Electrical and electronic systems in the vehicle

The amount of electronics in the vehicle has risen dramatically in recent years and is set to increase yet further in the future. Technical developments in semiconductor technology support ever more complex functions with the increasing integration density. The functionality of electronic systems in motor vehicles has now surpassed even the capabilities of the Apollo 11 space module that orbited the Moon in 1969.

Overview

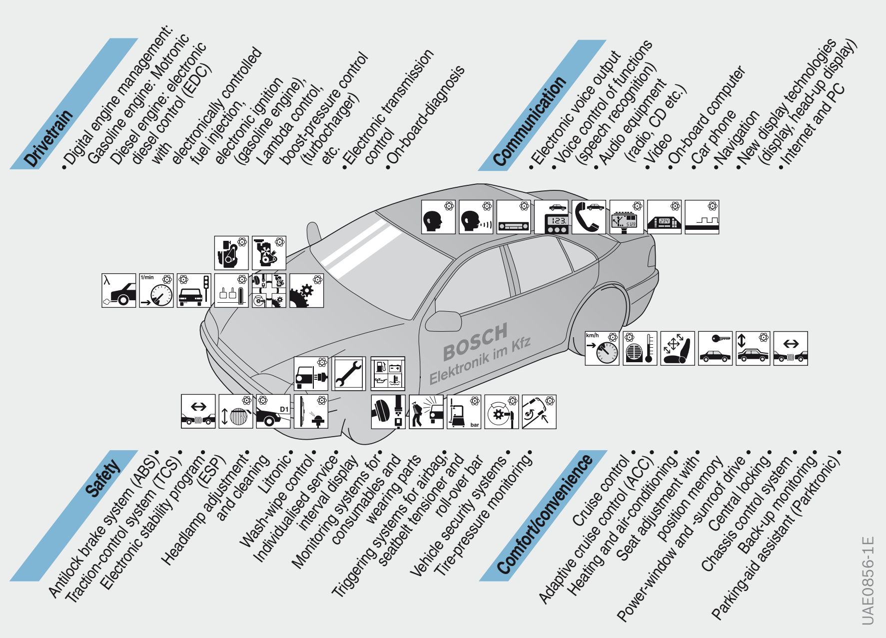
Development of electronic systems

Not least in contributing to the success of the vehicle has been the continuous string of innovations which have found their way into vehicles. Even as far back as the 1970s, the aim was to make use of new technologies to help in the development of safe, clean and economical cars. The pursuit of economic efficiency and cleanliness was closely linked to other customer benefits such as driving pleasure. This was characterized by the European diesel boom, upon which Bosch had such a considerable influence. At the same time, the development of the gasoline engine with gasoline direct injection, which would reduce fuel consumption by comparison with intake-manifold injection, experienced further advancements.

An improvement in driving safety was achieved with electronic brake-control systems. In 1978, the antilock brake system (ABS) was introduced and underwent continual development to such an extent that it is now fitted as standard on every vehicle in Europe. It was along this same line of development that the electronic stability program (ESP), in which ABS is integrated, would debut in 1995.

The latest developments also take comfort into account. These include the hill hold control (HHC) function, for example, which makes it easier to pull away on uphill gradients. This function is integrated in ESP.

1 Electronics in the motor vehicle



Robert Bosch GmbH (ed.), *Bosch Automotive Electrics and Automotive Electronics,*
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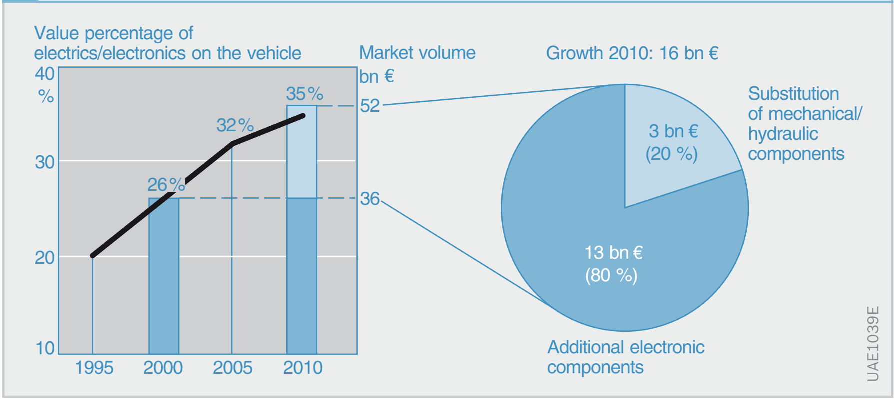
2 Market volumes of electrics/electronics in Europe (estimates)



Many kinds of new functions appear in conjunction with driver-assistance systems. Their scope extends far beyond today's standard features such as Parkpilot or electronic navigation systems. The aim is to produce the "sensitive vehicle" that uses sensors and electronics to detect and interpret its surroundings. Tapping into ultrasound, radar and video sensor technologies has led to solutions that play an important role in assisting the driver, e.g. through improved night vision or distance control.

Value creation structure for the future

The latest studies show that the production costs of an average car will increase only slightly by 2010 despite further innovations. No significant value growth for existing systems is expected in the mechanics/hydraulics domain despite the expected volume growth. One reason here being the electrification of functions that have conventionally been realized mechanically or hydraulically. Brake control systems are an impressive example of this change. While the conventional brake system was characterized more or less completely by mechanical components, the introduction of the ABS brake-control system was accompanied by a greater proportion of electronic components in the form of sensor technology and an electronic control unit. With the more recent developments of ESP, the additional functions, such as HHC, are almost exclusively realized by electronics.

Even though significant economies of scale are seen with the established solutions, the value of the electrics and electronics will increase overall (Fig. 1). By 2010, this will amount to a good third of the production costs of an average vehicle. This assumption is based not least on the fact that the majority of future functions will also be regulated by electrics and electronics.

The increase in electrics and electronics is associated with a growth in software. Even today, software development costs are no longer negligible by comparison with hardware costs. Software authoring is faced with two challenges arising from the resulting increase in complexity of a vehicle's overall system: coping with the volume and a clearly structured architecture. The Autosar initiative (Automotive Open Systems Architecture), in which various motor vehicle manufacturers and suppliers participate, is working towards a standardization of electronics architecture with the aim of reducing complexity through increased reusability and interchangeability of software modules.

Task of an electronic system

Open-loop and closed-loop control

The nerve center of an electronic system is the control unit. Figure 3 shows the system blocks of a Motronic engine-management system. All the open-loop and closed-loop algorithms of the electronic system run inside the control unit. The heart of the control unit is a microcontroller with the program memory (flash EPROM) in which is stored the program code for all functions that the control unit is designed to execute.

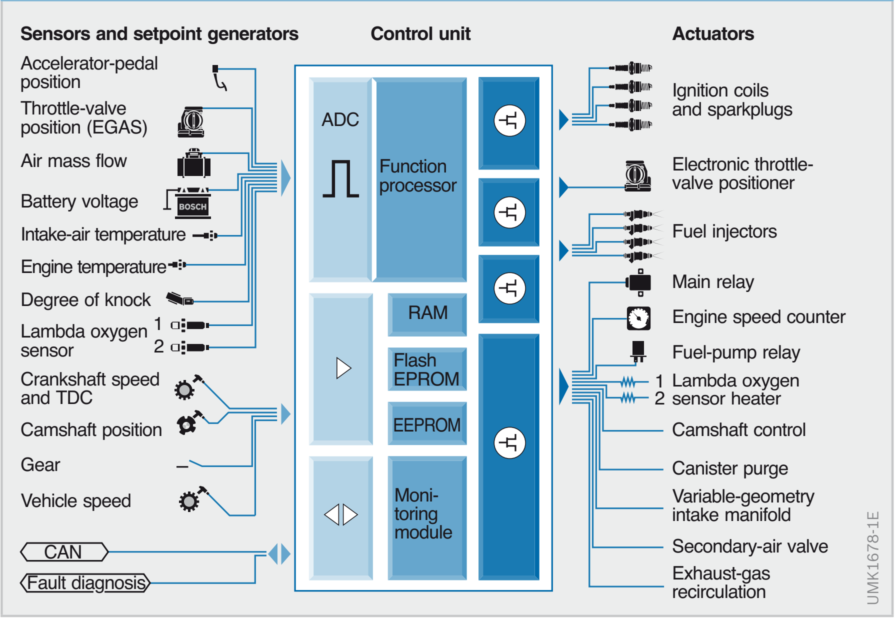
The input variables for the sequence control are derived from the signals from sensors and setpoint generators. They influence the calculations in the algorithms, and thus the triggering signals for the actuators. These convert into mechanical variables the electrical signals that are output by the microcontroller and amplified in the output stage modules. This could be mechanical energy generated by a servomotor (power-window unit), for example, or thermal energy generated by a sheathed-element glow plug.

Communication

Many systems have a mutual influence on each other. For example, it may sometimes be necessary to not only have the electronic stability program carry out a braking intervention in the event wheel spin but also to request that the engine-management system reduce torque and thus counteract wheel spin. Similarly, the control unit for the automatic transmission outputs a request to the engine-management system to reduce torque during a gearshift and thereby promote a soft gear change. To this end, the systems are networked with each other, i.e. they are able to communicate with each other on data buses (e.g. CAN, LIN).

In a premium-class vehicle, there may be up to 80 control units performing their duties. The examples below are intended to give you an insight into the operating principle of these systems.

3 Function modules of an electronic system



Motronic engine-management system

“Motronic” is the name of an engine-management system that facilitates open- and closed-loop control of gasoline engines within a single control unit.

There are Motronic variants for engines with intake-manifold injection (ME Motronic) and for gasoline direct injection (DI Motronic). Another variant is the Bifuel Motronic, which also controls the engine for operation with natural gas.

System description

Functions

The primary task of the Motronic engine-management system is:

- To adjust the torque desired and input by the driver depressing the accelerator pedal
- To operate the engine in such a way as to comply with the requirements of ever more stringent emission-control legislation
- To ensure the lowest possible fuel consumption but at the same time
- To guarantee high levels of driving comfort and driving pleasure

Components

Motronic comprises all the components which control and regulate the gasoline engine (Fig. 1, next page). The torque requested by the driver is adjusted by means of actuators or converters. The main individual components are:

- The electrically actuated throttle valve (air system): this regulates the air-mass flow to the cylinders and thus the cylinder charge
- The fuel injectors (fuel system): these meter the correct amount of fuel for the cylinder charge
- The ignition coils and spark plugs (ignition system): these provide for correctly timed ignition of the air-fuel mixture present in the cylinder

Depending on the vehicle, different measures may be required to fulfill the requirements demanded of the engine-management system (e.g. in respect of emission characteristics, power output and fuel consumption). Examples of system components able to be controlled by Motronic are:

- Variable camshaft control: it is possible to use the variability of valve timing and valve lifts to influence the ratio of fresh gas to residual exhaust gas and the mixture formation
- External exhaust-gas recirculation: adjustment of the residual gas content by means of a precise and deliberate return of exhaust gas from the exhaust train (adjustment by the exhaust-gas recirculation valve)
- Exhaust-gas turbocharging: regulated supercharging of the combustion air (i.e. increase in the fresh air mass in the combustion chamber) to increase torque
- Evaporative emission control system: for the return of fuel vapors that escape from the fuel tank and are collected in an activated charcoal canister

Operating variable acquisition

Motronic uses sensors to record the operating variables required for the open and closed-loop control of the engine (e.g. engine speed, engine temperature, battery voltage, intake air mass, intake-manifold pressure, Lambda value of the exhaust gas).

Setpoint generators (e.g. switches) record the adjustments made by the driver (e.g. position of the ignition key, cruise control).

Operating variable processing

From the input signals, the engine ECU detects the current operating status of the engine and uses this information in conjunction with requests from auxiliary systems and from the driver (accelerator-pedal sensor and operating switches) to calculate the command signals for the actuators.

1 Components used for open-loop electronic control of a DI-Motronic system (example of a naturally aspirated engine, λ = 1)

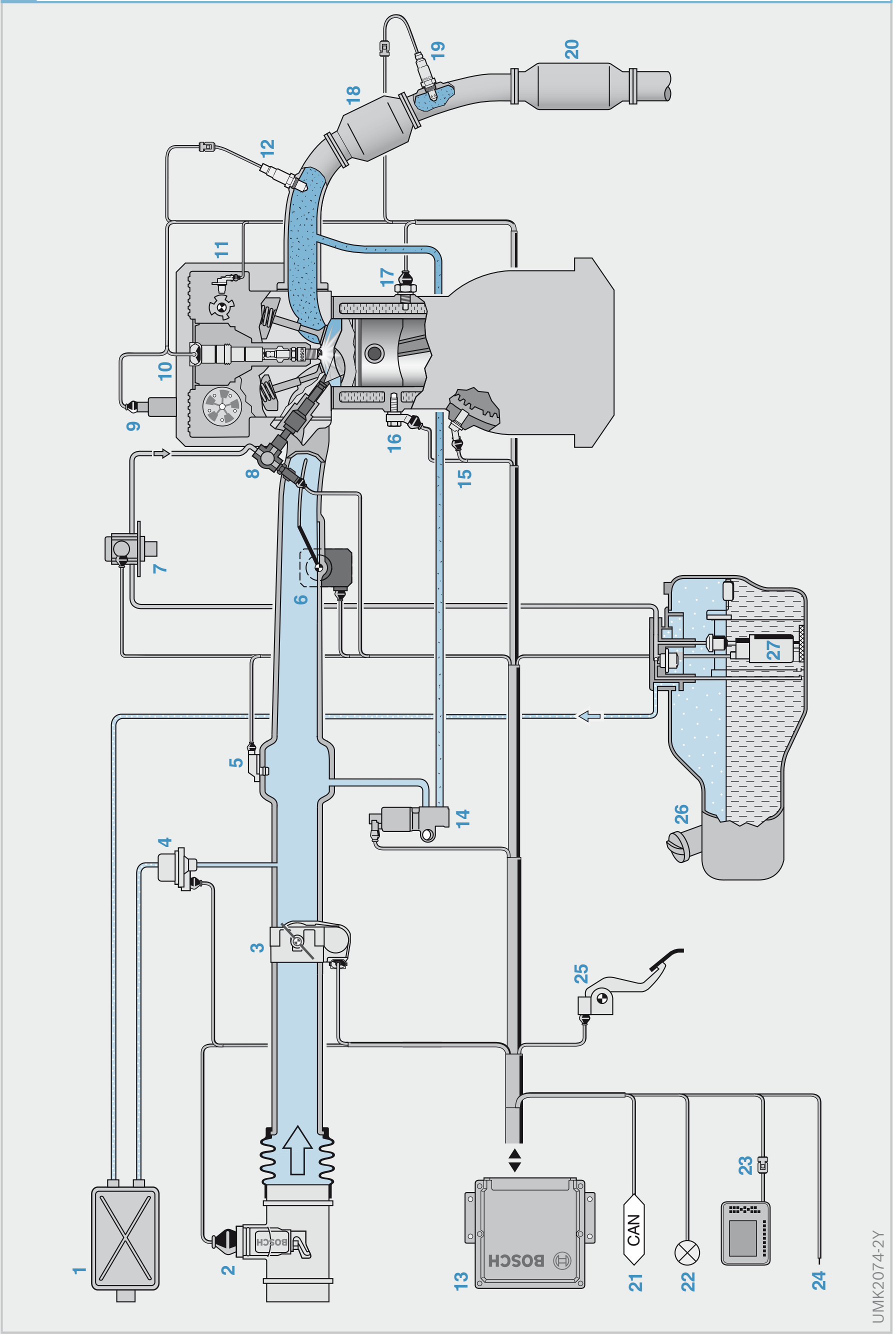


Fig. 1
1 Activated charcoal canister
2 Hot-film air-mass meter
3 Throttle device (ETC)
4 Canister-purge valve
5 Intake-manifold pressure sensor
6 Swirl control valve
7 High-pressure pump
8 Rail with high-pressure fuel injector
9 Camshaft adjuster
10 Ignition coil with spark plug
11 Camshaft phase sensor
12 Lambda oxygen sensor (LSU)
13 Motronic ECU
14 EGR valve
15 Speed sensor
16 Knock sensor
17 Engine-temperature sensor
18 Primary catalytic converter
19 Lambda oxygen sensor
20 Primary catalytic converter
21 CAN interface
22 Diagnosis lamp
23 Diagnosis interface
24 Interface with immobilizer control unit
25 Accelerator-pedal module
26 Fuel tank
27 Fuel delivery module with electric fuel-supply pump

Air system

A specific air-fuel mixture is required to achieve the desired torque. For this purpose, the throttle valve (Fig. 1, Item 3) regulates the air necessary for the mixture formation by adjusting the metering orifice in the intake port for the fresh air taken in by the cylinders. This is effected by a DC motor (Fig. 2) integrated in the throttle device that is controlled by the Motronic control unit. The position of the throttle valve is fed back to the control unit by a position sensor to make position control possible. This sensor may be in the form of a potentiometer, for example. Since the throttle device is a component relevant to safety, the sensor is designed with redundancy.

The intake air mass (air charge) is recorded by sensors (e.g. hot-film air-mass meter, intake-manifold pressure sensor).

Fuel system

The control unit (Fig. 1, Item 13) calculates the fuel volume required from the intake air mass and the current operating status of the engine (e.g. intake-manifold pressure, engine speed), and also the time at which fuel injection should take place.

In gasoline injection systems with intake manifold injection, the fuel is introduced into the intake duct upstream of the intake valves. To this end, the electric fuel-supply pump (27) delivers fuel (primary pressure up to approximately 450 kPa) to the fuel injectors. Each cylinder is assigned a fuel injector that injects the fuel at intermittent intervals. The air-fuel mixture in the intake passage flows into the cylinder during the induction stroke. Corrections are made to the injected fuel quantity, e.g. by the Lambda control (Lambda oxygen sensor, 12) and the canister purge (evaporative-emissions control system, 1, 4).

With gasoline direct injection, fresh air flows into the cylinder. The fuel is injected directly into the combustion chamber by high-pressure fuel injectors (8) where it forms an air-fuel mixture with the intake air. This requires a higher fuel pressure, which is generated by additional high-pressure pump (7). The pressure can be variably adjusted (up to 20 MPa) in line with the operating point by an integrated fuel-supply control valve.

2 Throttle device with potentiometric position feedback

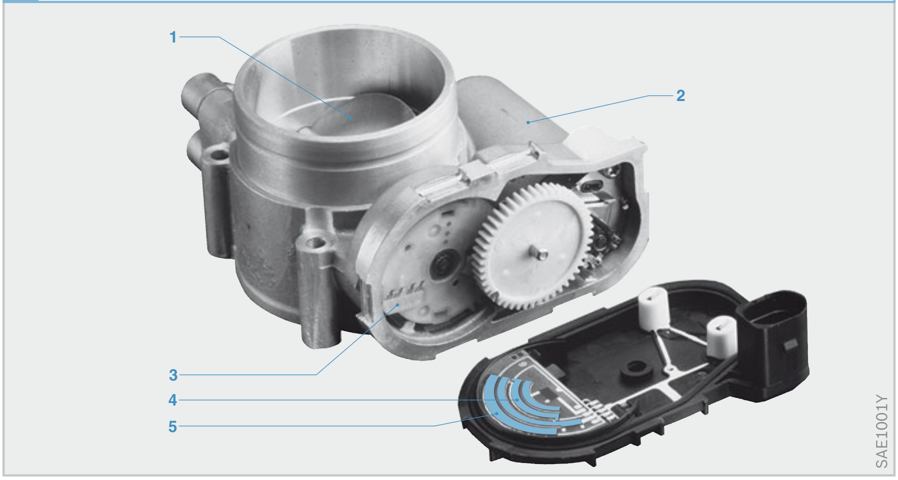


Fig. 2
1 Throttle valve
2 DC motor
3 Wiper
4 Resistance track 1
5 Resistance track 2

Fuel injector for intake-manifold injection

Function

The electromagnetic (solenoid-controlled) fuel injectors spray the fuel into the intake manifold at primary pressure. They allow fuel to be metered in the precise quantity required by the engine. They are actuated by driver stages which are integrated in the engine ECU with the signal calculated by the engine-management system.

3 EV14 electromagnetic fuel injector

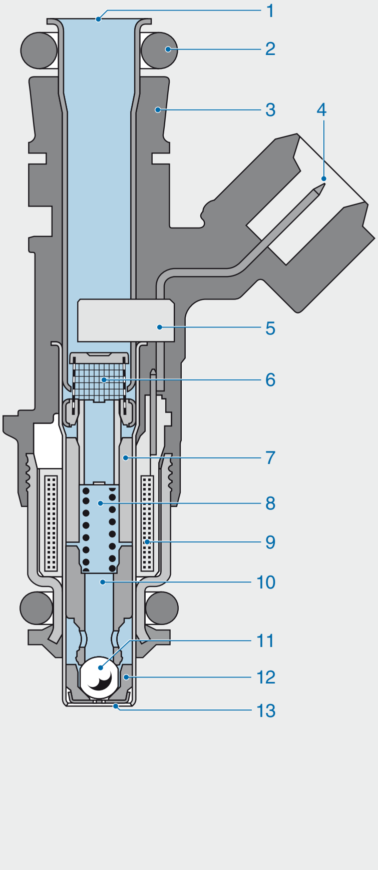


Fig. 3
1 Hydraulic port
2 O-ring
3 Valve housing
4 Electrical connection
5 Plastic clip with injected pins
6 Filter strainer
7 Internal pole
8 Valve spring
9 Solenoid coil
10 Valve needle with armature
11 Valve ball
12 Valve seat
13 Injection-orifice plate

Design and operating principle

Essentially, electromagnetic fuel injectors (Fig. 3) are comprised of the following components:

- Valve housing (3) with electrical connection (4) and hydraulic port (1)
- Solenoid coil (9)
- Moving valve needle (10) with solenoid armature and valve ball (11)
- Valve seat (12) with injection-orifice plate (13) and
- Valve spring (8)

In order to ensure trouble-free operation, stainless steel is used for the parts of the fuel injector which come into contact with fuel. The fuel injector is protected against dirt by a filter strainer (6) at the fuel inlet.

Connections

On the fuel injectors presently in use, fuel supply to the fuel injector is in the axial direction, i.e. from top to bottom (“top feed”). The fuel line is secured to the hydraulic port by means of a clamping fixture. Retaining clips ensure reliable fastening. The sealing ring (O-ring) on the hydraulic port (2) seals off the fuel injector at the fuel rail.

The fuel injector is electrically connected to the engine ECU.

Fuel injector operation

When the solenoid coil is de-energized, the valve needle and valve ball are pressed against the cone-shaped valve seat by the spring and the force exerted by the fuel pressure. The fuel-supply system is thus sealed off from the intake manifold. When the solenoid coil is energized, this generates a magnetic field which attracts the valve-needle solenoid armature. The valve ball lifts up from the valve seat and the fuel is injected. When the excitation current is switched off, the valve needle closes again due to spring force.

