

KNOWLEDGE BASE – RTSTAND LV124 / LV148

EVOLUTION OF AUTOMOTIVE ECU COMPLEXITY AND IN-VEHICLE NETWORKS

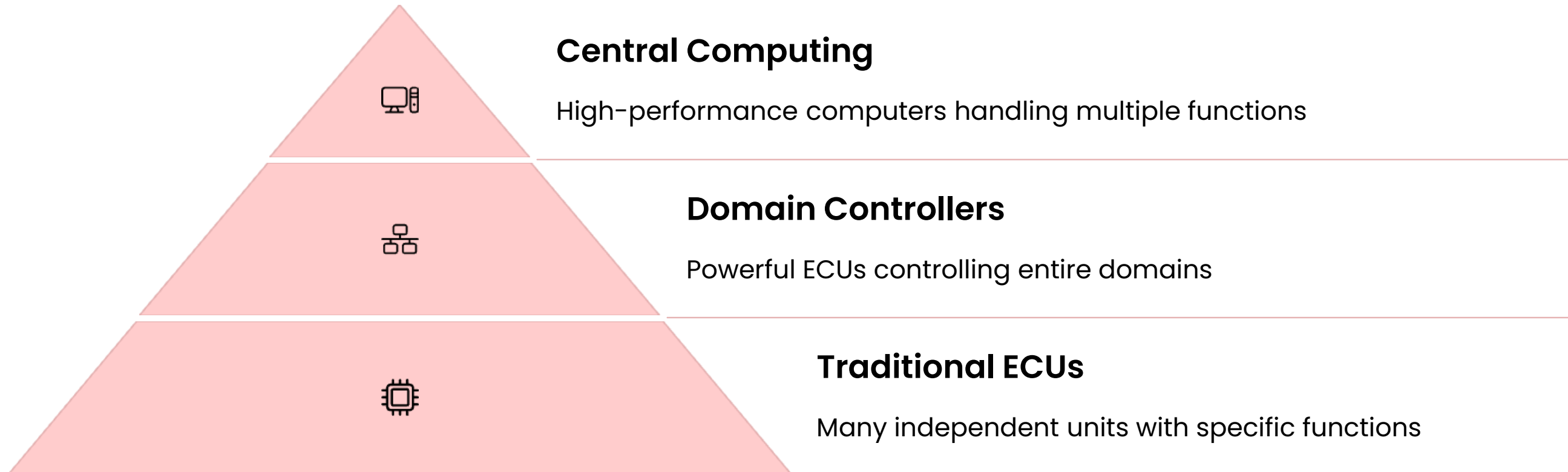
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Over the last five years, automotive electronic architectures have begun a dramatic shift. Vehicles are moving away from having dozens of independent Electronic Control Units (ECUs) towards a more consolidated approach with a few high-performance controllers.

This centralization – through domain-specific controllers and emerging zonal controllers – is driven by the need to handle increasing software complexity, data from advanced sensors, and reduce wiring and cost. Fewer but more powerful ECUs are becoming the norm, and this evolution is reshaping in-vehicle communication networks.



The Shift to Centralized Architecture



In traditional automotive designs (circa 2010s), it was not uncommon for a luxury vehicle to contain 100 or more ECUs, each dedicated to specific functions. Over the past five years, automakers have recognized that this "many ECUs" approach has become unsustainable as software complexity and wiring harness size grew.

The industry has been transitioning first to domain-based architectures – where one powerful ECU controls an entire domain (e.g. powertrain, chassis, infotainment) – and now towards centralized or zonal architectures, which further reduce the number of independent units.

Domain vs. Zonal Architecture

Domain Architecture

Several domain controllers handle major function areas (powertrain, body, infotainment) with a central gateway linking them.

Each domain controller manages all functions within its specific area, reducing the total number of ECUs while maintaining separation between systems.

This represents a major consolidation of computing power. In the last five years, early implementations of centralized/domain controllers have appeared in high-end vehicles. For example, domain controllers now often handle tasks like advanced driver assistance (ADAS) or connectivity for an entire domain rather than using many distributed modules.

Zonal Architecture

The vehicle is divided into physical zones each managed by a zonal controller, all tied to a central high-performance computer.

This approach further reduces ECU count, with each zone handling all functions in its physical area regardless of domain, dramatically reducing wiring complexity.

