Vehicle electrical systems

The vehicle electrical system of a motor vehicle comprises the alternator as the energy converter, one or more batteries as the energy accumulators and the electrical equipment as consumers. The energy from the battery is supplied to the starter (consumer), which then starts the vehicle engine. During vehicle operation, the ignition and fuel-injection system, the control units, the safety and comfort and convenience electronics, the lighting, and other equipment have to be supplied with power.

Electrical energy supply in the passenger car

When the engine is running, the alternator supplies electricity which, depending on the voltage level in the vehicle electrical system (determined by the alternator speed and the consumers drawing current), is normally enough to power the consumers and charge the battery as well. If the consumer current draw I_V in the vehicle electrical system is greater than the alternator current I_G (e.g. when the engine is idling), the battery is discharged. The vehicle system voltage falls to the voltage level of the battery from which current is drawn. If the consumer current draw I_V is less than the alternator current output I_G, a proportion of the current flows to the battery and acts as a battery charging current I_B. The vehicle system voltage increases to the setpoint value specified by the voltage regulator.

With careful selection of the battery, alternator, starter and the other electrical system consumers, it must be ensured that the charge balance of the battery is indeed balanced so that:

- It is always possible for the internal-combustion engine to be started
- It allows operation of specific electrical consumers for a reasonable period of time when the engine is off

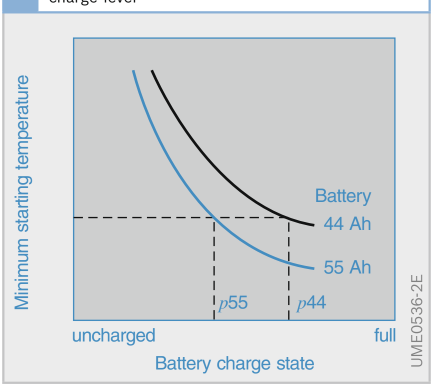
The lowest temperature at which the engine can be started depends on a number of factors, including the battery (capacity, low-temperature test current, state of charge, internal resistance, etc.) and the starter (design, size, and performance). If the engine is started at a temperature of –20 °C, for example, the battery must have a given minimum state of charge p.

Apart from the battery itself, the current output of the alternator and the power output of the consumers have a decisive influence on the charge balance of the battery.

Current output of the alternator

The current output of the alternator is speed-dependent. For an engine idling

1 Possible starting temperature versus battery charge level



2 Alternator current output I_G relative to alternator speed

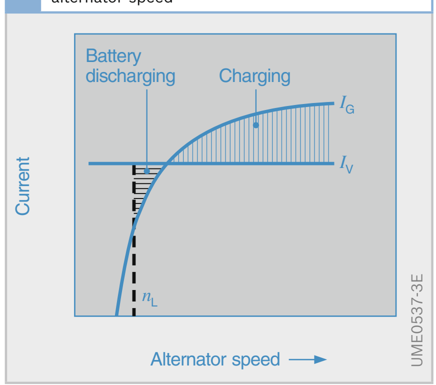


Fig. 1
p Minimum charge level

Fig. 2
I_V Consumer current draw
n_L Engine idling speed

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speed of n_L, the alternator can only supply some of its rated current if it has a conventional turns ratio ranging from 1:2 to 1:3 (crankshaft to alternator). By definition, the rated current is output at an alternator speed of 6,000 rpm.

Power output of the consumers

The electrical consumers have a variety of switch-on durations. A distinction is made between continuous consumers (ignition system, fuel injection, etc.), long-time consumers (lighting, rear-window heating, etc.) and short-term consumers (turn signals, stop lamps, etc.).

The use of a number of consumers is dependent on the time of year (air-conditioning system, seat heating). The on-time of electrical radiator blowers depends on the ambient temperature and vehicle operation. In winter, the vehicle is driven with the lights on most of the time.

The electrical load requirements encountered during vehicle operation are not constant. The first minutes after startup are generally characterized by high demand, followed by a sharp drop in electrical load requirements:

- A windshield heater requires up to 2 kW for 1 to 3 minutes after the engine is started in order to de-ice the windshield
- The secondary-air pump, which injects air immediately after the combustion chamber to burn the exhaust gas, runs for about 3 minutes after the engine is started
- Other electrical consumers such as heaters (rear window, seats, mirrors, etc.), fans and lights are switched on for longer or shorter periods depending on the situation, while the engine-management system is in operation all the time

Charging the battery

Due to the chemical processes that take place in the battery, the battery charge voltage has to be higher at low temperatures and lower at high temperatures. The gassing voltage curve shows the maximum voltage at which the battery does not produce gas. A regulator limits the voltage if the alternator current I_G is greater than the sum of the consumer equipment current draw I_V and the temperature-dependent, maximum permissible battery charging current I_B. Regulators are normally mounted on the alternator. If there is a significant deviations between the temperatures of the voltage regulator and the battery electrolyte, it is better to monitor the voltage regulation temperature directly at the battery. The voltage drop across the alternator/battery charging cable can be accounted for by a regulator which

1 Installed consumers taking account of the switch-on duration (examples)

Electrical consumer	Power input	Average electrical load requirements
Motronic, electric fuel-supply pump	250 W	250 W
Radio	20 W	20 W
Side-marker lamp	8 W	7 W
Low beam (dipped beam)	110 W	90 W
License-plate lamp, tail lamp	30 W	25 W
Indicator lamp, instruments	22 W	20 W
Heated rear window	200 W	60 W
Interior heating, fan	120 W	50 W
Electrical radiator ventilator	120 W	30 W
Windshield wiper	50 W	10 W
Stop lamp	42 W	11 W
Turn signal	42 W	5 W
Fog lamps	110 W	20 W
Rear fog lamp	21 W	2 W
Total		
Installed electrical load requirements	1,145 W	
Average electrical load requirements		600 W

Table 1

measures the actual value of the voltage at the battery.

The arrangement of the alternator, battery and consumers influences the voltage drop on the charging cable and thus the charge voltage. The total current $I_G = I_B + I_V$ flows through the charging cable if all electrical consumers are connected to the battery. In response to the relatively high voltage drop, the charge voltage falls proportionately sharply.

