Fast-Tracking Advanced Driver Assistance Systems (ADAS) and Autonomous Vehicles Development with Simulation

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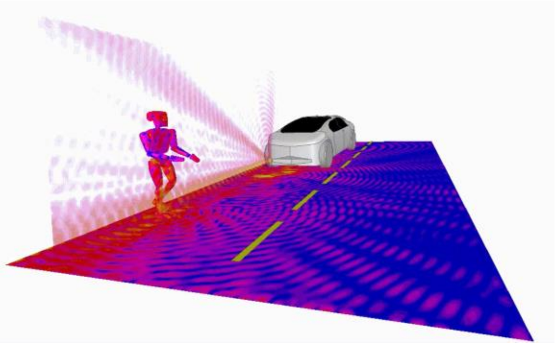
Developing Advanced Driver Assistance Systems (ADAS) and autonomous vehicles is a challenge without precedence. Whole new engineering fields – such as artificial intelligence – need to be developed, yet time-to-market is short with intense competition. Estimates indicate that billions of miles of road testing will be necessary to ensure safety and reliability of ADAS and autonomous vehicles. This seemingly impossible task can only be accomplished with the help of engineering simulation. With simulation thousands of driving scenarios and design parameters can be virtually tested with precision, speed and cost economy. This paper describes six specific areas where simulation is essential in the development of autonomous vehicles and advanced driver assistance systems. It also provides examples and substantiates the benefits of simulation while identifying the tools needed for ADAS and autonomous vehicle simulation.



High fidelity physics simulation of an automotive radar

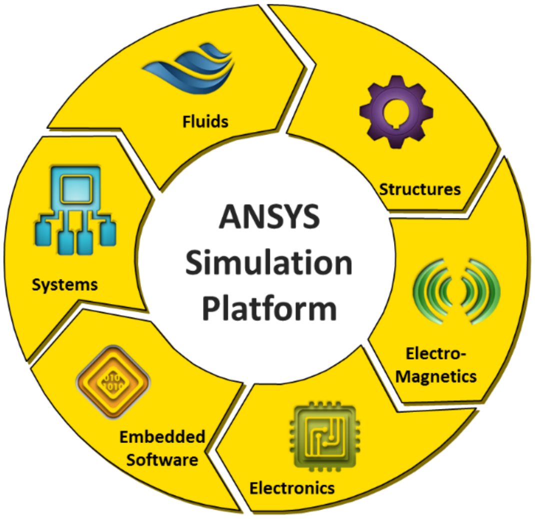
Background and Challenges in ADAS and Autonomous Vehicle Development

A revolution is underway in the transportation industry. The rise of autonomous vehicles will transform the industry and society itself as much as the nineteenth century shift from horse-carriages to automobiles did.

However, developing autonomous vehicle technology is a formidable challenge. It requires ambitious new developments in sensing technologies, machine learning and artificial intelligence, that are not only unprecedented in the automotive industry, but in all other industries as well.

The chief problem in replacing human drivers with artificial intelligence is that of machine perception. An autonomous vehicle's computer needs the ability to recognize other vehicles, pedestrians, road signs, road markings, trees, buildings, traffic lights and multitude of other things that we encounter everyday while driving, and that too in poor driving conditions such as in the darkness of the night, in rain and in snow.

The problem is nearly impossible to solve with traditional rule-based computer algorithms. Instead, neural-networks and machine-learning methods need to be used. In these methods the computer is trained rather than programmed. But driving is such a complex task that an immense amount of training will be needed to make a computer drive as safely and reliably as an average human. Analysis done by the Rand Corporation[1] indicates that an autonomous vehicle will need to be driven through billions of miles of road tests to train its artificial intelligence to the same level of safety and reliablity as a human driver.



The ANSYS simulation platform includes software packages for high fidelity physics simulations of structures, fluids and electronics, embedded software authoring, modeling and code generation, functional safety analysis and system simulation.

Toyota Motor Corporation's president Mr. Akio Toyoda echoed the same need at the 2016 Paris Auto Show, projecting that 8.8 billion miles of testing, including simulation, would be needed for developing self-driving cars[2]. In contrast Google recently completed a cumulative total of 2 million miles of testing with its fleet of self-driving cars over the past 6 years[3]. At that rate, it will take millennia to develop viable self-driving cars.