Factors Driving ECU Consolidation



Increased Processing Needs

New electric and autonomous features demand powerful computing that is easier to support with centralized hardware. Vehicles may soon carry hundreds of millions of lines of code.



Weight and Complexity Reduction

Reducing ECU count and relocating controllers into a few zones can cut total wiring length by up to 30–50%, saving weight and cost. Tesla's early adoption of a zonal design in the Model 3 cut wiring harness length roughly in half.



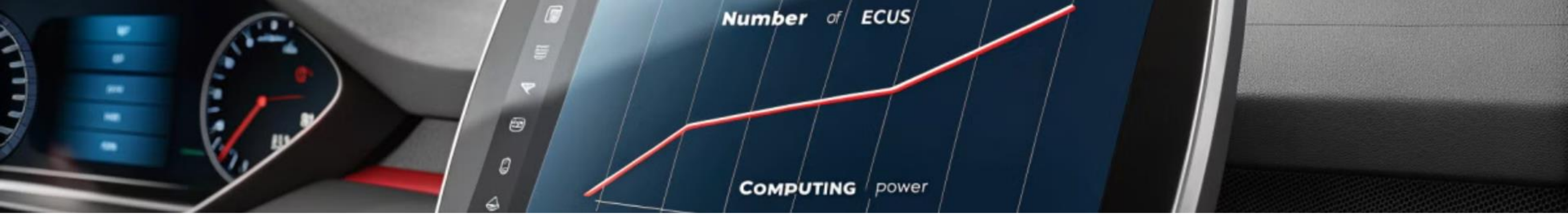
Better Integration & Maintenance

Fewer integration points simplify software updates and improve reliability by reducing connectors and potential points of failure. Zonal architectures localize connections for sensors/actuators to a nearby controller.



Electrical Efficiency

Especially in electric vehicles (EVs), shedding weight and optimizing power distribution can improve range and reduce energy loss.



Projected ECU Count Reduction

100+

ECUs in luxury vehicles circa 2010s

Traditional Vehicles

70-100

ECUs in typical modern vehicles

Current Vehicles

2%

Vehicles with zonal architecture by 2034

20-30

Projected ECUs in next decade's vehicles

Future Vehicles

38%

Vehicles with zonal architecture by 2034

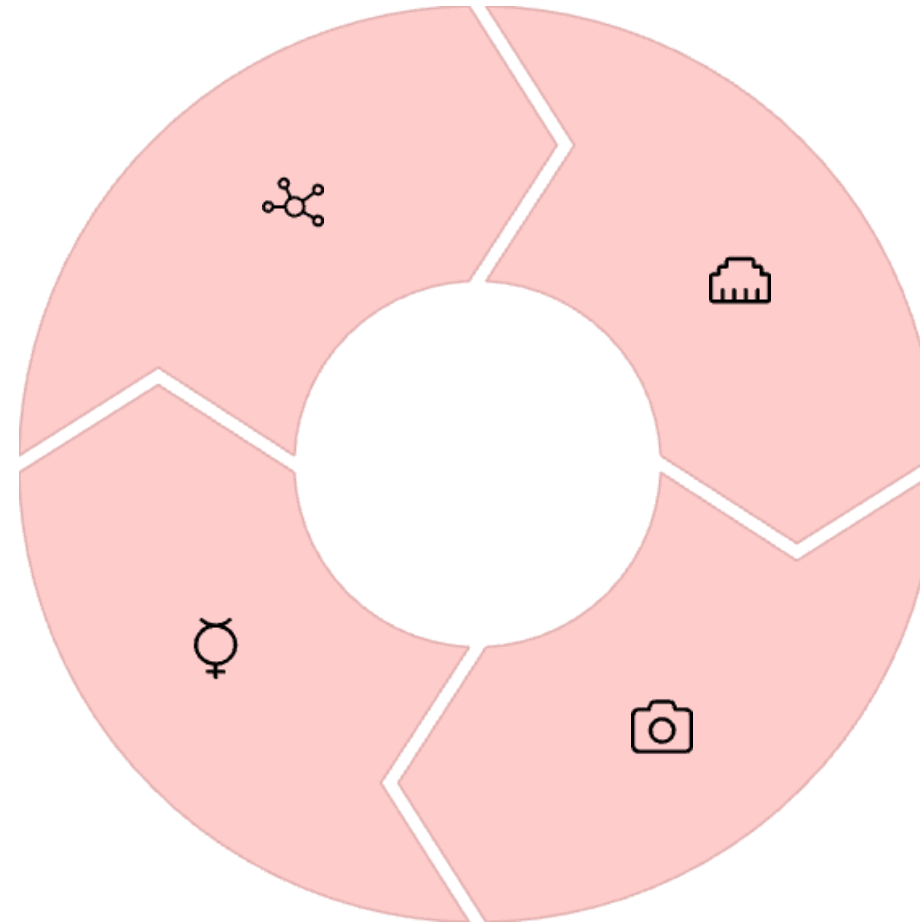
Industry analyses project that the number of computing units in a vehicle will drop significantly in the coming decade, even as vehicles handle more advanced functions. A few powerful processors (often multi-core SoCs) will replace dozens of separate microcontrollers, aggregating their tasks.

