

BOSCH

Automotive Handbook

6th
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Foreword to the 6th Edition

The history of the automobile's development is also an impressive documentation of technical innovations. New systems and detail enhancements make driving even safer and more comfortable, and continue to reduce the environmental impact by engine emissions and manufacturing processes. The 6th Edition of the "Automotive Handbook" reflects this development by including a number of new subjects and complete revisions of existing sections. Compared with the previous edition, the handbook has grown by about 270 pages.

The "Automotive Handbook" is an important reference work with worldwide distribution due to its up-to-date sections that are worded concisely. It is intended to provide an insight into the modern state of automotive technology for engineers and technicians, as well as those who are interested in technical matters.

The authors in the 6th Edition are experts from the Bosch corporation, universities, and the automotive industry. They have completely revised the contents of this handbook, brought it up-to-date, and expanded it with new subjects. We would like to take this opportunity of thanking all those involved for their cooperation.

In more than seven years the Automotive Handbook has grown from a calendar insert of 96 pages to an extensive work now with over 1,200 pages. In the meantime its circulation in several languages total more than a million copies.

The new edition has a revised page layout to provide better navigation for the reader. The left page title indicates the generic subject, while the right page title is the chapter heading. The redesigned and extended table of contents now contains all chapters and sections. This will help the reader to search for subjects more easily.

The Editors

For your information

The following subjects have been added since the 6th Edition:

Hydrostatics • Fluid mechanics • Mechatronics • Coating systems • Frictional joints • Positive or form-closed joints • Engine lubrication • Emission reduction systems • Diagnosis • Truck brake management as a platform for truck driver assistance systems • Analog and digital signal transmission • Mobile information services • Fleet management • Multimedia systems • Developments methods and application tools for electronic systems • Sound design • Vehicle wind tunnels • Environmental management • Workshop technology.

The following subjects have been totally revised and restructured:

Basic equations used in mechanics • Threaded fasteners • Springs • Air filtration • Exhaust-gas measuring techniques • Engine management for spark-ignition (SI) engines (including Motronic engine management) • Diesel-engine management • Car radio with auxiliary equipment • Vehicle antennas • Mobile and data radio • Passenger-car driver assistance systems.

The following subjects have been updated, expanded and restructured:

Acoustics • Heat • Electronics • Substances • Materials • Corrosion • Tribology • Lubricants • Fuels • Antifreeze and brake fluid • Chemicals • Heat treatment • Motor-vehicle dynamics • Motor-vehicle requirements • Internal-combustion engines • Engine cooling • Battery chargers • Exhaust-gas system • Alternative spark-ignition engine drive systems • Hybrid drives • Drivetrain • Suspension • Wheels • Tires • Braking systems • Braking systems for passenger cars and commercial vehicles • Vehicle stabilization systems for passenger cars and commercial vehicles • Vehicle bodies for passenger cars and commercial vehicles • Lighting technology (with cornering headlamps) • Instrumentation • Driving information system • Trip recorders • Parking systems • Navigation systems • Traffic control engineering • Electromagnetic compatibility • Occupant safety systems • Comfort and convenience systems • Starter batteries • Alternators • Starting systems.

Integrated analog circuits

- Basic structures:
 - Stabilized-voltage supply, stabilized-current supply, differential amplifier components, switching elements, potential shift, output stages.
- Application-oriented classes:
 - Operational amplifiers (OP), voltage regulators, comparators, timers, converters, interface circuits.
- Special analog ICs:
 - Voltage references, wideband amplifiers, analog multipliers, function generators, phase-lock circuits, analog filters, analog switches.

Integrated digital circuits

The spectrum ranges from LSI (simple logic chips) through to ULSI (memories, microcomponents).

Several conditions must be met before logic chips can be combined within a single system: The power supply, logic level, the circuit speed, and the signal transit time must all be identical. This requirement is met within the respective circuit families.

The most important are:

- Various bipolar types (e.g. TTL; Transistor-Transistor-Logic)
- MOS logic, in particular CMOS logic

MOS and CMOS chips make up more than 99% of the production of integrated digital circuits. Bipolar logic circuits are only used in exceptional cases. Here, too, CMOS devices are taking their place more and more.

Semiconductor memories

Data storage includes the following operations: recording (writing, entering), storage (data storage in the narrow sense), retrieval, and readout. The memory operates by exploiting physical properties that facilitate unambiguous production and recognition of two opposed states (binary information). In semiconductor memories, the states produced are "conductive/non-conductive" or "charged/discharged"; the latter state relies on special properties in the silicon/silicon oxide or silicon nitride/metal junction. In future magnetic memory chips (FDRAM) will also be used. They have small ferromagnetic areas integrated on the chip. The direction of the magnetic field is used to store information.

Semiconductor memories are divided into the two main categories of "volatile" and "non-volatile". Virtually all of them are manufactured according to CMOS technology.

- Volatile memories** (short-term memories) can be read and over written any number of times, and are therefore referred to as RAMs (Random Access Memories); the information content is lost when the power supply is switched off.

- Non-volatile memory chips** (long-term memories) retain their data even when the power supply is switched off; they are also referred to as ROMs (Read-Only Memory).

The chart on the facing page shows the relationships and classification of the most common types of memory chip.

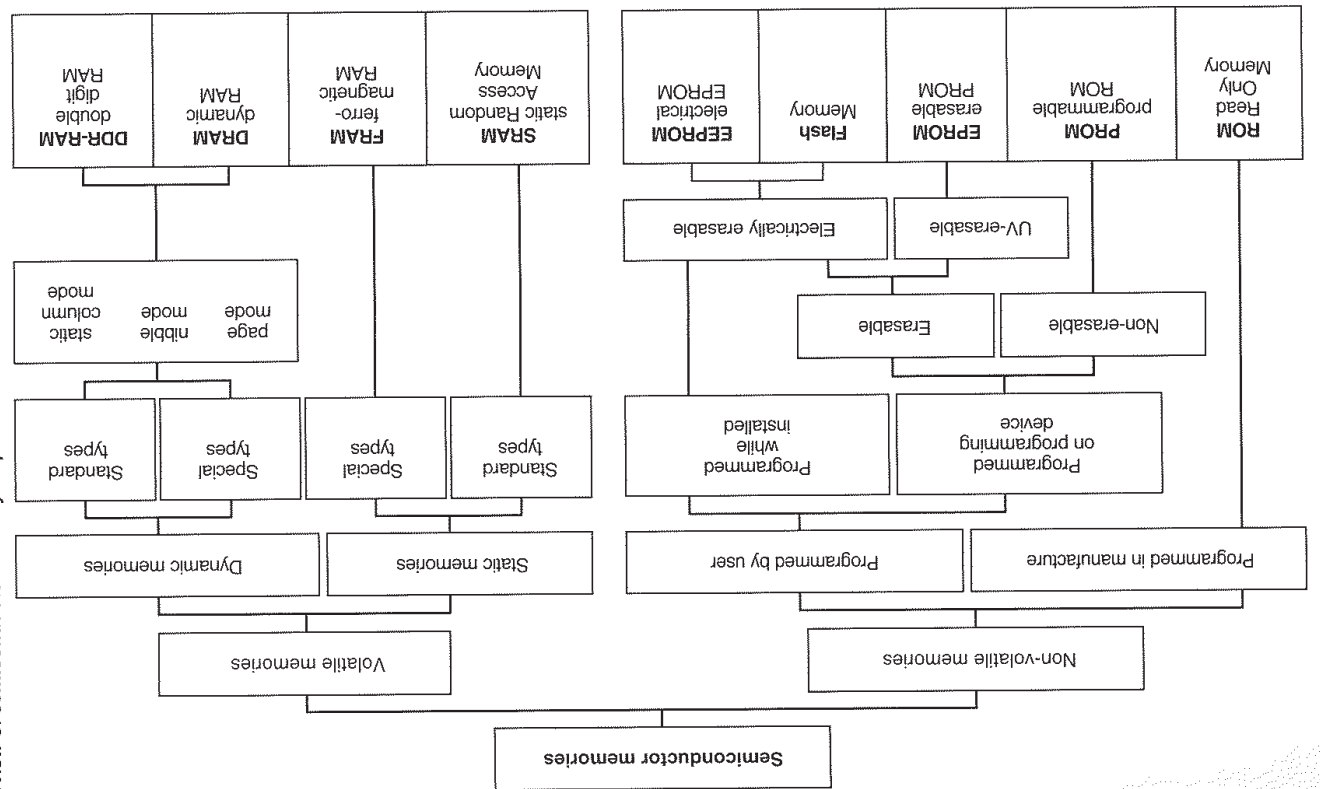
Microprocessors and microcomputers

The microprocessor represents the integration of a computer's central processing unit on a single chip. Microprocessor design seeks to avoid individualization in the face of large-scale integration, and the units can be programmed to meet the varied requirements associated with specific operating conditions. There are two different main groups of processor. A PC (Personal Computer) uses CISC processors (CISC: Complete Instruction Set Computing). These processors are very versatile and user-programmable. A WS (work station) normally uses RISC processors (RISC: Reduced Instruction Set Computing). These processors are very much faster for the specific tasks frequently associated with WS use, but are significantly slower for all other tasks. A microprocessor cannot operate by itself: it always acts as part of a microcomputer.

A microcomputer consists of:

- Microprocessor serving as CPU (central processing unit). The microprocessor contains the controller and the arithmetic-logic unit. The arithmetic and logic unit performs the operations indicated by its name, while the controller ensures implementation of the commands stored in the program memory. Input and output units (I/O), which control data communication with the peripherals.

Overview of semiconductor memory chips



- Program memory which provides permanent storage for the operating program (user program), thus ROM, PROM, or EPROM.
- Data memory for the data being run at any given time. This data changes continuously; thus, the storage medium for this application is the RAM. Part of the RAM (cache) is integrated on the microcomputer since CPU speed would otherwise be drastically reduced due to the high data rates, and there would be no use in deploying a high-speed processor if the required data were always sent over external buses. SRAMs are always used in these cases owing to the low access times required.
- Clock generator and power-supply system.
- The bus system links the individual elements in a microcomputer.
- A clock generator makes sure that all the operations in the microcomputer take place within a specified timeframe.
- Logic circuits are chips that carry out special tasks, such as program interrupts, inserting intermediate programs, etc.
- The periphery includes input/output devices and external memories, e.g. the main memory (DRAM) or the hard disk.

The main components of a microcomputer are normally combined as separate components on printed-circuit boards. "Single-chip" computers are becoming used more and more for simpler tasks, e.g. internet access in wireless communications, which is a growing trend, or functions integrated on a single silicon chip (SoC: System on a Chip). The performance of these high-integration systems is limited by the relatively small amount of RAM which can be accommodated at reasonable expense on the chip.

A microcontroller includes at least the CPU function, read-only memory (ROM, EPROM, or EEPROM), input/output capability (I/O), and random-access memory (RAM) on a single chip. In some cases, analog functions are only integrated on the chip. In contrast to a microcomputer, the controller reacts with a specified program that provides particular

output values depending on the input information. It is used to control self-governing systems, e.g. engine management.

The transputer is a special type of microprocessor which is especially useful for building parallel computer networks. In addition to the standard microprocessor components, the chip is also equipped with communications and processing hardware.

It has at least four serial bidirectional transmission channels (links), allowing extremely high-speed (> 1 Gbit/s per link) communications with many other transputers. As communications are completely asynchronous, distributed networks do not require a common clock circuit. Each link has its own DMA controller; once initialized by the CPU, it can carry out data transmission on its own. Thus, processing and communications are essentially parallel operations. Of particular significance are the extremely short process switchover and interrupt-response times of $\leq 1 \mu s$. The transputer does not need a real-time operating system for this; instead, it has the necessary processing commands directly in its command set.

The transputer operates as a communication node within the parallel network, meaning that it serves as both computer and communications interface. The transputer can therefore be employed to avoid one of the gravest liabilities of many parallel systems, which is the inherent need to share a common bus. Maximum-performance computers are therefore built using transputers.

Application-specific ICs

Application-specific IC (ASIC: Application Specific Integrated Circuits or also ASSP: Application Specific Standard Product) are only designed for a single application, as opposed to standard ICs. ASICs are produced for, and sold only to, one customer. ASSPs are application-specific ICs which are sold to several customers for the same application. Both are the result of a successful cooperation between users who share special system expertise, and producers who possess suitable technologies. The essential advan-

tages of ASICs: fewer components, lower system costs, increased reliability, more difficult to copy.

The ASIC family is generally classified according to the development method which has been selected: chip-mounted circuitry, constructed from individual function elements (full-custom IC), provides the best results with regard to operation and packaging density. It is, however, only suited for large-volume applications (time and expense).

Standardized basic circuit functions (developed and tested in advance) represent one step towards rationalizing the development process. The circuits are incorporated in cells of varying sizes (ROM, RAM, computer core, or individualized, application-specific circuit groups). Depending on the number of available application-specific cells, this method can be employed to reduce development times without sacrificing efficient exploitation of the chip surface.

The next stage is the use of standardized, relatively complex basic functions which are developed in advance in standard cells of the same height and variable width. They are available in the form of cell libraries. These standard cells are automatically placed in series and then automatically connected with polysilicon and aluminum conductors. A dual or triple-layer metallic coating can be applied to achieve even better utilization of the surface area.

Gate arrays are predeveloped as far as the transistor/gate connection, and are manufactured in advance, leaving only the final masking operations for later completion. The connection with the application-specific circuit is then automatic. Rationalization is achieved by providing standard circuits for frequent basic computer functions (similar to a cell library). Special gate arrays designed for specific applications have particular advantages (e.g. pure computer-oriented digital circuits under the general conditions usual for computers).

Programmable logic devices (PLD) - completely preassembled transistor arrays - are programmed by the user in

the same way as a special-application PROM. PLDs thus provide system developers with the option of producing silicon breadboard circuits within a short period of time. The production of complex systems in silicon is becoming increasingly important, as it allows the production of practical working models in the development phase.

Smart-power ICs

Automotive and industrial systems rely upon electronics to govern numerous functional-control elements and other loads. Circuit-breakers must be capable of assuming auxiliary functions extending beyond the control of circuit power: driver circuits for activating switching transistors, protective circuits for excess current, overvoltage, overtemperature, and fault acknowledgment in case of incorrect operation. Such bipolar or MOS-technology power ICs are generically termed smart-power ICs.

Film and hybrid circuits, MCM

Film circuits

The integrated film circuit features passive circuit elements - these include capacitor and inductors, as well as conductor tracks, insulators, and resistors. An integrated film circuit is produced by applying the layers which contain these elements to a substrate carrier. The terms "thin-film" and "thick-film" circuit derive from the fact that the film thickness was originally the determining factor for tailoring to specific performance characteristics; present technology employs a variety of manufacturing techniques to achieve the same end.

Thin-film circuits

Integrated film circuits on which the individual layers are applied to glass or ceramic substrates, usually in a vacuum coating process. Advantages: fine structures (to approx. 10 μm) provide high circuit-element density, extremely good HF characteristics, and low-noise resistor elements. On the minus side are the relatively high manufacturing costs.