Need and Benefits of Simulation

Engineering simulation is a time-tested tool for accelerating technology development. The automotive industry has been using simulation since a few decades. With simulation virtual tests can be conducted in a computer on virtual prototypes. Thousands of virtual tests can be completed within the time and budget available for a single physical test, thus greatly accelerating technology development.

Simulation provides three broad benefits:

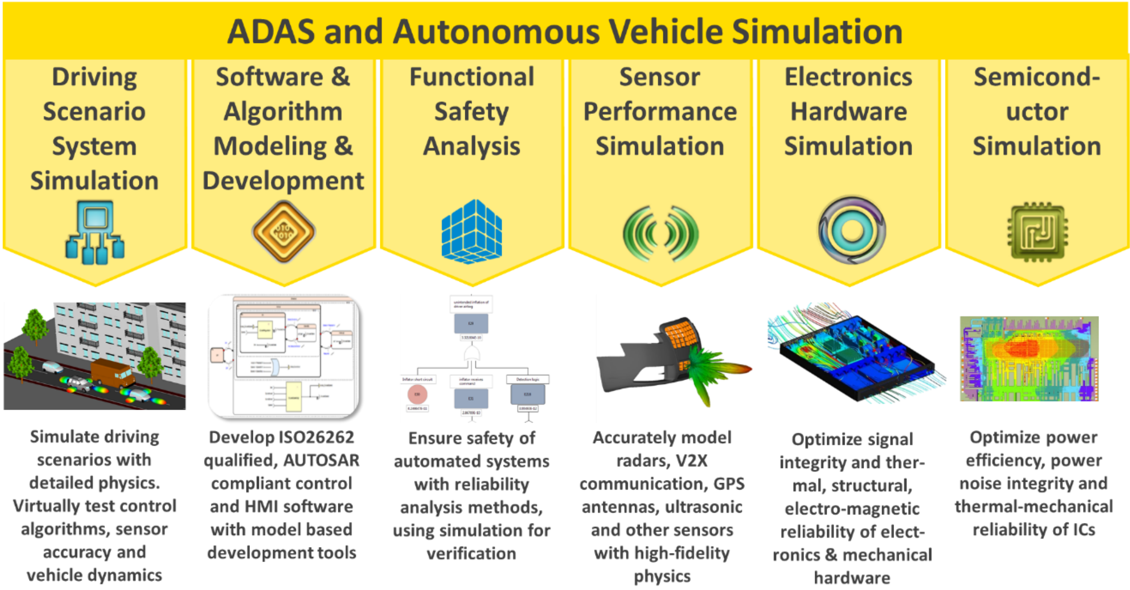
(a) Faster time-to-market: Simulation is conducted in a virtual environment and is significantly faster than physical prototyping and testing, expediting a new product's time-to-market
(b) Reduced cost: Being virtual, simulation is far less expensive than physical prototyping and testing, and can cut costs by an order of magnitude
(c) Enhanced product quality: Simulation provides deep insights into the underlying physics involved in the construction and operation of a product, helping solve quality issues upfront

Faced with the daunting challenge of billions of miles of road tests, ADAS and autonomous vehicle companies have quickly realized that simulation will be an essential technology for achieving development goals and timelines.

Six Aspects of ADAS and Autonomous Vehicle Simulation

Simulation accelerates ADAS and autonomous vehicle systems development in six areas (Figure 1) –

1. Driving Scenario System Simulation
2. Software and Algorithm Modeling and Development
3. Functional Safety Analysis
4. Sensor Performance Simulation
5. Electronics Hardware Simulation
6. Semiconductor Simulation



Simulate driving scenarios with detailed physics. Virtually test control algorithms, sensor accuracy and vehicle dynamics

Develop ISO26262 qualified, AUTOSAR compliant control and HMI software with model based development tools

Ensure safety of automated systems with reliability analysis methods, using simulation for verification

Accurately model radars, V2X communication, GPS antennas, ultrasonic and other sensors with high-fidelity physics

Optimize signal integrity and thermal, structural, electro-magnetic reliability of electronics & mechanical hardware

Optimize power efficiency, power noise integrity and thermal-mechanical reliability of ICs

Figure 1. Six aspects of ADAS and autonomous vehicle simulation

1. Driving Scenario System Simulation

Comprehensive driving scenario simulations can be conducted with a system level behavioral model of an autonomous or semi-automated vehicle. Such a vehicle model includes all sensors, control systems, drive systems and vehicle body, placed in situ in a virtual driving environment comprised of roads, building, pedestrians, road-signs, etc. In this simulated environment, thousands of driving scenarios can be evaluated rapidly, to test whether the vehicle's sensors, control algorithms, and drive systems perform as expected under situations.

