# CAN – From its early days to CAN FD

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In the early days, automobiles were driven by pure horsepower. Optimizations by an intelligent information flow, e.g. to achieve an efficient combustion process, were not in focus. The exchange of information between different control systems and their sensors and actuators were realized by discrete interconnection, i.e. point-to-point wiring [1]. High currents were passed between ECUs (electronic control units) and the transferred information was comprised of 1-bit signals (on/off) rather than dates.

Later, more and more electronic devices were implemented into modern vehicles in order to increase safety and comfort for the driver as well as to reduce fuel consumption and exhaust emissions. The electronic devices included engine management systems, active suspension, anti-lock braking, gear control, lightning control, air conditioning, airbags and central locking. The requirement for information exchange has then grown to such an extent that a cable network with a length of up to several miles and many connectors was required. This led to growing problems concerning material cost, production time and communication reliability. The revolutionary solution was the connection of the control systems via a serial bus system, the CAN network [1] invented by Robert Bosch in 1983. With CAN, point-to-point wiring was replaced by one serial bus connecting all control systems. This was accomplished by adding CAN-specific hardware to each control unit that provides the ”rules” or the protocol for transmitting and receiving information via the network.

The first vehicle using a CAN bus in series production was the Daimler S-Class W140 in 1991 [1]. In this first step towards interconnection of electronic components via CAN, five CAN nodes were used to connect the engine control unit, the anti-lock braking and traction control system, the ignition, the transmission control unit, and a diagnostic module. This interconnection allowed realizing different functions with the aim to reduce emissions and fuel consumption, improve driving behavior during warm-up, and optimize driving operation by interaction with the transmission control. For example, the slipping of a drive wheel could be reduced by intervention in ignition, fuel injection, and engine control.

## CAN as enabler for electronic architecture evolution

The complexity of automotive software has increased over time. This statement is underlined by different parameters shown in Figure 4 [2]. The number of systems in the vehicle that communicate with each other via a bus has increased over time. Between the years 1990 to 2000, the number of bus nodes grew from less than ten to greater than 40 systems. The addition and/or realization of ▷

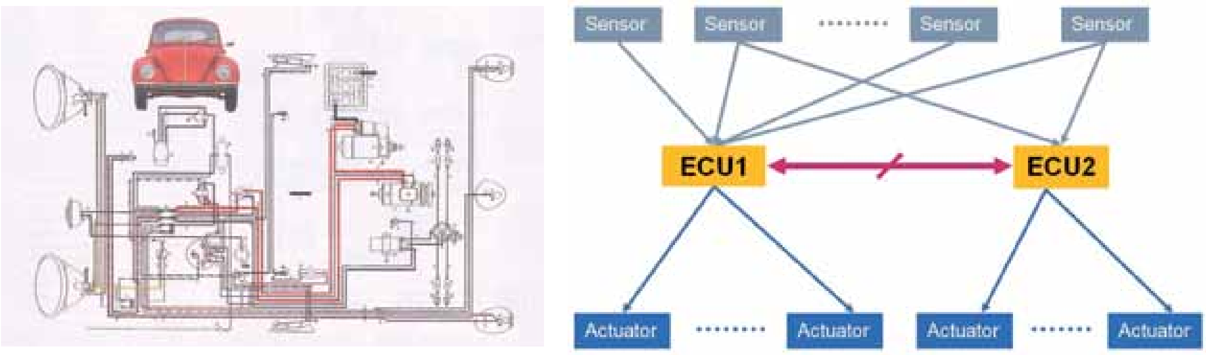


*Figure 1: The wiring topology of a Volkswagen Beetle (left) had discrete connections between controls and sensors, and control and actuators (right). The information content passed to an actuator comprised 1 bit, switching the actuator states on or off.*

