# Automotive Ethernet Testing

## The five stages of testing Automotive Ethernet switches & networks

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# TWO INDUSTRIES COLLIDE

## The automotive industry is merging traditional communications systems with Ethernet. But watch out - there can be danger ahead.

Ethernet is the de-facto standard for in-vehicle communication, especially for Connected Autonomous Vehicles (CAVs) and Electric Vehicles (EVs).

Why? Because the amount of data generated by sensors, cameras, radars, lidars and external data flows like V2x, telematics and infotainment exceeds what traditional automotive communication systems like CAN (1Mbit/s) to CanXL (10Mbit/s) can support

These legacy technologies will coexist with Automotive Ethernet for some time - especially for data rates below 10Mbit/s - which creates the demand for communication gateways between Ethernet and other technologies.

So currently the situation looks like this: Ethernet is a well-known communication technology from the telecommunication and information technology industry. It is also used extensively in other industries like industrial automation. The standard for Ethernet is IEEE 802.3 and it follows the OSI layer model of communication.

For automotive applications, various other organizations are involved such as the OPEN Alliance. Most of the automotive technology standards will eventually be integrated into IEEE standards and test specifications will be integrated into ISO standards.

Traditional Ethernet uses different types of physical transmission lines like twisted pair copper cable in unshielded and shielded variants with 4 to 8 wires. But it can also be used on fiber cable, coax cable or even in a wireless RF variant. In the past, Ethernet was mainly a BUS architecture like CAN or LIN, and we see new variants of Ethernet (e.g. 100Base-T1) that also use the BUS architecture.

Today, most Ethernet is based on the switching architecture. The biggest difference between Ethernet and Automotive Ethernet is the physical layer as Automotive Ethernet only uses a 2-wire unshielded twisted pair cable, like the cable used for CAN. This reduces the weight of the Ethernet cabling which improves the assembly process significantly.

The core problem with Ethernet in systems like in-vehicle networks - where safety is a top priority - is that most applications offer better ways of prioritizing data frames in the setup. Standard Ethernet networks use the “best effort” principle, which means network components forward a data frame from A-to-B on their “best effort”. However, with in-vehicle networks it’s essential to ensure that data frames relevant to safety have the highest priority, the smallest delay, and maximum reliability. Different network transport protocols are used to enable these features.

# WHY IS TESTING SWITCHES SO IMPORTANT?

## Ensuring safety and optimizing performance is essential.

Switches are the core backbone components in any well-performing Ethernet network and critical for robustness.

Typically operating at the data link layer (OSI Layer 2), switches are available in hundreds of different configurations based on the number of ports, different port speeds and supported data link layer protocols. Also, a switch-based network architecture allows multiple variants of how a switch behaves and performs in the network.

There are multiple challenges involved in designing, engineering, and setting up an Ethernet network. See the figure below for an example of an in-vehicle network with an Ethernet backbone.

The network includes different switch configurations, and switches are part of different device types in this setup. They are part of Domain Controller (DCUs), Gateways (GW3), and Electronic Control Units (ECUs). The switches have different numbers of ports, different speeds, and they are also part of different network architectures.

What we cannot easily see in this graphic is which kind of Layer 2 protocols they are using. If we assume they only use standard Layer 2 protocols like ARP, MAC, STP and VLAN, then an obvious question to ask is: “what switches do I have to use from which vendor and how do I test them?”

But before we dive into the details of testing, let’s return to the basic question of why “switch testing” is important to ensure a well performing in-vehicle network.

