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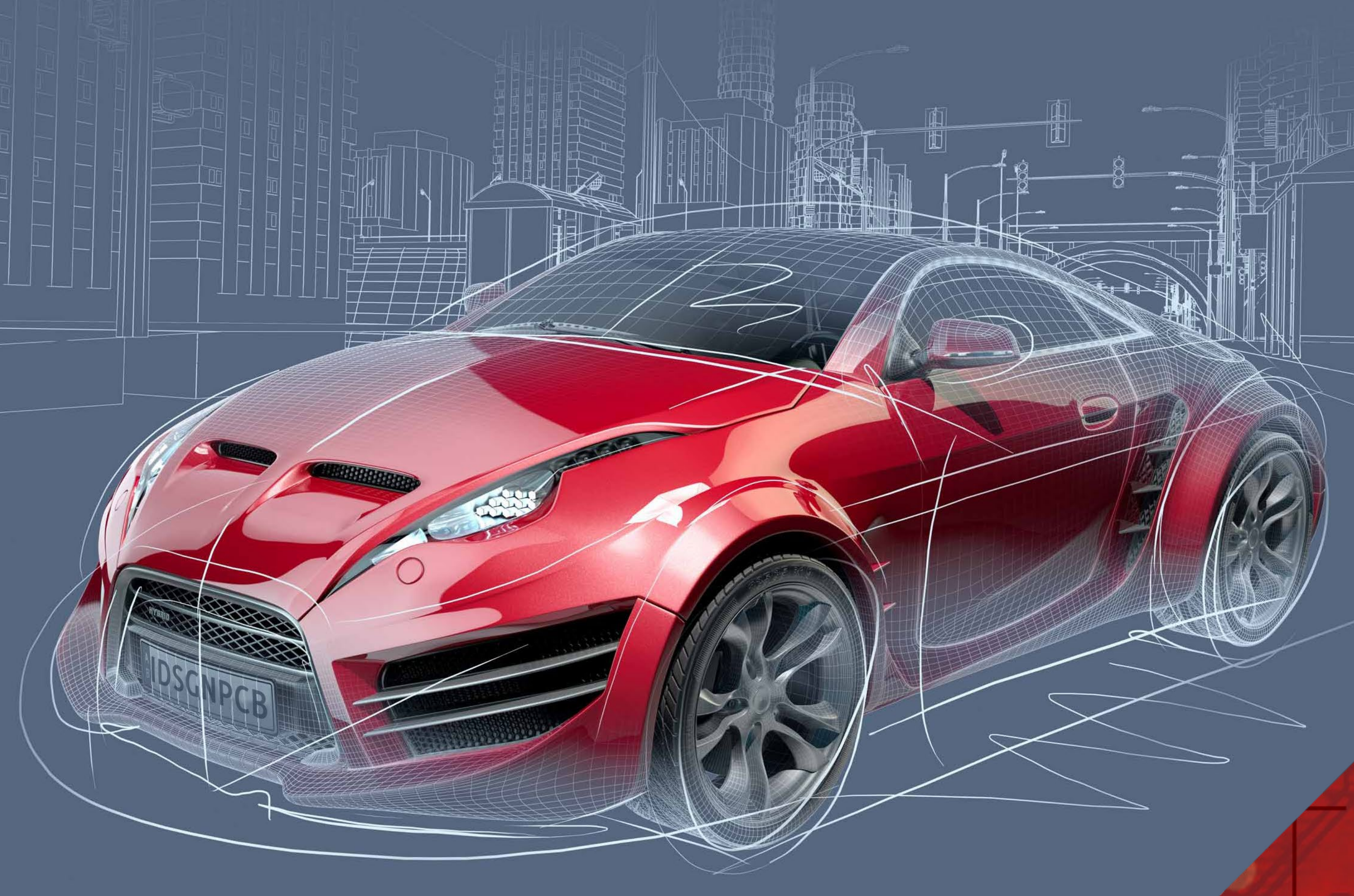
CARS: A Driving Force in the Electronics Industry