If all consumers are connected on the alternator side, the voltage drop is less and the charging voltage is higher. In the process, consumers that are sensitive to voltage peaks or voltage ripple (electronic circuits) may be damaged or suffer malfunctions. Electrical consumers which feature a high power input and relative insensitivity to overvoltage should therefore be connected close to the alternator, whereas voltage-sensitive consumers with a low power input should be connected close to the battery.

Voltage drops can be minimized by suitable conductor cross-sections and good connections with low contact resistance, even after a long service life.

Design of the vehicle electrical system

Dynamic system characteristic curve

The dynamic system characteristic curve maps the relationship between battery voltage and battery current during a driving cycle. The envelopes reflect the interrelationships between the battery, alternator, consumers, temperature, engine speed, and engine/alternator speed ratio. A large area in the envelope means that, with this type of vehicle electrical system, significant voltage fluctuations are occurring in the selected driving cycle and that the battery undergoes more powerful cyclization, i.e. its state of charge experiences powerful temporal changes. The system characteristic curve is specific to every different combination and every set of operating conditions, and is therefore a dynamic curve. Measuring systems can be connected to the battery terminals to plot the dynamic system characteristic curve.

Charge-balance calculation

The charge-balance calculation is used as the basis for defining the design of the alternator and battery. By means of a computer program, the battery charge level is calculated from the consumer load and the alternator output power at the end of a specified driving cycle. *Rush-hour driving* (low engine speeds) combined with *winter operation* (low charging-current input to the battery) is regarded as a normal passenger-car driving cycle. The battery must maintain a stable charge balance even under these very unfavorable conditions for

3 Dynamic system characteristic curve (envelope for urban driving)

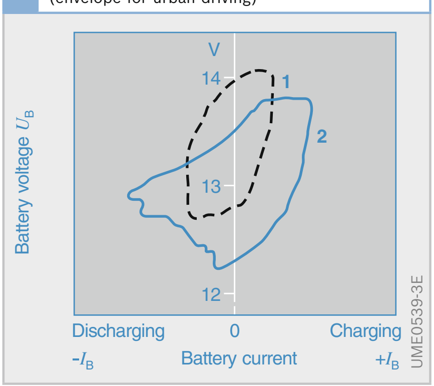
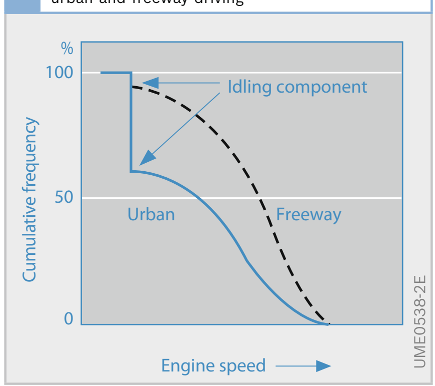


Fig. 3
1 With large alternator and small battery
2 With small alternator and large battery

4 Cumulative frequency of engine speed in urban and freeway driving



the energy balance of the vehicle electrical system.

Driving profile

The driving profile as an input variable for the charge-balance calculation is represented by the cumulative-frequency curve of the engine speed. It describes how often a specific engine speed is reached or exceeded.

In urban driving situations in rush-hour driving, a car's engine is running at idle speed for a large part of the time due to the frequency of stops at traffic lights and consequently high traffic density.

A city bus running on scheduled routes has a high idle percentage time due to interruptions in driving at bus stops. Another factor that has a negative effect on the battery's charge balance is electrical consumers that are operated when the engine is switched off. Long-distance buses generally spend only a small proportion of the time with the engine at idle speed, but on the other hand may have periods when consumers with a high power input are operated with the engine switched off.

Vehicle electrical system simulation

Contrary to the momentary view using a charge-balance calculation, model-based computer simulations can calculate electrical system power supply status at any time during the trip. They can also include electrical system management systems and assess their effectiveness.

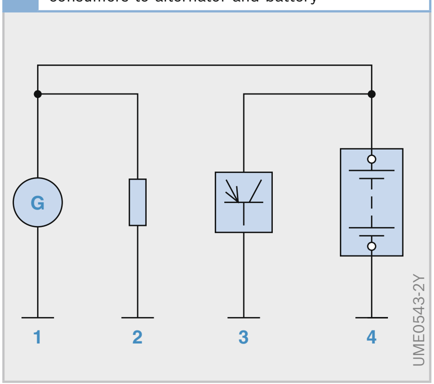
In addition to adjusting current levels in the battery, it is possible to record the vehicle-system voltage characteristic curve and the battery cycle at any time during a trip. Calculations performed using vehicle electrical system simulations are always useful when it comes to comparing electrical-system typologies and assessing the effectiveness of consumers with a high dynamic response or only brief switch-on durations.

Fuel consumption

Since one of the factors that affects the fuel consumption of a vehicle is its mass, the mass of the alternator is also an influence on consumption.

Even the generation of power by the alternator has an effect on fuel consumption: the additional consumption at 100 W of generated electrical output is in the order of 0.17 *l* per 100 km and depends on the efficiency of the alternator. For this reason, alternators with higher mid-range efficiency levels generally contribute to the engine's fuel efficiency despite being slightly heavier in weight.

5 Vehicle electrical system showing connection of consumers to alternator and battery



6 Electrical load requirements versus driving time

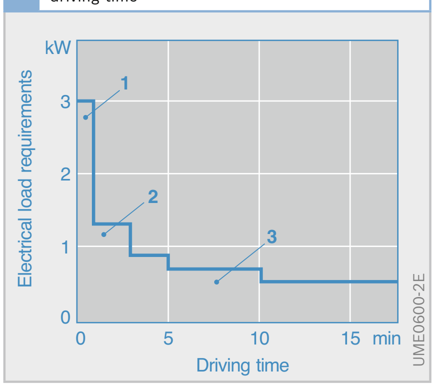


Fig. 5
1 Alternator
2 Consumer with relatively high power input
3 Consumer with low power input
4 Battery

Fig. 6
1 Windshield heater
2 Secondary-air pump
3 Heater, fan, engine management, etc.

Electrical energy management

An electrical energy management (EEM) system coordinates the interaction between alternator, voltage transformer, batteries and electrical consumers when the vehicle is in use. When the vehicle is parked, the EEM monitors the batteries, and switches standstill-draw and constant-draw consumers off as soon as the battery charge reaches a critical limit. The EEM regulates the entire electrical energy balance. It compares the power demand from the consumers with the power available within the vehicle electrical system and maintains a constant balance between supply and power output.

