

How Should the Automotive Industry Test V2X Systems?

**Why the connected car demands a
fundamental shift in vehicle testing and QA**

Introduction: Not Just Another Technology

Connected vehicles demand a step-change in automotive testing

Every day, new vehicles are becoming more connected—with each other, with the Internet, and with surrounding infrastructure. New systems are being developed and integrated at a rapid pace, as automotive brands compete to claim an edge by harnessing the potential to improve the driver and passenger experience—whether in terms of safety, information, convenience or entertainment.

Although exciting, this shift poses serious and increasingly urgent questions for anyone involved in automotive testing or QA. The nature of the technologies involved—and in particular the demand for interoperability and security—represent uncharted territory for the industry as a whole.

This paper outlines what's changing in the world of vehicle-to-anything (V2X) connectivity, why, and what the impact is likely to be. It also suggests how automotive suppliers and OEMs can begin to adapt their testing methods and approach.

V2X and the Connected Car: Challenges and Opportunities

What's driving the change?

When the US Secretary of Transportation announced¹ a proposal to plough \$3.9 billion of funding into autonomous vehicle pilots, he was confirming what the industry has known for some time: self-driving cars are coming – and soon.

Already, some vehicles are going beyond SAE International's automation levels 0 and 1², and putting multiple driving functions under the vehicle's control. USDoT and NHTSA updated its policy statement³ to allow for Level 4 vehicles capable of "high automation".

However, automation is just one of the drivers behind ever-increasing connectivity in vehicles. A number of objectives are converging around the need for in-vehicle systems to communicate with their surroundings—and each other:

- ADAS (Advanced Driver Assistance Systems) are passive and active safety systems designed to remove the human error component when operating vehicles of many types. The role of ADAS is to prevent deaths and injuries by reducing the number of car accidents and the serious impact of those that cannot be avoided.
- Internet connectivity for passenger information and entertainment
- Remote, real-time management in response to live traffic conditions, to improve vehicle fleet performance and reduce fuel spend
- Interaction with traffic signals and other roadside infrastructure to optimize traffic efficiency
- Availability of self-parking and other driver convenience functions

1. <https://www.transportation.gov/briefing-room/detroit-auto-show>

2. http://www.sae.org/misc/pdfs/automated_driving.pdf

3. <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Autonomous-Vehicles-PolicyUpdate-2016.pdf>

Independent of any technological considerations, road traffic is and has always been inherently cooperative to avoid crashes. Participants communicate with each other directly (person-to-person, e.g., using visual contact) or indirectly (i.e., using different technical means provided by their vehicle, e.g. turn signals, signal-horn, etc.). Because it replicates the mutually beneficial aspect of avoiding collisions in traffic, enhancing communication using more automation, V2X communication is an essential component of the autonomous vehicle ecosystem.

This was clearly acknowledged recently by the US Department of Transportation's (USDOT) National Highway Traffic Safety Administration (NHTSA) through its newly issued Notice of Proposed Rulemaking (NPRM) document⁴ aiming at mandating V2V Communication on light vehicles to help avoid potentially deadly crashes.

It seems inevitable that delivering V2X communications which work correctly, under all possible conditions, will soon become a critical part of vehicle development, and simply expected by drivers—with far-reaching consequences for brand reputation.

This presents all stakeholders with a unique combination of challenges.

Seven Barriers to Consistent V2X Communication

There are several hurdles that V2X stakeholders will need to overcome, and quickly, if the promised advances in connected vehicle functionality are going to meet users' expectations:

1. Integrating heterogeneous systems

Systems engineers will need to predict, account for and reconcile a rapidly increasing variety of factors—both inside and outside the vehicle itself—and enable the vehicle to process and prioritize the information correctly. For example:

- A proliferation of on-board sensors, accelerometers, gyroscopes, Radar/Lidar and digital signal processing
- In-vehicle and external Information Technologies
- External telecommunications and a variety of in-vehicle networks such as CAN bus and BroadR-Reach Ethernet
- A shifting landscape of V2X communication technologies—currently including ITS-G5 (in Europe), WAVE-DSRC (in US) and CCSA (in China) based around the IEEE 802.11p WiFi protocol, but potentially extending to a cellular physical layer, such as LTE-V or 5G⁵
- eCall rapid assistance systems

4. <http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Autonomous-Vehicles-PolicyUpdate-2016.pdf>

5. <https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf>

5GAA is actively working on providing connected mobility for people, vehicles and transport infrastructure with cellular layers. And for all these technologies, automotive systems developers will need to handle signals from multiple vendors, and—assuming the vehicle is designed for sale in more than one region—protocols and requirements that vary from one domain to another.