This consolidation is a key enabler of the software-defined vehicle concept, wherein software updates and features can be managed more centrally rather than across dozens of devices.

Communication Bus Evolution

Legacy Buses
CAN, LIN, FlexRay for specific functions

Hybrid Networks
Integration of all systems via gateways



Ethernet Backbone
High-bandwidth network connecting major systems

SerDes Links
Ultra-fast connections for cameras and displays

As vehicle electronics architecture evolves, the in-vehicle communication buses connecting various components are also changing. Historically, vehicles have used a layered mix of bus systems: low-speed networks for simple body electronics, higher-speed networks for powertrain and chassis control, and specialty links for multimedia.

Now, with central computers and data-intensive features, automakers are reassessing which buses to use where. The general trend is toward fewer distinct network types, with automotive Ethernet taking on a greater share of data transfer.

CAN and CAN FD – Evolving Workhorses

Classic CAN

Operating up to 1 Mbps, CAN has been the automotive workhorse for decades. Its reliability in noisy environments, error-checking, and low cost per node ensure it will remain in use for many sensor/actuator communications.

CAN FD

CAN Flexible Data Rate addresses bandwidth limitations by allowing higher throughput (up to 2 Mbps, sometimes 5 Mbps) with larger frame payloads. Over the last five years, it has been gradually adopted in new ECU designs, especially by German OEMs.

Future Role

Despite improvements, CAN cannot handle the "firehose" of data from modern sensors. It's increasingly not the backbone – rather, a subnet technology in a larger network architecture, confined within zones for local communications.

LIN – The Simple, Cost-Effective Solution



Ultra-Low Cost

Single-wire, single-master serial network



Low Speed (20 kbps)

Sufficient for simple control tasks



Simple Applications

Window lifts, seat controls, door locks, sensors

Local Interconnect Network (LIN) is a simple low-speed bus used for inexpensive microcontrollers and smart devices. LIN does not aim for high bandwidth or complex data – its selling point is simplicity and cost-efficiency for devices that only need to send a status or receive a command occasionally.

In the context of new zonal architectures, LIN might be used within a zone to connect a cluster of simple devices to the zonal controller. Since zonal ECUs are physically closer to devices, LIN's short-range limitation is not an issue.

FlexRay and MOST – Specialized Buses in Decline

FlexRay

Introduced as a deterministic, fault-tolerant bus for high-speed control (up to 10 Mbps with two channels), FlexRay was used for advanced applications like x-by-wire chassis control.

However, it never achieved widespread adoption due to its complexity and cost. Over the past five years, very few new vehicle platforms have adopted FlexRay; some automakers that used it have begun moving away from it.

Newer versions of automotive Ethernet, with Time-Sensitive Networking (TSN) extensions, can deliver similar deterministic communication but with far greater bandwidth and flexibility. Specialized buses like FlexRay and MOST are on the decline, their niche use-cases now addressed by more versatile Ethernet solutions.

MOST

Media Oriented Systems Transport was an optical/electrical bus used for infotainment in many 2000s-era cars. MOST could stream audio/video but topped out at 150 Mbps.

In recent years, MOST has largely been replaced by Ethernet-based systems; OEMs prefer not to manage a separate optical network when a single Ethernet network can handle both data and multimedia.

Automotive Ethernet – The New Backbone



100BASE-T1 (100 Mbps)

First widespread automotive Ethernet standard, also known as BroadR-Reach. Used mainly for infotainment networks and some cameras in vehicles from 2015–2020s.