Autonomous vehicle technologies and ADAS systems are essentially control loops, comprising of four basic elements – physical world, sensors, controllers and actuators (Figure 2). As the vehicle drives in the physical world, the sensors sense the objects around the vehicle, controllers make decisions based on the sensed objects, and actuators move the vehicle as commanded by the controllers.

Simulation of a complete driving scenario – for instance, a scenario where a car approaches an intersection, looks for crossing traffic, waits for crossing traffic to clear, finds a safe moment and crosses the intersection – requires a system simulation (Figure 3).

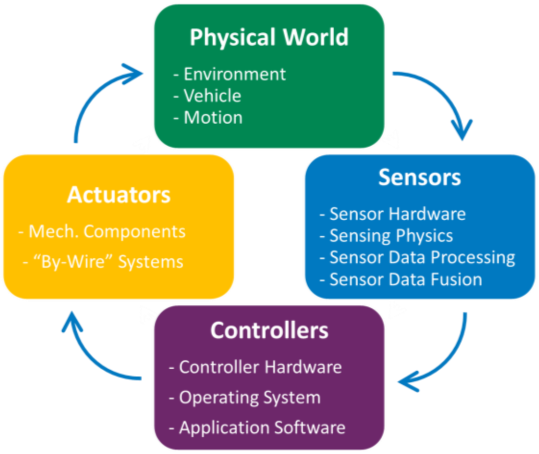


Figure 2. A control loop made of four elements

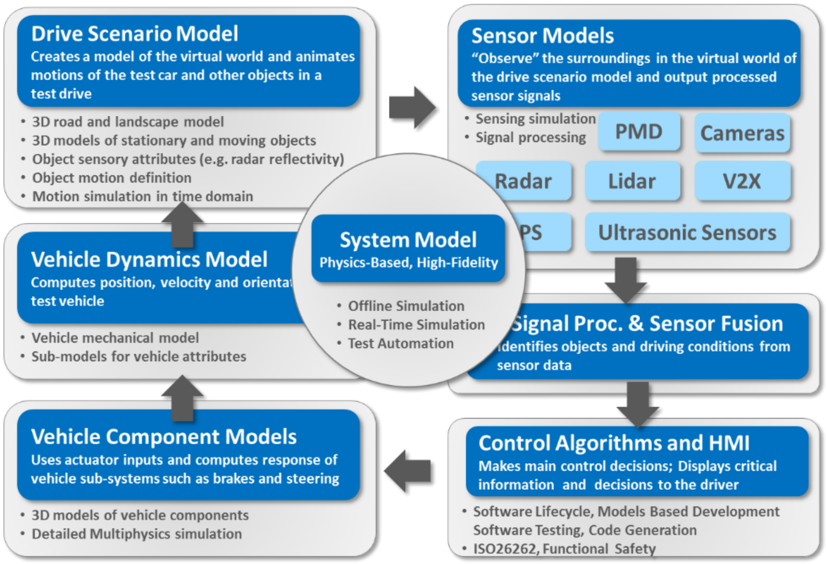


Figure 3. Simulation of the autonomous driving control loop

The first step of the system simulation is a world model comprising of virtual roads, buildings, pedestrians, other vehicles, etc. The vehicle being studied – referred to as the ego-vehicle – moves in this virtual world.

Next, the sensors on the ego-vehicle are modeled. Radars, ultrasonic sensors, cameras and other sensors on the vehicle observe the virtual world surrounding the ego vehicle and generate simulated sensor signals.

The sensor signals are then passed to signal processing, sensor fusion and control algorithms. The algorithms make decisions about altering the cars speed by accelerating or braking, and altering its direction by turning the steering wheel.