The basis for the EEM is the battery management. The objective of the battery management is to communicate to the EEM information about the current state of the battery and about predicted electrical behavior. Using this information, it is possible to implement operating strategies for increasing vehicle availability and profitability.

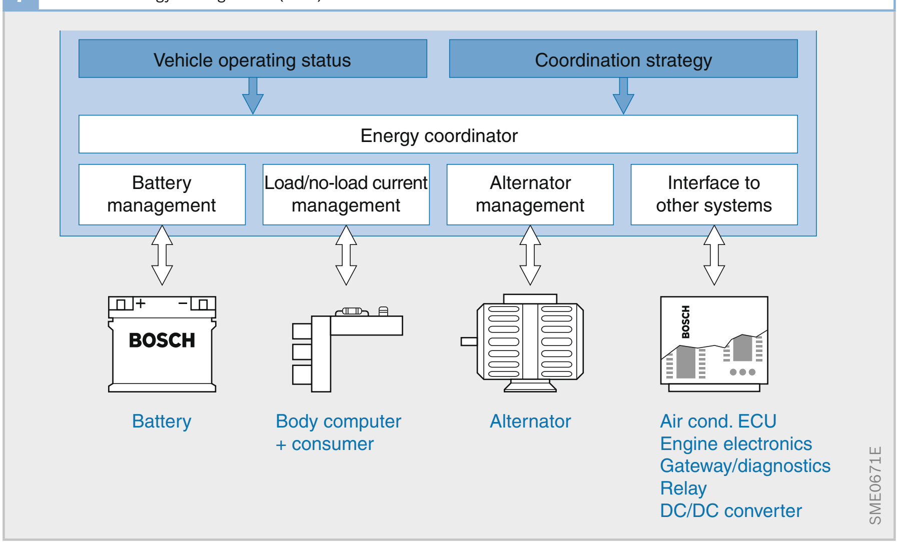
The battery management communicates to the EEM the variables relevant to the battery, e.g. the state of charge (SOC), the state of health (SOH) and the state of function (SOF) of the battery. SOF is a prediction of how the battery would react to a predefined load profile, e.g. whether a starting operation would be successful with the current battery status.

These values are calculated using complex, model-based algorithms from the measurement of battery current, voltage and temperature.

Using this battery data, the EEM is able to determine the optimal charge voltage and reduce the load on the electrical system (switch off consumers) in response to a degrading state of function and/or increase power generation (e.g. by increasing the idling speed).

If the battery's state of function falls below a specified threshold value despite the measures that have been implemented, the EEM can warn the driver that certain functions (e.g. engine start) will not be available with the current battery status.

7 Electrical energy management (EEM)



Battery status recognition

The control unit that makes battery status recognition (BSR) possible is the electronic battery sensor EBS (sometimes even EEM functions are implemented in this control unit). The sensor with integrated evaluation electronics records the fundamental battery variables of voltage, current and temperature. From these variables, it uses complex software algorithms to calculate the variables that describe the status of the car battery.

The electronic battery sensor comprises a chip, which contains the entire electronics, and a resistor element for current measurement. Together with the terminal clip, both of these form a single assembly unit that can be connected directly to the car battery and fits into the terminal recess of conventional car batteries.

The following tasks of the electrical energy management are made possible by the use of battery status recognition:

- Assurance of startability (SOF) through compliance with defined limit values of the battery state of function and an increase in vehicle availability
- Reductions in electrical load requirements and reductions in fuel consumption by means of alternator management with adaptation of alternator voltage
- Greater flexibility in the design of battery and alternator size by means of superordinate energy management (optimal economic efficiency)
- Extension of battery life (e.g. through prevention of exhaustive discharge)
- Battery change indication

For stop/start applications, the following functions can also be fulfilled:

- Prediction of startability after a defined stationary period (time, temperature, no-load current, power consumption during the stop phase)
- Assurance of a battery charge reserve in the stop phase (e.g. by switching off consumers)

8 Two-battery vehicle electrical system (layout)

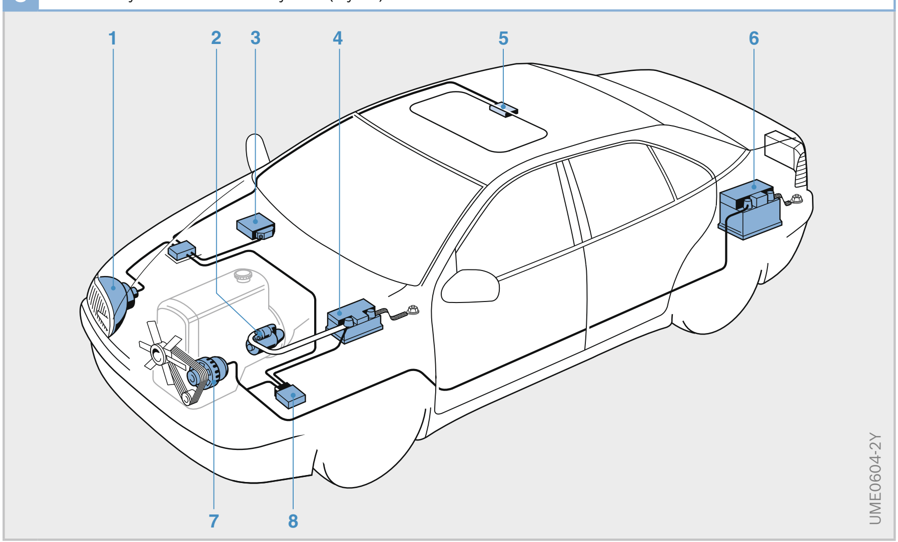


Fig. 8
1 Lighting system (vehicle electrical system)
2 Starter motor
3 Engine management (vehicle electrical system)
4 Starter battery
5 Other electrical-system consumers (e.g. power sunroof)
6 General-purpose battery
7 Alternator
8 Charging/isolating module

Two-battery vehicle electrical system

In the design of a vehicle battery, which supplies both the starter and the other consumers in the vehicle electrical system, a compromise has to be found between different requirements.