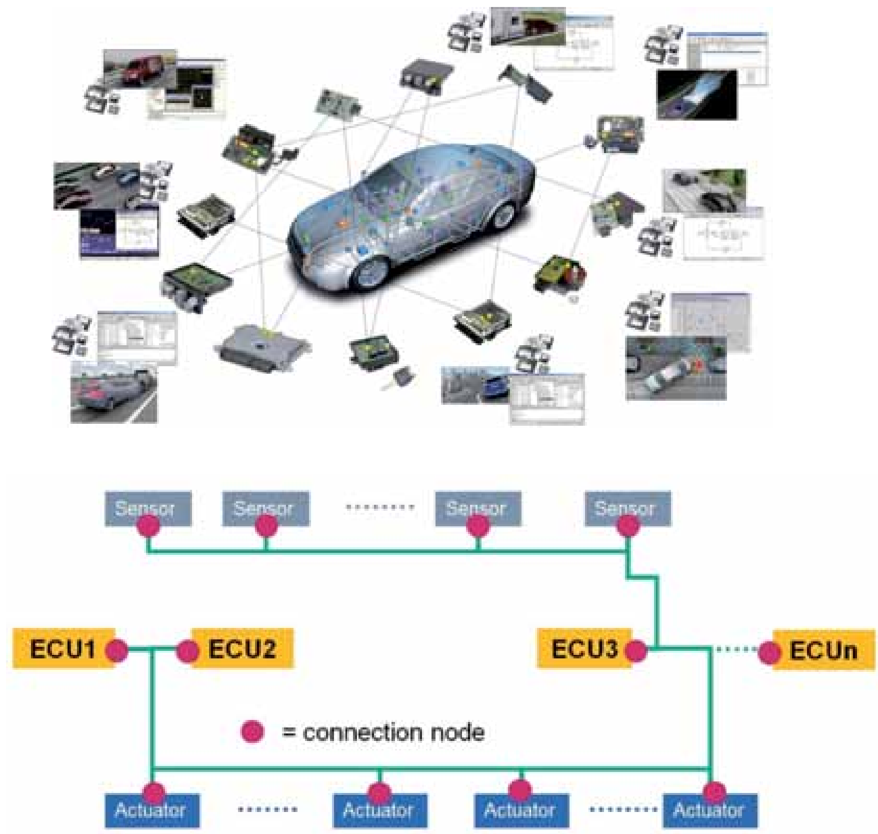


*Figure 2: Modern topologies (on top) connect control systems, sensors, and actuatorsby a serial bus (bottom).*

more complex functions in the engine control unit require more computing power. Approximately every ten years, the computing power of micro-controllers in automotive technology increased tenfold. This is related to Moore's Law, i.e. the doubling of the integration density on the semiconductor every 18 months. The lines of code for high-end cars and the memory requirements increased by two orders of magnitude over a time frame of ten years. Along with the growing number of connections, the number of exchanged signals grew by four orders of magnitude.

The electronic architecture of today's vehicles consists of more than 70 ECUs, which communicate via the CAN network. CAN played a significant role in the electrification of the system components. It facilitated the division of the electronic systems into manageable sub-systems, thus increasing development efficiency.

The evolutionary development of the vehicle architecture has shown that the complexity grows quicker than the number of functions [2]. This leads to a problem in that the integration of new functions is getting more expensive and therefore weakens the innovation trend. Only through a significant revision of the vehicle's electronic architecture and a leap in network technology can reduce the complexity to a manageable level. In the past, the means to decrease complexity had been the introduction of CAN.

## Quo vadis CAN

The increasing complexity of functions leads to higher data-rates, thus bringing CAN to its limit (1 Mbit/s). Time-triggered communication technologies, such as those used with Flexray (10 Mbit/s), are complex in handling and require careful planning of the network. CAN FD (CAN with flexible data rate) provides an intermediate step between both. It provides a flexible but highly topology-dependent data-rate of up to 8 Mbit/s.