Fuel outlet
The fuel is atomized by means of an injection-orifice plate in which there are a number of holes. These holes (injection orifices) are stamped out of the plate and ensure that the injected fuel quantity remains highly constant. The injection-orifice plate is insensitive to fuel deposits. The spray pattern of the fuel leaving the injector is produced by the number of injection orifices and their configuration.

The injector is efficiently sealed at the valve seat by the cone/ball sealing principle. The fuel injector is inserted into the opening provided for it in the intake manifold. The lower sealing ring provides the seal between the fuel injector and the intake manifold.

Essentially, the injected fuel quantity per unit of time is determined by

- The primary pressure in the fuel-supply system
- The back pressure in the intake manifold and
- The geometry of the fuel-exit area

Electrical activation
An output module in the Motronic ECU actuates the fuel injector with a switching signal (Fig. 4a). The current in the solenoid coil rises (b) and causes the valve needle (c) to lift. The maximum valve lift is achieved after the time t_{pk} (pickup time) has elapsed. Fuel is sprayed as soon as the valve ball lifts off its seat. The total quantity of fuel injected during an injection pulse is shown in Figure 4d.

Current flow ceases when activation is switched off. Mass inertia causes the valve to close, but only slowly. The valve is fully closed again after the time t_{dr} (dropout time) has elapsed.

When the valve is fully open, the injected fuel quantity is proportional to the time. The non-linearity during the valve pickup and dropout phases must be compensated for throughout the period that the injector is activated (injection duration). The speed at which the valve needle lifts off its seat is also dependent on the battery voltage. Battery-voltage-dependent injection-duration extension (Fig. 5) corrects these influences.

4 EV14 activation

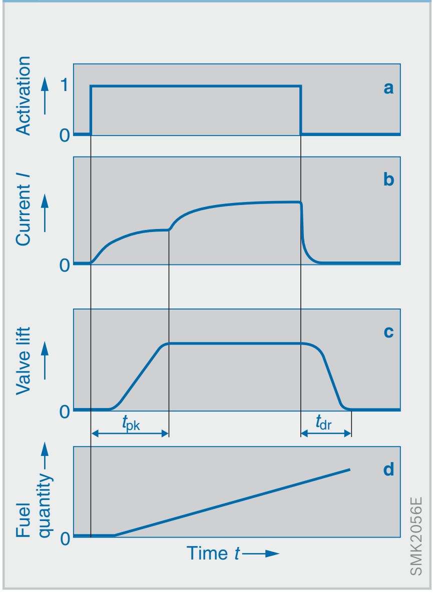
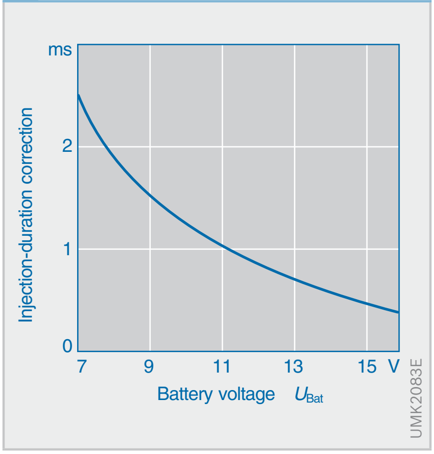


Fig. 4
a Activation signal
b Current curve
c Valve lift
d Injected fuel quantity

5 Voltage-dependent injection-duration correction



High-pressure fuel injector for gasoline direct injection

Function

It is the function of the high-pressure fuel injector (HDEV) on the one hand to meter the fuel and on the other hand by means of its atomization to achieve controlled mixing of the fuel and air in a specific area of the combustion chamber. Depending on the desired operating status, the fuel is either concentrated in the vicinity of the spark plug (stratified charge) or evenly distributed throughout the combustion chamber (homogenous distribution).

Design and operating principle

The high-pressure fuel injector (Fig. 6) comprises the following components:

- Inlet with filter (1)
- Electrical connection (2)
- Spring (3)
- Coil (4)
- Valve sleeve (5)
- Nozzle needle with solenoid armature (6) and
- Valve seat (7)

A magnetic field is generated when current passes through the coil. This lifts the valve needle off the valve seat against the force of the spring and opens the injector outlet bores (8). The primary pressure now forces the fuel into the combustion chamber. The injected fuel quantity is essentially dependent on the opening duration of the fuel injector and the fuel pressure.

When the energizing current is switched off, the valve needle is pressed by spring force back down against its valve seat and interrupts the flow of fuel.

Excellent fuel atomization is achieved thanks to the suitable nozzle geometry at the injector tip.

Requirements

Compared with manifold injection, gasoline direct injection differs mainly in its higher fuel pressure and the far shorter time which is available for directly injecting the fuel into the combustion chamber.

6 Design of HDEV5 high-pressure fuel injector

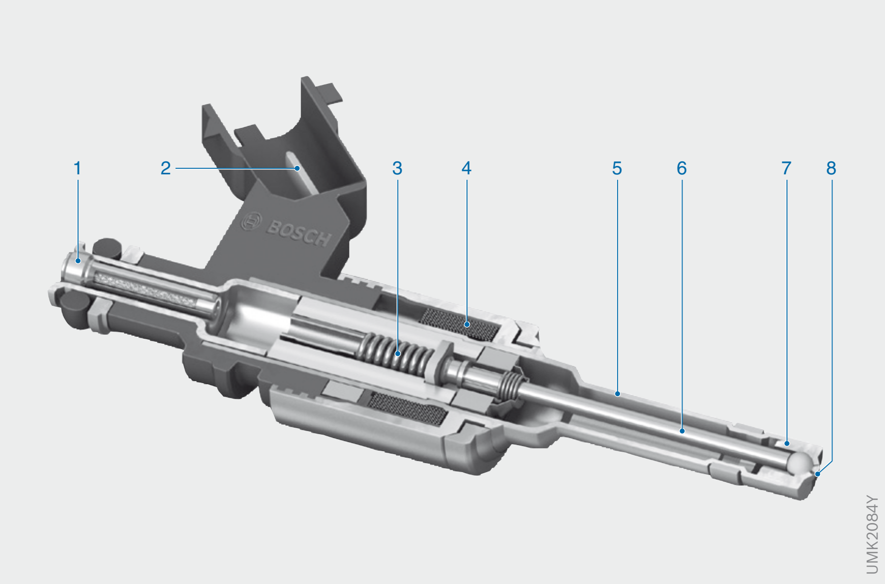


Fig. 6

1 Fuel inlet with filter
2 Electrical connection
3 Spring
4 Coil
5 Valve sleeve
6 Nozzle needle with solenoid armature
7 Valve seat
8 Injector outlet bores

Figure 7 underlines the technical demands made on the fuel injector. In the case of manifold injection, two revolutions of the crankshaft are available for injecting the fuel into the intake manifold. This corresponds to an injection duration of 20 ms at an engine speed of 6,000 rpm.

In the case of gasoline direct injection, however, considerably less time is available. In homogeneous operation, the fuel must be injected during the induction stroke. In other words, only a half crankshaft rotation is available for the injection process. At 6,000 rpm, this corresponds to an injection duration of 5 ms.

With gasoline direct injection, the fuel requirement at idle in relation to that at full load is far lower than with manifold injection (factor 1:12). At idle, this results in an injection duration of approx. 0.4 ms.

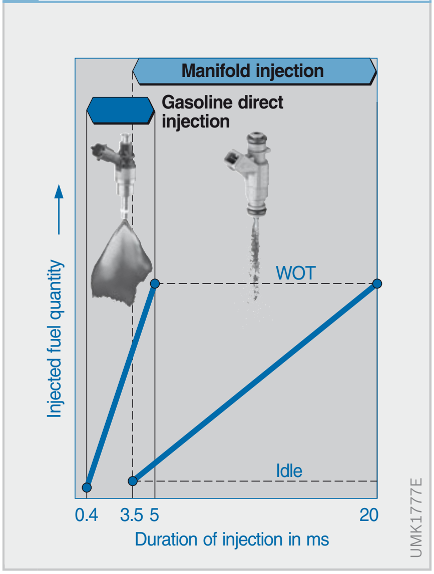
Actuation of HDEV high-pressure fuel injector

The high-pressure fuel injector must be actuated with a highly complex current curve in order to comply with the requirements for defined, reproducible fuel-injection processes (Fig. 8). The microcontroller in the engine ECU only delivers a digital triggering signal (a). An output module (ASIC) uses this signal to generate the triggering signal (b) for the fuel injector.

A DC/DC converter in the engine ECU generates the booster voltage of 65 V. This voltage is required in order to bring the current up to a high value as quickly as possible in the booster phase. This is necessary in order to accelerate the injector needle as quickly as possible. In the pickup phase (t_{pk}), the valve needle then achieves the maximum opening lift (c). When the fuel injector is open, a small control current (holding current) is sufficient to keep the fuel injector open.

With a constant valve-needle displacement, the injected fuel quantity is proportional to the injection duration (d).

7 Comparison between gasoline direct injection and manifold injection



8 Actuation of HDEV high-pressure fuel injector

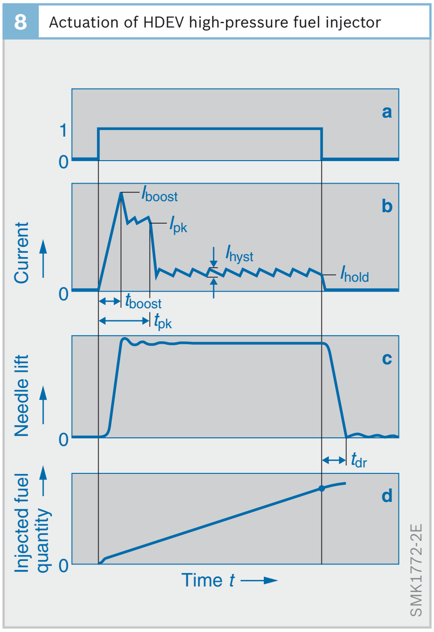


Fig. 7
Injected fuel quantity as a function of injection duration

Fig. 8
- a Triggering signal
- b Current curve in injector
- c Needle lift
- d Injected fuel quantity

Inductive ignition System

Ignition of the air-fuel mixture in the gasoline engine is electric; it is produced by generating a flashover between the electrodes on a spark plug. The ignition-coil energy converted in the spark ignites the compressed air-fuel mixture immediately adjacent to the spark plug, creating a flame front which then spreads to ignite the air-fuel mixture in the entire combustion chamber. The inductive ignition system generates in each power stroke the high voltage required for flashover and the spark duration required for ignition. The electrical energy drawn from the vehicle electrical system is temporarily stored in the ignition coil.

Design

Figure 9 shows the principle layout of the ignition circuit of an inductive ignition system. It comprises the following components:

- Ignition driver stage (4), which is integrated in the Motronic ECU or in the ignition coil
- Ignition coils (3)
- Spark plugs (5) and
- Connecting devices and interference suppressors

Generating the ignition spark

A magnetic field is built up in the ignition coil when a current flows in the primary circuit. The ignition energy required for ignition is stored in this magnetic field.

The current in the primary winding only gradually attains its setpoint value because of the induced countervoltage. Because the energy stored in the ignition coil is dependent on the current ($E = {}^1/_2LI^2$), a certain amount of time (dwell period) is required in order to store the energy necessary for ignition. This dwell period is dependent on, among others, the vehicle system voltage. The ECU program calculates from the dwell period and the moment of ignition the cut-in point, and cuts the ignition coil in via the ignition driver stage and out again at the moment of ignition.

Interrupting the coil current at the moment of ignition causes the magnetic field to collapse. This rapid magnetic-field change induces a high voltage (Fig. 10) on the secondary side of the ignition coil as a result of the large number of turns (turns ratio approx. 1:100). When the ignition voltage is reached, flashover occurs at the spark plug and the compressed air-fuel mixture is ignited.

9 Ignition circuit of an inductive ignition system

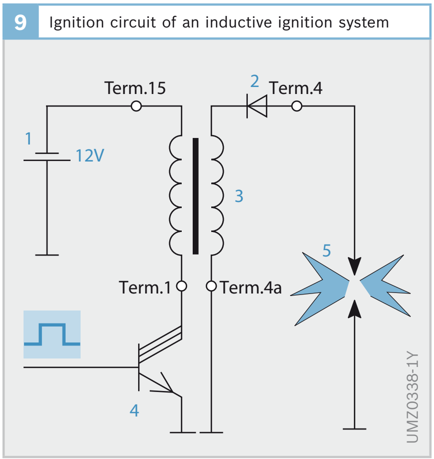


Fig. 9

1	Battery
2	AAS diode (integrated in ignition coil)
3	Ignition coil with iron core and primary and secondary windings
4	Ignition driver stage (integrated either in Motronic ECU or in ignition coil)
5	Spark plug

Term. 1, Term. 4, Term. 4a, Term. 15 Terminal designations

10 Voltage curve at the electrodes

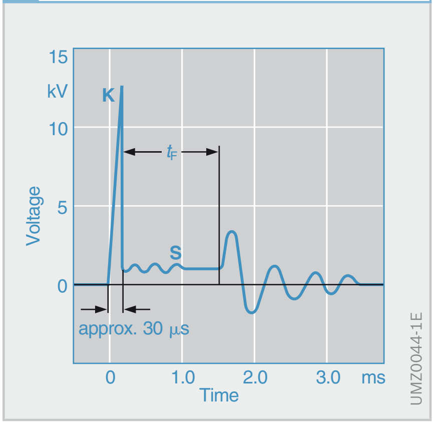


Fig. 10

K	Spark head
S	Spark tail
t_F	Spark duration

Flame-front propagation

After the flashover, the voltage at the spark plug drops to the spark voltage (Fig. 10). The spark voltage is dependent on the length of the spark plasma (electrode gap and deflection due to flow) and ranges between a few hundred volts and well over 1 kV. The ignition-coil energy is converted in the ignition spark during the combustion time; this ignition spark duration lasts from as little as 100 µs to over 2 ms. Following the breakaway of the spark, the damped voltage decays.

The electrical spark between the spark-plug electrodes generates a high-temperature plasma. When the air-fuel mixture at the spark plug is ignitable and sufficient energy input is supplied by the ignition system, the arc that is created develops into a self-propagating flame front.

Moment of ignition

The instant at which the ignition spark ignites the air-fuel mixture within the combustion chamber must be selected with extreme precision. This variable has a decisive influence on engine operation and determines the output torque, exhaust-gas emissions and fuel consumption.

The influencing variables that determine the moment of ignition are engine speed and engine load, or torque. Additional variables, such as, for example, engine temperature, are also used to determine the optimal moment of ignition. These variables are recorded by sensors and then relayed to the engine ECU (Motronic). The moment of ignition is calculated and the triggering signal for the ignition driver stage is generated from program maps and characteristic curves.

11 Schematic representation of ignition coils

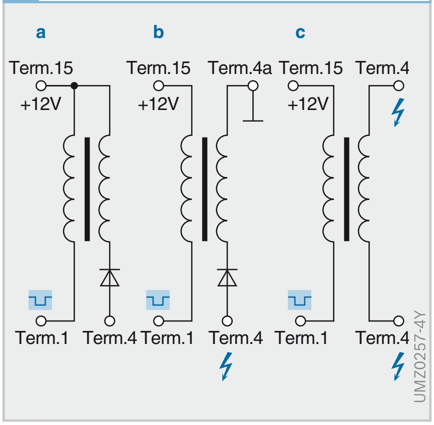


Fig. 11
- a Single-spark ignition coil in economy circuit
- b Single-spark ignition coil
- c Dual-spark ignition coil

Combustion knocks occur if the moment of ignition is too advanced. Permanent knocking may result in engine damage. For this reason, knock sensors are used to monitor combustion noise. After a combustion knock, the moment of ignition is delayed to too late and then slowly moved back to the pilot control value. This helps to counteract permanent knocking.

Voltage distribution

Voltage distribution takes place on the primary side of the ignition coils, which are directly connected to the spark plugs (static voltage distribution).

System with single-spark ignition coils

Each cylinder is allocated an ignition driver stage and an ignition coil (Figs. 11a and 11b). The engine ECU actuates the ignition driver stages in specified firing order. However, the system does also have to be synchronized with the camshaft by means of a camshaft sensor.

System with dual-spark ignition coils

One ignition driver stage and one ignition coil are allocated to every two cylinders (Fig. 11c). The ends of the secondary winding are each connected to a spark plug in different cylinders. The cylinders have been chosen so that when one cylinder is in the compression cycle, the other is in the exhaust cycle (only possible with engines with an even number of cylinders). It does not therefore need to be synchronized with the camshaft. Flashover occurs at both spark plugs at the moment of ignition.

Ignition coils

Compact ignition coil

Design

The compact coil's magnetic circuit consists of the O core and the I core (Fig. 12), onto which the primary and secondary windings are plugged. This arrangement is installed in the coil housing. The primary winding (I core wound in wire) is electrically and mechanically connected to the primary plug connection. Also connected is the start of the secondary winding (coil body wound in wire). The connection on the spark-plug side of the secondary winding is also located in the housing, and electrical contacting is established when the windings are fitted.

Integrated within the housing is the high-voltage contact dome. This contains the contact section for spark-plug contacting, and also a silicone jacket for insulating the high voltage from external components and the spark-plug well.

Following component assembly resin is vacuum-injected into the inside of the housing, where it is allowed to harden. This produces high mechanical strength, good protection from environmental influences and outstanding insulation of the high voltage. The silicone jacket is then pushed onto the high-voltage contact dome for permanent attachment.

Remote and COP versions

The ignition coil's compact dimensions make it possible to implement the design shown in Figure 12. This version is called COP (Coil On Plug). The ignition coil is mounted directly on the spark plug, thereby rendering additional high-voltage connecting cables superfluous. This reduces the capacitive load on the ignition coil's secondary circuit. The reduction in the number of components also increases operational reliability (no rodent bites in ignition cables, etc.).

In the less common remote version, the compact coils are mounted within the engine compartment using screws. Attachment lugs or an additional bracket are provided for this purpose. The high-voltage connection is effected by means of a high-voltage ignition cable from the ignition coil to the spark plug.

The COP and remote versions are virtually identical in design. However, the remote version (mounted on the vehicle body) is subject to fewer demands with regard to temperature and vibration conditions due to the fact that it is exposed to fewer loads and strains.

12 Compact-coil design

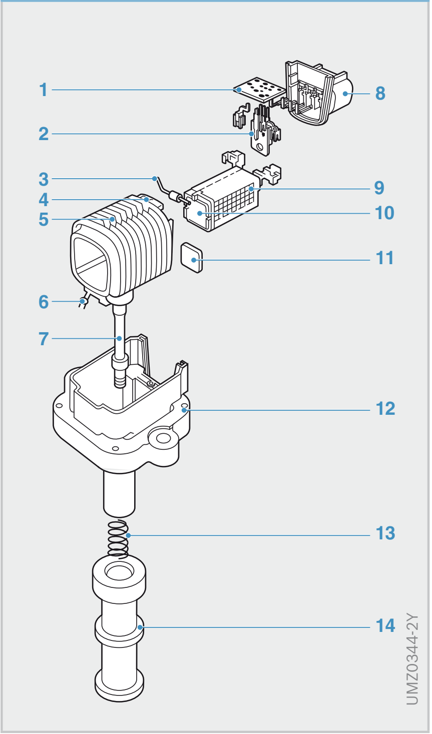


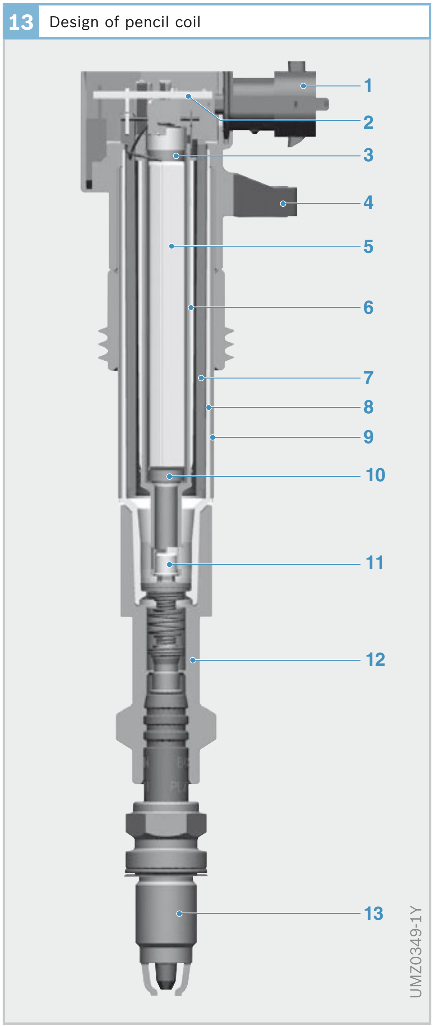
Fig. 12
1 Printed-circuit board
2 Ignition driver stage
3 AAS diode (activation arc suppression)
4 Secondary winding body
5 Secondary wire
6 Contact plate
7 High-voltage pin
8 Primary plug
9 Primary wire
10 I core
11 Permanent magnet
12 O core
13 Spring
14 Silicone jacket

Pencil coil

The pencil coil makes optimal use of the space available within the engine compartment. Its cylindrical shape makes it possible to use the spark plug well as a supplementary installation area for ideal space utilization on the cylinder head.

Because pencil coils are always mounted directly on the spark plug, no additional high-voltage connecting cables are required.

13 Design of pencil coil



Design and magnetic circuit

Pencil coils operate like compact coils in accordance with the inductive principle. However, the rotational symmetry results in a design structure that differs considerably from that of compact coils.

Although the magnetic circuit consists of the same materials, the central rod core (Fig. 13, Item 5) consists of laminations in various widths stacked in packs that are virtually circular. The yoke plate (9) that provides the magnetic circuit is a rolled and slotted sleeve – also in electrical sheet steel, sometimes in multiple layers.

Another difference relative to compact coils is the primary winding (7), which has a larger diameter and is above the secondary winding (6), while the body of the winding also supports the rod core. This arrangement brings significant benefits in the areas of design and operation. Owing to restrictions imposed by their geometrical configuration and compact dimensions, pencil coils allow only limited scope for varying the magnetic circuit (rod core, yoke plate) and windings.

In most pencil-coil applications, the limited space available dictates that permanent magnets be used to increase the spark energy.

The arrangements for electrical contact with the spark plug and for connection to the engine wiring harness are comparable with those used for compact pencil coils.

Fig. 13

1	Plug connection
2	Printed-circuit board with ignition driver stage
3	Permanent magnet
4	Attachment arm
5	Laminated electrical-sheet-steel core (rod core)
6	Secondary winding
7	Primary winding
8	Housing
9	Yoke plate
10	Permanent magnet
11	High-voltage dome
12	Silicone jacket
13	Attached spark plug

Electronic diesel control (EDC)

System overview

Electronic control of a diesel engine enables precise and differentiated modulation of fuel-injection parameters. This is the only means by which a modern diesel engine is able to satisfy the many demands placed upon it. Electronic diesel control (EDC) is subdivided into three system blocks: sensors/setpoint generators, ECU, and actuators.

Requirements

The lowering of fuel consumption and exhaust emissions (NO_X, CO, HC, particulates) combined with simultaneous improvement of engine power output and torque are the guiding principles of current development work on diesel-engine design. Conventional indirect-injection engines (IDI) were no longer able to satisfy these requirements.

