Bosch Professional
Automotive Information

Robert Bosch GmbH *Ed.*

Bosch Automotive Electrics and Automotive Electronics

Systems and Components, Networking and Hybrid Drive

5th Edition

Springer Vieweg

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Foreword

In recent decades, the development of the motor vehicle has been marked by the introduction of electronics. At first, electronic systems were used to control the engine (electronic fuel-injection systems), then electronic components entered the domain of driving safety (e.g. antilock brake system, ABS). More recently, completely new fields of application have emerged in the areas of driving assistance, infotainment and communication as a result of continuous advancements in semiconductor technology. Consequently, the proportion of electrics and electronics in the motor vehicle has continuously increased.

A typical feature of many of these new systems is that they no longer perform their function as stand-alone systems but operate in interaction with other systems. If the flow of information between these systems is to be maintained, the electronic control units must be networked with each other. Various bus systems have been developed for this purpose. Networking in the motor vehicle is a topic that receives comprehensive coverage in this book.

Powerful electronic systems not only require information about operating states, but also data from the vehicle's surroundings. Sensors therefore play an important role in the area of automotive electronics. The number of sensors used in the motor vehicle will continue to rise.

The complexity of the vehicle system is set to increase still further in the near future. To guarantee operational reliability in view of this complexity, new methods of electronics development are called for. The objective is to create a standardized architecture for the electrical system/electronics that also offers short development times in addition to high reliability for the electronic systems.

Besides the innovations in the areas of comfort/convenience, safety and infotainment, there is a topic that stands out in view of high fuel prices and demands for cutting CO_2 emissions: fuel consumption. In the hybrid drive, there is great potential for lowering fuel consumption and reducing exhaust-gas emissions. The combination of internal-combustion engine and electric motor enables the use of smaller engines that can be operated in a more economically efficient range. Further consumption-cutting measures are start/stop operation and the recuperation of brake energy (recuperative braking). This book addresses the fundamental hybrid concepts.

The traditional subject areas of automotive electrical systems are the vehicle electrical system, including starter battery, alternator and starter. These topics have been revised for the new edition. New to this edition is the subject of electrical energy management (EEM), which coordinates the interaction of the alternator, battery and electrical consumers during vehicle operation and controls the entire electrical energy balance.

The new edition of the "Automotive Electric/Automotive Electronics" technical manual equips the reader with a powerful tool of reference for information about the level of today's technology in the field of vehicle electrical systems and electronics. Many topics are addressed in detail, while others – particularly the electronic systems – are only presented in overview form. These topics receive in-depth coverage in other books in our series.

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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