Automotive Systems Design: A Support Engineer's Perspective

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Physics of Failure Durability Simulations for Automotive Electronics

by James G. McLeish & Tom O'Connor
DFR SOLUTIONS

Automotive electronics systems are becoming increasing complex and essential for the proper, safe operation of cars and trucks. Vehicle controls for basic operation and safety functions are increasingly being implemented by electronic modules. The ability of these electronic systems to function reliably is becoming a greater aspect of vehicle safety as was dramatically demonstrated by the 2009–2011 recall of over 9 million Toyota vehicles for unintended acceleration issues.

After the Toyota incident, the U.S. National Academy of Science issued "Special Report #038: The Safety Challenge and Promise of Automotive Electronics—Insights from Unintended Acceleration" in January 2012. The report cited that federal safety regulators in the National Highway Traffic Safety Administration (NHTSA) lack the expertise to monitor vehicles with increasingly sophisticated electronics, as was demonstrated by the need for NHSTA to call in NASA electronic personnel to assist in the investigation.

But 2014 was an even worse year for the auto industry, plagued with a record 700 recalls of over 60 million vehicles that has cost billions of dollars, involved numerous NHTSA safety investigations, record federal fines, damning publicity, unsettled legal liabilities, and congressional investigations. Severe new vehicle safety legislation is now under consideration. With many of these reliability issues, the vehicles' systems functioned for years before failures with safety consequences occurred. Others involved situations where product teams, executives and regulators did not recognize the safety consequences of product and system quality, reliability and durability (QRD) capabilities, especially when new technology is involved. The industry now searches for ways to ensure that this never occurs again.

While electronic reliability issues were widely suspected, but eventually ruled out as a root cause, the crisis revealed the challenges of evaluating, validating and investigating the reliability and safety assurance aspect of modern, distributed and interactive vehicle controls systems that are equally taxing on OEMs, electronic system suppliers and regulators.

Meanwhile, in Europe, the new standard ISO 26262, "Road Vehicles—Functional Safety," defines an automotive-specific approach for determining risk classes and requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety and reliability is being achieved.

CAE Apps and Physics of Failure

Reliability physics a science-based approach that is rapidly being employed in automotive electronics. It involves application of knowledge derived from physics of failure (PoF) research into how and why systems, components and materials fail. Knowledge of what initiates and propagates the failure mechanisms that result in failure modes enables product designers to evaluate the potential failure susceptibility and risks of specific materials, structures and technologies in specific applications. This enables a virtual "analyze and optimize" form of reliability where susceptibility to failure risks can be rapidly identified early, at low cost, and designed out or mitigated, while the design is still on the CAD screen. This article will provide an introduction to reliability physics methods and tools and discuss how they can be employed to optimize the product integrity (i.e., quality, reliability durability and safety [QRDS]) of vehicular electronics systems.

A new set of CAE tools can help evaluate the safety and reliability of vehicular electronics models to meet these needs and support the new ISO standard. CAE modeling and simulation tools are now widely viewed as an automotive engineering core competency. These tools are needed to reduce new product development time in order to get products to the market faster, at lower costs by helping to design them right on the first attempt.

Electrical and electronic (EE) engineers historically have gravitated to CAE tools for circuit, functional and software analysis with less emphasis on structural analysis tools that were viewed as less essential to their field. However, as advancements in electronic technology have produced smaller and smaller devices that handle ever-increasing amounts of power and heat, the micro-structural integrity of wire bonds, micro-terminals and solder joints become increasingly important, especially in the auto industry where the ability to endure 10–15 years of harsh environmental conditions is a requirement. This is underscored by the fact that the majority of field failures of electronic modules are physical and structural in nature, related to items such as thermal over stress and fracture or fatigue of wires, solder joints, component terminals, wire bonds, and circuit board through-hole vias.

