Automotive Ethernet: Enabling the Future of Autonomous Driving

Major innovation drivers in the automotive industry span three categories: enhanced safety, a cleaner environment, and improved convenience with connectivity. To achieve these goals, automakers, automotive suppliers, governments, academia, and even nontraditional automotive players such as wireless chipset makers, mobile device makers, and wireless service providers are developing advanced driver-assistance systems (ADAS), connected car technologies, and, ultimately, autonomous vehicles.

ADAS and autonomous vehicles require a high-bandwidth and low-latency network to connect sensors, cameras, diagnostics, communications, and central artificial intelligence (AI).

The wiring harness is now the third heaviest component in a vehicle and the third most costly system. Wiring harness installation represents 50% of labor costs during automobile assembly.

Automotive Ethernet is the emerging solution to these challenges in the same way that Wi-Fi is the foundation for dedicated short-range communications. Ethernet is a well-known, trusted, and ubiquitous solution in traditional local area networking (LAN). The advantages of Ethernet — multipoint connections, higher bandwidth, and low latency — are attractive to automobile manufacturers. However, traditional Ethernet is too noisy and interference-sensitive for use in automobiles. The Institute of Electrical and Electronics Engineers (IEEE) has new standards and protocols to deliver on the specific needs of the auto industry.

Autonomous vehicles and advanced driver-assistance systems are driving the need for higher bandwidth and lower latency.

Automotive Ethernet has become the new backbone for faster automotive networks.

Comprehensive testing of the transmitter, receiver, link segment, and higher-layer protocol functions ensures successful implementation.

KEYSIGHT TECHNOLOGIES

Autonomous Driving Equals More Data at Faster Speed

Technologies that enable autonomous vehicles span an array of electronic components. The first category allows sensor fusions across radar, light detection and ranging (lidar), and cameras. The second category covers wireless communications for vehicle-to-vehicle, vehicle-to-network, vehicle-to-infrastructure, vehicle-to-pedestrian, vehicle-to-utility, and eventually vehicle-to-everything (V2X) systems. Adjacent elements, such as high-definition mapping with high-precision navigation systems, powerful signal processing, and AI, round out the required components for autonomous driving.

These technologies generate, send, receive, store, and process enormous amounts of data. For example, a lidar module provides highly accurate, high-resolution 3D and 360-degree imaging data around the car. A lidar module can generate 70 Mbps, a camera can generate 40 Mbps, 100 Kbps for a radar module, and 50 Kbps for a navigation system.

Moreover, with higher levels of autonomous driving systems, the number of individual sensors will also dramatically increase, thereby increasing total data generation. For example, a Level 2 autonomous driving system provides longitudinal and transverse guidance, so drivers can free their hands and temporarily avert their eyes. It may use five radar sensors and five cameras. A fully autonomous driving system (Levels 4 and 5) would require up to 20 radar sensors and six cameras, plus V2X communications. Most experts agree that an autonomous vehicle will typically generate anywhere from 5TB and 20TB of data every day. The vehicle needs to transmit, store, and share this data with very short latency on a reliable high-speed network, building the case for a high-throughput, low-latency network based on automotive Ethernet.

An overview of automotive serial buses

We can better understand why autonomous vehicles and ADAS require automotive Ethernet by reviewing the main traditional automotive serial buses, including Controller Area Network (CAN), low-voltage differential signaling (LVDS), Local Interconnect Network (LIN), Media Oriented Systems Transport (MOST), FlexRay, and Controller Area Network Flexible Data-Rate (CAN FD).

CAN — 1983

CAN, developed by Bosch, is a shared serial bus that runs at up to 1 Mbps. The International Organization for Standardization (ISO) published the CAN standard in 1993. Its advantages are cost-effectiveness and reliability. Its disadvantages are shared access and low bandwidth. Power train, chassis, and body electronics use CAN.

LVDS — 1994

LVDS is a point-to-point link, not a shared bus. It has a much lower cost than MOST, and many automakers use it for camera and video data. However, each LVDS link can interface with only one camera or video output at a time.

LIN — 1998

A consortium of automakers and technology partners developed LIN. It runs at 19,200 bits per second and requires only one shared wire, compared with two for CAN. LIN uses a master-slave architecture, while CAN treats all nodes as equal. LIN costs less than CAN, and its speed and cost are suitable for body electronics such as mirrors, power seats, and accessories.