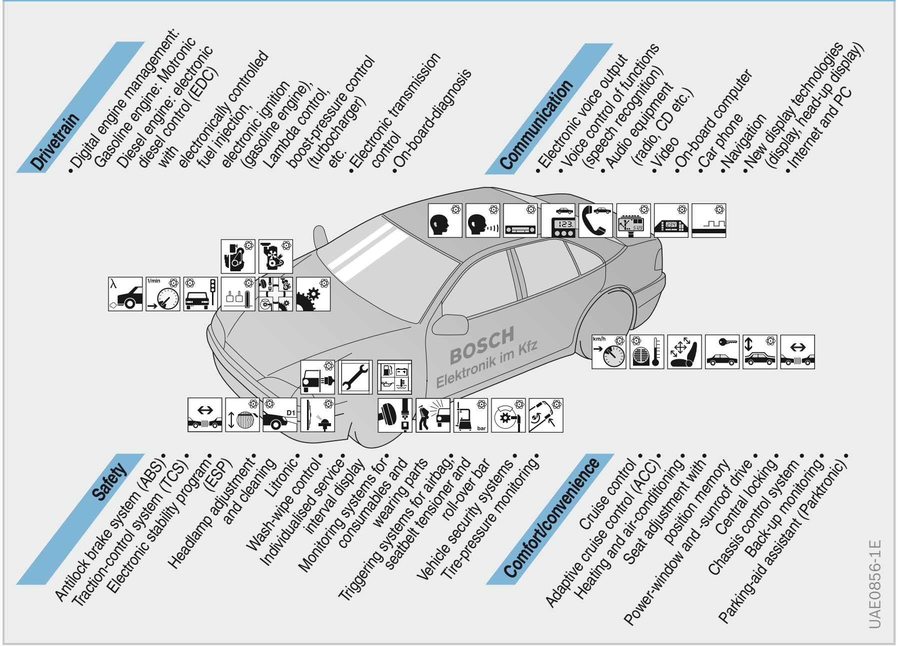
Development of electronic systems

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



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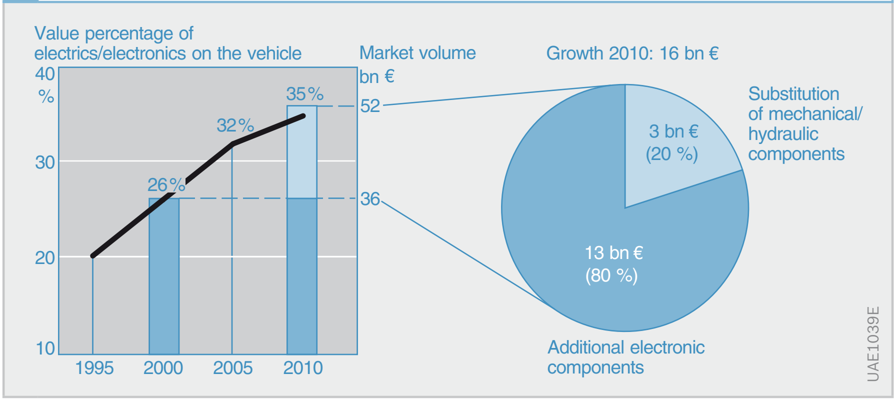
2 Market volumes of electrics/electronics in Europe (estimates)



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.

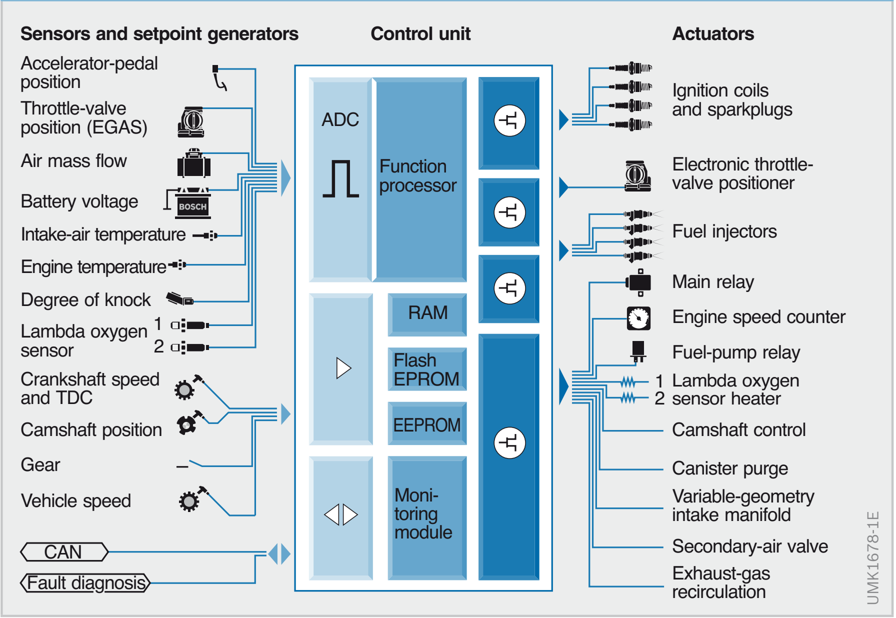
The input variables for the sequence control are derived from the signals from sensors and setpoint generators. They influence the calculations in the algorithms, and thus the triggering signals for the actuators. These convert into mechanical variables the electrical signals that are output by the microcontroller 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)

