Automotive electronics

What you need to know! Part 2
Electronics - your future?

The electronic share in vehicles is growing all the time – it is estimated that electronics will make up around 30% of the total material value by the year 2010.

On the one hand, this is a great opportunity, but on the other, the ever more complex technology makes it difficult to keep up with technical innovations. Hella would like help you with this. Our electronics experts have put together a selection of important information on the subject of automotive electronics.

We hope this booklet will provide you with interesting and helpful information for your day-to-day work. For further technical information please contact your local Hella Partner.
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Tighter statutory regulations have made it necessary to reduce exhaust emissions even further. This applies to both diesel and petrol engines. Emission of nitrogen oxides is reduced with the aid of so-called exhaust gas recirculation. In the case of petrol engines, fuel consumption is also reduced in part-load operation.

At high combustion temperatures, nitrogen oxides are produced in the engine’s combustion chamber. Recirculating part of the exhaust gas to the fresh intake air reduces the combustion temperature in the combustion chamber. The production of nitrogen oxides is avoided on account of the low combustion temperature.

The following table shows the exhaust gas recirculation rate for diesel and petrol engines:

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Petrol</th>
<th>Petrol (direct injection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGR-rate (max.)</td>
<td>50 %</td>
<td>20 %</td>
<td>Up to 50 % (depending on engine operation, homogeneous or stratified load)</td>
</tr>
<tr>
<td>Exhaust gas temperature when the EGR system is active</td>
<td>450 °C</td>
<td>650 °C</td>
<td>450 °C up to 65 °C</td>
</tr>
<tr>
<td>Why is an EGR system used?</td>
<td>Reduction of nitrogen oxides and noise</td>
<td>Reduction of nitrogen oxides and consumption</td>
<td>Reduction of nitrogen oxides and consumption</td>
</tr>
</tbody>
</table>
A distinction is made between two kinds of exhaust gas recirculation: “inner” and “outer” exhaust gas recirculation.

In the case of inner exhaust gas recirculation, the process of mixing exhaust gas and fresh air/fuel mixture takes place within the combustion chamber. In all 4-stroke engines this is done by the valve overlap of intake and exhaust valve particular to the system. On account of the design, the exhaust gas recirculation rate is very low and can only be influenced to a limited extent. Only since the development of variable valve timing has it been possible to actively influence the recirculation rate, depending on load and rpm.

Outer exhaust gas recirculation takes place via an additional pipe between the exhaust manifold/pipe and the intake manifold and the EGR valve. The first systems were controlled by a poppet valve, which is opened or closed by a vacuum element (pneumatic drive). The suction line pressure served as a control variable for the vacuum element. This meant that the position of the poppet valve depended on the engine’s operating state. To achieve more influence over the exhaust gas recirculation rate, pneumatic check valves, pressure limiting valves and delay valves were installed. Some systems also take the exhaust gas backpressure into account as control pressure for the vacuum element. In some operating states exhaust gas recirculation is switched off completely. This is made possible by installing electrical switchover valves in the control line. Despite these possibilities of influence, the system was still always dependent on the engine’s load state and the suction pipe vacuum this implied to control the vacuum element.

To meet the demands of modern engines and become independent from suction pipe vacuum, electrical drives were developed for exhaust gas recirculation valves. At the same time, sensors for recognizing valve position were integrated.
These developments enable exact control with short adjustment times. These days, direct current motors are also used as electrical drives, alongside stepper motors, lifting and rotary magnets. The actual control valve has also been modified over time. In addition to needle and poppet valves of different sizes and dimensions, rotary and flap valves are also used today.

**Exhaust gas recirculation valve**

The exhaust gas recirculation valve is the most important system component. It is the connection between the exhaust pipe and the intake tract. Depending on the control signal, it releases the valve opening and allows exhaust gas to flow into the intake manifold. The exhaust gas recirculating valve is available in different versions: Single or double membrane version, with and without position feedback or temperature sensor, and, of course, electrically controlled. Position feedback means that there is a potentiometer attached to the exhaust gas recirculation valve which forwards information about valve position to the control unit. This makes exact recording of the exhaust gas quantity recirculated possible in every load state. A temperature sensor can be integrated for self-diagnosis of the exhaust gas recirculating valve.

**Pressure converter**

Pressure converters have the task of controlling the necessary vacuum for the exhaust gas recirculating valve. They adapt the vacuum to the respective load state of the engine in order to keep a precisely defined recirculation rate. They are controlled mechanically or electrically.

**Thermal valves**

These have a similar task as pressure converters, but work dependent on temperature. Pressure converters and thermal valves can also be combined.
The EGR valve is certainly the greatest fault source on account of the high loads. Oil mist and soot from the exhaust gas soot the valve and the cross-section size of the valve opening is reduced over time until it is completely blocked. This results in a continual reduction of the recirculated exhaust gas quantity, which is reflected in exhaust gas behaviour. The high thermal load favours this process even further. The vacuum hose system is also often responsible for faults. Leaks lead to a loss of the required vacuum for the EGR valve, and the valve no longer opens. An EGR valve not working due to lack of vacuum can of course also be caused by a defective pressure converter or a thermal valve not working properly.

There are various possibilities of **checking the exhaust gas recirculation system**. These depend on whether or not the system is capable of self-diagnosis. Systems that are not self-diagnosis capable can be checked with a multimeter, a manual vacuum pump and a digital thermometer. But before these time-consuming tests are started, a visual inspection of all system-relevant components must be carried out. This means:

- Are all vacuum lines airtight, connected correctly and laid without being bent?
- Are all electrical connections on the pressure converter and changeover switch connected properly? Are the cables OK?
- Are there leaks on the EGR valve or the connected pipes?

If no faults are found during the visual inspection, the system must be checked using further tests and measurements.

