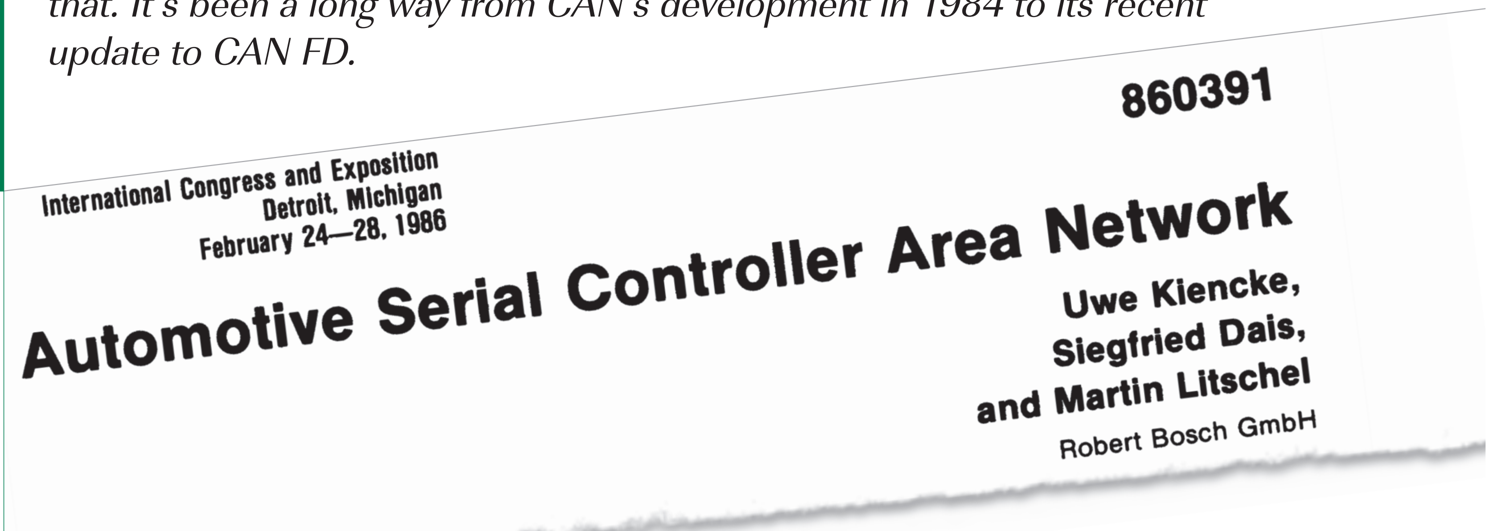
The dawn of CAN

CAN in Automation was founded 25 years ago, but CAN is even older than that. It's been a long way from CAN's development in 1984 to its recent update to CAN FD.


860391

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Automotive Serial Controller Area Network

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Figure 1: SAE paper 860391 (Photo: Bosch)

In the eighties, the functionality of automotive systems was greatly improved by the introduction of electronics. Electronic engine management impressively reduced fuel consumption and exhaust emissions at the same time, while ABS optimized braking distance and improved vehicle control. Following improvements in automotive electronics required linking different functions together, which operated separately before that. At that time, the interconnections needed a plurality of separate signal lines. The complexity of the cabling increased costs and caused difficulties for the conventional electrical connections regarding space limitations, reliability, and accessibility. By 1990, high-end vehicles had up to 100 cable connections to the dashboard. This rising intricacy was barely manageable. A fast serial communication link was needed to provide suitable communication between real-time controllers, sensors and actuators in cars, transmitting the information in a coded form, while requiring as few connector pins as possible. The conditions in the vehicle make specific requirements of a bus system:

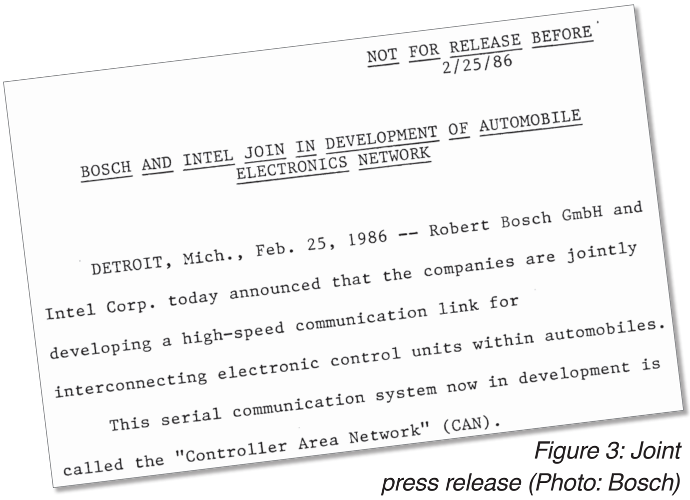
- Bus access priority must be granted dependent upon the importance of the information to be transferred.
- Short transfer times, high error immunity, and a computer load as low as possible must be guaranteed.
- A large number of different messages must be able to be processed.
- The overall costs of the system should be as low as possible.

The serial communication systems that were known at that time only partially met the requirements of the automobile industry. Simple interfaces such as UART (Universal Asynchronous Receiver/Transmitter) did not offer adequate performance. Expensive and complex communication systems such as those used to couple mainframes (Local Area Networks) were not suitable for coupling controllers in vehicles. These systems do not have real-time capabilities and were too expensive.

To bridge this performance and cost-related gap, Bosch developed a new serial communication protocol specifically with a view to in-vehicle data transfer: CAN. The main part of the development was done in 1984 and was immediately followed by the design of the first CAN implementation, in cooperation with Intel. The first publication on CAN was presented in February 1986 at the SAE conference in Detroit. At the same conference, Bosch and Intel released a press statement announcing the first CAN controller IC. In 1987, the Intel 82526 consisted of 30 000 transistors, had a size of 20 mm² in a 44-pin package and was produced in 1,5 μ CHMOS III technology. It was a so-called full-CAN controller, meaning that it stored received messages in dedicated messages buffers, depending on the results of acceptance filtering.

Figure 2: Typical CAN wiring harness (Photo: Bosch)

CAN was an immediate success, several other IC implementations followed soon (e.g. Philips, Motorola), and it was integrated into μCs. The second CAN IC (Philips 82C200) was a so-called basic-CAN controller, meaning that it stored received messages in a FIFO. The conformity of all CAN implementations was helped by standardization (ISO 11898) and by Bosch's ▷



NOT FOR RELEASE BEFORE
2/25/86

BOSCH AND INTEL JOIN IN DEVELOPMENT OF AUTOMOBILE
ELECTRONICS NETWORK

DETROIT, Mich., Feb. 25, 1986 -- Robert Bosch GmbH and Intel Corp. today announced that the companies are jointly developing a high-speed communication link for interconnecting electronic control units within automobiles.

This serial communication system now in development is called the "Controller Area Network" (CAN).

Figure 3: Joint press release (Photo: Bosch)

simulative reference model for verification. The first CAN evaluation boards and design tools arrived with the first silicon, allowing everyone to experiment with CAN networks.

The performance, robustness, and simplicity of CAN, combined with the multi-sourced availability of CAN controllers, created interest not only from the originally targeted automotive industry, but also from other areas, most prominently industrial automation. Even before the first automotive CAN application reached the market (five CAN nodes in the Mercedes-Benz S-Class of 1990, W140), CAN was used in several industrial control networks. At first, they were implemented using proprietary higher-layer protocols, but soon the first standards appeared, like CAN Kingdom, Devicenet, and SDS (Smart Distributed System).

This was also the reason for the founding of CAN in Automation 25 years ago: an organization for the joint development of standards around CAN and a meeting place for users and suppliers of CAN silicon, tools, and applications. CiA first standardized CAL (CAN application layer), which was the basis for the European research project ASPIC that developed CANopen. CANopen is now maintained by CiA and has been established as the main higher-layer protocol for CAN in industrial applications, leaving only minor roles for its predecessors.