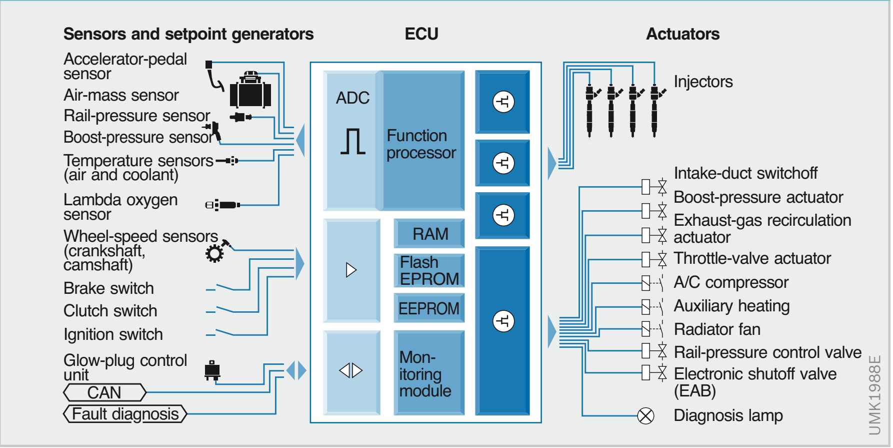
State-of-the-art technology is represented today by direct-injection diesel engines (DI) with high injection pressures for efficient mixture formation. The fuel-injection systems support several injection processes: pre-injection, main injection, and secondary injection. These injection processes are for the most part controlled electronically (pre-injection, however, is controlled mechanically on UIS for cars).

In addition, diesel-engine development has been influenced by the high levels of driving comfort and convenience demanded in modern cars. Exhaust and noise emissions are also subject to ever more stringent demands.

As a result, the performance demanded of the fuel-injection and management systems has also increased, specifically with regard to:

- High injection pressures
- Rate shaping
- Pre-injection and, if necessary, secondary injection
- Adaptation of injected fuel quantity, boost pressure and start of injection at the respective operating status
- Temperature-dependent excess-fuel quantity
- Load-independent idle speed control
- Controlled exhaust-gas recirculation
- Cruise control
- Tight tolerances for start of injection and injected-fuel quantity and maintenance of high precision over the service life of the system (long-term performance)
- Support of exhaust-gas treatment systems

1 EDC system blocks



Conventional mechanical RPM control uses a number of adjusting mechanisms to adapt to different engine operating statuses and ensures high-quality mixture formation. Nevertheless, it is restricted to a simple engine-based control loop and there are a number of important influencing variables that it cannot take account of or cannot respond quickly enough to.

As demands have increased, EDC has developed into a complex electronic engine-management system capable of processing large amounts of data in real time. In addition to its pure engine-management function, EDC supports a series of comfort and convenience functions (e.g. cruise control). It can form part of an overall electronic vehicle-speed control system ("drive-by-wire"). And as a result of the increasing integration of electronic components, complex electronics can be accommodated in a very small space.

Operating principle

Electronic diesel control (EDC) is capable of meeting the requirements listed above as a result of microcontroller performance that has improved considerably in the last few years.

In contrast to diesel-engine vehicles with conventional in-line or distributor injection pumps, the driver of an EDC-controlled vehicle has no direct influence, for instance through the accelerator pedal and Bowden cable, upon the injected fuel quantity. Instead, the injected fuel quantity is determined by a number of influencing variables. These include:

- Driver command (accelerator-pedal position)
- Operating status
- Engine temperature
- Interventions by other systems (e.g. TCS)
- Effects on exhaust emissions, etc.

The ECU calculates the injected fuel quantity on the basis of all these influencing variables. Start of injection can also be varied. This requires a comprehensive monitoring concept that detects inconsistencies and initiates appropriate actions in accordance with the effects (e.g. torque limitation or limp-home mode in the idle-speed range). EDC therefore incorporates a number of control loops.

Electronic diesel control allows data communication with other electronic systems, such as the traction-control system (TCS), electronic transmission control (ETC), or electronic stability program (ESP). As a result, the engine-management system can be integrated in the vehicle's overall control system, thereby enabling functions such as reduction of engine torque when the automatic transmission changes gear, regulation of engine torque to compensate for wheel slip, etc.

The EDC system is fully integrated in the vehicle's diagnosis system. It meets all OBD (On-Board Diagnosis) and EOBD (European OBD) requirements.

System blocks

Electronic diesel control (EDC) is divided into three system blocks (Fig. 1):

1. *Sensors and setpoint generators* detect operating conditions (e.g. engine speed) and setpoint values (e.g. switch position). They convert physical variables into electrical signals.

2. The *ECU* processes the information from the sensors and setpoint generators in mathematical computing processes (open- and closed-loop control algorithms). It controls the actuators by means of electrical output signals. In addition, the ECU acts as an interface to other systems and to the vehicle diagnosis system.

3. *Actuator*s convert the electrical output signals from the ECU into mechanical variables (e.g. solenoid-valve needle lift).

Data processing

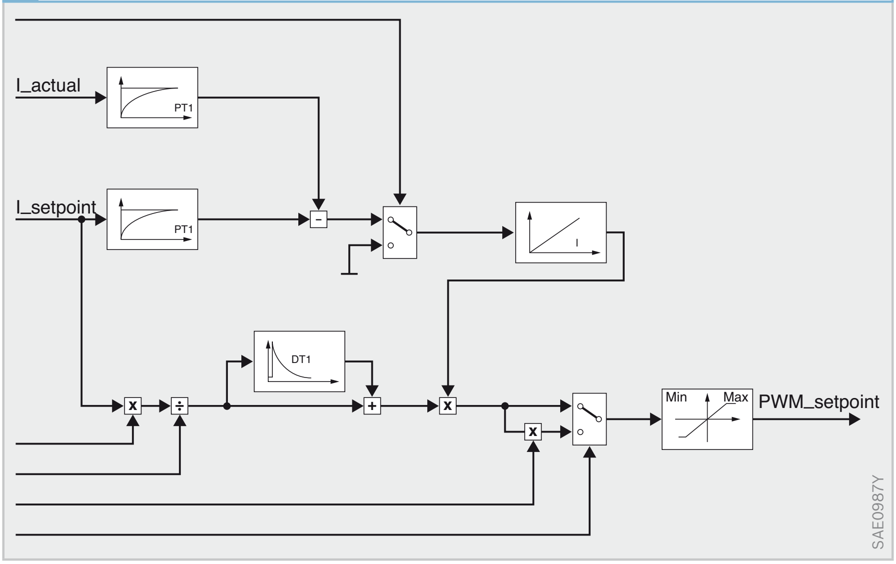
The main function of the electronic diesel control (EDC) is to control the injected fuel quantity and the injection timing. The common-rail accumulator injection system also controls injection pressure. Furthermore, on all systems, the engine ECU controls a number of actuators. The EDC functions must be matched to every vehicle and every engine. This is the only way to optimize component interaction (Fig. 3).

The control unit evaluates the signals sent by the sensors and limits them to the permitted voltage level. Some input signals are also checked for plausibility. Using this input data together with stored program maps, the microprocessor calculates the position and duration for injection timing. This information is then converted to a signal characteristic which is aligned to the engine's piston strokes. This calculation program is termed the "ECU software".

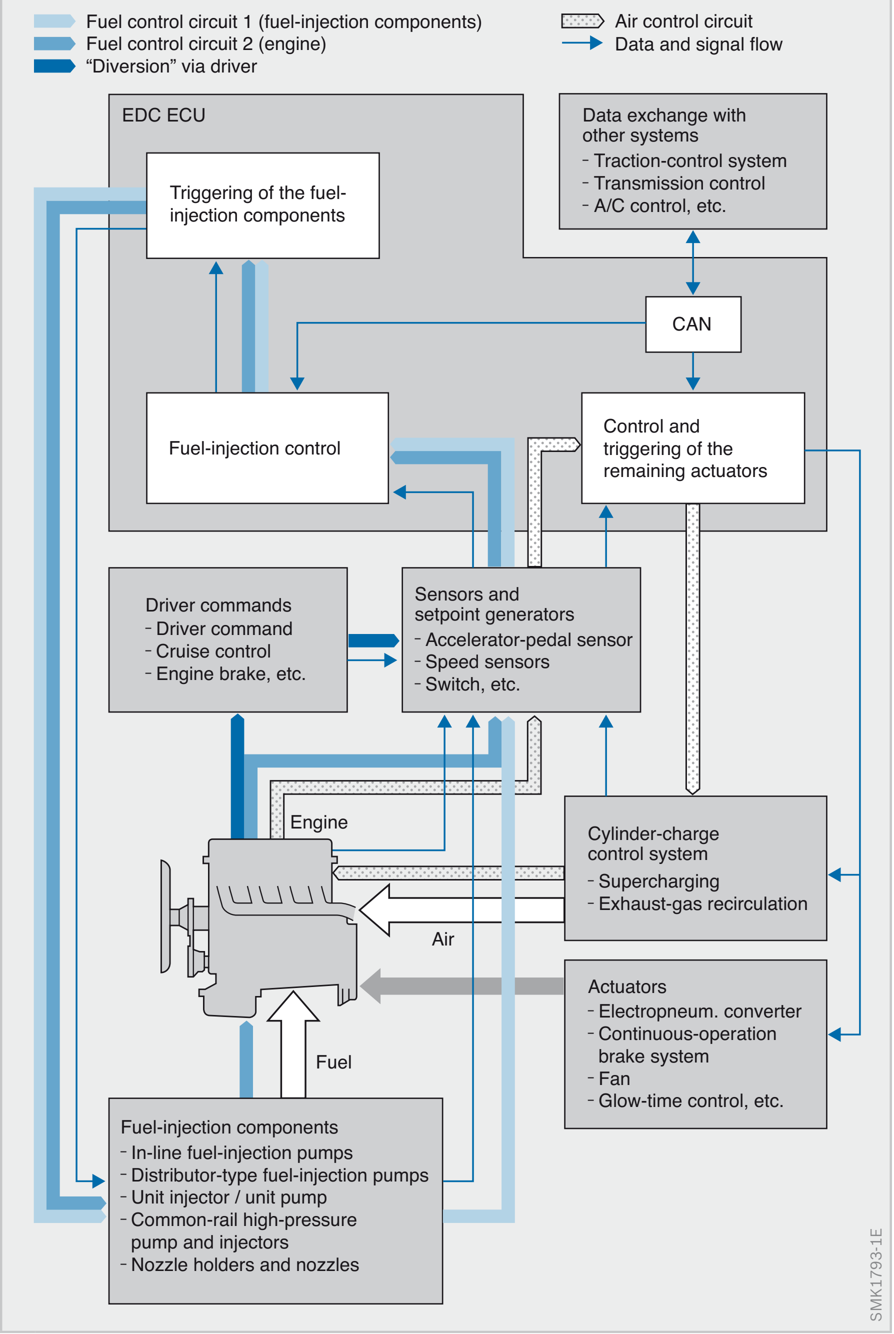
The required degree of accuracy together with the diesel engine's outstanding dynamic response requires high-level computing power. The output signals are applied to driver stages which provide adequate power for the actuators (for instance, the high-pressure solenoid valves for fuel injection, exhaust-gas recirculation positioner, or boost-pressure actuator). Apart from this, a number of other auxiliary-function components (e.g. glow relay and air-conditioning system) are triggered.

The driver-stage diagnosis functions for the solenoid valves also detect faulty signal characteristics. Furthermore, signals are exchanged with other systems in the vehicle via the interfaces. The engine ECU monitors the complete fuel-injection system as part of a safety strategy.

2 Schematic using the example of a current regulator



3 Basic sequence of electronic diesel control



Fuel-injection control

Table 1 provides an overview of the EDC functions which are implemented in the various fuel-injection systems. Figure 4 shows the sequence of fuel-injection calculations with all functions, a number of which are optional extras. These can be activated in the ECU by the after-sales service when retrofit equipment is installed.

In order that the engine can run with optimal combustion under all operating conditions, the ECU calculates exactly the right injected fuel quantity for all conditions. Here, a number of parameters must be taken into account. On a number of solenoid-valve-controlled distributor-type injection pumps, the solenoid valves for injected fuel quantity and start of injection are triggered by a separate pump ECU.

1 Overview of functions of EDC variants for motor vehicles

Fuel-injection system	**In-line fuel-injection pumps PE**	**Helix-controlled distributor-type injection pumps VE-EDC**	**Solenoid-valve-controlled distributor injection pumps VE-M, VR-M**	**Unit injector system and unit pump system UIS, UPS**	**Common-rail system CR**
Function					
Injected-fuel-quantity limit	●	●	●	●	●
External torque intervention	● 3)	●	●	●	●
Driving-speed limitation	● 3)	●	●	●	●
Cruise control	●	●	●	●	●
Altitude correction	●	●	●	●	●
Boost-pressure control	●	●	●	●	●
Idle-speed regulation	●	●	●	●	●
Intermediate-speed regulation	● 3)	●	●	●	●
Active surge damping	● 2)	●	●	●	●
BIP control	–	–	●	●	–
Intake-port shutoff	–	–	●	● 2)	●
Electronic immobilizer	● 2)	●	●	●	●
Controlled pre-injection	–	–	●	● 2)	●
Glow control unit	● 2)	●	●	● 2)	●
A/C switch-off	● 2)	●	●	●	●
Auxiliary coolant heating	● 2)	●	●	● 2)	●
Smooth-running control	● 2)	●	●	●	●
Fuel-balancing control	● 2)	–	●	●	●
Fan activation	–	●	●	●	●
EGR control	● 2)	●	●	●	●
Start-of-injection control with sensor	● 1) 3)	●	●	●	●
Cylinder shutoff	–	–	● 3)	● 3)	● 3)
Increment-angle learning	–	–	–	●	●
Increment-angle rounding	–	–	–	● 2)	–

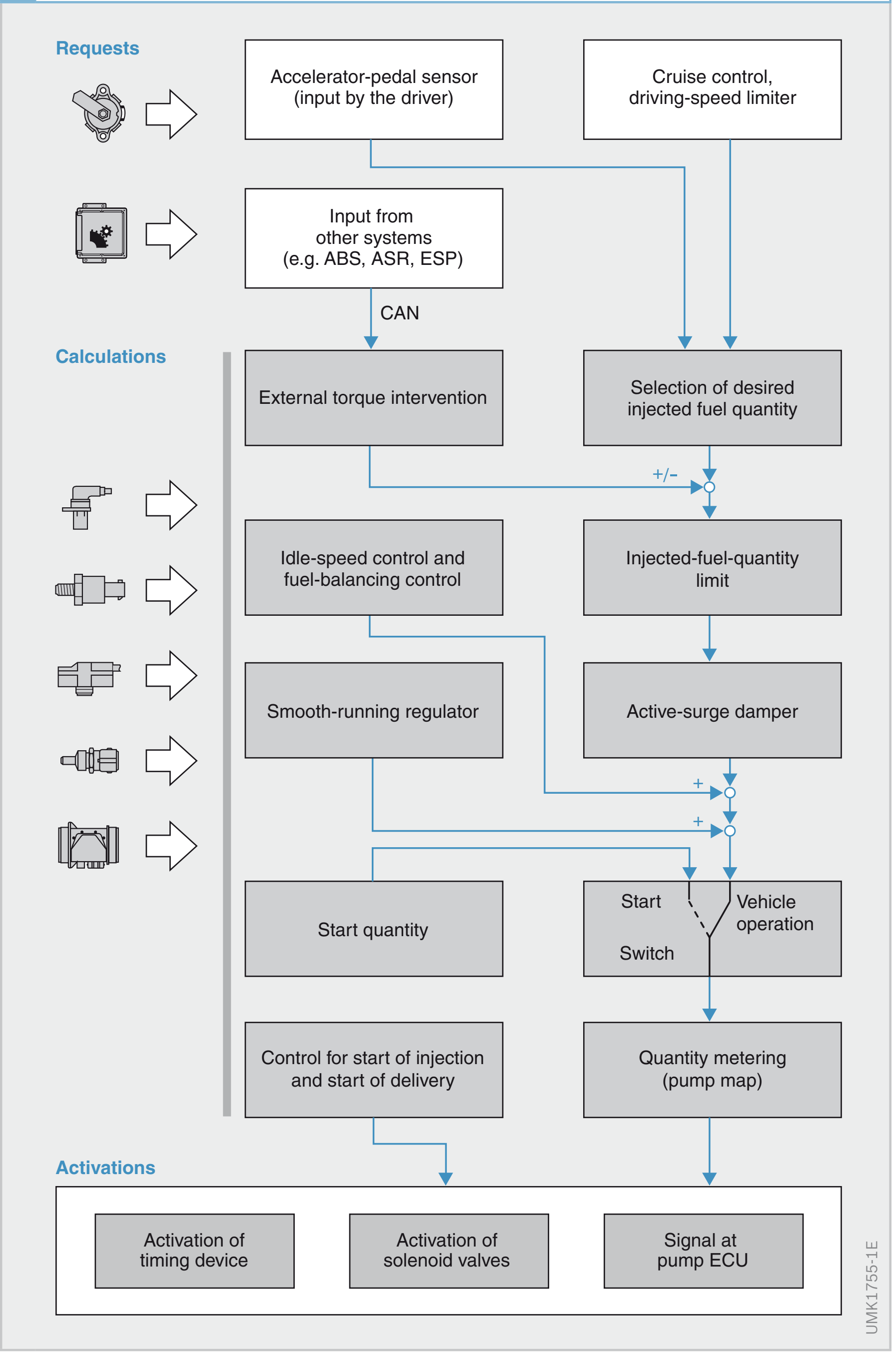
Table 1

1) Control-sleeve in-line fuel-injection pumps

2) Cars only

3) Commercial vehicles only

4 Calculation of fuel-injection process in ECU



Torque-controlled EDC systems

The engine-management system is continually being integrated more closely into the overall vehicle system. Vehicle-dynamics systems (e.g. TCS), comfort and convenience systems (e.g. cruise control/Tempomat), and transmission control influence electronic diesel control (EDC) via the CAN bus. Apart from this, much of the information registered or calculated in the engine-management system must be passed on to other ECUs via the CAN bus.

In order to be able to incorporate EDC even more efficiently in a functional alliance with other ECUs, and implement other changes rapidly and effectively, it was necessary to make radical changes to the newest-generation controls. These changes resulted in torque-controlled EDC, which was introduced with the EDC16. The main feature is the changeover of the module interfaces to the parameters as commonly encountered in practice in the vehicle.

Engine characteristics

Essentially, an engine's output can be defined using the three characteristics: power P, engine speed n, and torque M.

Figure 5 compares typical curves of torque and power as a function of the engine speed of two diesel engines. Basically speaking, the following formula applies:

$$P = 2 \cdot \pi \cdot n \cdot M$$

It is sufficient therefore, for example, to specify the torque as the reference variable while taking into account the engine speed. Engine power then results from the above formula. Since power output cannot be measured directly, torque has turned out to be a suitable reference variable for engine management.

Torque control

When accelerating, the driver uses the accelerator-pedal (sensor) to directly demand a given torque from the engine. Independently of the driver's requirements, other external vehicle systems submit torque demands via the interfaces resulting from the power requirements of the particular component (e.g. air-conditioning system, alternator). Using these torque-requirement inputs, the engine-management system calculates the output engine torque to be generated and controls the fuel-injection and air-system actuators accordingly. This has the following advantages:

- No system has a direct influence on engine management (boost pressure, fuel injection, preglow). The engine management system can thus also take into account other higher-level optimization criteria for the external requirements (e.g. exhaust-gas emissions, fuel consumption) and then control the engine in the best way possible.
- Many of the functions which do not directly concern the engine management system can be designed to function identically for diesel and gasoline engines.
- Expansions to the system can be implemented quickly.

5 Example of the torque and power-output curves as a function of engine speed for two car diesel engines with approx. 2.2 *l* engine displacement

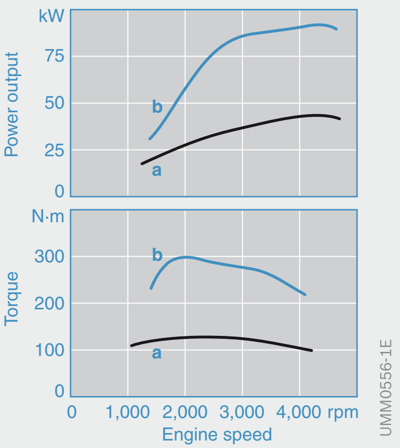


Fig. 5
a Build year 1968
b Build year 1998

Sequence of engine management

The setpoint values are processed further in the engine ECU. In order to fulfill their assignments efficiently, the engine management system's control functions all require a wide range of sensor signals and information from other ECUs in the vehicle.

Propulsion torque

The driver's input (i.e. the signal from the accelerator-pedal sensor) is interpreted by the engine management system as the request for a propulsion torque. The inputs from the cruise control and the vehicle-speed limiter are processed in exactly the same manner.

Following this selection of the desired propulsive torque, should the situation arise, the vehicle-dynamics system (TCS, ESP) increases the desired torque value when there is the danger of wheel lockup and decreases it when the wheels show a tendency to spin.

Further external torque demands

The drivetrain's torque adaptation must be taken into account (drivetrain transmission ratio). This is defined for the most part by the ratio of the particular gear, or by the torque-converter efficiency in the case of automatic transmissions. On vehicles with an automatic transmission, the transmission control stipulates the torque demand during the gearshift. This is reduced in order to produce a comfortable, smooth gearshift, thus protecting the engine. In addition, the torque required by other engine-powered auxiliary systems (e.g. air-conditioning compressor, alternator, servo pump) is determined. This torque demand is calculated either by the auxiliary systems themselves or by the engine management system. Calculation is based on the required power and engine speed, and the engine management system adds up the various torque requirements.

The vehicle's driveability remains unchanged notwithstanding varying requirements from the auxiliary systems and changes in the engine's operating states.

Internal torque demands

At this stage, the idle-speed control and the active surge damper intervene.

For instance, if demanded by the situation, in order to prevent mechanical damage, or excessive smoke due to the injection of too much fuel, the torque limitation reduces the internal torque demand. In contrast to previous engine-management systems, limitations are no longer only applied to the injected fuel quantity, but instead, depending on the required effects, also to the particular physical quantity involved.

The engine's losses are also taken into account (e.g. friction, drive for the high-pressure pump). The torque represents the engine's measurable effects to the outside. However, the engine management system can only generate these effects in conjunction with the correct fuel injection together with the correct injection point, and the necessary marginal conditions as apply to the air system (e.g. boost pressure and exhaust-gas recirculation rate). The required injected fuel quantity is determined using the current combustion efficiency. The calculated fuel quantity is limited by a protective function (e.g. protection against overheating), and if necessary can be varied by smooth-running control. During engine start, the injected fuel quantity is not determined by external inputs such as those from the driver, but rather by the separate "start quantity" control function.

Actuator triggering

The resulting setpoint value for the injected fuel quantity is used to generate the triggering data for the injection pumps and/or the fuel injectors, and for defining the optimum operating point for the intake-air system.