> **"The time and cost of building and testing prototype electronic components has been a limiting factor in efforts to accelerate the product development-validation process of automotive electronics."**

Today, evaluating and achieving the structural integrity, durability and reliability of automotive electronic modules still primarily depends on traditional design-build-test-fix (D-B-T-F) reliability processes that employ a variety of environmental stress and usage durability tests of physical prototypes. The time and cost of building and testing prototype electronic components has been a limiting factor in efforts to accelerate the product development-validation process of automotive electronics.

As vehicular electronic content continues to climb into and beyond the range of 70 to 80 modules per vehicle (on internal combustion engine vehicles), the burden of integrity assurance/reliability/durability testing is becoming an even greater drain on the industry. The conversion to hybrid and electric vehicles brings with it an even greater increase in electronic content. For example, the Chevy Volt lithium Ion battery module requires seven circuit board assemblies for battery system management and safety. Each of these assemblies must be tested in accordance with an extensive durability profile which costs hundreds of thousands of dollars and months of additional testing.

A True Physics-Based Modeling App

To address this situation, a new class of knowledge-based automated design analysis (ADA) CAE tools for performing physics of PoF durability simulations and reliability assessments to ensure the structural integrity of electronic modules has been developed. One new CAE program is called Sherlock Automated Design Analysis™ for its ability to investigate a design and predict its susceptibility to failure mechanisms related to the intended usage environment of the application. The program works by performing a durability simulation in a virtual environment and calculating the durability life and reliability distribution of various failure mechanisms for the electronic component and structural elements on the circuit boards of an electronic module. This is similar to the way structural durability analysis is now performed for vehicle body, chassis and other mechanical systems and parts.

Sherlock software is the result of years of PoF research to identify the failure mechanism