Internal-combustion engines

Operating concepts and classifications

The internal-combustion (IC) engine is the most frequently employed power source for motor vehicles. Internal-combustion engines generate power by converting chemical energy bound in the fuel into heat, and the heat thus produced into mechanical work. The conversion of chemical energy into heat is accomplished through combustion, while the subsequent conversion of this thermal energy into mechanical work is performed by allowing the heat energy to increase the pressure within a medium which then performs work as it expands.

Liquids, which supply an increase in working pressure via a phase transformation (vaporization), or gases, whose working pressure can be increased through compression, are used as working media.

The fuels – largely hydrocarbons – require oxygen in order to burn; the required oxygen is usually supplied as a constituent of the intake air. If fuel combustion

occurs in the cylinder itself, the process is called internal combustion. Here the combustion gas itself is used as the working medium. If combustion takes place outside of the cylinder, the process is called external combustion.

Continuous mechanical work is possible only in a cyclic process (piston engine) or a continuous process (gas turbine) of heat absorption, expansion (production of work) and return of the working medium to its initial condition (combustion cycle).

If the working medium is altered as it absorbs heat, e.g. when a portion of its constituents serve as an oxidant, restoration of its initial condition is possible only through replacement.

This is called an open cycle, and is characterized by cyclic gas exchange (expulsion of the combustion gases and induction of the fresh charge). Internal combustion therefore always requires an open cycle.

In external combustion, the actual working medium remains chemically unchanged, and can thus be returned to its initial condition by suitable measures (cooling, condensation). This enables the use of a closed process.

Table 1. Classification of the internal-combustion engine

Type of process	Open process		Closed process	
	Internal combustion		External combustion	
Type of combustion	Combustion gas Δ working medium		Combustion gas $\neq$ working medium	
			Phase transformation in working medium	
Type of ignition	Cyclic combustion		Continuous combustion	
	Auto-ignition		Externally supplied ignition	
Type of machine	Engine Δ machine enclosing a working chamber	Diesel	Spark ignition	Stirling
	Turbine Δ gas turbine	Hybrid	Gas	Hot steam
Type of mixture	Heterogeneous (in the combustion chamber)		Homogeneous (in a continuous flame)	
	Heterogeneous (in the combustion chamber)		Heterogeneous (in a continuous flame)	

Cycles

The p - V diagram

A basic precondition for continuous conversion of thermal energy into kinetic energy is a modification in the condition of the working medium. It is also desirable that as much of the working medium as possible be returned to its initial condition. For technical applications, the focus can rest on changes in pressure and the corresponding volumetric variations which can be plotted on a pressure vs. volume work diagram, or p - V diagram for short.

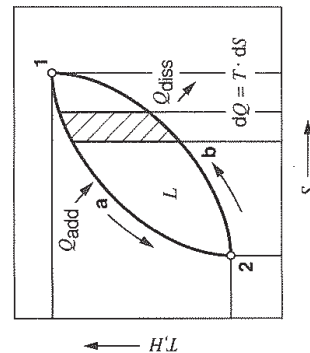
As the figure shows, the addition of heat and the change in condition of the working medium that accompany the progress of the process in the 1→2 phase must consume less energy than that required for the 2→1 phase. Once this condition is satisfied, the result is an area corresponding to the process work potential: $L = \oint V dp$.

The T - S diagram

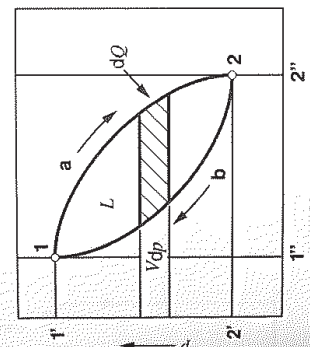
The temperature entropy, or T - S diagram, is used to provide a similar graphic representation of the bidirectional thermal energy transfers in this cyclic process.

In the T - S diagram, heat quantities can be represented as areas in the same manner that work is represented as an area in the p - V diagram. With known specific working-medium heats, the T - S diagram can be transformed into the H - S diagram, known as the enthalpy-entropy diagram, in accordance with the equation $dH = c_p \cdot dT$.

A thermodynamic cycle illustrated using the T - S or H - S diagram



A thermodynamic cycle illustrated using the p - V diagram



The cycle illustrated in the p - V diagram on P. 449 shows the amount of heat added along "a";

$$Q_{\text{add}} = \int_2^1 T_a \, ds$$

and the amount of heat dissipated along "b";

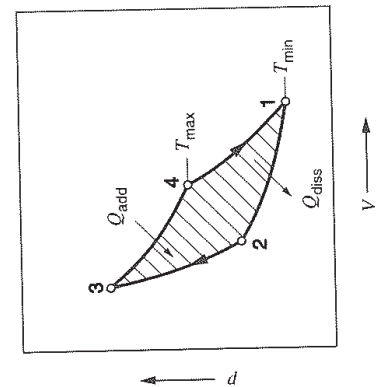
$$Q_{\text{diss}} = \int_1^2 T_b \, ds, \text{ where}$$

$$Q_{\text{add}} - Q_{\text{diss}} = L = \oint V dp$$

(difference between the amount of heat supplied and the amount of heat discharged) which corresponds to the available amount of mechanical work. The diagram also shows that a thermal efficiency $\eta_{\text{th}} = (Q_{\text{add}} - Q_{\text{diss}})/Q_{\text{add}}$ can be defined based on the equality of mechanical work and the difference between the heat quantities. It also illustrates the theoretical cycle providing the maximum amount of technical work, as found in the area between two specified temperatures for the working medium (Efficiency definition P. 453).

- 1) Isothermal change in condition: temperature does not change.
- 2) Isentropic change in condition: adiabatic (heat is neither added nor dissipated) and frictionless (reversible).
- 3) Isochoric change in condition: volume does not change; see P. 451.

The Carnot cycle in the p - V and T - S diagrams



The Carnot cycle

This cycle, described in 1824 by Carnot, consists of two isothermal¹⁾ and two isentropic²⁾ changes in condition, which yield the maximum area in the T - S diagram between T_{max} and T_{min} . As the Carnot cycle represents maximum process efficiency between the defined temperature limits, it is the theoretical optimum for converting heat into work:

$$\eta_{\text{thCarnot}} = (T_{\text{max}} - T_{\text{min}})/T_{\text{max}}$$

Real combustion processes

Internal-combustion engines operate according to different cycles, however, because isothermal compression, i.e. a pressure increase in the working medium without an increase in temperature, and isothermal expansion are not technically feasible.

Theoretical treatment today involves the following ideal combustion cycles:

- the constant-volume cycle for all piston engines with periodic combustion and generation of work, and
- the constant-pressure cycle for all turbine engines with continuous combustion and generation of work

Both cycles will be dealt with in more detail in the discussion of the corresponding machines.

Reciprocating-piston engines with internal combustion

Operating concept

All reciprocating-piston engines operate by compressing air or an air/fuel mixture in the working cylinder prior to igniting the mixture, or by injecting fuel into the hot compressed air to initiate combustion. The crankshaft assembly converts the work generated in this process into torque available at the end of the crankshaft.

The p - V diagram reflects the actual power-generation process in the engine as a function of piston travel. It shows the mean effective pressures p_{me} within the cylinder during a complete working cycle. Easier to produce are other diagrams such as the pressure vs. time (p - t) and the pressure vs. crankshaft angle (p - α) diagrams. The surfaces defined in these two diagrams do not directly indicate the amount of work generated, but they do provide a clear picture of essential data such as ignition point and peak injection pressure.

The product of the mean effective pressure in the cylinder and the piston displacement yields the piston work, and the number of working cycles per unit of time indicates the piston power or the internal power (power index) for the engine. Here it will be noted that the power generated

by a reciprocating-piston internal-combustion engine increases as engine speed rises (see equations on P. 498 to P. 505).

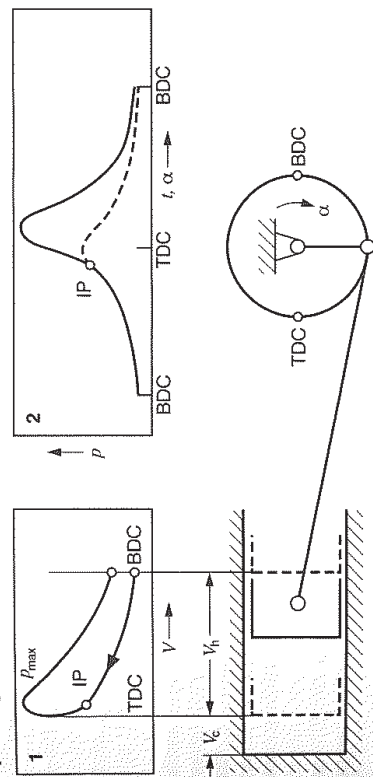
Ideal combustion cycle for piston engines with internal combustion

For reciprocating-piston engines with internal combustion, the ideal thermodynamic combustion process is the "constant-volume process" (see figure on P. 452). This process consists of isentropic²⁾ (see footnote on P. 450) compression (1-2), isochoric³⁾ heat supply (2-3, isentropic expansion (3-4) and isochoric reversion of the ideal working gas to its initial condition (4-1). This cycle is only possible if the following conditions are met:

- No heat or gas losses, no residual exhaust gas
- Ideal gas with constant specific heats c_p , c_v , and $\kappa = c_p/c_v = 1.4$
- Infinitely rapid heat supply and discharge
- No flow losses

The engine power cycle

1 in the p - V diagram (enclosed area corresponds to indicated work),
2 in the p - t and p - α diagrams.



Main components of reciprocating-piston engine

Piston

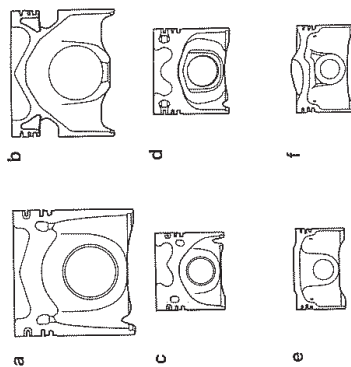
Pistons in today's motor-vehicle engines must perform a wide range of functions:

- They transmit the force generated by the combustion gas to the connecting rods.
- They serve as crossrails to define the connecting rods' travel paths within the cylinders.
- They support the normal force applied against the cylinder walls while the cylinder pressure is conveyed to the connecting rod.
- Together with their sealing elements, they seal the combustion chamber from the crankcase.
- They absorb heat for subsequent transfer to the cooling system.

Both the piston's design and the wristpin configuration employed to transfer the combustion gas forces to the connecting rod are largely determined by the combustion chamber's shape, including the geometry of the piston crown, while other variables include the selected combustion process and the associated pressure maxima. The priority is to produce the lightest possible piston in a unit capable of withstanding intense forces during operation in an environment with temperatures that can approach the physical limits of the materials used in its manufac-

Piston shapes in various engine designs

a) Commercial-vehicle aluminum diesel engine piston with ring carrier and cooling channel, b) Passenger-vehicle aluminum diesel engine piston with ring carrier and cooling channel, c) Passenger-vehicle aluminum diesel engine piston with ring carrier and cooling channel, d) Passenger-vehicle aluminum diesel engine piston with cooled ring carrier, e) Passenger-vehicle aluminum piston for MPI spark-ignition engine (Multi-Point Injection), f) Passenger-vehicle aluminum piston for GDI spark-ignition engine.



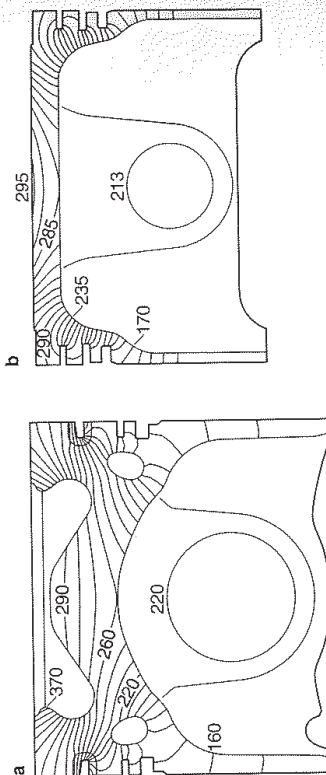
ture. Precise definition of the dimensions for the piston, wristpin and wristpin bushings are essential for achieving this goal.

The most frequently used materials for cylinder liners and pistons are gray cast iron and aluminum. Variations in piston clearance within the cylinder must be minimized to reduce noise (piston slap) and improve sealing, despite the fact that piston and cylinder liner have different coef-

Piston operating temperatures in motor-vehicle engines at WOT (schematic, values in °C)

a) Passenger-vehicle diesel engine piston 16 MPa ignition pressure, 58 kW/l.

b) Passenger-vehicle spark-ignition engine piston 7.3 MPa ignition pressure, 53 kW/l.



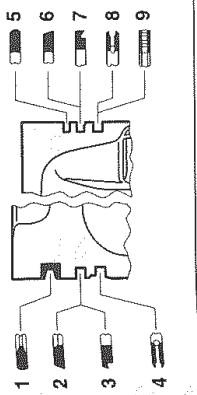
Piston-ring shapes and configurations

Diesel engine:

- 1 Keystone ring,
- 2 Taper-face compression ring with crowned, inner bevel,
- 3 Stepped compression ring,
- 4 Double-beveled ventilated oil control ring with spiral-type expander.

Spark-ignition engine:

- 5 Plain compression ring,
- 6 Taper-face compression ring,
- 7 Stepped ring,
- 8 Double-beveled ring,
- 9 Multipart steel oil ring.



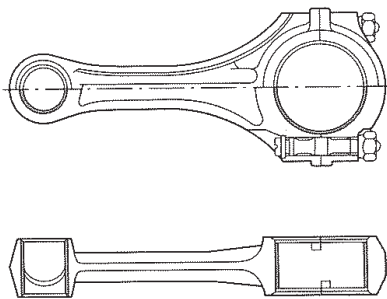
ficients of expansion. To this end, steel strips or similar elements are sometimes cast into the piston to limit its expansion.

Piston rings form the sealing element between the combustion chamber and the crankcase. The upper two – the compression rings – serve as gas seals. At least on additional ring (oil control ring or scraper ring, generally of a different design) ensures correct lubrication of the piston and the seals. Owing to the rings' extreme initial forces that they exert against the cylinder walls, they are a major source of friction loss within the reciprocating-piston engine.

Connecting rod

The connecting rod (conrod) is the joining element between piston and crankshaft. It

Passenger-car engine connecting rod



is subject to extreme tensile, compression and bending stresses, while it also houses the wristpin bushings and crankshaft bearings. Connecting-rod length is determined by the piston stroke and the counterweight radius; whereby the engine height can also be an important factor (usually the case in vehicle engines).

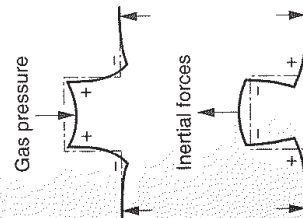
Crankshaft

The crankshaft with its rod extensions, or throws, converts the reciprocating motion of the pistons – conveyed to it by the connecting rods – into rotary motion, making effective torque available at the crankshaft's end. The forces acting on the crankshaft are characterized by highly variable periodicities and vary greatly according to location. These torques and bending moments, and the secondary vibrations which they generate, all represent intense and highly complex stress factors for the crankshaft itself. As a result, its structural properties and vibrational response patterns rely upon precise calculations and carefully defined dimensions. Calculations and dimensioning though are further complicated by the fact that too many multiple journal bearings are practically always installed as a precautionary measure.

