Autonomous Drive Emulation
Applying C-V2X test solutions across the automotive workflow

Autonomous driving holds out enormous potential for transforming the way we get around. Further, it promises to forever change not only vehicle design and manufacturing but also automobile ownership and, indeed, the overall business of transportation.

Achieving the goal of fully autonomous driving involves the development of highly complex software infused with artificial intelligence (AI) that can correctly interpret and act upon streams of real-time data arriving from the surrounding infrastructure and emanating from arrays of in-vehicle-based sensors. One consequence: thorough verification of the functionality, performance and safety of such systems will increasingly depend on detailed simulation and testing in the lab. This can be utilized throughout the automotive workflow, beginning long before new advances are deployed in vehicles operating on public roadways.

Understanding the role of V2X communication

The types of sensors most associated with advanced driver-assistance systems (ADAS) include radar, LIDAR, ultrasonic, and cameras. External inputs arriving via vehicle-to-everything (V2X) radio add important data into the mix.

The core purpose of V2X communication is to provide standardized safety services by means of broadcast messages alerting individual vehicles to the presence, position, trajectory and speed of surrounding vehicles. Communication between vehicles, and with roadside units such as traffic lights, is provided by a wireless link in the 5.9 GHz band. This has a range of 300 meters and is not limited by line-of-sight, enabling vehicles to “see” and detect others that may be obscured by buildings, trees, and so on.

In the immediate term, V2X applications are being defined in the form of Use Cases by standards bodies in Europe (C2C Forum), North America (SAE), China (C-SAE), and elsewhere. In the longer term, applications such as those being considered by 5GAA will be developed using V2X information along with other sensor data. Collectively, these define the scale and scope of testing that must be applied to ADAS designs that incorporate V2X.
Utilizing testing and simulation

Per the relevant standards, the functionality and safety of systems that incorporate V2X must be verified across a variety of situations and conditions. As the breadth and depth of such testing increases, it quickly becomes too expensive, impractical, and risky to contemplate the use of actual vehicles operating on closed tracks or public roadways.

The development of vehicles has long been guided by the ISO 26262 framework and the associated V-model for ensuring functional safety (Figure 1). Referring to the diagram, model-based testing begins at the upper-left and proceeds downwards through three layers: system, subsystem, and module. Here, requirements for an entire vehicle are ultimately broken down into requirements for the underlying modules and components. On the right-hand side, hardware-based testing proceeds in the reverse order through the same three layers, moving upward through module, functional, integration and system test.

Figure 1. The V-model provides an effective rubric for the design, implementation, integration, and testing of ADAS and AV designs.
Referring to Figure 1, below are some examples of tools that currently are used within each category:

- Traffic/road system modeling can be done with software such as Nordsys waveBEE Creator or IPG Carmaker.
- System and sub-system design can be done with a variety of simulation software like Keysight’s SystemVue or MATLAB Simulink.
- The right side of the V, under "Integration test" and "Functional test," is where Keysight’s ADE platform makes its core contribution by reducing the required amount of road testing.¹

In the case of electronically implemented functions, this approach is relevant to the development of electronic control units (ECUs) by original equipment manufacturers (OEMs) and their Tier 1 suppliers. The design of these capabilities into software, hardware, or both, follows the overall system breakdown shown in the V-model. In this case, activity on the right-hand side of the V ultimately results in validation of the functionality and safety of an entire vehicle.

**Performing wireless testing of V2X systems**

In the case of AVs and V2X applications, the entire vehicle itself is part of a larger traffic system that includes “network equipment” elements (e.g., roadside units transmitting data about traffic-light sequences). However, testing is most cost efficient at the component level: it is very expensive to test basic functionality of such components in a real vehicle, especially when there is a risk of defects that might result in harm to people, property and vehicles.

Let’s consider V2X as an example within the framework of the V-model. There is no dispute that testing is critical to delivery of V2X-based applications either alone or embedded in a larger system. Specifically, testing is required at many different levels of the V2X communications stack and at the application layer. Reliable and repeatable V2X communication depends upon complex software implementations, with multiple contributors up and down the stack.

Working up the right leg of the V-model for a V2X on-board unit (OBU), testing of radio modem functionality and its adherence to standards is normally done in a manner similar to that used for mobile phones and data devices in the wireless industry. Testing requirements map onto the ITS stack and the OSI model, as summarized in Figure 2. The sidebar, below, provides a more detailed description of the test process for a cellular V2X (C-V2X) OBU.

¹ Driving to Safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability? | RAND
### OSI Layers Testing Requirements

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<td>Emulation of network elements to establish link for RF and modulation measurements</td>
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<td>Protocol test tools</td>
<td>Relevant regional ITS certification body (i.e., OmniAir) using regional standard (i.e., SAE)</td>
<td>Ensure correct V2X message types and content are sent and received.</td>
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<td>Closed-loop or MHMI checking</td>
<td>SAE&amp;OEM proprietary definitions</td>
<td>Ensure functioning of application upon receipt of valid ITS messages</td>
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Figure 2. Testing of a V2X OBU covers all seven layers of the ITS stack and the major elements of the OSI model.
Test lifecycle of an OBU

For all cellular wireless devices, testing of the physical layer and the data link has typically been conducted by chipset makers and device vendors using wireless test sets and related tools. In this first step of validation, such tools provide an emulation of the network elements necessary to establish a wireless link with the DUT and thereby enable the necessary RF and modulation measurements.