During the engine starting sequence, the battery is subjected to high current loads (300 to 500 A). The associated voltage drop has an adverse effect on certain electrical consumers (e.g. units with microcontroller) and should be as low as possible. On the other hand, only comparatively low currents flow during vehicle operation; for a reliable power supply, the capacity of the battery is the decisive factor. Neither properties – rated output nor capacity – can be optimized simultaneously.

In vehicle electrical systems with two batteries (starter battery and general-purpose battery), the "high power for starting" and "general-purpose electrical supply" functions are separated by the electrical system control unit to make it possible to avoid the voltage drop during the starting process, while ensuring reliable cold starts, even when the charge level of the general-purpose battery is low.

Starter battery

The starter battery must supply a high amount of current for only a limited period of time (during starting). It is therefore designed for a high power density (high power for low weight). Compact dimensions allow installation in the immediate vicinity of the starter motor with short connecting cables. The capacity is reduced.

General-purpose battery

This battery only supplies the vehicle electrical system (excluding the starter). It provides currents for supplying the consumers of the vehicle electrical system (e.g. approx. 20 A for the engine-management system) but has a high cyclic capability, i.e. it can supply and store large amounts of power. Dimensioning is based essentially on the capacity reserves required for activated consumers, the consumers that operate with the engine switched off (e.g. no-load-current consumers, parking lights, hazard warning flashers, immobilizer), and the minimum permissible charge level.

Vehicle electrical system control unit

The vehicle electrical system control unit (EN ECU) in a two-battery vehicle electrical system separates the starter battery and the starter from the rest of the vehicle electrical system provided this can be supplied with sufficient power by the general-purpose battery. It therefore prevents the voltage drop that occurs during starting, affecting the performance of the vehicle electrical system. When the vehicle is parked, it prevents the starter battery from becoming discharged by activated

9 Two-battery vehicle electrical system (schematic)

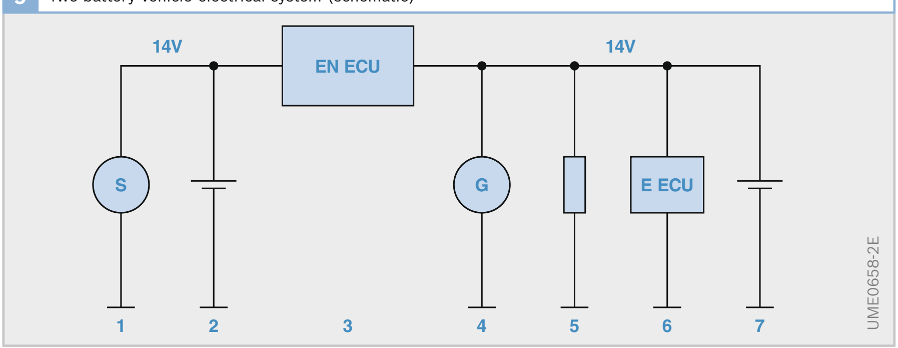


Fig. 9
1 Starter
2 Starter battery
3 Vehicle electrical system control unit
4 Alternator
5 Consumer
6 Engine control unit
7 General-purpose battery

consumers with the engine switched off and standstill-draw consumers.

By separation of the starting system from the remainder of the vehicle electrical system, there are theoretically no limits for the voltage level within the starting system. Consequently, the charge voltage can be optimally adapted to the starter battery by a DC/DC converter to minimize the charging time.

If there is no charge in the general-purpose battery, the control unit is capable of provisionally connecting both vehicle electrical systems. This means that the vehicle electrical system can be sustained using the fully-charged starter battery. In another possible configuration, the control unit for the starting operation would connect only the start-related consumers to whichever battery was fully charged.

Vehicle electrical systems for commercial vehicles

Battery changeover 12/24 V

Various heavy commercial vehicles have a combined 12/24 V system, i.e. the supply voltage can be switched between 12 and 24 V. In such cases, the alternator for voltage generation and the electrical components (starter excepted) are designed for nominal 12 V operation. The starter has a nominal voltage of 24 V. It is therefore possible to achieve the power output required to start larger diesel engines, for example.

The system consists of two 12 V batteries that are connected in parallel during vehicle operation and with the engine switched off. The voltage is no different with the parallel connection; the vehicle electrical system is supplied with 12 V. The total

10 Circuit of a starting system with battery changeover relay

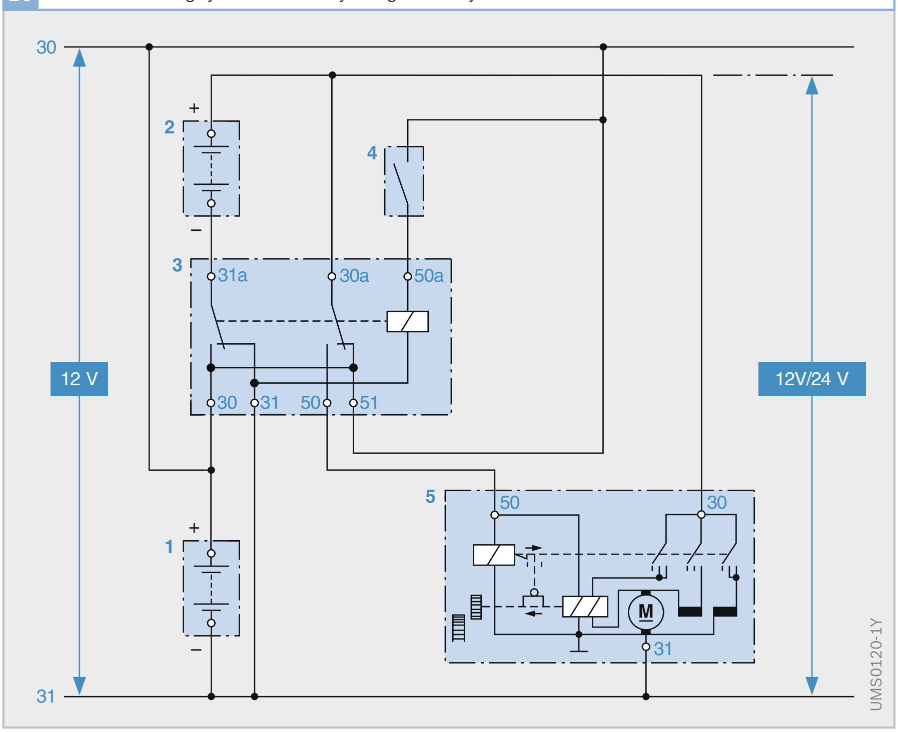


Fig. 10
1 12 V battery I
2 12 V battery II
3 Battery changeover relay
4 Ignition switch
5 24 V starting motor

capacity of the two batteries is the sum of the individual capacities.