The control decisions are then passed on to virtual models of the cars actuators such as brakes, steering, and virtual powertrain which control the vehicle's movement.

The vehicle's movement is computed by the vehicle dynamics module of the system simulation. It accounts for various details such as slippery road conditions and precisely predicts the movement of the vehicle, taking it to a new position in the world model. The entire control loop then repeats, endlessly until the driving scenario is completed.

Various parameters can be tested in such driving scenario system simulation with speed and ease. For instance, one can conduct a what-if study to see the effect of an unexpected failure of one of the vehicle's sensors.

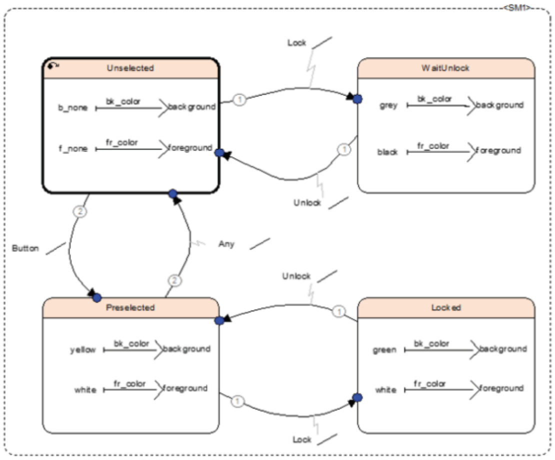


Figure 4. A SCADE software model example

Additionally, such scenario simulations are highly valuable for regression testing of software and algorithms. The speed, cost economy, accuracy and automation of scenario simulation makes it an indispensable tool for repetition of a pre-defined set of regression tests.

ANSYS's simulation software platform connects best-in-class tools to conduct high-fidelity scenario system simulations of autonomous vehicles.

2. Software and Algorithm Modeling and Development

Just as in hardware development, simulation has a key role to play in software development. Developing and testing signal processing routines, sensor fusion algorithms, object recognition functions, control algorithms, and human-machine interface (HMI) software, with model-based software development techniques makes the software robust, less error-prone, and safe.

Automotive manufacturers and suppliers increasingly follow the ISO 26262 standard for engineering active and passive safety systems in vehicles. Since ADAS and autonomous vehicle systems are inherently safety critical, the ISO 26262 standard is essential in their development.

Model-based embedded software development along with an ISO 26262 qualified code generator greatly expedites embedded software development. Once the software models are validated, the generated code is guaranteed to be error-free thus eliminating unit testing of the code, and reducing overall software development efforts nearly in half.

The SCADE (Safety Critical Application Development Environment) software development suite in the ANSYS simulation platform comprises of a model-based software development tool and a KCG code generator. The KCG code generator takes as input a SCADE software model, made of a combination of state machines and data flows (Figure 4), and outputs an equivalent C code.

The SCADE Suite KCG code generator has been qualified at TCL 3 – the highest Tool Confidence Level (TCL) in the ISO 26262 standard – by TÜV SÜD for use in developing automotive software. SCADE is qualified at the ISO 26262 ASIL-D level - the highest Automotive Safety Integrity Level (ASIL). SCADE Suite also complies with the AUTOSAR (AUTomotive Open System Architecture) standard that is being increasingly used by auto-makers and suppliers.

SCADE software can integrate with third-party Neural Network and Machine Learning software for the artificial intelligence (AI) functions of ADAS and autonomous driving.

By using an AUTOSAR compliant software development tool along with and ISO 26262 ASIL-D qualified automatic code generator, ADAS and autonomous vehicle companies get an estimated 40 percent savings in costs associated with software code validation and verification activities, due to significant time savings and lower personnel needs.

Software Code Modeling: Proven Results in the Aerospace Industry

The aerospace industry has been ahead of the automotive industry in developing autonomous systems. Today, most aircraft operate autonomously for more than 80 percent of their flight time. Model-based solutions for embedded code generation and verification have helped ensure the integrity of autopilot systems in commercial planes, as well as associated electronics such as radar, braking systems and communications technologies.

