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Integrated automotive circuit board design and verification

Digitalizing development of safety-critical ADAS, AV and EV electronics systems

The market for automotive printed circuit boards (PCBs) will surge with the widespread adoption of advanced driver assistance (ADAS) and autonomous vehicle (AV) systems. As self-driving vehicles become a reality on the highways, durability and reliability will become crucial to the success of safety-critical PCB applications. Regulations requiring ever-increasing safety standards are forcing companies who design and manufacture PCBs to adopt fast, efficient, sophisticated, right-first-time development practices. PCB suppliers can turn these challenges into opportunities with a fully digitalized, simulation-driven development process.

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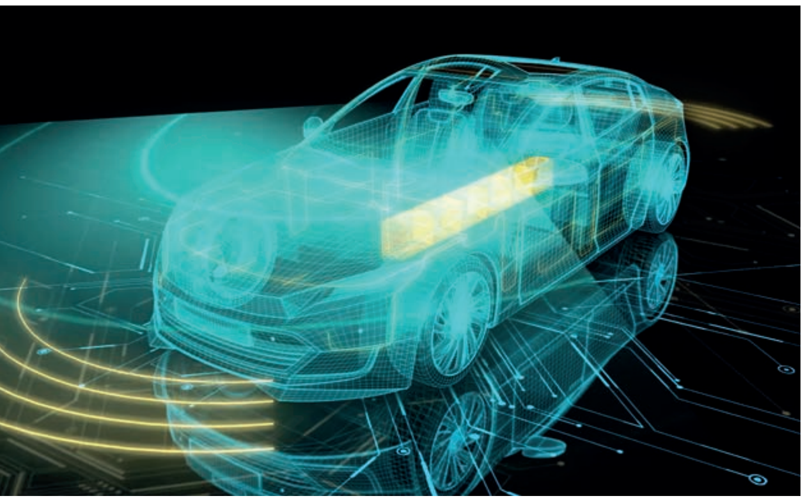
Developing safety-critical ADAS, AV and EV electronics systems



The ADAS and AV revolution

The use of PCBs in vehicles is already remarkable – systems and operations that currently use them include lighting, transmission controls, comfort controls, engine and emissions management, infotainment systems, power relay timing, radar, GPS, ADAS and much more. Traditionally, most automotive electronic systems circuit boards had marginal functional and reliability requirements. If an instrument panel or radio circuit board failed, it would require an inconvenient visit to the dealer for service. Failure of more safety-critical electronics – for engine or transmission controls, ignition, antilock braking, or transmission controls – results in an inoperable vehicle.

The stakes are enormously higher with the emergence of ADAS and AV technologies. Reliability of the electronics systems and their hardware/circuit boards is quickly becoming a paramount, urgent focus in the industry. An electrolytic capacitor that overheats or a surface mount component solder joint that fatigues and cracks due to thermal or vibration stress, for example, can result in potentially catastrophic system failure.