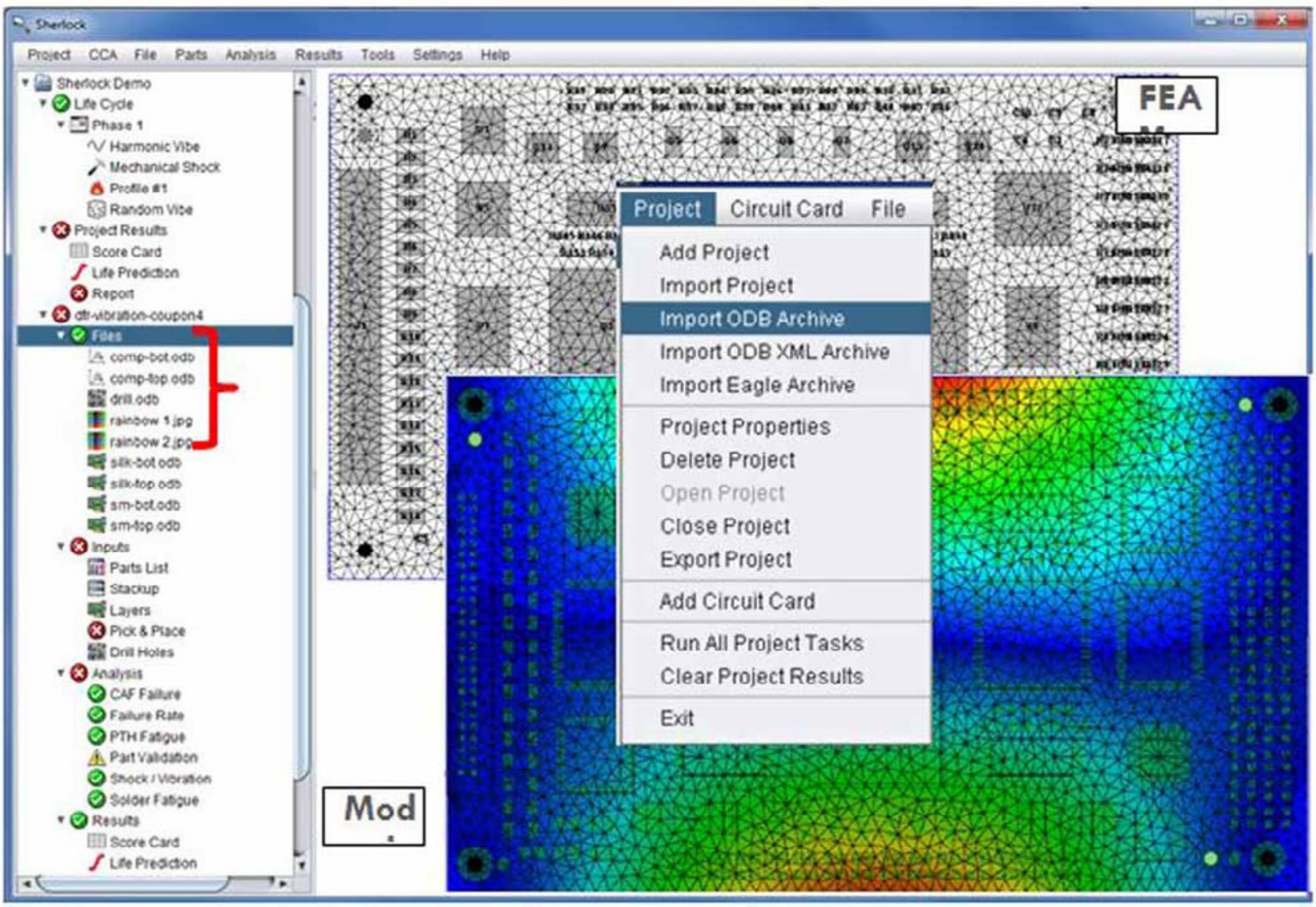

Figure 1: Sherlock software imports standard circuit board CAD/CAM Gerber files or ODB++ archives and uses them to automatically create and run finite element models for structural analysis and PoF durability simulations/reliability assessments.

of how and why different electronic components and materials fail, then develop and calibrate a mathematical model of each failure mechanism that could be incorporated into the CAE analysis program. Previously, these PoF analyses were performed by traditional finite element analysis (FEA) tools. This required a long, complicated, model creation process performed by a highly trained expert—a capability that was rarely available to most electronic engineers.

However, Sherlock software is designed to be used by non-CAE experts who quickly create and perform PoF durability simulations and reliability assessments. This is accomplished by a high degree of automation in the program that includes preloaded libraries of: component models, material properties, design templates, analysis wizards and environmental profiles for specific applications. The automation features enable electronics engineers, circuit board designers, and quality/reliability personnel to use the analysis tool to incorporate reliability into the design process.

First, a product life cycle is created for the PCBA. The life cycle is a combination of the expected life of the assembly and the failure rate at that time. A typical automotive life cycle would be 15 years with 5% failure at 15 years.

The creation of a virtual module of a circuit board assembly is greatly simplified by importing the same CAD files created during a typical circuit layout design process that are sent to a circuit board fabricator and a circuit board assembler for use in their CAM equipment. Once the CAD-CAM files in either a traditional Gerber or