Lighting technology

Automotive light sources

The most important light sources for the lighting systems on the vehicle front and rear are halogen lamps, bulbs, gas-discharge lamps and LEDs.

Thermal radiators

Thermal radiators generate light from heat energy. The major liability of the thermal radiator is its low working efficiency (below 10 %) which, relative to the gas-discharge lamp, leads to very low potential for luminous efficiency.

Incandescent (vacuum) bulb

Among the thermal radiators is the bulb (Fig. 1) whose tungsten filament (2) is enclosed by glass (1). A vacuum is created inside the glass, which is why the incandescent bulb is also known as a vacuum bulb.

At 10 to 18 lm/W (lumen/Watt), the luminous efficiency of an incandescent bulb is comparatively low. During bulb operation, the tungsten particles of the filament vaporize. The glass consequently darkens over the course of the bulb's service life. The vaporization of the particles ultimately leads to the filament breaking and thus failure of the lamp. For this reason, incandescent bulbs as light sources for the headlamps have been replaced by halogen lamps. For cost reasons, however, incandescent bulbs continue to be used for other lights and as light sources in the passenger compartment. Even the lighting of passive display elements (e.g. fan, heating and air-conditioning controllers, LCD displays) is generally performed by incandescent bulbs, the color of which is changed by means of color filters for the application and design concerned.

Halogen lamp

There are two types of halogen lamp: with one or two tungsten filaments. The halogen lamps H1, H3, H7, HB3 and HB4 (see table at the end of the chapter) only have one filament. They are used as light sources for the low-beam, high-beam and fog lights.

The bulb is made of quartz glass. The quartz glass filters out the low UV content of the beam that halogen lamps emit. Unlike an incandescent bulb, the glass of a halogen lamp contains a halogen charge (iodine or bromine). This makes it possible for the filament to heat up to temperatures approaching tungsten's melting point (around 3,400 °C), thereby achieving commensurately high levels of luminous power.

1 Incandescent bulb

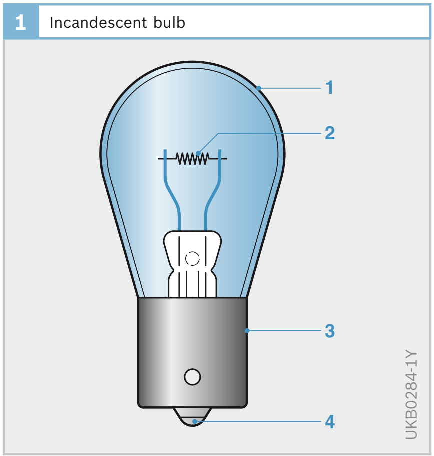


Fig. 1
1 Glass bulb
2 Filament
3 Lamp socket base
4 Electrical connection

2 H4 halogen lamp (detail from Fig. 3)

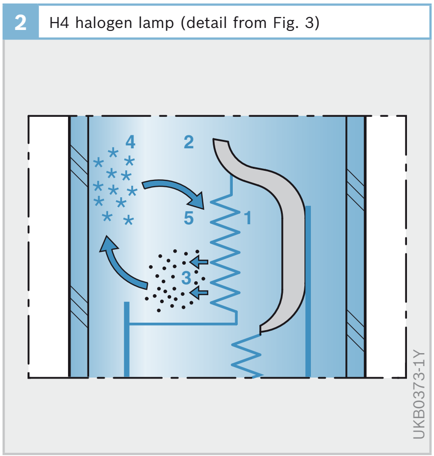


Fig. 2
1 Tungsten filament
2 Halogen charge (iodine or bromine)
3 Evaporated tungsten
4 Halogenated tungsten
5 Tungsten deposits

Close to the hot bulb wall, vaporized tungsten particles combine with the filler gas to form a transparent gas (tungsten halide). This is stable within a temperature range of approximately 200 to 1,400 °C. Tungsten particles re-approaching the filament respond to the high temperatures at the filament by dispersing to form a consistent tungsten layer. This cycle (Fig. 2) limits the wear rate of the filament. In order to maintain this cycle, an external bulb temperature of approx. 300 °C is necessary. The glass therefore encloses the filament tightly. It remains clear throughout the entire service life of the lamp.

The rate of filament wear is also limited by the high pressure that is generated in the bulb, limiting the vaporization rate of the tungsten.

The H4 halogen lamp generates the light beam in the same way but has two filaments (Fig. 3, Items 2 and 3). This means that only one lamp is required for each low-beam and high-beam headlamp.

The lower part of the low-beam filament is masked by a screen integrated in the headlamp. As a result, the light is only emitted into the upper part of the reflector (Fig. 8) and thereby prevents dazzling other road users.

Switching from low beam to high beam activates the second filament. Halogen lamps with an output of 60/55 W1) emit around twice as much light as incandescent bulbs with an output of 45/40 W. The high luminous efficiency of around 22 to 26 lm/W is primarily the result of the high filament temperature.

3 H4 halogen lamp

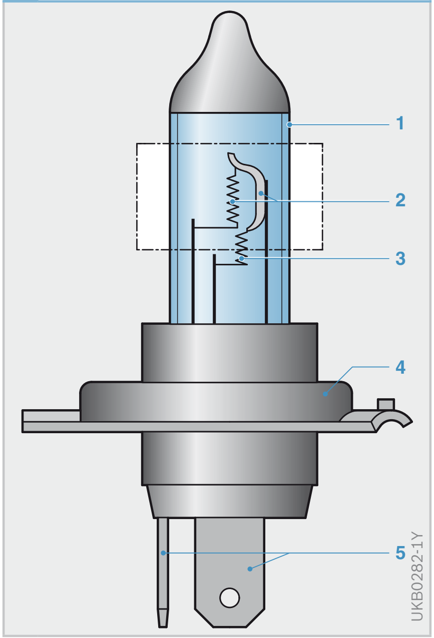


Fig. 3
1 Glass bulb
2 Low-beam filament with cap
3 High-beam filament
4 Lamp base
5 Electrical connection

Gas-discharge lamps

Gas discharge describes the electrical discharge that occurs when an electrical current flows through a gas and causes it to emit radiation (examples: sodium-vapor lamps for street lighting and fluorescent lamps for interior lighting).

The discharge chamber of the gas-discharge lamp (Fig. 4, Item 3) is filled with the inert gas xenon and a mixture of metal halides. The electrical voltage is applied between two electrodes (4) protruding into the bulb. An electronic ballast unit is required for switching on and operation. Application of an ignition voltage in the 10 to 20 kV range ionizes the gas between the electrodes, producing an electrically conductive path in the form of a luminous arc. With the alternating current (400 Hz) applied, the metallic charge is vaporized due to the temperature increase inside the bulb and light is radiated.

Under normal circumstances the lamp requires several seconds to ionize all of the particles and generate full illumination. To accelerate this process, an increased starting current flows until this point.

---

1) High beam/low beam

When maximum luminous power is achieved, limitation of lamp current commences. A sustained operating voltage of only 85 V is sufficient to maintain the arc.

Light sources relying on the gas-discharge concept acquired new significance for automotive applications with the advent of the “Litronic” electronic lighting system. This concept features several crucial benefits compared with conventional bulbs:

- Greater range of the headlamp beam
- Brighter and more even carriageway illumination
- Longer service life, as there is no mechanical wear
- High luminous efficiency (approximately 85 lm/W) due to the emission spectrum being predominately in the visible spectral range
- Improved efficiency thanks to lower thermal losses
- Compact headlamp designs for smooth front-end styling

The D2/D4-series automotive gas-discharge lamps feature high-voltage-proof sockets and UV glass shielding elements. On the D1/D3-series models, the high-voltage electronics necessary for operation are also integrated in the lamp socket. All series can be broken down into two subcategories:

- Standard lamp (S lamp) for projection headlamps (Fig. 4) and
- Reflection lamp (R lamp) for reflection headlamps (Fig. 5). They have an integrated shutter (3) to create the light-dark cutoff, comparable with the shutter in the H4 lamp.

Until now, gas-discharge lamps with the type designations D1x and D2x were used. From 2007, the D3/D4-series will also be fitted as standard. These have a lower operating voltage, a different charge gas composition, and different arc geometries.

4 D2S gas-discharge lamp

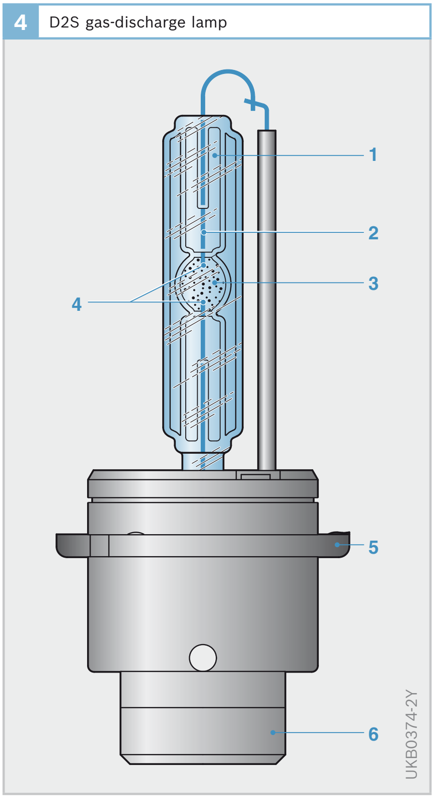


Fig. 4
Gas-discharge lamp for projection headlamps
1 Glass capsule with UV shield
2 Electrical lead
3 Discharge chamber
4 Electrodes
5 Lamp base
6 Electrical connection

5 D2R gas-discharge lamp

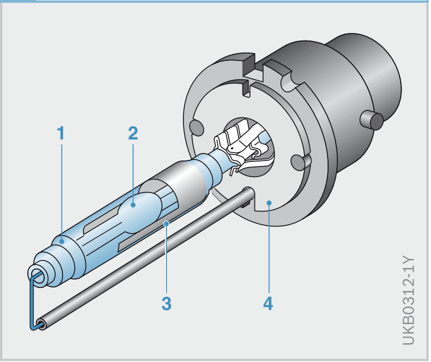


Fig. 5
Gas-discharge lamp for reflection headlamps
1 UV inert-gas bulb
2 Discharge chamber
3 Shutter
4 Lamp base

Light emitting diodes

The light emitting diode (LED) is an active light element. If an electrical voltage is applied, current flows through the chip. The electrons of the atoms of the LED chip are highly energized by the voltage. As light is emitted, they return to their initial state of low energy charge.

The 0.1 to 1 mm small semiconductor crystal is seated on a reflector that directs the light with pin-point precision.

LEDs are commonly used as light sources for lights on the rear of the vehicle, especially the additional stop lamps located in the center. They make it possible for a narrow, linear beam to be emitted.

By comparison with incandescent bulbs, LEDs are beneficial in that they emit maximum output in less than a millisecond. An incandescent bulb takes approximately 200 ms. LEDs, for example, are therefore able to emit the brake signal sooner and thus shorten the response time to the brake signal (brake pedal depressed) for drivers behind.

In the motor vehicle, LEDs are used as illuminators or in displays, in the interior they are used for lighting, in displays or display backlighting. In the lighting system, they find use as auxiliary stop lamps and tail lamps, and, increasingly in future, as daytime running lamps and in headlamps.

▶ Technical lighting variables

Luminous intensity
The brightness of light sources can vary. Luminous intensity serves as an index for comparing them. It is the visible light radiation that a light source projects in a specific direction.

The unit for defining levels of luminous intensity is the candela (cd), roughly equivalent to the illumination emitted by one candle. The brightness of an illuminated surface varies according to its reflective properties, the luminous intensity and the distance separating it from the light source.

Examples of permissible values
Stop lamp (individual): 60 to 185 cd
Tail lamp (individual): 4 to 12 cd
Rear fog lamp (individual): 150 to 300 cd
High beam (total, maximum): 225,000 cd

Luminous flux
Luminous flux is that light emitted by a light source that falls within the visible wavelength range.
Values are expressed in lumen (lm).

Illuminance
The illuminance is the luminous flux arriving at a given surface. It increases proportionally along with the light intensity, and decreases with the square of the distance.

Illuminance is expressed in lux (lx):
$1 \text{ lx} = 1 \text{ lm/m}^2$

Range
The range is defined as the distance at which the illuminance in the light beam still has a given value (e.g. 1 lx). The geometric range is the distance at which the horizontal part of the light-dark cutoff is shown on the road surface with the headlamps on low beam.

Main headlamps (Europe)

Function

On the one hand, the main headlamps must provide maximum visual range while at the same time ensuring that the glare effect for oncoming traffic is kept to a minimum and that light distribution immediately in front of the vehicle remains in line with the requirements of safe operation. It is vital to provide the lateral illumination needed to safely negotiate bends, i.e. the light must extend outward to embrace the verge of the road. Although it is impossible to achieve absolutely consistent luminance across the entire road surface, it is possible to avoid sharp contrasts in light density.

High beam

The high beam is usually generated by a light source located at the reflector's focal point, causing the light to be reflected outward along a plane extending along the reflector's axis (Fig. 7). The maximum luminous intensity which is available during high-beam operation is largely a function of the reflector's mirrored surface area.

In four and six-headlamp systems, in particular, purely parabolic high-beam reflectors can be replaced by units with complex geometrical configurations for simultaneous use of high and low beams.

7 High beam (beam projection)

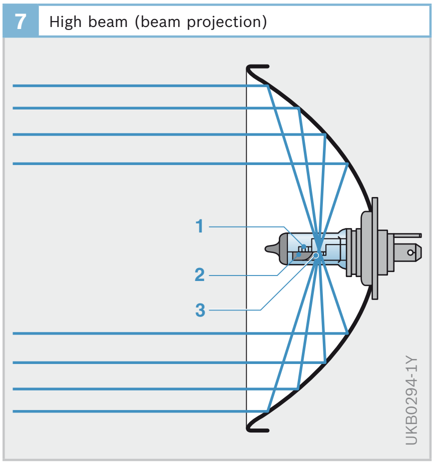


Fig. 7
1 Low-beam filament
2 Cap
3 High-beam filament at focal point

In these systems the high-beam component is designed to join with the low beam (simultaneous operation) to produce a harmonious overall high-beam distribution pattern. This strategy abolishes the annoying overlapping sector that would otherwise be present at the front of the light pattern.

Low beam (dipped beam)

The high traffic density on modern roads severely restricts the use of high-beam headlamps. The low beams serve as the primary source of light under normal conditions. Basic design modifications implemented within recent years are behind the substantial improvements in low-beam performance. Developments have included:

- Introduction of the asymmetrical low-beam pattern, characterized (RHD traffic) by an extended visual range along the right side of the road.
- Introduction of new headlamp systems featuring complex geometrical configurations (PES[1], free-form surfaces[2], facetted reflectors[3]) offering efficiency-level improvements of up to 50 %.
- Headlamp leveling control (also known as vertical aim control) devices adapt the attitude of the headlamps to avoid dazzling oncoming traffic when the rear

8 Low beam (beam projection)

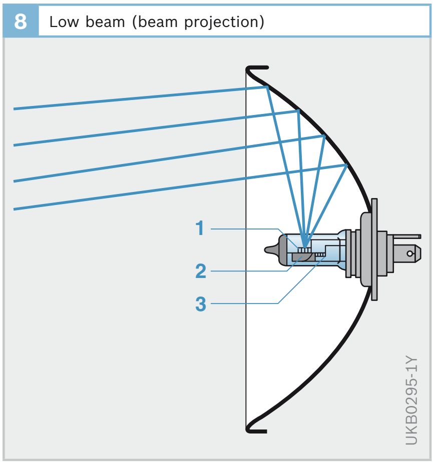


Fig. 8
1 Low-beam filament
2 Cap
3 High-beam filament

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[1] The PES (Poly-Ellipsoid System) headlamp system works with an imaging optical lens. Unlike with conventional headlamps, the light pattern generated by the reflector is reproduced on the roadway by the lens together with a screen for creating the light-dark cutoff.

[2] Reflectors with small short focal length whose shape is calculated using special programs (CAL: Computer Aided Lighting). In this way, three separate reflectors for low beam, high beam and fog lamp can be accommodated within the same space needed by a conventional parabolic reflector, while luminous efficiency is increased at the same time.

[3] With facetted reflectors, the surface is divided into individually optimized segments. This results in reflector surfaces with high levels of homogeneity and sideways beam spread.

of the vehicle is heavily laden. Vehicles must also be equipped with headlamp washer systems.

- "Litronic" gas-discharge lamps supply more than twice as much light as conventional halogen lamps.

Operating concept

Low-beam headlamps need a light-dark cutoff in the light pattern. In the case of H4 halogen headlamps and Litronic headlamps with D2R bulbs, this is achieved by the image from the shield (H4) or the shutter (D2R). On headlamps for all-round use (H1-, H7-, HB11 bulbs), the light-dark cutoff is achieved by the special imaging of the filament.

Headlamp systems

Dual-headlamp systems rely on a single shared reflector for low- and high-beam operation, e.g. in combination with a dual-filament H4 bulb (Fig. 9 a).

In quad headlamp systems one pair of headlamps may be switched on in both modes or during low-beam operation only, while the other pair is operated exclusively for high-beam use (Fig. 9 b).

9 Headlamp systems

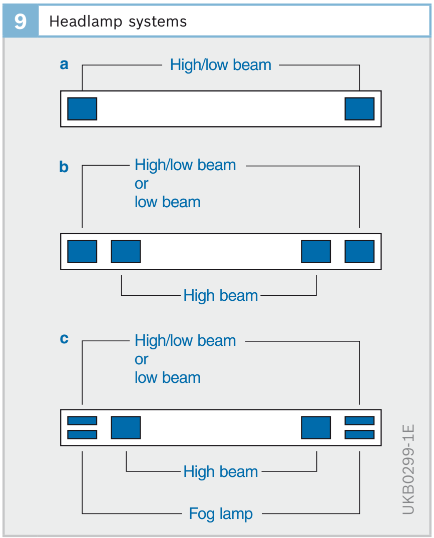


Fig. 9
a Dual-headlamp system
b Quad-headlamp system
c Six-headlamp system

Six-headlamp systems differ from the quad configuration by incorporating a supplementary fog lamp within the main headlamp assembly (Fig. 9 c).

Main headlamps (North America)

High beam

The designs for high-beam headlamps are the same as in Europe. Facetted reflectors with, for example, HB5 or H7 lamps are used.

Low beam (dipped beam)

Headlamps with a light-dark cutoff that rely on visual/optical adjustment procedures have been approved in the USA since 1 May, 1997. This has made it possible to equip vehicles for Europe and the USA with headlamps of the same type and, in some cases, even the same reflectors.

Regulations

The regulations for the attachment and wiring of main headlamps are comparable with the European regulations (Federal Motor Vehicle Safety Standard [FMVSS] No. 108 and SAE Ground Vehicle Lighting Standards Manual).

An amendment to FMVSS 108 that entered effect in 1983 made it possible to start using headlamp units of various shapes and sizes with replaceable bulbs. These were known as the RBH, or Replaceable Bulb Headlamps.

Headlamp systems

North America mirrors European practice in employing dual, quad and six-headlamp systems.

Litronic

Overview

The “Litronic” (Light-Electronics) headlamp system uses xenon gas-discharge lamps that produce a powerful lighting effect despite the low front-end surface area requirement. The illumination of the carriageway represents a substantial improvement over that provided by conventional halogen units (Fig. 10).

The light generated contains a higher proportion of green and blue and is thus more similar to the spectral distribution of sunlight. Night-time driving is therefore less exacting for the driver.

Design

The components of the Litronic headlamp system are:

- Optical unit with xenon gas-discharge lamp (S lamp, R lamp; see “Gas-discharge lamps” section)
- Electronic ballast unit with igniter and ECU

10 Light pattern on the road (comparison)

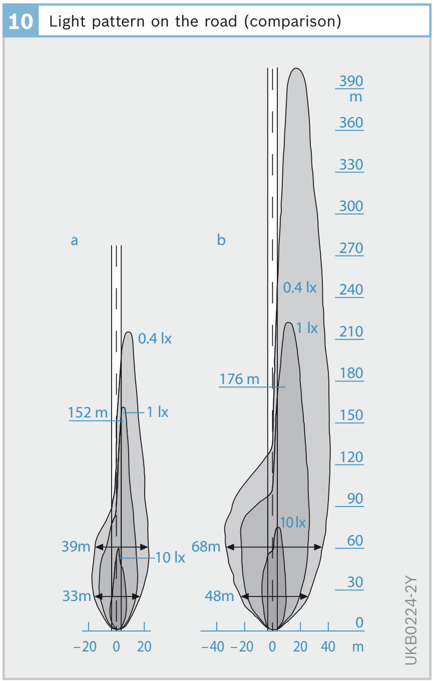


Fig. 10
a H4 lamp
b Litronic PES D2S lamp

For low beam, the headlamps with xenon gas-discharge lamps are installed in a quad system that is combined with the high-beam headlamps of the conventional design.

With the Bi-Litronic system, however, the low and high beams are generated by only one gas-discharge lamp from a dual-headlamp system.

An integral part of the headlamp is the electronic ballast unit responsible for activating and monitoring the lamp. Its functions include:

- Ignition of the gas discharge (voltage 10 to 20 kV)
- Regulated power supply during the warm-up phase when the lamp is cold
- Demand-oriented supply in continuous operation

The control units for the individual lamp types are generally developed for a specific design type and are not universally interchangeable.

Operating principle

In the gas-discharge lamp, the arc is ignited when the light is switched on. A high voltage of 18 to 20 kV is required for this to be possible. 85 V are required to maintain the arc after ignition. The voltage is generated and regulated by an electronic

11 Electronic ballast unit

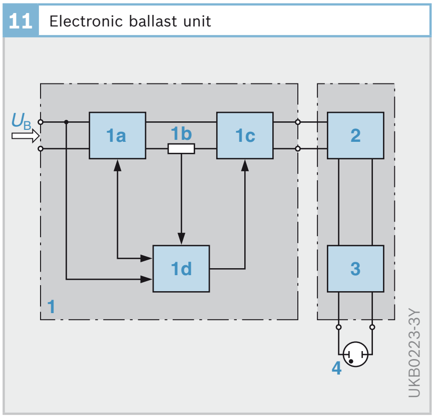


Fig. 11
Electronic ballast unit for 400 Hz alternating current supply and pulse ignition of the lamp

1 Control unit
1a DC/DC converter
1b Shunt
1c DC/AC converter
1d Microprocessor
2 Igniter
3 Lamp socket
4 D2S lamp
U_B Battery voltage

ballast unit (igniter, Fig. 11). After ignition, the gas-discharge lamp is operated for approximately 3 secs with an elevated starting current (approximately 2.6 A) so that it achieves maximum luminosity with minimal delay. The bulb’s output in this period is anywhere up to 75 W. During continuous-running operation, it is 35 W.

The maximum luminous efficiency of approximately 90 lm/W is achieved once the plasma has heated the quartz glass to approximately 900 °C. Once the gas-discharge lamp has achieved maximum luminosity, the ballast unit reduces the current output to the bulb to approximately 0.4 A for continuous-running operation.