Airbus has used SCADE from ANSYS to design embedded systems for its Airbus A380, A400M, A350 jets. Airbus engineers reported a 50 percent reduction in the costs associated with software development and verification, along with a 2x reduction in the time required to gain certification for the system design. While cutting time and costs from the development cycle, SCADE also delivered a high level of system integrity. "Airbus never experienced any bug in flight in our software produced automatically with SCADE," said Jean-Charles Dalbin of Airbus. SCADE solutions from ANSYS now help automotive systems engineers achieve these same benefits.

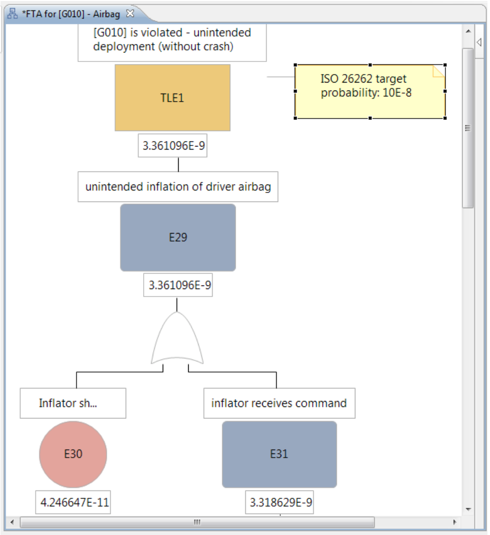


Figure 5. Fault Tree Analysis for an airbag system.

3. Functional Safety Analysis

ADAS and autonomous driving technologies greatly multiply the complexity of vehicle systems. Not only do they create more possible causes of failure, but also many more failure cascade paths. Since ADAS and autonomous driving systems inherently have safety implications, any failure can easily be catastrophic, even fatal. Conducting functional safety analyses of such complex systems, is tedious, error prone, and vulnerable to gaps and flaws. Automated functional safety analysis tools are therefore essential to ensure safety of ADAS and autonomous driving systems.

The ANSYS simulation platform includes medini Analyze – which efficiently implements core activities of functional safety analysis and conveniently integrates them into product development processes.

medini Analyze performs safety analysis and design according to ISO 26262 for software controlled safety related functions as well as hardware systems, and quality analysis for product design and related processes according to the SAE J1739 standard and VDA quality handbook. It integrates architectural and functional design with quality, reliability and functional safety analysis methods and performs driving situation analysis, hazard and risk analysis, Fault Tree Analysis (FTA) (Figure 5), Failure Mode and Effects Analysis (FMEA), probabilistic analysis and hardware failure metrics. medini Analyze provides complete end-to-end traceability of faults and failure, customizable document generation and tools for teamwork with detailed compare and merge.

Having a functional safety analysis tool in a simulation platform streamlines and expedites virtual testing of possible failure modes to evaluate their criticality and to develop counter-measures. Use cases include the utilization of simulation to provide evidence for earlier assumptions in functional and technical safety concepts as well as the ability of understanding potential failure modes through simulation.

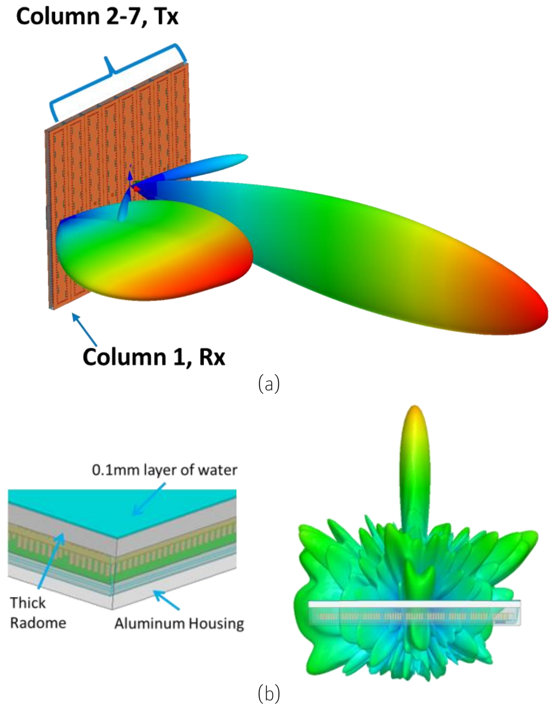


Figure 6. (a) Radar antenna pattern simulation (b) Effect of radome on radar antenna pattern.