Meanwhile, the nature of third party actors in the architecture is no less diverse. As well as other cars, vans, trucks and motorcycles on the road, the vehicle will need to recognize and interact appropriately with pedestrians and cyclists, various kinds of roadside infrastructure and, potentially, mobile devices carried by passengers—both in the vehicle itself, and others.

2. Sheer Technical Complexity

Even by the high standards of the automotive industry, creating a working V2X system is a difficult technical challenge.

Each V2X system will need to interface on many fronts—including several that are wireless, or based on technologies which are new and, as yet, not fully proven. This, and the sheer number of technologies that need to be combined and prioritized within a single structure, make developing a connected vehicle a complex, multi-disciplinary task.

This complexity is itself multiplied by the fact that many of the external actors in the wider system will themselves be moving, behaving in inherently unpredictable ways, and subject to changing signal conditions—which may intermittently affect communication.

3. Satisfying stringent requirements

Before a V2X system is deemed acceptable for market, it will need to deliver consistently high standards across a range of requirements:

- **Functionality:** Simply, the system must consistently behave as the user expects, and deliver the performance promised in any reasonable scenario.
- **Interoperability:** In the automotive industry, the need to interact well with other manufacturers' vehicles, as well as other third parties, is a new challenge. Failure to confirm interoperability will negatively impact safety, customer experience and public trust in a brand.
- **Safety:** Whatever happens, the system must not place the driver in danger. This applies both to reliability (that it works) and latency (that it works quickly enough).
- **Quality of Service:** QoS is well established in telephony and computer networking, as a measure of the performance experienced by users. As vehicles become increasingly connected, it is essential to check in-vehicle networks deliver as they should.
- **Type Approval:** As standards become established for V2X functionality, they will become integral to vehicle type approval specifications and other regulations—which may vary between territories.

4. Susceptibility to channel interference

Any wireless communication channels that a V2X system uses could be affected by signal interference and other impairments. This might include lack of coverage, network load, atmospheric interference, physical obstructions and deliberate or accidental jamming by high-powered RF sources.

Whether the effect is a reduction in the quality, availability or completeness of communication, or an increase in latency, the system's ability to recognize and respond to unpredictable signal conditions is a further level of complexity—and essential to a safe, high-quality experience for the driver.

5. Improving security against cyber attacks

The risks to connected vehicles from deliberate hacking and spoofing are real, current, and growing.

In July of 2015, a Wired magazine article⁶ revealed how hackers had been able to remotely seize control of key functions of a new Jeep Cherokee—including its transmission and brakes—while being driven by a journalist on the highway.

V2X signals provide a significant exposure to such threats, and the widespread availability of the necessary technology and expertise make hacking all but inevitable. Systems need to be robust, and able to recognize and respond to attacks, to protect brands' reputations, public confidence in connected car technology and, most importantly, the safety of road users.

6. Meeting regulatory legislation and standardization

To ensure safety and interoperability, authorities in the US and EU are taking an active interest in V2X, establishing standards, with regulatory legislation likely to follow.

- **Europe:** The European standards for Intelligent Transport Systems (ITS) are overseen by the European Telecommunications Standards Institute⁷. It publishes 20 different ITS standards; the most relevant for V2X communications is the conformance test specifications for GeoNetworking ITS-G5, based upon IEEE WiFi Protocol 802.11p.
- **United States:** The agreed US WAVE/DSRC protocol stack is similarly based on IEEE 802.11p. The standards for the higher layers are set out in IEEE 1609. The USDOT certification framework for V2X pilots puts forward a modular approach—giving a clear indication of likely certification standards for production vehicles.
- **Asia/Pacific:** China communications Standard Association is closely aligned to the US model, based around IEEE 1609 and IEEE 802.11p.