### Potential faults and their causes

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 °C</td>
<td>&gt; 1000 k</td>
</tr>
<tr>
<td>70 °C</td>
<td>160 – 280 k</td>
</tr>
<tr>
<td>100 °C</td>
<td>60 – 120 k</td>
</tr>
</tbody>
</table>
Use a hot air gun or hot water to heat the system. Use the digital thermometer to check the temperature and compare the measured values with the reference values.

Valves with two membranes

Valves with laterally offset vacuum connections are only opened by one connection. These can be located above one another or offset laterally on one level. Valves in which the vacuum connections are arranged above one another work in two stages. Above the lower connection, the valve is partly opened, above the upper connection the valve is completely opened. Valves with laterally offset vacuum connections are only opened by one connection. The connections are colour coded. The following combinations are possible:

- Black and brown
- Red and brown
- Red and blue

The vacuum supply line is connected to the red or black coded connection. Leak tests are carried out under the same conditions as for valves with one membrane, but must be carried out on both vacuum connections. To check the vacuum supply to the valve, the manual vacuum pump can be used as a manometer. It is connected to the EGR valve supply line. The prevailing vacuum is indicated with the engine running. In the case of valves with connections arranged above one another, the manual vacuum pump must be connected to the line of the lower connection, with laterally offset connections to the line of the red or black connection.

Leak test on an EGR valve

EGR valves on diesel engines can be tested in the same way as those on petrol engines

A vacuum of approx. 500 mbar must be created using the manual vacuum pump with the engine switched off. This vacuum must be maintained for 5 minutes and may not drop. A visual inspection can also be made. To do this, create a vacuum again using the manual vacuum pump via the vacuum connection. Observe the valve rod (connection between membrane and valve) through the openings. They must move evenly when the manual vacuum pump is actuated.
Testing pressure converters, switchover valves and thermal valves

EGR valves with potentiometer
Some EGR valves have a potentiometer for valve position feedback. The EGR valve is tested as described above. The following procedure must be followed when testing the potentiometer: Remove the 3-pin plug and measure the overall resistance at pin 2 and pin 3 of the potentiometer using a multimeter. The measured value must be between 1500 Ω and 2500 Ω. In order to measure the resistance of the loop track, the multimeter must be connected to pin 1 and pin 2. Open the valve slowly using the manual vacuum pump. The measured value begins at approx. 700 Ω and increases up to 2500 Ω.

Testing mechanical pressure converters
With this test, the manual vacuum pump is not used to produce a vacuum but rather as a manometer. Remove the vacuum hose leading from the pressure converter to the EGR valve from the pressure converter and connect the vacuum pump. Start the engine and slowly move the pressure converter rods. The manometer display of the vacuum pump must move accordingly.

Testing electro-pneumatic pressure converters
Here, too, the manual vacuum pump is used as a manometer. Connection to the electro-pneumatic pressure converter is again at the vacuum connection leading to the EGR valve. Start the engine and remove the plug from the electrical connection of the pressure converter. The vacuum indicated on the manometer must not exceed 60 mbar. Insert the plug again and increase the engine speed. The value indicated on the manometer must increase simultaneously.

Testing a pressure converter

In order to test the resistance of the coil of the pressure converter, remove the electrical connection plug again and connect a multimeter to the two connection pins. The resistance value should be between 4 Ω and 20 Ω.
To test the control of the pressure converter, connect the multimeter to the plug connections and observe the voltage value indicated. This must change as the engine speed changes.

**Testing electrical pressure converters**

Electrical pressure converters are tested in exactly the same way as electrical switchover valves.

**Testing electrical switchover valves**

Electrical switchover valves have three vacuum connections. If only two connections are occupied, the third connection must be fitted with a sealing cap that must not be airtight. For the test, the manual vacuum pump is used to carry out a continuity test on the output lines of the switchover valve. The vacuum pump is connected to an output line for the test. If a vacuum can be generated, the switchover valve must have a voltage supply. **Important:** If the polarity of the connections (+ and -) is prescribed at the connection of the switchover valve, these must not be mixed up. If voltage is applied to the switchover valve, it must switch over and the created vacuum is reduced. Repeat the same test for the other connection.

**Testing thermal valves**

The vacuum hoses have to be removed for the thermal valves to be tested. Connect the manual vacuum pump to the central connection. The thermal valve must not be open when the engine is cold. When the engine is up to operating temperature, the valve has to open the passage. To be independent of the engine temperature, the thermal valve can be removed and heated in a water bath or by hot air gun. The temperature must be continually monitored to find out the switching points.
All the test values detailed here are approximate values. Vehicle-specific connection diagrams and testing values must be available to obtain exact values.

EGR systems that are diagnosis capable can be tested with a suitable diagnostic unit. Here again, the testing depth of the unit used and the system to be tested are decisive. Sometimes it is only possible to read out the fault memory, sometimes the measured value blocks can be read out and an actuator test carried out.

Testing using a diagnostic unit

EGR data list

<table>
<thead>
<tr>
<th>Bauteil</th>
<th>Wert</th>
<th>Einheit</th>
<th>Beschreibung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drehzahlgeber</td>
<td>2600</td>
<td>rpm</td>
<td></td>
</tr>
<tr>
<td>Luftmassendruckmesser</td>
<td>250.0</td>
<td>mg/H</td>
<td>(Sollwert)</td>
</tr>
<tr>
<td>Luftmassendruckmesser</td>
<td>44.0</td>
<td>mg/H</td>
<td>(Istwert)</td>
</tr>
<tr>
<td>EGR Ventil</td>
<td>28</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

EGR actuator test

It is important in this context that components with only an indirect influence on the EGR are also tested. The mass air flow meter or engine temperature sensor, for example. If the mass air flow meter sends an incorrect value to the control unit, the quantity of exhaust air to be recirculated will also be calculated incorrectly. This can lead to deterioration of the exhaust gas values and major engine running problems. With electrical EGR valves it is possible that no faults are indicated during the diagnosis, and even an actuator test provides no clues about the source of the problem. In this case, the valve can be heavily soiled and the valve opening no longer releases the cross-section required by the control unit. In such cases, it is advisable to remove the EGR valve and check it for soiling.
EDC – Electronic Diesel Control

At some point in the course of development of diesel engines, mechanical control was no longer sufficient to keep pace with technical process. More and more stringent exhaust gas standards and the wish to both reduce consumption and increase engine power made the development of an electronic control system necessary for diesel engines. The first EDC (Electronic Diesel Control) was used in 1986. Today, EDC is a standard component in modern high-pressure diesel injection systems. Without it, realising convenient and powerful diesel injection systems would be impossible.