The number of crankshaft bearings is primarily determined by the overall load factor and maximum engine speed. To accommodate their intense operating pressures, all diesel-engine crankshafts incorporate a main bearing journal between

Crankshaft throw

Primary stresses and deformations due to gas pressure and inertial forces.



Residual exhaust gas

The residual exhaust gas in the charge is formed by:

- The exhaust-gas mass which remains in the cylinder and is not discharged when the exhaust valve is open.
- The mass of recirculated exhaust gas in systems with exhaust-gas recirculation (EGR).

The amount of residual exhaust gas is determined by the charge cycle. It does not contribute directly to the combustion process, but does influence ignition and the combustion process as a whole. At the wide-open throttle, the amount of residual exhaust gas generally needs to be as small as possible in order to maximize the fresh-air mass and also the power output of the engine.

At part load, however, the amount of residual exhaust gas is desirable in order to reduce fuel consumption. This is achieved by a more favorable cycle, resulting from a change in mixture composition, and also to a reduction in pump losses during the charge cycle, as a higher intake-manifold pressure is required for the same air charge. A specifically introduced amount of residual exhaust gas can likewise reduce the emission of nitrogen oxides (NO_x) and unburned hydrocarbons (HC).

Controlling the air charge

On spark-ignition engines with external mixture formation, and on systems with internal mixture formation and homogeneous cylinder charge, the torque delivered by the engine is determined by the air charge. By contrast, on systems with internal mixture formation and excess air, the engine torque can also be controlled directly by varying the injected fuel mass (stratified-charge operation, P. 612).

Throttle valve

The critical adjustment mechanism for controlling air-mass flow is the throttle valve. When the throttle valve is not fully open, the air flow drawn in by the engine is throttled, thus reducing maximum engine torque. This throttling effect is dependent on the position, and thus the opening cross-section of the throttle valve, as well as on engine speed. The maximum engine torque is achieved when the throttle valve is fully open (see figure).

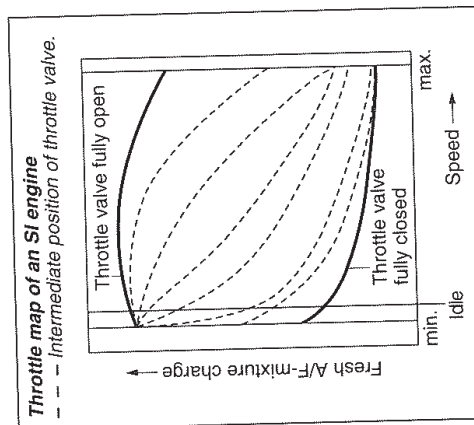
On systems with electronic throttle control (ETC), the required air charge is calculated from the desired engine torque (accelerator-pedal position), and the throttle valve is opened accordingly.

On conventional systems, the driver directly controls the opening of the throttle valve by pressing the accelerator pedal.

Charge cycle

The charge cycle of fresh A/F mixture and residual exhaust gas is controlled by the opening and closing of the intake and exhaust valves. The opening and closing times of the valves (control times) and the valve lift curve are critical factors.

The valve overlap, i.e. the overlapping of the opening times of the intake and exhaust valves, has a decisive impact on the residual exhaust-gas mass in the cylinder. The quantities of fresh A/F mixture and residual exhaust gas in the cylinder can be controlled by changing the valve-lift time curves.



By varying the valve timing accordingly, it is possible to control the air-mass flow, and thus engine performance, without having to use the throttle valve. The amount of residual exhaust gas can also be adjusted by means of valve timing.

On today's systems, the valves are actuated mechanically via the camshaft. Actuation can be varied to a certain extent by additional measures (e.g. variable-valve timing or camshaft-lobe control, P. 474). However, these mechanical systems cannot dispense with the throttle valve completely.

Exhaust-gas recirculation (EGR)

As described in the "Charge cycle" section, the mass of residual exhaust gas can be controlled by means of the intake and exhaust valve control times. This situation involves "interior exhaust-gas recirculation". The mass of residual exhaust gas in the cylinder can also be increased by "exterior exhaust-gas recirculation" (EGR). In this case, an additional EGR valve connects the intake manifold and exhaust pipe (P. 540). When the valve is open, the engine draws in a combination of fresh A/F mixture and exhaust gas. The engine control unit calculates the level of EGR for a specific operating state, and the EGR valve is activated accordingly.

Supercharging

The torque obtainable is proportional to the charge of fresh gas filling. It is therefore possible to increase maximum torque by compressing the air in the cylinder by dynamic supercharging, mechanical supercharging, or exhaust-gas turbocharging (P. 476 onwards, P. 528 onwards).

Air-system components

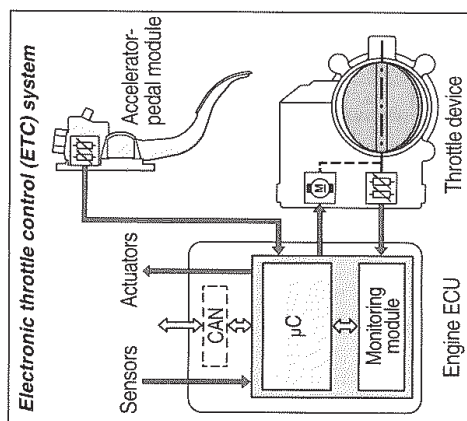
The main components responsible for controlling air charge are shown in the figure on page 593. The throttle valve is the most important component on modern systems.

Electronic-throttle control (ETC) components

The electronic throttle control system consists of the accelerator-pedal module, the engine control unit, and the throttle device. The throttle device mainly consists of the throttle valve, the electric throttle-valve drive element, and the throttle-valve position sensor. The drive element is a DC motor, which acts on the throttle-valve shaft via a gear unit. The throttle-valve position sensor, designed as a redundant unit, detects the position of the throttle valve.

The driver command is detected by a redundant sensor system in the accelerator-pedal module, and the signal is sent to the engine control unit. This calculates the required cylinder charge, based on the current engine operating point, and regulates the opening angle of the throttle valve by means of the throttle-valve drive element and the throttle-valve position sensor.

The redundancy incorporated in the accelerator-pedal module and the throttle device is part of the ETC monitoring concept for avoiding malfunctions.



The graphs (P. 605) show the dependence of specific fuel consumption, unburned fuel, and pollutant buildup on the excess-air factor for a typical engine with intake-manifold injection at constant engine performance. It can be deduced from these graphs that there is no ideal excess-air factor at which all the factors assume the most favorable value. For engines with intake-manifold injection, excess-air factors of $\lambda = 0.9$ to 1.1 have proven effective in realizing "optimum" consumption at "optimum" power output.

Engines with direct injection and charge stratification involve different combustion conditions so that the lean-misfire limit occurs at significantly higher lambda values. These engines can therefore be operated in the part-load range at significantly higher excess-air factors (up to $\lambda = 4$).

For catalytic exhaust-gas treatment using a three-way catalytic converter, it is absolutely essential to adhere exactly to $\lambda = 1$ with the engine at normal operating temperature. To achieve this, the air mass drawn in must be precisely recorded and an exactly metered fuel mass added to it.

For optimum combustion in engines with intake-manifold injection that are common today, not only is a precise injected fuel quantity necessary, but also a homogeneous A/F mixture. This requires efficient fuel atomization. If this precondition is not satisfied, large fuel droplets will precipitate on the intake manifold or the

combustion-chamber walls. These large droplets cannot fully combust and will result in increased hydrocarbon emissions.

Mixture-formation systems

It is the job of fuel-injection systems, or carburetors, to provide an A/F mixture which is adapted as well as possible to the relevant engine operating status. Fuel-injection systems, especially electronic systems, are better designed to maintaining narrowly defined limits for A/F mixture composition. This helps to improve fuel consumption, drivability, and power output. Increasingly stringent emission-control legislation has meant that, in the automotive sector, fuel-injection systems have completed superseded the carburetor.

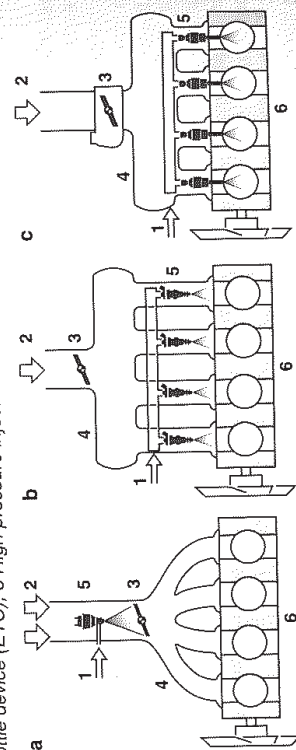
Until now, the automotive industry has almost exclusively used systems in which A/F mixture formation takes place outside the combustion chamber. Systems with internal A/F mixture formation, i.e. where the fuel is injected directly into the combustion chamber, are designed to reduce fuel consumption even further and are therefore becoming increasingly important.

Schematic representation of fuel-injection systems

a Single-point injection, b Multipoint fuel injection, c Gasoline direct injection.

1 Fuel, 2 Air, 3 Throttle valve, 4 Intake manifold, 5 Injector, 6 Engine,

7 Throttle device (ETC), 8 High-pressure injector.



Fuel-metering systems

Main system

The fuel is metered by the main jet. Correction air is added as a delivery aid to the fuel through orifices in the side of the venturi tube.

Idle and progression systems

At idle, the vacuum, which the air flow produces at the fuel outlet, is not sufficient to withdraw fuel from the main system. For this reason, there is a separate idle system with an outlet located downstream from the throttle valve at the point of maximum vacuum. The emulsion required for idling emerges from the idle system after initial processing by the idle fuel and air-correction jets.

During transitions to the main metering system, the throttle valve controls a series of orifices (or a slit), drawing fuel from the idle system.

Other systems

The basic systems are supplemented by a range of additional systems. They are designed to adapt carburetor performance to the program map of a hot engine (part-load control, full-load enrichment), to compensate for fuel accumulation within the intake manifold during acceleration (accelerator pump), and to

Carburetors

Carburetor system

Fuel is transported from the fuel tank to the carburetor by a fuel-supply pump (usually a diaphragm pump) driven by the camshaft or distributor shaft. The system is designed to limit the maximum delivery pressure. A fine-mesh fuel filter can be installed upstream or downstream of the pump as required.

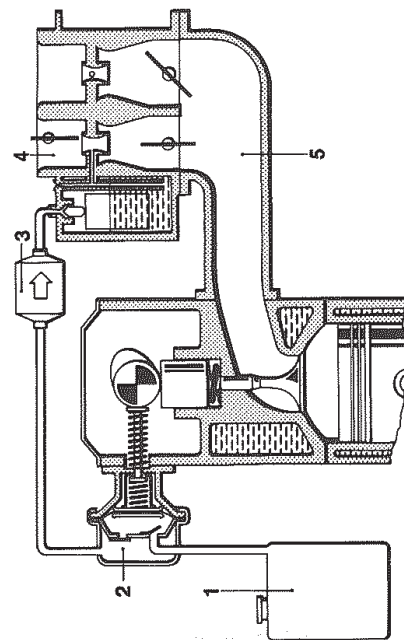
Design and operating concept

The driver uses the accelerator pedal to vary the throttle-valve aperture so that the air flow rate into the engine is varied and with it the engine power output. The carburetor varies the amount of fuel metered to the engine to reflect the current air flow rate. Together with the needle valve, the float regulates the fuel flow to the carburetor while maintaining a constant fuel level in the float chamber.

The air flow rate is monitored by an air funnel designed to induce a venturi effect. The progressively narrower cross-section increases the air velocity, producing a corresponding vacuum at the narrowest point. The resulting pressure differential relative to the float chamber helps to supply and deliver the fuel. Metering systems adapt fuel delivery to air flow rate.

Schematic of a carburetor system

1 Fuel tank, 2 Fuel supply pump, 3 Fuel line filter, 4 Carburetor, 5 Intake manifold.



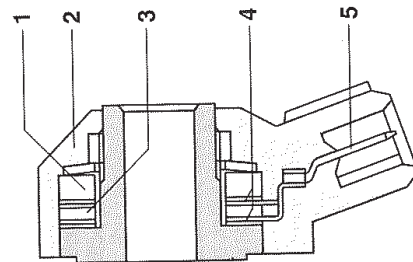
Knock sensor

A typical symptom of combustion knock is high-frequency vibrations which are superimposed on the low-pressure curve in the combustion chamber. These vibrations are best detected directly in the combustion chamber by means of pressure sensors. Since it is relatively complex and costly to install these pressure sensors in the cylinder head for each cylinder, the vibrations are usually detected by knock sensors located externally on the engine. The piezoelectric acceleration sensors detect the characteristic vibrations of combustion knock and convert them into electrical signals.

There are two types of knock sensor. A broadband sensor, with a typical frequency band of 5 to 20 kHz, and a resonance sensor, which preferably transmits only one knock-signal resonant frequency. When combined with the flexible signal-evaluation system in the ECU, it is possible to evaluate different or several resonant frequencies from one broadband knock sensor. This improves knock detection performance, which is why the broadband knock sensor is increasingly replacing the resonance sensor.

Knock sensor

1 Seismic mass, 2 Sealing compound, 3 Piezoceramic element, 4 Contacts, 5 Terminals.



Knock control

Control algorithm for ignition adjustment on a 4-cylinder engine.

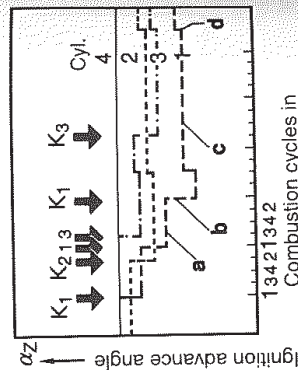
K_{1,3} Knock in cylinders 1...3, cylinder 4,

no knock;

a Delay prior to ignition retard, b Drop height,

c Delay before return to original ignition point,

d Ignition advance.



Knock detection

The variable produced by the signal-evaluation circuit is classified in a knock-detection algorithm as "knock" or "no knock" for each cylinder and for each combustion process. This is done by comparing the variable for the current combustion process with a variable which represents combustion without knock.

Ignition-angle control system with adaptation facility

If combustion knock is detected in a cylinder, the moment of ignition for that cylinder is retarded. When knock stops, the moment of ignition is advanced again in stages up to the precontrol value. The knock-detection and knock-control algorithms are matched in such a way as to eliminate any knock that is audible and damaging to the engine, even though each cylinder is operated at knock limit within the optimum efficiency range.

Real engine operation produces different knock limits, and thus different moments of ignition for individual cylinders. In order to adapt precontrol values for the moment of ignition to a particular knock limit, the ignition retard values are stored for each cylinder dependent on the operating point. They are stored in non-volatile program maps in the permanently powered RAM for load and engine speed. In this way, the engine can be operated at optimum efficiency at each operating point and without audible combustion knocks, even if there are rapid load and engine-speed changes.

This adaptation even allows the use of fuels with lower antiknock qualities (e.g. regular instead of super gasoline).

