or other damage on the surface layers (visual) and internal layers (X-ray). X-ray inspection is also used to inspect BGA or QFN packages for sufficient solder and closed connections.	Pass/fail
Peel test	Measures the force required to peel apart laminates in the PCB stackup once the stackup is constructed and fully cured (copper-to-laminate or laminate-to-laminate tests according to IPC-TM-650).	Pass/fail + specific value
Solder pot and float tests	Determines the solderability of plated through hole (PTHs), as well as whether the via barrel can withstand thermal stress during soldering before failing.	Pass/fail
Automated optical inspection (AOI)	Used to automatically spot assembly defects, such as insufficient solder, cracked joints, open connections (e.g., keyholing or tombstoning in extreme cases). Newer AOI methods developed with deep learning are being used to spot cold joints.	Pass/fail

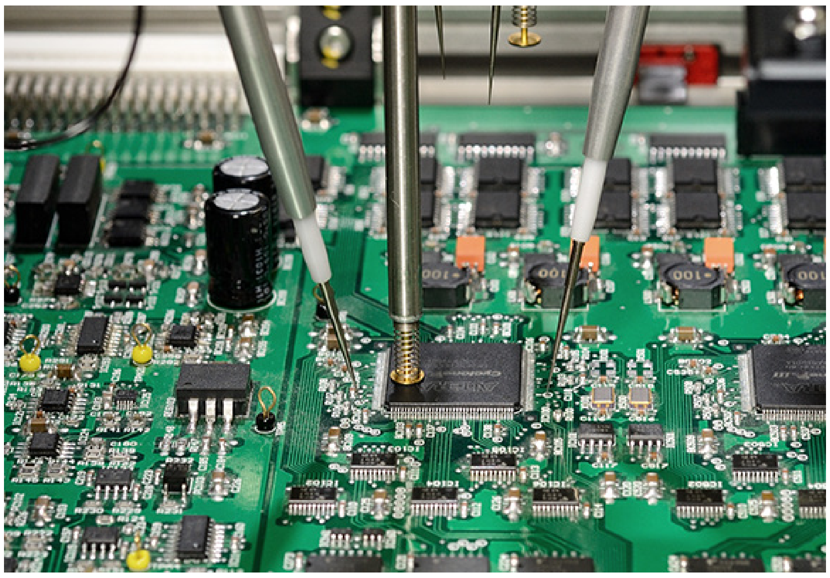
These tests can be used to determine whether there is some quality problem inherent in the manufacturing process, what rework steps might be required, or whether there is some aspect of the design that leads to a failed test.



Electrical PCB Testing During Manufacturing

Electrical testing is also performed during manufacturing to check for any faults, impedance deviations, or conductive residues from soldering:

- **Continuity test:** This measurement checks for opens and shorts with DC current in a bare board.
- **Hi-pot test:** A high potential test involves bringing the board up to a high potential in order to check that the board has sufficient isolation between different nets. This test is recommended for high voltage PCBs and on PCBs with thin dielectric layers.
- **In-circuit testing:** This test also measures for the presence of opens and shorts, as well as specific voltage/current values on test points. Sometimes a test fixture is used to measure a specific waveform. In addition, power-on or power-off electrical tests may be used with specific components or test points to check for component faults.
- **Resistivity of solvent extract (ROSE) test:** This conductivity measurement is used to check for any residue that may be leftover from solder flux.
- **Time domain reflectometry (TDR):** This test is used to measure impedance in single-ended and differential traces. This may be performed on a test coupon or on a test board with an attached fixture. Some subsequent de-embedding and analysis is needed to fully evaluate signal integrity.



Flying probe testers are used to probe specific points on the PCB to check for faults.

Controlled impedance tests are one area where you should rely on your manufacturer's data and experience before creating your design. If you request a controlled impedance service as part of your manufacturing order, they will be able to verify that your will hit your impedance specifications for their material set. Just make sure this is clearly specified for your manufacturer, such as in your fabrication notes.

PCB Stress Testing

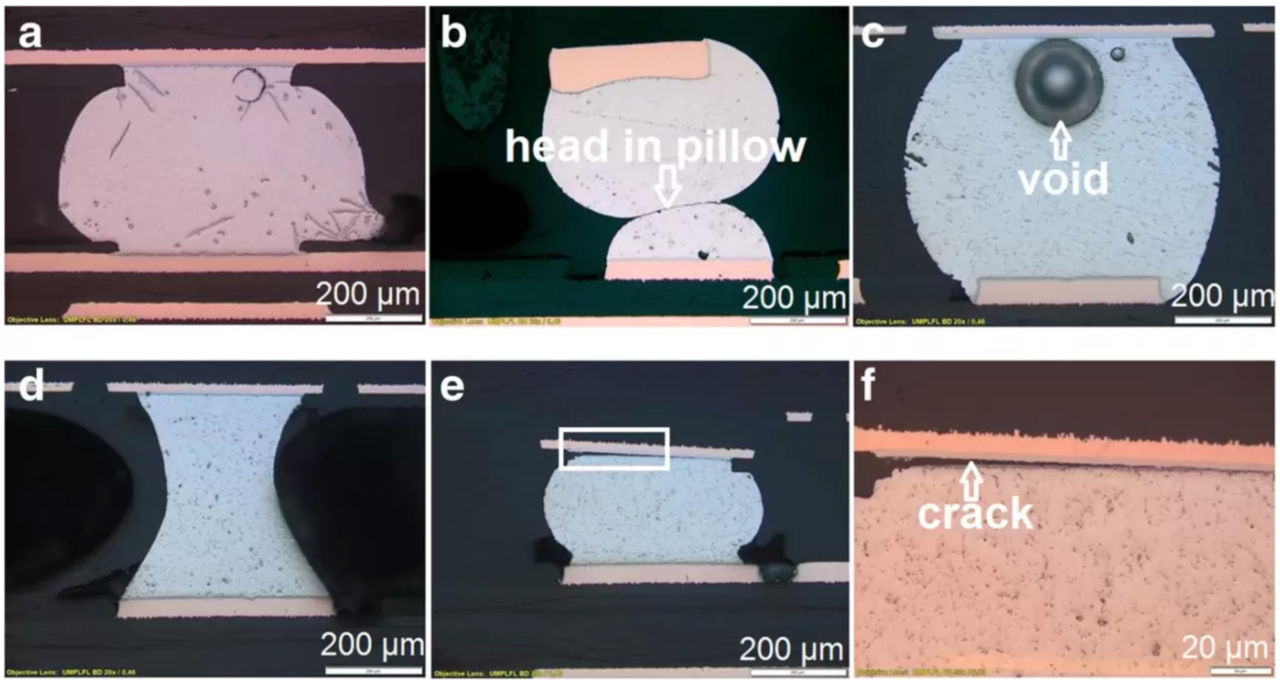
The above list includes the fundamental tests needed to ensure successful fabrication and to spot defects. In addition to the basic tests listed above, your board may need to pass through more stringent tests that are designed to stress a PCB to its limits. Once a PCB has passed through assembly, it might be put through a battery of stress tests to ensure it will meet minimum performance and reliability requirements. PCB stress tests aim to assess long-term and short-term reliability against idealized environmental conditions. Not all boards will need to have this set of tests performed by a manufacturer. For short prototype runs, these tests aren't generally performed, including by a manufacturer. Instead, the bare board and the finished assembly can be evaluated against reliability standards through inspection procedures.

- Vibration tests, e.g., under mil-aero standards
- NEMA/NFPA/FAA fire safety tests
- Thermal shock tests
- HALT/HASS tests (burn-in testing)
- Environmental exposure tests
- Electrical stress tests
- UL safety tests
- Any other product/industry-specific tests (IEC, ISO, etc.)

If your manufacturer cannot perform these more advanced tests, there are specialty testing companies that will qualify new products with a comprehensive methodology and a series of tests to order. UL tests and electrical stress tests are usually the most important when developing consumer or commercial products as they provide the baseline requirements for reliability. For other products in areas like medical, automotive, or aerospace, there will be much stricter standards both in terms of IPC Classes and other industry standards (SAE, MIL-STD, etc.).

Reliability and PCB Failure Analysis

What goes into reliability analysis and understanding root causes of failure? Once a board is stressed to the point of failure, or it simply doesn't pass the qualifications listed above, some investigation is needed to determine the root cause of failure. The first place to start is with functional testing (see below) to determine which specific features or capabilities have failed. If you start there, then you can narrow down to the specific point in the design where the failure likely occurred. In addition to electrical testing around the board, microsections are often used to investigate which specific points in the design may have failed and to determine the exact mechanism.



Here are some interesting examples of failures that can be seen in a microsection. [Source: Grosshardt, et al.]

If you have access to simulation applications and plenty of computing power, you can even run stress simulations to quantify things like mean time to failure, exact location and types of thermally-induced mechanical failures, and design exploration procedures to determine how the design or fabrication process should change.

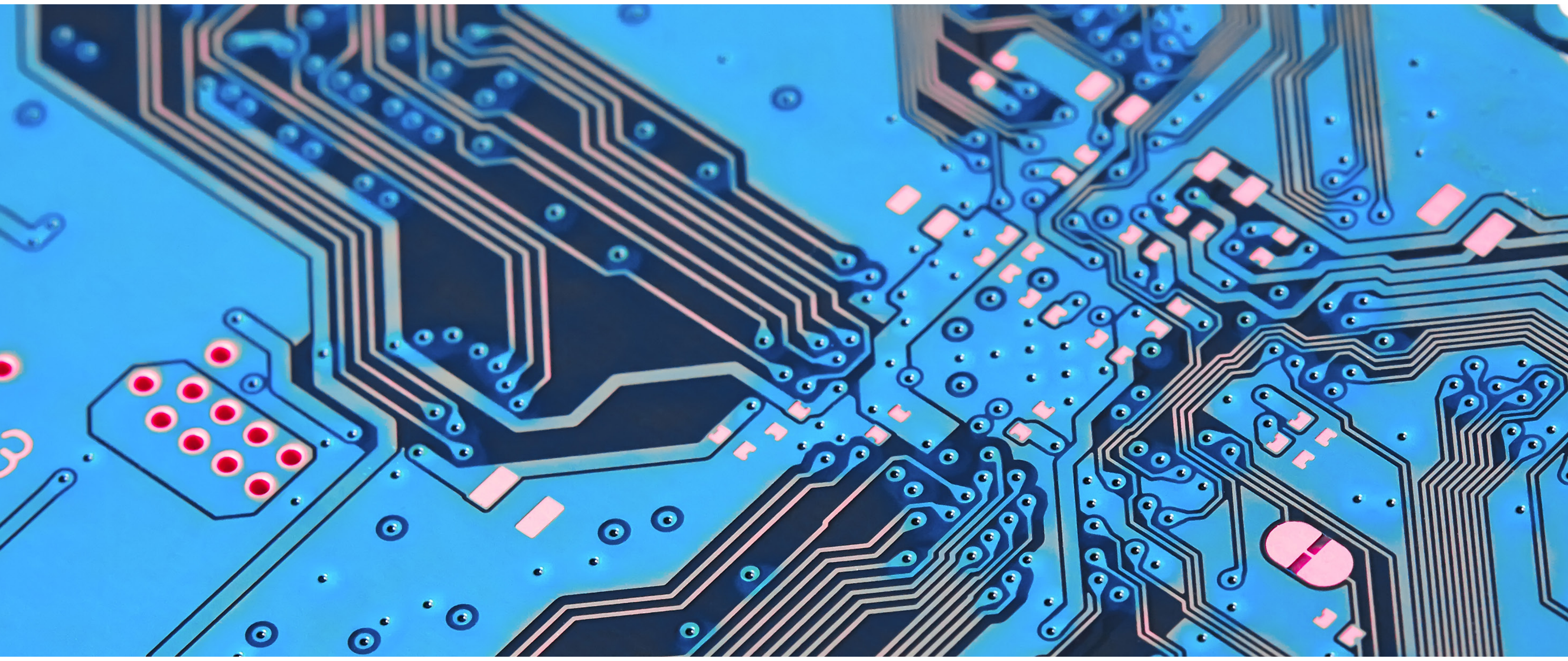
When failure is noticed and it is found to occur outside of normally anticipated operating conditions, you can consider this a success as long as the design is compliant with your design and reliability standards. No design is invincible, so don't be surprised if, eventually, the design fails under extreme stress. The goal is to determine that the design can perform reliably under some reasonable expectation of the conditions encountered during deployment. Reliability standards have been developed to address this specific point, and designing your PCB to be compliant with these standards is the first step in ensuring reliability.