How does the EDC work?

Basically, it can be compared with an injection system in petrol engines. The EDC can be divided into three component parts:

- Sensors
- Control unit
- Actuators

The sensors

The sensors map all actual and reference states. This means, for example, that engine temperature and fuel pressure are mapped as actual values at the same time as reference values such as the accelerator pedal position. The sensors map the operating conditions and convert measured physical or chemical values into electrical signals, which they then forward to the control unit. The demanding requirements made on sensors have caused them to become increasingly smaller and more powerful over the past few years. Conventional sensors are usually individual components that transmit an analogue signal to the control unit where it is then processed further. New sensors in the EDC are equipped with signal processing, an analogue/digital converter and sometimes even evaluation electronics. Signal transmission to the control unit is digital. This results in numerous advantages:

- The sensors can map smaller measured values.
- Transmission to the control unit is immune to interference.
- The computer capacity of the control unit can be reduced.
- The sensors are databus-capable and their information can be used for several applications.
The various sensors

Speed sensors

Depending on the injection system, the speed sensors map the speeds and positions of various rotating shafts. The most important sensor is the engine speed sensor. This records the engine speed and position of the crankshaft. The speed sensor is usually an inductive sensor (passive sensor). It consists of an iron core with a coil wound around it and is connected to a permanent magnet. If the trigger wheel turns, the magnetic flow in the coil changes, inducing a sine-shaped voltage. The frequency and amplitude are proportional to the engine speed. By changing the tooth spacing on the trigger wheel, the signal can be changed and provide information about the position of the crankshaft. Some vehicle manufacturers also use active sensors. These sensors work according to the Hall sensor principle. Pairs of magnetic poles (one north pole and one south pole alternately) are attached to the trigger wheel in place of the teeth. Here, too, the reference mark to the crankshaft position is produced through a changed spacing. As opposed to the inductive sensor, the Hall sensor generates a rectangular signal, the frequency of which is also proportional to the engine speed.

Camshaft sensor

The position of the camshaft is also necessary for engine start-up. The control unit needs to know which cylinder is currently in the compression stroke. The position of the camshaft is determined via a Hall sensor that scans one or more reference marks on the camshaft. This results in a rectangular signal, which is forwarded to the control unit. In the case of unit injector systems, there is one tooth on the camshaft wheel for every cylinder, with respective spacing. To be able to assign the teeth to a cylinder, a further reference mark is arranged for the cylinders at different distances (not for the fourth cylinder). The control unit can assign the signals to the individual cylinders by comparing the time offset of the two rectangular signals.

Air mass sensor

In order to determine the exact injection quantity and exhaust gas return rate, the control unit requires information about the quantity of intake air. The mass air flow is measured using the air mass sensor installed in the intake manifold.
Temperature sensors

Temperature sensors are usually designed as NTC. This means that there is a precision resistor made of semi-conductor material with a negative temperature coefficient (NTC) in the housing. These have a high resistance at low temperatures, with resistance decreasing as temperature increases.

The engine temperature sensor is installed in the engine coolant circuit. It maps the coolant temperature, which provides information about the engine temperature. The control unit requires the engine temperature as a corrective value for calculating the injection quantity.

The fuel temperature sensor is installed on the low-pressure side of the fuel system. It records the fuel temperature. As the temperature changes, the fuel density also changes. The control unit requires the fuel temperature to precisely calculate the injection starting point and quantity. Any fuel cooling is also controlled using the value measured by the temperature sensor.

The air temperature sensor maps the temperature of the intake air. The intake air temperature sensor can be installed in the intake tract as a separate sensor or is integrated in the intake pipe pressure sensor. As with the fuel, the density of the air also changes as its temperature changes. The control unit uses the information about the intake air temperature as a corrective value for charge air control.

Pressure sensors

There is an electronic evaluation unit and a measuring cell in the pressure sensor housing. This measuring cell contains a membrane that encloses a reference pressure chamber to which four expansion resistors are attached in a bridge circuit. Two of these expansion resistors are used as measuring resistors and are in the centre of the membrane. The two other resistors are attached to the outside of the membrane and are used as reference resistors to compensate temperature. If the shape of the membrane changes due to the pressure applied, the conductivity of the measuring resistances changes and thus the measuring voltage. This measuring voltage is processed by the evaluation electronics and forwarded to the engine control unit.

The charge pressure sensor records the pressure in the intake pipe between the turbocharger and the engine. The charge pressure is not measured against environmental pressure but rather against a reference pressure in the sensor. The sensor provides the control unit with information about the charge pressure. The reference and actual values are compared in the characteristic diagram for charge pressure regulation, and the charge pressure is adapted to the engine requirements via the charge pressure limitation.
The environmental pressure sensor (height sensor) maps the environmental pressure. Since this fluctuates depending on altitude, the control unit uses this value to correct the charge air regulation and the exhaust gas re-circulation system. The environment pressure sensor is often integrated in the control unit, but can also be housed in the engine compartment as a separate sensor.

The fuel pressure sensor maps the fuel pressure. There are two applications here: The fuel pressure sensor in the low-pressure area, in the fuel filter for example. This allows the fuel filter soiling to be monitored. The second application is monitoring the fuel pressure on the high-pressure side. The rail pressure sensor is used here in the common rail system.