6. <https://www.wired.com/2015/07/hackers-remotely-kill-jeep-highway/>

7. https://www.its.dot.gov/research_archives/connected_vehicle/connected_vehicle_cert_plan.htm

7. Rapidly changing market conditions

Drivers have always demanded absolute reliability from automotive systems—with significant brand damage if a manufacturer acquires a poor reputation. However, the rise of social media has amplified word of mouth, and significantly raised the stakes for all concerned.

Meanwhile, the convergence of in-vehicle and consumer communications technology means customers' expectations are inflated by the experience and rapid pace of innovation in the personal electronics market – with the result that time-to-market is a more critical factor than ever before.

Automotive manufacturers are therefore challenged to respond more quickly to technological opportunities, and shorten development cycles, while retaining quality and keeping their overall investment under control.

This requires a new emphasis on agility—and also the awareness to predict future trends, and back the winner when technologies compete.

To the victor, the spoils

For those who can overcome these challenges and make a success of V2X, the rewards could be vast.

Combining the technologies currently in development offers a dizzying array of potential vehicle features and functions – and while some will doubtless become de rigueur, the industry has its greatest opportunity in decades for a brand to steal a march on its competitors and seize the market's imagination with some smart, creative engineering.

Perhaps for the first time, brands have the potential to release a vehicle that can simply do things others can't.

In the longer term, however, the opportunities are greater still. In the same way that digital disruption has fundamentally transformed entire industries—taxis, accommodation, video rental and music, to name only a few – V2X and automated vehicles could begin to change the established relationship between the manufacturer and the driver. Whole new business models are possible, and maybe even the notion of vehicle ownership could change.

But every one of these challenges and opportunities hinge on the ability to subject emerging V2X systems to rigorous, thorough and cost-effective tests.

Three Basic Goals for V2X Tests

Clarifying testing objectives reveals the appropriate approach

Before defining V2X test methodology and equipment, it would be helpful to establish the purpose for the test itself. Broadly, tests fall into three categories, each demanding a different approach.

Some, like those ensuring V2X-enabled vehicles meet set criteria and perform as the driver expects, are in principle no different to the kinds of tests the industry has always needed to introduce new technologies: define the right tests, and iterate to ensure the vehicle passes.

Others, however, involve more of a paradigm shift. Because as vehicles grow ever more connected to the digital world, they become a realistic target for signal spoofing and other abuses—requiring a whole new approach to security. And as cars get more connected to each other, system interoperability becomes a real issue: arguably for the first time in its 130-year history, the automotive industry needs to act as one—a true team play.

Goal 1: Testing V2X for conformance and interoperability

Connected vehicles need to interact with roadside infrastructure—and, just as importantly, each other. That means all manufacturers will need to conform to a common set of agreed standards.

As with all new automotive technology, consumers' trust will be essential to adoption—and any failures, particularly those affecting safety, will reflect directly upon the brand involved, irrespective of where the actual blame lies.

But in many respects, interoperability is a new challenge for the automotive sectors. OEMs and their supply chains have an excellent track record in setting, meeting and policing their own standards—but direct interoperability, based upon shared protocols, will be something many automotive test engineers are facing for the first time.

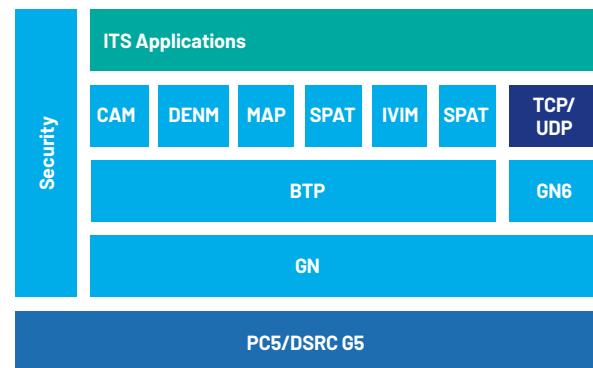


Figure 1. ETSI ITS-G5 Protocol Stack (Europe)

