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Semiconductors: How high-voltage architecture shapes safety and long-term performance

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Background

Challenge: Meeting high demand for EV ICs at sustainable costs while demonstrating they meet requirements for safety, reliability and performance in harsh environments.
Approach: UL Solutions offers architectural assessment and testing of the ICs that control and monitor EV powertrains.

Results: Our services support manufacturers in their efforts to:

- Enhance EV powertrain functional safety.
- Mitigate risk of susceptibility to cyber attack.
- Lower chip production failure rates.
- Meet regulatory compliance requirements and adhere to customer advocacy policies.
- Understand and apply ISO 26262 standards.

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Safety science is key as the auto industry migrates to high-powered integrated circuits

Throughout its history, the semiconductor industry has produced increased throughput with each new generation of its integrated circuits (ICs), or chips, which, in turn, has led to an ever-widening circle of applications. One of these applications is the rapidly evolving automotive space, where innovations such as battery-powered, hydrogen-fueled and self-driving vehicles are now emerging as the new wave of transportation.

According to Fortune Business Insights, the global semiconductor market size was valued at $611 billion in 2023 and is projected to grow from $681 billion in 2024 to $2,062 billion by 2032, exhibiting a compound annual growth rate (CAGR) of 14.9% during the forecast period (2024-2032). The U.S. semiconductor market is expected share in that growth and reach an estimated value of $258 billion in 2032.[1] Boston Consulting Group (BSG) cites that automotive semiconductors alone are a $65 billion business and is projected to grow by 9% annually through 2030.[2] The increasing number of automotive systems requiring microcontrollers, sensors and analog devices is helping to drive this growth.

Semiconductors serve diverse automotive applications, including driver assist, safety systems, powertrain, battery management, comfort, in-vehicle information gathering, entertainment, and security. In fact, a bill of materials of an electric vehicle (EV) battery management system can include 40-50 ICs. Within an EV, braking systems, motor generators and fuel cell engines are all complicated systems needing monitoring and control. The integrated circuit chip count can be as high as 100 per vehicle in large-format transportation EV powertrains requiring multiple battery packs or multiple fuel cell stacks. However, the opportunity to supply automotive and truck makers with all these chips comes with a challenge: making the many ICs needed at a low enough cost while still demonstrating that they perform safely in harsh environments.

The emergence and implications of high-voltage ICs

The automotive industry, as a significant consumer of ICs, has increasingly focused on what are known as power programmable system on a chip (PSoC) ICs. These are smart chips, made up of numerical processors that control the operation of critical EV power train components. In addition, complimentary ICs are application-specific integrated circuits (ASICs) or customer-specific products (CSPs). ASICs incorporate math functions; they can monitor automotive battery cells or fuel cells for voltage or current leakage or isolation faults.

Over time, the voltage capability of these power conversion and energy management ICs has increased. In the early 2000s, EV powertrains were 100- and 200-volt DC systems. Between 2016 and 2020, IC technology advances enabled EV powertrain voltages to increase to 300-460 volts. In 2024, manufacturers have released 700-800-volt powertrains; by 2026, 1,000-1,200-volt production EV powertrain systems are likely. The higher-voltage capabilities of IC technologies make it possible to increase the power density of the EV drivetrain and enable EVs to travel longer distances before having to recharge.

As an example, consider the commercial medium duty trucks category of EVs. In 2020, the range of a state-of-the-art “semi” or delivery truck was approximately 150 miles per charge. That limitation was mostly due to power density — the maximum current into the powertrain that the system can tolerate to deliver torque to the powertrain. Now that power conversion and higher withstand voltages on chips are increasing (due to advancements at the chip component and system levels), an 80,000-pound truck can achieve a range of 300-350 miles per charge. Therefore, from a payload and delivery fleet utilization standpoint, an EV truck achieves parity with what an internal combustion truck engine can deliver.

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We can implement a system-of-systems testing approach, leveraging database tools to streamline the process. Rather than tackling everything at once, we can efficiently break the task into manageable, focused segments for quicker execution and better organization.“execute.”