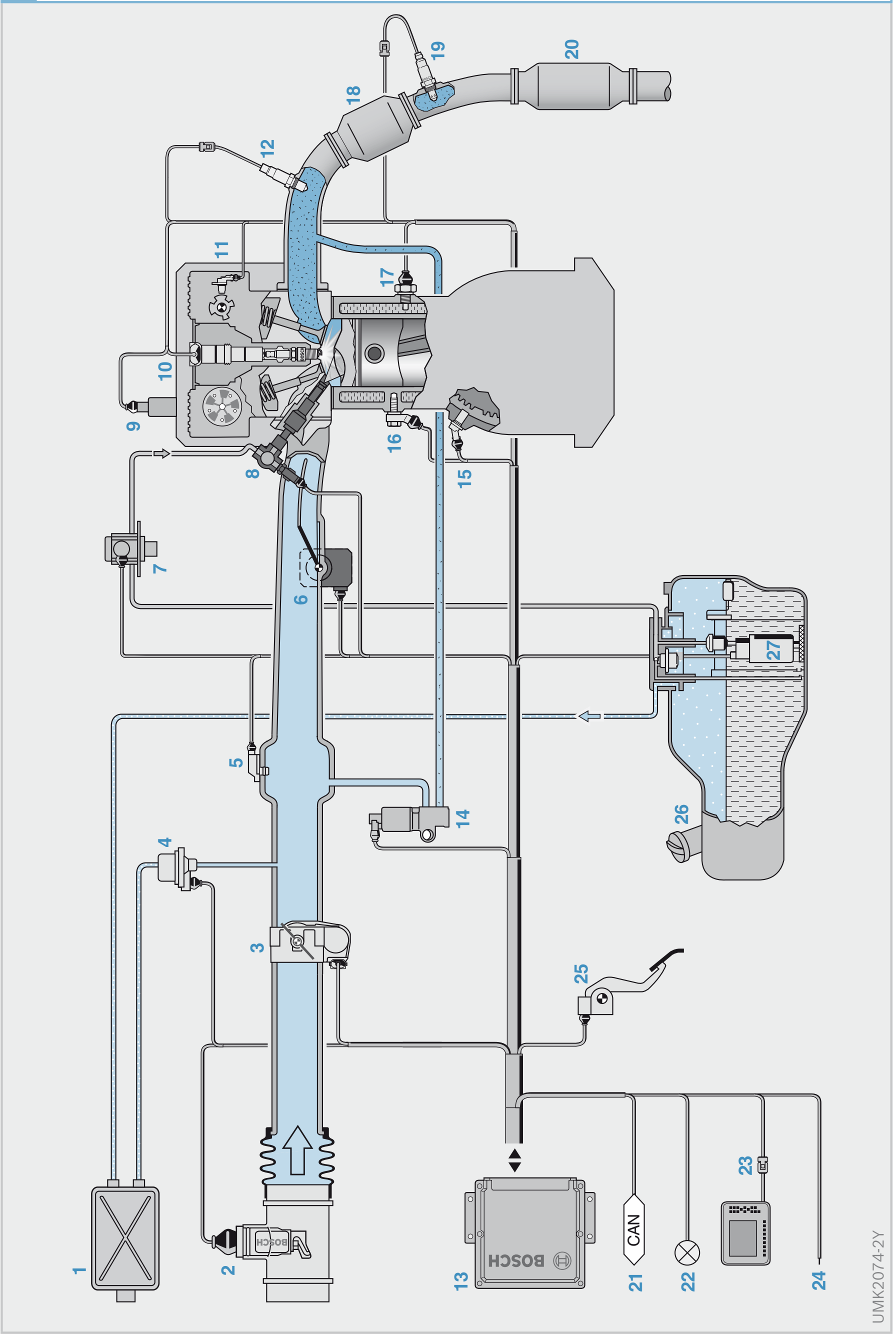


Fig. 1

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

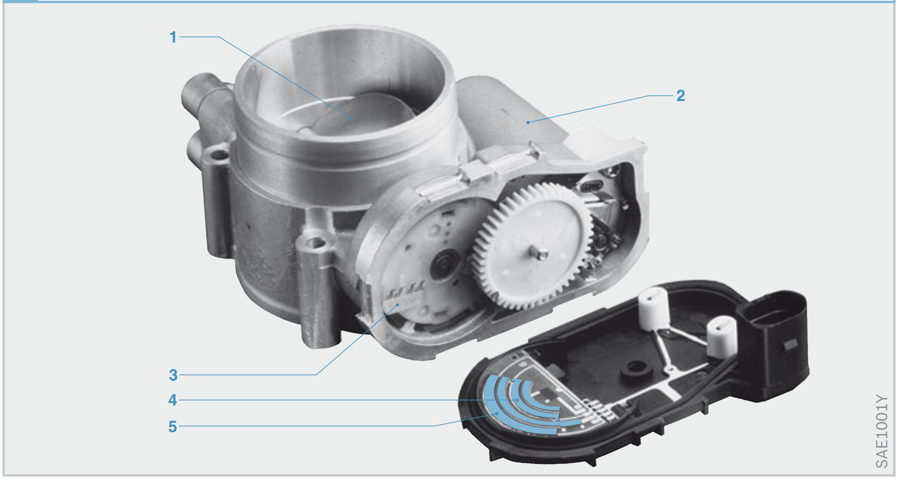


Fig. 2

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

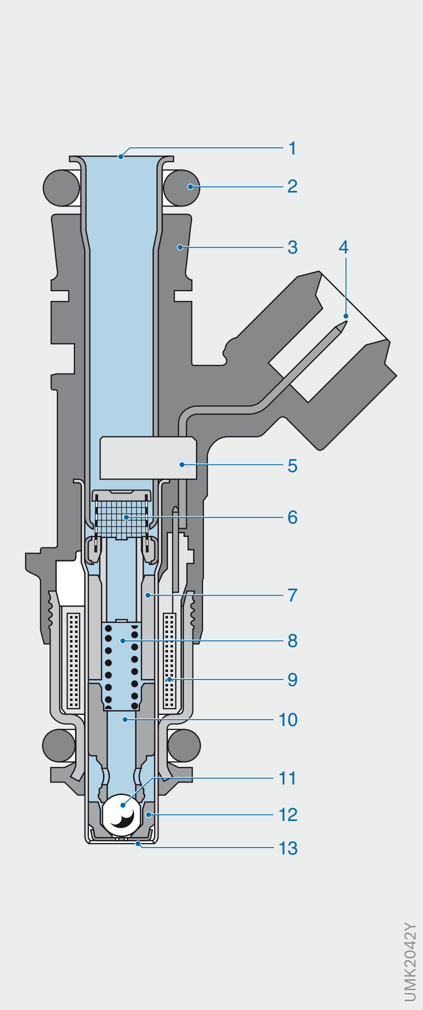


Fig. 3

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