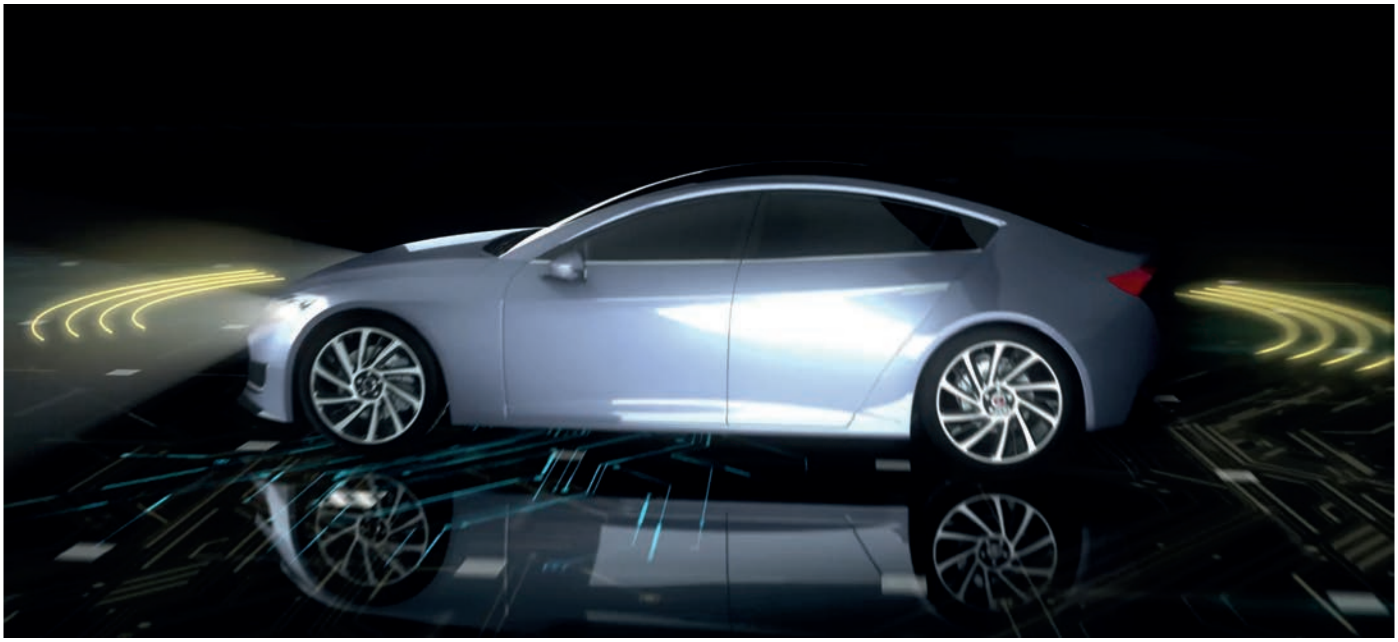
Suppliers of PCBs are already expected to deliver boards with materials that can withstand harsh use and long lifecycles. The industry demands durable, high-temperature PCBs that can dissipate heat quickly, but with the revolution of ADAS and AV systems, automotive applications of PCBs will explode. Electronics and software will drive the evolution as sophisticated processors, sensors, radar, LIDAR, cameras and software systems become crucial in ensuring precise car dynamics.

Focus on safety

Safety is the primary requirement for self-driving vehicles, and the only requirement that matters. As safety and reliability remain in the forefront, so does the need to account for all aspects of electronic systems – including operational environments, power duty cycles, component tolerances, assembly and manufacturing variances, and others.

For the industry to make self-driving cars a reality, PCB suppliers must develop durable, robust and reliable systems, and convince a skeptical public and regulators that electronic systems will work 100 percent of the time. Traditionally, this proof was provided through physical testing in thermal chambers and vibration cells. Failures in testing required a redesign or new components resulting in cost overruns and missed deadlines.

The traditional approach is no longer sufficient to demonstrate that a circuit board design will meet safety-critical requirements. Currently, companies want proof early in the development process to verify that designs are safe and robust. The answer is simulation.



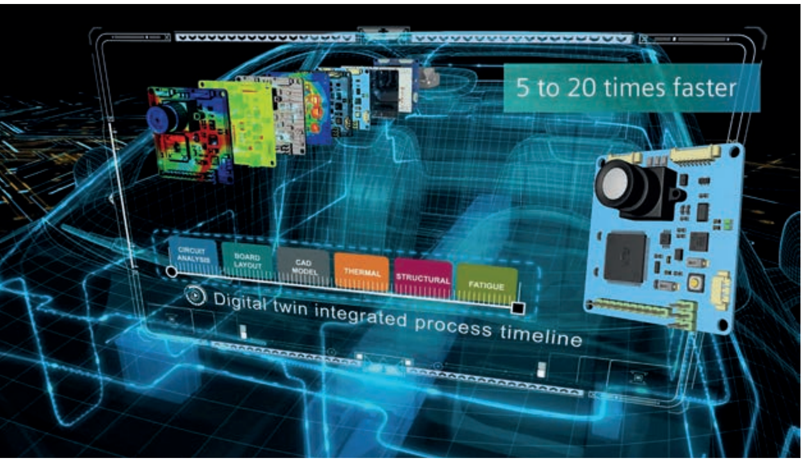
Simulating all aspects of performance

Simulation today is typically limited to circuit simulation for functionality, circuit board trace layout and usually a basic level of thermal analysis. Current simulation processes are disjointed, disconnected and inflexible. The limitations are further exacerbated by the fact that different engineering domains – electrical and mechanical – are involved. Changes in one domain often are not accounted for or evaluated in the other. An electronic component change that results in higher power dissipation can trigger a thermal overload if not evaluated.