Qualification

Before subjecting your board to a battery of reliability tests, make sure you're designing with reliability and safety standards in mind. Certain aspects of a design that determine reliability are mandated by some of the IPC standards:

- IPC-6011 General Performance Specification for Printed Boards
- IPC-6012D Qualification and Performance Specification for Rigid Printed Boards
- IPC-6013D Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards

These standards provide specific dimensional guidelines and tolerances to which a manufactured board must adhere. To be clear, the guidelines do not specify specific pad, trace, hole, or other feature sizes that your board must hit. However, they do specify a set of minimum criteria that must be met in a manufactured board for each of the IPC classes of products. Depending on a manufacturer's fabrication allowances and the class of product, certain dimensional targets with which the fabricated board must comply can be determined. A prototypical example is annular rings for Class III devices under the IPC 6012 standard.



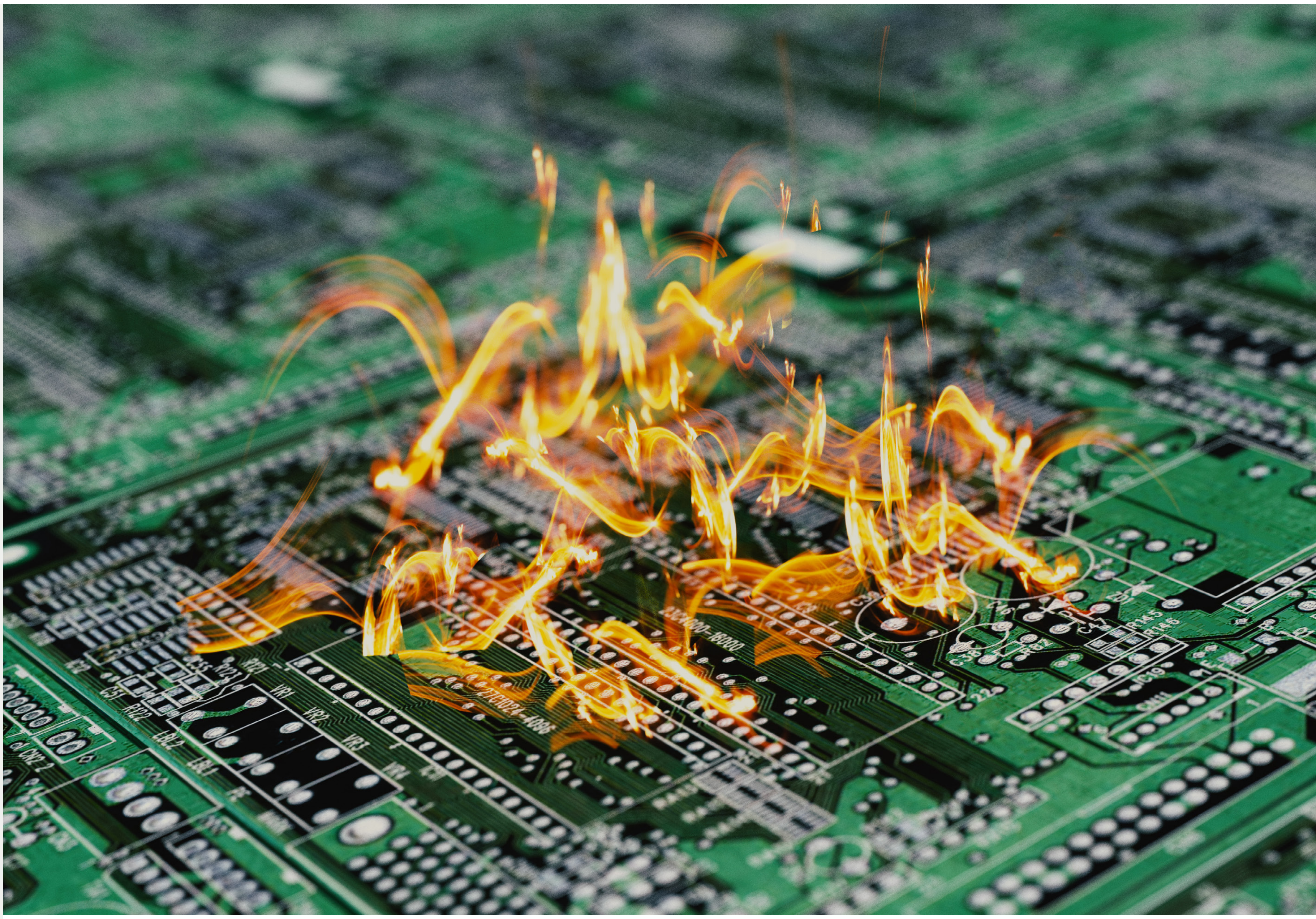
PCB Functional Testing

Functional testing for electronics includes a range of possible tests, many of which are focused on ensuring the product provides the desired user experience and end functions that were intended in the design. This is the responsibility of the design team during the prototyping phase, rather than the responsibility of the manufacturer. Remember, your manufacturer's job is to give you a PCBA that electrically matches the design data you give them, it is not typically their responsibility to perform functional verification unless you can help automate this testing.

In the event the design doesn't produce the expected functional test results, it's up to the designer to troubleshoot and debug the design to determine the problem. The designer or test engineer may need to manually gather some electrical measurements, experiment with firmware, and retrace problems through the design to locate the causes of any defects. Once these are located, they can be addressed in the next design revision and, ideally, can be incorporated as test requirements as the product is moved into higher volume.

If you're making the transition into higher volume, and your product's functionality or standards conformance requires passing specific electrical, thermal, or mechanical tests, you should specify these for your manufacturer, develop testing procedures in-house, or contract these services through an external testing firm. Talk to them early to make sure they understand what you need and that they have the capabilities to automate these tests to ensure product quality. It takes time up-front to complete these tasks, but you'll have some piece of mind knowing every possible fault has been anticipated in the design.

The best PCB design tools in Altium Designer® give you everything needed to define PCB testing requirements in your schematics and as attached documents. When you're ready to send your design out for manufacturing, you can easily release your design data to your manufacturer with the Altium 365™ platform. Altium 365 and Altium Designer give you everything you need to pass a design review, communicate test requirements, and communicate design changes.



What is Burn-in Testing for Electronics?

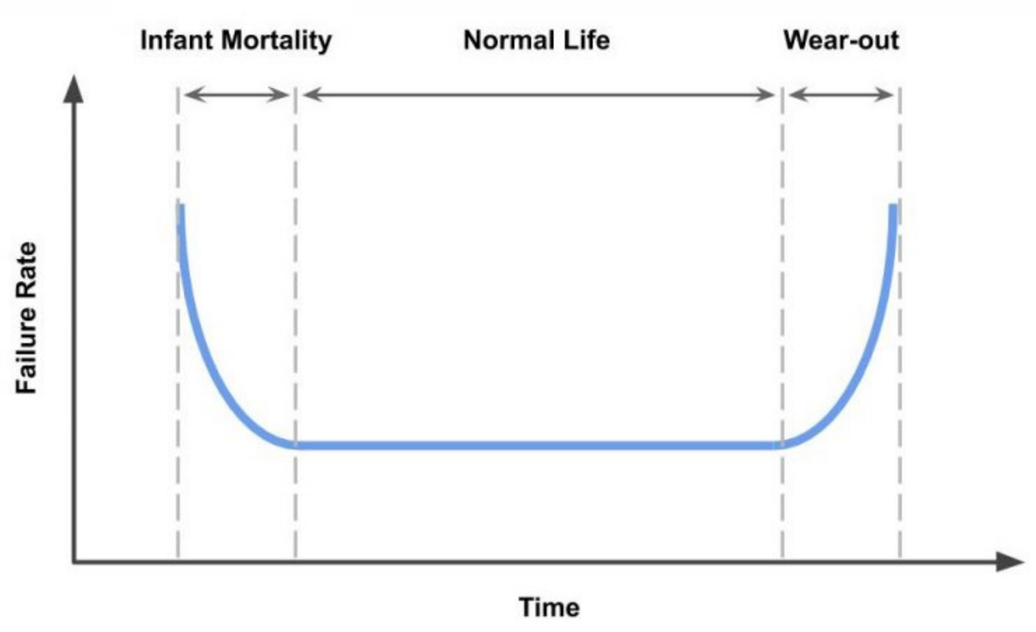
Once you're planning for production of any new board, you'll likely be planning a battery of tests for your new product. These tests often focus on functionality and, for high speed/high frequency boards, signal/power integrity. However, you may intend for your product to operate for an extreme period of time, and you'll need some data to reliably place a lower limit on your product's lifetime.

In addition to in-circuit tests, functional tests, and possibly mechanical tests, the components and boards themselves can benefit from burn-in testing. If you're planning to produce at scale, this is best performed before ramping up to high volume.

What is Burn-in Testing?

During burn-in testing, components on a special burn-in circuit board are stressed at or above their rated operating conditions in order to eliminate any assemblies that would prematurely fail before the rated lifetime of their components. These varied operating conditions can include temperature, voltage/current, operating frequency, or any other operating conditions that are specified as an upper limit. These types of stress tests are sometimes called accelerated lifetime tests (a subset of HALT/HASS), as they mimic the operation of a component for an extended period of time and/or under extreme conditions.