Fluctuations in the vehicle system voltage are for the most part compensated for by the ballast unit to prevent luminous flux variations. If the bulb goes out, e.g. due to an extreme voltage drop (below 9 V) or increase (above 16.5 V) in the vehicle electrical system, it is automatically reignited without delay. The reignition is limited to five attempts for safety reasons. The power supply is then interrupted by the ballast unit.

Bi-Litronic “Reflection”
The “Reflection” Bi-Litronic system makes it possible to generate the low and high beams using only one gas-discharge lamp (DR2 lamp) from a dual-headlamp system. The concept relies on an electromechanical positioner that responds to the high/low-beam switch by varying the attitude of the gas-discharge lamp within the reflector. It alternates between two different positions to generate separate projection patterns for low and high beam (Fig. 12).

This layout gives Bi-Litronic the following major advantages:

- Xenon light for high-beam operation
- Visual guidance provided by the continuous shift in light distribution from close to extended range

12 Bi-Litronic “Reflection”

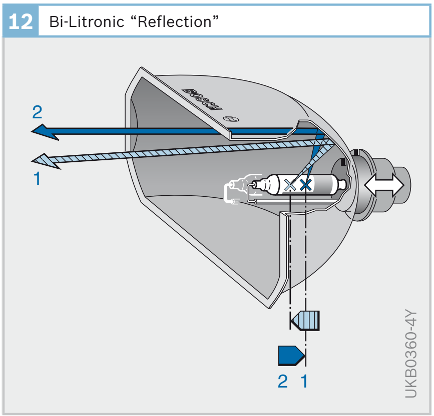


Fig. 12

1	Low beam
2	High beam

13 Litronic 4 system in reflection headlamp with integral dynamic headlamp leveling control (example)

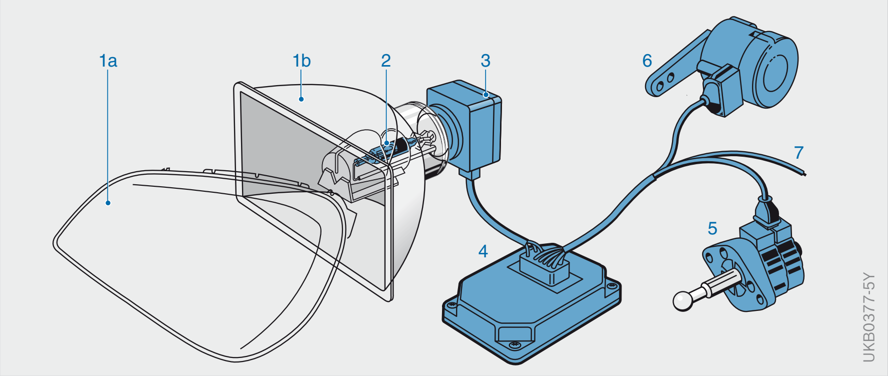


Fig. 13

1a	Lens with or without scatter optics
1b	Reflector
2	Gas-discharge lamp
3	Igniter
4	Control unit
5	Stepper motor
6	Axle sensor
7	To the vehicle electrical system

- Substantial reduction in space requirements as compared to a conventional quad headlamp system
- Lower costs through the use of just one gas-discharge bulb and one ballast unit per headlamp
- Greater freedom in headlamp design due to the individual reflector shape.

Special design variants of the Bi-Litronic "Reflection" lamp involve solutions in which the entire reflector is moved or individual components of the bulb cover are opened.

14 Bi-Litronic "Projection"

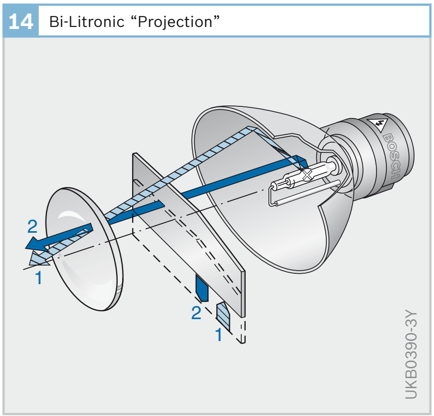


Fig. 14
1 Low beam
2 High beam

Bi-Litronic "Projection"
The Bi-Litronic "Projection" system is based on a PES Litronic headlamp. It shifts the position of the shutter for the light-dark cutoff to provide xenon light for high-beam operation.

With lens diameters of 60 and 70 mm, the Bi-Litronic "Projection" is the most compact combined low- and high-beam headlamp on the market, yet it still provides superb illumination.

The essential advantages of the Bi-Litronic "Projection" are:

- Xenon light for high-beam operation
- Most compact solution for high and low beams
- Modular system

Headlamp leveling control

Function

Without headlamp leveling control, the range of the headlamps would alter with a change in load or operating condition of the vehicle (constant-speed travel, stationary, acceleration, braking). The headlamp leveling control adjusts the tilt angle of the low beam to the tilt angle of the vehicle body. This results in a permanently good visual range with no dazzling of oncoming traffic under all load conditions.

15 Litronic 2 system in projection headlamp (example)

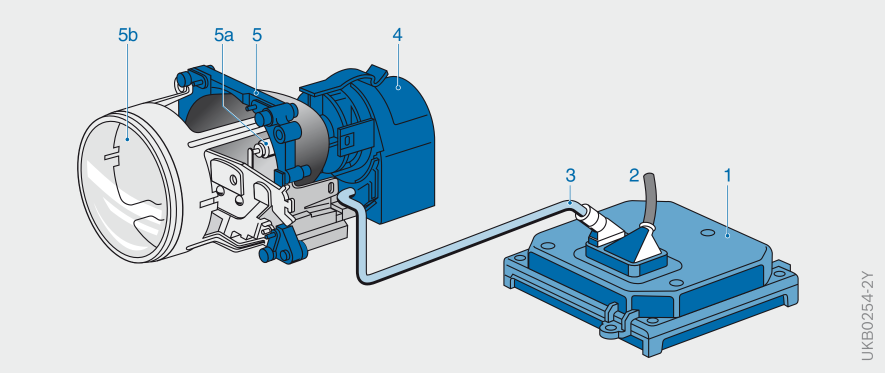


Fig. 15
1 Control unit
2 To the vehicle electrical system
3 Shielded cable
4 Igniter
5 Projection module
5a D2S lamp
5b Lens

Designs

All headlamp leveling controls feature actuators that move the headlamp reflector (housing-type design) or headlamp unit up and down. Automatic systems rely on sensors that monitor suspension travel as the basis for generating proportional signals for transmission to the aiming actuators. Manually operated units employ a switch near the driver's seat to control the setting.

Automatic headlamp leveling control

Automatic headlamp-leveling control systems fall into two categories: static and dynamic. While static systems compensate for load variations in the luggage and passenger compartments, dynamic systems also correct headlamp aim during acceleration – both from standing starts and when underway – and when braking.

The components of a typical headlamp-leveling control system include (Fig. 16):

- Sensors on the vehicle axles (Items 3 and 6) to measure the body's inclination or tilt angle.
- An ECU (5) that uses the sensor signals as the basis for calculating the vehicle's pitch angle. The ECU compares this data with the specified values and responds to deviations by transmitting appropriate triggering signals to the headlamps' servomotors.
- Servomotors (2) to adjust the headlamps to the correct angle.

Static system

In addition to the signals from the suspension sensors, the static system's control unit also receives a speed signal from the electronic speedometer. The controller relies on this signal to decide whether the vehicle is stationary, undergoing a dynamic change in speed, or proceeding at a constant speed. Automatic systems based on the static concept always feature substantial response inertia, so the system corrects only those vehicle inclinations that are consistently registered over relatively long periods.

Each time the vehicle has pulled away, it corrects the headlamp adjustment as a function of the vehicle's load. This adjustment is checked again when the vehicle steadies into constant-speed travel and is then corrected if necessary. Deviations between the target and actual position are evened out by the system.

The static system only generally requires a sensor on the rear axle of the vehicle. A DC motor is used as each headlamp's actuator.

16 Principle of an automatic headlamp-leveling control system (dynamic system)

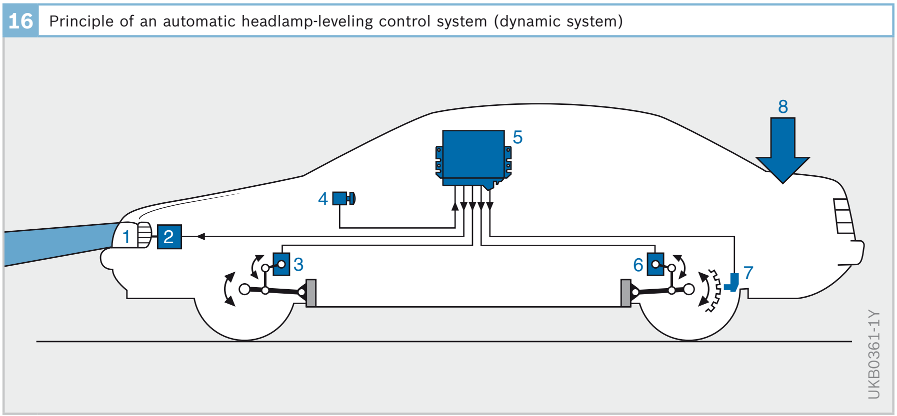


Fig. 16

1	Headlamp
2	Actuator
3	Front-suspension travel sensor
4	Light switch
5	Electronic control unit
6	Rear-suspension travel sensor
7	Speed sensor
8	Load

Dynamic system

The dynamic automatic system relies on two distinct operating modes to ensure optimal headlamp orientation under all driving conditions. Supplementary capabilities in speed-signal analysis over the static headlamp leveling control endow the system with the ability to differentiate between acceleration and braking.

With the vehicle driving at constant speed, the dynamic system, like the static system, remains in the range that features a high level of damping but as soon as the controller registers acceleration or braking, the system immediately switches to its dynamic mode. Faster signal processing and the higher servomotor adjustment speed allow the headlamp range to be re-adjusted within fractions of a second. Following acceleration or braking, the system automatically reverts to operation in its delayed-response mode.

Due to the greater dynamics requirements, the dynamic system needs one sensor per vehicle axle and rapid stepping motors to adjust the headlamps.

Adaptive lighting systems

Adaptive frontlighting system (AFS)

From 2007, function enhancements for headlamp systems based on a new EC control are permitted. The vehicle may then also have motorway lights, adverse weather lights and city lights. The optimum light pattern for each of the functions is identified and automatically selected by the vehicle electronics in response to evaluation of various vehicle sensors.

The first vehicles with AFS systems were registered back in mid-2006 thanks to an EU waiver for road traffic.

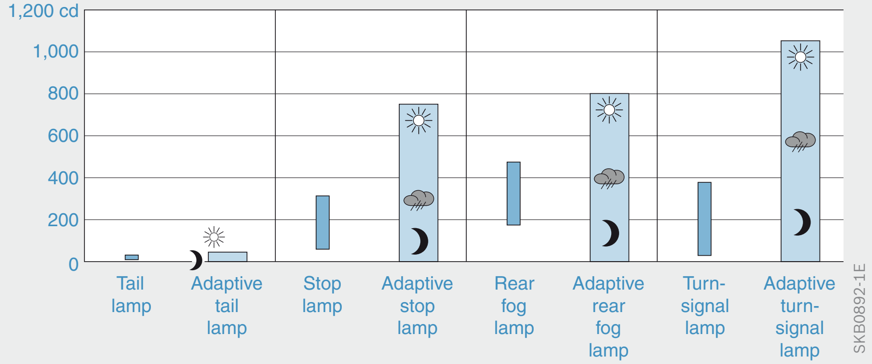
Adaptive rearlighting system (ARS)

Until now, the rear lights for vehicle perimeter lighting were equipped with single level switching. Depending on the type and design, these produced an invariable luminous intensity within the legal limit values.

Today, a multitude of sensors are used to determine environmental parameters and light conditions (brightness, dirt, visual range, wet conditions, etc.). To achieve optimum visibility (sufficient luminous intensity without excessive glare), the rear lights may in future vary luminous intensity to suit the vehicle surrounding (Fig. 17).

A stop lamp, for example, would be lit with high luminous intensity in sunlight and with low luminous intensities at night to ensure that other road users are able to recognize and draw the correct conclusion from the action of the vehicle.

17 Permitted luminous intensity of adaptive rear lights by comparison with conventional systems



Cornering lights (Europe)

The cornering lights function that has been approved for use in Germany since 2003 improves visual range on corners and in turning situations. This is made possible by a variation of the horizontal illumination of the area in front of the vehicle. With static cornering lights, this is achieved by supplementary reflectors being switched; with dynamic cornering lights, the headlamp module is pivoted laterally (Fig. 18).

During the control process, the light module or the reflector elements are pivoted by a stepping motor. The pivot angle and pivot speed are calculated by the cornering lights ECU as a function of vehicle speed and the steering angle. Sensors detect the adjustment angle of the headlamps and use failsafe algorithms to prevent dazzling of oncoming traffic in the event of a system malfunction.

18 Aiming strategy of the basic and turning modules of a static/dynamic cornering headlamp (left side)

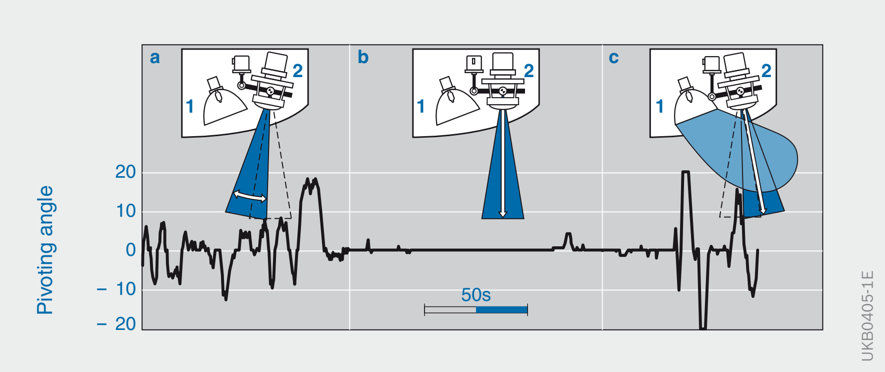


Fig. 18

- a “Country road/ bends” position
- b “Motorway” position
- c “Town/turning” position
- 1 Turning module
- 2 Basic module

19 Improvement in the adaptive light pattern of the cornering headlamps

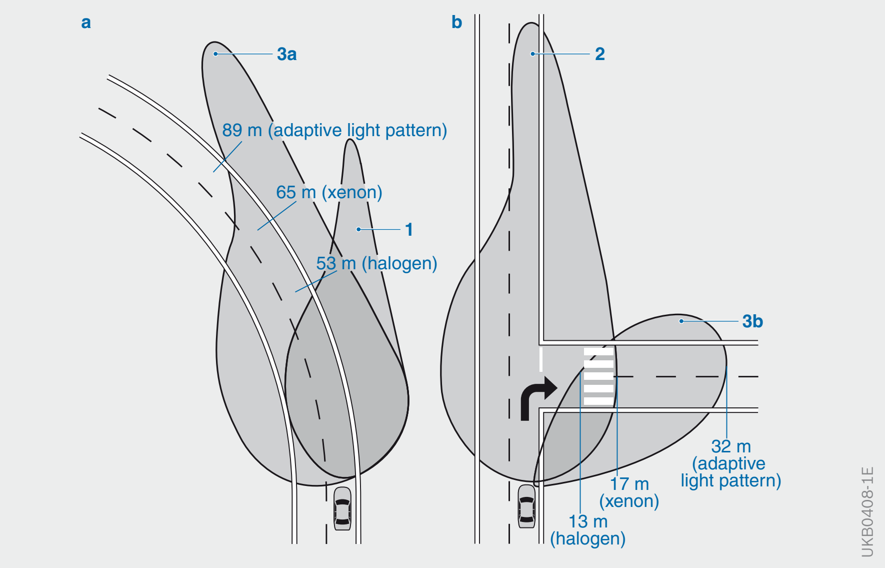
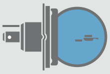
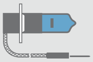
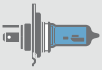
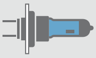
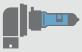
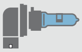
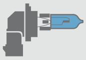
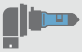
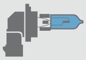
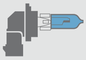
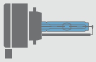
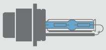
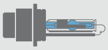


Fig. 19

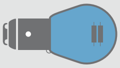
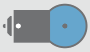
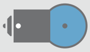
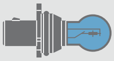
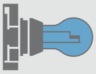
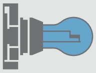
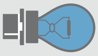
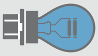
- a Dynamic cornering lights, cornering to the left
- b Static cornering light, turning to the right
- 1 Light pattern of halogen headlamps
- 2 Light pattern of xenon headlamps
- 3a Adaptive light pattern: dynamic cornering lights
- 3b Adaptive light pattern: static cornering lights

Table 1

1 Specifications for motor-vehicle bulbs (2-wheeled vehicles not included)

Application	Category	Voltage rated value V	Power rated value W	Luminous flux setpoint value Lumen	IEC base type	Illustration
High beam, low beam	R2	6 12 24	45/40 1) 45/40 55/50	600 min/ 400–550 1)	P 45 t-41	
Fog lamp, high beam, low beam in 4-headlamps	H1	6 12 24	55 55 70	1,350 2) 1,550, 1,900	P14.5 e	
Fog lamp, high beam	H3	6 12 24	55 55 70	1,050 2) 1,450 1,750	PK 22 s	
High beam, low beam	H4	12 24	60/55 75/70	1,650/ 1,000 1), 2) 1,900/1,200	P 43 t-38	
High beam, low beam in 4-headlamps, fog lamp	H7	12 24	55 70	1,500 2) 1,750	PX 26 d	
Fog lamp, static cornering light	H8	12	35	800	PGJ 19-1	
High beam	H9	12	65	2,100	PGJ 19-5	
Fog lamp	H10	12	42	850	PY 20 d	
Low beam, fog lamp	H11	12 24	55 70	1,350 1,600	PGJ 19-2	
Low beam in 4-headlamps	HB4	12	55	1,100	P 22 d	
High beam in 4-headlamp	HB3	12	60	1,900	P 20 d	
Low beam, high beam	D1S	85 12 5)	35 approx. 40 5)	3,200	PK 32 d-2	
Low beam, high beam	D2S	85 12 5)	35 approx. 40 5)	3,200	P 32 d-2	
Low beam, high beam	D2R	85 12 5)	35 approx. 40 5)	2,800	P 32 d-3	
Stop, turn-signal, rear fog, reversing lamp	P 21 W PY 21 W 6)	6 12 24	21	460 3)	BA 15 s	

1 Specifications for motor-vehicle bulbs (continued)

Application	Category	Voltage rated value V	Power rated value W	Luminous flux setpoint value Lumen	IEC base type	Illustration
Stop lamp/ tail lamp	P 21/5 W	6 12 24	21/5[4] 21/5 21/5	440/35[3], [4] 440/35[3], [4] 440/40[3]	BAY 15 d	
Side-marker lamp, tail lamp	R 5 W	6 12 24	5	50[3]	BA 15 s	
Tail lamp	R 10 W	6 12 24	10	125[3]	BA 15 s	
Daytime running light	P 13 W	12	13	250[3]	PG 18.5 d	
Stop lamp, turn signal	P 19 W PY 19 W	12 12	19 19	350[3] 215[3]	PGU 20/1 PGU 20/2	
Rear fog lamp, reversing lamp, front turn signal	P 24 W PY 24 W	12 12	24 24	500[3] 300[3]	PGU 20/3 PGU 20/4	
Stop, turn-signal, rear fog, reversing lamp	P 27 W	12	27	475[3]	W 2.5 x 16 d	
Stop lamp/ tail lamp	P 27/7 W	12	27/7	475/36[3]	W 2.5 x 16 q	
License-plate lamp, tail lamp	C 5 W	6 12 24	5	45[3]	SV 8.5	
Reversing lamp	C 21 W	12	21	460[3]	SV 8.5	
Side-marker lamp	T 4 W	6 12 24	4	35[3]	BA 9 s	
Side-marker lamp, license-plate lamp	W 5 W	6 12 24	5	50[3]	W 2.1 x 9.5 d	
Side-marker lamp, license-plate lamp	W 3 W	6 12 24	3	22[3]	W 2.1 x 9.5 d	

[1] High/low beam. [2] Setpoint values at test voltage of 6.3; 13.2 or 28.0 V.
[3] Setpoint values at test voltage of 6.75; 13.5 or 28.0 V. [4] Main/secondary filament.
[5] With ballast unit. [6] Yellow-light version.

Electronic stability program (ESP)

The electronic stability program (ESP) is a closed-loop system designed to improve driveability through programmed intervention in the brake system and/or drivetrain. The integrated functionality of ABS[1] prevents the wheels from locking when the brakes are applied, while TCS[2] inhibits wheel spin during acceleration. The overall role of ESP is to prevent the vehicle's tendency to "plow" or become unstable and break away to the side, provided the vehicle remains within its physical limits.

Braking is activated on individual wheels in a targeted manner, such as the inner rear wheel to counter understeer, or the outer front wheel during oversteer, and helps to keep the vehicle's course stable under all driving conditions. ESP can also accelerate the driven wheels by specific engine-control interventions to ensure the stability of the vehicle.

Using this *individual control* concept, the system has two options for steering the vehicle: it can brake selected wheels (selective braking) or accelerate the driven wheels.

Figure 1 shows ESP control in a schematic diagram with
- The sensors that determine the controller input parameters
- The ESP control unit with its hierarchically-structured controller, featuring a higher-level vehicle dynamics controller and the subordinate slip controllers
- The actuators used for control of braking, drive and side forces

Controller hierarchy of ESP

Higher-level vehicle dynamics controller

Function

The vehicle dynamics controller is responsible for
- Determining current vehicle status based on the yaw-rate signal and the sideslip angle estimated by the "monitor", and then

1 ESP control loop in vehicle

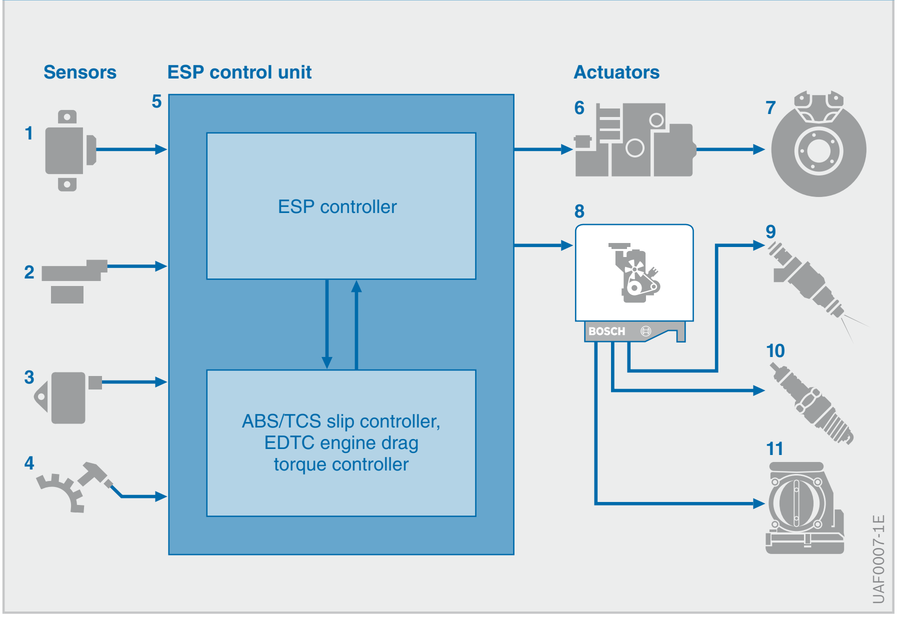


Fig. 1
1 Yaw-rate sensor with lateral-acceleration sensor
2 Steering-wheel-angle sensor
3 Brake-pressure sensor
4 Wheel-speed sensors
5 ESP control unit
6 Hydraulic modulator
7 Wheel brakes
8 Engine-management system ECU
9 Fuel injection

Only for gasoline engines:
10 Ignition-timing intervention
11 Throttle-valve intervention (ETC)

[1] Antilock brake system

[2] Traction-control system

- achieving maximum possible convergence between vehicle response in the limit range and its characteristics in the normal operating range (nominal behavior).