Ignition systems

On modern vehicles, the ignition systems are almost always incorporated as sub-systems of the engine-management system. Separate ignition systems are only used in special applications (e.g. low-power engines). Coil ignition (inductive ignition) with one dedicated ignition circuit per cylinder (static HT distribution system with single spark coils) is the usual choice for vehicle ignition systems. Also used, but to a lesser extent, are high-voltage capacitor ignition systems (capacitive ignition), or other special designs, such as solenoid ignition for low-power engines. The next section will focus on coil ignition alone.

Coil ignition (inductive ignition)

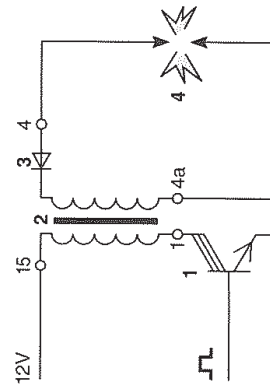
Principle of coil ignition

The ignition circuit of a coil-ignition system consists of:

- An ignition coil with a primary and secondary winding.
- An ignition driver stage to control current in the primary winding (incorporated in the engine control unit or the ignition coil).
- A spark plug, which is connected to the high-voltage connection of the secondary winding.

Structure of an ignition circuit with single spark coils

1 Ignition driver stage, 2 Ignition coil, 3 Activation arc diode (suppression of activation spark), 4 Spark plug, 15, 1, 4, 4a Terminal designations, 1 Triggerring signal.



Before the desired moment of ignition, the ignition driver stage switches a current from the vehicle electrical system through to the primary winding of the ignition coil. While the primary current circuit is closed (dwell period), a magnetic field builds up in the primary winding.

At the moment of ignition, the current through the primary winding is interrupted again, and the magnetic-field energy is discharged, mainly via the magnetic-coupled secondary winding (induction). In the process, a high voltage is produced in the secondary winding, which in turn generates the spark at the spark plug. The ignition voltage required at the spark plug (ignition voltage demand) must always be less than the maximum possible ignition voltage in the ignition system (ignition voltage supply).

After flashover, the remaining energy is converted at the spark plug while the spark is present.

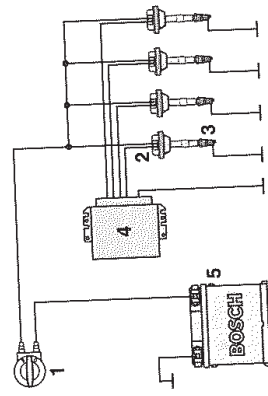
Functions of an ignition system

with coil ignition

The basic functions of an inductive ignition system are:

- To determine the moment of ignition.
- To determine the dwell period.
- To release the ignition energy.

Ignition system with single spark coils
1 Ignition lock, 2 Ignition coil, 3 Spark plug, 4 ECU, 5 Battery.



Determining the moment of ignition

The instantaneous moment of ignition is determined from program maps as a function of the operating point (see P. 620), and the ignition energy is then released.

Determining the dwell period

The required ignition energy is made available at the moment of ignition. The amount of ignition energy is dependent on the amount of primary current at the moment of ignition (cutoff current) and the inductance of the primary winding. The amount of cutoff current is mainly dependent on the operating time (dwell period) and on the battery voltage at the ignition coil. The dwell periods required to achieve the desired cutoff current are contained in characteristic curves or program maps as a function of the steady-state voltage. The change in dwell period with temperature can also be compensated for.

Ignition release

Ignition release ensures that the ignition spark occurs at the right cylinder at the right time and with the required level of ignition energy. On electronic-controlled systems, a trigger wheel with a fixed-angle reference mark (typically 60-2 teeth) located on the crankshaft is usually scanned by an induction-type pulse generator (sensor system). From this, the ECU can calculate the crankshaft angle and the momentary rotational speed. The ignition coil can be switched on and off at any required crankshaft angle. An additional phase signal from the camshaft is required for the unambiguous identification of the cylinder.

For each combustion process, the ECU calculates the switch-on point from the desired moment of ignition, the required dwell period, and the current rotational speed, and switches on the driver stage accordingly. The moment of ignition, or the switchoff point for the driver stage, can be triggered either when the dwell period expires or when the desired angle is reached.

Ignition components

Ignition output stage

Function

The ignition output stage is responsible for switching the current in the ignition coil.

Design and operating concept

The ignition output stages are usually three-stage power transistors in BIP technology (Bosch Integrated Power, bipolar technology). The "primary-voltage limitation" and "primary-current limitation" functions are monolithically integrated onto the ignition output stage and protect the ignition components from overloading.

The ignition output stage and ignition coil heat up when operating. To ensure that the permissible operating temperatures are not exceeded, suitable measures must be in place to dissipate the resulting heat losses into the environment, even when operating at high temperatures. To avoid high heat losses in the ignition output stage, the primary-current limitation function is only responsible for limiting current in the event of a fault (e.g. short-circuit) (current safety wire).

Risk of accidents

All electronic ignition systems are high-voltage systems. To avoid any risks, always switch off the ignition, or disconnect the power supply when working on the ignition system. Such work includes, for example:

- Replacing parts such as spark plugs, ignition coils, or ignition transformers, ignition distributors, high-tension ignition cables, etc.
- Connecting engine analyzers, such as stroboscopic lamps, dwell angle/rotational speed testers, ignition oscilloscopes, etc.

When testing the ignition system with the ignition switched on, dangerous voltages will occur throughout the entire system. Therefore, test work should only be carried out by trained specialists.

In the future, three-stage circuit breakers will be superseded by the new IGBTs (Insulated Gate Bipolar Transistor, a combination of a field-effect and bipolar transistor), which have also been developed for ignition-system applications. IGBTs have certain advantages over BIPs:

- Virtually no power required for activation (voltage-controlled instead of current-controlled).
- Lower saturation voltage.
- Higher load current.
- Low switching times.
- Higher terminal voltage possible.
- Higher continuous operating temperature.
- Protection against polarity reversal in the 12-V vehicle electrical system.

Design variations

Ignition output stages are divided into internal and external driver stages. The internal driver stages are incorporated on the printed-circuit board of the engine ECU. The external driver stages are located in a separate housing outside of the engine ECU. For cost reasons, external driver stages will no longer be used on new products.

Another increasingly popular option is to integrate the driver stages into the ignition coil. This solution avoids having to have cables in the wiring harness, which carry high currents and are subjected to high voltages. Likewise, the power loss in the Motronic ECU is correspondingly lower.

Ignition output stages integrated in the ignition coil are being subjected to increasing requirements in terms of activation, diagnostics capability, and temperature loads.

ME-Motronic

The ME-Motronic comprises all the components required to control an engine with intake-manifold injection and electrically adjustable throttle valve (ETC, electronic throttle control) (see system diagram). It is based on the M-Motronic. The main difference between the two systems is that, on ME-Motronic, the throttle valve is actuated electrically, and there is no bypass air actuator.

Setting the torque

To set the operating status required by the driver, the accelerator pedal position, detected by the pedal-travel sensor, is converted into an engine torque setpoint value by the microcontroller. Taking into consideration the mass of real-time operating data available to the ME-Motronic, the setpoint value is converted into the variables that determine engine torque:

- Charging the cylinders with fresh air
- The mass of the injected fuel
- The ignition angle

These variables are set by means of:

- The electrically activated throttle valve (ETC)
- The fuel-injection system (correctly timed injector activation)
- The ignition system (correctly timed ignition coil activation)

Torque guidance

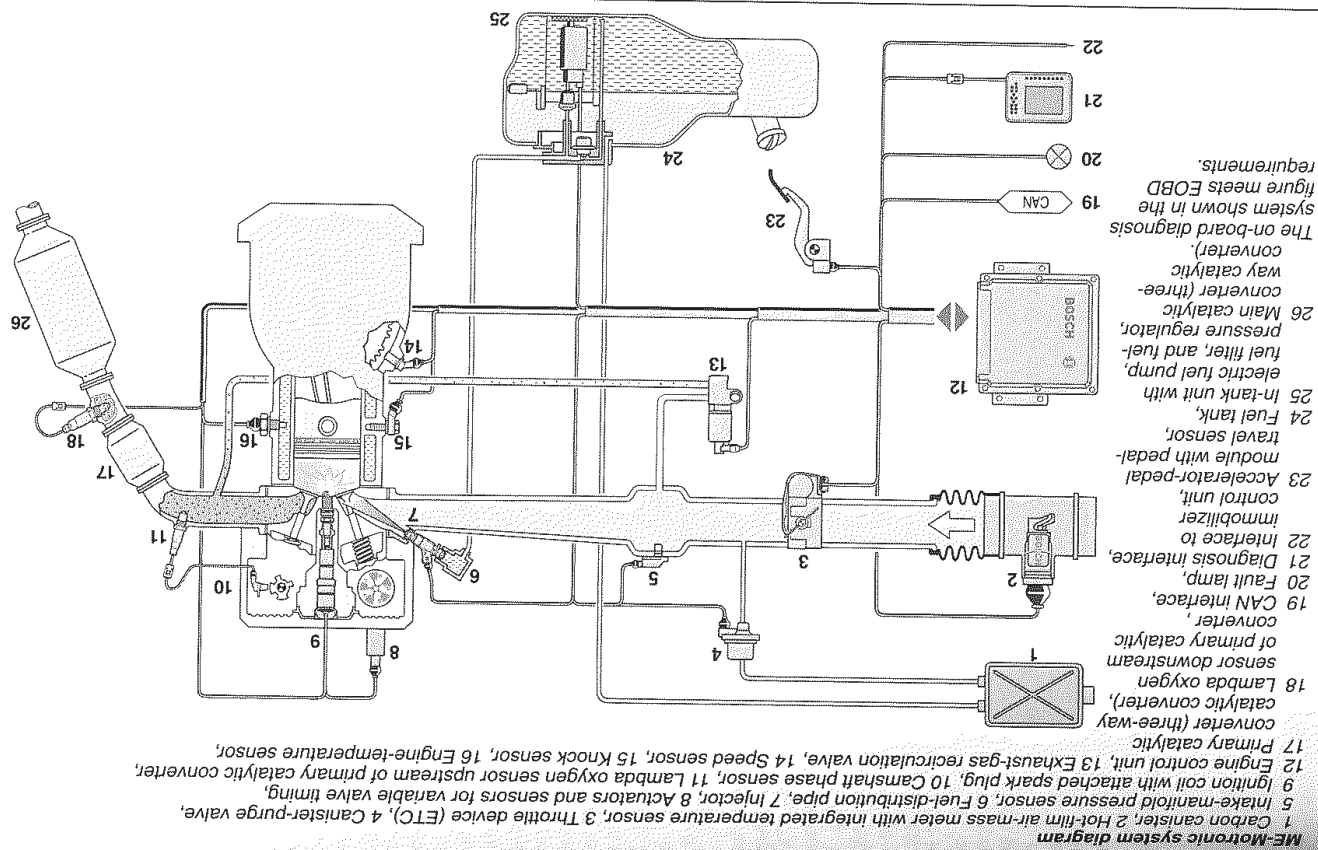
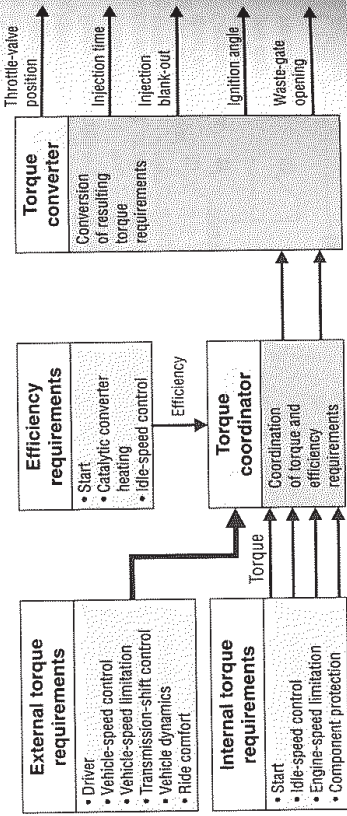
The ME-Motronic saw the introduction of torque structure. The aim of torque guidance is to sort the many, sometimes very different, functions that require a torque.

Most additional open- and closed-loop control functions also affect engine torque (e.g. transmission-shift control, ASR or ESP, idle-speed control, catalytic converter heating). Each of these functions requires a separate engine torque. In a torque-guided control system, these functions are prioritized with the driver commands. The torque-guided ME-Motronic uses torque coordination to sort often contradictory torque requirements, and then to implement the most important requirement.

Exhaust-gas treatment and catalytic-converter control

Voltage-jump sensors (2-point sensors), and optionally continuous broadband O₂ sensors, are used upstream of the three-way catalytic converter to control the air/fuel mixture. The sensors downstream of the catalytic converter are always voltage-jump sensors (see Lambda closed-loop control, P. 665 onwards).

ME-Motronic torque-based system structure



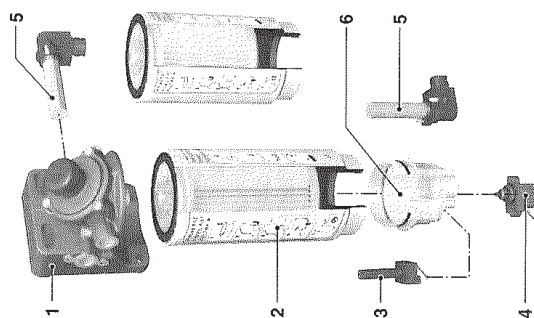
For extra heavy-duty requirements, an additional preliminary filter/water separator, with a filter fineness adapted to the fine filter, is fitted on the suction or pressure side. Preliminary filters of this type are mostly used for commercial vehicles in countries where diesel quality is poor.

New-generation diesel filters integrate additional modular functions such as:

- Fuel preheating (electric; fuel return) to prevent paraffin clogging during winter operation.
- Fuel cooling.
- Maintenance indication by way of a differential-pressure measurement, and
- Filling and venting devices.

Diesel filter with water drain

1 Filter head with filler pump, 2 Easy-change filter element, 3 Water sensor, 4 Automatic water discharge valve, 5 PTC heater in filter head and in collector tank (optional), 6 Transparent water collector tank.



Diesel fuel-injection systems

Overview

In the diesel combustion process, the fuel is always injected directly into the combustion chamber at a nozzle pressure ranging from 200 to > 2,000 bar. Depending on the combustion process, fuel is injected into a prechamber in indirect-injection engines (at a relatively low pressure of < 350 bar). In the meantime, direct injection has become the most common process, in which fuel is injected (at high pressure up to > 2,000 bar) into the non-divided combustion chamber.

For more details on diesel fuel-injection systems, refer to the bibliography on P. 711.

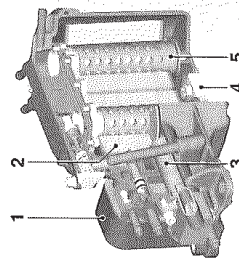
Diesel-engine management

Requirements

The power output P from a diesel engine is determined by the available clutch torque and the engine speed. The clutch torque is produced from the torque generated by the combustion process, reduced by the friction torque and the charge-cycle losses, and the torque required for operating the auxiliary systems driven directly by the engine. The combustion torque is generated in the power cycle and is de-

Modular diesel housing filter for passenger cars with additional functions

1 Fuel cooler, 2 Thermostat-controlled return line, 3 Electric PTC heater, 4 Water sensor, 5 Two nonmetal superfilter elements.