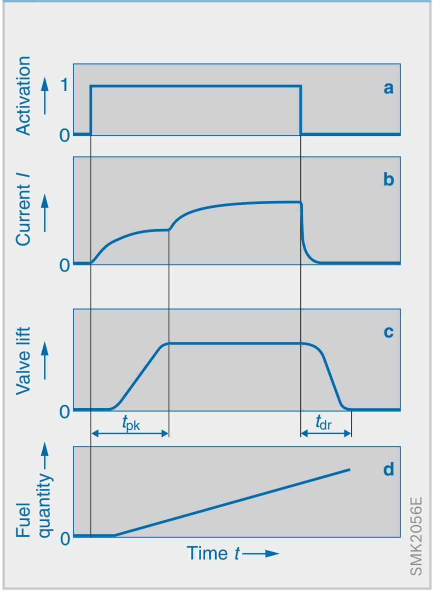
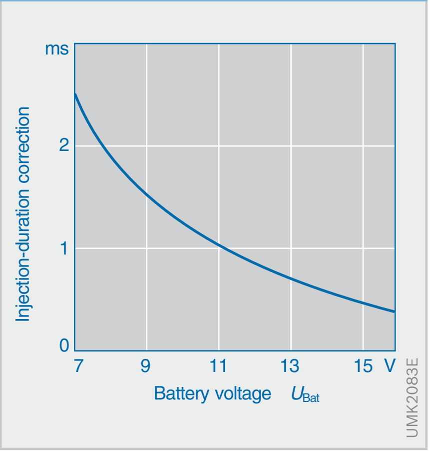


Fig. 4
a Activation signal
b Current curve
c Valve lift
d Injected fuel quantity

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

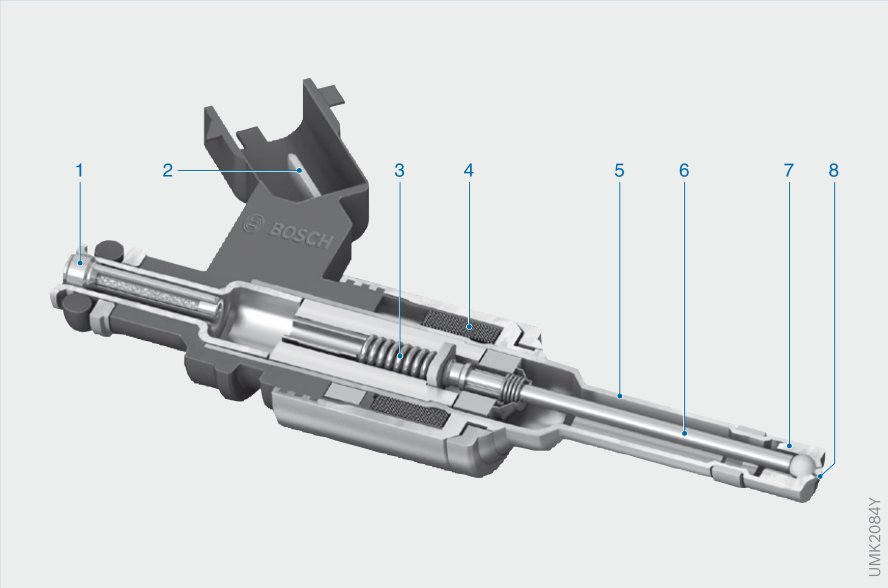


Fig. 6

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.

