Occupant-protection systems

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

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

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

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

Seat belts and seat-belt pretensioners

Function

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

Operating principle

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

1 Electronic impact protection system

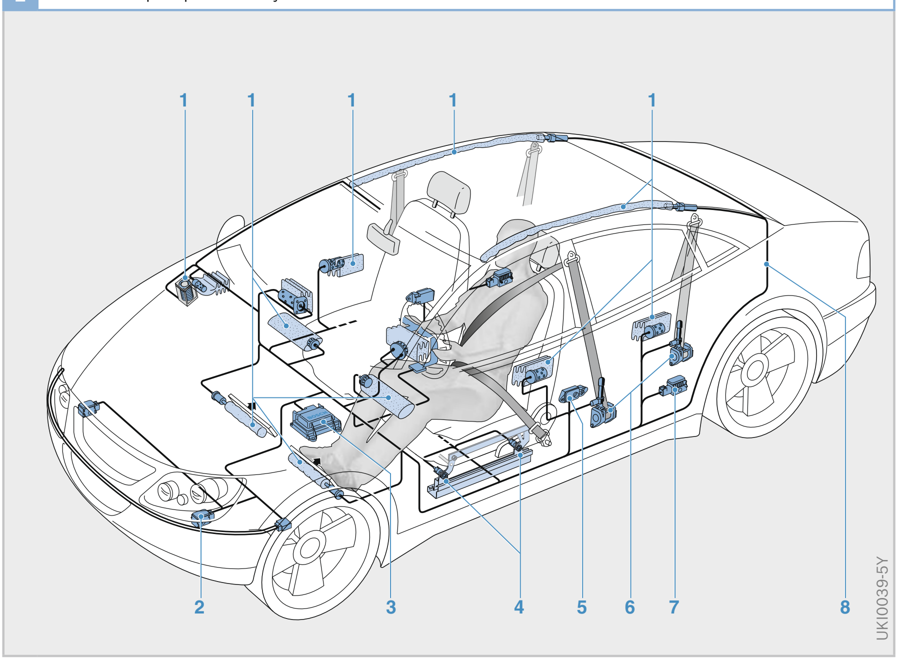

Fig. 1
1 Airbag with gas inflator
2 Upfront sensor
3 Central electronic control unit with integrated rollover sensor
4 iBolt™
5 Peripheral pressure sensor (PPS)
6 Seat-belt pretensioner with propellant charge
7 Peripheral acceleration sensor (PAS)
8 Bus architecture (CAN)

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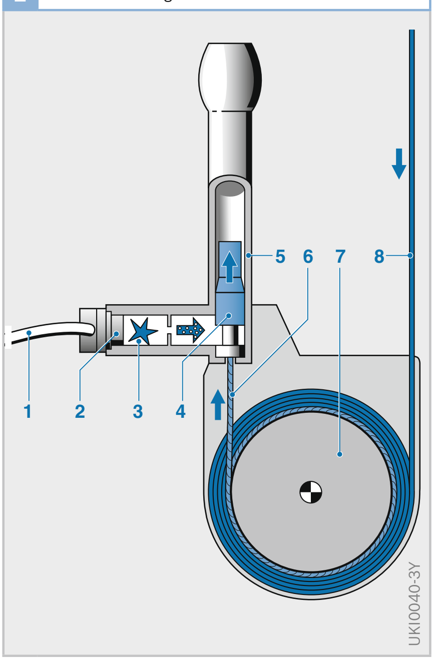
which turns the belt reel via a steel cable in such a way that the belt is held tightly against the body (Fig. 2).