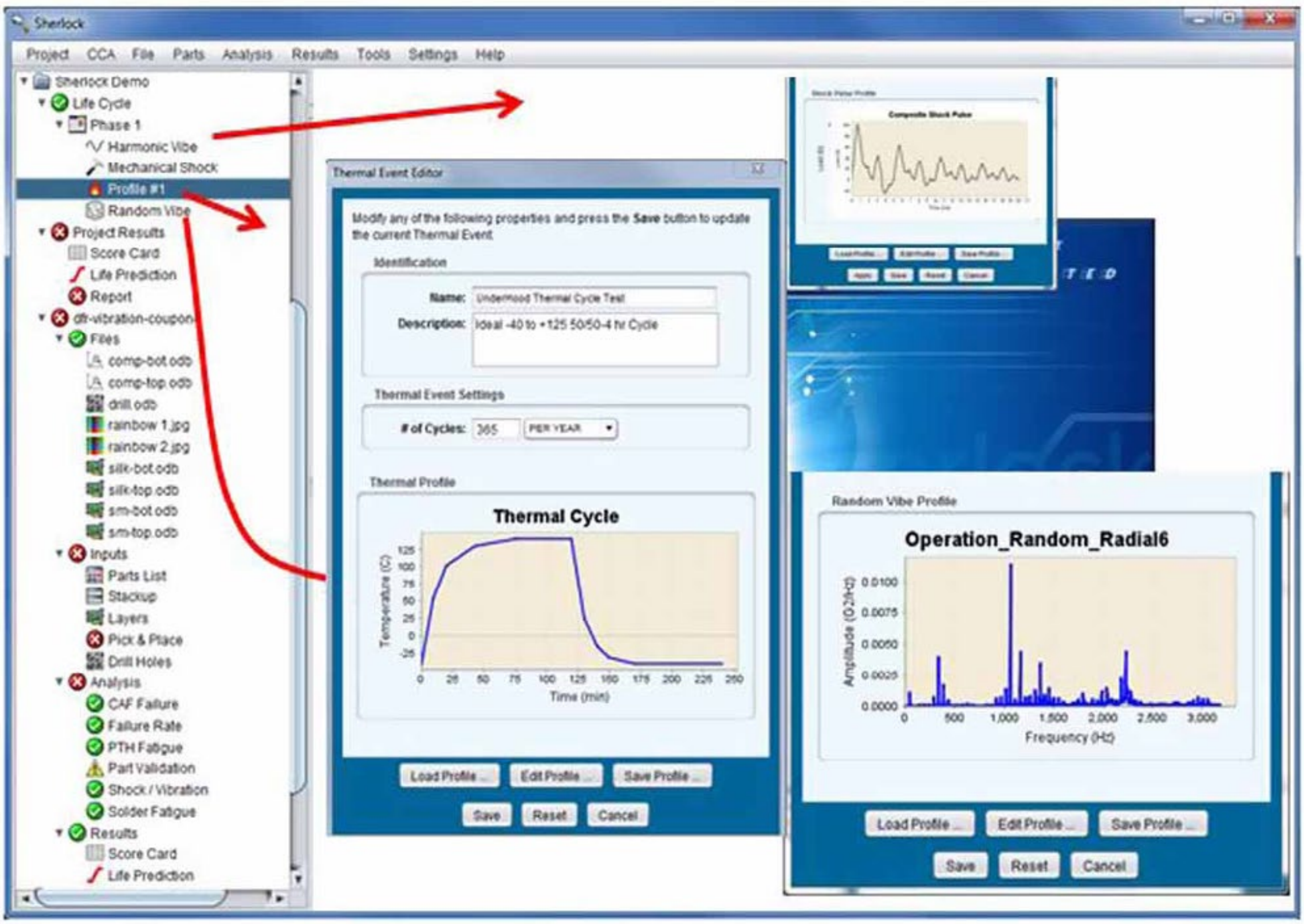

Figure 2: The user can define and save an unlimited number of test or field environmental and usage stress profiles to perform virtual test to field correlations and simulated aided testing studies.