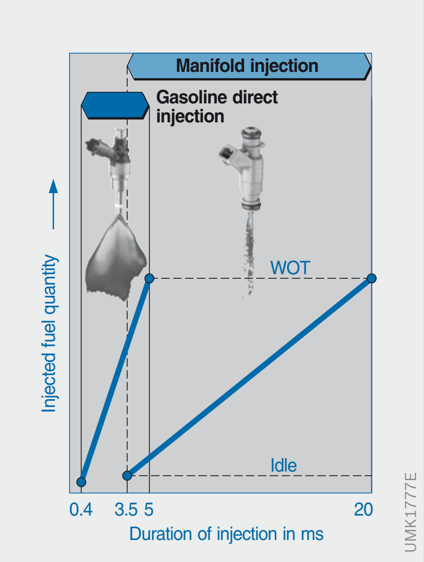
Actuation of HDEV high-pressure fuel injector

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

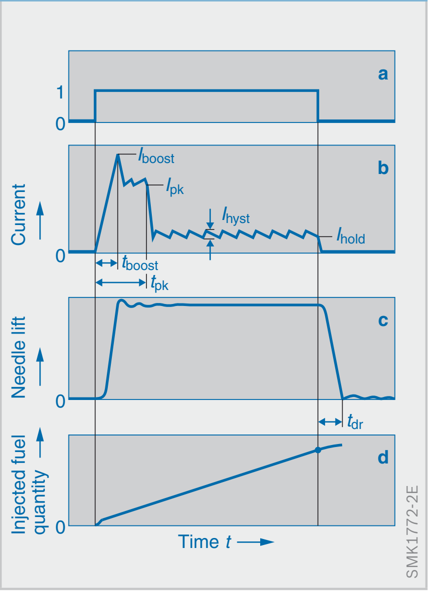


Fig. 7
Injected fuel quantity as a function of injection duration

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

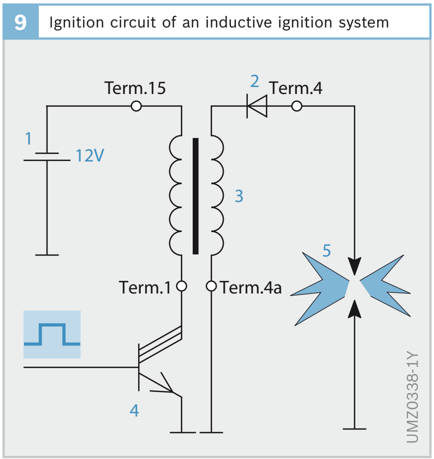


Fig. 9
1 Battery
2 AAS diode (integrated in ignition coil)
3 Ignition coil with iron core and primary and secondary windings
4 Ignition driver stage (integrated either in Motronic ECU or in ignition coil)
5 Spark plug

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

10 Voltage curve at the electrodes

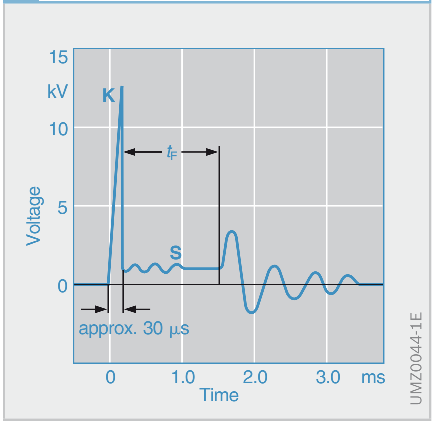


Fig. 10
K Spark head
S Spark tail
t_F Spark duration

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

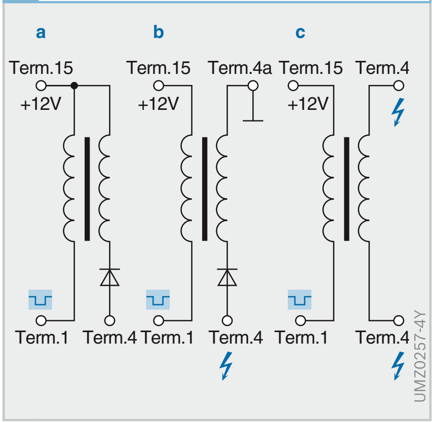


Fig. 11

- 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.

12 Compact-coil design

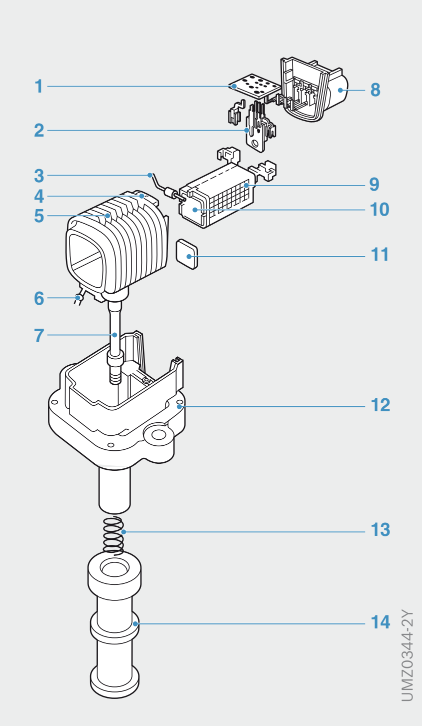


Fig. 12

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

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.