When the ignition switch is turned, a battery changeover relay automatically switches the two batteries in series so that 24 V is applied across the starting-motor terminals during the cranking process. All other consumers are still supplied with 12 V.

As soon as the engine has started, that is when the ignition switch has been released and the starting motor switched off, the battery changeover relay automatically connects the batteries in parallel again. With the engine turning, the 12 V alternator recharges both batteries.

The capacities of two batteries connected in parallel should be equal to achieve uniform current distribution during the charging and discharging process. From the wiring viewpoint, connections should also be as symmetrical as possible, with identical lengths of connection cable and conductor cross-sections.

Components in the vehicle electrical system

At the present time, the components described can also be used in passenger-car electrical systems. Here, however, they are not common and tend to be fitted as optional equipment.

Battery master switch

Generally, the vehicle's electrical installation is wired such that when the key is pulled from the ignition switch the electrical lines leading from the switch to, for example, the ignition system, the control units (Motronic, ABS), the wipers, etc. are no longer supplied with current.

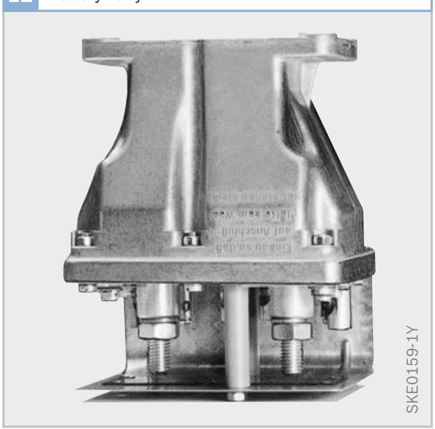
On the other hand, the lines leading to the ignition switch, to the starter, and to the light switch remain "live". In other words there is still voltage on these lines, and if they have frayed or worn-through points these can lead to low resistances which can cause leakage currents or short circuits which result in a discharged battery. The consequences are a discharged battery or the possibility of a fire. A battery master switch makes it possible to completely isolate the battery from the vehicle electrical system to eliminate the risk of these dangers.

The single-pole battery master switch is installed in the battery's ground cable (negative terminal) as near to the battery as possible. It should be within convenient reach of the driver.

On installations equipped with three-phase current alternators, due to the danger of voltage peaks (with the attendant destruction of electronic components), it is forbidden to operate the vehicle without the bat-

11 Battery master switch

12 Battery relay



tery connected. On such installations therefore, the battery master switch may only be actuated with the engine at standstill.

Battery relay

Legislation stipulates that in buses, road tankers etc. a battery relay must be installed as the master switch to separate the vehicle electrical system from the battery. Not only short circuits are avoided (during repairs for instance), but also the decomposition effects due to leakage currents on current-carrying components.

For this type of installation with three-phase current alternator, in order to prevent excessive voltage peaks it is necessary to fit a 2-pole electromagnetic battery main switch. This prevents the alternator being separated from the battery when the engine is running.

Battery-cutoff relay

The battery-cutoff relay (NO contact) separates the starter battery from a second battery used for ancillary equipment. It protects the starter battery against discharge when the three-phase current alternator is not delivering charge current. This relay is provided with a diode for reverse-polarity protection, and a decay diode to suppress the inductive voltage peaks caused by switching.

Battery charging relay

The battery charging relay is needed when an additional 12V battery is to be charged in a 24 V vehicle system voltage. It is provided with resistors across which at 10 A charging current a voltage drop takes place which reduces the charge voltage to 12 V. This of course necessitates the 24 V alternator being able to generate the additional 10 A.

13 Battery-cutoff relay symbol

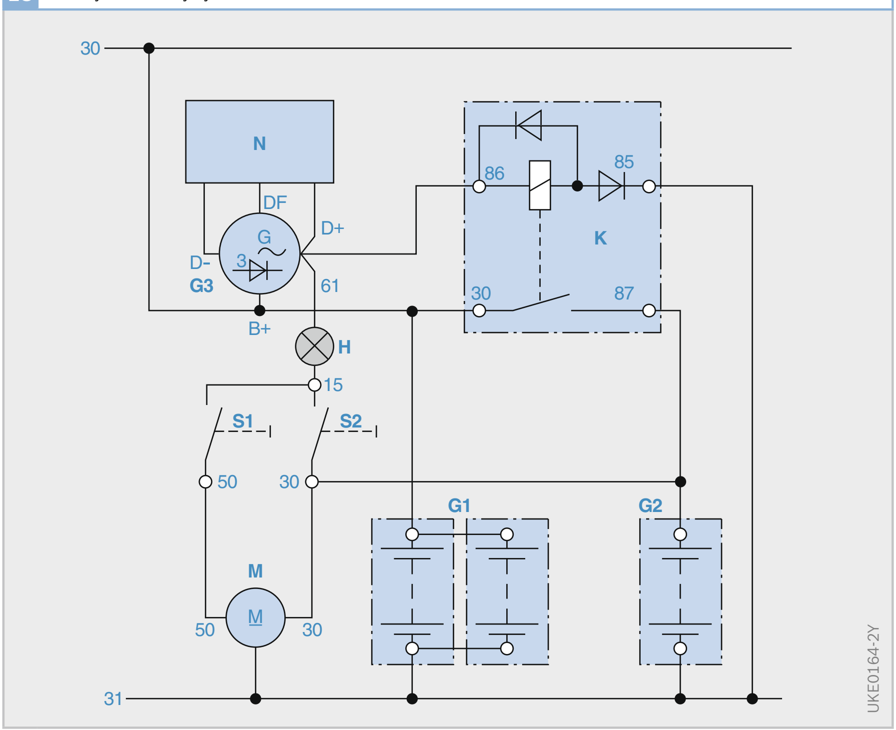


Fig. 13
G1 Battery for ancillary equipment
G2 Starter battery
G3 Three-phase current alternator
H Charge-indicator lamp
K Battery-cutoff relay
M Starter
N Alternator regulator
S1 Ignition switch
S2 Driving switch

Wiring harnesses

Requirements

The purpose of the wiring harness is to distribute power and signals within a motor vehicle. A wiring harness in the present day, mid-class passenger car with average equipment has approximately 750 different lines, their length totaling around 1,500 meters. In recent years the number of contact points has practically doubled due to the continuous rise in functions in the motor vehicle. A distinction is made between the engine compartment and body wiring harness. The latter is subject to less demanding temperature, vibration, media and tightness requirements.