An integrated, end-to-end development process

To prove that the reliability, robustness and roadworthiness of AV systems meet safety standards, PCB suppliers must adopt an integrated, multi-domain, simulation-driven development process that evaluates all aspects of circuit board performance, including:

- Circuit performance – with advanced circuit design and analysis, engineers can verify that the target functionality, reliability and robustness are achieved in concept.
- Layout optimization – optimizes board reliability by evaluating component placement, trace routing, the number of layers, manufacturing rules, electromagnetic compatibility and electromagnetic interference.
- 3D CAD modeling – a complete CAD model of the circuit board is required to evaluate mechanical physics through simulation of flow, thermal and vibration behavior, a crucial safeguard for safety-critical systems. A 3D PCB model is also required to assess mechanical packaging and assembly concerns for manufacturing.
- Thermal analysis – provides insights that help engineers optimize heat conduction and transfer, thermal and electrical conductivity, airflow and other factors that can compromise the integrity of safety-critical designs.
- Structural analysis – simulates, in detail, the structural physics behavior of the board to evaluate thermal and vibrational stresses that are the primary causes of failure.
- Fatigue analysis – virtually validates that circuit boards are optimized for durability and fatigue performance.
- Performance optimization – helps identify the best design alternatives to temperature, mass, cost and other factors.



Circuit design and verification

The starting point for electronic systems is the circuit schematic, which represents the functional layout of electronic components including resistors, capacitors, transistors, microcontrollers and other electrical components. Connected symbols typically represent these for each component for the system in a methodical format, and the schematics can be mathematically simulated to evaluate and assess required functionality before hardware is created.

Timing is paramount as the next generation of vehicle products are under intense research and development. New electronic components are coming to the market every day and providing key functionality to such systems, even just before launch. It's critical to evaluate such changes quickly or risk a slow simulation process that prevents you from getting to the market faster than your competitors.

Layout optimization

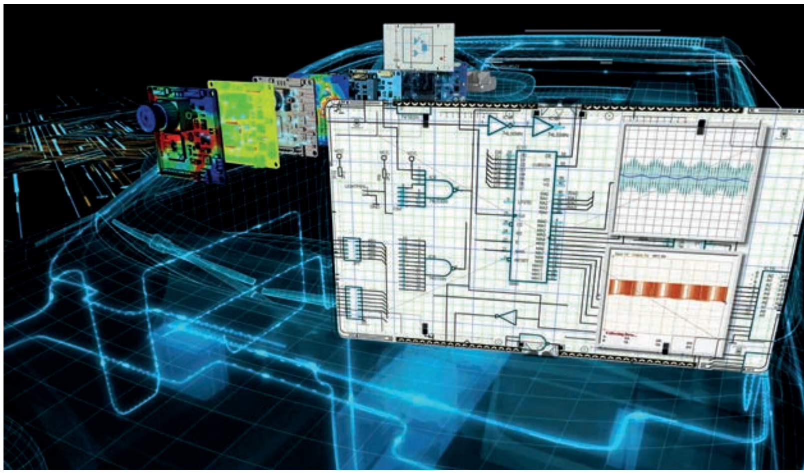
The role of the circuit board will be critical in autonomous and electric vehicles. With so many components and a higher need to verify vehicle safety, the layout of the circuit board will become crucial to ensure the vehicle performs at the highest possible functionality, and will do so safely.

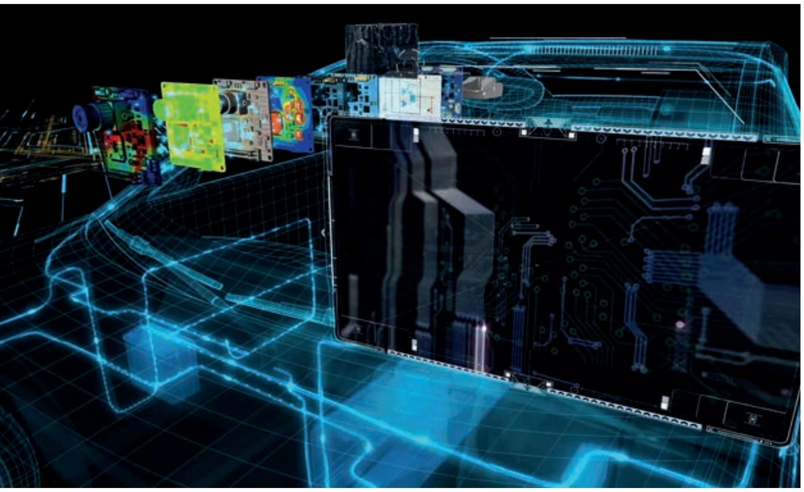
Once the circuit schematic is complete, it needs to be translated into the real world. The circuit board represents the physical incarnation of the circuit. The difficulty is in putting all the necessary electronic components onto a board, and routing the essential copper traces providing the interconnections. This process becomes quite a challenge, as the copper traces cannot physically touch and cross one another. Multilayers are then needed to allow these traces to bridge each other by going into the layers of the circuit board.