4. Sensor Performance Simulation

Sensors are key new components that need to be developed for automated and autonomous vehicles. Simulation uses high-fidelity physics to predict the performance of sensors such as radars, V2X antennas, and ultrasonic sensors. For instance, simulation predicts radar patterns and gain in specific driving scenarios, eliminating expensive and time-consuming physical testing. Further, simulation computes the changes in performance of a radar when it is mounted on a vehicle, and when it operates in rain or snow, providing precise insights into real-life radar operation, at a fraction of the cost and time needed for field tests.

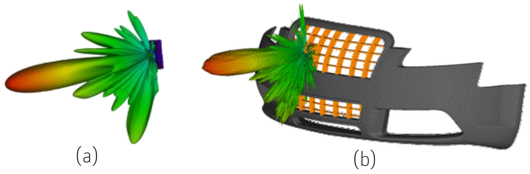


Figure 7. (a) Pattern of radar in kept in free space (b) Changed pattern when same radar is installed in a vehicle fascia.

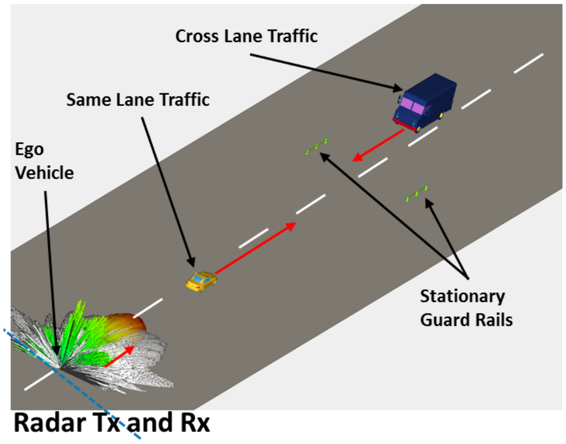


Figure 8. High-fidelity physics simulation of a radar operating in a traffic scene. The radar is mounted on the ego-vehicle on the left. The colored pattern is for Tx and the grey pattern for Rx.

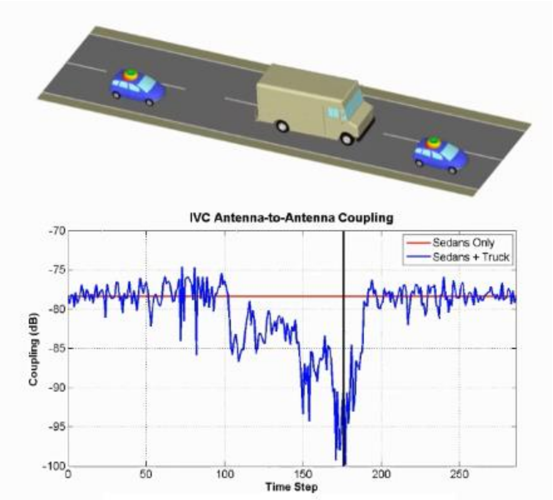


Figure 9. Vehicle-to-vehicle communication simulation. The coupling of antennas on two cars drops significantly when a third vehicle intercedes.

The ANSYS simulation platform includes an electromagnetic field solver (HFSS – High Frequency Structural Simulator) and a shooting-bouncing rays solver (SBR+). These solvers are used for performing high-fidelity simulations of automotive radars. These simulations accelerate four radar development aspects, as follows:

(a) Isolated Radar Simulation: Here the radar antenna(s) and radome are simulated as placed in free space. Rapid parametric studies are conducted in such simulations to optimize geometric and material design of antennas and radomes. (Figure 6.)

(b) As-Installed Radar Simulation: Here the radar is simulated as installed on a vehicle to determine the degradation of radar performance due to obstructions caused by the vehicle's fascia or bumpers. (Figure 7.)

(c) In-Environment Radar Simulation: Here the performance of a radar is simulated in a large, realistic environment comprising of other vehicles, buildings, pedestrians, trees, etc. Given an input signal at the radar's transmit antenna(s), the high-fidelity physics simulation computes the output signal at the radar's receive antenna(s) based on what the radar "observes" in the virtual environment that it is placed in. (Figure 8.)