The goal in these reliability tests is to gather enough data to form a bathtub curve (an example is shown below). The unfortunately-named "infant mortality" portions comprises early component failures due to manufacturing defects. These tests are normally performed at 125 °C, which just happens to be the upper limit for high-reliability semiconductors. The test could be performed at a variety of temperatures while operated electrically to get a complete view of product reliability.



Bathtub curve showing product reliability

Burn-in tests and environmental stress tests can be performed with a prototype board at 125 °C, or above the glass transition temperature for the intended substrate material. This will provide some extreme data on mechanical stress failures for the board alongside data on component failures. Burn-in testing comprises two different types of tests:

Static Testing

A static burn-in involves simply applying extreme temperatures and/or voltages to each component without applying input signals. This is a simple, low-cost, accelerated lifetime test. Probes simply need to run into an environmental chamber, the chamber is brought up to temperature, and the device is brought up to the desired applied voltage. This type of test is best used as a thermal test to mimic storage at extreme temperatures. Applying a static voltage during the test will not activate all nodes in the device, so it does not give a comprehensive view of component reliability.

Dynamic Testing

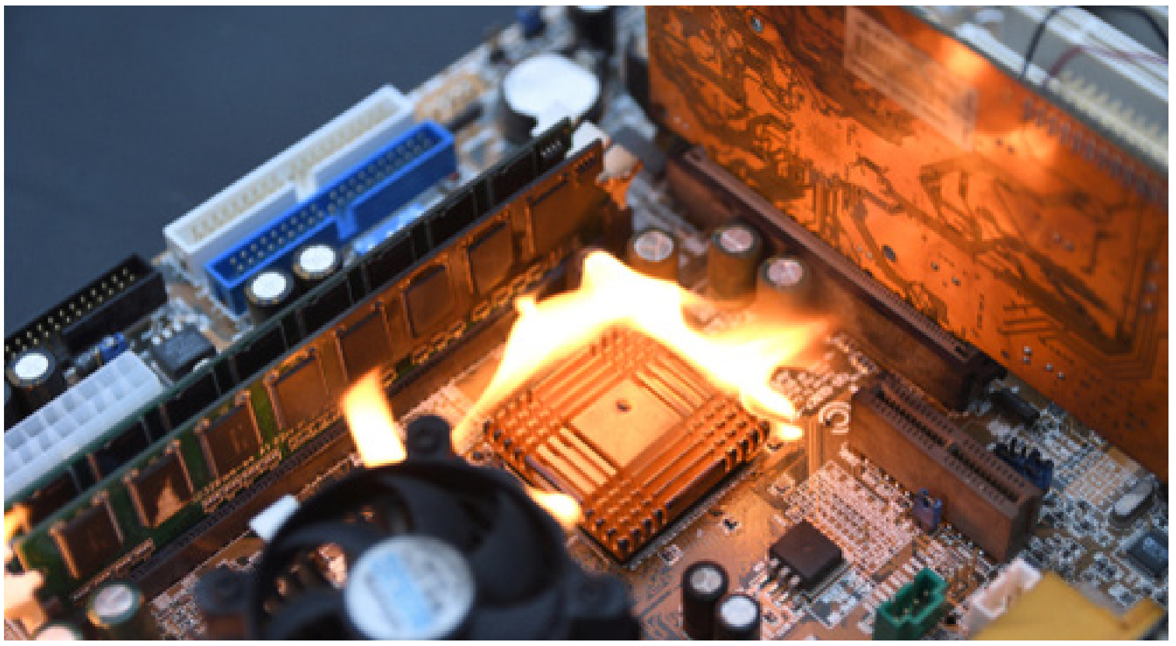
This type of test involves applying input signals to each component while a burn-in board is exposed to extreme temperatures and voltage. This provides a more comprehensive view of component reliability, as internal circuitry in ICs can be assessed for reliability. The outputs can be monitored during a dynamic test, giving some view of exactly which points on the board are most vulnerable to failure.

Any burn-in test that leads to failure needs to be followed up with a thorough inspection. This is especially true in stress tests for prototype boards. These tests can be time-consuming and expensive in terms of time and materials, but they are critical for maximizing the useful lifetime of your product and qualifying your design choices. These tests go far beyond in-circuit tests and functional tests, as they stress a new product to its breaking point.

Board-level vs. Component-level Reliability Tests

Burn-in tests do not refer specifically to stress tests with prototype boards—this is normally given the name HALT/HASS. Burn-in tests, alongside other environmental/stress tests, can reveal board-level and component-level failures. These tests can be performed exactly at specifications or above specified operating conditions.

Some board designers may be hesitant to accept results from burn-in tests and other stress tests that are above component specs, or outside the intended operating conditions for the board/components. The logic behind this is that the board and/or components will never see such operating conditions when deployed in its intended environment, so the test results must not be valid. This misses the point of over-spec'd burn-in tests and stress tests in general.



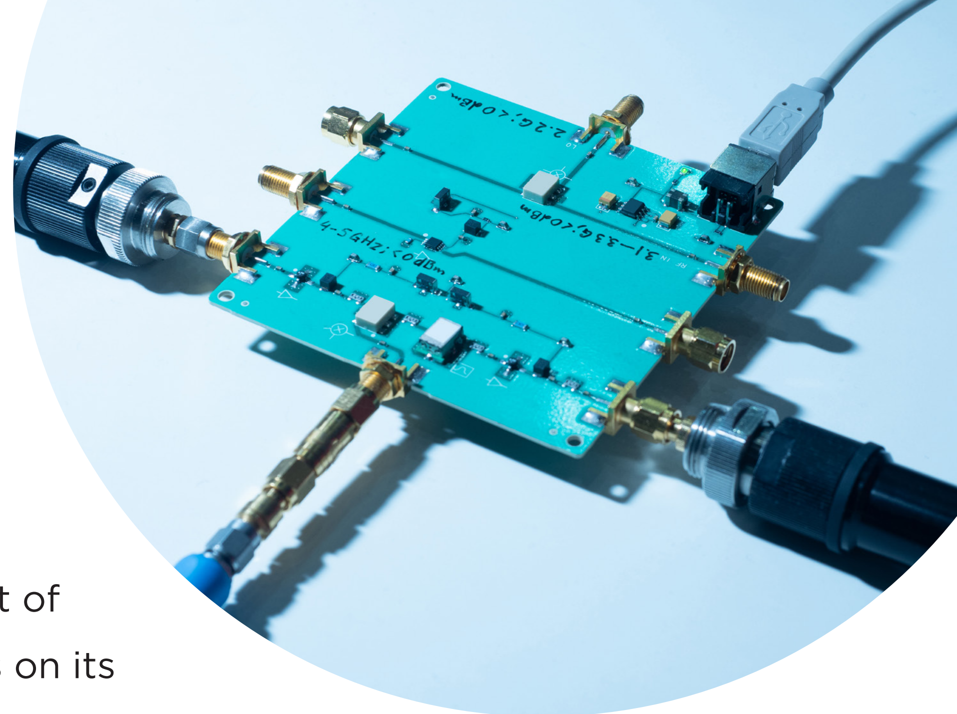
Board-level stress testing can prevent this type of disaster in your next design.

Running these tests over-spec allows more failure points to be located. Running multiple tests in series allows you to see how these failure points arise over time, giving you a much better view of reliability. Running over-spec simply provides greater acceleration of your product's lifetime and gives you a deeper view of the bathtub curve.

If you can address any failure points identified during an over-spec'd test, you can significantly increase the lifetime of your finished board. If you have access to supply chain data in your design software, you can easily swap out components with suitable replacements that have longer rated lifetimes. All these steps go a long way toward increasing the lifetime of your finished product.

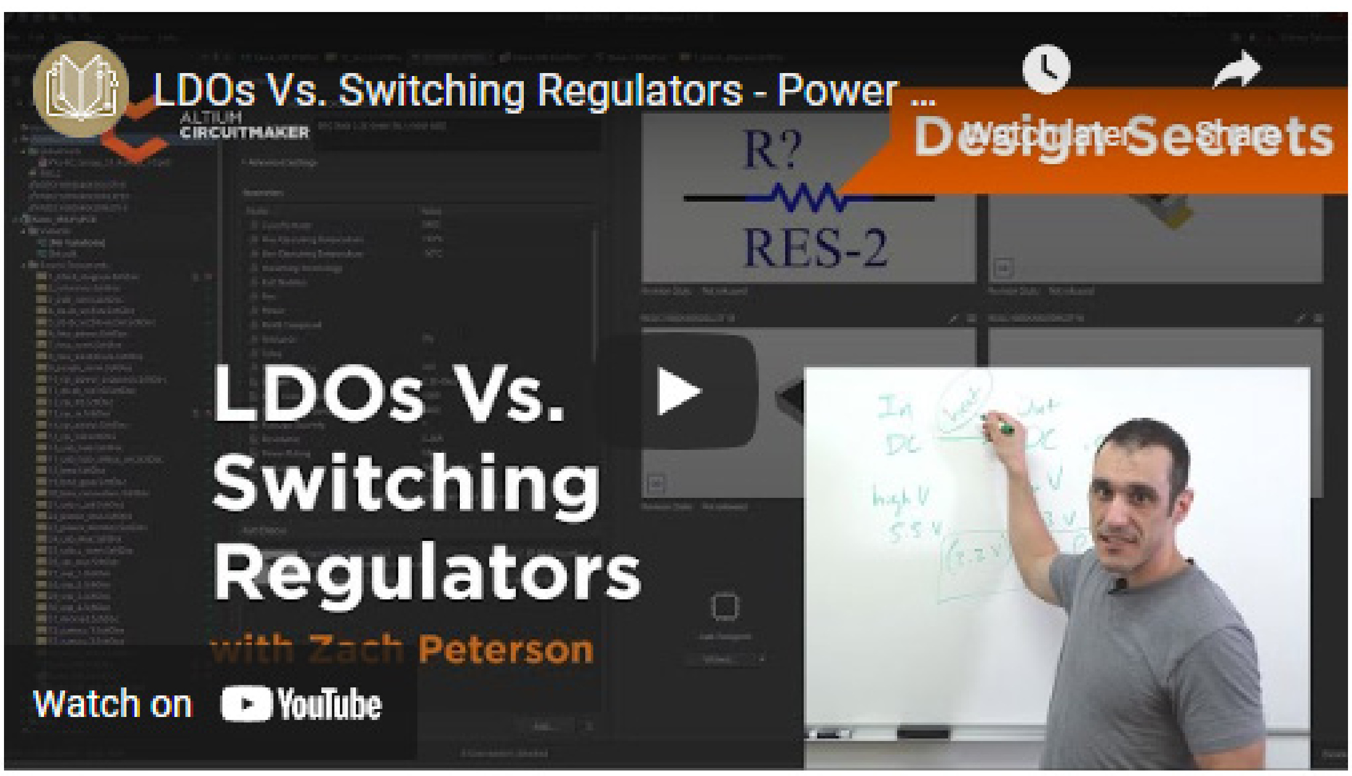
Once you get your burn-in test results from your manufacturer and you're planning design changes, you can quickly modify your layout and prepare for a new fabrication run with Altium Designer®. In addition to the industry-standard routing and layout features, you'll have access to a complete set of data management, design reuse, and supply chain visibility tools that make design modification easy.