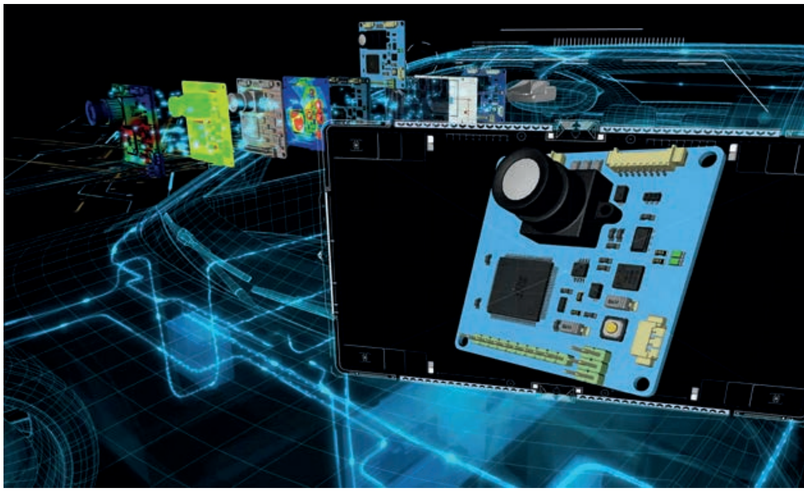
This stage in the process represents a critical phase in its development. There are millions of routings possible resulting in a different number of board sizes and layers. However, there are also numerous rules, guidelines and ultimately space limitations that require an optimization approach to achieve all the goals.

An automation process that evaluates thousands of possible routings quickly plays an integral role in the development process. Downstream development may identify performance problems with the location of a capacitor or controller due to vibration or temperature. Moving the components would require a new copper trace routing configuration. In the past, this would represent a substantial investment in time. Moreover, it may not be possible to trigger an increase in the number of layers and board size.

The circuit trace layout process accounts for the topological structure of copper traces and components. A 3D CAD representation is required to evaluate the physical performance of a model, and this step represents a significant challenge in the industry.







3D CAD modeling

Creating an accurate, detailed 3D model of the circuit board is a key enabling factor for precisely predicting the mechanical physics of the design. Unfortunately, 3D modeling of PCBs (including all board layers, components, holes, traces and vias of multilayer designs) has traditionally been a time-consuming, brute-force process and a luxury that few companies could afford. As an alternative, many companies have resorted to simplified 3D models that can only support preliminary, approximate simulations of thermal and airflow performance. Given the increased complexity and power densities of today's integrated circuit (IC) and PCB designs, companies need to know the precise temperatures, airflows and mechanical stress of the circuit board system to prevent failures.

Fortunately, advanced technologies are available that can automatically generate fully detailed 3D CAD models from PCB layouts created in electronic design automation solutions. Working directly from the board layout data, the automated creation of the CAD model streamlines and accelerates the process, reducing the time and effort required from days or weeks to minutes or hours.

A 3D CAD model of the circuit board enables many other critical processes, including component data management, manufacturing development, design for assembly, design for manufacturing, costing and bill of materials management.

Thermal analysis

The software and electronics content of autonomous and electric vehicles is growing exponentially beyond that of current vehicles, meaning that the next generation of circuit boards will be required to have the maximum design robustness to guarantee functionality and safety. One aspect that will be key is ensuring that heat won't be an issue in causing the circuit board to malfunction.

The fundamental enemy of electronics is heat; higher temperatures reduce the life expectancy of components, solder joints and circuit boards. For every five degrees of temperature reduction achieved, life expectancy improves by 50 percent. Even small temperature reductions are important.

Thermal analysis is extremely valuable for evaluating cooling concepts to achieve these improvements. Two main factors drive the thermal performance of an electronic system: the power of the components, and the environment around the electronic module.

Component power

Some components have a constant voltage and current applied and run all the time. Other components turn on and off throughout operation, depending on the functional need of the system as determined by the software strategies employed. These duty cycles are unique to the electronic system and have a significant impact on thermal performance. For improved simulation and prediction of performance, these duty cycles should be evaluated as a transient time-based response. Some components have different technologies and packaging configurations that respond better or worse to the applied voltages and currents.