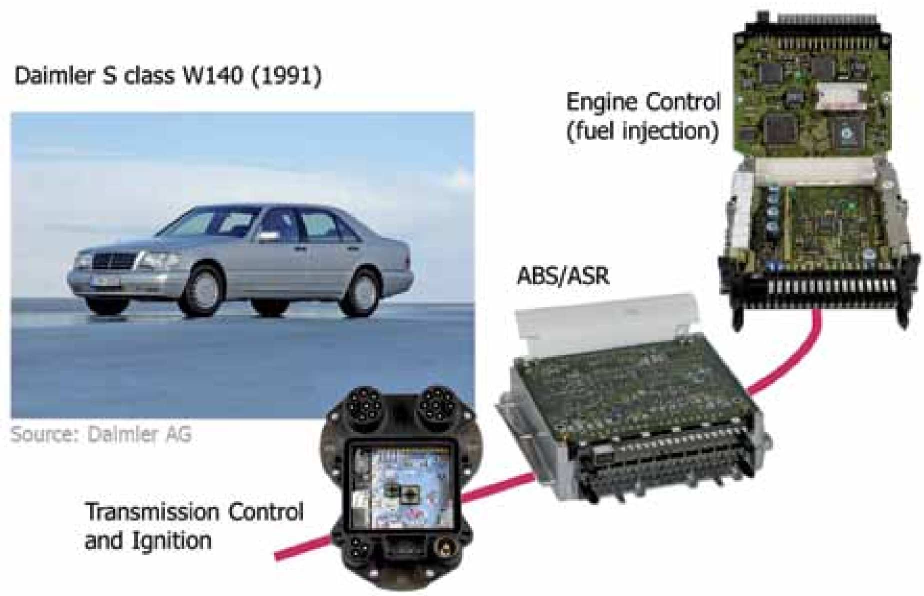


*Figure 3: The Daimler S-Class W140 was the first vehicle using CAN with five connected nodes*

***References***
*[1] Dr. S. Dais, CAN – Die Innovation im Automobil, Eduard-Rhein-Technologiepreis, 2008*
*[2] Bundesminsterium für Wirtschaft und Technik, Ecar-IKT-System-architektur für Elektromobilität, 2011*
*[3] T. Hogenmüller, M. Schaffert, B. Triess, Data Engine für schnelle Ethernet Architekturen, Hanser Automotive Edition 12, 2012*

## Facts explaining the success of the CAN technology

Although developed for vehicle technology, CAN has been adopted in many other industries with various technical applications. CAN chips are found in elevator systems of large buildings, ships, trains, aircrafts, X-ray machines and other medical equipment, logging equipment, tractors and combines, coffee makers, and other major appliances. In the automotive industry, CAN has become the industry standard for communication systems in vehicles, where today every new car built has at least one CAN system on board. Following facts mainly drove the success of the CAN technology:

- CAN was the first “real” protocol bus in the vehicle allowing the implementation of more complex functionality while reducing the need for wiring in the vehicle.
- The open license policy of Bosch facilitated the availability of CAN on chip by micro-controller vendors in a very short time frame.
- CAN required small silicon area and low computing power. The low-cost CAN is available even on simple micro-controllers.
- The planning of time-triggered protocols such as Flexray, i.e. protocols, which assign each bus participant fixed time slots for communication is complex and inflexible. Even though the real-time behavior of a time-triggered protocol is predictable, the low planning effort of a CAN network is one of its key success factors. Its flexibility allows for adding unplanned CAN nodes to the network at any time.
- CAN resolves network collision via a bitwise arbitration (CR: collision resolution). This means that the message with higher priority is sent. Contrary to this, Ethernet detects the collision but does not resolve it. With Ethernet, the message transmission is stopped. Both senders wait a random amount of time and then begin sending the message again. Collision resolution is the preferable method in a real-time communication network as messages with high priority have precedence.