The needle movement sensor maps the actual opening time-point of the injection nozzle. The control unit needs this information in order to compare the start of injection with the data from the characteristic diagram so that injection always takes place at exactly the right moment. The needle movement sensor is made up of a pressure bolt surrounded by a magnetic coil. If the pressure bolt is mechanically actuated by the nozzle needle opening, the magnetic field in the magnetic coil changes. This in turn changes the voltage applied in the coil, which has a constant voltage supply from the control unit. From the time lag between the information of the needle movement sensor and the OT signal of the speed sensor, the control unit can calculate the real start of injection.

The accelerator pedal sensor records the position of the accelerator pedal. This can be done by measuring path or angle of the accelerator pedal. The accelerator pedal sensor can be attached directly to the accelerator pedal (accelerator pedal module) or located in the engine compartment. In this case, it is connected to the accelerator pedal sensor via a Bowden cable. There are different kinds of accelerator pedal sensors. Some work with a potentiometer that forwards different voltages to the control unit and which are then compared with a characteristic curve. The control unit calculates the position of the accelerator pedal on the basis of the characteristic curve. Inductive sensors have a permanently installed Hall sensor instead of the potentiometer. There is a magnet on the accelerator pedal, which changes its position depending on the position of the accelerator pedal. The signal thus produced is amplified and forwarded to the control unit as a voltage signal. The advantage of these inductive sensors is that they are not subject to wear. The idling switch is integrated in the accelerator pedal sensor, as is the kick-down switch in vehicles with automatic transmission.
**Brake switch**

The brake switch is on the foot pedal and is usually combined with the stoplight switch. It passes a signal on to the control unit when the brake pedal is pressed. This results in the control unit reducing engine power to prevent simultaneous braking and accelerating.

**Clutch pedal switch**

The clutch pedal switch is also located on the foot pedal. It informs the control unit whether the clutch pedal is being pressed or not. If the control unit receives the information that the clutch pedal is being pressed, it reduces the fuel injection quantity briefly in order to achieve *smooth* gear changing.

**Air conditioner**

The EDC control unit receives a signal indicating whether the air conditioner is switched on or off. This information is required in order to increase the idling speed with the air conditioner switched on. This prevents the idling speed decreasing too much when the compressor clutch is applied.

**Speed signal**

The EDC control unit requires information about current speed in order to control the radiator fan (radiator fan run-down), to dampen jolting during gear changing and for the speed control system, if fitted.

**Speed control system**

The EDC control unit receives information from the speed control system as to whether the system is switched on or off, whether the driver would like to accelerate, slow down or maintain speed.
The EDC control unit

All the information provided by the sensors is processed in the EDC control unit, and outputted as control signals for the actuators. The actual control unit, a PCB with all electronic components, is mounted in a metal housing. Sensors and actuators are connected by means of a four-pin plug-type connection. The power components necessary for the direct triggering of the actuators are installed on heatsinks in the metal housing in order to dissipate the heat that builds up.

Further requirements have to be taken into account with the design. These requirements concern the environment temperature, mechanical load and humidity. Just as important is resistance to electromagnetic interference and the limitation of radiated high-frequency interference signals. The control unit has to work perfectly at temperatures from -40 °C to approx. +120 °C.

To enable the control unit to output the correct triggering signals for the actuators in every engine operating state, the control unit must be “realtime-capable”. This requires high computer power and computer architecture.
The sensor input signals reach the control unit in different forms. For this reason, they are routed via protective circuits, and amplifiers and signal converters if necessary, and then processed directly by the microprocessor. Analogue signals indicating the engine and intake air temperature, the amount of air suctioned in, the battery voltage, oxygen sensor etc. are converted into digital values in the microprocessor by an analogue/digital converter. To prevent interference pulses, signals from inductive sensors, such as speed mapping and reference mark sensors, are processed in a part of the circuit.

The microprocessor needs a program in order to process the input signals. This program is stored on a read-only memory (ROM or EPROM). In addition, this read-only memory contains the engine-specific characteristic values and curves required for engine control. To be able to realise the function of some vehicle-specific features or engine variants, the vehicle manufacturer or garage carries out a variant coding. This is necessary if the control unit is to be replaced as a spare part or if individual sensors or actuators are renewed. To keep the number of different control units at the vehicle manufacturers to a minimum, the complete data records with some unit types are not installed on the EPROM until the end of production (EOL = End Of Line Programming).

As well as the ROM or EPROM, a read/write memory (RAM) is required. This has the task of storing calculated values, adaptation values and any faults that may occur in the whole system so that they can be read out using a diagnostic unit. This RAM memory requires a permanent power supply. If the power supply is interrupted because the battery is disconnected, for example, the stored data are lost. In this case all adaptation values have to be determined again by the control unit. To avoid the loss of variable values, these are stored in an EPROM instead of a RAM in some unit types.

Signal output to control the actuators takes place through final stages. The microprocessor controls these final stages that are powerful enough to be directly linked to the individual actuators. These final stages are protected in such a way that they cannot be destroyed by short-circuits to ground and battery voltage or excess electrical load.

Thanks to self-diagnosis, any faults occurring at any of the final stages can be recognised and the output switched off if necessary. This fault is then stored in the RAM and can be read out in the garage using a diagnostic unit.
Actuators

The actuators carry out the commands calculated by the control unit. This means they convert electrical signals from the control unit into physical force parameters. The most important actuators are the solenoids for pressure, quantity and injection point regulation. There are various differences here, depending on the injection system in question (unit injector, common rail). Further actuators are the electro-pneumatic pressure actuators. Using a vacuum box controlled by an electro-magnetic valve with partial vacuum, the electrical signals of the EDC control unit are converted into mechanical control. Electro-pneumatic pressure converters are:

The exhaust gas re-circulation valve

The exhaust gas re-circulation valve controls the quantity of exhaust air added to the intake air.