MOST — 1998

MOST has a ring architecture running at up to 150 Mbps (MOST150) using fiber or copper interconnects. Each ring can contain up to 64 MOST devices. MOST has the advantage of relatively high bandwidth for the automotive market, but it is costly. It was initially intended only for camera or video connections.

FlexRay — 2000

FlexRay is a shared serial bus running at up to 10 Mbps. The FlexRay Consortium, a group of semiconductor manufacturers, automakers, and infrastructure providers, developed FlexRay. Unlike CAN, FlexRay has no built-in error recovery; the application layer takes care of error handling. It has higher bandwidth than CAN, but has a higher cost and shared media. High-performance power train and safety systems, such as drive by wire, active suspension, and adaptive cruise control, use FlexRay.

CAN FD — 2012

CAN FD, released by BOSCH in 2012, is an extension to the original CAN bus protocol, intended to accommodate increases in bandwidth requirements in automotive networks. CAN FD enables more accurate and near-real-time data by minimizing protocol delays and delivering higher bandwidth. CAN FD is compatible with existing CAN networks.

Automotive Ethernet

Although traditional automotive serial buses have played important roles in various automotive applications, they have limitations that automotive Ethernet overcomes. For example, most of the automotive serial buses cannot transmit at the 70 MB per second data rate required by lidar. When integrating diverse sensing technologies and wireless communications, it is common to use lidar, radar, cameras, and V2X communications at the same time. In this case, the amount of data transmitted is beyond the capacity of traditional automotive serial buses. That is why the auto industry is looking to automotive Ethernet to make autonomous driving and ADAS a reality.

What is automotive Ethernet?

Automotive Ethernet is a wired network that connects electronic components in a car. It is intended to meet the bandwidth, latency, synchronization, interference (for example, electromagnetic interference [EMI]), security, and network management requirements of the automotive industry. Broadcom introduced the concept of automotive Ethernet, and the OPEN (One-Pair Ethernet) Alliance adopted and regulated it. The OPEN Alliance sponsored Broadcom's 100 Mbps BroadR-Reach as a multivendor licensed solution. The 100 Mbps PHY implementation uses technologies from 1 Gbps Ethernet to enable 100 Mbps transmission over a single pair in both directions. This works with echo cancellation using more advanced encoding to reduce the base frequency to 66 MHz (from 125 MHz), allowing automotive Ethernet to meet automotive EMI specifications. IEEE and the OPEN Alliance have created and maintained physical-layer standards for 100 Mbps and 1000 Mbps automotive Ethernet in the IEEE 802.3 and 802.1 groups.

In its early years, Ethernet was intended for diagnostics and firmware updates through a single 100BASE-T1 1TPCE link from the DLC diagnostics port to the gateway. Figure 1 shows the evolving role of automotive Ethernet as the new backbone using higher-speed Gigabit Ethernet 1000BASE-T1 RTPGE links.