Emission-control legislation calls for highly precise control of the injected fuel quantity and start of injection as a function of variables such as temperature, speed, load, height, etc. This can only be provided effectively by electronic control.

This form of control has become widespread not just in the automotive field. This is the only form of control that permits continuous monitoring of the emission-related function of the fuel-injection system. Legislation also requires on-board diagnosis in some applications.

Control of injected fuel quantity and start of injection is performed in EDC (Electronic Diesel Control) systems by means of low- or high-pressure solenoid valves or other electrical actuators. Control of the rate of discharge, i.e. the quantity provided per crankshaft degree, can be performed indirectly by means of servo valves and needle-lift control.

Details

A fuel-injection system comprises a low-pressure stage and a high-pressure stage. The low-pressure delivery circuit has already been discussed in the chapter headed "Fuel supply". The system-specific differences will be explained for the different fuel-injection systems in the relevant sections.

Mechanical and electronic (EDC) control systems will be described in general first.

Mechanical control is used exclusively for discrete fuel-injection (PF) pumps, in-line fuel-injection and axial-piston distributor pumps. There are a multitude of governors and add-on modules which are required for in-line fuel-injection and distributor injection pumps, depending on the application. Mechanical control is always a compromise when compared with electronic control, as the latter is more precise, permits a whole range of influencing variables to be taken into consideration, and allows ongoing adaptation of manipulated variables in the closed-control loop. The advantages are:

terminated by the following variables if the excess air is sufficient:

- the supplied fuel mass,
- the start of combustion determined by the start of injection,
- the injection/combustion process.

In addition, the maximum speed-dependent torque is limited by:

- smoke emissions,
- the cylinder pressure,
- the temperature load of different components, and
- the mechanical load of the complete drivetrain.

Primary function of engine management

The primary function of engine management is to adjust the torque generated by the engine or, in some applications, to adjust a specific engine speed within the permitted operating range (e.g. idling).

In a diesel engine, exhaust-gas treatment and noise suppression are performed to a great extent inside the engine, i.e. by controlling the combustion process. This, in turn, is performed by engine management by changing the following variables:

- cylinder charge,
- tempering of the cylinder charge during the induction stroke,
- composition of the cylinder charge (exhaust-gas recirculation),
- charge motion (intake swirl),
- start of injection,
- injection pressure, and
- rate-of-discharge curve control (e.g. pilot injection, divided fuel injection, etc.).

Until the 1980s fuel injection in vehicle engines, i.e. injected fuel quantity and start of ignition, was governed exclusively by mechanical means. Here, the injected fuel quantity is varied via a helix on the plunger or via sleeves as a function of load and speed. In the case of mechanical injection, the start of injection/delivery is adjusted by flyweight governor (speed-dependent), or hydraulically by pressure control as a function of speed and load. This is discussed in more detail in the sections headed "In-line injection pump" and "Distributor injection pump".

Electronic governor

Instead of a mechanical governor, the electronic governor for the in-line fuel-injection pump uses a solenoid actuator with a non-contacting inductive position sensor to position the control rack (control-rack travel sensor). The solenoid actuator is triggered by an ECU.

The ECU microprocessor compares accelerator-pedal position, rpm, and a number of additional correction factors with the program maps stored in its memory in order to determine the correct injected fuel quantity, i.e. the control-rack setpoint position.

An electronic controller compares the monitored control-rack position with the specified setpoint in order to determine the required excitation-current input to the solenoid, which operates against a return spring. When deviations are detected, the excitation current is regulated to shift the control rack to precisely the specified position.

An inductive speed sensor monitors a camshaft-mounted sensor ring; the ECU uses the pulse intervals to calculate engine speed.

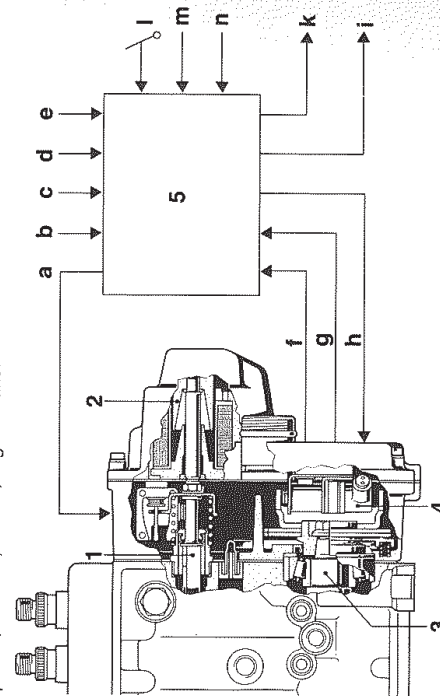
As it can monitor a number of engine and vehicle parameters and combine

them to calculate the injected fuel quantity, an electronic governor has a number of additional functions, thus giving it an advantage over a mechanical unit:

- Engine can be switched on and off with key.
- Complete freedom in determining the full-load curve.
- Maximum injected fuel quantity can be precisely coordinated with the charge-air pressure in order to remain below the smoke limit.
- Corrections for air and fuel temperatures.
- Temperature-dependent excess-fuel quantity.
- Engine-speed control for auxiliary power take-offs.
- Cruise control.
- Maximum-speed limiter.
- Constant, low idle speed.
- Surge damping control.
- Smooth-running control.
- Option for intervention in traction control (TCS)/automatic transmission.
- Signal outputs for display of fuel consumption and engine speed.
- Service support through integral error diagnosis.

Electronic diesel control (EDC) for in-line fuel-injection pumps

1 Control rack, 2 Actuator, 3 Camshaft, 4 Engine-speed sensor, 5 ECU Input/output quantities: a Redundant shutoff, b Boost pressure, c Vehicle speed, d Temperature (water, air, fuel), e Fuel-quantity command, f Engine speed, g Control-rack travel, h Solenoid position, i Fuel-consumption and engine-speed display, k Diagnostics, l Accelerator position, m Speed preset, n Clutch, brakes, engine brake.



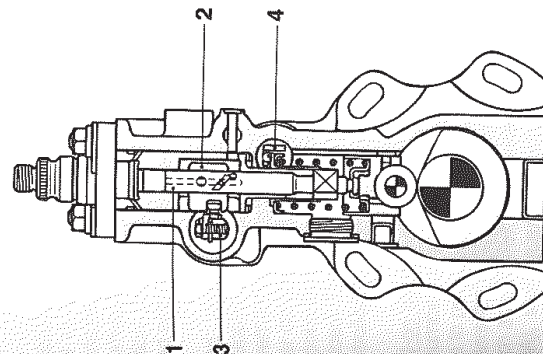
In-line control-sleeve fuel-injection pump

The in-line control-sleeve fuel-injection pump makes it possible to provide electronically controlled adjustment of port closing (start of pump delivery). It is, therefore, an in-line fuel-injection pump with integrated timing device. A control-sleeve pump is only available for size P. The spill port, which on conventional in-line pumps is fixed in the housing, is incorporated in the control sleeve which is a movable component in each plunger-and-barrel assembly. A setting shaft, with control-sleeve levers which engage the sleeves, changes the positions of all sleeves at the same time.

Depending on the position of the control sleeve (up or down), the start of delivery is advanced or retarded relative to the

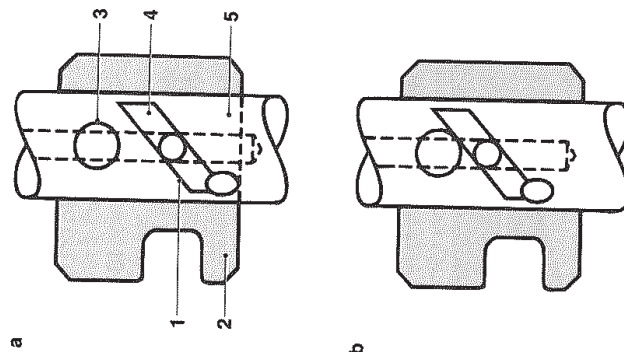
In-line control-sleeve fuel-injection pump

1 Pump plunger, 2 Control sleeve, 3 Control-sleeve shaft, 4 Control rack.



Plunger-and-barrel assembly with control sleeve

a) Start of delivery, b) End of delivery, 1 Helix, 2 Control sleeve, 3 Spill port, 4 Control groove, 5 Pump plunger.



position of the camshaft lobe. An electromagnetic actuator mechanism similar to that used for fuel-delivery control in the distributor injection pump turns the setting shaft, but without position feedback.

A needle-motion sensor monitors the start of injection directly at the nozzle. It transmits a signal to the ECU, which compares it with the setpoint value as a function of rpm, injected fuel quantity, etc. in order to adjust the solenoid-excitation current to achieve congruence between the actual and setpoint values for start of injection.

The engine-speed sensor obtains precise information on the start of injection relative to TDC by monitoring pulses from reference marks on the crankshaft flywheel.

Drivetrain

Quantities and units

Quantity	Unit
a Acceleration	m/s ²
c_d Drag coefficient	—
e Rotational inertia coefficient	—
f Rolling resistance coefficient	m/s ²
g Gravitational acceleration	—
i Transmission ratio	—
m Vehicle mass	kg
n Rotational speed	rpm
r Dynamic tire radius	m
s Wheel slip	—
v Road speed	m/s
A Frontal area	m ²
D System diameter	m
I Overall conversion range	—
J Mass moment of inertia	kg · m ²
M Torque	N · m
P Power	kW
α Angle of inclination	°
η Overdrive factor	—
η Efficiency	—
λ Performance index	—
μ Conversion	—
ρ Density	kg/m ³
ω Angular velocity	rad/s
ν Speed ratio	—

Subscripts:	eng Engine
eff Effective	o Towards maximum output
tot Total	dt Drivetrain
hydr Hydraulic	G Gearbox
max Maximum	P Pump
min Minimum	R Roadwheel
fd Final drive	T Turbine

Equilibrium relation between drive forces and running resistance

The equation defining the equilibrium relation between drive forces and resistance factors is applied to determine various quantities, such as acceleration, top speed, climbing ability, etc.

Available power = Running resistance at drive wheels (power requirement)

$$M_{eng} \cdot \frac{i_{tot}}{r} \cdot \eta_{tot} = m \cdot g \cdot f \cdot \cos \alpha + m \cdot g \cdot \sin \alpha + e \cdot m \cdot \alpha + c_d \cdot A \cdot \frac{\rho}{2} \cdot v^2$$

Driving force applied to tire footprint	Rolling resistance	Climbing resistance	Acceleration resistance	Aerodynamic drag
---	--------------------	---------------------	-------------------------	------------------

Where rotational inertia coefficient $e = 1 + \frac{J}{m \cdot r^2}$ and mass moment of inertia $J = J_A + \frac{\rho}{6} \cdot J_A \cdot \frac{D^2}{16} \cdot I_m$

Function

The function of the automotive drivetrain is to provide the thrust and tractive forces required to induce motion. Energy in chemical (fuels) or electrical (batteries, solar cells) form is converted into mechanical energy in the power unit, with spark-ignition and diesel engines representing the powerplants of choice. Every power unit operates within a specific speed range as defined by two extremities: idle speed and the maximum engine speed. Torque and power are not delivered at uniform rates throughout the operating range; the respective maxima are available only within specific bands. The drivetrain's conversion ratios adapt the available torque to the momentary requirement for tractive force.

Design

The dynamic condition of an automobile is described by the running-resistance equation. It equates the forces generated by the drivetrain with the forces required at the driving wheels (running resistance). From the running-resistance equation, it is possible to calculate acceleration, maximum speed, climbing ability and also the overall conversion range I of the transmission.

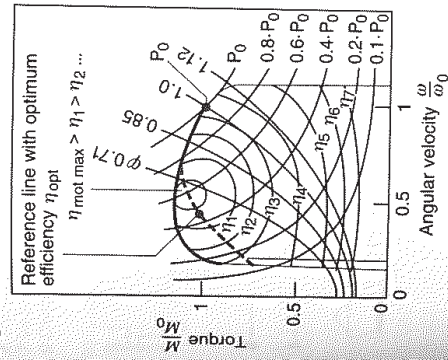
$$I = \frac{(i/r)_{\max}}{(i/r)_{\min}} = \frac{\tan \alpha_{\max} \cdot v_o}{(P/(m \cdot g))_{\text{eff}} \cdot \varphi}$$

The overdrive factor φ is

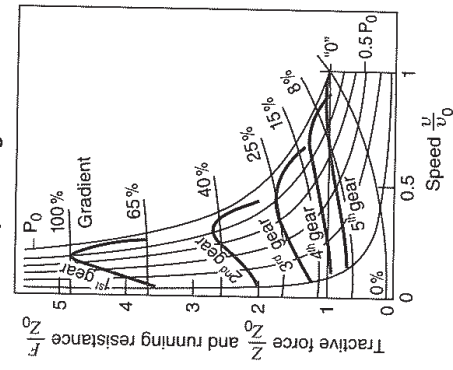
$$\varphi = \frac{(i/r)_{\min}}{\omega_o / v_o}$$

Calculations of effective specific output should always be based on the power P which is actually available for tractive application (net power minus driven ancillaries, power losses, altitude loss). Special conditions, such as trailer towing, must be factored in the weight $m \cdot g$. $\varphi = 1$ is true when the curve for cumulative running resistance in top gear directly intersects the point of maximum output. The φ factor determines the relative positions of the curves for running-resistance and engine output in top gear. It also defines the efficiency level at which the engine operates. $\varphi > 1$ displaces engine operation to an inefficient performance range, but also enhances acceleration reserves and hill-climbing ability in top gear. In contrast, selecting $\varphi < 1$ will increase fuel economy, but only at the price of much slower acceleration and lower climbing reserves. Minimum fuel consumption is achieved along the operating curve η_{opt} . $\varphi > 1$ reduces, $\varphi < 1$ increases the required transmission conversion range I .

Engine map with running-resistance curves



Tractive force/speed diagram



Drivetrain configurations

The layout of the automotive drivetrain varies according to the position of the engine and the powered axle:

Drive configuration	Engine position	Driven axle
Standard rear-wheel drive	Front	Rear axle
Front-wheel drive	Front, longitudinal or transverse	Front axle
All-wheel drive	Front, occasionally rear or middle	Front axle and rear axle
Rear-wheel drive with rear-mounted engine	Rear	Rear axle

Drivetrain elements

The elements of the drivetrain must perform the following functions:

- remain stationary even with the engine running,
- achieve the transition from stationary to mobile state,
- convert torque and rotational speed,
- provide for forward and reverse motion,
- compensate for drive-wheel speed variations when cornering,
- ensure that the power unit remains within the program map that permits minimum fuel consumption and exhaust emissions.

Stationary idle, starting off and interruptions in the power flow are all made possible by the clutch. The clutch slips to compensate for differences in the rotational speeds of engine and the drivetrain when the vehicle is starting off from standstill. When different conditions demand a change of gear, the clutch disengages the engine from the transmission while the gearshift operation takes place. On automatic transmissions, the hydrodynamic torque converter assumes the start-off procedure. The transmission modifies the engine torque and engine speed and adapts them to the vehicle's momentary tractive requirements.

The overall conversion of the drivetrain is the product of the constant transmission ratio of the axle differential and the variable transmission ratio of the transmission — assuming there are no other transmission stages involved. Transmissions are almost always multiple fixed-ratio gearboxes, though some have continuously variable ratios.