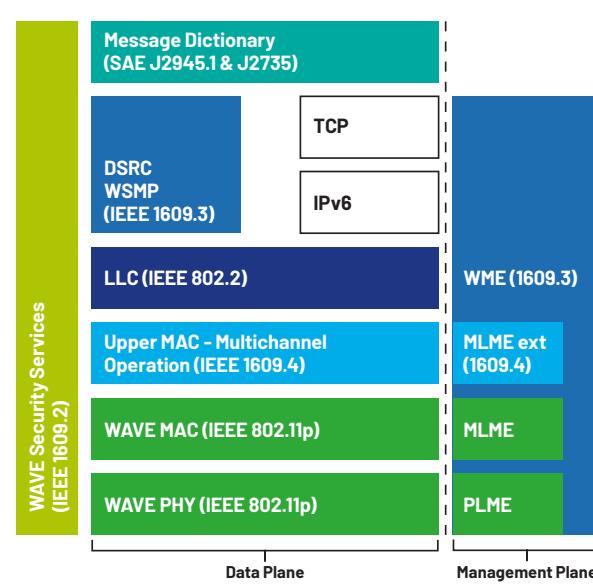


Figure 2. WAVE-DSRC Protocol Stack (US, AIPAC)

Helpfully, other sectors—most notably IT—have well-established working methods in this area that can give a strong starting point, and regulatory bodies in both the US and EU are giving clear guidance over emerging protocols.

Manufacturers in the sector therefore need to define test cases that will enable them to confirm any new V2X systems conform fully to the relevant protocols for each territory.

While ITS-G5 and WAVE/DSRC are both based on IEEE 802.11p, the protocol standards from the upper MAC layer upwards are quite different.

Goal 2: Testing V2X for functionality and performance

Conformance with agreed protocols is only a first step. As with any automotive system, it is essential to test that every new connected vehicle is safe, performs well, and will respond to real-world situations and challenges in the way the user would expect.

For V2X, this means it needs to send, receive and interpret signals correctly, interact well with infrastructure and other vehicles, and make sense of all this information to react appropriately in every case—including when signals are weak, or interrupted in the normal course of driving. Naturally, the system will also need to fail safely when overloaded.

A sensible framework for tests would include:

- **Evaluating response to real-world challenges** such as radio channel impairments, obstacles to reception, and both deliberate and accidental cyber attacks
- **Including other on-board units (OBUs) and roadside units (RSUs)** to scale up the complexity of the environment, and see how systems cope with a changing variety of V2X signals at once
- **Finding failure points** by pushing the system beyond its limits, to evaluate its tolerances and discover how it behaves
- **Capturing how the device under test (DUT) behaves**, with clear reporting to enable performance comparisons and confirm whether it responded as expected
- **Testing at a component and system level** including both software-in-the-loop (SiL) and hardware-in-the-loop (HiL), as appropriate

Goal 3: Confirming V2X security

Alongside any tests for standards conformance or system performance and functionality, it is essential that your V2X test regime confirms security in the face of a growing number of increasingly realistic threats:

Deliberate and accidental jamming. Self-contained signal jammers, that plug into a vehicle's cigarette lighter socket and block telematics systems, are widely available online. And although currently aimed at GPS, it is likely that similar devices will become increasingly common for V2X if there is an opportunity to evade road tolls or congestion charges.

What's more, it is not only devices within the vehicle itself that are a risk: one jammer can affect a wide area. In 2013, a single pickup truck on the New Jersey turnpike caused harmful interference to GPS-based landing systems being tried out at Newark Airport⁸.

Similarly, other signal sources—like nearby radio broadcast equipment—can interfere with in-vehicle systems, quite accidentally.

Advanced hacking and spoofing. Two Chinese security researchers—with no special GPS expertise—stunned delegates at Nevada's DEFCON 23 conference by using a cheap, off-the-shelf components and open source code to control the GPS receivers of a smartphone, a drone, and a car's satellite navigation system⁹.

This is no distant, or futuristic threat. V2X communications give hackers a direct route into a vehicle's systems—and the technology and knowhow to abuse that opportunity are widely available now. The more automated those systems become, the greater the potential for vandalism, theft or, worse, deliberately endangering a vehicle's occupants.

Consumer level spoofing. Even without attempting grand theft or intentionally endangering life, the ability to broadcast fake V2X signals, if unchecked, could quickly present unscrupulous consumers with a number of potential benefits. False accident reports could redirect traffic to clear certain routes, while others could gain priority by recreating the signature of an emergency vehicle.