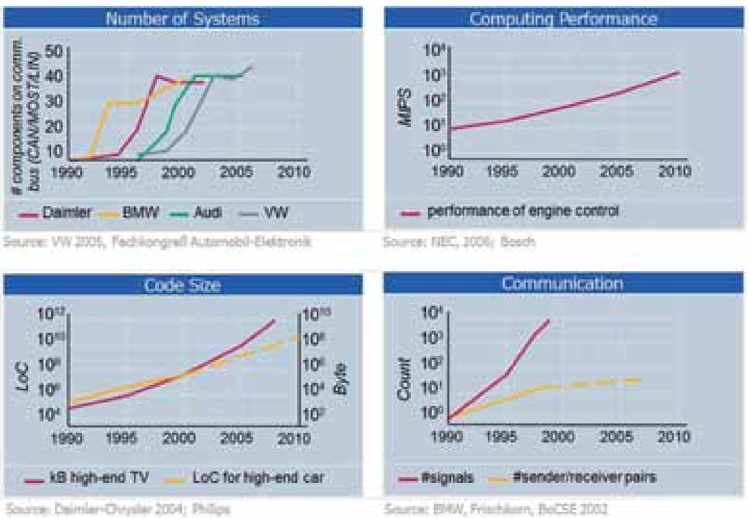


*Figure 4: Increased functional complexity in the automotive industry over time. Top left: Number of components communicating on a bus. Top right: The computing performance of engine controls in million instructions per second (MIPS). Bottom left: The number of lines of code and the memory requirements. Bottom right: The number of exchanged signals.*

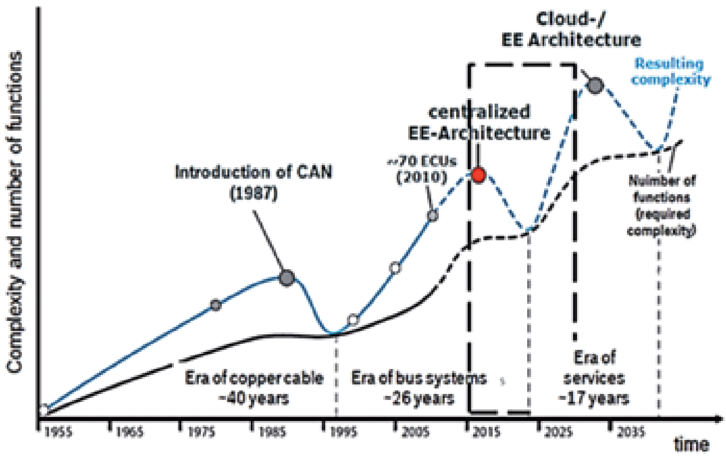


*Figure 5: The complexity grows quicker than the number of functions. In the past, a turning point in complexity was the introduction of CAN. Today’s turning point will be a different approach in organizing the vehicle’s electronic architecture.*

It is backward compatible with classic CAN and the migration effort is low:

- CAN wiring harnesses are available in the vehicle.
- CAN and CAN FD nodes can be mixed within a network.
- CAN FD needs low power consumption.

CAN FD meets future bandwidth requirements and builds a bridge towards Ethernet. One question arising in this context is whether CAN FD can co-exist with future network technologies such as Ethernet. Both technologies might co-exist in parallel for a long time, especially when taking into account the cost advantages and low migration effort. One possible future electronic architecture could be CAN FD sub-nets in the body and powertrain domain, which are integrated into an Ethernet backbone architecture, with local gateways for the protocol conversion (see Figure 6). With such architecture the success of CAN will continue with CAN FD.

The introduction of high-speed communication networks leads to additional challenges. High bandwidth requires high computing power, thus increasing ▷