New technologies can force many system modifications. Software is often considered the easy way to address functional shortcomings of a system. While it may be easy to change lines of code, the resulting consequences on operational temperatures can be catastrophic. Apparently benign software modifications can trigger many problems. Changing duty cycle from 50 to 70 percent may be simple to encode, but the resulting temperature impacts on the metal-oxide-semiconductor field-effect transistor (MOSFET) can exceed die temperature ratings, resulting in early failure.

The electronic module environment

In the latter part of the 20th century, most automotive electronics were placed in relatively stable thermal environments like the dashboard. However, as packaging space, wire harness length and location became more critical, electronic systems were often placed in more inhospitable locations. In one instance, an electronic module was placed near the exhaust manifold.

For newer ADAS and autonomous vehicle technologies, it may not be so obvious when a location is problematic. For example, ADAS cameras are mounted at the rear-view mirror, high up in the windshield area.

However, the use-case scenarios need to be thought out. On cold mornings, for example, the windshield defroster generates a blast of hot air that blows directly on the camera module. Quick thermal changes are trouble for such systems. Likewise, desert locations can wreak havoc due to solar thermal radiation, causing high temperatures on ADAS cameras. The first thing a driver will do upon entering the car is turn on the air conditioning, blasting cool air onto the camera.

Until recently, such temperature conditions were mitigated by putting electronics in thermal-friendly locations in the car. However, as development moves forward, the electronics have to be more robust and reliable to survive the new environments demanded by advancing vehicle technologies.

Structural analysis

Conducting stress analysis of electronic systems is not a new concept, but until recently, it has not been practical. In any electronic system that's functioning and heating up, temperature changes and vibration introduce stresses. Let's take each one separately.

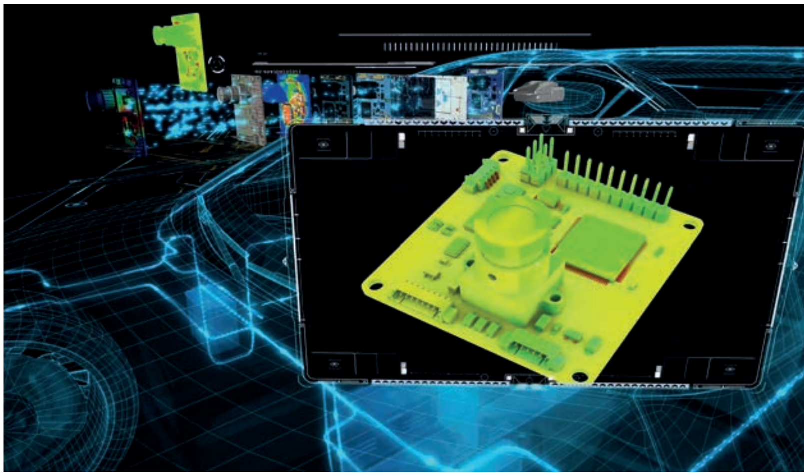
Thermal stress

Temperature changes and the difference in thermal growth of materials trigger structural stress.

When a microcontroller starts to run, it initially heats up locally, causing the chip to expand. The circuit board, however, is not heating up as fast and does not expand at the same rate. This circuit board issue is further complicated by the fact that the chip and board have different rates of growth in response to the temperature.

The net effect is that the controller solder joints become strained due to this growth difference. As this cycle repeats, cracks can initiate and ultimately propagate through the joint, resulting in a break in the electronic circuit. In many cases, this is the primary failure mechanism of such systems.

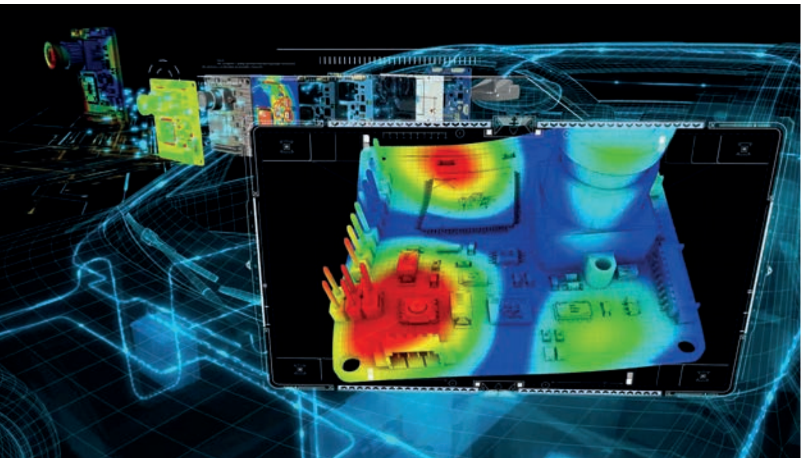
If you consider the number of solder joints connecting resistors, capacitors, controllers and transistors in such a system, and that a failure in any one of them can result in operation malfunction, it is not surprising that safety-critical systems need to be stringent to address these issues.