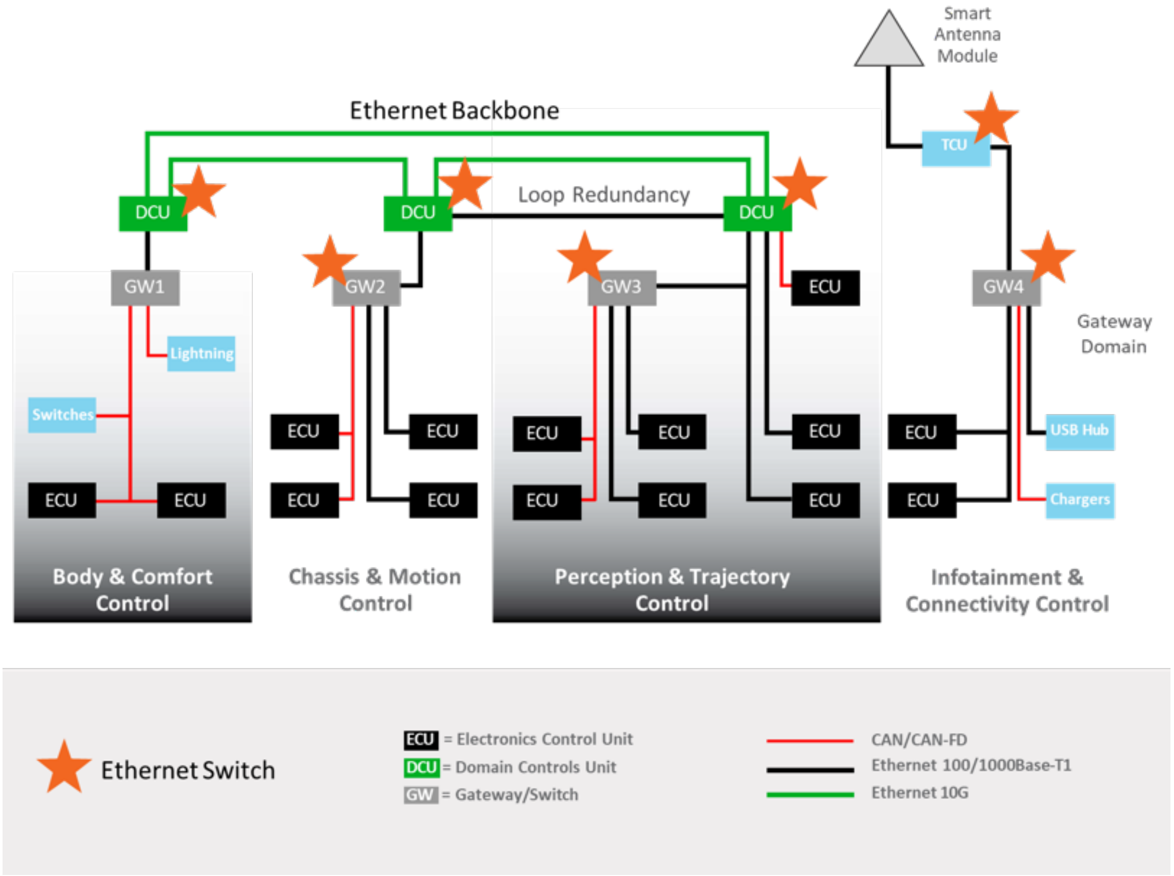
As mentioned earlier, switches are the backbone of an Ethernet network, and due to the architecture of Ethernet networks, one non-performing switch out of dozens in the network could cause a major communications failure. While not every application message on the network will go through every switch in the network, a misconfigured or poorly chosen switch can create a flood of unnecessary traffic across the entire network, possibly impacting the “good” communication messages. This kind of “bad” traffic is called a “broadcast storm”.

Modern in-vehicle networks use multiple ECUs and switches from different vendors. Ensuring the interoperability of the switches and using the same configuration parameters are essential for a well-functioning Ethernet network. We need to acknowledge that the switch functionalities are as important as the different functions of an ECU or the connected end-devices and therefore deserves the same degree of functional testing.