1000BASE-T1 (1 Gbps)

Gigabit automotive Ethernet now appearing in luxury and high-tech vehicles. Used for sensor data and as backbones between domain or zonal controllers.



Multi-Gigabit Ethernet

Standards for 2.5G, 5G, up to 10 Gbps over short links have been established, anticipating future needs like high-resolution sensor fusion and connected car V2X data.



Time-Sensitive Networking (TSN)

Extensions to Ethernet enabling deterministic, time-aligned communication for safety-critical applications, approaching the real-time performance of FlexRay but with more flexibility.

Advantages of Automotive Ethernet



High Bandwidth

Orders of magnitude higher than CAN or LIN, with scalability to multi-gigabit speeds. Essential for ADAS and high-resolution infotainment.



IP Protocol Support

Easy integration with modern software and cloud services through support for the TCP/IP protocol stack.



Flexibility

A single Ethernet backbone with VLANs or TSN scheduling can replace several separate networks, potentially simplifying architecture.



Cost Efficiency

At scale, Ethernet's cost is becoming comparable to CAN. The ability to use a single network for multiple purposes can reduce the total number of transceivers and wiring.

Automotive Ethernet is gaining primacy as the core network in modern vehicles, owing to its high bandwidth and versatility. It is not completely replacing CAN or LIN – rather, it works in concert with them, with gateways ensuring old and new systems talk to each other.

High-Bandwidth SerDes Links



While standard Ethernet is excellent for many high-data applications, there is a class of automotive interfaces specifically designed for ultra-high-bandwidth, real-time video and sensor data. These are often Serializer/Deserializer (SerDes) links, proprietary to certain vendors, used for point-to-point connections.

Notable examples include Maxim/Analog Devices' GMSL (Gigabit Multimedia Serial Link), Texas Instruments' FPD-Link III, and Inova Semiconductors' APIX (Automotive Pixel Link) series. These interfaces have become crucial for connecting modern cars' cameras, displays, and other high-speed peripherals.

SerDes Link Evolution

GMSL1/FPD-Link III (2-4 Gbps)

Popular in the late 2010s for 720p/1080p camera feeds and displays. Enabled 1080p rear backup cameras, night vision IR cameras, etc.



GMSL3/APIX3 (12 Gbps)

Latest generation introduced ~2021. Allows uncompressed 4K video at 90 frames/sec over a single coax or multiplexing of multiple camera feeds on one cable.



GMSL2 (6 Gbps)

Widely used in high-end camera modules. Sufficient for 1-2 megapixel cameras at 30-60 frames per second, or for streaming compressed video.



Future SerDes (24+ Gbps)

Industry working on standardized SerDes interfaces like MIPI A-PHY, which aims to offer a unified approach with speeds up to 24 Gbps.



Why Use SerDes Instead of Ethernet?

Ultra-Low Latency

SerDes links can send uncompressed video from a camera to a central processor with only microseconds of latency, which is important for real-time machine vision. Ethernet would introduce protocol overhead and more latency.

Practical Cabling

These SerDes can transmit over a single coax cable up to 10-15 meters with built-in clock synchronization. They often also deliver power over the same cable (Power-over-Coax), making them one-plug solutions.