The automotive industry as a whole will need to develop systems capable of spotting and rejecting such counterfeit signals.

For many automotive test engineers, these worries are entirely new territory, and demand a new way of working, to stay ahead of a constantly-evolving mix of threats. However, the more connected vehicles become—and the more central V2X communications are to their operation—the more these attacks become not only likely, but inevitable.

To mitigate the risk, V2X systems need to be robust, reliable, and capable of recognizing when they are under attack—and these capabilities need to be tested.

No automotive brand would want the reputation damage of being the first to fall victim to a widespread security exploit, so it is essential that V2X test equipment includes the flexibility to recreate current and future threats as they emerge. A configurable, GUI-based emulator gives the control required.

8. <https://www.cnet.com/culture/truck-driver-has-gps-jammer-accidentally-jams-newark-airport/>

9. <https://defcon.org/html/defcon-24/dc-24-index.html?ref=infosec-conferences.com>



Three Further Requirements for a V2X Test Regime

As well as enabling stakeholders to meet the three broad objectives for V2X testing, there are three additional demands which should help to define how those tests are carried out.

Requirement 1: Cost efficiency

Given the endless variety of challenges a V2X system might face in use, the cost of adequate field testing—in fuel, maintenance and engineer time alone—is likely to be prohibitive. These costs then increase exponentially when the systems are tested for a variety of locations worldwide. Developers therefore face a challenge to define how much testing, within budget, is enough.

The more cost-efficient a test regime can become, the more room there might be within budget for engineers to increase the scope of tests—further fine-tuning performance and protecting against live issues emerging for consumers.

Requirement 2: Flexibility

V2X systems comprise an array of technologies—from satellite signals to in-vehicle sensors, WiFi and networking—so in order to be effective, a test solution needs the flexibility to cover the various elements, both individually and in combination.

Requirement 3: Long-term adaptability

The technological environment around V2X—and the connected car as a whole—is dynamic, and can potentially change quickly. While some areas—such as the preference for WiFi over cellular communication as a physical layer—are currently relatively clear, it is likely that new practices, features and technical capabilities will emerge. The numbers and types of on board units (OBUs) and roadside units (RSUs) could also grow exponentially.

The industry therefore requires test solutions that can be adapted and updated to reflect the environment as it evolves.

V2X Testing Methods: Lab Vs. Field Tests

Although live, drive testing in the field remains a key part of developing any automotive system, laboratory-based tests also have a critical role to play. The two approaches have complementary strengths.

Lab-based V2X testing

Testing on the laboratory bench can use either simulated or pre-recorded signal information, to evaluate and compare a system's behavior. Its key strengths include:

- **Precision:** Parameters like speed, direction, timing and position are known absolutely, and are not subject to human (typically, driver) error and interpretation. For example, it is far easier to recreate precise braking or acceleration, at an exact moment in time. This allows much finer analysis and comparison with known "truth" data.
- **Repeatability:** No two live test runs are exactly alike. Even if the dynamic position of the vehicle can be replicated, other elements like atmospheric conditions and satellite geography are constantly changing—making true, like-for-like comparisons impossible. A lab-based simulation gives a controlled set of known conditions, that can be repeated at will, enabling iterative testing of fixes and upgrades.
- **Cost & Time Efficiency:** Possible V2X test permutations are almost endless, making field tests an expensive option in terms of fuel, maintenance, engineer time and travel. With a lab test, the extra cost of each additional location or test case is negligible. And because test programs can be pre-defined and automated, they can be run overnight or in parallel with other engineer work.
- **Versatility:** Lab-based tests can be performed at any stage of a product's lifecycle—from initial component comparison and selection (where rapid iteration can speed time to market) through integration, HiL testing and, potentially, warranty fault recreation. It can also be used to give a higher degree of confidence in a system before field tests commence.
- **Safety:** Lab-based testing enables safety-critical functions to be pushed to the limit without endangering people or property. For example, it enables an Intersection Collision Risk Warning (ICRW) system to be tested with fast-moving vehicles, without endangering the drivers if it fails to activate.

However, lab-based testing is unlikely to be sufficient in isolation. Certain failures may never occur if the engineer has not chosen to simulate the situation concerned, and indeed some functionalities, features and failure states may not even be possible to recreate accurately in the lab.