Overview of Electrical Stress Test Methods for PCBAs



Quality control in volume production and prototyping have one important set of tasks in common: the need for PCB testing. The specific set of tests you'll need to perform in your PCBA depends on its application area, idealized service conditions, and of course the relevant industry standards on your product. Some basic tests and inspection tasks can be requested for your PCB/PCBA during fabrication and assembly, and it is a good idea to perform these tests at least to ensure continuity, accurate assembly, and simply to spot any obvious defects that might require rework.

High reliability applications may require more than simple electrical testing and inspection, either during fabrication/assembly, once prototypes get into the hands of a design team, and/or by an external testing lab. An electrical stress test is just one of the possible tests that should be performed in high reliability assemblies to ensure the PCBA can withstand demanding electrical conditions.



Electrical Stress Test Basics

To start, whenever something like testing gets brought up, new designers might think they've forgotten something or that they have to plan to do some extreme testing before they should accept a board as provided by their manufacturer. You'll be doing plenty of functional testing, but you won't need to worry about specifically quantifying stress limits in your board unless you're under some scrutiny from a standards organization (such as UL), regulatory requirements arise for your product, of you're making the transition to high volume.

If you're prototyping, or you're only producing small quantity of throwaway boards, then don't overthink this. Hobby projects, simple prototypes, demo board projects, or one-offs are not normally candidates for electrical stress testing. There are some QTY 1 exceptions, such as highly specialized aerospace products (satellites, drones, etc.). If your board won't be deployed in an area or conditions where there is risk of extreme electrical stress, then you probably don't need electrical stress testing.

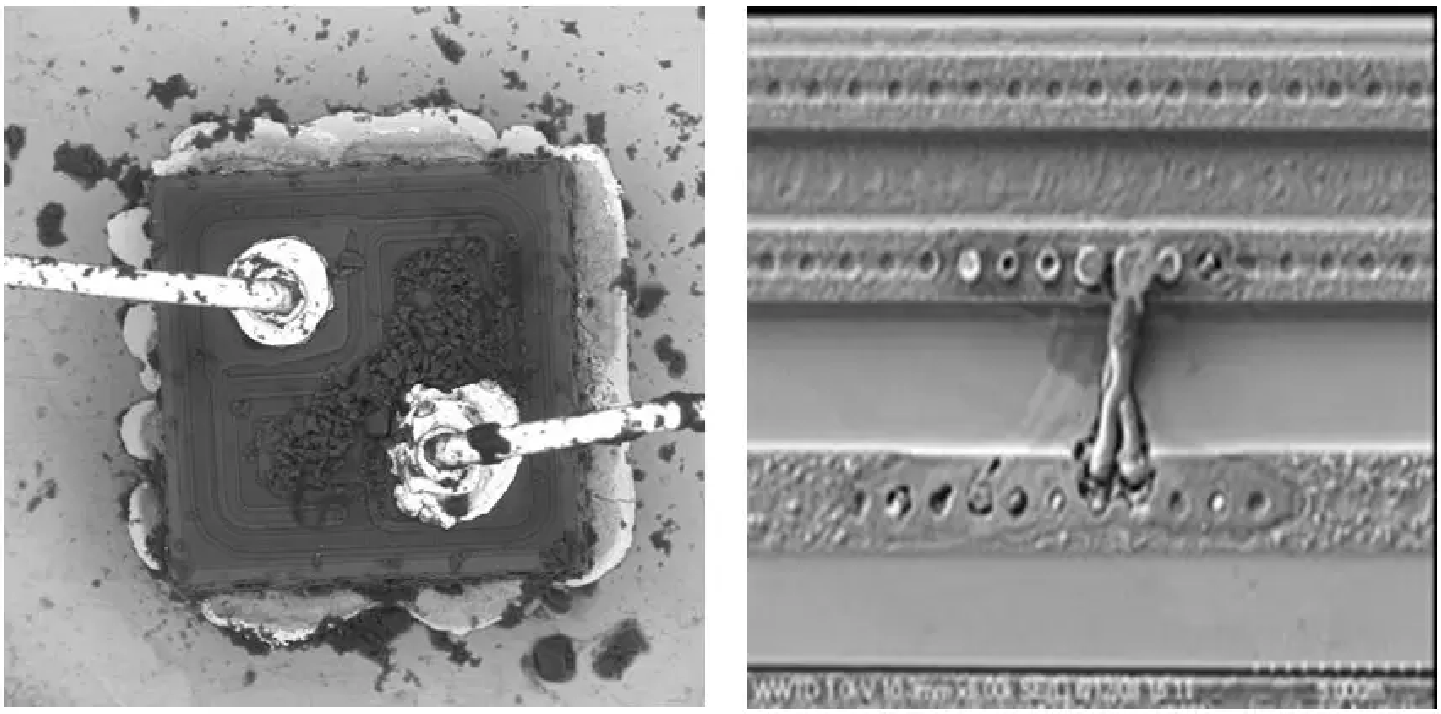
With that out of the way, what is the current state of the art in electrical stress testing, and what exactly is being "stressed"? Some of the main stress test methods might fall into these areas:

- Electrical overstress tests
- Electrostatic discharge (ESD) tests
- Environmental stress screening
- Accelerated life tests

The idea is to identify problems that would create an unintended failure in the board, or to simply quantify when the board specifically does fail (or both). While there are other quality control tests that might be performed during manufacturing, we'll focus on the above list for the moment.

Electrical Overstress (EOS) Tests

This is sometimes lumped in with ESD as they are both forms of overstress on components. An EOS test is probably the simplest electrical stress test that can be performed: components are basically overpowered, and the DUT is monitored until the device fails. This is normally performed at the wafer level or individual device level simply to quantify when the device will fail, as well as its failure mechanism.



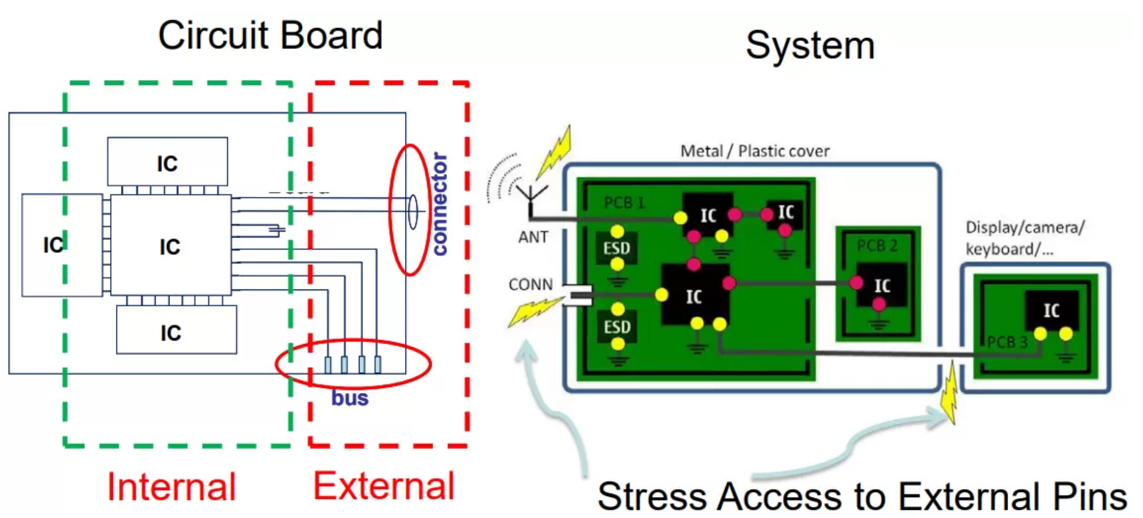
EOS failure (left panel) compared with ESD failure (right panel) for individual transistors. Note that the ESD failure creates a short between the collector and emitter regions. [Source: Desco Industries]

If you’re looking at the absolute maximum ratings in a datasheet, you’re seeing recommendations based on results from EOS tests for individual components. These ratings are defined with some margin of safety, so you might be able to exceed these values. What you’re not looking at is electrical overstress at the system level. This is where you’ll need to manually apply overstress to your system at each interface and power, and you’ll want to monitor performance or outputs to ensure the device can withstand any expected overstress.

Electrostatic Discharge (ESD) Tests

This test is exactly as it sounds: it tests the extent to which the PCBA can withstand ESD events. When an ESD event occurs, your PCBA will interact with a very strong electrical pulse, possibly reaching over 10,000 V and exceeding several amperes of current. Such an event can destroy components if it is not diverted back to a safety ground in your system. ESD circuits are designed to absorb and/or divert ESD pulses away from components and into the safety ground region in your system. Some digital interfaces, such as IEEE 802.3 standards on Ethernet PHYs, have their own ESD requirements that must be met at the component level.

JEDEC differentiates between ESD at the component level and at the system level. PCB designers need to consider what happens at the system level because this is the area that they can control.



This graphic shows where system-level ESD is likely to occur. Exposed IOs and connectors are obvious locations where an ESD event can propagate an electrical pulse into the system and possibly damage components. You can learn more from JEDEC.

A system level ESD event occurs within the PCBA and may affect multiple components, leading to one of the following outcomes:

- The system continues to work without problem
- The system experiences upset/lockup (soft failure), but no physical failure.
- The system experiences physical damage (hard failure)

Various industry standards beyond the IPC standards place requirements on the ability of a device to withstand electrostatic discharge. The specific test method depends on which standards will govern your product (such as IEC 62368-1/IEC 61000, ISO 10605 for automotive, DO-160 for avionics, etc.). Refer to the relevant safety standards for your product and industry to determine the level of ESD protection your product will require.

Environmental Stress Screening (ESS) Tests

These tests are meant to closely simulate the idealized deployment environment for a device. ESS testing could involve applying thermal cycling, drop tests, vibration tests, thermal/mechanical shock tests, and any other environmental or mechanical exposure a device will be expected to receive during operation. More specialized testing methods might involve crash tests, pressure and humidity tests, and even altitude tests. Highly reliable systems will need to stand up to all of these environmental factors during electrical operation, so a combination of tests is generally needed to ensure reliability.

A large controlled environmental chamber is used for pressure, thermal, and humidity testing while a device is in operation. In some devices, these stresses may change the probability of failure in an overstressed device.

Functional testing is also performed before, during, and after these tests to fully qualify whether the design will fail and whether functionality is compromised. These tests don't just look at the electrical stresses, they also qualify functionality in a variety of stressful situations that might be inclusive of electrical overstress or even ESD. Since this is typically a combination of specialized tests that need to be performed, rigorous evaluation is performed by the design team, and not a manufacturer.