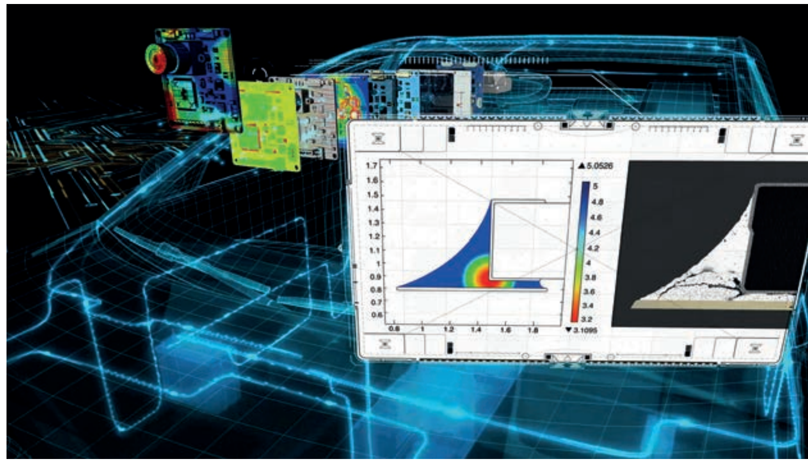


Vibration stress

Vibration stress is often neglected from the simulation process, and one of the major challenges is new random vibration requirements.

Previously, vibration testing was done using harmonic sine sweep processes. The electronic module was placed on a vibration shaker table and shaken at one sinusoidal frequency, and over time, this frequency was





changed to higher or lower levels. Evaluating this using stress fatigue simulation is fairly straightforward.

However, real-life vibration is represented by multiple frequencies acting at the same time in a more random pattern. While testing protocols have been developed to reproduce such scenarios, vibration stress simulation that can be used in fatigue assessment still lags behind. The industry is making headway and improvements in this area, though: new simulation technologies designed to evaluate stress response to random vibration and related cycle counting techniques for fatigue and durability assessment are now available in simulation codes.

Traditionally, circuit boards were overdesigned to meet durability and robustness targets, resulting in higher costs, mass and time to market. Alternatively, circuit boards were designed to be expendable to compensate for what could not be simulated in real life. However, this is no longer an option. Companies need to achieve optimal performance and the lowest costs. Ultimately, thermal and vibration stress simulations should be performed together, as this represents real life.

Fatigue analysis

The results of structural simulations must be applied in fatigue and durability studies that can help understand overall durability and robustness over time. Assuming that the solder joint stress does not surpass ultimate strength and fail on the first power up and vibration, it will take time for the cracks to form and propagate.

Companies ensure safety and robustness over the forecasted life of an electronic system by thoroughly evaluating the stresses. Are the stress levels below the endurance limit of the materials? If the answer is yes, then there is high probability it will function for the lifetime of the system. If the stress is above the endurance limit, it then is a matter of time until the crack occurs; if so, how long will it take to fail? Given enough time, most everything will degrade. However, if a crack takes 100 years to fail, that can be considered acceptable. This assessment and risk analysis process is performed in all engineering industries.

Many electronic system components and materials have not been investigated to this level of detail. Fatigue assessments don't exist to quantify life expectancy and are further complicated by the solder being reformulated to remove or reduce levels of lead due to regulatory pressures and requirements. Material fatigue characterization often lags in such situations and inhibits accurate forecasts of life expectancy. This is a typical issue in the industry, as fatigue testing of new materials takes time and incurs considerable costs.

In response, the industry has leveraged general risk factor assessments and empirical knowledge to guide development. While they are useful, these often result in overdesigned products to achieve design and safety margins. As the simulation capabilities for electronic systems improve as required by the next generation of vehicle development, the industry will demand these new material properties.

View *the automotive circuit board development video*

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