Testing V2X communication in the field

Real-life drive testing provides essential proof that an automotive system works. It is, however, slow, expensive and imprecise. System failures can be dangerous, and it is difficult to iterate—both because test slots are arranged far in advance, and because of the difficulty in recreating test runs like-for-like—so failure states can be hard to recreate.

But live field testing has two vital strengths:

- **Realism:** Tests are based upon use cases that recreate the end-user's actual experience. It therefore gives test engineers a far more accurate reflection of how the system will behave when it is used in practice, helping to improve satisfaction and ensure the finished product is a success.
- **Unpredictability:** Most lab-based tests will only reflect the world as the engineer has created it. Their scope is therefore clearly defined and planned. Live tests, by contrast, can encounter almost anything— giving the broadest possible scope to find potential issues caused by real-world factors that may not have been thought of and included in a designed simulation.

The Growing Gap Between Lab and Field

How long can the industry harness the best of both approaches?

Both laboratory and field testing have important roles to play in the future of V2X development, and the industry should make the best possible use of both in order to drive innovation in a safe, robust and cost-effective way.

However, as the technologies involved become more sophisticated and numerous, the gap between the two approaches is growing. It is becoming increasingly difficult to reflect all the internal and external influences upon the connected car in a laboratory environment—meaning it is difficult to connect the two in a meaningful way, and harness the respective strengths of both.

There is a pressing need for smarter integration of lab test equipment, with a higher standard of simulation, to give a more precise, accurate and controllable lab-based version of live test conditions.

A joint testing solution

In order to achieve truly flexible and robust V2X testing, the test setup needs accurate simulation of location and signal environments, varying levels of interference, and both radio and CAN bus communication—all in a fast, flexible, user-definable package.

VIAVI V2X Virtual software allows engineers to test the dynamic behavior of V2X entities (both OBUs and RSUs) in a virtual environment that accurately re-creates the key conditions such devices would face in the field.

The user can choose test scenarios for pre-set V2X safety applications, as well as the geographical location where the test will play out—giving the freedom to simulate tests anywhere in the world. Other key parameters, such as performance metrics, acceptance criteria and the number of vehicles present, are also under the user's control.

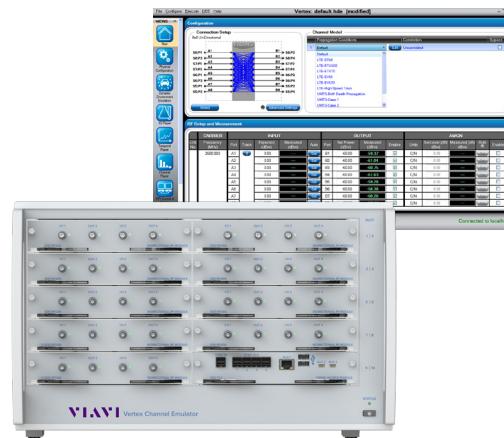
Importantly, the emulator combines software and hardware simulation, creating a comprehensive, virtual field test environment. The DUT uses real signals to communicate with virtual vehicles and its environment, while performing well-established safety application trials.

There is also the option to apply fading models to the various communication channels dynamically, to give an accurate reflection of changing real-world impairments (such as weather, multi-path loss, reflection and physical obstructions) that the vehicle would realistically face while moving through its virtual test route. For example, if the defined path shows a tall building as the vehicle approaches an intersection, VIAVI Vertex channel emulator can dynamically impair the radio channel accordingly.