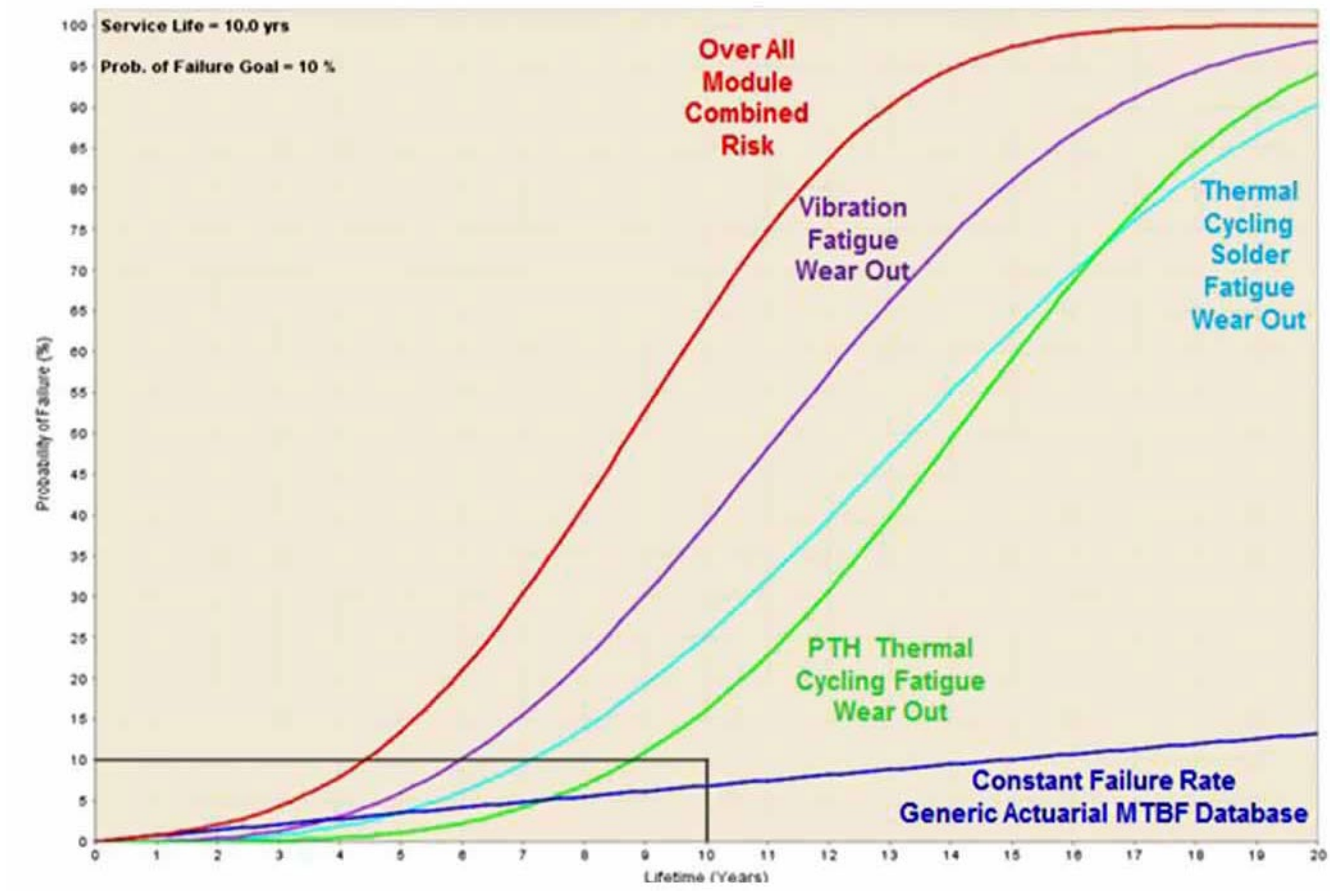

Figure 3: Sherlock software plots individual and overall combined risk timelines curves for the failure mechanisms the device is susceptible to. This early identification of specific risks allows the design to be improved, at low cost, while the design is still on the CAD screen.

the ODB++ format are loaded, Sherlock automatically self-generates the virtual FEA models needed for structural analysis as shown in Figure 1. The environmental and usage conditions to be evaluated along with the durability time frame and reliability objectives of the application are then defined.

Next, the user selects the types of stress analysis to be performed which determines the types, intensity and loading frequency of the stresses the device is required to endure during its service life as shown in Figure 2. The stress conditions automatically become inputs to various PoF failure mechanism model to determine the susceptibility of the electronic assembly's devices, materials and components to various failure mechanisms which produces a projection of the time to mean failure and the failure distribution about the mean of each susceptible failure mechanism to each element in the design.