Accelerated Life Tests

This refers to a set of possible tests that are meant to determine the approximate useful lifetime of a new device. Accelerated life tests are often lumped together as "burn-in testing", although there are several variations of these tests. Accelerated life tests can be divided into the following areas:

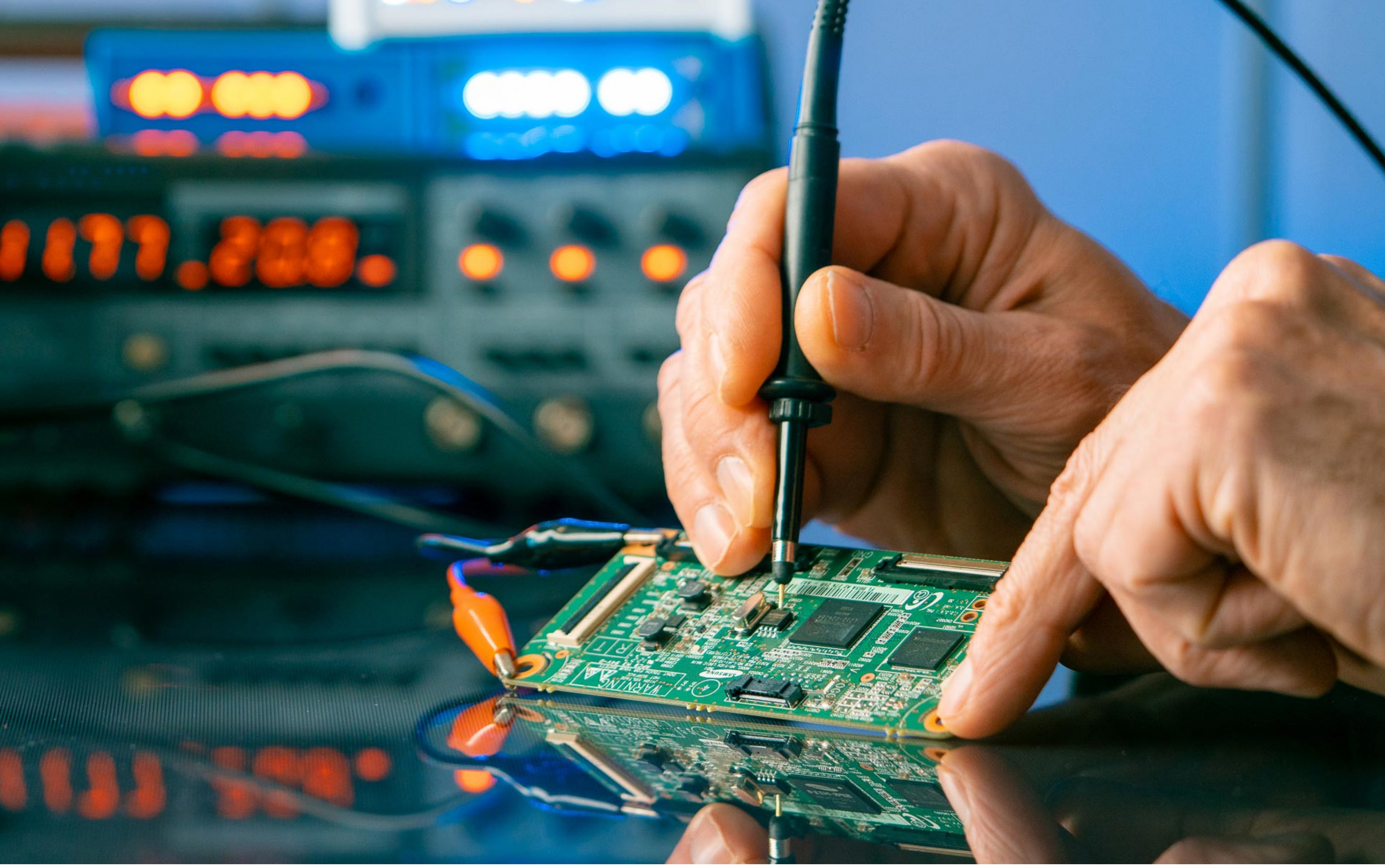
- **Burn-in testing:** A method for identifying which components and/or assemblies will fail early using statistical techniques.
- **Highly accelerated life testing (HALT):** Here the goal is to stress a device until it fails in gross overoperation. This mimics overoperation in the actual environmental conditions where the device will be deployed.
- **Highly accelerated stress testing (HAST):** Similar to HALT in that the design is stressed until total failure.
- **Highly accelerated stress screening (HASS):** Uses the same environmental stresses as in HASS, but at lower levels, and typically after a complete HALT test is completed.

Any of these lifetime/stress tests could be performed along the other test methods mentioned above as long as the right testing chambers and equipment are available. Such combinations of tests can be highly specialized, but they are essential to determining lifetime and identifying failure mechanisms in electronics.

Failure Analysis

The above electrical stress tests are intended to both identify the limits of a device, while also evaluating whether it can withstand environmental conditions during operation. If you find that the design can't stand up to the expected level of stress and it fails, some failure analysis is required to determine the root cause of the failure in your device. Failure could occur at the component level, board level, or both, and some forensic investigation is needed to determine the failure mechanism with certainty. We'll look at these points in some upcoming articles.

When you need to specify your electrical stress test requirements, inspection requirements, and even mechanical performance requirements, use the complete set of design and documentation features in Altium Designer®. The integrated manufacturing tools and the Draftsman utility can help you specify your performance requirements for your product. When you've finished your design, and you want to release files to your manufacturer, the Altium 365™ platform makes it easy to collaborate and share your projects.



Overview of PCB/PCBA Reliability Testing and Failure Analysis

Reliability testing and failure analysis of a PCB/PCBA go hand-in-hand; when designs are stressed to the limit, their failure modes need to be determined through thorough inspection and analysis. Some of these tests and potential causes of failure are handled by manufacturers as they might arise during bare board fabrication, while other potential problems with the PCBA should be addressed by a design team during prototyping and design qualification. High reliability designs, such as in areas like avionics and defense, can require extensive environmental testing and qualification to ensure they will function in the intended environment.

To get started on this topic, it's important to understand the qualification aspects that will govern your bare board design and the PCBA. We'll look at the various dimensions of PCB/PCBA reliability, as well as some of the standard failure analysis techniques used to identify potential design change requirements.

PCB Reliability Testing Standards Overview

Reliability testing broadly involves exposure of a PCB or finished PCBA to extreme environmental conditions (heat, corrosion, humidity, etc.), followed by performance tests to ensure the device can withstand those conditions. Within the discipline of reliability testing, there are many possible sources of stress on a PCB and the finished PCBA:

- Mechanical loading (static load, vibration, and shock testing under MIL-STD/IPC/SAE stadnards)
- Thermal or climate loading (heat flux, extreme temperature, thermal shock under IPC-TM-650 2.6.7 and MIL-STD-202G; thermal cycling under MIL-STD-883 Method 1011, IPC-9701A [6], and JEDEC JESD22-A106)
- Electrical loading (high power, derating verification, EMC, all in conformance with IPC/IEC/SAE standards) and UL conformance
- Chemical loading (corrosion or other chemical exposure to match deployment environment)
- Exposure to ionizing radiation (computed as total ionizing dose (TID))
- Exposure to dust, particles, and liquids
- Artificial aging tests for electronics assemblies (HALT, HASS, HATS, etc.)

What's Involved in Reliability Testing?

A PCB reliability assessment requires a set of tests that focus on each of the areas listed above. Basic fabricated board tests will be performed on your stackup by your fabricator, and they should be able to certify the bare board will conform to your requirements as you specify in your PCB fabrication notes. For the PCBA, testing and reliability can be more extensive. Your fabricator/assembler will perform their own series of tests and inspections to verify conformance to an IPC product class and basic IPC standards on bare boards, but it will often be up to the design team or a contract testing firm to run more specialized tests (environmental or chemical tests) on the design to verify reliability.

Guides to tests in any of these areas would involve a series of articles, so I won't get into all of these aspects of reliability testing and verification. Standards documents provided by IPC, MIL-STD, SAE, NASA/DO, and other organizations provide guidance in this area, as well as specific procedures for performing these tests. IPC-TM-650 contains standardized test methods for PCBs, but the other documents mentioned above may go beyond the requirements in IPC-TM-650 for specific products and industries.

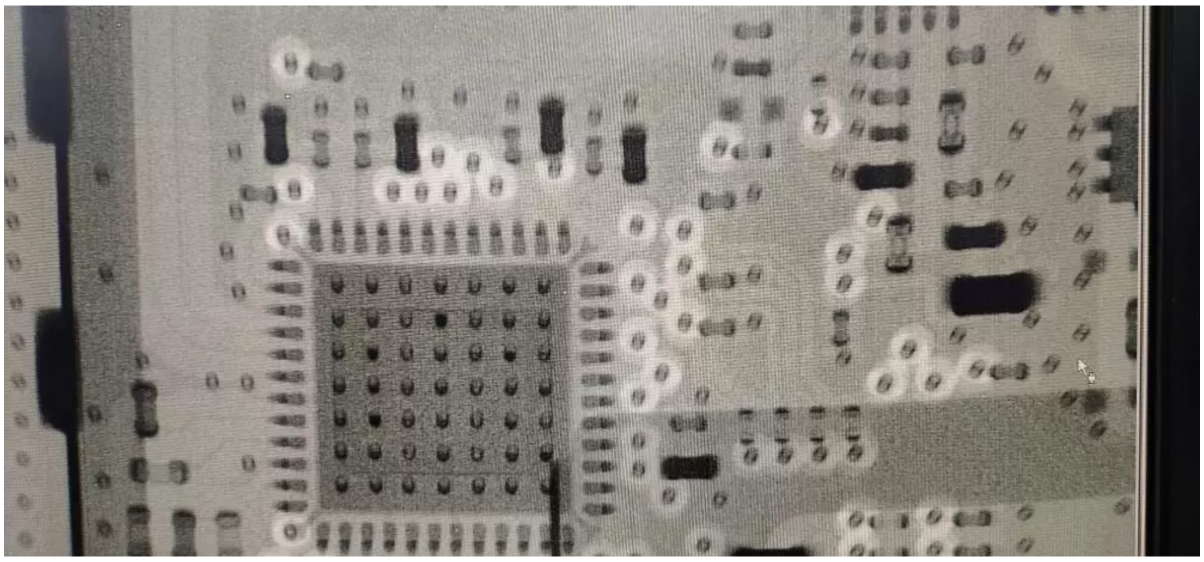
PCB Failure Analysis

Determining the limits of PCB reliability is all about pinpointing failures, as well as how they arise in the device. Once a board failure occurs, it needs to be investigated and Failure can arise gradually due to accumulated damage (e.g., fatigue), erratically (random or intermittent), or sudden (due to shocks). When failure modes are being investigated, application of the above tests involve cumulatively stressing the PCBA until failure (thermal, mechanical, and environmental), followed by examining the board to locate and examine the specific failure.