Transmissions generally fall into one of two categories: manually shifted transmissions with spur gears in a countershaft arrangement, and load-actuated automatic transmissions with planetary gear sets. The transmission also allows the selection of different rotational directions for forward and reverse operation.

The differential allows laterally opposed axles and wheels to rotate at varying rates when cornering to provide uniform distribution of the driving forces. Limited-slip final drives respond to slip at one of the wheels by limiting the differential effect. This shifts additional power to the wheel at which traction is available.

Torsion dampers, hydrodynamic transmission elements, controlled-slip friction clutches or mass-suspension systems dissipate high vibration amplitudes. They protect against overload and provide added ride comfort.

Power take-up elements

Dry-plate friction clutch

The friction clutch consists of a pressure plate, a clutch disk — featuring bonded or riveted friction linings — and a mating friction surface represented by the engine-

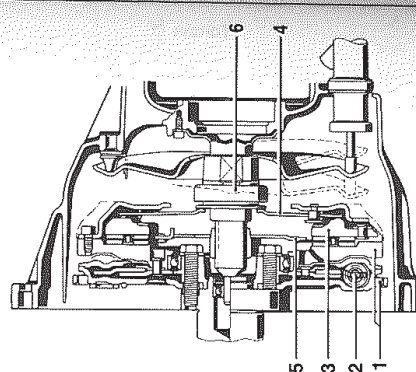
mounted flywheel. The flywheel and pressure plate provide the thermal absorption required for friction operation of the clutch; flywheel and pressure plate are connected directly to the engine, while the clutch disk is mounted on the transmission's input shaft.

A spring arrangement, frequently in the form of a central spring plate, applies the force which joins the flywheel, pressure plate and clutch disk for common rotation; in this state, the clutch is engaged for positive torque transfer. To disengage the clutch (e.g. when gearshifting), a mechanically or hydraulically actuated throwout bearing applies force to the center of the pressure plate and releases pressure at the periphery. The clutch is controlled either by a clutch pedal or an electrohydraulic, electropneumatic or electromechanical final-control element. A single- or multi-stage torsion damper, with or without predamper, may be integrated in the clutch disk to absorb vibration.

A two-section (dual-mass) flywheel featuring a flexible intermediate element can be installed forward of the clutch for maximum insulation against vibrations. The resonant frequency of this spring/mass system is below the excitation frequency (ignition frequency) of the engine at idle speed, and is a therefore

Clutch with dual-mass flywheel

1 Dual-mass flywheel, 2 Flexible element, 3 Pressure plate, 4 Spring plate, 5 Friction plate, 6 Throwout bearing.



outside the operating speed range. It acts as a vibration insulating element between the engine and the other drivetrain components (low-pass filter).

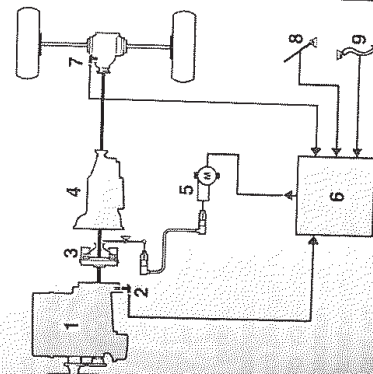
When used together with electronic control units, the automatic clutch can provide either gradual engagement for start-off, or it can be applied in conjunction with a servo-operated shifting mechanism to form a fully automatic transmission unit. Traction control and disengagement of power transmission during braking are also possible.

Wet-plate friction clutch

The wet-plate friction clutch has the advantage over the dry-plate version that its thermal performance is better as it can be flooded with oil to enhance heat dissipation. However, its drag losses when disengaged are considerably higher than for a dry clutch. Use in combination with synchromesh gearboxes presents problems due to increased synchronous load when gearshifting. The wet clutch was introduced as a standard component on continuously variable car transmissions. It has space-saving advantages, particularly when one or more friction-drive gearshift components (multiplate clutch or clutch stop) can also be used for the start-off process.

Automatic clutch, limited to clutch actuation

1 Engine, 2 Engine-speed sensor, 3 Clutch, 4 Transmission, 5 Servomotor, 6 ECU, 7 Velocity sensor, 8 Accelerator pedal, 9 Clutch pedal.



Hydrodynamic torque converter

The hydrodynamic torque converter consists of an impeller which is the drive element, a turbine which is the driven component, and a stator which assists the torque converter function. The torque converter is filled with oil and transmits engine torque by means of the flowing forces of the oil. It compensates for speed differences between the engine and the other drivetrain components, and is therefore ideally suited for the start-off function. An impeller converts mechanical energy into fluid energy. This is converted back to mechanical energy in a second transformation that takes place in the turbine impeller. The impeller's input torque M_p and input power P_p are calculated as follows:

$$M_p = \lambda \cdot \rho \cdot D^5 \cdot \omega_p^2$$

$$P_p = \lambda \cdot \rho \cdot D^5 \cdot \omega_p^3$$

λ Performance index

ρ Density of medium

($\approx 870 \text{ kg/m}^3$ for hydraulic fluid)

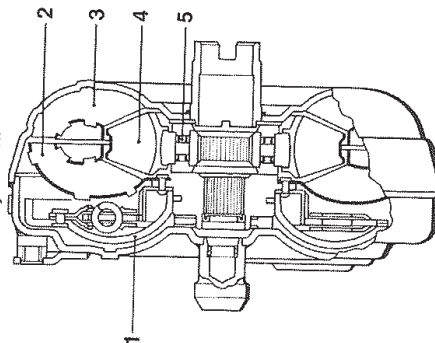
D Circuit diameter in m

ω_p Angular velocity of impeller

A stator located between impeller and turbine diverts the hydraulic oil back to the input side of the impeller. This raises the torque beyond the initial engine output

Hydrodynamic converter with converter lockup clutch

1 Lockup clutch, 2 Turbine, 3 Impeller, 4 Stator, 5 One-way clutch.



Braking-force apportioning valve

The braking-force apportioning valve is not a closed-loop control element, like the brake-pressure regulating valve as used for ABS, but rather an open-loop control element. The individual apportioning valves have different functions, depending whether they are acting as braking-force limiters or reducers, or different control parameters, such as braking pressure, axle load or rate of deceleration.

The braking force is apportioned between the front and rear axles in accordance with the dimensions of the particular wheel brakes. It is the job of the apportioning valve to adjust this braking-force apportionment in order to achieve a closer approximation to the ideal distribution, i.e., the parabolic curve. The ideal braking-force distribution is determined solely by the vehicle's center of gravity and the nature of the particular braking maneuver. These relationships can be shown in a dimensionless braking-force distribution diagram. The weight-related braking forces at the front and rear axles are entered on the coordinate axes. The lines for identical braking appear as straight lines with a negative slope (-1). The ideal braking-force distribution curves for the vehicle conditions "curb weight" and "permissible total weight" are in the form of parabolas. Diagram "a" is for a braking-force limiter and diagram "b" a braking-force reducer.

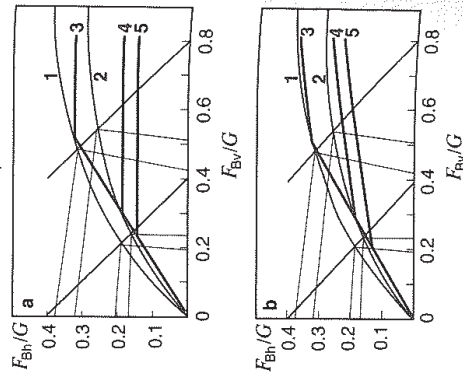
Pressure-sensitive apportioning valves achieve good approximation of ideal distribution with the vehicle in the "curb weight" state. On the other hand, under "permissible total weight" conditions (upper parabola), they deviate from the ideal once the limiter or reducer becomes operative (bend in the curve), i.e. the proportion of the total braking force directed toward the rear axle decreases as the rear-axle load increases.

The load-sensitive apportioning valve responds to increased loads by displacing the triggering point upward, allowing a reasonable approximation of ideal braking-force distribution under all load conditions.

The deceleration-sensitive apportioning valve is triggered by a specific rate of deceleration, and is thus basically insensitive to load. The apportioning valve must be designed to ensure that braking-force distribution remains on or below the

Braking-force distribution diagram

- a) Braking-force limiter;
b) Braking-force reducer.
 F_{Bh} Rear braking force, G Weight.
 F_{Bv} Front braking force, G Laden, load-sensitive,
1 Laden, 2 Unladen, 3 Laden, load-sensitive,
4 Unladen, pressure-sensitive; unladen,
deceleration-sensitive and laden; unladen,
load-sensitive, 5 Laden, pressure-sensitive.



ideal curve. The potential effects of fluctuations of the pad/lining friction coefficient, as well as of engine braking torque and tolerances of the valve itself, must all be considered in preventing overbraking of the rear axle. In practice, this means that actual installed distribution (with bend in curve) should remain well below the ideal. The criteria according to which the apportioning valve is designed include the following:

- ABS compatibility
- Complexity in split-circuit braking systems, in which each rear wheel is served by a separate circuit (e.g. diagrammally split circuits (X distribution))
- Bypass function for dealing with brake-circuit failure, especially with braking-force limiters
- Facility for testing correct setting and function

Vehicles with balanced load conditions are not necessarily equipped with an apportioning valve, as the disadvantages of an undetected defect in the apportioning valve outweigh its minimal advantages.

Vehicle stabilization systems for passenger cars

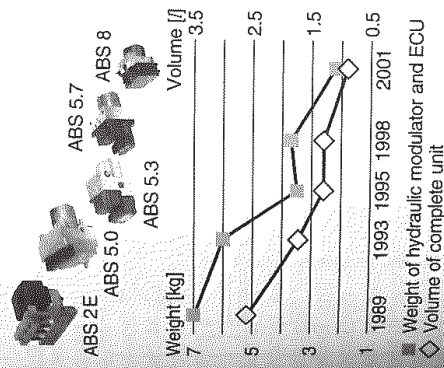
Volume-production antilock braking systems (ABS) have been in use since the end of 1978. They are now firmly established as safety systems. In Europe and North America, the equipment rates for ABS (fitting to all new vehicles) are around 80%; worldwide they are roughly 70%. In some countries, it has virtually become standard. As a result of a voluntary obligation, ABS will become standard equipment on cars in Europe as of 2004.

Bosch produced its 100 millionth system in 2003, 25 years after ABS was first introduced.

The Electronic Stability Program (ESP) went into volume production in 1995. In Europe, it has rapidly gained a foothold. The total number of Bosch systems produced exceeded the 10-million mark in 2003.

The graph below illustrates the gradual reduction in weight and size of ABS systems from 1978 to 2003.

Weight and volume of ABS/ESP systems over time



Antilock braking systems (ABS)

Function

Antilock braking systems (ABS) are braking-system closed-loop control devices which prevent wheel lock when braking and, as a result, retain the vehicle's steerability and stability. In general, they also shorten braking distances compared with braking scenarios when the wheels lock completely. This is particularly the case on wet roads. The reduction in braking distance may be 10% or several times this figure, depending on how wet the conditions are and the road/tire friction coefficient.

Under certain very specific road-surface conditions, braking distances may be longer, but the vehicle still retains vehicle stability and steerability.

Requirements

The requirements placed on an ABS system are described in the ECE Regulation 13. This regulation defines ABS as a component of a service-brake system which automatically controls wheel slip in the direction of wheel rotation on one or more wheels when braked.

ECE Regulation 13 Annex 13 defines three categories. The present generation of ABS meets the highest level of requirements (Category 1).

Operating concept

A 2/2-way solenoid valve (inlet valve) with two hydraulic connections and two switching positions is fitted between the master cylinder and the wheel-brake cylinder of a conventional braking system (see figure overleaf). When the valve is open (normal setting for standard braking action), braking pressure can be generated in the wheel-brake cylinder. The outlet valve, also a 2/2-way solenoid valve, is closed at this point.

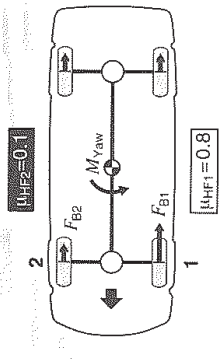
If the wheel-speed sensor detects an abrupt deceleration of the wheel (risk of wheel lock), the system prevents any further increase of braking pressure at the wheel concerned. The inlet and outlet valves are closed, and the braking pressure remains constant.

ble range of the adhesion/slip curve. After the (+ α) signal has dropped off, the braking pressure is slowly raised until, when the wheel acceleration again falls below the (- α) threshold, the second control cycle is initiated, this time with an immediate pressure drop.

In the first control cycle, a short pressure-holding phase was necessary initially to filter out any faults. In the case of high wheel moments of inertia, low friction coefficient and slow pressure rise in the wheel-brake cylinder (cautious initial braking, e.g., on black ice), the wheel might lock

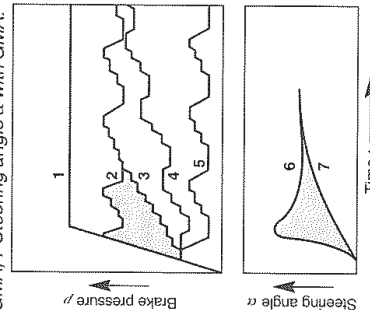
Yaw-moment buildup induced by large differences in friction coefficients

M_{yaw} Yaw moment, F_B Braking force, $\mu_{\text{H/L}}$ Coefficient of friction, 1 "High" wheel, 2 "Low" wheel.



Curves for braking pressure/steering-angle characteristic with yaw-moment buildup delay (GMA)

1 Master-cylinder pressure p_{MC} , 2 Braking pressure p_{high} w/o GMA, 3 p_{high} with GMA 1, 4 p_{high} with GMA 2, 5 p_{low} at "low" wheel, 6 Steering angle α w/o GMA, 7 Steering angle α with GMA.



without any response from the deceleration switching threshold. In this case, therefore, the wheel slip is also included as a parameter in the brake control system.

Under certain road-surface conditions, passenger cars with all-wheel drive and with differential locks engaged pose problems when the ABS system is in operation; this calls for special measures to support the reference speed during the control process, lower the wheel-deceleration thresholds, and reduce the engine-drag torque.

Braking control with yaw-moment buildup delay (GMA)

When the brakes are applied on a road surface with uneven grip (for instance, left-hand wheels on dry asphalt, right-hand wheels on ice), vastly different braking forces at the front wheels result and induce a turning force (yaw moment) about the vehicle's vertical axis.

On smaller cars, ABS must be supplemented by an additional yaw-moment buildup delay device (GMA) to ensure that control is maintained during panic braking on asymmetrical road surfaces. GMA delays the pressure rise in the wheel-brake cylinder on the front wheel with the higher coefficient of friction at the road surface ("high" wheel).

The GMA concept is demonstrated in the diagram: Curve 1 represents the master-cylinder pressure p_{MC} . Without GMA, the braking pressure at the wheel running on asphalt quickly reaches p_{high} (Curve 2), while the braking pressure at the wheel running on ice rises only to p_{low} (Curve 5); each wheel brakes with the maximum transferable braking force (individual control).