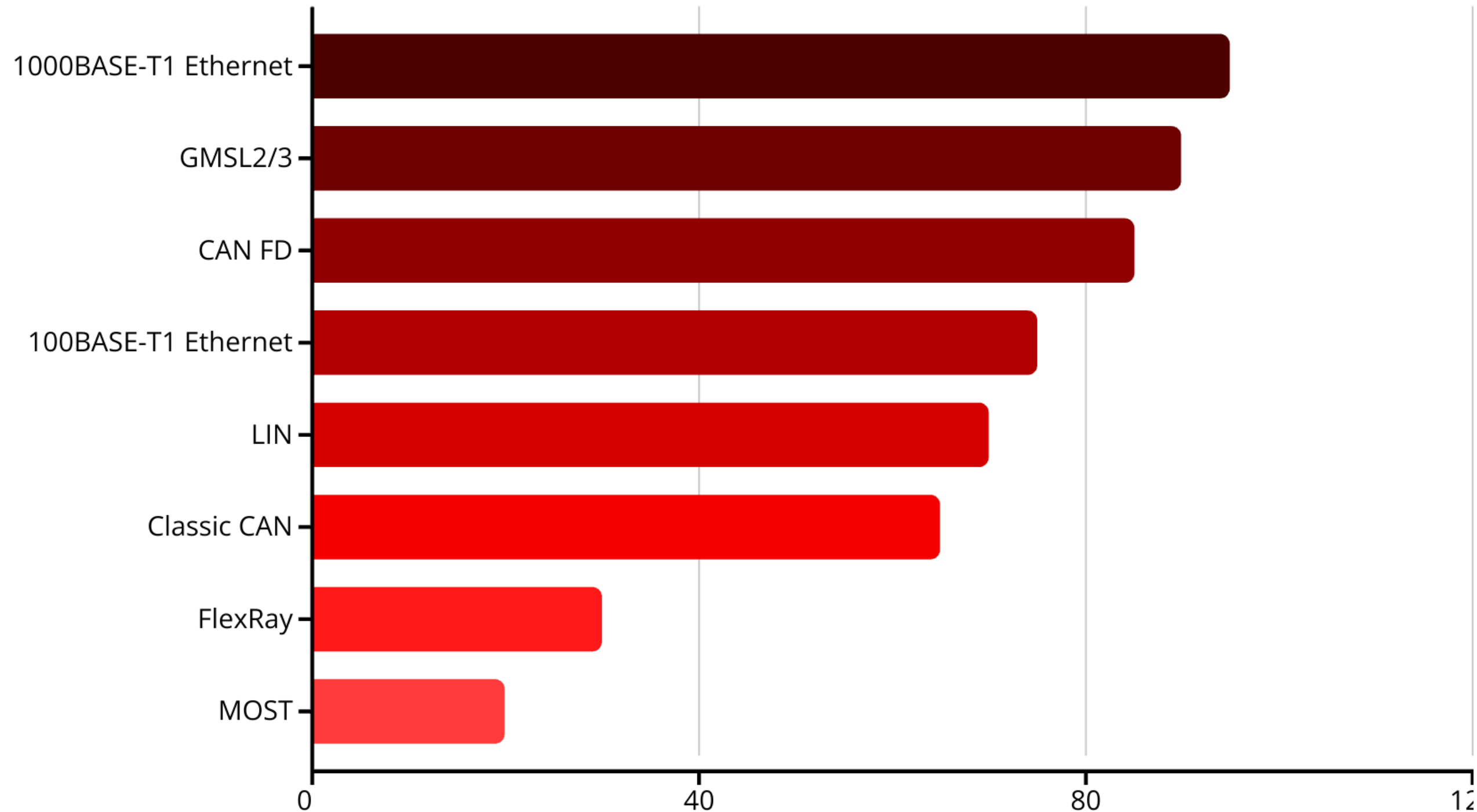
Noise Immunity

Very robust to noise using modulation and encoding techniques over shielded coax, plus features like forward error correction, which suits the automotive environment of electromagnetic interference.

Safety Features

Include cyclic redundancy checks and link monitoring to meet ASIL requirements for ADAS sensors, essential for safety-critical applications.

Current and Future Bus Relevance

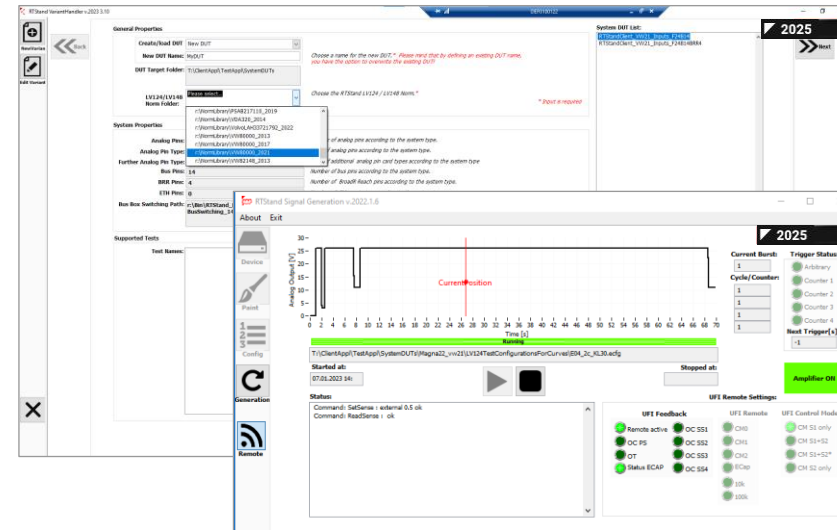


Implications for Electrical Testing



Higher Stakes with Centralized ECUs

When vehicles had many independent ECUs, a short power dropout might only affect one module at a time. Now, with a few centralized ECUs carrying a lot of functionality, the stakes are higher – if a domain controller glitches due to a power interruption, it could momentarily disable numerous vehicle functions at once.