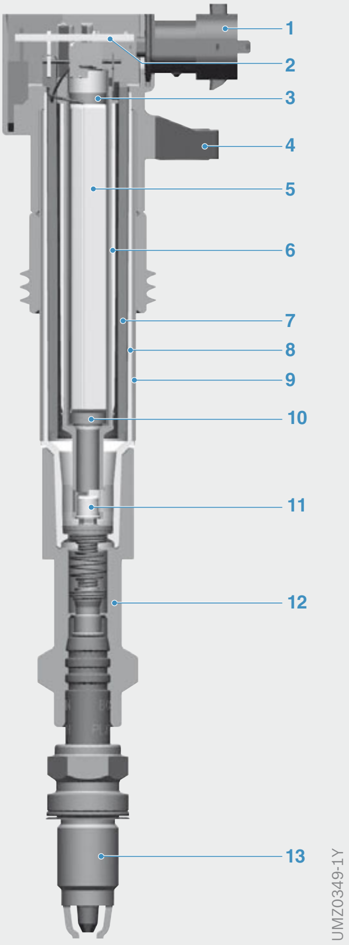
The COP and remote versions are virtually identical in design. However, the remote version (mounted on the vehicle body) is subject to fewer demands with regard to temperature and vibration conditions due to the fact that it is exposed to fewer loads and strains.

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.

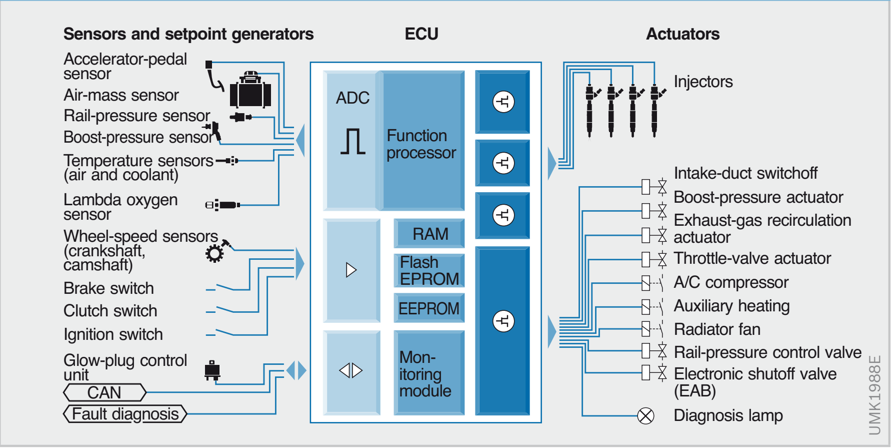
State-of-the-art technology is represented today by direct-injection diesel engines (DI) with high injection pressures for efficient mixture formation. The fuel-injection systems support several injection processes: pre-injection, main injection, and secondary injection. These injection processes are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

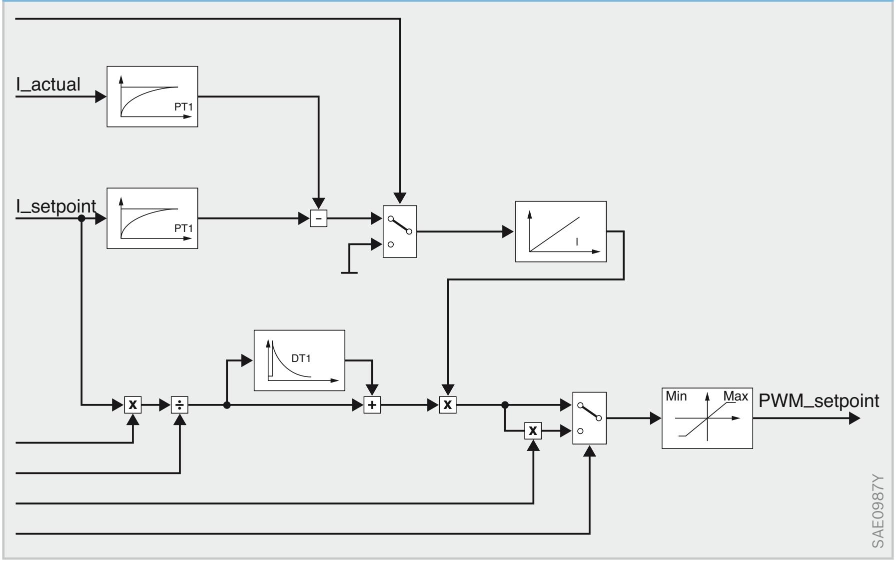
The main function of the electronic diesel control (EDC) is to control the injected fuel quantity and the injection timing. The common-rail accumulator injection system also controls injection pressure. Furthermore, on all systems, the engine ECU controls a number of actuators. The EDC functions must 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".