(d) In-Driving-Scenario Radar Simulation: Here, reduced order models (ROMs) of high-fidelity radar simulations are used to create fast-executing, yet high accuracy, models of radars that can be used in driving scenario simulations described in item 1 above.

The same simulation tools are also used for developing and placing antennas for V2X communication and ensuring signal integrity in real-world scenarios such as those where other vehicles or buildings impede in the signal path between two vehicles. (Figure 9.)

The ANSYS simulation platform also includes acoustics solvers that are used for simulating ultrasonic sensors. In the example shown in Figure 10, the response of an ultrasonic sensor mounted on the rear corner of a model car is simulated with high-fidelity computation of acoustic waves as the car backs into a cylindrical pole.

5. Electronics Hardware Simulation

Automated and autonomous vehicles contain far more electronics hardware than in today's cars, in the form of radars, lidars, cameras, other sensors, V2X communication systems, signal processing systems sensor fusion boards,

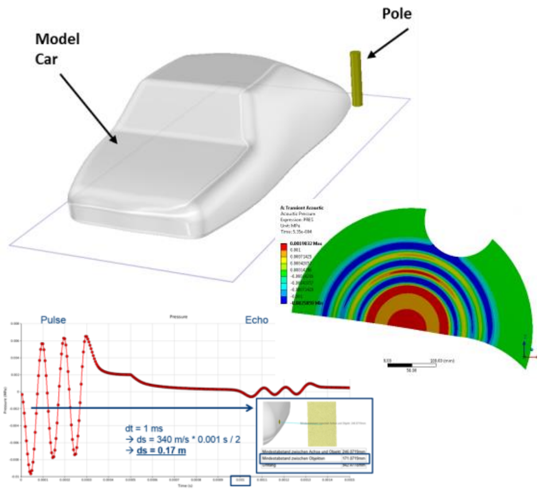


Figure 10. Acoustic simulation of an ultrasonic sensor mounted on the rear bumper of a model car.

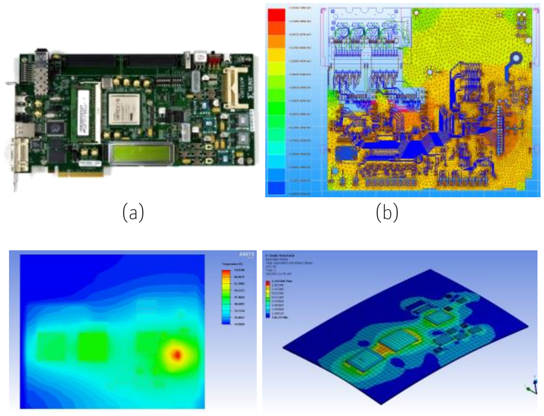

(a) (b) (c) (d)

Figure 11. Simulation of electronics reliability of a Printed Circuit Board (PCB) (a) PCB (b) Power map (c) Temperature distribution (d) Mechanical stress distribution.

artificial intelligence computers, controllers, actuators, and HMIs (human-machine interfaces). Many of these are safety critical components, and their hardware needs to be designed to withstand electrical, thermal, vibrational, and mechanical loads without failure over the lifetime of the vehicle. Simulation greatly expedites the speed of testing designs and provides physical insights that enable engineers to optimize electronics component and make them robust.

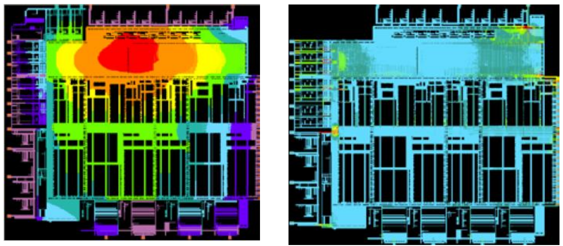
The ANSYS simulation platform provides specific tools such as Icepak, SIwave and Mechanical, to analyze various physical phenomena across electronic packages, boards, enclosures, and systems, such as power optimization, power integrity, electrostatic discharge (ESD), electromagnetic interference/ electromagnetic compatibility (EMI/EMC), thermal and structural reliability.