LV124/LV148 Standards

These rigorous testing standards defined by German OEMs include a battery of electrical stress tests: voltage drops, transients, interruptions, electromagnetic compatibility, etc., to ensure that automotive components can withstand real-world electrical conditions.



Short Interruption Tests

These tests simulate momentary loss of power or ground while the ECU is operating, to verify that the device properly handles it. With centralized architectures, testing must verify that all interfaces recover properly after interruptions.

Challenges with High-Bandwidth Interfaces



Ethernet Recovery Time

A 1000BASE-T1 Ethernet link typically takes some tens to hundreds of milliseconds to auto-negotiate and link up after either side resets. This recovery time must be acceptable or handled by system design.



Camera Link Synchronization

High-speed camera links like GMSL have lock and synchronization sequences. If an ADAS camera ECU browns out, the central computer might lose that video feed and then get a burst of data when the link re-locks.



Ultra-Fast Switching

Mechanical relays are too slow for sub-millisecond interruptions at multi-GHz frequencies. Specialized solid-state switches are needed to cut power or communication lines cleanly at high speeds.



Multi-Interface Monitoring

With centralization, ECUs often integrate multiple network interfaces. During a short power dip test, all of these interfaces need to be observed simultaneously.

Testing Solutions for Modern Networks



RTStand LV124/LV148

Modern automated test system designed to cover comprehensive requirements of the LV124/LV148 standards and OEM-specific derivatives.



Ultra-Fast Interrupter (UFI)

Specialized device that can perform microsecond-range interruption on supply lines and even on communication lines like Automotive Ethernet.



Synchronized Monitoring

Captures behavior on all interfaces within microseconds of a disturbance, essential for verifying complex ECU recovery.



Future-Proof Design

Roadmap includes support for GMSL2/3, APIX3, and SerDes up to 12 Gbps, aligning with industry trends.

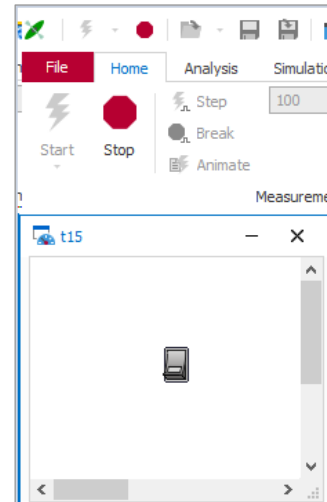


Real-World Testing Example



Test Setup

An ADAS domain controller rated at 60A peak, containing a 1000BASE-T1 port, two CAN FD ports, and four camera GMSL2 inputs is connected to the test system.



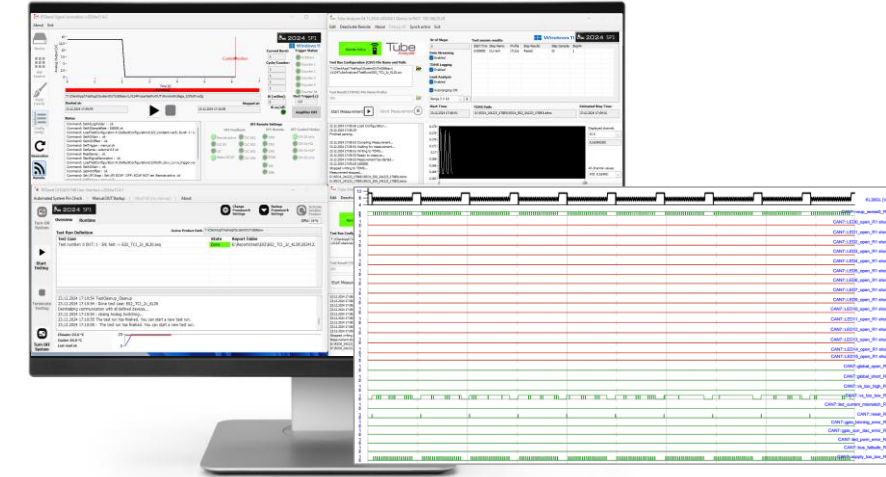
Bus Simulation

The system simulates the ECU's CAN and Ethernet with appropriate traffic and feeds proper video signals into its GMSL inputs using camera simulators.