The charge pressure actuator

The charge pressure actuator controls the charge pressure. This can be done by opening and closing a bypass valve or by means of a turbocharger with variable turbine geometry or by adjusting the pitch angle of the conductive blades.
The control flap

The control flap is used to improve exhaust gas re-circulation. In the lower speed and load range, overpressure is built up in the intake pipe and makes it easier for the re-circulated exhaust gas to flow into the combustion chamber.

The twist actuator

The twist actuator influences the rotating movement of the intake air. Increasing the twist movement in the low speed range and reducing the twist at high speeds results in a better mixture of intake air and fuel in the combustion chamber. This leads to better combustion.

The intake pipe flap

The intake pipe flap is closed when the engine is switched off. It stops the supply of fresh air and thus makes “smooth” engine run-down possible.

Further tasks and components accomplished and controlled by the control unit:

Pre-heating system
The control unit regulates the pre-heating system through an additional pre-heating relay or a further pre-heating control unit.

Fuel cooling
Fuel cooling is also controlled by an additional relay.

Radiator fan
The radiator fan is triggered depending on coolant temperature. The radiator run-down is also controlled depending on the load state of the last driving cycle.

Booster heating
The booster heating is triggered depending on generator load.

Air conditioner
In order to achieve full engine power, the air conditioner compressor is switched off at full load, when the engine temperature is too high and in emergency running mode in order to go easy on the engine.
Warning lights
The engine warning light is activated when faults occur. The pre-heating warning light is triggered if required.

In addition, the control unit provides signals for the speed sensor and/or multi-function display. It includes the communication interfaces for other vehicle systems and the diagnosis.

Diagnosis and troubleshooting
Diagnosis and troubleshooting in an EDC system are no longer different than for fuel induction systems in petrol engines. A suitable diagnostic unit is now required here, too. In addition to the diagnostic unit, a multimeter or better still an oscilloscope should be available, if these are not integrated in the diagnostic unit.

With the EDC too, the testing depth depends on the released diagnosis functions of the vehicle manufacturer and the possibilities of the diagnostic unit manufacturer.

Reading out the fault memory
The first diagnosis step should always be to read out the fault memory in the control unit. Faults that have occurred are stored through the possibility of self-diagnosis. The stored fault codes can sometimes include additional information. Details are displayed as to whether the fault occurs sporadically or is present permanently. Information such as "short-circuit / cable interruption" or "faulty signal" can also be displayed.
It is important to bear in mind that an entry in the fault memory always covers all the components of the sensor/actuator affected. This means that the fault can also be in the cabling, the plug or possibly be due to mechanical damage.

By reading out the measured value blocks (actual value inquiry), the sensor signals processed in the control unit can be shown.

It must be noted here, too, that no exact statement can be made about possible faults solely on the basis of the actual values. The necessary reference values must be available for conclusions to be drawn about possible faults by comparing reference and actual values. If these reference values are not stored in the diagnosis unit, further information systems or vehicle specifications are required. Reading out the measured value blocks is particularly suitable for finding faults where no entries are made in the fault memory. One classical example is the air mass sensor. By comparing the reference / actual values during a test drive, it is possible to establish whether the measured values comply with the requirement.
**Actuator test**

With the actuator test, the diagnostic unit creates the possibility of checking the actuators easily. During the test, the actuators are triggered consecutively by the control unit. The tester can hear, see or feel whether the actuator reacts to the signal and carries out a function. The actuator test can also be used to check the signal of the control unit, the cables and the plug connections. To do this, a multimeter or oscilloscope must be attached to the actuator during the actuator test. If the signal measured is OK, it can be assumed that the cables and plug connections are OK. The actuator should then be checked for electrical or mechanical damage. If the control signal is missing or is faulty, the plug connections and cables must be checked. Here, too, vehicle-specific information such as circuit diagrams and measured values are necessary.

To be able to carry out safe troubleshooting, it is important to be very well familiar with the engine system to be diagnosed. Not all faults that occur must necessarily have an electronic cause. It is always possible that faults in the mechanics, e.g. poor compression, defective injection nozzles result in problems that lead technicians astray during troubleshooting procedures. The basic pre-condition is always perfect mechanical function. Which is why it is always advisable to take part in training sessions, both on the subject of injection systems as well as on how to handle diagnostic and measuring equipment. Only those who understand how everything fits together, and know when the measured sensor values and the position of the actuators have which effects within the overall system, are in a position to carry out safe fault diagnosis. Various specialist books can be of help in learning about injection systems and measuring techniques.
Why is a secondary air system used?

This system is used to further reduce the HC and CO values during the cold-start phase before the catalytic converter becomes active.

In petrol engines with stoichiometric operation, 3-way catalytic converters are used to achieve a conversion rate of over 90 percent. On average, up to 80 % of emissions of a driving cycle are produced during the cold start. But because the catalytic converter only starts working effectively from a temperature of approx. 300 - 350 °C, other measures must be used during this time to reduce emissions. This is the task of the secondary air system. Provided there is sufficient residual oxygen available in the exhaust gas system and the temperature is high enough, the HC and CO react in a subsequent reaction to produce CO2 and H2O. To make sure there is enough oxygen available for the reaction in the cold-start phase when the mixture is extremely rich, additional air is added to the exhaust gas flow. In the case of vehicles fitted with a three-way catalytic converter and a lambda control, the secondary air system is switched off after approx. 100 seconds. Due to the heat produced by the subsequent reaction, the working temperature of the catalytic converter is quickly reached. The secondary air can be added actively or passively. In the case of the passive system, pressure fluctuations in the exhaust gas system are exploited. Through the partial vacuum produced by the flow speed in the exhaust gas pipe, the additional air is suctioned in through a timed valve. In the case of the active system, the secondary air is blown into the system by a pump. This system enables a better control.