The following components register driver commands and the system evaluates their signals as the basis for defining nominal behavior:
- Engine-management system (e.g. apply accelerator pedal)
- Brake-pressure sensor (e.g. apply brakes) or
- Steering-wheel-angle sensor (turning the steering wheel)

At this point the driver command is defined as the specified response. The coefficient of friction and the vehicle speed are also included in the calculation. The “monitor” estimates these factors based on signals transmitted by the sensors for
- Wheel speed
- Lateral acceleration
- Braking pressures and
- Yaw velocity

The desired vehicle response is brought about by generating a yaw moment acting on the vehicle. In order to generate the desired yaw moment, the system influences the tire-slip rate, and thus indirectly the longitudinal and side forces. The system influences the tire slip by varying the desired specifications for slip rate, which must then be executed by the subordinated ABS and TCS controllers.

The intervention process is designed to maintain the handling characteristics that the vehicle manufacturer intended the vehicle to have and to serve as the basis for ensuring consistently reliable control.

The vehicle dynamics controller generates the specified yaw moment by relaying corresponding slip-modulation commands to the selected wheels.

The subordinate-level ABS and TCS controllers trigger the actuators governing the brake hydraulics and the engine-management system using the data generated in the ESP controller.

Antilock brake system (ABS)

The antilock brake system (ABS) detects incipient lock on one or more wheels and makes sure that the brake pressure remains constant or is reduced. By so doing, it prevents the wheels from locking up and the vehicle remains steerable.

Wheel-speed sensors

The speed of rotation of the wheels is an important input variable for the ABS control system. Wheel-speed sensors detect the speed of rotation of the wheels and pass the electrical signals to the control unit.

A car may have three or four wheel-speed sensors depending on which version of the ABS system is fitted (ABS system versions). The speed signals are used to calculate the degree of slip between the wheels and the road surface and therefore detect incipient lock on individual wheels.

Electronic control unit

The ECU processes the information received from the sensors according to defined mathematical procedures (control algorithms). The results of these calculations form the basis for the triggering signals sent to the hydraulic modulator.

Hydraulic modulator

The hydraulic modulator incorporates a series of solenoid valves that can open or close the hydraulic circuits between the master cylinder (Fig. 2, Item 1) and the wheel-brake cylinders (4). In addition, it can connect the wheel-brake cylinders to the return pump (6). Solenoid valves with two hydraulic connections and two valve positions are used (2/2 solenoid valves).

The intake valve (7) between the master cylinder and the wheel-brake cylinder controls pressure build-up, while the exhaust valve (8) between the wheel-brake cylinder and the return pump controls pressure release. There is one such pair of solenoid valves for each wheel-brake cylinder.

Under normal conditions, the solenoid valves in the hydraulic modulator are at the “pressure build-up” setting. That means the intake valve is open. The hydraulic modulator then forms a straight-through connection between the master cylinder and the wheel-brake cylinders. Consequently, the brake pressure generated in the master cylinder when the brakes are applied is transmitted directly to the wheel-brake cylinders at each wheel.

As the degree of brake slip increases due to braking on a slippery surface or panic braking, the risk of the wheels locking up also increases. The solenoid valves are then switched to the “maintain pressure” setting. The connection between the master cylinder and the wheel-brake cylinder is shut off (intake valve is closed) so that any increase of pressure in the master cylinder does not lead to an increase in brake pressure.

If the degree of slip of any of the wheels increases further despite this action, the pressure in the wheel-brake cylinder(s) concerned must be reduced. To achieve this, the solenoid valves are switched to the “pressure release” setting. The intake valve is still closed, and in addition, the exhaust valve opens to allow the return pump integrated in the hydraulic modulator to draw brake fluid from the brake(s) concerned in a controlled manner. The brake pressure in the wheel-brake cylinder is thus reduced so that wheel lock-up does not occur.

ABS control loop

Overview

The ABS control loop (Fig. 3) consists of the following:

2 Principle of hydraulic modulator with 2/2 solenoid valves (schematic)

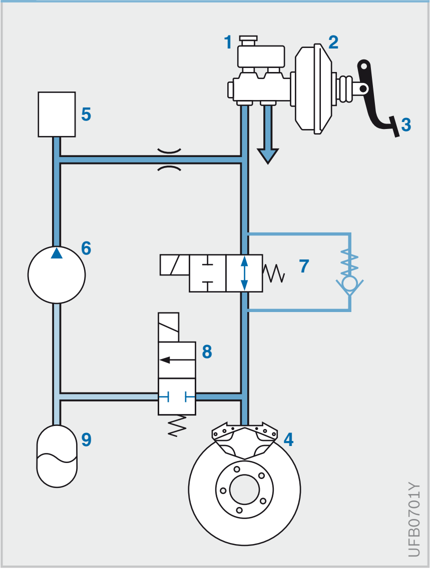


Fig. 2
1 Master cylinder with expansion tank
2 Brake booster
3 Brake pedal
4 Wheel brake with wheel-brake cylinder
Hydraulic modulator with
5 Damping chamber
6 Return pump
7 Intake valve
8 Exhaust valve
9 Brake-fluid accumulator

Intake valve: shown in open setting
Exhaust valve: shown in closed setting

3 ABS control loop

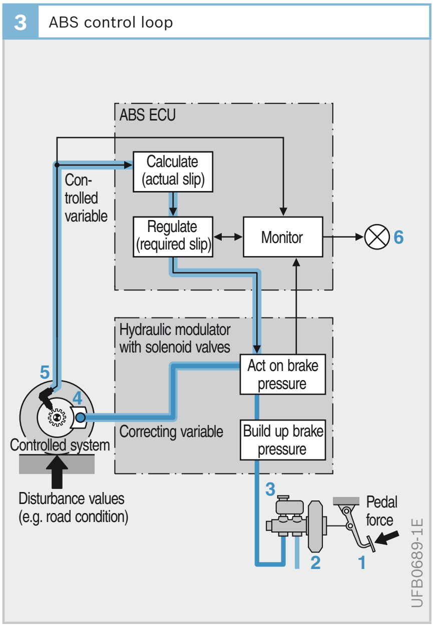


Fig. 3
1 Brake pedal
2 Brake booster
3 Master cylinder with expansion tank
4 Wheel-brake cylinder
5 Wheel-speed sensor
6 Warning lamp

Controlled system

- The vehicle and its wheel brakes
- The wheels and the friction pairing of tire and road surface

The disturbance values affecting the control loop

- Changes in the frictional connection between the tires and the road surface caused by different types of road surface and changes in wheel load, e.g. when cornering
- Irregularities in the road surface causing the wheels and axles to vibrate
- Lack of circularity of the tires, low tire pressure, worn tire tread, differences in circumference between wheels, (e.g. spare wheel)
- Brake hysteresis and fade
- Differences in master-cylinder pressure between the two brake circuits

Controller

- The wheel-speed sensors
- The ABS control unit

Controlled variables

- Wheel speed and, derived from it, wheel deceleration
- Wheel acceleration and brake slip

The reference variable

- The foot pressure applied to the brake pedal by the driver – amplified by the brake booster – generates the brake pressure in the brake system

The correcting variable

- Brake pressure in the wheel-brake cylinder

Controlled system

The data-processing operations performed by the ABS control unit are based on the following simplified controlled system:

- A non-driven wheel
- A quarter of the vehicle's mass apportioned to that wheel
- Wheel brake
- An idealized coefficient of friction slip curve (substitute for the friction pairing of tire and road)

That curve is divided into a stable zone with a linear gradient and an unstable zone with a constant progression (μ_{HFmax}).

As an additional simplification, there is also an assumed initial straight-line braking response that is equivalent to a panic-braking reaction.

Figure 4 shows the relationships between brake torque M_B (the torque that can be generated by the brake through the tire), or road frictional torque M_R (torque that acts against the wheel through the friction pairing of tire and road surface), and time t, as well as the relationships between the wheel deceleration ($-a$) and time t, whereby the brake torque increases in linear fashion over time. The road frictional torque lags slightly behind the brake torque by the time delay T, as long as the braking sequence is within the stable zone

4 Initial braking phase, simplified

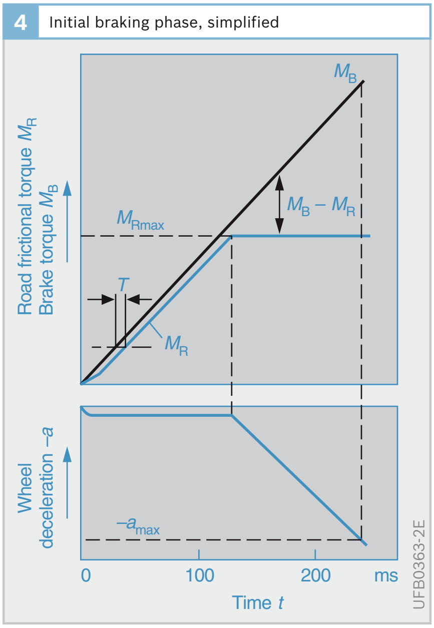


Fig. 4

($-a$)	Wheel deceleration
($-a_{max}$)	Maximum wheel deceleration
M_B	Brake torque
M_R	Road frictional torque
M_{Rmax}	Maximum road frictional torque
T	Time delay

of the curve for coefficient of friction versus brake slip. After about 130 ms, the maximum level (μ_{HFmax}) – and therefore the unstable zone – of the curve for coefficient of friction versus brake slip is reached. From that point on, the curve for coefficient of friction versus brake slip states that while the brake torque M_B, continues to rise at an undiminished rate, the road frictional torque M_R, cannot increase any further and remains constant. In the period between 130 and 240 ms (this is when the wheel locks up), the minimal torque difference $M_B - M_R$, that was present in the stable zone rises rapidly to a high figure. That torque difference is a precise measure of the wheel deceleration ($-a$) of the braked wheel (Fig. 4, bottom). In the stable zone, the wheel deceleration is limited to a small rate, whereas in the unstable zone it increases rapidly, according to the amount. As a consequence, the curve for coefficient of friction versus wheel slip reveals opposite characteristics in the stable and unstable zones. The ABS exploits these opposing characteristics.

Controlled variables

An essential factor in determining the effectiveness of an ABS control system is the choice of controlled variables. The basis for that choice is the wheel-speed sensor signals from which the ECU calculates the deceleration/acceleration of the wheel, brake slip, the reference speed and the vehicle deceleration. On their own, neither the wheel deceleration/acceleration nor the brake slip are suitable as controlled variables because, under braking, a driven wheel behaves entirely differently to a non-driven wheel. However, by combining those variables on the basis of appropriate logical relationships, good results can be obtained.

As brake slip is not directly measurable, the ECU calculates a quantity that approximates to it. The basis for the calculation is the reference speed, which represents the speed under ideal braking conditions (optimum degree of brake slip). So that speed can be determined, the wheel-speed sensors continuously transmit signals to the ECU for calculating the speed of the wheels. The ECU takes the signals from a pair of diagonally opposed wheels (e.g. right front and left rear) and calculates the reference speed from them. Under partial braking, the faster of the two diagonally opposite wheels generally determines the reference speed. If the ABS cuts in under emergency braking, the wheel speeds will be different from the vehicle speed and can thus not be used for calculating the reference speed without adjustment. During the ABS control sequence, the ECU provides the reference speed based on the speed at the start of the control sequence and reduces it at a linear rate. The gradient of the reference-speed graph is determined by analyzing logical signals and relationships.

If, in addition to the wheel acceleration/deceleration and the brake slip, the vehicle deceleration is brought into the equation as an additional quantity, and if the logical circuit in the ECU is modulated by computation results, then ideal brake control can be achieved. This concept has been realized in the Bosch antilock brake system (ABS).

Traction-control system (TCS)

The antilock brake system (ABS) prevents the wheel lock when the brakes are applied by lowering the wheel brake pressures. The traction-control system (TCS) prevents wheel spin by reducing the drive torque at each driven wheel.

In addition to this safety-relevant task of ensuring the stability and steerability of the vehicle when accelerating, TCS also improves the traction of the vehicle by regulating the optimum slip. The upper limit here is, of course, set by the traction requirement stipulated by the driver.

The TCS regulates the slip of the driven wheels as quickly as possible to the optimum level. To do this the system first determines a setpoint value for the slip. This value depends on a number of factors that represent the current driving situation. These factors include:

- The basic characteristic for TCS reference slip (based on the slip requirement of a tire during acceleration)
- Effective coefficient of friction
- External tractive resistance (deep snow, rough road, etc.)
- Yaw velocity, lateral acceleration, and steering angle of the vehicle

TCS interventions

The measured wheel speeds and the respective drive slip can be influenced by changing the torque balance M_{tot} at each drive wheel. The torque balance M_{tot} at each driven wheel results from the drive torque $M_{Kar}/2$ at this wheel, the respective brake torque M_{Br} and the road torque M_{Str} (Fig. 5).

$M_{tot} = M_{Kar}/2 + \mathrm{M}_{Br} + M_{Str}$
(M_{Br} and M_{Str} are negative here.)

This balance can obviously by influenced by the drive torque M_{Kar} provided by the engine as well as by the brake torque M_{Br}. Both these parameters are therefore correcting variables of the TCS which can be used to regulate the slip at each wheel to the reference slip level.

In gasoline-engine vehicles, the drive torque M_{Kar} can be controlled using the following engine-control interventions:

- Throttle valve (throttle valve adjustment)
- Ignition system (ignition-timing advance)
- Fuel-injection system (phasing out individual injection pulses)

In diesel-engine vehicles, the drive torque M_{Kar} is influenced by the electronic diesel control system (EDC) (reduction in the injected fuel quantity).

The brake torque M_{Br} can be regulated for each wheel via the brake system. The TCS function requires the original ABS hydraulic system to be expanded because of the need for active pressure build-up.

5 Drive concept of a single-axle driven vehicle with TCS

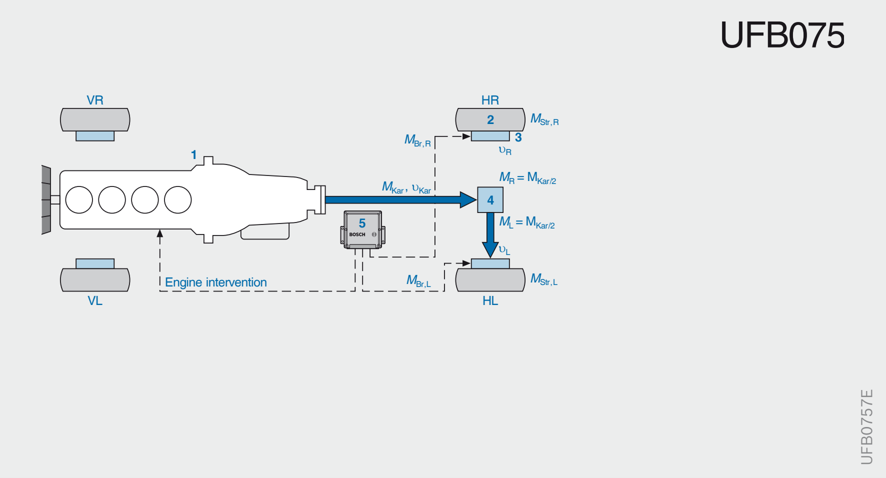


Fig. 5

1	Engine with transmission
2	Wheel
3	Wheel brake
4	Transversal differential
5	Electronic control unit with TCS functionality

Engine, transmission, gear ratio of differential and losses are combined in one unit.

M_{Kar}	Drive axle torque
υ_{Kar}	Cardan speed
M_{Br}	Brake torque
M_{Str}	Torque transferred to the road
υ	Wheel speed
R	Right
L	Left
V	Front
H	Rear

ABS versions

Evolution of the ABS versions

Technological advances in the areas of

- Solenoid-valve design and manufacturing.
- Assembly and component integration.
- Electronic circuitry (discrete components replaced by hybrid and integrated circuits with microcontrollers).
- Testing methods and equipment (separate testing of electronic and hydraulic systems before integration in the hydraulic modulator).
- Sensor and relay technology have enabled the weight and dimensions of ABS versions to be more than halved since the first-generation ABS2 in 1978. As a result, modern systems can now be accommodated even in vehicles with the tightest space restrictions. Those advances have also lowered the cost of ABS systems to the extent that they are now fitted as standard on all types of vehicle.

1 Evolution of ABS configurations

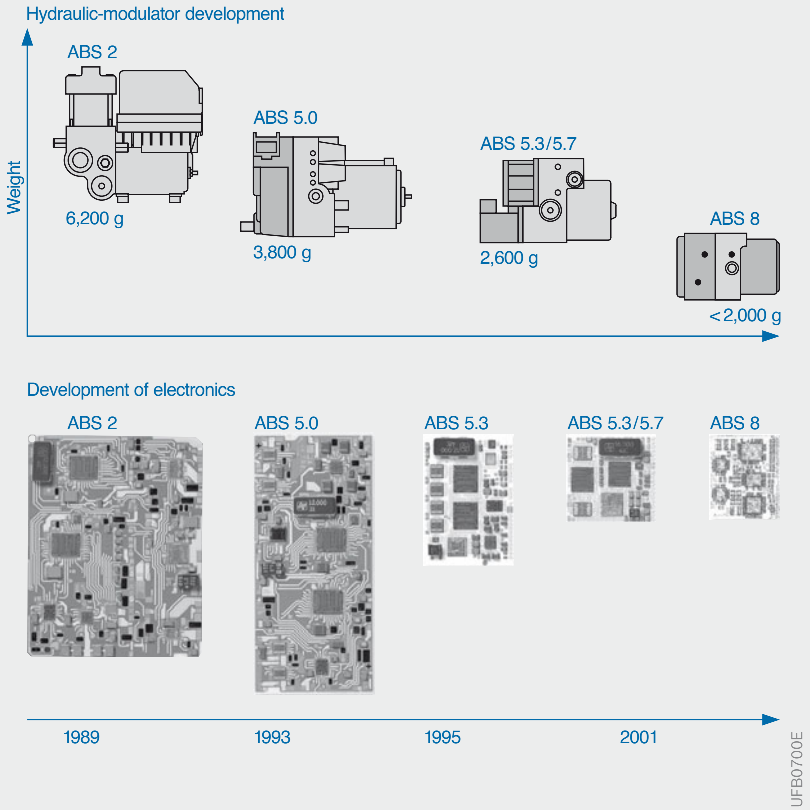


Fig. 1
Historical development of ABS showing technological advances: Decreasing weight accompanied by increasing processing power.

History of radar

Technology to mimic the animals

Radar (RAdiation Detecting And Ranging) is a wireless method for locating objects that has traditionally been used mainly in air travel and shipping. Since radar-supported air defence was introduced in World War 2, radar has also been a feature of weapons technology. More recently, radar has found application in space travel, weather forecasting and ultimately in road traffic as part of measuring distances between vehicles using ACC (Adaptive Cruise Control).

The basis for the development of radar was the sonar system (Sound Navigation and Ranging) possessed by animals for navigation and determining distances. Echolocating bats, for example, emit orientation sounds in the form of shrill whistles in the 30 to 120 kHz *ultrasound range*. They then pick up the echo from obstacles or their prey with their ears. They use the information contained in the echo to decide what to do next.

Radar functions in a similar way but uses *radio signals* not sound waves. The distance measurement method of radar is based on the measurement of the time that elapses between the emission of the *electromagnetic waves* and the reception of a signal echo reflected by an object.

While air travel and shipping radar systems, for example, operate in the 500 MHz to 40 GHz frequency range, ACC is authorized to use the 76 to 77 GHz frequency band.

Stages in the development of radar

The development of electromagnetic, long-range search facilities was a great challenge for design engineers. Only a small part of the energy originally emitted was reflected back. It is therefore necessary to emit a large amount of energy and to concentrate it in as narrow a beam bundle as possible. The only devices suitable for this are very sensitive transmitters and receivers for waves that are shorter than the dimensions of the target.

The development path that led to radar technology is punctuated by the following historical milestones and characters:

1837 **Morse:** Message transmission over long distances by means of electrical pulses sent by the telegraph was the first method to find widespread use

1861/1876 **Reis** and **Bell:** Replacement of telegraphs by the telephone makes message transfer much more direct and user-friendly

1864 **Maxwell, Hertz** and **Marconi:** Existence of “radio waves” proven theoretically and experimentally. Radio waves reflect off metallic objects in the same way as light waves reflect off a mirror

1922 **Marconi:** The pioneer of the radio proposes further investigations into earlier research approaches to radio measuring technology

1925 **Appleton** and **Barnett:** The principle of radio measuring technology is used to detect conducting strata in the atmosphere

Breit and **Tuve:** Development of pulse modulation that permits exact development measurements

1935 **Watson Watt:** Invention of the radar

1938 **Ponte:** Invention of the magnetron (velocity-modulated tube for generating high-frequency vibrations)

Adaptive cruise control (ACC)

System description

Like the basic cruise-control system that has been available as a standard feature for many years, ACC (Adaptive Cruise Control) can be categorized as a driver-assistance system. Cruise control regulates driving speed to maintain the desired speed selected by the driver using the cruise-control unit. In addition to the basic cruise-control function, ACC measures the distance to the vehicle in front and its relative speed, and uses this information together with other collected data (position of other vehicles in the same or different lane; in future, even stationary objects) to regulate the time gap between the vehicles. ACC is thus able to adapt the vehicle's speed to match the speed of the vehicle traveling in front and maintain a safe distance from it. The driver is able to override or switch off the ACC function at any time (e.g. by depressing the gas or brake pedal).

Distance sensor

In the main, ACC systems currently have a radar sensor (Fig. 1, Item 1) that operates in a frequency range of between 76 and 77 GHz and emits four radar lobes. Once activated, ACC detects a range of up to approximately 200 m in front of the vehicle. The radar beams reflected by vehicles in front are analyzed for timing, Doppler shift and amplitude ratio. These factors are used to calculate distance, relative speed and angle position relative to vehicles in front.