The rapid spreading of CAN into other applications, combined with the long development cycles in the automotive industry, had the astounding consequence that the number of CAN nodes produced in industrial automation was larger than the number of CAN nodes in cars, until CAN was introduced into the high-volume cars in the mid-nineties. The experience from the first CAN networks merged into two updates of the CAN protocol: CAN 1.2 (1990) increased the oscillator tolerance, allowing the use of ceramic resonators and CAN 2.0 (1991) introduced the extended identifiers. These 29-bit long identifiers are needed to map predefined identifier sets for open architectures (e.g. SAE J1939). This concept allows nodes to be added or replaced in a network without needing to change the setup of the remaining nodes. The CAN controller Intel 82527 (1992) was the first implementation of CAN 2.0. In the beginning, some other protocols were considered for vehicle networks, but those did not go into production (Abus) or they were phased out again (J1850, ▷

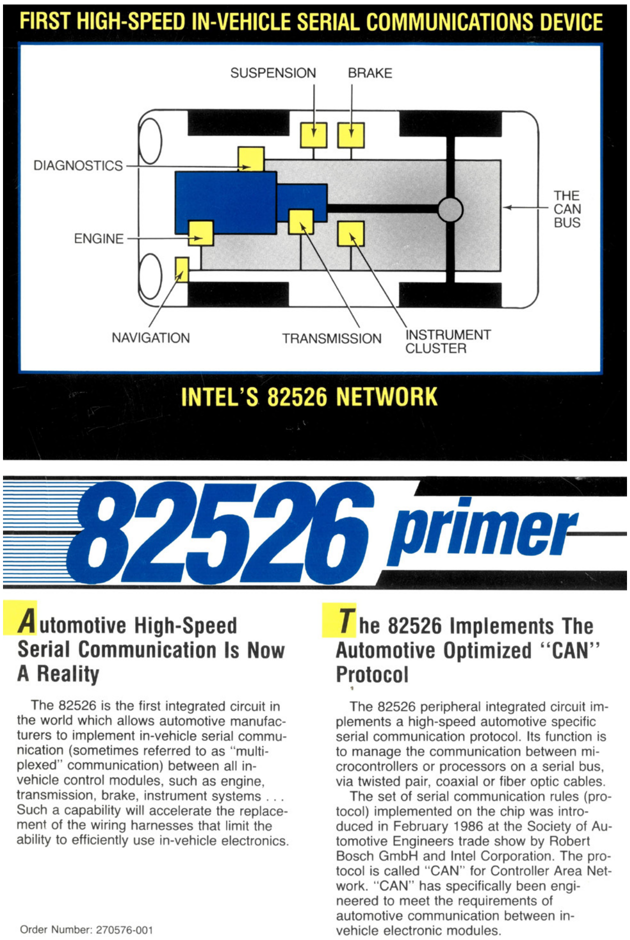


Figure 4: Intel 82526 advertisement (Photo: Bosch)

VAN). Ten years after the first CAN network, few cars did not use CAN, and most had several CAN networks for different functions.

When CAN entered automotive volume production, it turned out that the structure of the car's wiring harness did not agree with the original idea of how to build a CAN line: the so-called ISO-topology with terminations at both ends of the bus line and all nodes connected by short stubs. A wiring harness is usually pre-produced in an "E"-or "H"-shape, so most CAN networks are built as passive star networks. This degrades the signal quality, which is why most automotive CAN networks use a bit-rate of 0,5 Mbit/s instead of the 1 Mbit/s for which the CAN protocol was designed. At the lower speed, the robust CAN protocol can easily tolerate the ringing introduced by the bus topology.

The higher bit-rate is still used in so-called "Private CAN" networks: point-to-point connections between two nodes. While the first CAN networks used discrete transistors as bus line drivers, this was soon followed by dedicated CAN transceiver ICs. Different transceiver types were developed, but ISO 11898-2:2016 is now the standard in automotive applications, with or without the partial networking extension where the transceiver is able to decode wakeup messages. In industrial applications, galvanically isolated CAN transceivers are preferred.

Besides the first two fields of application, several other industries specified their own CAN standards, like Arinc-825 for aviation and ESA's ECSS-E-ST-50-15C for on-board spacecraft communications and control systems. This enabled CAN networks to reach the Moon (Smart-1, 2004) and Mars (ExoMars, 2016). In the automotive world, CAN remains the predominant bus system, although some other protocols have been added for specific applications, like LIN for master-slave sub-networks and Most for infotainment. Ethernet was also introduced into automotive applications, first only for tasks with high data volumes, but lately also for control applications.