Design and operation of the active secondary air system

1. Air filter
2. Secondary air pump
3. Engine control unit
4. Triggering relay
5. Change-over valve
6. Combination valve
### Structure and function of the active secondary air system

The active secondary air system usually comprises an electrical pump, control relay, a pneumatic control valve and combination valve. Control of the system is taken over by the engine control unit. While the system is working, the electrical pump is switched on by the engine control unit via the control relay. At the same time, the pneumatic control valve is triggered. This opens and allows the partial vacuum from the intake pipe to act on the combination valve. The partial vacuum opens the combination valve and the additional air transported by the pump is pumped into the exhaust gas pipe downstream from the outlet valves. As soon as the lambda control becomes active, the secondary air system is switched off. The engine control unit deactivates the electrical pump and the pneumatic control valve. The combination valve is also closed and thus prevents hot exhaust gases getting to the electrical pump and causing damage.

### Fault symptoms when the secondary air system fails

The lack of “afterburning” leads to increased exhaust gas values during the cold-start and warm-up phase. The catalytic converter only reaches its working temperature later. Secondary air systems that are monitored by self-diagnosis of the engine control unit cause the engine warning light to come on if faults occur.

### Reasons for failure of the secondary air system

A frequent reason for failure is a defective pump. Humidity penetration leads to damage to the pump, which in turn causes pump seizure. Lack of ground and voltage supply can also lead to pump failure. Blocked or leaking pipes also cause system failure or malfunction. The control and combination valves fail due to blockage, damage or lack of control.

### Troubleshooting and diagnosis work on the secondary air system

As with all other troubleshooting and diagnosis work, a visual inspection and additional acoustic test should be carried out first. The electrical pump can be heard during the acoustic test with the cold engine in idling. Even when the engine has been switched off, the run-out noise of the pump is clearly audible. During the visual inspection, all components must be checked for damage. Particular attention should be paid to the pipes and hose connections. They must be inserted correctly onto the components and must not be chafed. They must not be bent either or blocked by radii being too tight. Fuses must also be checked to make sure they are present and correct and not damaged. If no faults are found during these tests, a suitable diagnostic unit can be consulted for further diagnosis. The basic pre-condition is that the system is diagnosis-capable from the vehicle manufacturer’s side.
Any faults stored can be read out from the fault memory and remedied.

If there are no faults stored in the fault memory, an actuator test can be used to switch the electrical pump on. During this test, the function of the control relay is also checked. The triggering of the control valve can also be checked by the actuator test. The function of the control valve can also be checked without a diagnostic unit. To do this, remove the vacuum pipe that leads to the combination valve. Start the cold engine.

It should be possible to feel a partial vacuum at the control valve tube (a vacuum pump can also be connected) as soon as the secondary air pump begins to run.

If no partial vacuum can be felt, check the triggering of the control valve using a multimeter. If this is OK, a faulty control valve can be assumed.

The function of the combination valve can be checked with the aid of a vacuum pump. To do this, remove the vacuum pipe at the combination valve and connect the vacuum pump to the valve.
Now loosen the hose connection (photo hose connection) from the secondary air pump to the combination valve at the pump. Blow air under slight pressure into the pipe (do not use compressed air). The combination valve must be closed. Apply a partial vacuum to the combination valve and blow air into the hose connection again. The combination valve must now be opened. If the combination valve does not open or is permanently opened, then the valve is defective.

If possible, the vehicle manufacturer's instructions should always be observed in all diagnosis and testing work. Vehicle type specifications and testing methods may vary depending on manufacturer and must be taken into consideration.
The Electronic Stability Program is now a standard feature in many vehicle models. As the number of vehicles fitted with ESP increases, the fault frequency and garage repair requirements also increase, of course. Here, we would like to briefly outline the function, the individual system components and diagnosis possibilities.

**Task of the ESP**

The task of the ESP is to avoid the vehicle breaking away to the side when driving through bends or in critical situations such as evasive actions (high-speed swerve test). The system intervenes specifically in the braking system, engine and gear management and keeps the vehicle on track. It is important to remember, however, that physical laws cannot be cancelled. As soon as the limits are exceeded, even the ESP system cannot prevent the vehicle breaking away.

**How it works**

What happens when the ESP is active?
For the ESP to become active, a critical driving situation has to occur. A critical situation is recognized as follows: The system requires two basic pieces of information to recognize a critical driving situation. Firstly, the driver’s wish, and secondly, which direction the vehicle is driving in. If a comparison of these two pieces of information results in differences, i.e. if the vehicle is driving in a different direction to the one being steered by the driver, this results in a critical driving situation for the ESP. This can be noticed through understeering or oversteering. If the vehicle is understeered, specific intervention in the braking system and the engine management compensate the tendency to understeer. The brake is applied separately to the inner rear wheel. If the vehicle is oversteered and the vehicle tends to skid, specific braking intervention on the outer front wheel will counteract the oversteering.

In the following we would like to explain the system’s sensors and actuators. It must be noted here that there are differences in certain functions or structure depending on the vehicle manufacturer. We will focus on a system such as the one installed in a VW Passat, model year 97.
With this system, the ESP control unit is not connected to the hydraulic unit. It is installed in the right-hand front footwell on the bulkhead. The control unit consists of a high-power computer. To guarantee the greatest possible safety, the system is made up of two computers with their own voltage supply and diagnosis interface that use the same software. All the information is processed in parallel and the computers monitor each other. The control unit is also responsible for regulating the ABS/ASR and EDS. All the systems are contained in one control unit.

The steering angle sensor determines the steering angle and forwards the information to the control unit. The steering angle sensor is installed on the steering column. How does the steering angle sensor work? It works in the same way as a light barrier. A coding disc with two rings in the form of a shadow mask, an absolute ring and an incremental ring, is slipped over a light source situated between the two rings. Two optical sensors are arranged opposite the light source.
When the steering wheel is turned and light passes through the openings of the shadow masks onto the optical sensors, a voltage is produced in these. The different shapes of the shadow masks result in different voltage sequences. A regular signal is produced on the incremental ring side, whereas an irregular signal is generated on the absolute ring side. By comparing the two signals, the control unit can calculate how far the steering wheel has been turned. In addition, the steering angle sensor has a counter that counts the full number of steering wheel turns. This is necessary because the angle sensors usually only map angles up to 360° whereas the steering wheel can be turned through a total of +/- 720° (four full turns). The reset ring with slip ring for the airbag are on the underside of the steering wheel sensor.