V2X Virtual Software



Vertex Channel Emulator



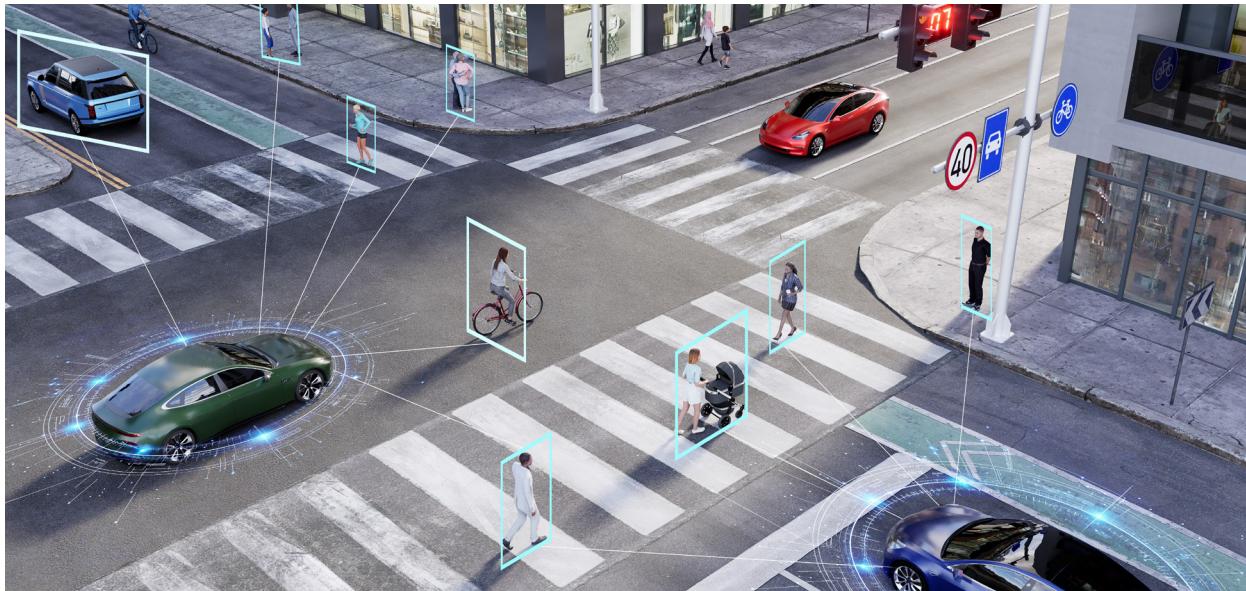
C-V2X Hardware Platform

VIAVI V2X Virtual is a solution for conformance testing and for functional validation and performance testing of devices and systems implementing V2X applications. This integrated and scalable environment combines several components for testing V2X applications at any stage of the product development cycle, from early prototyping to pre-production.

The solution supports the execution of traffic scenarios on the testbench in a virtual environment that reflects all communication properties of field testing. This can help optimize costly and risky field tests by making them more efficient and targeted.

Benefits

- Real-life conditions in the lab
- Modular and scalable test solution
- Open APIs for integrating with existing Model-in-the-Loop (MiL) & Hardware-in-the-Loop (HiL) test environments
- Reduce deployment, operation & maintenance costs
- Optimize the effort of field tests regarding test results analysis
- Performance assessment and benchmarking of V2X safety applications
- Measure Mobile Network and Road Infrastructure readiness for C-V2Xs
- Open architecture for 3rd party functions (Traffic Sim, Vehicle Sim, GNSS Sim, Test Control)
- Multi-region C-V2X protocol stack support
- Dedicated C-V2X Hardware Platform with C-V2X LTE-V PC5 (Side-Link) Radio Modules, Ethernet & CAN FD ports



In Conclusion

Building new approaches upon well-established foundations

Increasing integration of V2X, ADAS and automated systems present automotive test engineers with a number of challenges for the first time: most notably, interoperability and cyber security.

However, the overall premise—to find a reliable, robust, and cost-effective way to ensure the vehicle and all its components deliver the best and safest experience for the driver—remains the same as it has always been.

Similarly, solutions for testing the next generation of connected vehicles should be built upon proven methods, technologies and techniques—brought together in innovative ways to give the flexible, adaptable answer engineers need to perform the right tests in a fast, cost-effective way.

For years, VIAVI engineers have worked alongside many of the world's top automotive, engineering and systems test teams, to devise technical solutions, processes and support that deliver robust results, while enabling rapid innovation. Our new joint V2X Emulator is merely one example of that approach, complementing our existing [conformance test solutions](#) for that technology.

That process is ongoing—so if you're developing or testing V2X systems, we'd love to talk to you about your challenges, share some of our experience, and find out what you most need.



Contact Us: +1 844 GO VIAVI | (+1 844 468 4284). To reach the VIAVI office nearest you, visit [viavisolutions.com/contact](#)

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