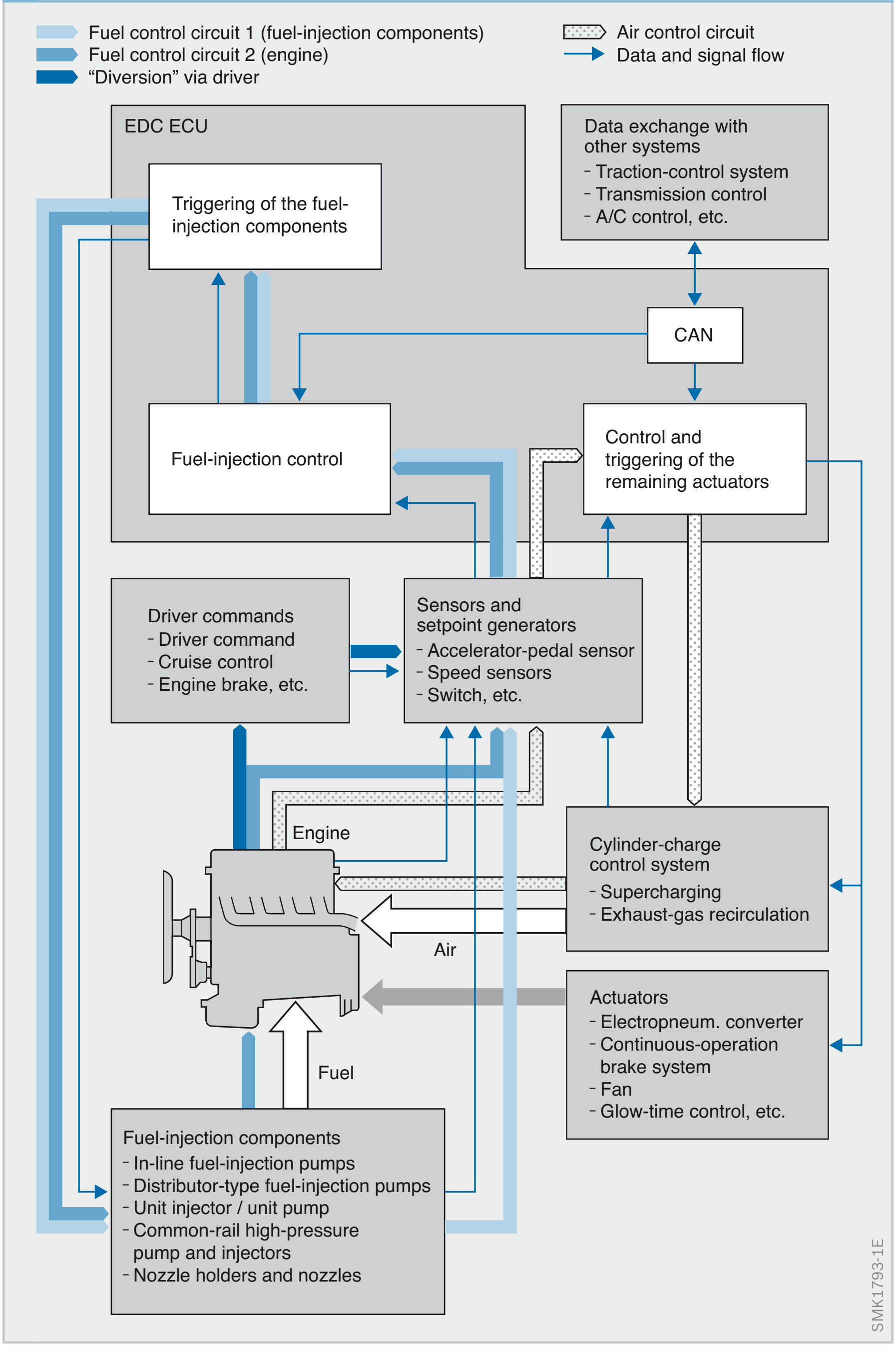
The required degree of accuracy together with the diesel engine's outstanding dynamic response requires high-level computing power. The output signals are applied to driver stages which provide adequate power for the actuators (for instance, the high-pressure solenoid valves for fuel injection, exhaust-gas 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)	–