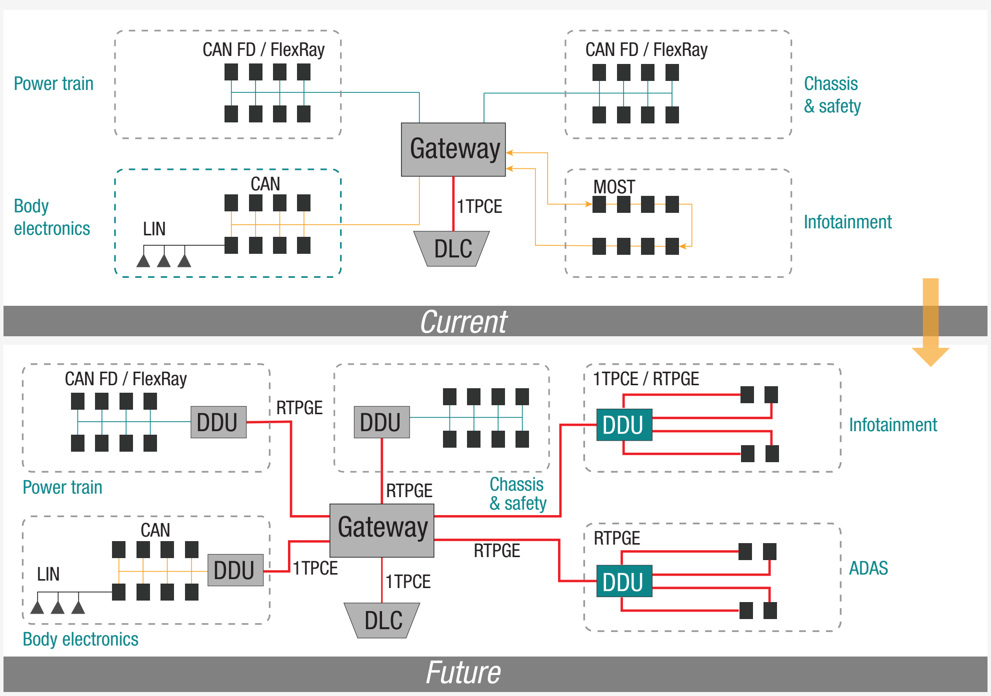

Figure 1. Evolving role of automotive Ethernet

Why automotive Ethernet?

Automotive Ethernet is the obvious choice over traditional automotive serial buses for in-vehicle electronic systems connections and communications, autonomous driving, and ADAS. Car electronics architectures are becoming more complex, with more sensors, controllers, and interfaces; higher bandwidth requirements; more computers; and more communication links.

The wiring harness that connects these systems is the third costliest and third heaviest component in a car. Today, automakers use multiple proprietary standards for communication; most components use a dedicated wire or cable. Automotive Ethernet serves as the unifying standard for all communications. It is carried on a single cable pair from each electronic component to a central networking switch. Using unshielded twisted-pair cable and smaller compact connectors could reduce connectivity costs by up to 80% and cabling weight by up to 30%, according to a joint study by Broadcom and Bosch.

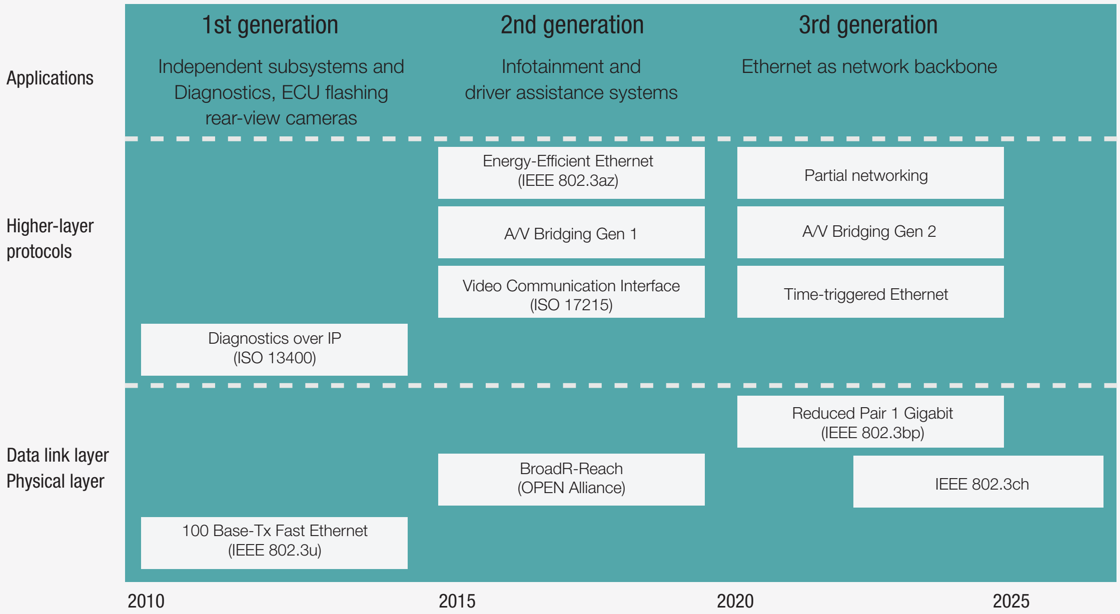

Figure 2. Automotive Ethernet progress

The evolution of automotive Ethernet technologies

Advances in multiple technologies areas have made the progress in Figure 2 possible. Those advances include the following:

AUTOSAR (Automotive Open System Architecture)

AUTOSAR is the open and standardized automotive software architecture. Automobile manufacturers, suppliers, and toolmakers jointly develop the architecture. AUTOSAR includes the automotive TCP / IP stack used in automobiles. The auto industry has effectively agreed on AUTOSAR as the standard, with different automakers competing on implementation rather than on the standard itself. The standard implementation allows many devices to run seamlessly on a single shared network.