Network architecture

The ACC function cannot be represented independently as a stand-alone system; various subsystems (engine-management system, electronic stability program, transmission control, instrument cluster) must be networked with each other. The evaluation and control electronics (control unit) of the ACC are integrated in the sensor housing. They receive and send data on a CAN data bus from and to other electronic control units.

Course setting

To ensure reliable ACC operation no matter what the situation – e.g. also on bends – it is essential that the preceding vehicles can be allocated to the correct lane(s).
For this purpose, the information from the ESP sensor system (yaw rate, steering angle, wheel speeds and lateral acceleration) is evaluated with regard to the ACC-equipped vehicle's own curve status.

1 Adaptive cruise control (ACC)

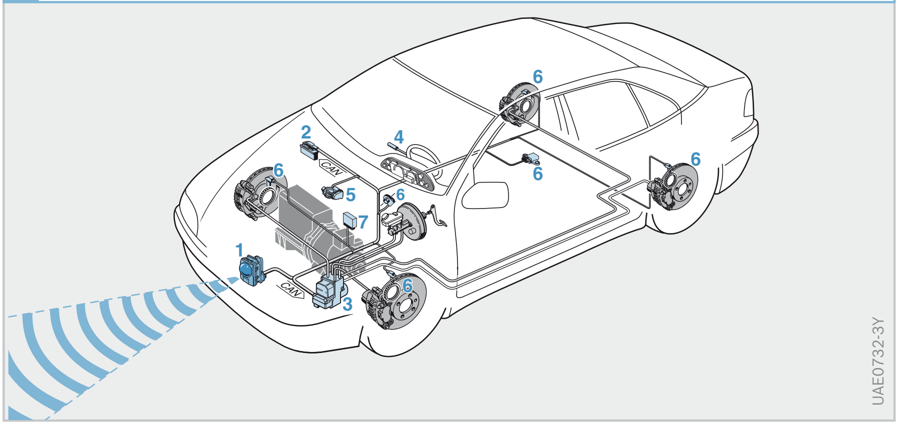


Fig. 1

1 ACC sensor and control unit
2 Engine-management system ECU (ME or DI Motronic) for gasoline engines or electronic diesel control (EDC) for diesel engines
3 Active brake intervention via ESP
4 Control and display unit
5 Engine-control intervention by means of electrically adjustable throttle valve (ME or DI Motronic)
6 Sensors
7 Transmission-shift control by means of electronic transmission control (optional)

Setting options

The driver inputs the desired speed and the desired time gap; the time gap available to the driver usually ranges from 1 to 2 s. The time gap to the vehicle in front is calculated from the radar signals and compared with the desired time gap specified by the driver. If this value is shorter than the desired value, the ACC system responds in a manner appropriate to the traffic situation by initially reducing engine torque, and only if necessary by automatically braking the vehicle. If the desired time gap is exceeded, the vehicle accelerates until either the speed of the vehicle in front or the desired speed set by the driver is reached.

Engine-control intervention

Speed control requires an electronic engine-performance control system. The ME or DI Motronic engine-management system and the electronic diesel control (EDC) are integrated with this function. This system allows the vehicle to be accelerated to the desired speed or, if an obstacle appears, to be decelerated by means of automatic throttle closing.

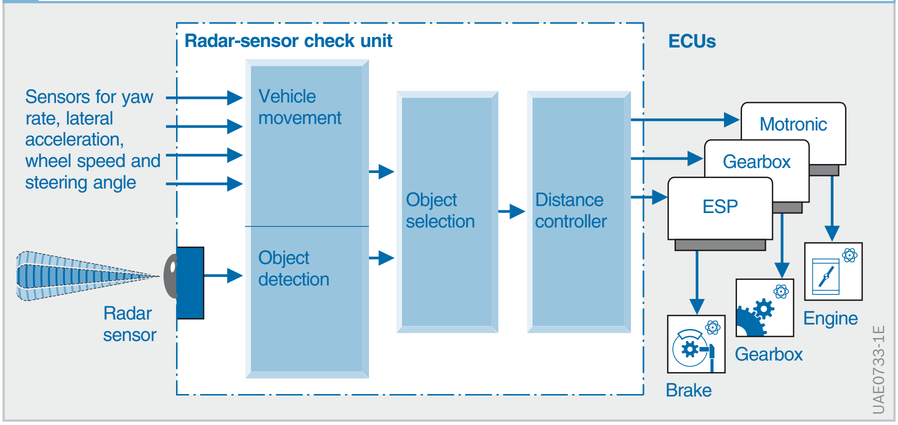
Brake intervention

If the rate of deceleration achieved by easing off the gas is not sufficient, the vehicle will have to be braked. The electronic stability program (ESP) is required here as it is able to initiate the brake intervention.

Due to the design of ACC as a comfort system, the braking deceleration calculated by the ACC controller is limited to approximately 2 to 3 m/s² with current ACC systems. If this is not sufficient for the current traffic situation (e.g. if the vehicle in front brakes sharply), the vehicle audibly requests the driver to take over responsibility for braking. The necessary braking deceleration is then to be achieved using the service brake. Safety functions, such as panic braking, are not part of the ACC system.

The other stabilizing systems of ABS, TCS or ESP may be active as normal during an active ACC control intervention as necessary. Depending on the parameter settings of ACC, stabilization interventions may result in ACC being deactivated.

2 Basic structure and components of the ACC control system



Control and display

Controls include switches, push-buttons or thumbwheels for

- Activating the function and
- Setting the desired speed and
- Desired time gap

The following information may be displayed to the driver in the instrument cluster:

- Desired speed
- Information on the activation status
- The time gap selected by the driver
- Indication of the follow-up mode, which informs the driver as to whether the system is controlling the distance to a detected target object or not

System limits

ACC does not yet permit control operations in city environments. This system can only be activated at speeds in excess of 30 km/h.

Control algorithms

The control system basically consists of three control modules:

- *Control module 1: cruise control*
  If the radar sensor has not detected any vehicles in front, the system maintains the desired speed set by the driver.
- *Control module 2: follow-up control*
  The radar sensor has detected vehicles in front. Control essentially maintains the time gap to the nearest vehicle at a constant setting.
- *Control module 3: control when cornering*
  When negotiating tight bends, the radar sensor can “lose sight” of the vehicle in front because of the limited width of its “field of vision”. Until the vehicle comes in sight of the radar again, or until the system is switched to normal cruise control, special measures come into effect. Depending on the manufacturer, the speed would then be maintained, the current rate of lateral acceleration adapted or the ACC function deactivated, for example.

Object detection and lane allocation

The central task of the radar sensor and its integrated electronics is to detect objects and allocate them either to the same lane as the one on which the vehicle is traveling, or to a different lane. Firstly, lane allocation demands the precise detection of vehicles in front (high angle resolution and accuracy), and secondly, a precise knowledge of the motion of the system’s own vehicle. Vehicle motion is calculated from the signals sent by sensors also used for the electronic stability program (ESP) (course prediction). These include the wheel-speed sensors and driving-dynamics sensors for the yaw rate and lateral acceleration. Optionally, information supplied by a steering-angle sensor may also be processed. The decision as to which of the detected objects is used as the reference for adaptive cruise control is essentially based on a comparison between the positions and motion of the detected objects and the motion of the system’s own vehicle.

Adjustment

The radar sensor is fitted at the front end of the vehicle. Its radar lobes are aligned relative to the vehicle longitudinal axis. This is done using adjusting screws at the fastening part of the sensor. If it is moved out of alignment by physical force, e.g. deformation of the mounting due to accident damage or any other effect, realignment must be carried out. Small degrees of misalignment are automatically corrected by the permanently active alignment routines implemented in the software. If manual realignment is required, this is indicated to the driver.

Ranging radar

The radar (RAdiation Detecting And Ranging) transceiver unit transmits packets of electromagnetic waves using an antenna. These reflect off an object made of electrically conductive materials (e.g. vehicle body) and are then received. The signals received in this manner are “compared” with the transmitted signals with respect to their propagation time and/or frequency.

Measuring principles

Propagation time measurement

For all radar methods, the distance measurement is based on the direct or indirect propagation time measurement for the time between when the radar signal is transmitted and when the signal echo is received. The direct propagation time measurement is used to measure period τ. With direct reflection, this is equal to twice the distance d to the reflector divided by the speed of light c:

$$\tau = 2d/c$$

For a distance of d = 150 m and $c \approx$ 300,000 km/s, the propagation time is

$$\tau \approx 1\ \mu\text{s}.$$

Frequency modulation

Direct propagation time measurement requires much effort; an indirect propagation time measurement is simpler. The method is known as FMCW (Frequency Modulated Continuous Wave). Rather than comparing the times between the transmitted signal and received echo, the FMCW radar compares the frequencies of the transmitted signal and received echo. The prerequisite for a meaningful measurement is a modulated transmit frequency.

With the FMCW method, radar waves linearly modulated in their frequency are transmitted for a duration of typically a few milliseconds and in a cycle of a few hundred MHz (f_s, continuous curve in Fig. 3). The signal reflected off a vehicle in front is delayed in accordance with the signal propagation time (f_e, dashed line in Fig. 3). In the rising ramp, the frequency is lower; in the falling ramp, the frequency is higher by the same amount. The difference in frequency Δf is a direct measure for the distance.

If there is additionally a relative speed between the vehicles, the receive frequency f_e is increased (f_e', dotted line in Fig. 3) by a specific amount Δf_d in both the rising and falling ramp due to the Doppler effect. This produces two different frequency differences Δf_1 and Δf_2. Their addition produces the distance between the vehicles, and their subtraction the relative speed of the vehicles.

The signal processing in the frequency range therefore delivers a frequency for each object that as a linear combination produces a term for distance and relative speed. From the measured frequencies of two ramps with a different gradient, it is possible to determine the distance to and the relative speed of an object. For situations involving several targets, several ramps with a different gradient are required.

3 FMCW method

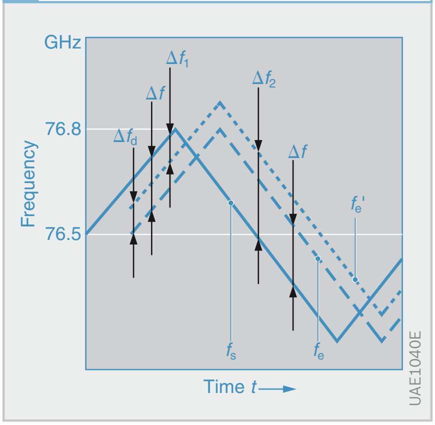


Fig. 3

f_s Transmission signal

f_e Return signal at same road speed

f_e' Return signal with relative road speed

Doppler effect

Although the relative speed of the other vehicle can be measured using a number of subsequent distance measurements, it is calculated more quickly, more reliably and more accurately when the Doppler effect is utilized in the measurement.

For an object moving relative to the radar sensor with a relative speed (relative speed v_{rel}), the signal echo undergoes a frequency shift f_{D} compared to the emitted signal. At the relevant differential speeds, this is represented as:

$$f_{\text{D}} = -2 f_{\text{C}} \cdot v_{\text{rel}} / c$$

f_{C} is the carrier frequency of the signal. At the radar frequencies commonly used for ACC, $f_{\text{C}} = 76.5$ GHz, there is a frequency shift of $f_{\text{D}} \approx -510 \cdot v_{\text{rel}}/\text{m}$, and thus 510 Hz at a relative speed of −1 m/s (approaching).

Angle measurement

The third basic dimension which is needed is the side offset (angle) of the preceding vehicle. The only way this can be measured is by radiating the radar beam in a number of different directions. The (reflected) signals are then applied to determine from which direction the strongest reflection came. This method needs either high-speed back-and-forth movement of the beam (scanning), or the installation of a multi-beam antenna array.

High-frequency part of the ACC sensor

The high-frequency part can be broken down into four functional groups.

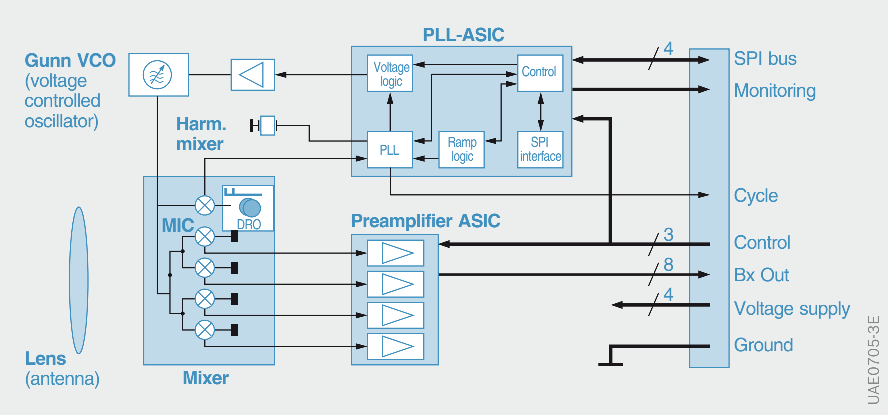
HF generation

The HF generation and control section makes the high frequency available for transmission (Fig. 4). The HF output of between 76 and 77 GHz is generated using a voltage-controlled oscillator (VCO) comprising a Gunn diode in a mechanical resonator. A small part of the output generated is downmixed into an intermediate frequency band using a dielectrical resonance oscillator (DRO) with harmonic mixer and supplied to the control electronics (PLL-ASIC, PLL = Phase Locked Loop). The latter controls the VCO by means of an output driver and provides frequency stabilization and modulation.

Transmission and reception circuit

In the transmission and reception circuit, the HF output is divided between four transmission/reception channels by three Wilkinson splitters. Using bandpass mixers, this output is supplied to the antenna while the return signal is downmixed to the basic band.

4 Block diagram of a 4-channel FMCW radar



Amplification

Signals in the basic band are amplified in an ASIC. It has four channels, switching amplification, and a special characteristic curve. To some extent, this compensates for the large signal dynamics in that high frequencies (correspondingly high distances) are more strongly amplified. In addition, the characteristic is integrated with a low-pass anti-aliasing filter for subsequent scanning.

Antenna system

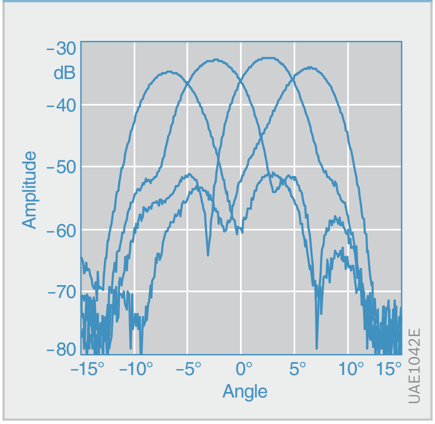
The antenna system is a monostatic system. It comprises four combined transmitter and receiver patches on the HF substrate, four polyrods (plastic cones) for prefocusing and a plastic lens for beam concentration. As part of the housing, the lens also acts as a radar-optical window and shield. The radar waves are emitted simultaneously and coherently by the four antenna patches to produce a single transmission wave. The beams are only actually split into four separate beams on the receiver side. Four separate receiver channels are used here.

The transmit frequency is modulated by the voltage-controlled oscillator (VCO) in a linearly ramped fashion (Fig. 3) with a gradient of $m = \mathrm{d}f/\mathrm{d}t$. While the received signal returns after the propagation time $\tau = 2d/c$ the transmit frequency has changed in the meantime by the differential frequency $f_\mathrm{D} = \tau \cdot m$. Therefore, the propagation time, and thus the distance, can be measured indirectly by ascertaining the differential frequency between the transmitted and received signals. The differential frequency, in turn, can be ascertained using a mixer, followed by low-pass filtering. To determine the frequency, the signal is digitized and converted into a frequency spectrum using an FFT (Fast Fourier Transformation).

However, the information about the difference frequency does not only contain information for the propagation time but also for the Doppler shift. This situation means that there is at first a certain ambiguity in the evaluation. It can be resolved by applying multiple FMCW modulation cycles with different gradients.

To determine the angle at which the radar locates an object, multiple radar lobes are transmitted and evaluated. At least two overlapping radar beams are required to measure the angle. No conclusions on the angle of sight can be drawn from the relationships between the amplitudes that are measured for an object in adjacent beams. If, for example, four radar beams are used, the horizontal angular dependence of which is shown in Figure 5 in the form of a two-way antenna diagram as an example, it is possible to determine the horizontal angle of sight by comparing amplitude and phase of the measured radar signals using the antenna diagram.

5 Two-way antenna diagram



Radar signal processing

The low-frequency part of the FMCW radar comprises several components (Fig. 6).

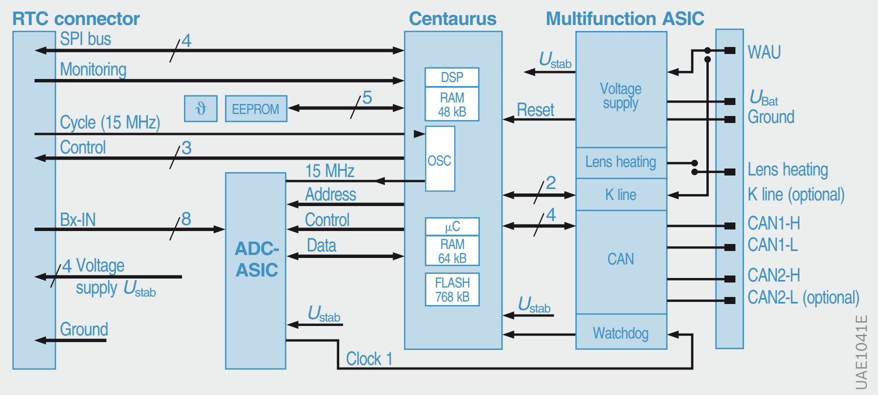
A dual-core processor is used for digital data processing. The digital signal processor (DSP) contained in this module is used for data acquisition, calculating the fast fourier transform (FFT) and for other basic signal processing. The processor also contains a microcontroller in which additional signal processing, the application software and control unit functions are executed. Furthermore, various peripherals are integrated in the dual processor: serial interfaces, two CAN controllers (Controller Area Network), an analog/digital converter and various digital ports.

The processor is surrounded by various peripheral modules. The analog radar signals from the HF PCB are converted into digital sample values in an analog/digital converter (ADC). This takes place simultaneously for four channels. A digital low-pass filter is also integrated in this module to ensure limitation to the Nyquist bandwidth. An EEPROM is used as an external, non-volatile memory. Application parameters and, if applicable, fault codes are stored here. A multifunction ASIC is used to generate the supply voltages (different DC voltages) and as an output driver (K line, CAN, lens heating to prevent icing). In addition, a watchdog is also integrated. Using a temperature sensor, it is possible to measure the internal temperature of the system.

The unit is connected to the vehicle by an eight-pin connector. The connector supplies battery voltage (approximately 12 V), ground (GND), two CAN buses, or alternatively a wakeup or K line, or a radome heater, or a time gap signal.

The low-frequency circuit can be designed using standard printed-circuit board technology. Figure 7 provides a look inside the unit.

6 Low-frequency block diagram



7 Exploded view of an FMCW radar with integrated signal processing

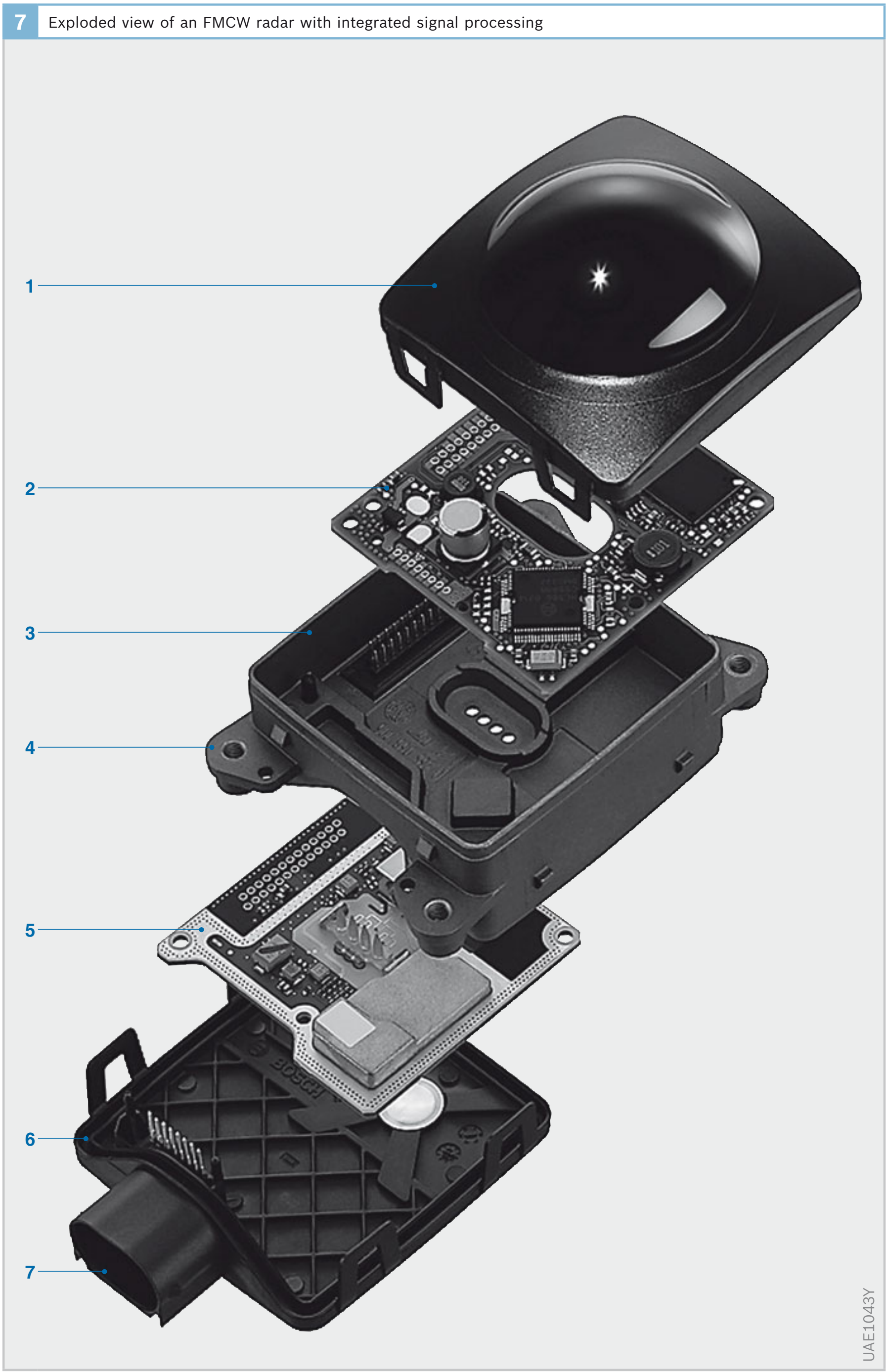


Fig. 7

1 Upper housing section with lens
2 HF PCB
3 Bearing points for alignment
4 Intermediate carrier
5 LF PCB
6 Housing base
7 Plug

Occupant-protection systems

In the event of an accident, occupant-protection systems are intended to keep the accelerations and forces that act on the passengers low and lessen the consequences of the accident. These passive vehicle safety systems include:

- Seat belts with seat-belt pretensioners
- Airbags and
- Rollover protection systems (on cabriolets)

Seat belts and seat-belt pretensioners provide the greater part of the protective effect since they absorb 50 to 60 % of impact energy. With front airbags, the energy absorption is about 70 % if deployment timing is properly synchronized.