Interruption Test

The test system performs an LV124 pin interruption test by dropping the supply voltage to 0V for 10 ms via the Ultra-Fast Interrupter, ensuring the drop is clean and precisely timed.



Monitoring & Analysis

All the ECU's outputs are monitored: CAN messages are logged, Ethernet link state is recorded, and video feed output is checked to verify proper recovery within time limits.

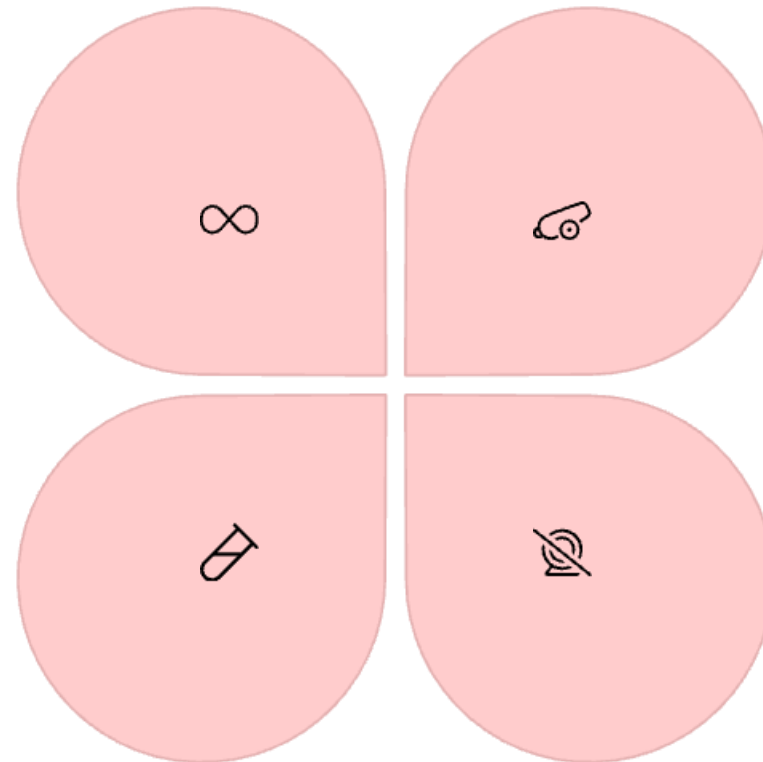
Conclusion: The Future of Automotive Networks

Ethernet Backbone

Automotive Ethernet will become the primary backbone in modern vehicles, with 1 Gbps standard and multi-gigabit for advanced applications.

Advanced Testing

Test systems must evolve to handle both legacy and cutting-edge interfaces under stringent electrical conditions, with ultra-fast switching and synchronized monitoring.



Legacy Bus Evolution

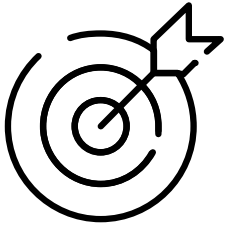
CAN FD will gradually replace Classic CAN, while LIN remains for simple devices. FlexRay and MOST will be phased out.

SerDes Proliferation

High-speed SerDes links will continue to multiply as camera counts increase and resolutions grow to support advanced ADAS and autonomous driving.

The automotive industry's transition to centralized, high-performance computing architectures is driving a parallel evolution in vehicle networks. As fewer but more powerful ECUs handle increasing amounts of data, the communication infrastructure must adapt with higher bandwidth, better determinism, and improved reliability.