Kyle Edwards, systems engineer, UL Solutions

Since the higher operational powertrain voltages enable increased power density and more miles of operation over a given period, EV fleet owners can generate more revenue per truck asset. This helps owners to achieve their fleet performance and cost management goals more easily.

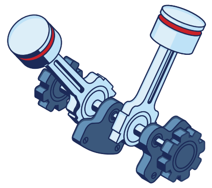
As those EVs travel across the nation's roads, they must also access distributed charging stations to complete payload and delivery schedules. These are fast chargers that fleet managers pay to use. EV power chip system engineering must allow the EV truck to interface with these chargers in an efficiently and securely.

Through testing, certification, assessments and audits, UL Solutions helps manufacturers and developers advance high-voltage system safety and security by evaluating PSOCs and their microcode to applicable standards.

Integrated circuits as key technology enabler

High voltage electric powertrains enhancing performance, range, payload, and safety

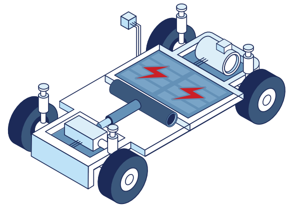
19xx – 2010



12V / 24V ICE

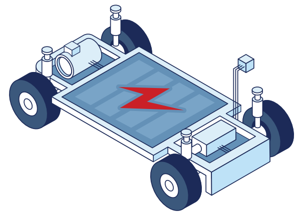
48V MHEV

2024 – 2035



800~1200Vdc HEV BEV FCEV

2010 – 2024



200~300V HEV

400V 800V BEV

ICE	Internal Combustion Engine
MHEV	Mild Hybrid Electric Vehicle
HEV	Hybrid Electric Vehicle
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle

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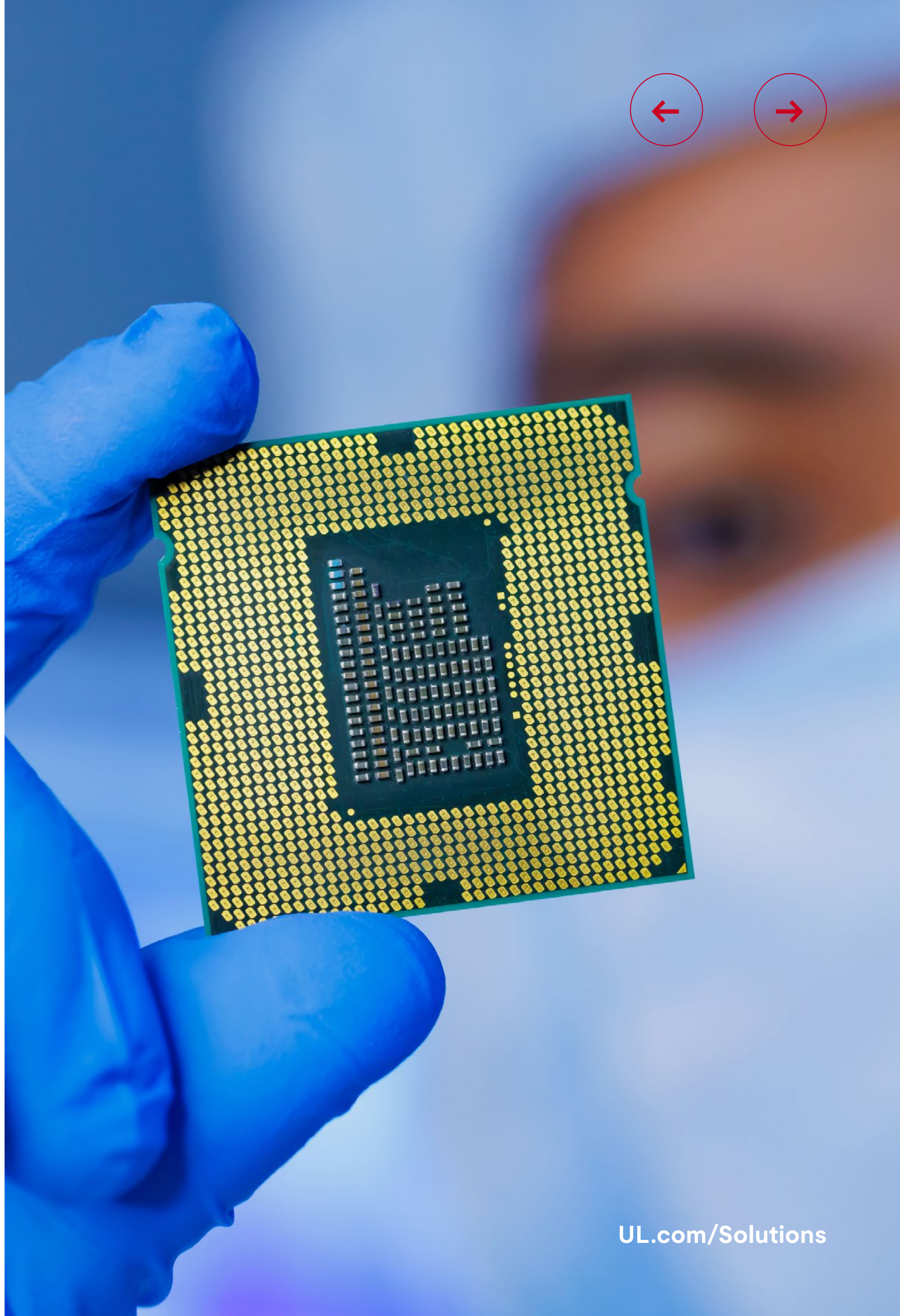
Challenges