In order to achieve optimum protection, the response of all components of the complete occupant-protection system must be adapted to one another.

Seat belts and seat-belt pretensioners

Function

The function of seat belts is to restrain the occupants of a vehicle in their seats when the vehicle impacts against an obstacle. In the event of a frontal impact, seat-belt pretensioners pull the seat belts tighter against the body and hold the upper body as closely as possible against the seat backrest. This prevents unimpeded forward displacement of the occupants caused by inertia. Seat-belt pretensioners thus improve the restraining characteristics of a three-point inertia-reel belt and increase protection against injury.

Operating principle

In an impact, the shoulder-belt tightener eliminates the seat belt slack and the “film-reel effect” by rolling up and tightening the belt webbing. On activation, the system electrically fires a pyrotechnic propellant charge. The rising pressure acts on a piston,

1 Electronic impact protection system

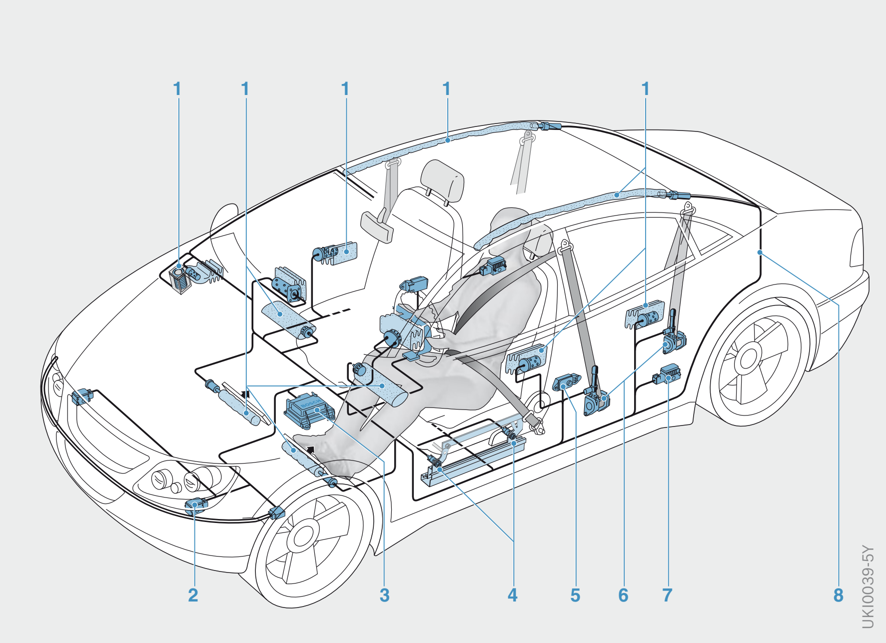


Fig. 1
1 Airbag with gas inflator
2 Upfront sensor
3 Central electronic control unit with integrated rollover sensor
4 iBolt™
5 Peripheral pressure sensor (PPS)
6 Seat-belt pretensioner with propellant charge
7 Peripheral acceleration sensor (PAS)
8 Bus architecture (CAN)

which turns the belt reel via a steel cable in such a way that the belt is held tightly against the body (Fig. 2).

Variants

In addition to the shoulder-belt tighteners, there are variants which pull the seat-belt buckle back (buckle tighteners) and simultaneously tighten the shoulder and lap belts. Buckle tighteners further improve the restraining effect and the protection to prevent occupants from sliding forward under the lap belt ("submarining effect").

A further improvement is achieved by the use of belt-force limiters. In this case, the seat belt tighteners initially tighten fully (using the maximum force of approx. 4 kN, for example) and restrain the occupants. If a certain belt tension is exceeded, the belt gives thereby extending the degree of forward movement. The kinetic energy is converted into deformation energy, which prevents the occurrence of acceleration peaks. Deformation elements include a torsion rod in the inertia reel shaft. However, there is also an electronically controlled single-stage belt-force limiter, which reduces the belt tension to 1 to 2 kN by firing a detonator a specific period after deployment of the second front airbag stage and after a specific extent of forward movement is reached.

2 Shoulder-belt tightener

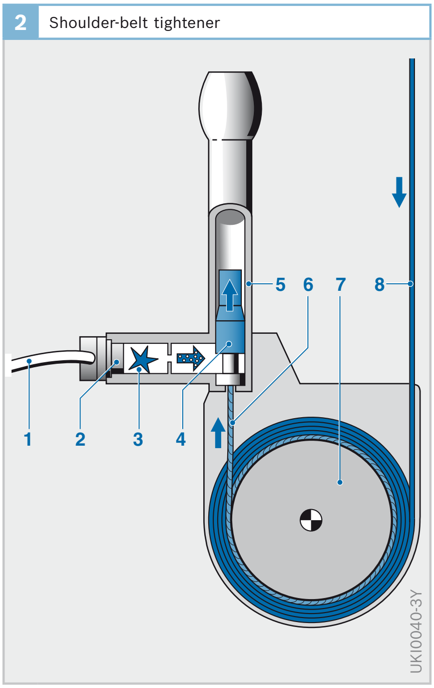


Fig. 2

1 Firing cable
2 Firing element
3 Propellant charge
4 Piston
5 Cylinder
6 Wire rope
7 Belt reel
8 Belt webbing

Front airbag

Function

The function of front airbags is to protect the driver and front passenger against head and chest injuries in a vehicle impact with an obstacle. In a serious accident, a seat-belt pretensioner cannot keep the head from striking the steering wheel.

Operating principle

To protect driver and front passenger, pyrotechnical gas inflators inflate the driver and passenger airbags highly dynamically after a vehicle impact detected by sensors. In order to provide maximum protection, the airbag must be fully inflated before the occupant plunges into it. Once the occupant makes contact with it, the airbag partly deflates in order to "gently" absorb impact energy acting on the occupant with noncritical (in terms of injury) surface pressures and declaration forces.

The maximum permissible forward displacement of the driver before the airbag on the driver's side has inflated is approximately 12.5 cm. This equates to a time of approximately 40 ms from the start of impact (in the case of an impact with a hard obstacle at 50 km/h). 10 ms elapse before the electronics detect the impact and trigger the electronic ignition system. A further 30 ms is required for the airbag to inflate. The airbag is deflated through the outlet openings after another 80 to 100 ms. The entire process takes little more than a tenth of a second.

Impact detection

The deceleration arising from the impact is detected by one (or two) longitudinal acceleration sensor(s) and the change in speed is calculated from it. In order to be able to better detect oblique and offset impacts, the deployment algorithm can also evaluate the signal from the lateral acceleration sensor.

The impact must also be analyzed in addition to the crash sensing. The airbag should not trigger from a hammer blow in the workshop, gentle impacts, bottoming out, driving over curbstones or potholes. With this goal in mind, the sensor signals are processed in digital analysis algorithms whose sensitivity parameters have been optimized with the aid of crash data simulations. Depending on the vehicle manufacturer's production concept, the deployment parameters and the vehicle's equipment level can also be programmed into the ECU at the end of the assembly line ("end-of-line programming").

In order to prevent airbag-related injuries to "out-of-position" occupants (e.g. leaning too far forward) or to small children in reboard (rearward-facing) child seats, it is essential that the front airbags be triggered and inflated in accordance with the particular situations. The following measures are implemented for this purpose:

Deactivation switch

This can be used to disable the passenger airbag. The status of the airbag function is indicated by lamps.

Intelligent airbag systems

The introduction of improved sensing functions and control options for the airbag inflation process, with the accompanying improvement in protective effect, is intended to result in a gradual reduction in the risk of injury. Such functional improvements are:

- Impact severity detection through further optimization of the deployment algorithm or the use of one or two upfront sensors (Fig. 4). The latter are acceleration sensors installed in the vehicle's crumple zone (e.g. on the radiator crossmember) which facilitate early detection of and distinction between different types of impact, such as ODB (Offset Deformable Barrier) crashes, pole or underride impacts. They also allow an assessment of the impact energy.
- Seltbelt usage detection.
- Occupant presence, position and weight detection.
- Seat position and backrest inclination detection.
- Use of front airbags with two-stage gas inflators or with single-stage gas inflators and pyrotechnically triggered gas-discharge valves.
- Use of seat-belt pretensioners with occupant-weight-dependent belt-force limiters.
- Through data exchange with other systems, e.g. ESP (Electronic Stability Program), and environment sensors, it is possible to use information from the phase shortly before the impact to further optimize the deployment of the restraints.

Side airbag

Function

Side airbags, which inflate along the length of the roof lining for head protection (inflatable tubular systems, window bags, inflatable curtains) or from the door or seat backrest (thorax bags, upper body protection) are designed to cushion the occupants and protect them from injury in the event of a side impact.

Operating principle

Due to the lack of a crumple zone, and the minimum distance between the occupants and the vehicle's side structural components, it is particularly difficult for side airbags to inflate in time. For this reason, the time required for crash sensing and activating of the side airbags is approximately 5 to 10 ms for hard side impacts. The inflation time of the approximately 12 l capacity thorax bag is not permitted to be more than 10 ms.

These requirements can be fulfilled through evaluation of peripheral (at suitable points on the body, e.g. b-pillar or door), lateral (sideways) acceleration and pressure sensors.

Rollover protection systems

Function

In the event of an accident where the vehicle rolls over, open-top vehicles such as convertibles lack the protecting and supporting roof structure of closed-top vehicles. Extendable rollover bars or the extendable head restraints provide protection against injury for occupants.

Operating principle

Current sensing concepts no longer trigger the system at a fixed threshold but rather at a threshold that conforms to a situation and only for the most common rollover situation, i.e. about the longitudinal axis. The Bosch sensing concept involves a surface micromechanical yaw-rate sensor and high-resolution acceleration sensors in the vehicle's transverse and vertical axes (y and z axes).

The yaw-rate sensor is the main sensor, while the y and z-axis acceleration sensors are used both to check plausibility and to detect the type of rollover (slope, gradient, curb impact or “soil-trip” rollover). On Bosch systems, these sensors are incorporated in the airbag triggering unit.

Deployment of occupant-protection systems is adapted to the situation according to the type of rollover, the yaw rate and the lateral acceleration, i.e. systems are triggered after between 30 and 3,000 ms by automatic selection and use of the algorithm module appropriate to the type of rollover.

Combined ECUs for seat-belt pretensioners, front and side airbags and rollover protection equipment

Optimum occupant protection against the effects of frontal, offset, oblique or pole impact is obtained through the precisely coordinated interaction of electronically detonated pyrotechnical front airbags and seat-belt pretensioners. To maximize the effect of both protective devices, they are activated with optimized time response by a common ECU installed in the passenger cell.

The following functions are currently incorporated in the central ECU, also referred to as the trigger unit:

- Crash sensing by acceleration sensor and safety switch or by two acceleration sensors without safety switch (redundant, fully electronic sensing).
- Rollover detection by yaw rate and acceleration sensors that record y and z axis acceleration in the low-*g* range (up to approximately 5 *g*).
- Prompt activation of front airbags and seat-belt pretensioners in response to different types of impact in the vehicle longitudinal direction (e.g. frontal, oblique, offset, pole, rear-end).
- Control of rollover protection equipment.
- For the side airbags, the ECU operates in conjunction with a central lateral sensor and two or four peripheral acceleration sensors. The peripheral acceleration sensors (PAS) transmit the triggering command to the central ECU via a digital interface. The central ECU triggers the

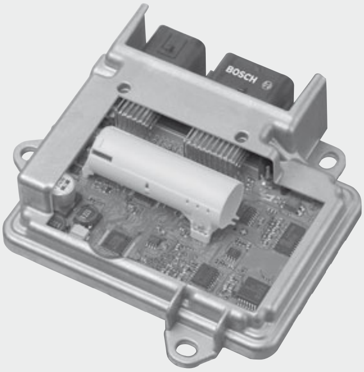
4 Central combined airbag 9 ECU (block diagram)

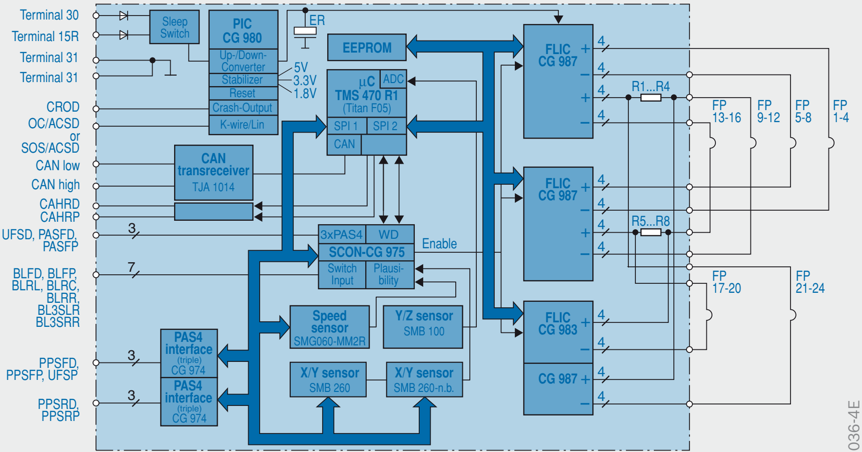
Terminal designations:

Terminal 30	Direct battery positive, not fed through ignition lock
Terminal 15R	Switched battery positive when ignition lock in “radio”, “ignition on” or “starter” position
Terminal 31	Body ground (at one of the device mounting points)

Abbreviations:

CROD	CRash Output Digital
OC/ACSD	Occupant Classification/ Automatic Child Seat Detection
SOS/ACSD	Seat-Occupancy Sensing/ Automatic Child Seat Detection
CAN low	Controller Area Network, low level
CAN high	Controller Area Network, high level
CAHRD	Crash Active Head Restraint Driver
CAHRP	Crash Active Head Restraint Passenger
UFSD	UpFront Sensor Driver
PASFD	Peripheral Acceleration Sensor Front Driver
PASFP	Peripheral Acceleration Sensor Front Passenger
BLFD	Belt Lock (switch) Front Driver
BLFP	Belt Lock (switch) Front Passenger
BLRL	Belt Lock (switch) Rear Left
BLRC	Belt Lock (switch) Rear Center
BLRR	Belt Lock (switch) Rear Right
BL3SRL	Belt Lock (switch) 3rd Seat Row Left
BL3SRR	Belt Lock (switch) 3rd Seat Row Right
PPSFD	Peripheral Pressure Sensor Front Driver
PPSFP	Peripheral Pressure Sensor Front Passenger
UFSP	UpFront Sensor Passenger
PPSRD	Peripheral Pressure Sensor Rear Driver
PPSRP	Peripheral Pressure Sensor Rear Passenger
ZP	Firing pellets 1...4 or 21...24
FLIC	Firing Loop Integrated Circuit
PIC	Periphery Integrated Circuit
SCON	Safety CONtroller
µC	Microcontroller





side airbags provided the internal lateral sensor has confirmed a side impact by means of a plausibility check. Since the central plausibility confirmation arrives too late in the case of impacts into the door or above the sill, peripheral pressure sensors (PPS) inside the door cavity are used to measure the adiabatic pressure changes caused by deformation of the door. This will result in rapid detection of door impacts. Confirmation of "plausibility" is now provided by PAS mounted on supporting peripheral structural components. This is now unquestionably faster than the central lateral-acceleration sensors.

- Voltage transformer and energy accumulator in case the supply of power from the vehicle battery is interrupted.
- Selective triggering of the seat-belt pretensioners, depending on monitored seat-belt buckle status: firing of the airbag only takes place if the belt is engaged in the belt buckle. At present, proximity-type seat-belt buckle switches are used, i.e. Hall IC switches which detect the change in the magnetic field when the buckle is fastened.
- Setting of multiple trigger thresholds for two-stage seat-belt pretensioners and two-stage front airbags depending on the status of belt use and seat occupation.
- Reading of signals from the interior sensors and appropriate triggering of restraints.
- Watchdog (WD): airbag triggering units must meet high safety standards with regard to false activation in non-crash situations and correct activation when needed (crashes). For this reason, ninth-generation (AB 9) airbags launched in 2003 incorporate three independent hardware watchdogs (WDs): WD1 monitors the 2 MHz system eClock using a dedicated, independent oscillator.
  WD2 monitors the realtime processes (time base 500 µs) for correct and complete sequence. For this reason, the safety controller (SCON, see Fig. 4) sends the microcomputer eight digital messages to which it must respond by sending eight correct replies to the SCON within a time window of 1 ± 0.3 ms.
  WD3 monitors the background processes such as the built-in self-test routines of the ARM core for correct operation. The microcomputer's response to the SCON in this case must be provided within a period of 100 ms.
- With AB 9, sensors, analyzer modules and driver stages are linked by two SPIs (Serial Peripheral Interfaces). The sensors have digital outputs and their signals can be transmitted directly via SPIs. Shunts therefore remain on the printed-circuit board without effect, unlike with analog sinusoidal transfers, and a high level of functional reliability is achieved. Deployment is only permitted if an independent hardware plausibility channel has also detected the impact and enables the driver stages for a limited period.
- Diagnosis of internal and external functions and of system components.
- Storage of failure modes and durations with crash recorder; readout via the diagnosis or CAN-bus interface.
- Warning-lamp activation.

Acceleration sensors

Acceleration sensors for crash sensing can be located at the following points in the vehicle:

- Directly integrated in the ECU (seat-belt pretensioners, front airbag)
- At selected points on the right and left-hand side of the vehicle on supporting structural parts such as seat crossmembers, door sills, b and c-pillar (side airbag) or
- In the deformation zone at the front end of the vehicle (upfront sensors for "intelligent airbag systems")

These sensors are surface micromechanical sensors consisting of fixed and moving finger structures and spring pins. Since the sensors only have low working capacitances (approximately 1 pF), it is necessary to accommodate the evaluation electronics in the same housing in the immediate proximity of the sensor element so as to avoid stray capacitance and other forms of interference.

Gas inflators

The pyrotechnical propellant charges of the gas inflators for generating the airbag inflation gas and for actuating seat-belt pretensioners are activated by an electrical firing element. The gas inflator in question inflates the airbag with charge gas. The driver airbag built in the steering-wheel hub (volume approx. 60 l) or, as the case may be, the passenger airbag fitted in the glove compartment space (approx. 120 l) is inflated in approx. 30 ms from firing.

AC firing

In order to prevent inadvertent triggering through contact between the firing element and the vehicle system voltage (e.g. faulty insulation in the wiring harness), the firing element is fired by alternating-current pulses with a frequency of approx. 80 kHz (AC firing). A small ignition capacitor with a capacitance of 470 nF incorporated in the firing circuit in the firing element plug galvanically isolates the firing element from the DC current. This isolation from the vehicle system voltage prevents inadvertent triggering, even after an accident when the airbag remains untriggered and the occupants have to be freed from the deformed passenger cell by emergency services. It may even be necessary to cut through the (permanent +) firing circuit wires in the steering column wiring harness and short-circuit them according to positive and ground.

Passenger-compartment sensing

For passenger classification, an absolute weight measuring method is available with the iBolt (intelligent bolt). These force-measuring iBolts (Fig. 1) secure the seat frame (seat link) to the sliding rail and replace the four mounting screws otherwise used. They measure the weight-dependent change in the gap between the bolt sleeve and the internal bolt with integral Hall-element IC connected to the sliding base.

Micromechanics

Micromechanics is defined as the application of semiconductor technology in the production of mechanical components from semiconductor materials (usually silicon). Not only silicon's semiconductor properties are used but also its mechanical characteristics. This enables sensor functions to be implemented in the smallest-possible space. The following techniques are used:

Bulk micromechanics

The silicon wafer material is processed using anisotropic (alkaline) etching and, where needed, an electrochemical etching stop. The material is etched away from the reverse side of the silicon layer (Fig. 1, Item 2) in those areas where it is not protected by the etching mask (1). This method can be used to create very small diaphragms (a) with typical thicknesses of between 5 and 50 µm, holes (b) and bars and ridges (c), e.g. for pressure or acceleration sensors.

Surface micromechanics

The substrate material here is a silicon wafer on whose surface very small mechanical structures are formed (Fig. 2). First of all, a "sacrificial layer" is applied and shaped (A) using semiconductor production processes (e.g. etching). An approx. 10 µm polysilicon layer is then deposited on top of this (b) and structured vertically using a mask and etching (c). In the final processing step, the "sacrificial" oxide layer underneath the polysilicon layer is removed by means of gaseous hydrogen fluoride (d). In this way, structures such as flexible electrodes (Fig. 3) for acceleration sensors can be created.

Wafer bonding

Anodic and seal glass bonding are methods used to join wafers together by the action of electricity and heat or heat and pressure in order, for instance, to hermetically seal a reference-vacuum chamber or to protect sensitive structures by placing a cap over them.

1 Structures produced by bulk micromechanics

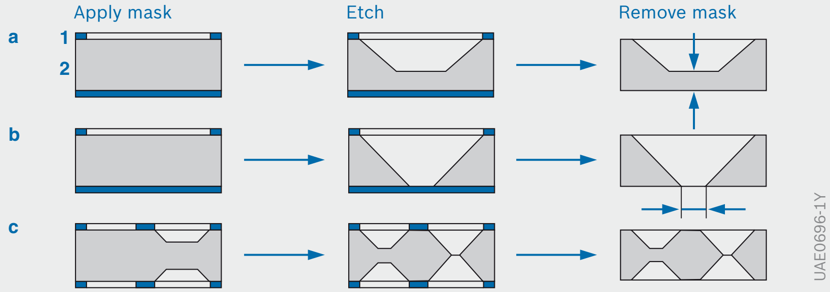


Fig. 1
a Production of diaphragms
b Production of holes
c Production of bars and ridges

1 Etching mask
2 Silicon

2 Surface micromechanics (processing steps)

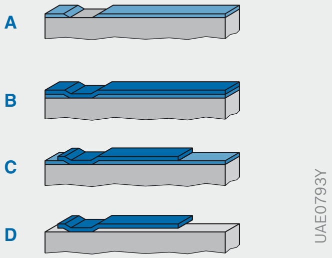


Fig. 2
A Cutting and structuring the sacrificial layer
B Cutting the polysilicon
C Structuring the polysilicon
D Removing the sacrificial layer

3 Surface micromechanics (structure details)

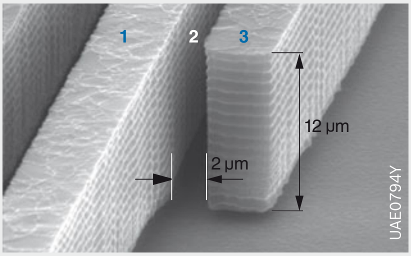


Fig. 3
1 Fixed electrode
2 Gap
3 Spring electrode