- 1995** Founded as **test bench manufacturer and testing solution provider**
- 1995-2014** Transition from Testbench specialist to **LV124 / LV148 focus**
First software and hardware developments for LV124 / LV148 testing
- 2014 and 2016** Technical **Innovation Awards** for LV124 / LV148 automation platform and hardware components
- 2015** First half automated testing system for LV124 / LV148
- 2018** **First series of fully LV124/LV148 automated testing systems**
- 2019-2020** First LV124/LV148 systems sold in the **US and Asia**
- 2022** Fully automated integration for **Automotive Ethernet 1000base-T1 and GMSL** testing
- 2022- present** Continuous improvements and customer setup integrations
New market entries and partnerships
New developments for **Automotive Ethernet 10G base-T1 and GMSL 2**





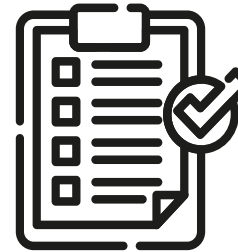
Reduced testing time of up to 75% through fully automating testing



Improved testing workflow through generic setup and meaningful report structure



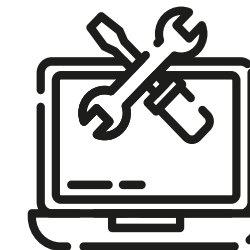
Improved testing insights by combining high resolution analog data with bus communication data



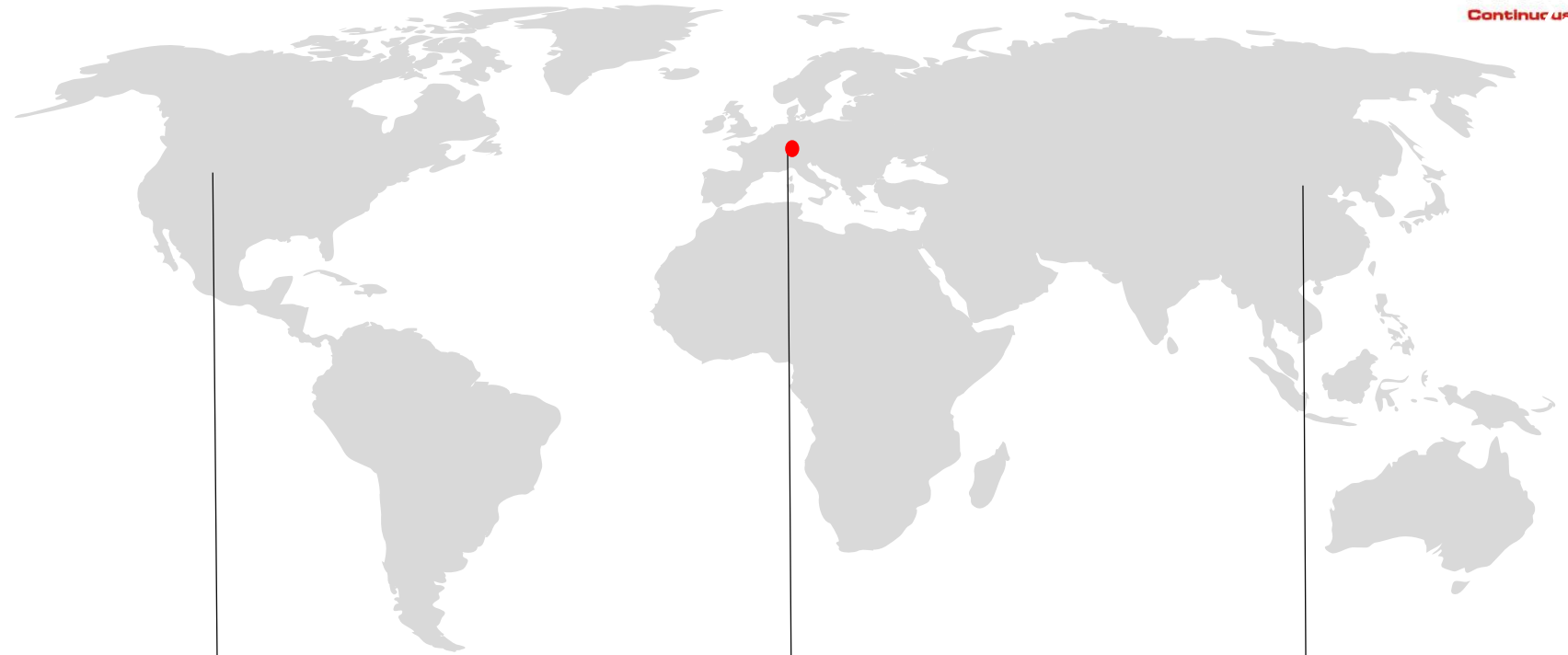
Fast support and engineering services



Regular maintenance and updates



RTStand LV124 / LV148 Let's accelerate your testing



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