The table below matches the standard PCB failure modes to inspection and failure analysis methods used in a PCB.

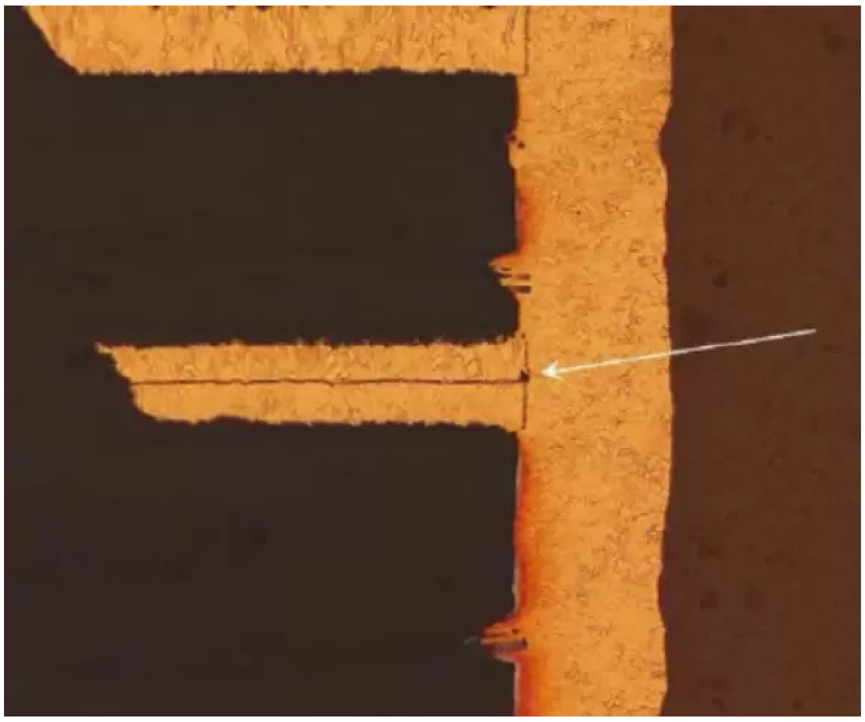
Inspection Method	Failure Mode
Optical inspection	This involves using high power optical microscopes to inspect the surface layer of a PCB. Failures to be located include corrosion, failed solder joints, shorts or opens, build-up of solid contaminants (e.g., corrosion), or damage to the surface layer.
Microsection analysis	This requires cutting out a small section of the board and inspecting it either optically or with a scanning electron microscope (SEM). This is most often used to inspect lamination, plating migration, via reliability, and roughness.
Contamination testing	This would be used to investigate specific contaminants that might accumulate on the board during assembly (e.g., flux) or during operation. In some environments, boards might be exposed to hazardous chemicals, and it's important to quantify the extent to which these substances could contaminate the PCBA.
SEM/EDX inspection	When something on the surface or microsection is identified and requires much deeper inspection, SEM would be used to visualize the sample. EDX analysis can be used for chemical composition determination, and it would be used
X-ray inspection	Anything that cannot be seen visually or in a microsection test. This can be used for in-plane failure inspection, BGA failure inspection, or other in-plane failure modes.

Identifying defects in each of these areas takes some skill. Some of these are obvious, such as extreme corrosion due to exposure to moisture, while others are only obvious to the trained eye. For example, identifying a failure from an X-ray image is not so obvious due to the contrast and resolution in the recorded image.



Example X-ray image showing a QFN package with ground pad.

Something like conductive anodic filamentation due to prolonged operation at high voltage or fracture of a via barrel during operation is quite easy to spot, either from a microsection sample or from an SEM image. Both are clearly visible with the right imaging technique. As an example, the image below shows fracture clearly visible in a microsection, which may create an intermittent failure.



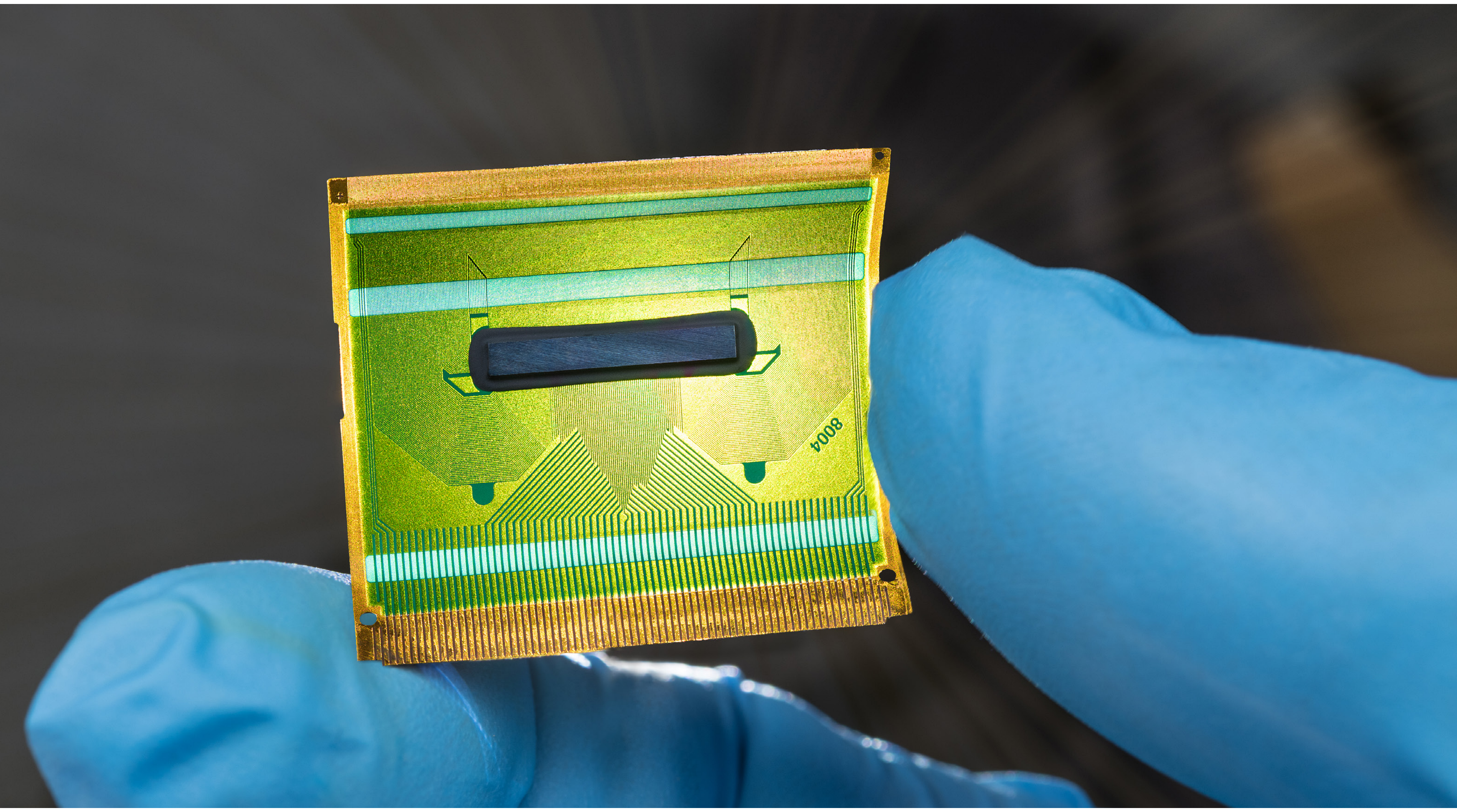
Example via barrel failure during a thermal excursion. Image courtesy of NASA.

Once a defect or failure is identified, some steps should be made to prevent the problem from occurring during operation, or to modify the design so that it is more resilient against this type of problem. This has to be approached on a case-by-case basis, depending on the type of defect and mechanism that caused the failure.

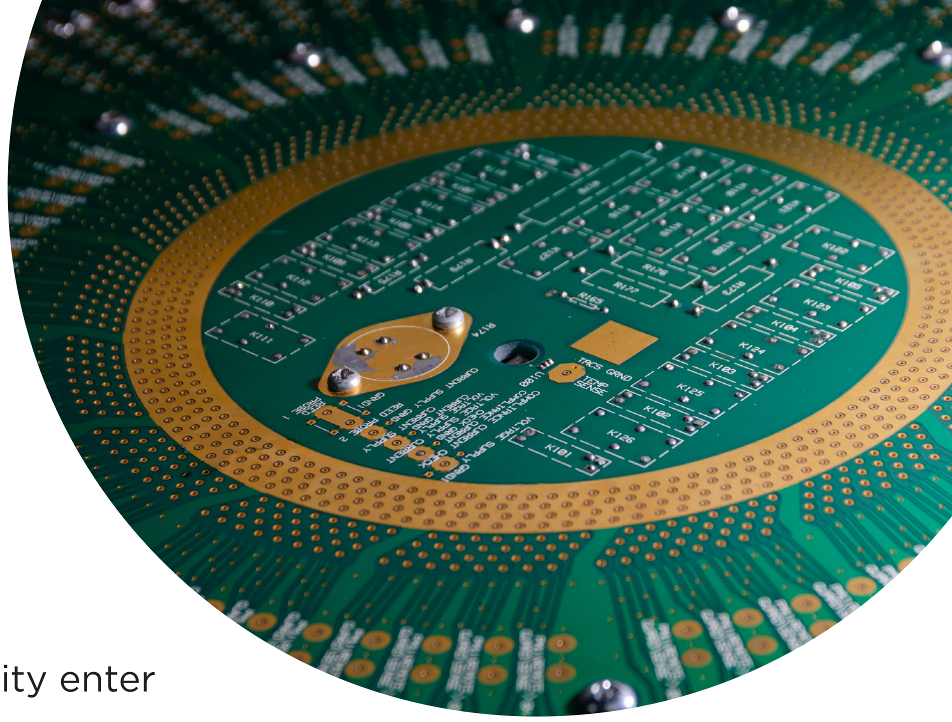
Final Thoughts

The key to remember here is that no PCBA will be invincible, and any design can eventually be stressed until catastrophic failure. If the applied stresses are so extreme that they are highly unlikely to be ever encountered during operation when deployed in the product's intended environment, then you can consider your design successful from a reliability perspective. When testing for reliability and investigating failures, it pays to consider the failure modes your device will be most likely to experience during operation and address those first.

Once you've used your PCB failure analysis results to identify required redesigns, you can implement design changes with the complete set of layout features in Altium Designer®. When you've finished your design, and you're ready to release files to your manufacturer, the Altium 365™ platform makes it easy to collaborate and share your projects. Your manufacturer can also complete their own design review to help ensure high yield and quality as you scale.