Quality, cost control and compliance

Many chip manufacturers grapple with lowering their chip failure rates. One manufacturer, cited in a published McKinsey industry study, experienced yield losses across eight major steps of its semiconductor production process of almost $68 million per year, including almost $19 million during electrical testing alone.[3]

Most semiconductor firms face similar challenges and are prioritizing failure rate reductions for multiple reasons:

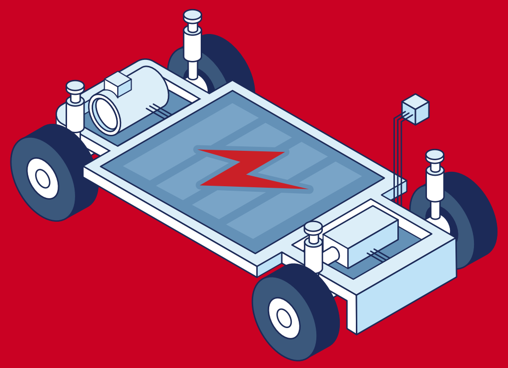
- **Better quality and higher profitability** – High quality is difficult to maintain when chip manufacturers try to keep pace with new-generation chip technology, high power density and higher sampling rates for diagnostic coverage challenges. Despite the growing complexity of EVs and the chips that support them, high reliability and safety — though more difficult to attain — must remain a top priority. The chips must achieve a long life cycle under difficult conditions to meet an EV fleet manager's goal. A Class 8 EV truck can cost upwards of $400,000, so its longevity is critical to managing costs.
- **Regulatory compliance** – As ICs expand into thousands of new application areas, regulations become more stringent, and higher compliance thresholds are set. Regulators are also placing more emphasis on consumer protections, also known as customer advocacy regulatory policies. Organizations within the European Union (EU), through standards such as EU Global Technical Regulations (GTRs), and the National Highway Traffic Safety Administration (NHTSA) in the United States regulate not only safety and security but also customer advocacy issues including vehicle reliability. Consumers expect EVs to last for a long period of time, which means that they expect critical elements such as powertrains and the ICs that support them to be durable, safe, secure and resilient.