The two most important factors when selecting and validating switches for in-vehicle networking are:

- Performance & Interoperability: non-blocking architecture, average delay, average jitter, and start-up time. Most of them (and even more) are available in pre-defined test suites like RFC2889 and RFC2544.
- Security & Robustness: VLAN separation, broadcast storms, redundancy

# WHY IS TESTING SWITCHES SO IMPORTANT?



# WHICH TEST EQUIPMENT IS REQUIRED?

## Test solutions are needed from when the car is on the drawing-board to when it leaves the factory.

Test & validation needs to be precise and reproducible. For this reason, software-based test solutions are not recommended as the additional hardware required for the tests could be different for each engineer involved, and the performance of the hardware is not predictable for the test software being used. Also, a switch or network test usually requires multiple test ports to perform the needed test cases.

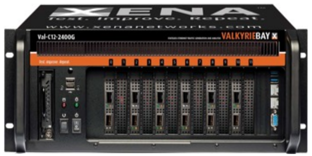
Ideally, the test solution should combine dedicated soft- & hardware where the test management and analysis are done with the software and the test execution is done by the hardware (and embedded software). The test tool should also natively support the different kinds of interfaces, related to speed and physical layer, to avoid using additional components like media converters or adapters which potentially could influence the test results.

Teledyne Lecroy Xena's Odin-Z1-3S-6P-1T-RT45 is an Ethernet test module designed for Automotive Ethernet test applications, with native 1000BASE-T1, and 100BASE-T1 interfaces.

It has 6-ports and can test 2 speeds: 1 Gbps and 100Mbps and is available for Xena's scalable 4U 12-slot XenaBay chassis and the fixed 1U 1-slot XenaCompact chassis.

It comes complete with a full range of test software (as part of the Xena Value Pack) including predefined test suites for RFC 2544, and comprehensive test automation options.

Odin-Z1-3S-6P-1T-RT45 *has native 1000BASE-T1 and 100BASE-T1 interfaces for testing automotive Ethernet.*




*XenaBay TGA chassis – can hold up to 12 Odin test modules*


*XenaCompact TGA chassis - has 1 Odin test module*

# 1. SELECTING A VENDOR

## Supply chain management emphasizes the importance of verifying your components can do the job.

Selecting a vendor for components should achieve two goals:

- Validate that components meet minimum performance metrics
- Accurately compare components from two different vendors

While the requirements and test cases required for these two goals are very general, the focus is ensuring reproducible test results during the validation of different switch configurations from different vendors. This requires that every test is conducted exactly the same as the one before.

To make these tests as transparent as possible, Xena recommends using these pre-defined test suites:

- RFC2889 “Benchmarking Methodology for LAN Switching Devices”
- RFC2544 “Benchmarking Methodology for Network Interconnect Devices”

Another useful test suite is the Y.1564 “Ethernet service activation test methodology”.

These test scenarios can be adjusted and customized to the specific use case and can be re-used for multiple tests during a validation cycle. Using these test suites will guarantee reproducible and reliable test results.


Teledyne Lecroy Xena’s platform includes software applications for testing RFC2544, RFC2889 and Y.1564.

Called Xena2544, Xena2889 and Xena1564, these applications make it easy for automotive test engineers to evaluate switch components from different vendors.