The transverse acceleration sensor has the task of establishing which lateral forces are acting and trying to bring the vehicle off track. It is always installed as near as possible to the vehicle’s centre of gravity. How does the transverse acceleration sensor work? The transverse acceleration sensor is made up of a permanent magnet, a Hall sensor, a damper plate and a spring. Together, the damper, the spring and the permanent magnet form a magnet system. The permanent magnet, which is connected to the spring, can oscillate freely backwards and forwards over the damper plate. If transverse acceleration acts on the vehicle, the damper plate moves away from under the permanent magnet, which follows this movement after a short delay due to its inertia. This movement generates eddy currents in the damper plate and which builds up an opposing field to the magnetic field of the permanent magnet. The weakening of the overall magnetic field resulting from this changes the Hall voltage. How much the voltage changes is proportional to the transverse acceleration. In other words, the greater the movement between the permanent magnet and the damper plate, the weaker the overall magnetic field will become and the more the Hall voltage will change. As long as there is no transverse acceleration, the Hall voltage remains constant.
The yaw rate sensor has the task of establishing whether the vehicle tends to turn around its own vertical axis (spin). It must also always be installed as near as possible to the vehicle’s centre of gravity. The yaw rate sensor is made up of a hollow cylinder which has 8 piezo electronic elements attached to it. Four of these elements cause resonant oscillation on the hollow cylinder. The other four elements register whether there is any change to the oscillation nodes where they are located. If a torque acts on the hollow cylinder, the oscillation nodes are displaced. The displacement is recorded by the piezo elements and forwarded to the control unit. This uses the information to calculate the yaw rate.

In newer systems these two sensors are both contained in one housing. They are mounted on a PCB and work according to the micro-mechanical principle. This has a number of advantages such as reduced design space and a more accurate alignment of the two sensors to one another. This combined sensor also has a different structure than the individual sensors. The transverse acceleration sensor is structured as follows: A capacitor plate with a moving mass is suspended in such a way that it can oscillate backwards and forwards. This moving plate is framed by two capacity plates installed in fixed positions. This results in two capacitors (K1 and K2) switched one behind the other. The charge quantity (capacity C1 and C2) that the two capacitors can absorb can now be measured through electrodes. In the quiescent state the measured charge quantities are identical for the two capacitors. If a transverse acceleration acts on the sensor, the movable plate is displaced against the direction of acceleration by inertia. This displacement changes the distance between the plates and thus the charge quantity of the capacitors. This change in capacity quantity is the measured variable for the control unit.

The yaw rate sensor is located on the same board as the transverse acceleration sensor but in a different spot. It is structured as follows: An oscillating mass to which conductive tracks are attached is fixed in a carrier in a constant magnetic field between a north pole and a south pole. If alternating current is applied, the oscillating mass with the tracks begins to oscillate in a straight line to the applied alternating current. If a rotary movement now occurs, the inertia of the oscillating mass changes the regular backwards and forwards movement. The change in movement of the mass in the magnetic field also causes a change in the electrical behaviour of the tracks.
This electrical change is the variable to measure the amplitude of the rotary movement. This structure is installed in duplicate to guarantee maximum safety.

The sensor for the brake pressure is installed in the hydraulic pump for the ESP. It has the task of recording the current braking pressure in the braking circuit for the control unit. The control unit uses the values of the braking pressure sensor to calculate the wheel brake forces that are integrated in the calculations when the brakes are used. The braking pressure sensor is made up of a piezo electrical element, on which the pressure of the brake fluid acts, plus an electronic evaluation unit. A change in pressure leads to a change in the charge distribution in the piezo electrical element. If the element is without pressure, the charges are distributed evenly. As pressure increases, the charges are displaced and voltage is generated. The more the pressure increases the more the charges are separated. The voltage continues to increase. The evaluation electronics amplify this voltage and pass it on to the control unit.

In certain situations it makes sense to switch off the ESP system, e.g. on a capacity test stand or when driving with snow chains on the vehicle. To enable the driver to do this, an on/off switch is installed. If the system is switched off via the switch and not switched on again, it will switch on again automatically after the engine has been restarted. If the ESP system is active it cannot be switched off. Nor can it be switched off if a certain speed has been exceeded.
The necessary preliminary pressure on the intake side of the return feed pump of the ABS system is generated with the aid of the hydraulic pump. The return feed pump is not able to build up the necessary preliminary pressure if the brake pedal is not pressed and there is no pressure in the system.

The shift valves for the individual wheel brakes, which are necessary to control the braking pressure, are in the hydraulic unit. These are used to regulate the necessary 3 pressure states in the hydraulic unit: pressure build-up, pressure retention, pressure reduction.

The wheel speed sensors map the wheel revolution speed of the individual wheels. The control unit uses this information to calculate the speed of the wheel rim.

The brake pedal switch records the position of the brake pedal and informs the control unit whether the brake pedal is actuated or not. The stoplight switch is responsible for triggering the stoplights.
There are three warning lights in the instrument panel that are important for the ESP system. The warning light for the ABS, the braking system and the ESP/ASR. Faults or failure of the respective systems are indicated through these warning lights. Since all the systems are dependent upon one another, faults or the failure of one system can cause problems in one of the other systems.

The ESP control unit is also connected with the engine control unit and gear control unit (automatic only) as well as with the navigation control unit, if fitted. Information about operating states of the individual units is exchanged. If the ESP system is triggered, intervention also occurs in the engine and gear management.