Wiring harnesses have considerable influence on the costs and quality of a vehicle. The following points must be taken into consideration in wiring harness development:

- Leak-tightness
- EMC compatibility
- Temperatures
- Damage protection for the lines
- Line routing
- Ventilation of the wiring harness

It is therefore necessary to involve wiring harness experts as soon as in the system definition stage. Figure 1 shows a wiring harness that was developed as a special intake-module wiring harness. Thanks to the optimization of routing and security in conjunction with engine and wiring harness development, it was possible to achieve an advancement of quality as well as to yield cost and weight advantages.

Dimensions and material selection

The most important tasks for the wiring harness developer are:

- Dimensioning the line cross-sections
- Material selection
- Selection of suitable plug-in connections
- Routing of lines under consideration of ambient temperature, engine vibrations, acceleration and EMC
- Consideration of the environment in which the wiring harness is routed (topology, assembly stages in vehicle manufacture and equipment on the assembly line)

1 Wiring harness (example)

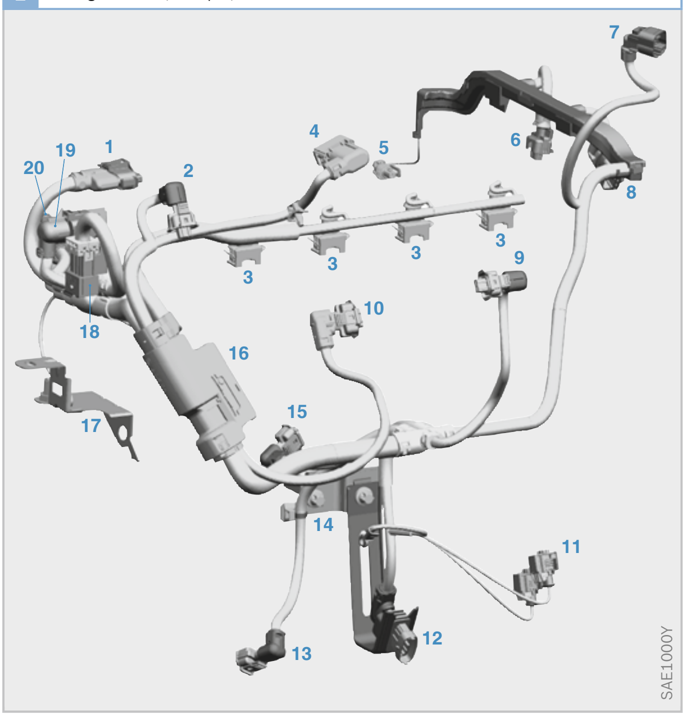


Fig. 1
1 Ignition coil module
2 Channel deactivation
3 Fuel injectors
4 Throttle device DV-E
5 Oil-pressure switch
6 Engine-temperature sensor
7 Intake-air temperature sensor
8 Camshaft sensor
9 Canister-purge valve
10 Intake-manifold pressure sensor
11 Charge-current indicator lamp
12 Downstream Lambda oxygen sensor
13 Speed sensor
14 Terminal 50, starter switch
15 Knock sensor
16 Engine control unit
17 Engine ground
18 Disconnecter plug for engine and transmission wiring harness
19 Upstream Lambda oxygen sensor
20 EGR valve

Line cross-sections

Line cross-sections are defined based on permissible voltage drops. The lower cross-section limit is determined by the line strength. Convention has it that no lines with a cross-section of less than 0.5 mm^2 are used. With additional measures (e.g. supports, protective tubes, tension relief), even a cross-section of 0.35 mm^2 may be permissible.

Materials

Copper is usually used as the conductive material. The insulation materials for the lines are defined by the temperature to which they are exposed. It is necessary to use materials that are suitable for the high temperatures of continuous operation. Here, the ambient temperature must be taken into consideration as much as the heating caused by the flow of current. The materials used are thermoplastics (e.g. PE, PA, PVC), fluoropolymers (e.g. ETFE, FEP) and elastomers (e.g. CSM, SIR).

If the lines are not routed past particularly hot parts (e.g. exhaust pipe) in the engine topology, one of the criteria for the selection of the insulation material and the cable cross-section could be the derating curve of the contact with its associated line. The derating curve represents the relationship between current, the temperature increase that it causes, and the ambient temperature of the plug-in connection. Normally, the heat generated in the contacts can only be carried away along the lines themselves. It should also be noted that the change in temperatures results in a change in the modulus of elasticity of the contact material (metal relaxation). It is possible to influence the relationships described by means of larger line cross-sections and the use of suitable contact types and more noble surfaces (e.g. gold, silver) and thus higher limit temperatures. For highly fluctuating current intensities, it is often useful to measure the contact temperature.

Plug-in connections and contacts

The type of plug-in connections and contacts used depends on various factors:

- Current intensity
- Ambient temperatures
- Vibration load
- Resistance to media and
- Installation space

Line routing and EMC measures

Lines should be routed in such a way as to prevent damage and line breaks. This is achieved by means of fasteners and supports. Vibration loads on contacts and plug-in connections are reduced by fastening the wiring harness as close to the plug as possible and at the same level as the vibration where possible. The line routing must be determined in close cooperation with the engine and vehicle developers.

Where EMC problems arise, it is recommended to route sensitive lines and lines with steep current flanks separately. Shielded lines are not straightforward to produce and are therefore expensive. They also need to be grounded. The twisting of lines is a more cost-favorable and effective measure.

