Controller Area Network

The Controller Area Network (CAN) is a serial bus communications protocol developed by Bosch in the early 1980s. Controller Area Network (CAN or CAN-bus) is basically a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer. It defines a standard for efficient and reliable communication between sensor, actuator, controller, and other nodes in real-time applications. CAN is the de facto standard in a large variety of networked embedded control systems. The early CAN development was mainly supported by the vehicle industry. CAN is found in a variety of passenger cars, trucks, boats, spacecraft, and other types of vehicles. By networking electro-mechanical subsystems, it becomes possible to modularize functionalities and hardware, which facilitates reuse and adds capabilities.

![Fig. 1](image)

which facilitates production and increases reliability. Introducing networks in vehicles also makes it possible to more efficiently carry out diagnostics and to coordinate the operation of the separate subsystems. The adoption of CAN in a variety of application fields has led to the development of several higher-layer protocols, including SAE J1939, CANopen, DeviceNet, and CAN Kingdom. Their characteristics reflect differences in requirements and traditions of application areas. An example is the adoption of certain communication models, such as either the client-server model or the distributed data-flow model. The progress and success of CAN are due to a number of factors. The use of CAN in the automotive industry has caused mass production of CAN controllers. Today, CAN controllers are integrated on many microcontrollers and available at a low cost.

A Brief History:

The evolution of microelectronics paved the way for introducing distributed control systems in vehicles. In the early 1980s there was, however, no low-cost and standardized protocol that was suitable for real-time control systems. Therefore, as we stated before, in 1983 Kiencke started the development of a new serial bus system at Bosch, which was presented as CAN in 1986 at the SAE congress in Detroit. The development of CAN was mainly motivated by the need for new functionalities, but it also substantially reduced the need for wiring. The Bosch CAN Specification 2.0 was published in 1991 and then two years later the CAN protocol was internationally standardized as ISO 11898-1. The need for higher-layer protocols was recognized early. In 1991, CAN Kingdom was introduced by Kvaser. DeviceNet, another higher-layer protocol, was introduced by Allen-Bradley in 1994, and CANopen by CAN in Automation (CiA) in 1995. CiA is an international users and manufacturers group, which was founded in 1992. Mercedes-Benz has been using CAN in its passenger cars since 1992. Originally, CAN was used only for engine control, but today there are a
variety of CAN nodes not only for powertrain and chassis control but also for body electronics and infotainment systems. Many other car manufacturers base their control architecture on CAN, including BMW, Fiat, Renault, Saab, Volkswagen, and Volvo. The CAN architecture for a Volvo passenger car is described in the next paragraph.

**SCANIA Truck**

In the automotive industry, there has been a remarkable evolution over the last few years in which embedded control systems have grown from standalone control systems to highly integrated and networked control systems. Originally motivated by reduced cabling and the specific addition of functionalities with sensor sharing and diagnostics, there are currently several new systems under development that involve distributed coordination of many subsystems. The control architecture for a Scania truck is shown in Fig. 3. It consists of three CAN buses, denoted green, yellow, and red by Scania due to their relative importance. The leftmost (vertical) CAN contains less critical ECUs such as the audio system and the climate control. The middle (vertical) CAN handles the communication for important subsystems that are not directly involved in the engine and brake management.

**Green Bus**
- AUS Audio system
- CSS Crash safety system
- ACC Automatic climate control
- WTA Auxiliary heater water-to-air
- ATA Auxiliary heater air-to-air
- CTS Clock and timer system
- RTG Road transport info gateway
- RTI Road transport info system

**Yellow Bus**
- LAS Locking and alarm system
- AWD All wheel drive system
- ICL Instrument cluster system
- TCO Tacho-graph system
- VIS Visibility system
- APS Air processing system
- BWS Body work system
- BCS Body chassis system

![Fig. 2](image-url)
Red Bus
GMS Gearbox management system
ACS Articulation control system
EMS Engine management system
EEC Exhaust emission control
BMS Brake management system
SMS Suspension management system
SMD Suspension management dolly

For example, connected to this bus is the instrument cluster system. Finally, the rightmost (horizontal) bus is the most critical CAN. It connects all ECUs for the driveline subsystems. The coordinator system ECU (COO) is a gateway between the three CAN buses. Connected to the leftmost CAN is a diagnostic bus, which is used to collect information on the status of the ECUs. The diagnostic bus can thus be used for error detection and debugging. Variants of the truck are equipped with different numbers of ECUs (the figure illustrates a configuration close to maximum). As for passenger cars, there are also sub-networks, but these are not shown in the figure.