Using PCB Thermal Simulation and Analysis Software in Your Design Workflow



PCB design follows a specific workflow involving schematic capture, PCB layout, and generation of outputs. Where should thermal analysis and reliability enter in to the standard PCB design workflow? These considerations arise at multiple points during design as thermal management challenges create reliability problems in components and the completed PCBA.

Thermal management in your printed circuit board focuses on directing heat from hot to cool areas, ultimately reducing the temperature and producing an even temperature distribution throughout the printed circuit board. Your arrangement of components, the PCB stackup, and other components can be used to direct heat away from an assembly and into the enclosure, or it can be carried away with forced airflow. Design software that integrates with an external field solver will help you qualify your PCB stackup and eliminate hot spots in the PCBA during operation.

PCB design software for advanced electronics that interfaces with many 3rd party applications, including PCB thermal analysis software.

PCB thermal analysis can involve multiple tasks that are intended to evaluate heat transfer through the structure of the PCB. This requires pinpointing where heat will be generated and the expected temperature of components during operation, as well as understanding how the structure of a PCB substrate will aid heat transport. Unfortunately, these are complex multiphysics problems that involve field solvers to fully evaluate. Once airflow is driven through the PCBA, the effect of airflow before prototyping can only be evaluated with CFD simulations, something with which not all designers may be familiar.

Designers that have access to these advanced field solvers should use PCB design software that can interface with PCB thermal analysis software within the standard workflow. Before exporting into a PCB thermal analysis tool, there are some simple steps a designer can take to help manage heat generation in the board and prevent excessive temperature rise during operation.

Identify High Temperatures and Prevent Hot Components

PCB thermal management focuses on three principle areas:

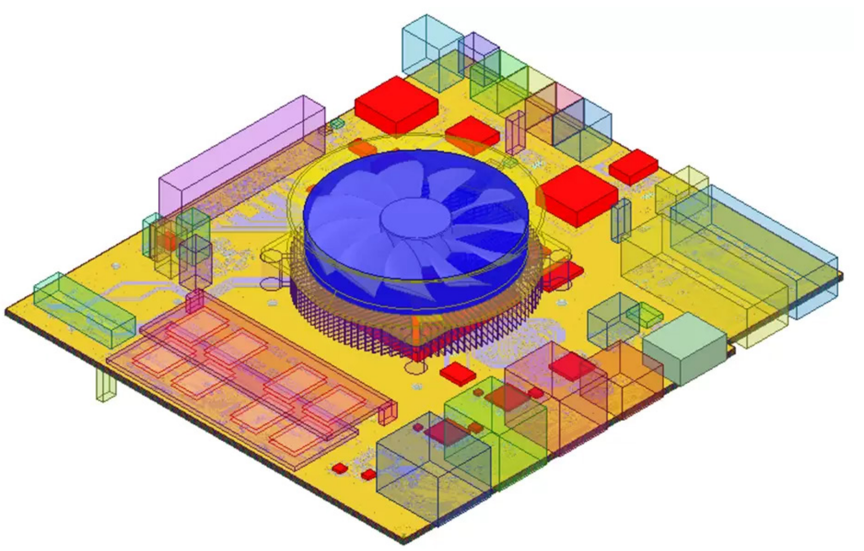
- Identifying excessive temperature rise in components and in the board substrate
- Selecting board materials to provide heat transport and produce an even temperature distribution
- Moving heat from hot to cool areas via airflow or conduction

PCB thermal analysis software can help with these tasks at various points in the design phase. The best time to use PCB thermal analysis software is once the PCB layout is completed but before prototyping. However, if you can implement some basic analysis strategies before exporting your design into a PCB thermal analysis software program, you can reduce the extent of any required redesigns with some best practices for thermal integrity.

Component Heating

One step you can take to aid thermal analysis and ensure you've identified any hot components in the board is to use thermal resistance values for components to determine their operating temperature. Some components will obviously run at very high temperatures, such as large processors with high I/O counts. However, other smaller components may get very hot even though they can run within their operational limits. LDOs, PMICs, MMICs, and some ASICs are great examples. Identifying these early may help inform where to place these on the PCB so that they receive airflow or connect to a heat sinking element or back to the enclosure. Another possibility is to separate these parts into different areas if possible so that large hotspots do not develop in one area of the board.

Learn more about thermal resistance specifications.



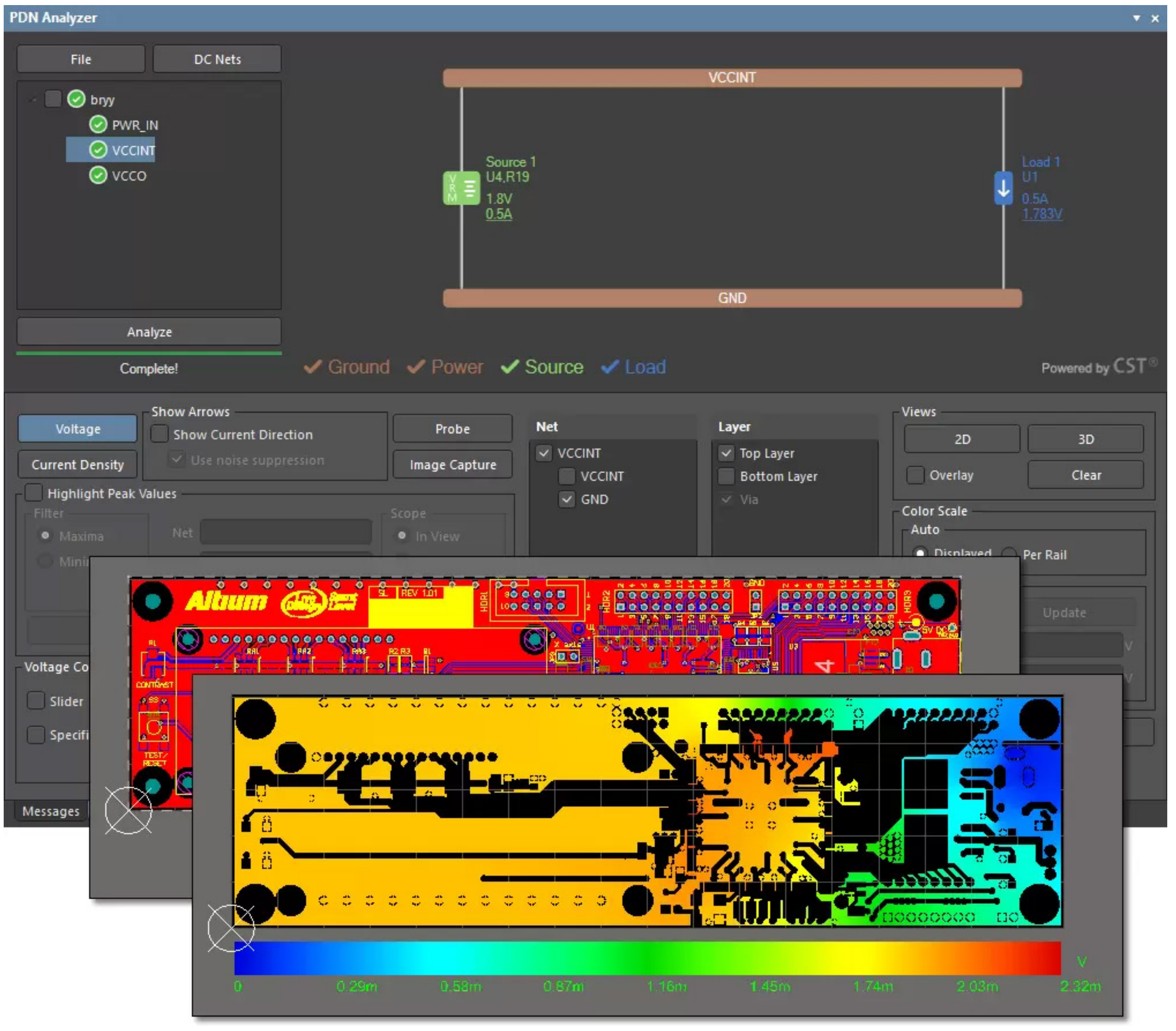
In this heat map, the components that generate the most heat are marked in red.

DC Power Loss

DC power loss is one contributor to heat generation in a PCB, particularly in power electronics. Smaller digital design and most analog designs will not need this type of simulation. However, power electronics need to ensure power is transferred with minimal loss as this will help minimize heating and maximize power delivery efficiency. DC power losses in your system can be evaluated with a PDN analysis simulation, which will calculate DC power distribution in the PDN.

While a PDN analyzer does not directly show you the amount of heat dissipated or the temperature in your PCB layout, it will show you where hot spots in the PDN are likely to occur. Simple changes can then be made to help improve the integrity of the design and prevent board-level failures.

Learn more about using the PDN Analyzer in Altium Designer.



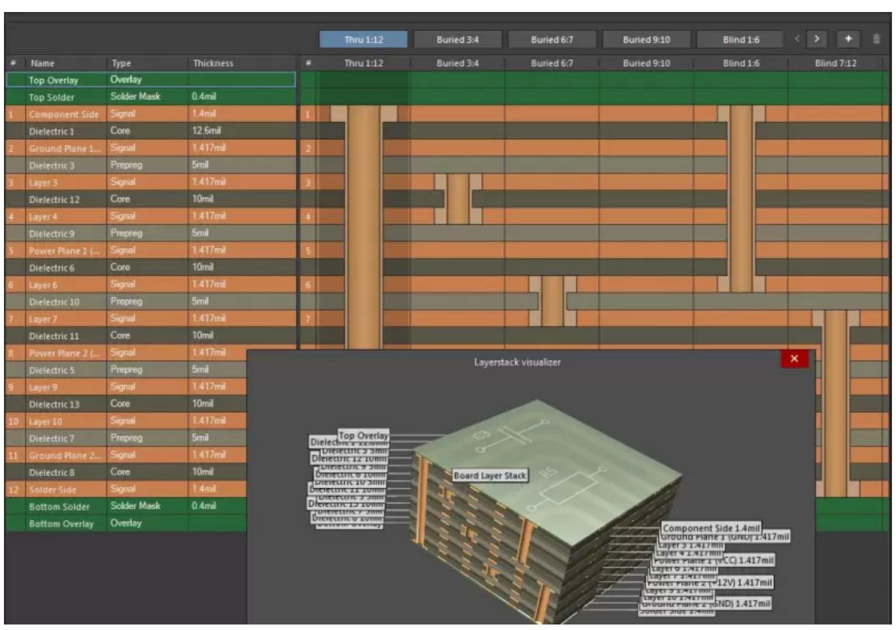
Power dissipation simulation results with the PDN Analyzer in Altium Designer. These results can be used to identify any areas where power dissipation in the PCB is excessive.

PCB Material Selection and Stackup Design

Material selection in a PCB requires choosing a resin and curing agent system, material thickness, and copper weight. The thickness of dielectric layers between hot copper regions and nearby planes is also important as it determines how easily heat can be transported around the PCB.