EV Ecosystem

Safety and security impacts all levels of an EV

Vehicle

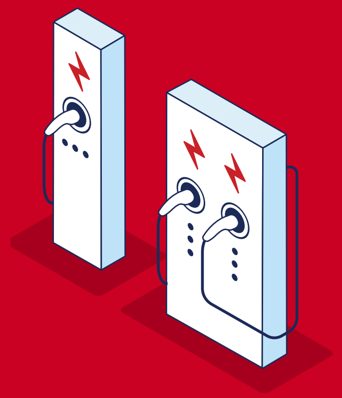


HEV – Hybrid Electric Vehicle

BEV – Battery Electric Vehicle

FCEV – Fuel Cell Electric Vehicle

Sub-System

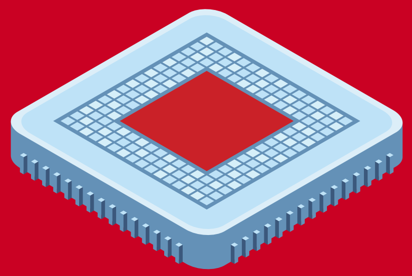


BMS – Battery Management System

PDU – Power Distribution Unit

On Board Charger,
Off Board Charger, Inverters

Integrated Circuits and Semiconductors



Automotive ICs,
Industrial Electronics,
Wired Communication,
Wireless Communication,
MCUs, PSOCs

Customer advocacy also addresses the issue of traceability. For example, assume that an IC is part of vehicle voltage control system and that a separate IC is acting as a monitor. Monitoring chips must report health status, perform self-tests and generate safety fault codes. Once the chips generate a safety-related fault code, the fault code cannot be erased and becomes permanent.

Prior to consumer protections being enacted and enforced, owners selling their vehicles could erase existing fault codes and then sell the fault-code-free vehicle to another individual. Evolving regulations and standards help ensure customer protections for new-generation ICs and EVs.

- **Cost control surrounding warranty fulfillment** – An EV powertrain and the ICs that control it are expected to last for prolonged periods. Replacements should not be necessary until after a warranty period expires. That's why regulators impose a mandated warranty, requiring the manufacturer on record to replace the powertrain at no cost to the consumer if it fails during the warranty period. Accelerated life testing (ALT) can help manufacturers keep IC pre-warranty expiration failures to a minimum.

Approach

Because the new EVs operate at extremely high currents (hundreds of amps per phase) and high voltages (1,000 volts or greater when charging), the ICs that control and monitor the powertrain components must be designed to minimize risk of electric shock. The ability to monitor chip performance and detect small or hazardous voltage leakages onto EV frames, chassis and connectors is critical.

UL Solutions can help semiconductor organizations to address architecture challenges in high-voltage systems, adding value in multiple ways, including:

- **Augmenting knowledge** – Semiconductor manufacturers can benefit from expert support to gain a deeper understanding of EV safety requirements, powertrain architecture and how to meet safety requirements while integrating their ICs into a system of systems. UL Solutions can help manufacturers determine the critical metrics needed to detect normal performance and safety-critical voltage anomalies in a vehicle.

Electric currents' effect on the human body

The effects of electricity on the human body depend on many variables.

- The strength of the current
- Duration of contact
- Body mass
- Biological sex of the person
- Moisture of the body
- The path of the current

Current	Reaction
1 milliampere	• Perception level, a faint tingle
5 milliamperes	• Slight shock felt, not painful, but disturbing • Average individual can let go • Strong involuntary reactions to shocks in this range can lead to injuries
6-25 milliamperes (adult females)	• Painful shock • Muscular control is lost
9-30 milliamperes (adult males)	• Freezing current or "let go" range
50-150 milliamperes	• Extreme pain • Respiratory arrest • Severe muscular contractions* • Individual cannot let go • Death is possible * If the extensor muscles are excited by the electric shock, the person may be thrown away from the circuit
1,000-4,300 milliamperes	• Ventricular fibrillation** • Muscular contraction and nerve damage • Death is most likely ** The rhythmic pumping action of the heart ceases
10,000+ milliamperes	• Cardiac arrest • Severe burns • Probable death

Citations:

1. www.osha.gov%2Fsites%2Fdefault%2Ffiles%2F2019-04%2FBasic_Electricity_Materials.pdf
2. Source: W.B. Kouwenhoven, "Human Safety and Electric Shock," Electrical Safety Practices, Monograph 112, Instrument Society of America, p. 93.