One specific automotive protocol, Flexray, has been added to CAN networks. Flexray was developed for x-by-wire systems, where mechanical and hydraulic linkages are replaced by bus systems, so that the car can be controlled with a joystick. These control loops require synchronized nodes communicating on redundant channels. Flexray was developed by the Flexray consortium targeted for a bit-rate of up to 10 Mbit/s. As with CAN, the network topology needs careful consideration to achieve high bit-rates; Flexray at 10 Mbit/s requires active stars or linear bus lines with a limited number of nodes. A time-triggered extension of the CAN protocol (TTCAN) was developed for the same x-by-wire applications. TTCAN has been standardized as ISO 11898-4:2004. The targeted x-by-wire systems never appeared in volume produced cars, so time-triggered communication lost its main purpose and the ECUs still operate with event-driven control messages.

The ever increasing need for bandwidth in automotive control networks raised the number of CAN networks in a car, requiring gateways and a backbone for interconnection. While Flexray is already used as such a backbone, its time-triggered communication schedule is not easily integrated into the event-driven operation of automotive ECUs. A solution for this data bottleneck was required, ideally without the need of

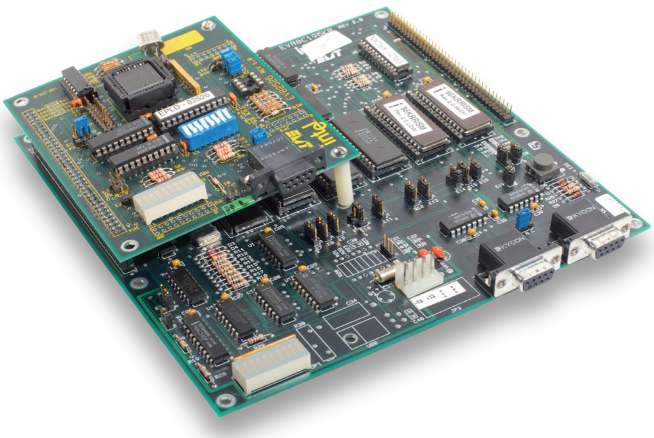


Figure 5: The 82526 evaluation board (Photo: Bosch)

Figure 6: Intel 82527 advertisement (Photo: Bosch)

a radical transformation of automotive networking. For that reason, Bosch upgraded the CAN protocol to CAN FD.

CAN FD was first published in a white paper in April 2011, soon followed by hardware demonstrators. It increases CAN's data rate in two ways: First by switching to a higher bit-rate for the payload of a CAN frame and second by extending the frame's data field to improve the header/payload ratio. The maximum data length in CAN FD is 64 bytes. The rest of the Classical CAN features, like arbitration, acknowledge, and error handling, are left unchanged. There is no disruptive transition when switching from CAN to CAN FD; the design environment and hardware can be upgraded incrementally. CAN FD nodes are still able to take part in Classical CAN network communication.

The physical layer and bus topology of Classical CAN may be left unchanged when the network is upgraded to CAN FD; the signal delay times that limit the Classical CAN's bit-rate are not relevant for the bit-rate in CAN FD's data phase. This bit-rate is still limited by transceiver asymmetry and by ringing on the bus line. The advantages of CAN FD have been accepted in the CAN community, so several CAN controller ICs are available today, as well as design and measurement tools. Standardization started early and culminated in the integration of the CAN FD frame format in ISO 11898-1:2015. The physical layer standardization in ISO 11898-2 also considers CAN FD, e.g. by new parameters for bit symmetry. Transceivers released for CAN FD are already in production. Volume production of the first cars using CAN FD is expected to ramp up in 2017.

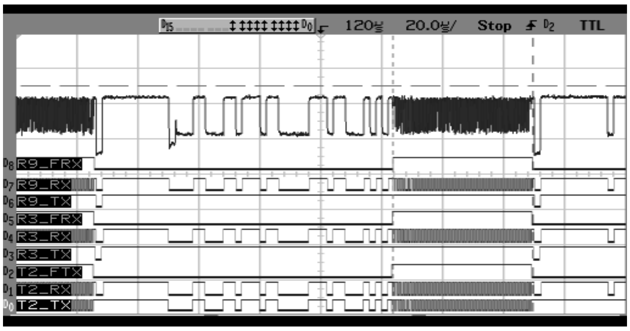


Figure 7: CAN FD frame (Photo: Bosch)

For industrial automation, CiA's working groups upgrade the CANopen software standards to integrate CAN FD. Other standards (CiA 601) provide guidelines for hardware integration. New security concepts for CAN networks have also been developed, enabled by the longer data fields of CAN FD that allow adding a signature for message authentication.

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