For example, Figure 11 shows a multiphysics simulation of a Printed Circuit Board (PCB) for improving its electrical, thermal and mechanical reliability. First, a DC simulation of power delivery in board components is conducted. It provides power dissipation information for all metal layers of the board which is then used in conducting a thermal simulation. The thermal simulation determines whether board and component temperatures are within allowable ranges. The thermal solution also provides guidance in determining various cooling options for PCB and components, such as selecting a fan or including a heat sink on a critical component. Further, a mechanical thermal–stress simulation is conducted using the temperature fields which evaluates thermal deformation of the board and components and predicts thermal fatigue in solder joints from temperature cycling. These simulations enable engineers to make decisions about connection locations, stiffeners, component placement, clamping loads, and other aspects to reduce thermal-mechanical stress failures of the board.

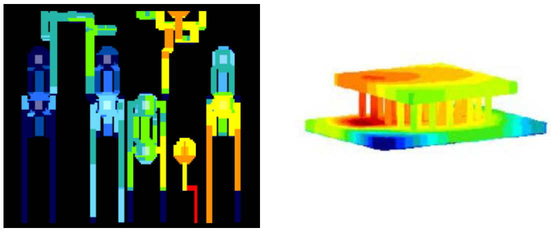
6. Semiconductor Simulation

ADAS and autonomous vehicle systems require a vast amount of signal processing and computation to be done in real-time onboard the vehicle. As a result semiconductor companies are developing devices with greater performance, while balancing energy consumption, structural and thermal reliability and device size. The physics associated with shrinking geometries, especially in the emerging 3D-IC, FinFET and stacked-die architectures bring out design challenges related to power and reliability.

Simulation and modeling tools help chip designers with accuracy and performance needed to reduce power noise and improve reliability of ICs. Through simulation, engineers identify and address key physical issues such as electromigration, thermal effects and electrostatic discharge.



(a) Dynamic Voltage Drop (b) Electromigration



(c) Electrostatic Discharge (ESD) (d) 3D-IC

Figure 12. Aspects of semiconductor simulation.

The RedHawk-3DIC package in the ANSYS simulation platform performs complete multi-die concurrent analysis of a 3-D IC/2.5-D system for noise analysis. The package can model interposers, through silicon vias (TSVs) and microbumps in power supply noise computation.

The PowerArtist package in the ANSYS simulation platform helps engineers design power efficient digital ICs by providing the ability to analyze and debug RTL code. PowerArtist can achieve predictable RTL power accuracy within 10 to 15 percent of that provided by gate level power analysis tools.

Large system-on-chips (SoCs) using advanced FinFET technologies offer the benefits of lower current leakage, higher performance and density in a smaller area. The challenges designers face are higher temperatures from higher current densities, self-heat, electromigration (EM) and electro-static discharge (ESD). These issues need to be identified and controlled. An increase in temperature of 25°C typically leads to 3x to 5x degradation of the expected lifetime of devices. The ANSYS simulation platform provides accurate thermal analysis with robustness and connectivity checks, power and signal EM checks, full-chip ESD analysis, and effects of self-heating (Figure 12).

Summary

Developing Advanced Driver Assistance Systems (ADAS) and Autonomous Vehicles requires vastly more test cases and operating scenario evaluations as compared to systems on today's vehicles. Engineering simulation is the tool needed to accomplish this prohibitively expensive, time-consuming task. With the speed and cost economy of engineering simulation, ADAS and autonomous vehicle engineers can virtually evaluate thousands of test cases, scenarios and design parameters, in the cost and time needed for a single physical test.
The ANSYS simulation platform provides high-fidelity simulation tools with deep capabilities to bring accuracy and confidence to ADAS and autonomous vehicle simulations. The single platform addresses six primary simulation needs in ADAS and autonomous vehicle development:

1. Driving Scenario System Simulation
2. Software and Algorithm Modeling and Development
3. Functional Safety Analysis
4. Sensor Performance Simulation
5. Electronics Hardware Simulation
6. Semiconductor Simulation

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Learn More

- “A Cost-Effective Model-Based Approach for Developing ISO 26262 Compliant Automotive Safety Related Applications,” Technical Paper, ANSYS Inc http://www.ansys.com/Support/resource-library/conference-paper/cost-effective-model-based-approach-for-developing-iso-26262-compliant-auto-safety-related-apps

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