- **Software safety evaluation** – With more software now embedded into chips, software safety becomes a prerequisite to IC-level testing. EV powertrains and associated controllers can have up to 10-20 thousand lines of code and 20-30 chips per controller. When it comes to designing power chips for EVs, a one-size-fits-all approach is not optimal. The problems that power monitoring ICs try to detect on a particular vehicle platform may be unique. Different vehicle models may have varying voltage levels and unique signatures. Therefore, the monitoring IC must be flexible, configurable and secure. As chipmakers produce new and unique designs, engineers must validate the software safety and security detection functions. UL Solutions offers software security and vulnerability assessments.
- **Cybersecurity assessment and tools** – Among the large array of new production chips, some are networked and operate as a subsystem on a circuit board. Therefore, EVs must protect themselves from potential cyberattacks, where hackers could trigger a cascade of failures that would disable fleets of vehicles. UL Solutions provides information security expertise that helps identify potential attack surfaces and can assess the safety and security of all the circuit board communications, including control modules and external ports.
- **Architecture assessment** – UL Solutions applies assessment to every stage of the "engineering V" development cycle. This assessment cycle includes the various stages of architecting, designing, development, testing and production of an IC. In the first stage of the engineering V cycle, an assessment characterizes and parameterizes the capability of an architecture through metrics. Then that architecture undergoes a significant requirements phase and that then leads to a design. Finally, engineers can assess the technology and manufacturing readiness levels of the design.

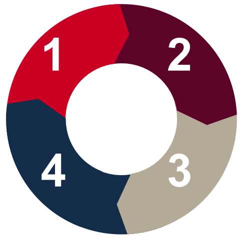
  The output of the assessment is a comprehensive risk and capability matrix used for working through the development phases of the engineering V-model. The development assessment then determines a confidence interval, which helps systems engineers to select the most appropriate development tools. The final stage is testing, which involves ALT and is critical for quality control. These types of tests simulate thermal cycles, voltage cycles and current cycles to evaluate whether the life cycle of the IC can meet the overall performance goals of the vehicle. Testing should also include processor-in-the-loop (PIL), hardware-in-the-loop (HIL) and vehicle-in-the-loop (VIL) testing. Once the engineers integrate the modules into the vehicle, experts assess how the ICs perform within the more comprehensive vehicle super system.

- **Standards compliance** – ISO 26262, Road Vehicles — Functional Safety, covers the safety of vehicle electric and electronic (E/E) systems installed in series production road vehicles. UL Solutions experts offer testing, inspection and certification to ISO 26262. They also apply their detailed knowledge of the standard to offer training and advisory services, providing guidance to manufacturers on applying the standard to IC safety, testing and production.

UL Solutions also performs functional safety assessments and audits by partitioning key functions and identifying which functions are critical and potentially hazardous. Experts then associate monitoring and safety mechanisms with those functions. The safety assessment expert uses analysis data to generate capability metrics regarding the safety and security of those networks and ICs.