# 2. DEVICE INTEGRATION

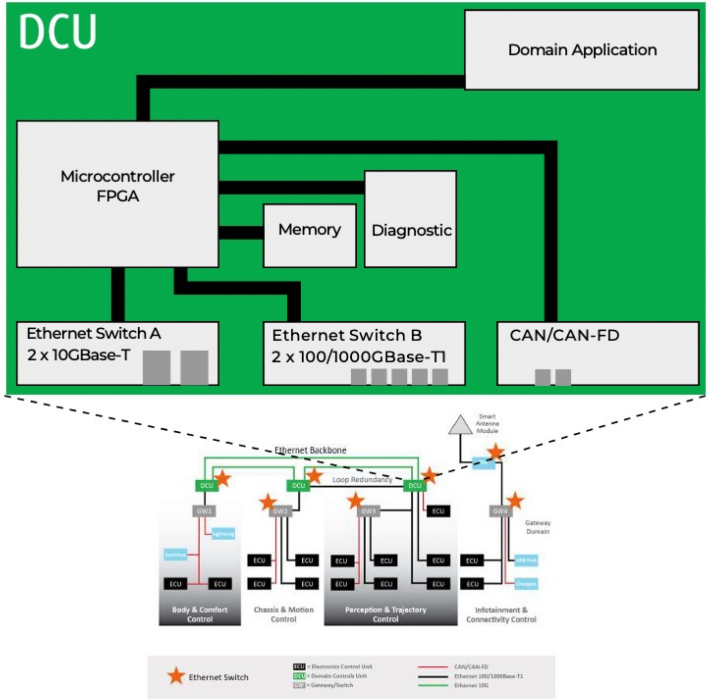
OPEN ALLIANCE

## Does a device meet its own specifications - also when functioning together with other components?

Once a key component like a switch has been selected, it needs to be integrated into a device such as an ECU (Electronic Controller Unit) or DCU (Domain Controller Unit) as shown. This stage is also known as “Sample A” i.e., a prototype with limited functionalities.

Device integration testing compares the device against its own test specifications and repeats the testing against generally available test plans like the RFCs mentioned earlier.

Industry-specific test specification are usually integrated into this phase of testing. An example of a broadly used test specification in the automotive sector is the OPEN Alliance TC11 test specification. This includes test cases from the RFCs as well as adjustments and additional test cases that meet specific needs of in-vehicle networking devices.




*Example architecture of a switch integration into a domain controller*

# 3. REGRESSION TESTING

## As more components and new software is added, the need for test automation becomes important.

Once a device moves into a broader development stage, continuous regression testing is needed in parallel with the engineering process. At dedicated milestones, a pre-defined test plan is performed to validate the engineering milestone.

The goal is to identify any effects of the implementations on the key functionality of the Ethernet switch. The regression test plans can vary for each engineering task, but it is important that test plans are not changed during this stage as this would invalidate the results.

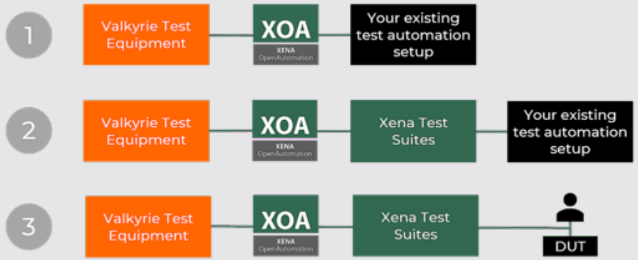
Regression testing is usually fully automated – ideally there should only be a “start” button and a “pass/fail” result. If a test fails, a detailed report should be generated by the test tool.

From an Automotive perspective we can describe this engineering stage as “Sample B”: fully integrated hardware with partially integrated software or software under development. At this stage, the Ethernet switch functionalities are usually already fully integrated as a hardware-only part, but with some configuration options. However, as the software and its configuration can still influence the performance and functionality of the switch device, switch regression testing is mandatory in this stage.

**Xena OpenAutomation (XOA)** is an open-source test automation framework for use with all Teledyne Lecroy Xena solutions.

Fast, easy to use and extremely flexible, XOA features a Python API that runs on any OS, enabling you to use XOA in whichever way suits your test needs.

There are three main options:



# 4. HiL SYSTEM INTEGRATION TESTING

## With Hardware-in-the-Loop testing we go from testing components to testing whole systems.

The following stages is known as hardware in-the-loop (HiL) testing. This is where the single device is integrated into the physically available or partially simulated full system, like the Ethernet backbone, the ADAS-Domain, Infotainment-Domain or even the whole vehicle's electronics. The related Automotive development stage can be described as "Sample C/D" fully functional hardware and software or production grade.