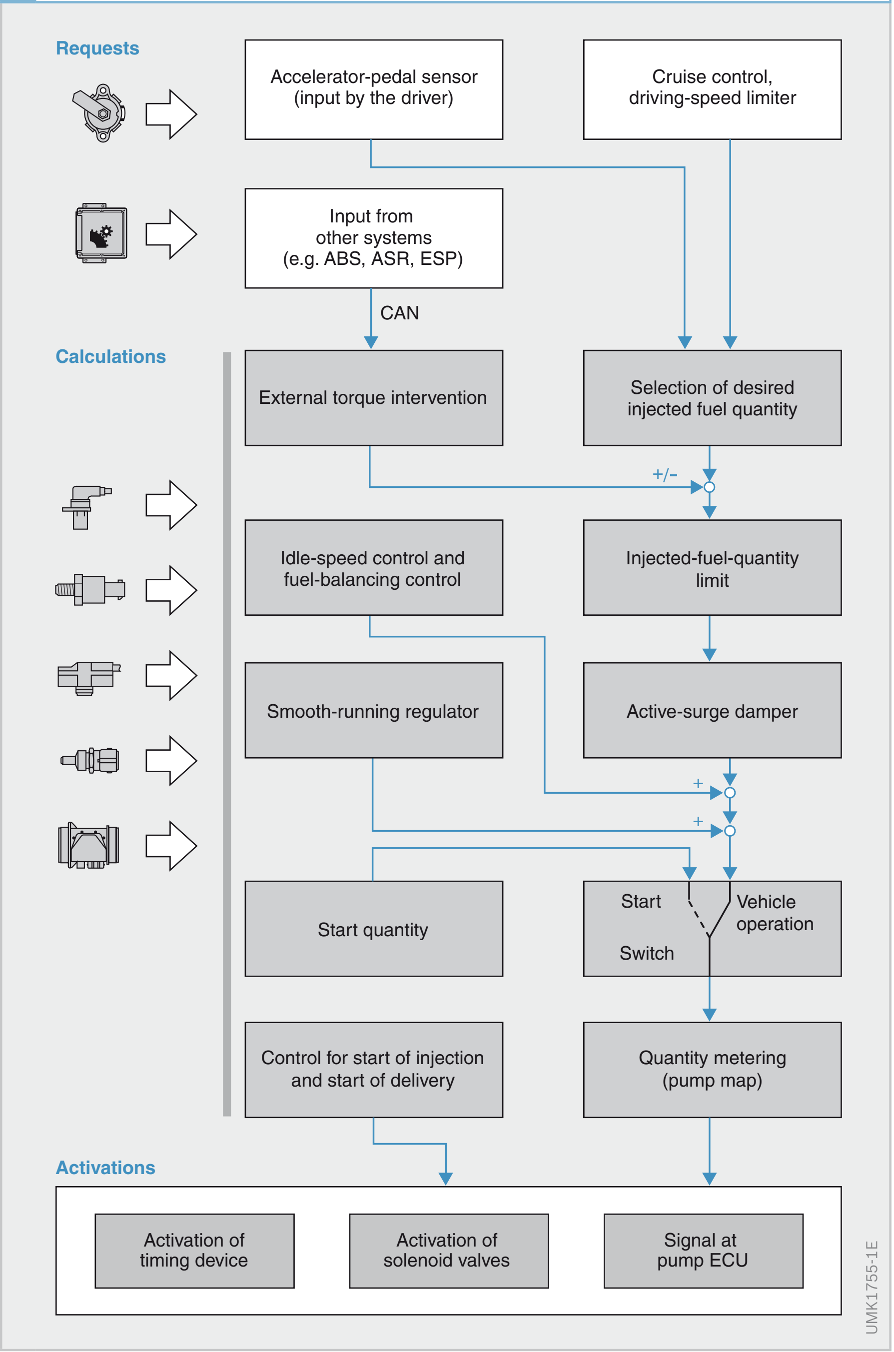
Table 1

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

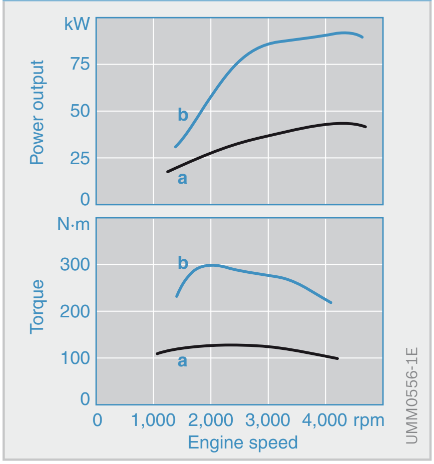


Fig. 5
a Build year 1968
b Build year 1998