- **Copper weight:** Boards with heavier copper weight can withstand higher current for a given target equilibrium temperature.
- **Resin content:** Prepregs with higher resin content will tend to have higher thermal conductivity. These materials may also be preferable in some power electronics, such as in high voltage boards.
- **Glass transition temperature:** Any board that will experience large thermal excursions should have a high glass transition temperature. Typical high-Tg laminates will experience a glass transition at 170-180 °C.
- **Plane layers and laminate thickness:** Placing a plane layer closer to a hot area of copper will help remove heat from the hotter region and transport that heat to other areas of the board.

After selecting these specifications on laminate materials, you can build the PCB stackup and send it to your fabrication house for validation. Make sure you understand all the relevant material properties of PCB laminates when selecting materials.



Learn more about PCB laminate material properties.

Material selection and stackup design will help address thermal challenges in a PCB. During stackup design, copper and laminate selection will determine the thermal resistance of the PCB and its equilibrium temperature during operation.

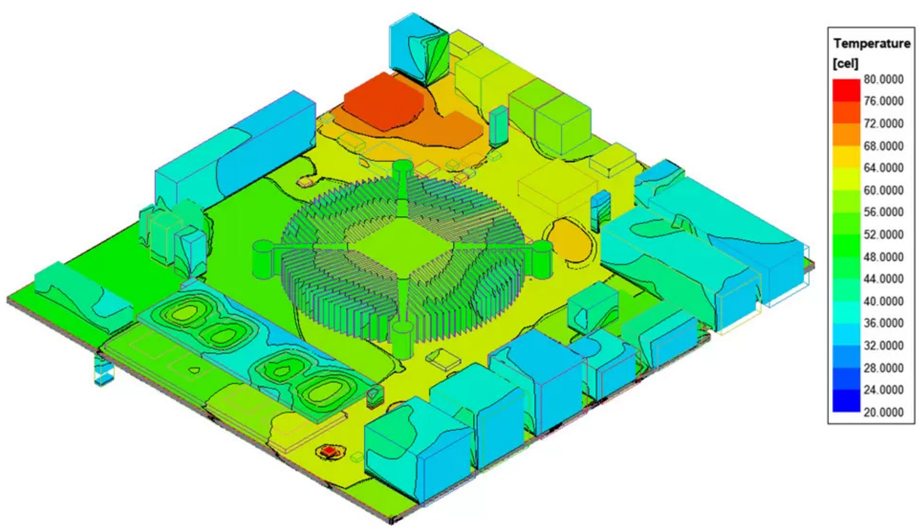
Once these design tasks are completed and the PCB layout is finished, the design can be exported into an intermediate file format for use in simulations. An external tool should be used for comprehensive thermal simulation and analysis before finalizing the PCB and preparing for production.

What to Watch For in PCB Thermal Analysis Software

Inside your PCB thermal analysis software, your goal is to determine the equilibrium temperature distribution given typical operating conditions for the PCB assembly. The simulation results you generate for your PCB should show the temperature distribution in space, as well as additional information on deformation if possible. However, if the equilibrium temperature is known in different regions of the board, it's possible to estimate deformation from these data.

3rd party field solver applications like Ansys that interface with Altium Designer can be used to run these simulations. These powerful tools can be used to determine deformation in the PCB due to thermal excursions, thermal shocks, and thermal cycling. The combination of these tools gives you everything you need to assess reliability in your PCBA as fatigue failure is an important point to examine in a PCB layout.

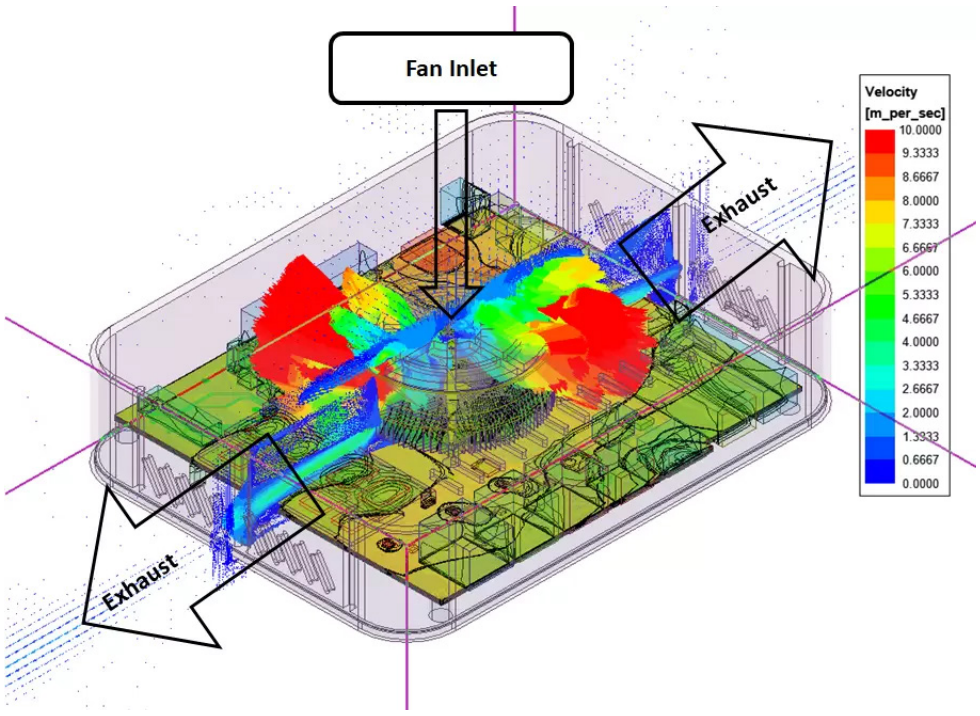
Learn more about PCB thermal reliability evaluation.



Equilibrium temperature distribution for an Altium Designer PCB. These simulation results were prepared in Ansys.

When devices are running at higher temperatures and significant heat reduction is needed, airflow is often added to a design alongside heat sinks, thermal compounds, and additional copper. The effectiveness of fans that provide airflow, or natural convection, can be evaluated using CFD-thermal co-simulations. These more advanced field solvers help you examine how heat spreads around the PCB due purely to airflow. Additional points to consider in the PCB layout include the mechanical placement of the fan, which requires an MCAD tool to prevent interferences and design the enclosure for maximum heat dissipation and airflow.

Learn more about integrated ECAD/MCAD workflows.



Share, access, and download your embedded firmware code directly from your Altium Designer project files in Altium 365.

Share Your Thermal Simulation Models With Altium 365

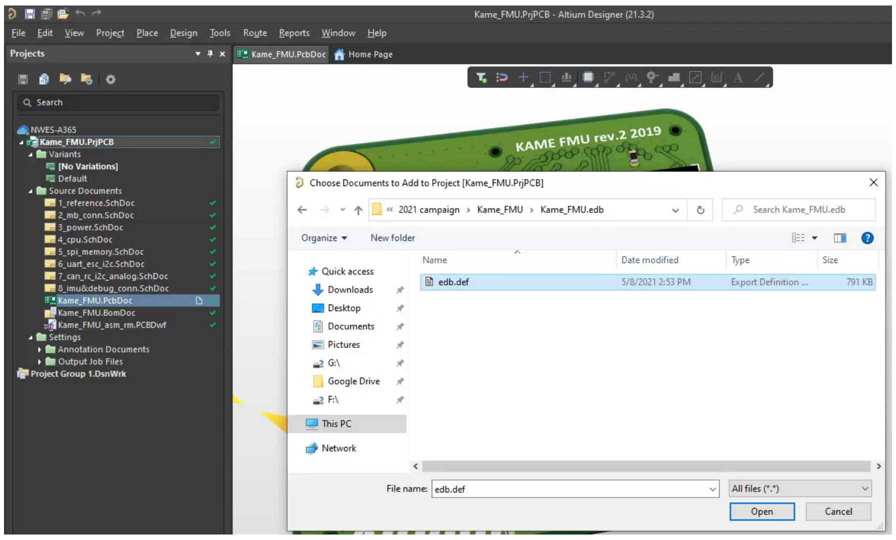
Altium Designer is already the industry-standard PCB design software package, providing the highest quality set of design and manufacturing tools needed to create advanced electronics. Users can expand their design and simulation capabilities using an external PCB thermal analysis software package that interfaces with Altium Designer via an intermediate file format.

The current tool in Altium Designer for generating these simulation model files is the EDB Exporter extension, which will create an EDB file from your PCB layout for use in Ansys field solvers. The Altium 365 platform makes it easy to share these simulation model files with a collaborator, hold them in a project and place files in version control, and release all project data to manufacturing.

Interface With External Field Solvers Via Altium 365

Altium Designer and Altium 365 give users a unique way to interface with external field solver applications for PCB thermal analysis. Altium Designer users have multiple exporter utilities available to generate vendor-specific and vendor-neutral files for use in PCB thermal analysis software. When you generate these files, you can easily share them with your design team and collaborators using the Altium 365 platform. Sharing is secure via a cloud platform and includes a built-in Git-based version control system.

- Altium Designer gives users everything they need to create advanced electronics and prepare circuit board layout documentation.
  Learn more about Altium Designer's complete toolset for printed circuit board design.
- Altium Designer includes many extensions to expand the capabilities of the design environment, including an EDB file exporter to interface with Ansys thermal simulation applications.
  Learn more about the Ansys EDB Exporter extension for Altium Designer.
- Altium 365 is ideal for storing and sharing all your project data, including simulation models for use in advanced field solver applications.
  Learn more about using Altium 365 to share your simulation models and data.



Instantly export your design data into a standard simulation file format and interface with 3rd party PCB thermal simulation software free in Altium Designer and Altium 365.

Altium Designer on Altium 365 delivers an unprecedented amount of integration to the electronics industry until now relegated to the world of software development, allowing designers to work from home and reach unprecedented levels of efficiency. Once you've shared your thermal simulation model with collaborators, they can place comments in the design and suggest modifications to help ensure the highest level of quality and reliability. Once a design is finished and is ready for release to production, Altium 365 lets you release your designs into production via an online platform or through the standard toolset in Altium Designer.

ABOUT ALTIUM

Altium LLC (ASX: ALU) is a multinational software corporation headquartered in San Diego, California, that focuses on electronics design systems for 3D PCB design and embedded system development. Altium products are found everywhere from world leading electronic design teams to the grassroots electronic design community.

With a unique range of technologies Altium helps organisations and design communities to innovate, collaborate and create connected products while remaining on-time and on-budget. Products provided are Altium Designer®, Altium Vault®, CircuitStudio®, PCBWorks®, CircuitMaker®, Octopart®, Ciiva® and the TASKING® range of embedded software compilers.

Founded in 1985, Altium has offices worldwide, with US locations in San Diego, Boston and New York City, European locations in Karlsruhe, Amersfoort, Kiev and Zug and Asia-Pacific locations in Shanghai, Tokyo and Sydney. For more information, visit www.altium.com. You can also follow and engage with Altium via Facebook, Twitter and YouTube.