OPEN Alliance

Broadcom developed BroadR-Reach as a proprietary PHY standard to enable longer distances of copper Ethernet connectivity at 100 Mbps. This PHY uses technologies from the Gigabit Ethernet copper, including multilevel PAM3 signaling and better encoding to reduce the bandwidth required on the cable. It also uses echo cancelers to transmit bidirectional data on a single pair. This standard meets automotive EMI requirements because, at 27 MHz bandwidth, it is lower than the 62.5 MHz bandwidth of 100BASE-T. The OPEN Alliance SIG created a licensed open standard with sponsorship from major players in the automotive market. The industry realized that 100 Mbps is enough for video transmission, but not enough to act as a backbone in the car, especially for ADAS and autonomous driving systems. It pushed for the creation of a task force in the IEEE 802.3 working group (802.3bp) to define a new standard for 1000 Mbps (1 Gbps) over a single twisted pair. This Gigabit Ethernet PHY is known as 1000BASE-T1 (1 stands for one pair). A working group for even faster standards, 802.3ch for 2.5/5/10G, was established in 2019. A task force is also now looking at 25 and 50G.

Time synchronization

Some car algorithms require either simultaneous sampling of multiple sensors or referencing the time a measurement was taken. As these measurements occur in different nodes, time synchronization needs to be accurate between all the nodes in the car, down to sub-microsecond resolution. IEEE 802.1AS Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks became the synchronized timing standard. This standard uses a profile for IEEE 1588 v2 and introduces simplified, faster methods for choosing a master clock.

Time-Triggered Ethernet

Some time-sensitive controls require communication latency in the single-microsecond range so that the controller can quickly get the sensor readings or control a time-critical function. In traditional Ethernet, a new packet would have to wait until an existing packet is complete, taking hundreds of microseconds, even at gigabit speeds. The IEEE 802.3br (Interspersing Express Traffic) task force is addressing this problem by developing a system in which a high-priority packet (called an express packet) can interrupt existing packets, and the interrupted packets continue after transmission of the express packet.

AV bridging

ADAS relies on getting data from cameras and other sensors in a timely manner. Unlike watching videos on a computer, where buffering is used to compensate for the unreliable timing of the network, automotive AV systems require both controlled latencies and guaranteed bandwidth. The Time-Sensitive Networking Task Group provides the specifications that allow time-synchronized low latency streaming services.

Comprehensive test requirements for successful implementation

Automotive Ethernet engineers deal with the ordinary high frequency board design challenges including signal noise, signal quality, cross talk, reflection, impedance matching, and DC power integrity.

Automotive Ethernet also requires comprehensive physical layer, protocol, conformance testing, security, and harness testing to ensure successful implementation and reliable operation.

There are three testing points for physical-layer compliance, as described in Figure 3:

- the transmitter with protocol trigger and decode
- the link segment, including harness and connectors
- the receiver

Note that although this figure shows linear Tx on one end and Rx on the other, automotive Ethernet is a bidirectional bus and both ends of the link will need to be tested for both Tx and Rx.

Figure 3. Automotive Ethernet physical-layer test points

Transmitter testing

The transceiver tests are similar to other high-speed digital PHY characterization solutions. It is imperative to choose a testing solution that offers a protocol trigger and decode software package that will view the data traffic and the protocol layer, saving debugging time early in design. All the compliance tests need to be prepackaged in setup, configuration, and reporting so that designers can focus on their core mission and deadlines.

Receiver testing

A robust receiver compliance solution providing bit error rate, SQI, and Alien crosstalk noise rejection testing should automatically configure all the necessary test equipment, simplifying and speeding up the overall test process:

- Simplify receiver compliance testing.
- Automatically configure all the required equipment to reduce test time.
- Show connections to the device under test in diagrams.
- Create a printable pass / fail HTML report with margin analysis.