During intervention of the ESP system, the following things happen: The control unit recognizes a critical driving situation on the basis of the values transmitted by the sensors. In the hydraulic unit, the pressure build-up process begins for the respective brake circuits. The hydraulic pump begins to feed brake fluid from the reservoir into the brake circuit. The braking pressure is now available very quickly at the wheel brake cylinders and the return feed pump. The return feed pump also begins to feed in order to increase the braking pressure even further. Once sufficient braking pressure has been built up, it is kept constant. The input valve is closed and the return feed pump stops working. Since the outlet valve is also closed, the pressure remains constant. If no further braking pressure is required, the output valve opens, and the shift valve simultaneously. The brake fluid can now flow back through the main braking cylinder into the reservoir. Since the input valve remains closed, no new brake fluid can flow into the system and the brake pressure is reduced.

Besides numerous mechanical problems and leaks, the electronic system can also fail. Individual sensors, shift valves or the control unit can fail. The most frequent defects can certainly be found in the wheel speed sensor and steering angle sensor areas. It is important to realize that maladjusted wheel tracking can also lead to faults in the system.
Diagnosis

If the ESP system fails, this is indicated by the warning light being permanently on. A visual check-up should always be carried out first before beginning with a complex diagnosis. Special attention must be paid to leaks and component damage. If nothing unusual is found during the visual check-up, a diagnostic unit is used for further tests. The ESP system has a self-diagnosis feature. This means it recognizes faults such as cable interruptions, short-circuits to ground or plus, or defects in the sensors. These faults can be stored in the fault memory of the control unit and read out. The following components are mapped by self-diagnosis: The control unit, transverse acceleration sensor, yaw rate sensor, braking pressure sensor, the shift and high-pressure valves in the hydraulic unit and the hydraulic pump. Faults in the on/off switch are not mapped by the self-diagnosis.

Tests with the diagnosis unit

Diagnosis of the ESP system can be carried out with a suitable diagnostic unit. Depending on the specific unit, there are numerous testing possibilities available, even including specially prescribed system tests.

First of all, the fault memory should be read out. Any faults that have occurred are stored here and give first indications of the possible reason for the fault. The stored fault can be an indication of a faulty component (photo fault memory 2) or a short-circuit/cable interruption. In this way, specific repair work can be carried out.

If there are no faults stored in the fault memory, the actual value inquiry (photo parameter 1) can be used to inquire and evaluate specific parameters. Technical documents with the required reference values are needed to evaluate the actual values shown if they are not stored in the diagnosis unit. Faults stored in the fault memory are also shown during the actual value inquiry. A further testing possibility is the actuator test. With this test, individual components can be triggered by the diagnostic unit and thus have their function tested.
The specially prescribed system tests are used to carry out a guided test of the individual components.

The diagnostic unit prescribes the individual test steps and indicates the results in a similar way to the actual value inquiry. Here again, the state of components can be evaluated. A meaningful diagnosis is very difficult without a suitable diagnostic unit. No inquiries can be made of the fault memory, and the faults stored cannot be deleted following successful repair. For this reason, a suitable diagnostic unit is necessary. It is still possible, however, to check individual components with the multimeter or oscilloscope. Technical documents such as circuit diagrams and reference values are necessary for this.

**Testing wheel speed sensors**

Test with the multimeter:
Resistance measurement: Separate the sensor plug connection and use an Ohmmeter to measure the internal resistance at the two connection pins. **Important:** Only carry out this measurement if it is clear that the sensor involved is an inductive sensor. A Hall sensor will be destroyed by resistance measurement. The resistance measurement should be between 800 and 1200 (note reference values). If the value is 0, this indicates a short-circuit, whereas infinite resistance indicates a cable interruption. A ground connection test from the respective connection pin to vehicle ground must result in an infinite resistance value. Voltage test: Connect the multimeter to the two connection pins. The measuring range of the multimeter has to be set to alternating voltage. If the wheel is turned by hand, the sensor produces an alternating current of approx. 200 mV.

The oscilloscope makes it possible to visualize the signal produced by the sensor in a graphical representation. To do this, connect the measuring cable of the oscilloscope to the signal cable of the sensor and the mass cable to a suitable mass point. The oscilloscope should be set to 200 mV and 50 ms. When the wheel is turned, a sine signal becomes visible on the oscilloscope if the sensor is intact. The frequency and the voltage generated depend on the wheel speed.
Testing active sensors

We recommend using a specially designed testing unit to test active sensors. Active sensors require a voltage supply to function and thus cannot be tested when disconnected. With the aid of the testing unit, the output current, the number of north/south poles on the encoder wheel, an oversized or undersized air gap and a short-circuit to ground and plus can be established.

Testing the voltage supply to the control unit

It is important that the battery voltage is OK so that any drops in voltage at the cables / plugs can be recognized during measurement.

Measuring the voltage and ground supply at the control unit

To do this, disconnect the plug from the control unit. Read the pin assignment off the circuit diagram and connect the red measuring cable of the multimeter to the respective pin and the black measuring cable to any suitable ground point on the vehicle. Make sure the ground point is clean and the measuring cable is firmly contacted. Proceed very carefully when connecting the control unit plug to prevent damage to the plug contacts. Check whether there is voltage to the battery by measuring the voltage.

Check the ground connection of the control unit using resistance measurement.

To do this, look for the respective ground pins in the circuit diagram and connect the measuring cable of the multimeter. Connect the second measuring cable to the ground point on the vehicle again. The resistance value should not exceed approx. 0.1 Ohm (approximate value that can vary depending on cable cross-section and length).

What is important when replacing individual components?

If it is necessary to replace the steering angle sensor or the control unit, basic adjustment must be carried out after installation. However, when the steering angle sensor is being installed, care must be taken to ensure that front wheels and the steering wheel are in the straight forward position and the new sensor is in the centre position. Proceed very carefully when replacing the combined yaw rate/transverse acceleration sensor or the individual sensors. These sensors are extremely sensitive. They may only be installed in their prescribed position. No tension or forced pressure with the aid of the attachment screws may be applied to the sensors in their installation position. Changing the installation direction is not permissible either.