The main purpose of HiL testing is to validate the system functionality. But why do we need to test the switch or even the network functionality once again?

During the initial vendor selection stage, we already validated the interoperability of the switch integrated in the device under development. However, within the whole system there is a high probability that some ECUs are from third-party vendors, and there's no guarantee that these devices are fully compliant with the general switch and networking specifications.

Also, the behavior of single device integrated into a network can be different compared to a standalone test of the switch functionalities.

It is critical for the main HiL test process to ensure a 100% working and performing communication infrastructure made up of the actual switches and the network built with those switches. If this isn't done, it will be difficult to find out if the failure was caused by an application error or a network communication error.

The most efficient approach is to validate the communication layer first so you can exclude the network in any subsequent troubleshooting.

The required test plans include a subset of the test cases executed in earlier stages, together with some new test scenarios. These are mainly related to:

- core switch and network performance metrics, like end-to-end performance (simulation of the Ethernet end devices),
- network impairments (jitter, delay, and packet loss) to validate redundancy,
- robustness and Quality of Service (QoS) testing to validate the overall network functionality.

# 5. PRODUCTION LINE TESTING

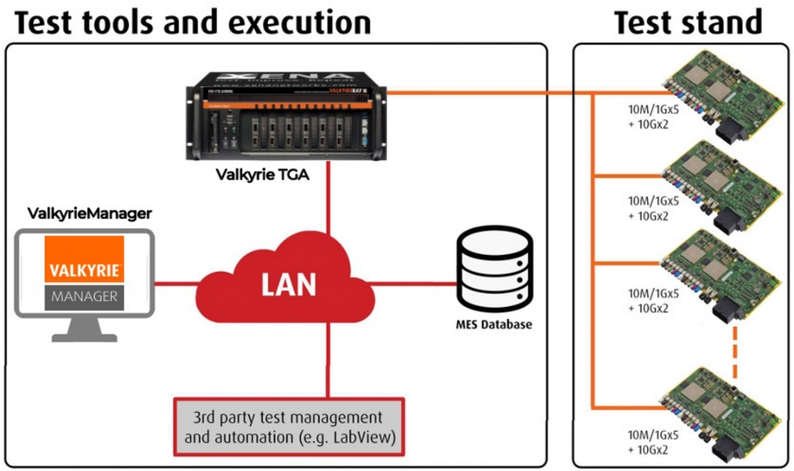
## The last chance to make sure everything is working 100%.

The final stage in the development and test process is the start of production (SoP) which usually includes a set of device bring-up tests. As key functions are validated in this process some of the Ethernet functions need to be validated as well. After providing the soft- and firmware, the device must be tested to verify that the switch is configured correctly, and that the hardware specifications match the requirements.

Typical production line test scenarios are:

- interface speed check,
- internal loopback packet loss test,
- Ethernet switching performance check
- basic Quality of Service (QoS) analysis

Production line testing demands a test station that can do a high number of simultaneous device testing with a quick turn around time. The tests need to be fully automated with simple pass/fail criteria and integration into the quality documentation process. Teledyne Lecroy Xena's platform is ideal for production line testing.



# CONCLUSION

The most important conclusion is that Ethernet - as the “new” network communication technology - implements a second layer of key functionalities to the devices and the system. The “network” is no longer just a wire, like with CAN. Instead, the network is a set of switches (or other active network components like routers) plus the wires.

As a result, these components need to be tested as separate functional components. We can not assume that if we validate the ECU functionalities as “Pass” that the switch in the ECU will also have a “Pass” - if it is connected to the system network, you potentially have all communication traffic going through this switch (ECU) and not just the messages belonging to this device.

Switch and network testing must be an integrated test procedure - in all development stages - to ensure the expected network communication quality.

LEARN MORE:

TELEDYNE LECROY XENA SOLUTIONS FOR AUTOMOTIVE ETHERNET

www.xenanetworks.com