Link segment testing

A complete link segment compliance solution needs to support cable test, connector test, communication channel test, connector test for cross talk, and a cross talk test across the entire communication channel.

High-layer protocol testing

Automotive Ethernet does not stop at the physical layer. Validating solutions requires higher-layer test methodologies that include the automotive TCP / IP stack, time synchronization (IEEE 802.1AS), audio-video bridging transport (802.1Qav), and scheduled traffic transmission (IEEE 802.1Qbv) protocol implementations. Figure 4 illustrates the complete automotive Ethernet stack.

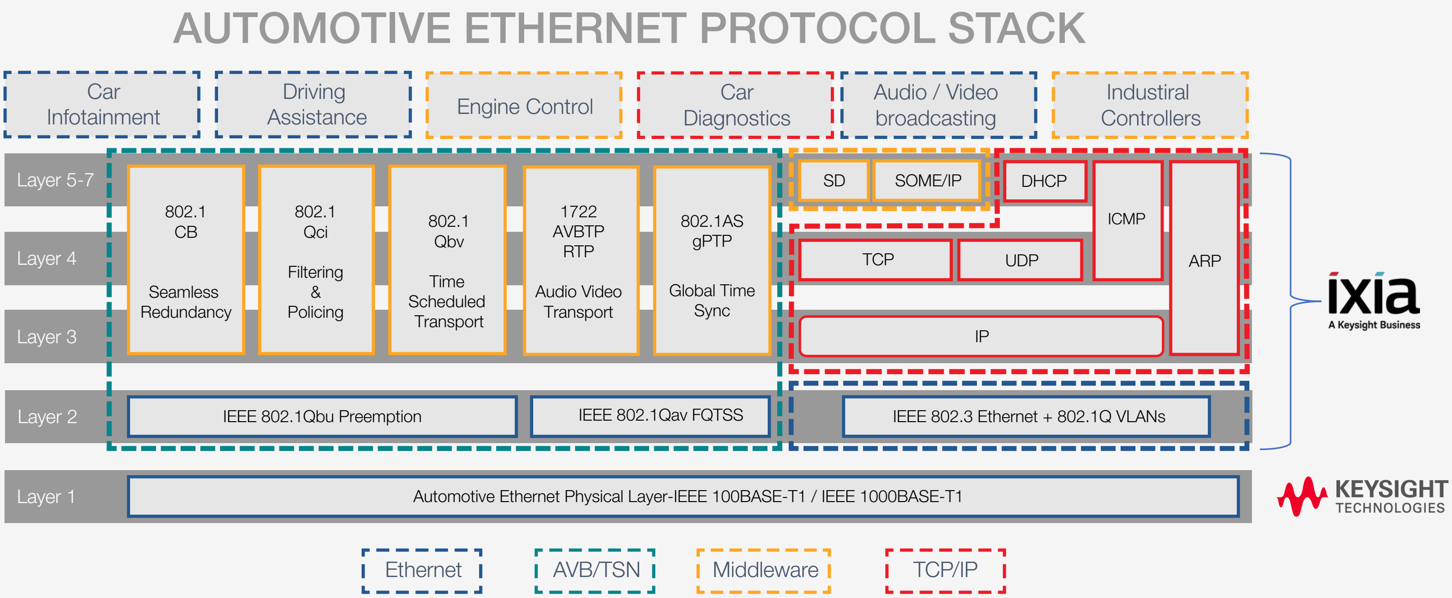

Figure 4. Automotive Ethernet full stack

A Better Way Forward

Autonomous driving and ADAS will bring benefits to society but will present engineers with new test challenges. With increasing demands for high data rates, bandwidth, data security, and future-readiness, automotive Ethernet offers advanced capabilities and overcomes limitations of traditional automotive serial buses for in-vehicle electronic systems connections and communications.

Keysight helps engineers successfully implement automotive Ethernet by providing solutions to thoroughly test transmitter, link segment, receiver, and higher-layer protocol functions.

For more information, please visit

www.keysight.com/find/autonomous-driving