Line protection

Lines need to be protected against chafing and against making contact with sharp edges and hot surfaces. Adhesive tapes are used for this purpose. The level of protection is determined by the interval and winding density. Corrugated tubing (material savings from corrugation) with the necessary connecting pieces are often used as line protection. However, tape fixing is still an essential means of preventing movement of individual lines inside the corrugated tube. Optimal protection is offered by cable ducts.

Plug-in connections

Design and requirements

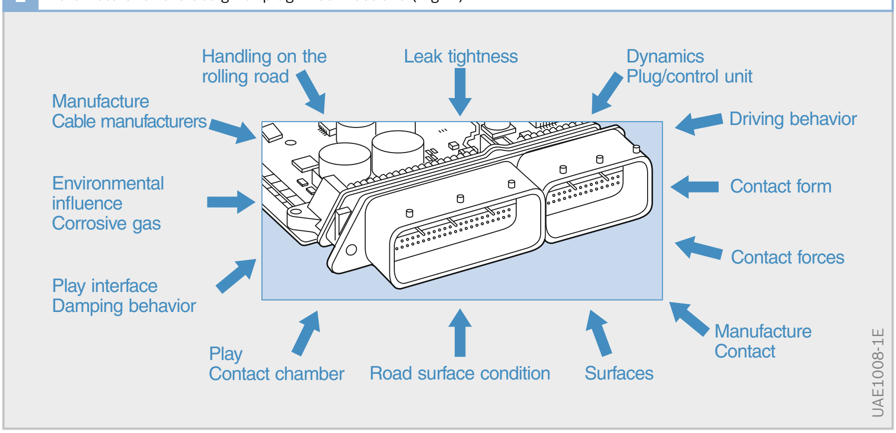
The high integration density of electronics in the motor vehicle places high demands on a car's plug-in connections. Not only do they carry high currents (e.g. activation of ignition coils), they also carry analog signal currents with low voltage and current intensity (e.g. signal voltage of the engine temperature sensor). Throughout the service life of the vehicle, the plug-in connections must ensure the reliable transmission of signals between control units and to the sensors whilst maintaining tolerances.

The increasing demands of emission-control legislation and active vehicle safety are forcing the ever more precise transmission of signals through the contacts of the plug-in connections. A large number of parameters must be taken into consideration in the design, arrangement and testing of the plug-in connections (Fig. 1).

The most common cause of failure of a plug-in connection is wearing of the contact caused by vibrations or temperature change. The wear promotes oxidation. This results in an increase in ohmic resistance – the contact may, for example, be subjected to thermal overload. The contact part may be heated beyond the melting point of the copper alloy. In the case of highly resistant signal contacts, the vehicle controller often detects a plausibility error by comparison with other signals; the controller then enters fault mode. These problem areas in the plug-in connection are diagnosed by the on-board diagnosis (OBD) required by emission-control legislation. However, it is difficult to diagnose the error in the service workshops because this defect is displayed as being a component failure. It is only possible to diagnose the faulty contact indirectly.

For the assembly of the plug-in connection, there are various functional elements on the plug housing intended to ensure that the cables with their crimped contacts can be joined to the plug-in connection reliably and defect-free. Modern plug-in connections have a joining force of < 100 N so that the assembly operative is able to reliably join the connector to the component or control-unit interface. The risk of plug-in connections being connected to the interface incorrectly increases with higher connecting forces. The plug would come loose during vehicle operation.

1 Parameters for the design of plug-in connections (Fig. A)



1 Areas of application for plug-in connections

	No. of poles	Special features	Applications
Low-pin-count	1 to 10	No joining force support	Sensors and actuators (many different requirements)
High-pin-count	10 to 150	Joining force support by slide, lever, modules	Control units (several, similar requirements)
Special connectors	any	e.g. integrated electronics	Special applications (individual, matched requirements)

Table 1

Design and types

Plug-in connections have different areas of application (Table 1). These are characterized by the number of poles and ambient conditions. There are different classes of plug-in connection: hard engine attachment, soft engine attachment, and body attachment. Another difference is the temperature class of the installation location.

High-pin-count plug-in connections

High-pin-count plug-in connections are used for all control units in the vehicle. They differ in their number of poles and the geometry of the pins. Figure 2 shows a typical design of a high-pin-count plug-in connection. The complete plug-in connection is sealed at the connector strip of the respective control unit by means of a continuous radial seal in the plug housing. This, together with three sealing lips, ensures a reliable seal against the control unit sealing collar.

The contacts are protected against the ingress of humidity along the cable by a seal plate, through which the contacts are inserted and the line crimped to them. A silica-gel mat or silica mat is used for this purpose. Larger contacts and lines may also be sealed using a single-core seal (see “Low-pin-count plug-in connections”).

When the plug is assembled, the contact with the line attached is inserted through the seal plate that is already in the plug. The contact slides home into its position in the contact carrier. The contact latches on its own by a locking spring that engages in an undercut in the plastic housing of the plug.

2 High-pin-count plug-in connection (Fig. B)

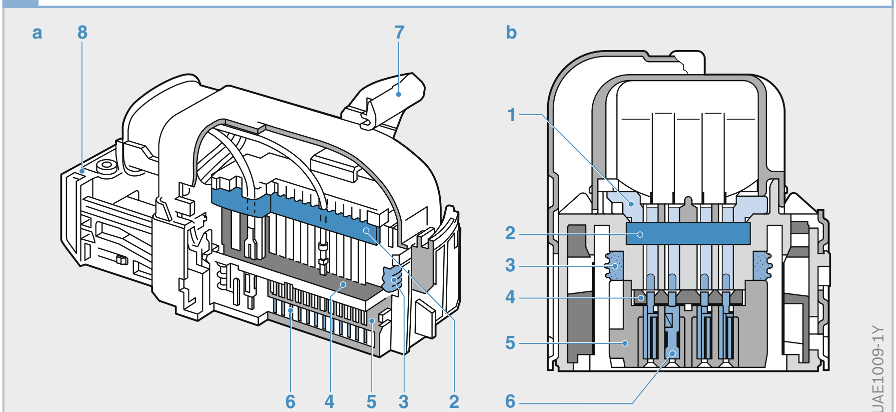


Fig. 2
a 3D view
b Sectional view

1 Pressure plate
2 Seal plate
3 Radial seal
4 Slide pin (secondary lock)
5 Contact carrier
6 Switch contact
7 Lever
8 Slide mechanism

Once all contacts are in their final position, a slide pin is inserted to provide a second contact safeguard, or secondary lock. This is an additional security measure and increases the retaining force of the contact in the plug-in connection. In addition, the sliding movement is a means of checking that the contacts are in the correct position. The operating force of the plug-in connection is reduced by a lever and a slider mechanism.