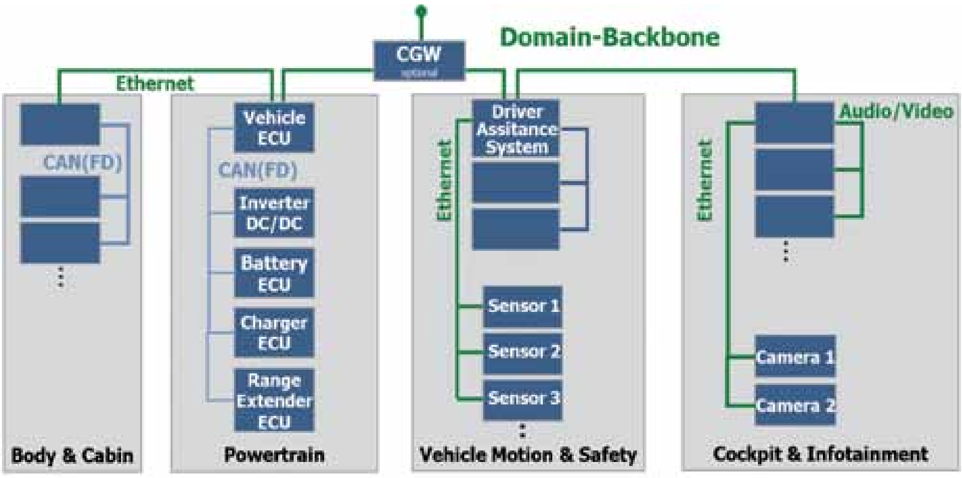


*Figure 6: A modern centralized electronic architecture organized in domains. Automotive Ethernet is a candidate for inter-domain communication, while CAN FD might substitute for CAN in the powertrain and body domain. An optional central gateway (CGW) connects the domain with the outer world.*

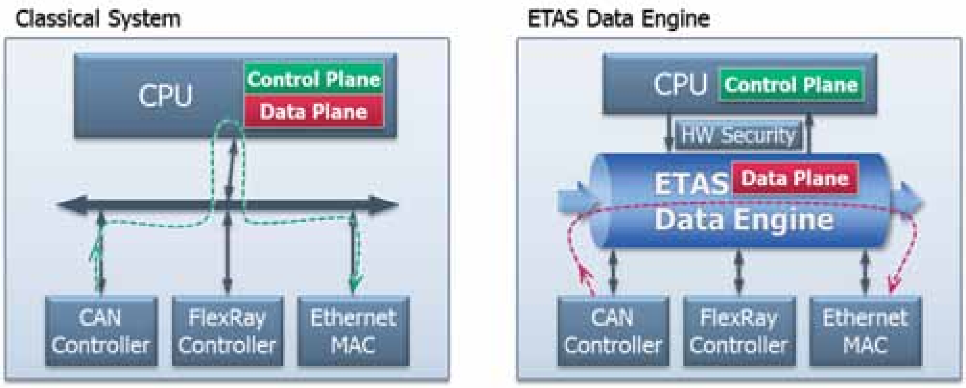


*Figure 7: Left: In a classical approach the data and control plane are implemented in firmware. The CPU controls the communication controller. Right: The Etas Date Engine implements the data plane in hardware. The CPU controls the hardware engine.*

the power consumption. Real-time communication generally demands low latency, low jitter and high determinism. Low latency communication is achieved by transmitting the data in short frames, leading to high event rates. High event rates lead to high interrupt rates and the system efficiency decreases.

In classical implementations the control and data plane are both implemented in software on a CPU and will not keep up with the new demands in terms of performance and power consumption. A solution is the introduced Etas Data Engine (EDE). The EDE is an FPGA-based IP-core for high data traffic handling. The CPU only controls the EDE and is unburdened from data transport tasks. The EDE allows a latency of less than 5 μs with negligible jitter, as well as a throughput of up to 3 Gbit/s [3]. A possible deployment of the EDE is a gateway controller that is responsible for translating protocols between network domains with minimum delay. This solution is suited for design of gateways. To reduce the number of ECUs in the vehicle, the gateway functionality can be combined with domain-specific ECUs. The company is going to offer the data engine on the open market and for high-volume production based on an IP-Core license model.

The introduction of Automotive Ethernet to the vehicle and the increasing connectivity between vehicle and outer world drives the discussion towards possible illegal access to the vehicle's network (hack attacks). A possible future enhancement of the EDE could cover this aspect by adding a hardware security module (e.g. SSL (secure sockets layer) protocol in hardware). ◀

***Outlook***

*The long-term trend towards electric mobility and the associated electrification of the powertrain, as well as the idea of vehicles interconnection with the environment (car-to-car, car-to-X), are a catalyst for a change in the communication architecture for the vehicle of the future. The vehicle communication is becoming increasingly important and is thus a driving factor for innovation.*

*Due to increasing requirements in terms of bandwidth, flexibility, and economy of networking systems, the demand for using network technologies with high bandwidth, such as Internet Protocol and Ethernet, will increase. CAN FD is a promising bridge in terms of bandwidth, cost, and migration effort towards this future.*