The GMA 1 System (Curve 3) is designed for use on vehicles with a less critical handling characteristics, while GMA 2 is designed for cars which display an especially marked tendency toward yaw-induced instability (Curve 4).

In all cases in which GMA comes into effect, the "high" wheel is under-braked at first. This means that the GMA must always be very carefully adapted to the vehicle in question in order to limit increases in stopping distances.

ABS version (as at 2003)

Hydraulic modulator

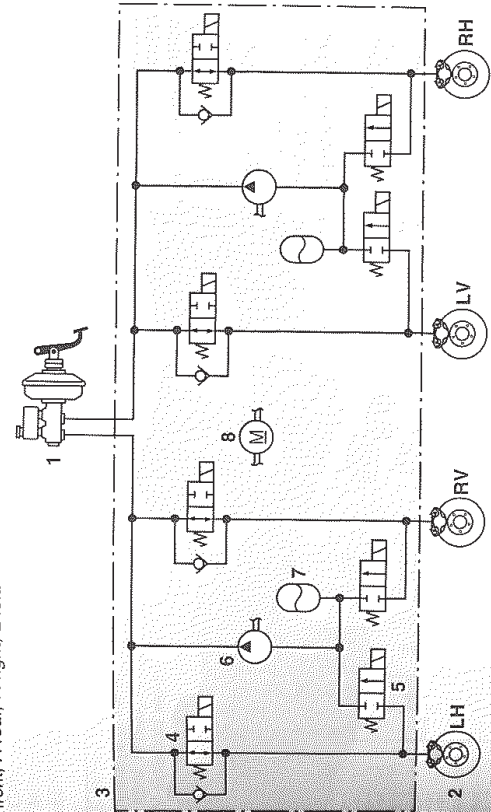
The development of solenoid valves with two hydraulic switching positions (2/2-way valves, used in Bosch ABS systems from the ABS 5 generation onwards) allowed a complete redesign of ABS as compared with the ABS2S/ABS2E version which used 3/3-way valves. This rationalized design and manufacture radically. However, the basic hydraulic concept of ABS has not changed since volume production was first launched in 1978. It means that the sealed brake circuits and the return principle are unchanged.

The main hydraulic components of the hydraulic modulator are the following:

- One return pump per brake circuit
- Accumulator chamber
- Damping functions, previously performed by an accumulator chamber and a flow restrictor, are now performed both hydraulically and by control systems, i.e. software
- 2/2-way solenoid valves with two hydraulic positions and two hydraulic connections

Hydraulic system for ABS 8

1 Master cylinder, 2 Wheel-brake cylinder, 3 Hydraulic modulator, 4 Inlet valves, 5 Outlet valves, 6 Return pump, 7 Accumulator, 8 Pump motor.



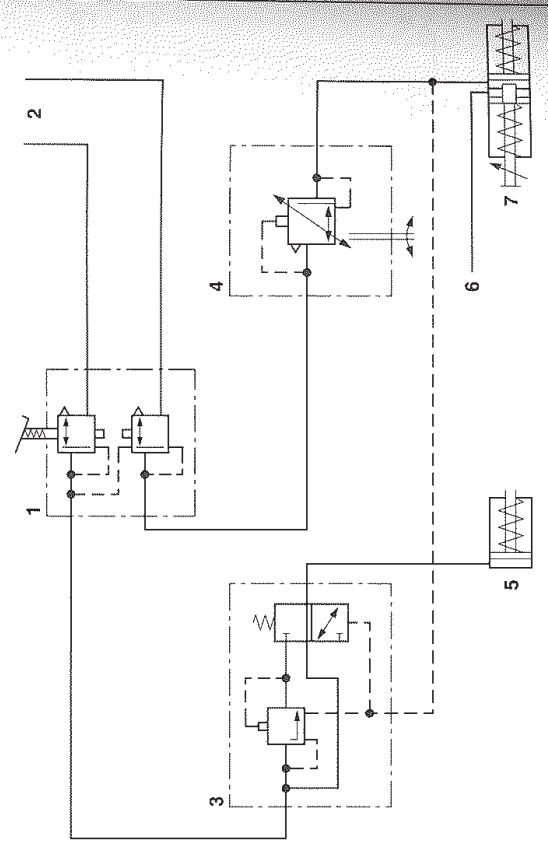
Basic comments on "kinked" braking-force metering

Load-sensitive braking-force metering devices adjust the installed braking-force metering to the dynamic (ideal) metering level and prevent the wheels of a given axle from locking prematurely. However, at low adhesion coefficients and low rear-axle loads, the wheels may skid because the metering device's switchover point can enter the unstable range of braking-force metering if one of the following occurs: high engine braking torque, retarder braking torque, tolerance fluctuations in the metering device, and/or high parameter fluctuations at the wheel brakes.

A braking system which works precisely under all braking conditions is only possible if load-sensitive braking-force metering is optimized. Commercial vehicles with extreme differences between empty and fully laden states require braking systems with automatic load-sensitive braking-force control (ALB) on the rear axle together with empty/load valves (in order to increase the working range of the ALB, Figure F).

ALB function diagram for four-wheel vehicles (Figure F)

1 Service-brake valve, 2 From pressure generator, 3 Load/empty valve (FA), 4 ALB valve (RA), 5 Diaphragm-type cylinder (FA), 6 From parking brake, 7 Combination brake cylinder (RA), FA = Rear axle, RA = Front axle.



Wheel brakes

On medium-sized and heavy-duty commercial vehicles, disc brakes are becoming increasingly popular. Currently, drum brakes are in the majority worldwide.

The brake coefficient C^* is an assessment criteria for brake performance and indicates the ratio of braking force to application force. This value takes into account the influence of the internal transmission ratio of the brake as well as the friction coefficient, which in turn is mainly dependent on the parameters of speed, braking pressure and temperature (Figure).

Drum brakes

The actual construction of a drum brake depends on the requirements imposed by brake-shoe application, anchorage, and adjustment.

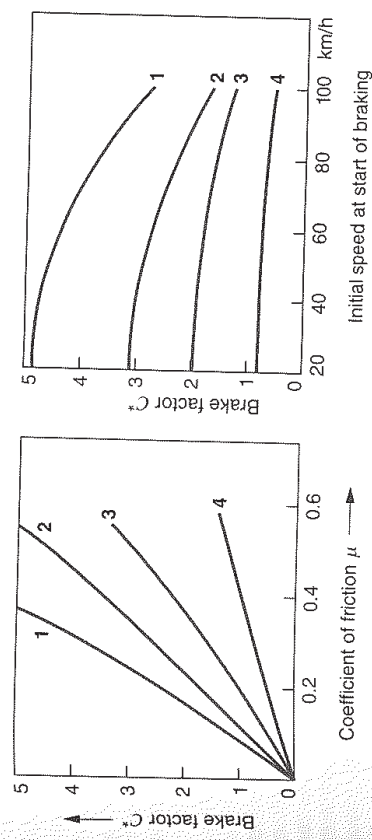
Simplex drum brakes (Figure H)

These differ in particular according to their type of application (floating, fixed) and type of support or anchorage (rotating shoes, sliding shoes). Wheel brakes

with floating-brake application and rotating-shoe support are common. In the case of hydraulic braking-force actuation, for instance, the brakes are applied by means of floating pressure pistons. Piston travel is not fixed, and they develop actuating forces which are equal in both directions. One shoe is the leading shoe and the other is the trailing shoe. In the leading shoe, the friction forces between the brake lining and the brake drum support the actuating force. In the trailing shoe, however, the friction forces oppose the actuating force.

For this reason, the trailing shoe often has a much thinner lining than the leading shoe.

Brake coefficient C^* as a function of the coefficient of friction and initial road speed (Figure G)
1 Duo-servo drum brake, 2 Duo-duplex drum brake, 3 Simplex drum brake, 4 Disc brake.



Simplex drum brakes (Figure H)

Design	Rotating shoe	Wedge	S-cam
Schematic diagram			
Brake factor	$C^* = C_1 + C_2$		
Brake shoes	1 Leading shoe, 2 Trailing shoe		
	$C^* = 4/(1/C_1 + 1/C_2)$		

Data processing and communication networks in motor vehicles

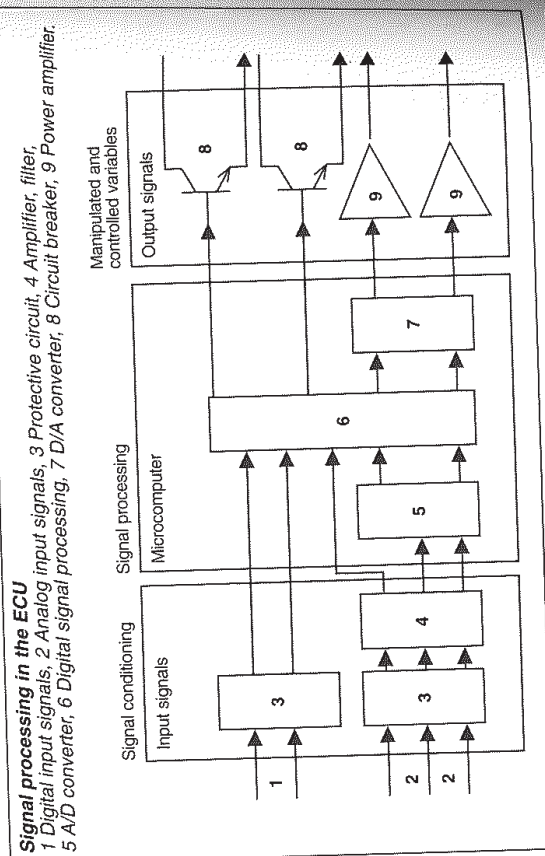
Requirements

Highly sophisticated state-of-the-art open-loop and closed-loop control concepts are essential for meeting the demands for function, safety, environmental compatibility and convenience associated with the wide range of automotive subsystems installed in modern-day vehicles. Sensors monitor reference and controlled variables, which an electronic control unit (ECU) then converts to the signals required to adjust the final-control elements/actuators. The input signals can be analog (e.g. voltage characteristic at pressure sensor), digital (e.g. switch position) or pulse-shaped (i.e. information content as a function of time, e.g. engine-speed signal). These input signals are processed after appropriate conditioning (filtering, amplification, pulse-shape modification) and converted (analog/digital), preferably by digital signal-processing methods.

With modern semiconductor technology, powerful microcomputers can be integrated on relatively few chips together with their accompanying program and data memories, and special peripheral circuits designed specifically for real-time applications.

Modern vehicles are equipped with 20 to 60 electronic control units, e.g. for engine management, Antilock Braking System (ABS), and transmission-shift control. Improved performance and additional functions are obtained by synchronizing the processes controlled by the individual ECUs and by mutual real-time adaptation of the respective parameters. An example of this type of function is traction control (TCS), which reduces the drive torque if the driving wheels spin.

Originally, data exchange between the ECUs (in the example cited above, ABS/TCS and engine management) took place via separate wires. However, this type of point-to-point connection is only suitable for a limited number of signals. The introduction of automotive-compatible communication networks for serial transmission of information and data between ECUs has expanded the data transfer capabilities and represents the logical development of autonomous "microcomputers" in motor vehicles.



Electronic control unit (ECU)

ECUs developed for use in motor vehicles all have a similar design. Their structure can be subdivided in the conditioning of input signals, the logic processing of these signals in the microcomputer, and the output of logic and power levels as regulation or control signals (see figure).

Digital input signals

Detect a switch position or digital sensor signals (e.g. rotational-speed pulses from a Hall-effect sensor).

Analog input signals

Signals from analog sensors (lambda sensor, pressure sensor).

Pulse-shaped input signals

Signals from inductive wheel-speed sensors. After signal conditioning, they are then processed as digital signals.

Initial conditioning of input signals

Protective circuits (passive: R and RC circuits; active: special surge-proof semiconductor components) are used to limit the voltage of the input signals to acceptable levels (operating voltage of the microcomputer). Filters remove most of the superimposed noise from the useful signals, which are then amplified to the microcomputer's input voltage.

Signal processing

ECUs generally process signals in digital form. Rapid, periodic, real-time signals are processed in hardware modules specifically designed for the particular function. Results, e.g. a counter reading or the time of an event, are sent in registers to the CPU for further processing. This procedure substantially reduces the CPU's interrupt-response time (µs range).

The amount of time available for calculations is determined by the controlled system (e.g. milliseconds in the case of engine management). The software contains the actual control algorithms. Depending on the data, almost any logical operation can be implemented, and any data records can be stored and processed in the form of parameters, characteristic curves, or multidimensional pro-

gram maps. For more complex requirements in the field of image processing, the use digital-signal processors (DSP) is becoming more widespread.

Manipulated and controlled variables

Manipulated and controlled variables in the output module provide the required signals or power levels for peripheral actuators (e.g. electric motors for seat adjustment, power windows or power-assisted steering). Circuit breakers and amplifiers raise the microcomputer's output-signal levels (0...5 V, a few mA) to the power levels required for the actuators concerned (e.g. up to 100 A for short periods for engine cooling).

Architecture

The structural building blocks are assembled in hardware platforms or modular kits by using identical components (chips). These modules are also increasingly used for multiple applications (e.g. engine management for gasoline and diesel engines).

The same procedure is also suitable for function modules for control algorithms, which then become modular, reusable components within the overall system. Essentially, there are two elements that are important for implementing this type of methodology transfer:

- A concept for configuring and structuring functionality within the vehicle (CARTRONIC).
- Communication networks over which ECUs can interexchange information.

The building plan for assembling functions, network hardware and software is referred to as the architecture. System architecture describes the entirety of the structural and dynamic characteristics of distributed systems.

Mobile and data radio

Telecommunications networks

Telecommunications networks consist of terminals and an infrastructure. Mobile radiocommunications networks can be classified as belonging to telecommunication networks based on the mobility of the terminals and the method these terminals use to access the infrastructure.

	Access method	
	Wired	Wireless
Fixed	- Traditional phone network - Internet, LAN	Radio relay
Mobile		- Mobile/data radio - Private mobile radio - Radio broadcasting - Marine/aeronautical radio - Cordless phones

Components and structure

Mobile radiocommunications networks can be subdivided in mobile radio telephones and infrastructure.

Mobile radio telephones

Mobile radio telephones include cellular phones and automotive radiocommunication devices. A mobile radio telephone is made up of three functional components:

- an operator unit (microphone, speaker, display, and keypad)
- Radio modem (modem, modulator/demodulator) to convert voice and data signals to electrical signals
- a radio transmitter/receiver unit.

Data terminal devices without radio transmitter/receiver units such as laptop computers or PDAs (Personal Digital Assistants) can communicate with a mobile radio communication system through an internal or external radio modem.

Mobile radiocommunications infrastructure

The mobile radiocommunications infrastructure consists of the fixed radio trans-

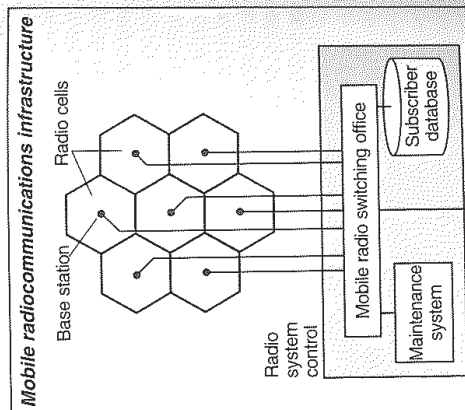
mitter/receiver stations and the radio system control. A radio transmitter/receiver station consists of a base station, which provides radio coverage of an area, and a base-station control system. The positioning of base stations depends on several considerations, including topographical constraints and expected communications traffic levels (maximum subscriber capacity). A cellular network structure allows the few radio frequencies available to be reused in adjacent cells.