An example: With a C-V2X OBU, the PC5 vehicle-to-vehicle (V2V) wireless link relies on the radio- and lower-level protocol stacks in a chipset. These must be tested and, over the years, the wireless industry has evolved a chain of test solutions that are used during the development of the radio and protocol layers. Certified operation of both layers ensures interoperability between devices that use chipsets from different vendors.

Bodies such as 3GPP and GCF specify standardized tests of the different layers of the modem implementation. Beyond verification of interoperability, these tests also ensure the modem meets requirements such as range and data throughput. Such tests typically use a wireless test set that has an independent modem implementation along with protocol test tools and calibrated parametric physical-layer measurements.

Above that, protocols associated with the transport of data as defined by the relevant regional ITS stack are put in place by ITS stack vendors (e.g., GeoNetworking in the European-defined system, and IPv6 and TCP/UDP for North America).

In addition, OBUs containing an integrated upper ITS stack are tested to ensure the correct V2X message types and content are sent and received. Certification regimes for C-V2X OBUs and roadside units (RSUs) are still being established. In the United States, the OmniAir Consortium is leading the way by creating a clear set of Test Cases covering adherence to the technical specifications each OBU and RSU must pass to achieve certification.

Integrating into the vehicle

Once individual testing confirms an OBU can successfully send and receive defined messages, the next step is to verify that the vehicle uses these messages correctly in the application layer to either guide the human operator or, in the case of an AV, take direct action.

Applications are described by Use Cases, which are then interpreted by the engineers at an OEM or a Tier 1 supplier, and they implement these within a vehicle. At this level, the output is linked to the driver’s human-machine interface (HMI) display or, ultimately, into vehicle control surfaces.

Simple applications may still be tested on an OBU or integrated telematic control unit (TCU) level. However, as advanced applications begin to involve control surfaces beyond the HMI, closed-loop system testing will become more useful. In the V-model, this is represented by moving all the way up the right-hand side to System Test.
Applying hardware-in-the-loop testing

The automotive industry typically uses hardware-in-the-loop (HIL) techniques to emulate the vehicle systems that surround and connect to any newly developed components (e.g., an OBU). This allows a variety of components to be tested individually before the system is assembled using the constituent elements. Eventually, a full vehicle is created and can be tested without the cost or physical risk of actual drive testing around a closed track or along public roadways.

When one considers V2X applications, the vehicle itself is merely part of a much larger road-traffic system that is intended to manage factors such as road-space usage, traffic flow, public safety, and efficiency (e.g., energy and emissions). Even though OBU functionality and conformance can be tested extensively using open-loop methods, the operation and performance of the entire system may still be impaired by issues in the wireless domain. The resulting problems will emerge in closed-loop functional testing when the OBU can, for example, be put into corner-case situations that include traffic congestion, radio-propagation impairments, and so on.

While open-loop testing uncovers many of the basic errors in the system, closed-loop or HIL testing reveals more systemic issues. The issues found during closed-loop testing often incur much higher cost when found at the test track or on open roads.

While pure software simulation as portrayed on the left-hand side of the V-model has a key part to play, emulation of realistic scenarios (e.g., traffic and road conditions) provides a more rigorous test of actual vehicle system performance. Figure 3 shows an example test performed using such a software-based simulation.

Figure 3. This software-based simulation tests V2X applications using realistic traffic and RF congestion conditions for the host vehicle and all surrounding remote vehicles per the defined Use Cases in the relevant standards.
Looking ahead

In the pursuit of excellence in ADAS and AV designs, it’s clear that automotive OEMs will continue to invest in multiple new technologies simultaneously: radar, LIDAR, C-V2X, SerDes, 4K cameras, and more. The amount of testing applied to any new vehicle design has always been massive, but that burden becomes enormous when the amount of technology in a car is quadrupled, with terabytes of data moving within a single car every day. The upfront investments in development and testing are huge, but so is the potential payout, with some forecasts suggesting the AV market may grow into a trillion-dollar business in the next 20 to 30 years.

Naturally, the aspiration is to have it all, and this depends on parallel investments: one stream is dedicated to refreshing and slowly upgrading current makes and models, and the other supports creation of the automated vehicles of tomorrow. The winners will be those that can capture the present and future markets.

Realizing your vision of mobility

To achieve the goal of fully autonomous driving, OEMs and their suppliers need a way to test in a closed-loop environment using real-world signals in a lab. Keysight’s visionary ADE platform brings the road to the lab, thereby enabling the testing of real sensors with real data in a closed-loop system. Ultimately, this translates into confidence, cost savings and a competitive edge in the race to achieve fully autonomous transportation over the roadways.

As you continue to create what comes next, Keysight is ready with test solutions that can accompany you from concept to reality. Our goal is to help you excel—and accelerate—in those areas that are redefining future mobility: sensor systems, wireless links, in-car networks, batteries, and cells, and beyond. It’s all about getting there first and realizing your company’s vision of mobility.

To learn more, please visit www.keysight.com/find/ade

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