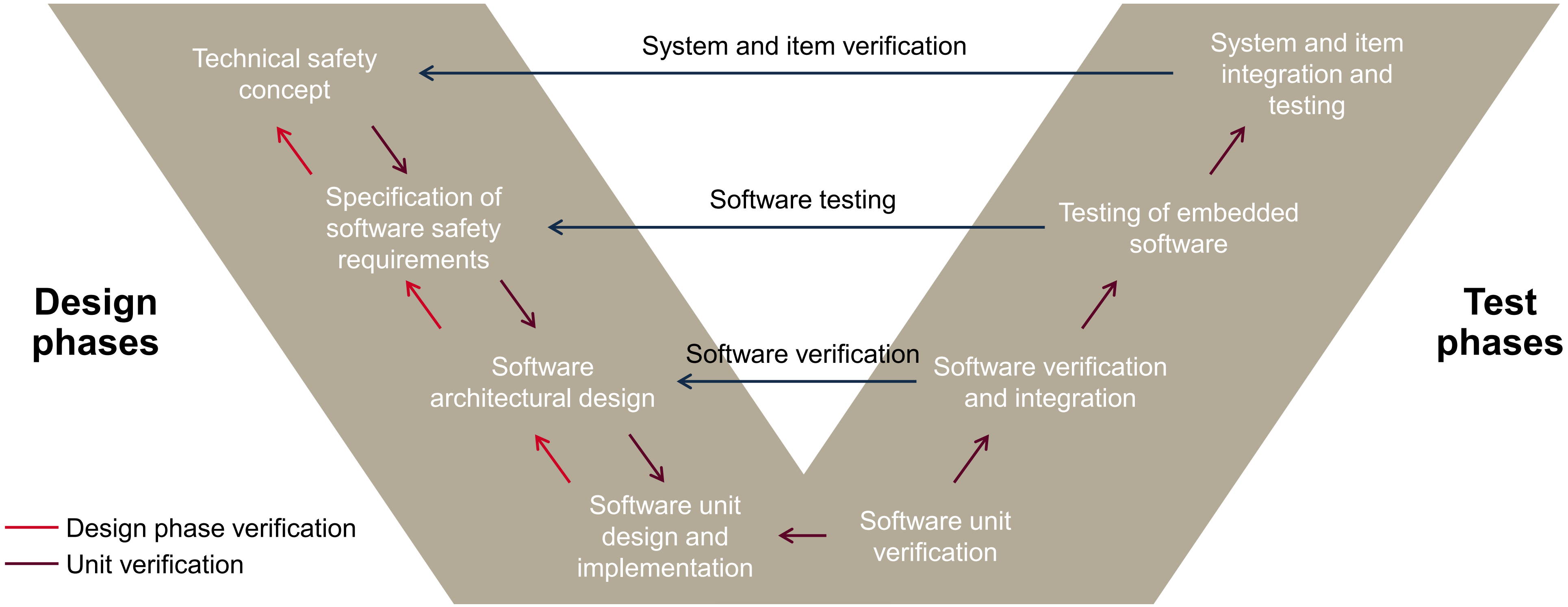
1A Technology Readiness Assessment - TRA
1B Technology Readiness Level - TRL

4A Market Acceptance Assessment - MAA
4B Market Acceptance Level – MAL



2A Compliance Readiness Assessment - CRA
2B Compliance Readiness Level - CRL

3A Manufacturing Readiness Assessment - MRA
3B Manufacturing Readiness Level - MRL



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Conclusion

When executing a system of systems testing approach, experts compartmentalize the safety assessment task into manageable segments. This can help chip producers gain an early understanding of the capability of their chip architecture, which can lead to potential benefits including reduced time to market and production failure and waste and increased profitability. This can also help chip producers avoid going through a design and development cycle only to find that, in the end, their product fails to meet warranty, life cycle expectancy, or compliance requirements associated with safety and security goals.

As a global safety science leader, UL Solutions services allow organizations demonstrate safety, enhance sustainability, strengthen security, improve quality, manage risk and achieve compliance with applicable standards. Visit us at **UL.com/functionalsafety** to learn more about our safety assessments, audits and certification for the semiconductor industry. To learn more about our wide range of cybersecurity services, visit us at **UL.com/cybersecurity**.

LEARN MORE

End note:

1. Fortune Business Insights. (2024). **Semiconductor Industry Outlook Analysis 2024-2032**. Retrieved 10/28/2024
2. Boston Consulting Group. (2022). **Tracking the Next Phase of the Automotive Semiconductor Shortage**. Retrieved 10/28/2024
3. McKinsey. (2018). **Taking the Next Leap Forward in Semiconductor Yield Improvement**. Retrieved 10/28/2024. https://www.mckinsey.com/industries/semiconductors/our-insights/taking-the-next-leap-forward-in-semiconductor-yield-improvement

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