Radio system control

The mobile radio switching office controls call connection between mobiles that are in the same or even in different radio cells. It also controls the switching of radio traffic to the wire-line telephone network. In order to control call switching automatically, the mobile radio switching office must know the location of all mobiles within the radio cells at all times. The is made possible by continuously exchanging an identification signal between the mobiles and the base stations. A base station can detect when a mobile moves to an adjacent cell by the drop in field strength or quality of the received signal.

The subscriber database performs the job of authenticating subscribers, and stores each subscriber's location within the radio cells.

A maintenance and control system continuously monitors network operation.



Mobile radiocommunications networks

GSM and DCS 1800 mobile radio networks

The standardized digital mobile communications network for Europe, GSM (Global System for Mobile Communication), has been in operation since 1992. In contrast to analog radio networks, it transmits voice and control data in digital form. GSM radio networks operate in the 900 MHz band, and each has a capacity of around 2 million subscribers. The similar DCS 1800 (Digital Cellular System) network operates using identical technology in the 1800 MHz band, and has been in service since 1994. Each radio cell has several high-frequency channels, each with a bandwidth of 200 kHz. Each high-frequency channel transmits seven voice channels (traffic channels) and one control channel in succession in short time slots within a time frame. When a call is set up, the high-frequency channel is available to each cellular phone every 4.6 ms for the duration of the time slot (time-division multiplexing). The time delay of 4.6 ms between two consecutive identical time slots is short enough to guarantee perfect speech quality.

Each traffic channel can transmit a maximum gross data stream of 22.8 kbit/s. To compensate for errors during radio transmission, digitized speech is only transferred at a data rate of 9.6 kbit/s. The difference between this and 22.8 kbit/s is used for error correction. Instead of speech, a traffic channel can also transfer data (e.g. a fax transmission).

A time slot between the terminals is permanently reserved for the duration of a mobile radio connection (line connection), regardless of whether the connection carries speech or data.

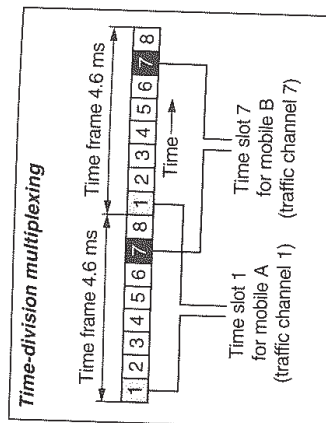
Short Message Service (SMS)

SMS (Short Message Service) offers economical data transmission within GSM mobile radio networks for text messages of up to 160 characters in length. The text in an SMS message is transmitted without occupying a separate voice channel by using unused capacity in the control channels. SMS messages can be sent

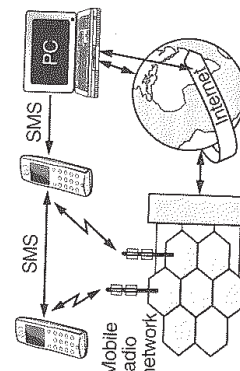
from one mobile to another or from a PC to a mobile via the Internet. After an SMS message is sent, it is temporarily stored on the mobile radio network, and automatically sent out as soon as the receiving mobile is switched on ("store and forward" principle).

HSCSD data transmission procedure

The HSCSD (High Speed Circuit Switched Data) data transmission procedure involves GSM networks combining up to four adjacent traffic channels for data-transmission purposes (line connection). With a net data transmission rate of 14.4 kbit/s per traffic channel, channel bundling provides an overall data rate of 57.6 kbit/s. The cost of an HSCSD connection is calculated on the basis of the connection time and the number of traffic channels used.



SMS Short Message Service



GPRS data transmission procedure

In 2001 the packet-based data transmission procedure GPRS (General Packet Radio Service) was introduced to complement the GSM radio network. GPRS data channels and normal voice channels share the time slots in a time frame. GPRS data channels are dynamically allocated according to voice-channel priority. During transmission pauses in GPRS connections, other GPRS connections can use the temporarily "unused" time slots. In contrast with the HSCSD procedure, a data stream is subdivided in individual consecutively numbered data packets for transmission. The data packets are transmitted independently of one another. The receiving mobile rearranges the data packets into the correct order on the basis of their consecutive numbering. Transmission costs are calculated on the basis of the data volume transmitted. A mobile equipped with a GPRS module can connect to data networks (e.g. the Internet).

WAP data service

The WAP (Wireless Application Protocol) service in GSM radio networks is based on a special data-transmission protocol derived from the widely adopted Internet protocol. This service has been defined independently of mobile radio standards. Therefore, it can be used not only in GSM networks, but also in the future 3G/UMTS radio network. A microbrowser integrated in the mobile can access data from the Internet (World Wide Web, e-mail, etc.). In contrast with the SMS and MMS services, access to stored data/messages (WAP pages or e-mails) on the Internet is actively initiated by the user ("store and retrieve" principle). In order to display WAP pages on a small cellular phone or PDA screen, they are specially adapted for the small display format, and are frequently stored in parallel to the regular web pages on the Internet. Typical applications are the transmission of messages (e-mail), weather, traffic, and stock-exchange bulletins.

i-Mode wireless data service

The i-Mode wireless data service ("I" stands for Internet or interactive) in Europe is part of the DC1800 mobile radio network and has been very successful in

Japan as an alternation to the WAP service. Both services use GPRS data-transmission technology.

MMS data service

MMS (Multimedia Messaging Service) allows the transmission of images, graphics, video clips, audio files, etc. to or from a mobile. The MMS service was defined for the transmission of MMS messages in GSM networks, using GPRS/WAP technology, and in the UMTS radio network. Before transmitting multimedia objects to a mobile, the display format must be adapted. Special computers in the mobile-radio networks therefore configure the multimedia data. Any combination of individual multimedia objects can also be created and reproduced on the mobile based on a specific time plan. In addition to "fun applications" (sending photos live on vacation), there are also possible business uses, such as sending presentations, product data, or directions to field staff on their mobiles.

3G/UMTS mobile radiocommunication network

The future mobile radiocommunications network is 3G/UMTS (3rd generation; Universal Mobile Telecommunication System) is an advance development of the GSM network. The radio communication interface has been optimized for multimedia applications, such as voice, data, music, images, video, games, etc., and packet-based data transmission. The 3G/UMTS radio network operates in Europe in the 1.9...2.2 GHz frequency band. The radiocommunications infrastructure is divided into three levels as follows:

1. The macrocellular network, as the highest network level, consists of radio transmitter/receiver stations with a cell size of approx. 2 km. It provides nationwide network coverage. The maximum data transmission rate is 144 kbit/s.
2. The microcellular network, as the middle network level, supplies smaller areas (cell size approx. 1 km, primarily for large conurbations). The maximum data transmission rate is 384 kbit/s.

3. The picocellular network (cell size approx. 60 m, max. data transmission rate 2 Mbit/s) primarily supplies buildings (e.g. airports).

In contrast with GSM time-division multiplexing, G3/UMTS transmits all data within a radio cell simultaneously on the same radio channel.

WCDMA (Wideband Code-Division Multiple-Access) codes separate data for different mobiles in a high-frequency channel. The base station and the mobile negotiate these codes with each other. WCDMA technology allows more efficient utilization of radio channels compared with GSM technology. Thus, the data transmission capacity for a connection can be flexibly adapted to suit the service in use. Voice transmission, for example, requires a lower data rate than the transmission of multimedia applications, such as images and video clips.

Data radio networks

Special data radiocommunications networks, such as Bluetooth and WLAN, provide a data link between mobile terminals, or within a data network such as the Internet.

Bluetooth

Bluetooth is an alternative to infrared links, and is used to provide wireless connection between PCs and external devices, such as printers, digital cameras, etc.

The Bluetooth network operates in the unlicensed 2.4 GHz frequency band (like appliances such as microwave ovens). "Bluetooth" is derived from the name of a Viking king called Harald Blåtand (meaning "Bluetooth") in recognition of the leading contribution to the development of the technology by Danish companies. The transmitter output is 1 mW over a range of approx. 10 m. In order to eliminate errors in transmission as far as possible, the frequency is changed 1,600 times a second (frequency hopping). The individual frequency divisions transmit the data sequentially as data packets. If a frequency

division experiences a fault during data transmission, an error correction procedure can completely reconstruct a frequency division on the receiver side.

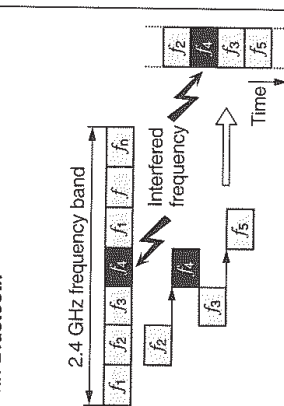
The maximum data rate is 721 kbit/s. In Bluetooth networks, no particular data-encryption method is employed. Data security is limited simply to synchronizing the frequency hopping procedure between devices.

WLAN

WLAN networks (Wireless Local Area Network) offer mobile telephones and Bluetooth networks a wireless link to computer networks in the 2.4 GHz frequency band. In contrast with Bluetooth, the frequency is changed only every 2.5 seconds. The transmit output is up to 100 mW, which allows a range of up to 100 m in buildings. Using WLAN, data links to the Internet with a maximum data rate of 11 Mbit/s can be created at a low investment cost. As distinct from Bluetooth, WLAN radio networks also employ an effective data-encryption process.

The terminals used are laptop computers or PDAs equipped with an appropriate radio LAN interface module. WLANs replace or complement cable-based LANs in enterprises, universities, and airports, etc. In order to allow billing in public WLANs (airports, railway stations, etc.), the mobiles must be fitted with a SIM (Security Identify Module) for identification.

Data transmission and error correction with Bluetooth



Multimedia systems

Multimedia means the combination of different media. All known media are interconnected and are available for use.

Various sound and information sources, and communication installations can form a common mobile driver-information system consisting of radio, cassette player, CD player, phone, navigation and traffic telematics equipment, and even computer, video player, and TV.

Multimedia broadcasting

The digital audio broadcasting systems developed in recent years (DAB, DRM) allow the transmission of any type of data at high bit rates so that the radio of the past is currently developing into a genuine multimedia system for the future. It permits transmission of audio data (music, news), textual information (messages), and video data (from individual images through to TV broadcasts). With such capabilities, DAB becomes DMB (Digital Multimedia Broadcasting). This is illustrated by the following conceivable examples:

Traffic and travel information

Traffic and travel information may encompass the following services:

- Traffic announcements may be transmitted as audio (synthetic voice), or as text, or map extracts (on a display).
- TMC or TPEG-coded traffic announcements may be transmitted for navigation devices, thus allowing dynamic route guidance. In addition, updated digital road maps may be transmitted to ensure that route guidance by navigation systems is based on information that is completely up-to-date.
- Travel guides may use maps to provide directions to vacation destinations, or to business appointments, and offer information about the locality, the hotel, local events, parking facilities (with details of parking lots with free spaces), filling stations, timetables, local stores, etc. Along with the information about the "Points of Interest" (POI), details of their location (references) may also be

transmitted so that the navigation system can locate them automatically without any driver input.

Transmission of text and images

Text data is an extension of radio broadcasts, and may contain a large amount of additional information, such as title and composer of a music track currently being played, information about the present station tuned, including phone number/address to request additional information, or even an electronic program listing. The DAB standard offers the following modes for transmitting text:

- Station name and type.
- Dynamic label for the station, the speed of the label is controlled by the transmitting station.
- Interactive text pages in HTML or XML format, which can be displayed in various formats.

Mobile Internet

Combination with mobile communication media, such as GSM and UMTS, permits interaction with servers on the Internet so that interactive services can be offered. Wireless Application Protocol (WAP) is the name of the internationally established protocol which links the two worlds together.

The aim is to integrate the various communication elements such as navigation system, car tuner, mobile radiocommunications, digital audio broadcasting, and Internet.

For mobile access to the Internet from a motor vehicle (or on board a train), it must be possible to receive over the air interface, even when traveling at high speeds. In addition, there is certainly a challenge in meeting the demands for consistent Internet-access quality while moving between city and rural surroundings, with the resulting wide variations in transmission conditions.

The Internet is an open medium or marketplace for users and information providers and has a wide variety of services for the mobile consumer. International bodies, such as the Open Mobile Alliance (OMA), the World Wide Web Consortium (W3C), or the International Engineering Task Force (IETF) define interfaces and protocols so that the new services can be used anywhere at any time:

- A hotel or restaurant may encode its geographical coordinates on its website so that they can be accessed by a navigation system. This would then direct the driver automatically to the desired destination. A reservation inquiry could be made and confirmed in advance over the mobile radiocommunications channel.
- Vehicle functions, such as remote diagnosis and remote maintenance support, could connect automatically to a service center via the Internet in case of a breakdown or accident. The service center would then produce a diagnosis of the vehicle's condition, and accompany the vehicle to the workshop, or inform the breakdown assistance or emergency services.

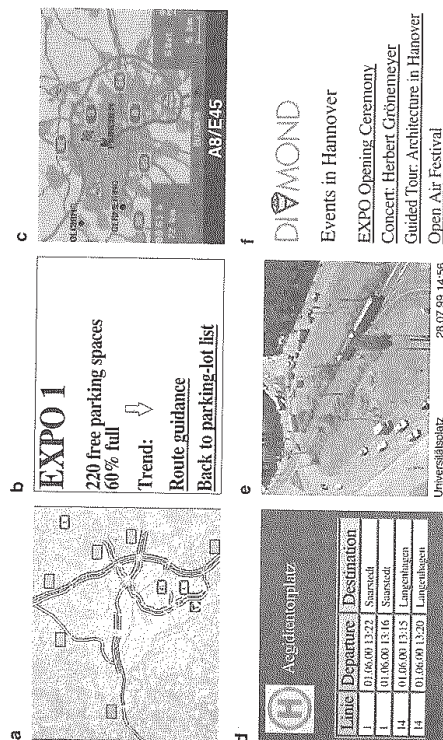
- Future traffic management systems will take account of traffic flow in city areas as well. The number of organizations involved will be so large that coordination over the Internet will become necessary, as this is the medium accessible to everyone. Traffic flow in selected areas will be shown online on graphical displays, or will be distributed in machine-readable form as network lists. The navigation system will then be able to use this information to compute the best route.

- In addition, other specially prepared services may be accessible over the Internet. This includes e-mails, e-commerce, or news, weather, and sports announcements, or online transactions with banks, hotels, cinemas, or travel agents.

- With the ever shorter development cycles in the fields of information and communications technology, software updates via the Internet will allow the longer-lasting components of motor vehicles to be kept up-to-date.

Mobile Internet services (examples)

- a) Traffic-holdup maps (with forecast), b) Parking information and parking guidance system, c) Dynamic navigation, d) Public transport information, e) Camera shots of traffic situation, f) Information about events.



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