Low-pin-count plug-in connections

Low-pin-count plug-in connections are used for actuators (e.g. fuel injectors) and sensors. Their design is similar in principle to that of a high-pin-count plug-in connection (Fig. 3). The operating force of the plug-in connection is not usually supported.

The connection between a low-pin-count plug contact system and the interface is sealed with a radial seal. Inside the plastic housing, however, the lines are sealed with single-core seals secured to the contact.

Contact systems

Two-part contact systems are used in the motor vehicle. The inner part (Fig. 4) – the live part – is pressed from a high-quality copper alloy. It is protected by a steel overspring, which at the same time increases the contact forces of the contact by means of an inwardly acting spring element. A catch arm pressed out from the steel overspring engages the contact in the plastic housing part. Contacts are coated with tin, silver or gold, depending on requirements. To improve the wear characteristics of the contact point, not only are different contact coatings used but also different structural shapes. Different decoupling mechanisms are integrated into the contact part to decouple cable vibrations from the contact point (e.g. meandering routing of the supply lead).

The cables are crimped onto the contact. The crimp geometry on the contact must be adapted to the cable concerned. Pliers or fully automatic, process-monitored crimping presses with contact-specific tools are available for the crimping process.

3 Low-pin-count plug-in connection (Fig. C)

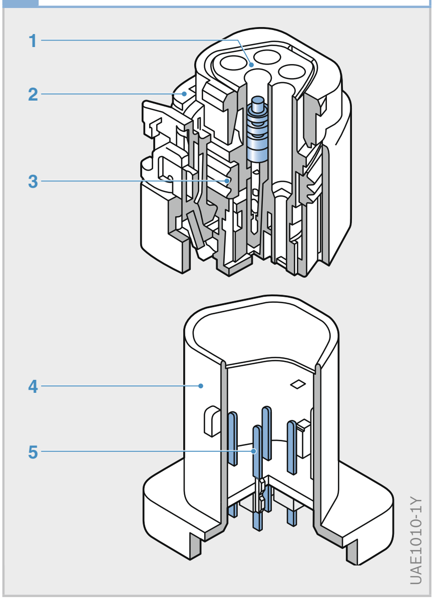


Fig. 3
1 Contact carrier
2 Housing
3 Radial seal
4 Interface
5 Flat blade

4 Contact (Fig. D)

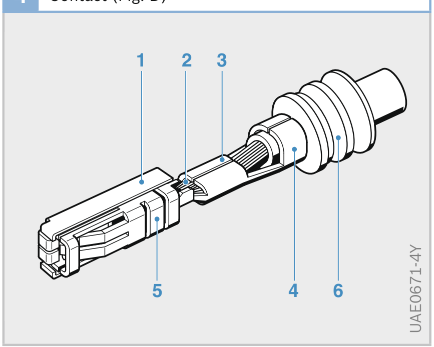
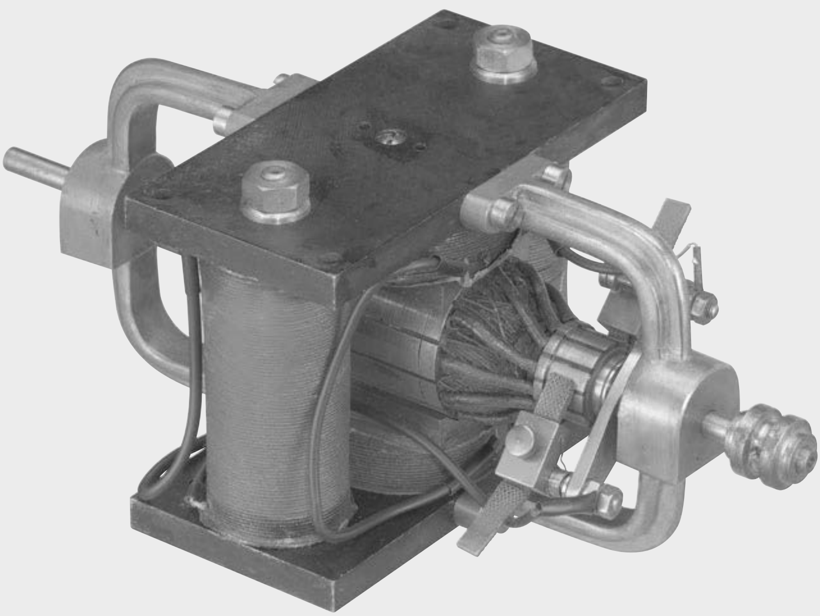


Fig. 4
1 Steel overspring
2 Single conductor (single core)
3 Conductor crimp
4 Insulation crimp
5 Wave-shaped interior design
6 Single-core seal

History of the alternator

At the turn of the century, the introduction of electrical lighting to motor vehicles to take the place of the previously used horse-and-carriage lighting meant that a suitable source of electrical power had to be available in the vehicle. The battery alone was completely unsuitable since, when discharged, it had to be removed from the vehicle for re-charging. In around 1902, the model for a dynamo (the basis for today's alternator) was created at Robert Bosch. It mainly comprised permanent magnets as stators, an armature with commutator and a contact breaker for ignition (see Fig.). The only difficulty here, though, was the fact that the dynamo's voltage was dependent on the engine's speed which varied considerably.

Endeavors, therefore, concentrated on the development of a DC dynamo with voltage regulation. Finally, electromagnetic control of the field resistor as a function of the machine's output voltage proved to be the answer. Around 1909, using the knowledge available at that time, it thus became possible to build a complete "Lighting and Starting System for Motor Vehicles".
This was introduced to the market in 1913 and comprised a dynamo (splashwater-protected, encapsulated 12-V DC dynamo with shunt regulation and a rated output of 100 W), a battery, a voltage-regulator and switch box, a freewheeling starter with pedal-operated switch, and a variety of different lighting components.



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