SAE J1939 is the dominant higher-layer protocol for trucks. It facilitates plug-and-play functionality, but makes system changes and optimization difficult, partly because the priorities for scheduling the network traffic cannot be reconfigured. Manufacturers are using loopholes in SAE J1939 to work around these problems, but their existence indicates deficiencies in the protocol.

Vehicle Dynamics Control System (VDC)
Vehicle dynamics control systems* are designed to assist the driver in over steering, under-steering and roll-over situations. The principle of a vehicle dynamics control (VDC) system is illustrated in Fig. 3.

The VDC system compares the driver’s estimated intended course, by measuring the steering wheel angle and other relevant sensor data, with the actual motion of the vehicle. When these deviate too much, the VDC will intervene by automatically applying the brakes of the individual wheels and also by controlling the engine torque, in order to make the vehicle follow the path intended by the driver as closely as possible. The central components of VDC are illustrated on the right in Fig. 3. In essence, the VDC will assist the driver by making the car easier to steer and by improving its stability margin.

* Also Known as Electronic Stability Program patented by Robert Bosch GmbH.
A block diagram of a conceptual VDC is shown in Fig. 4. The cascade control structure consists of three controllers: (1) the yaw/slip controller, which controls the overall vehicle dynamics in terms of the vehicle yaw rate and the vehicle side slip angle; (2) the brake controller, which controls the individual wheel braking forces; and (3) the engine controller, which controls the engine torque. The inputs to the yaw/slip controller include the driver’s commands: accelerator pedal position, steering wheel angle, and brake pressure. Based on these inputs and other sensor data, nominal values for the yaw rate and the vehicle side slip are computed. They are compared with the measured yaw rate and the estimated side slip. A gain-scheduled feedback control law is applied to derive set-points for the engine and brake controllers; for example, during over-steering, braking actions are normally performed on the front outer wheel and for under-steering normally on the rear inner wheel. The gains of the controllers depend on the driving conditions (e.g., vehicle speed, under-steering, over-steering). The brake and the engine controllers are typically proportional-integral-derivative (PID) controllers and also use local sensor information such as wheel speed. The VDC system has to take the driver behavior into account as well as disturbances acting on the vehicle, including cross-wind, asymmetric friction coefficients, and even a flat tire. The VDC system utilizes the CAN bus, as it is depending on several ECUs, although the main functionality resides in a specific ECU. The implementation strongly depends on the choice of braking mechanics (e.g., hydraulics, pneumatics, electro-hydraulics, or even electro-mechanics), the availability of a transmission ECU, and the interface to the engine ECU. A separate distributed control system is often used for the brakes, extending from a brake control node; for example, trucks often have one ECU per wheel pair and an additional controller for the trailer. Since some of the control loops of a VDC system are closed over a vehicle CAN, special care has to be taken with respect to end-to-end delays and faults in the distributed system. The left figure shows a situation where over-steering takes place, illustrating the case where the friction limits are reached for the rear wheels causing the tire forces to saturate (saturation on the front wheels will instead cause an under-steer situation). Unless the driver is very skilled, the car will start to skid, meaning that the vehicle yaw rate and vehicle side slip angle will deviate from what the driver intended. This is the situation shown for the left vehicle. For the vehicle on the right, the on-board VDC will detect the emerging skidding situation and will compute a compensating torque, which for the situation illustrated is translated into applying a braking force to the outer front wheel. This braking force will provide a compensating torque and the braking will also reduce the lateral force for this wheel.

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