Variants

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

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

2 Shoulder-belt tightener



Front airbag

Function

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

Operating principle

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

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

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

Impact detection

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

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

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

Deactivation switch

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

Intelligent airbag systems

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

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

Side airbag

Function

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

Operating principle

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

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

Rollover protection systems

Function

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

Operating principle

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

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

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

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

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

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

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

4 Central combined airbag 9 ECU (block diagram)

Terminal designations:

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

Abbreviations:

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

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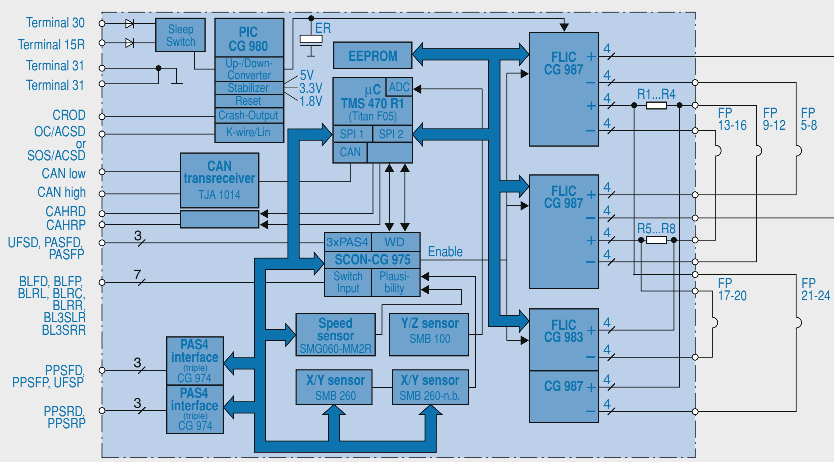

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side airbags provided the internal lateral sensor has confirmed a side impact by means of a plausibility check. Since the central plausibility confirmation arrives too late in the case of impacts into the door or above the sill, peripheral pressure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

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

Acceleration sensors

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

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

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

Gas inflators

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

AC firing

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

Passenger-compartment sensing

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

Micromechanics

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

Bulk micromechanics

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

Surface micromechanics

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

Wafer bonding

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

1 Structures produced by bulk micromechanics

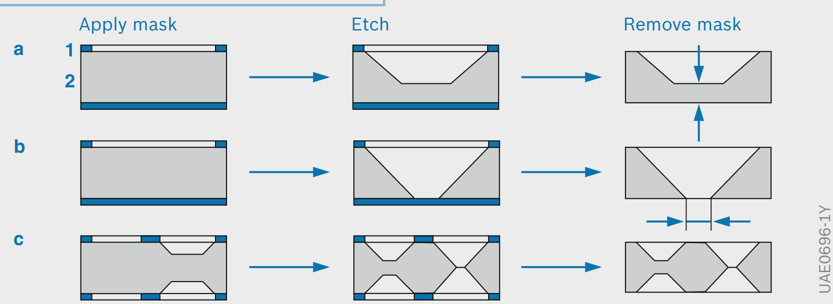

Fig. 1
a Production of diaphragms
b Production of holes
c Production of bars and ridges

1 Etching mask
2 Silicon

2 Surface micromechanics (processing steps)

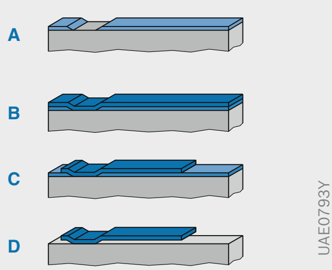

Fig. 2
A Cutting and structuring the sacrificial layer
B Cutting the polysilicon
C Structuring the polysilicon
D Removing the sacrificial layer

3 Surface micromechanics (structure details)

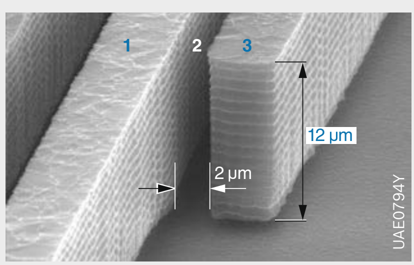

Fig. 3
1 Fixed electrode
2 Gap
3 Spring electrode