Sherlock then tallies all the failure risks of each element to calculate a combined failure risk life curve for each failure mechanism and an overall risk life curve for the complete electronic module (Figure 3). It also produces an ordered Pareto list that identifies the components or features projected to have the greatest risk of failure for each failure mechanism that enables easy identification and prioritization of all the weak link items. It also identifies why they are expected to fail, so that corrective actions can be implemented while the design is still on the CAD screen, without the time and expense of building prototype modules for physical reliability/durability testing.

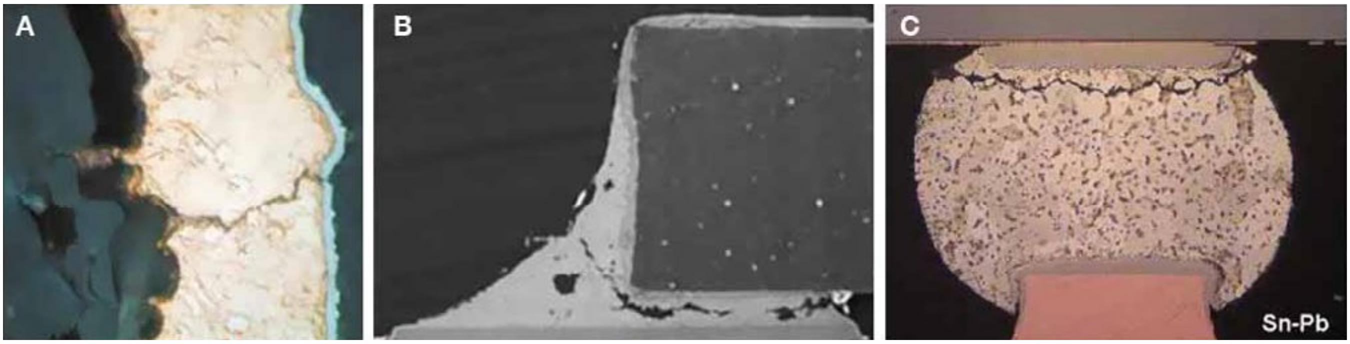

Figure 4: Examples of typical circuit board structural failures: (a) cracked copper barrel wall in a signal carrying plated through-hole via, (b) solder attachment crack at a surface mount resistor, and (c) solder ball crack in a BGA integrated circuit.

Sherlock performs the following stress, wearout or overstress failure simulations and risk assessments:

- FEA vibration modal analysis—stress assessment
- FEA shock modal analysis—stress assessment
- Thermal cycling fatigue of solder joints—wearout failure mechanism
- Thermal cycling fatigue of plated through hole vias—wearout failure mechanism
- Mechanical vibration fatigue of solder joints—wearout failure mechanism
- Mechanical shock fracture of solder joints—overstress failure mechanism
- Conductive anodic filament formation—risk assessment
- Thermal derating

Examples of real-world failures that this type of analysis can detect and prevent are shown in Figure 4.

Case Study

An automotive OEM that has now owned Sherlock for over two years performed a before and after study on four assemblies that used Sherlock this past year. Before purchasing Sherlock the company used the classic D-B-T-F reliability process for DVT. For the year that Sherlock was used on the four assemblies the OEM calculated it saved an average of $346K/PCBA. The saving was just for the reduced testing done in DVT. It did not include savings of getting the product to market more quickly. The total saving for the four assemblies was over $1.3 million. But, most importantly, the OEM feels that they are providing a more reliable, durable product to their customers.

Meanwhile, other automotive OEMs are working with their Tier 1 suppliers to evaluate using Sherlock to improve their products' reliability. The OEMs are determining if the Tier 1 passes a Sherlock analysis with the OEM's environmental conditions whether they can give the Tier 1 credit for passing their first EVT.

This is a win/win/win. The OEM gets a better product at less cost with better reliability data. The Tier 1 supplier gets a deeper commitment from the OEM. And the customer gets a better automobile at a lower cost. Physics-based modeling is the way of the future to make automotive electronics reliable, durable and cost-effective. **PCBDESIGN**

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