1 Introduction

This chapter introduces to the field of automotive vehicle safety, safety electronics and concepts for occupant protection. In addition, the motivation for networking of active and passive safety electronics in future vehicle safety scenarios is given. More details on the topics mentioned in the following can be found in [65], [48] and [33].

1.1 Motivation

The most undesirable situation in road traffic is a collision with either other road users or obstacles on or off the road. Thus, development of adequate protection means for occupants in such a severe situation has been started over 50 years ago. In 1952, the first patent for an airbag-like protection system was assigned to American engineers. However, early approaches for inflatable cushions suffered from extensive inflation times, heavy weight, large installation spaces and poor functional safety of the components. As shown in figure 1.1, the whole plot of a collision lasts for only about 150 milliseconds, which is not much more than the time for a blink of an eye, from the first contact until the damaged car comes to standstill again. These timing demands could never be met by inflation strategies based on high-pressure gas, which is why developers switched to composite gas generators as known from military and space rockets in the early 1970's.
It took until 1980 – almost 30 years of research! – to put airbags into serial operation, when Mercedes-Benz offered for the S-Class (W126) a system composed of a driver-airbag and belt tensioners, available as extra equipment for 1526 DM. Nowadays, even compact cars may be equipped with front-, side-, window- and knee-airbags and hence offer a high level of passive occupant protection. Consequently, the number of road traffic fatalities decreased significantly in the last decades since the development of effective occupant protection systems has been

started. This is mainly the merit of distinctively adjusted passive safety systems, consisting of a stiff vehicle body to absorb as much energy in a crash as possible and quickly deployed airbags and pyrotechnical belt tensioners. Of course, legal enforcements during this time, like speed limits or penalties for driving without fastened seat belts, contributed to the reduction of deaths in traffic, too.

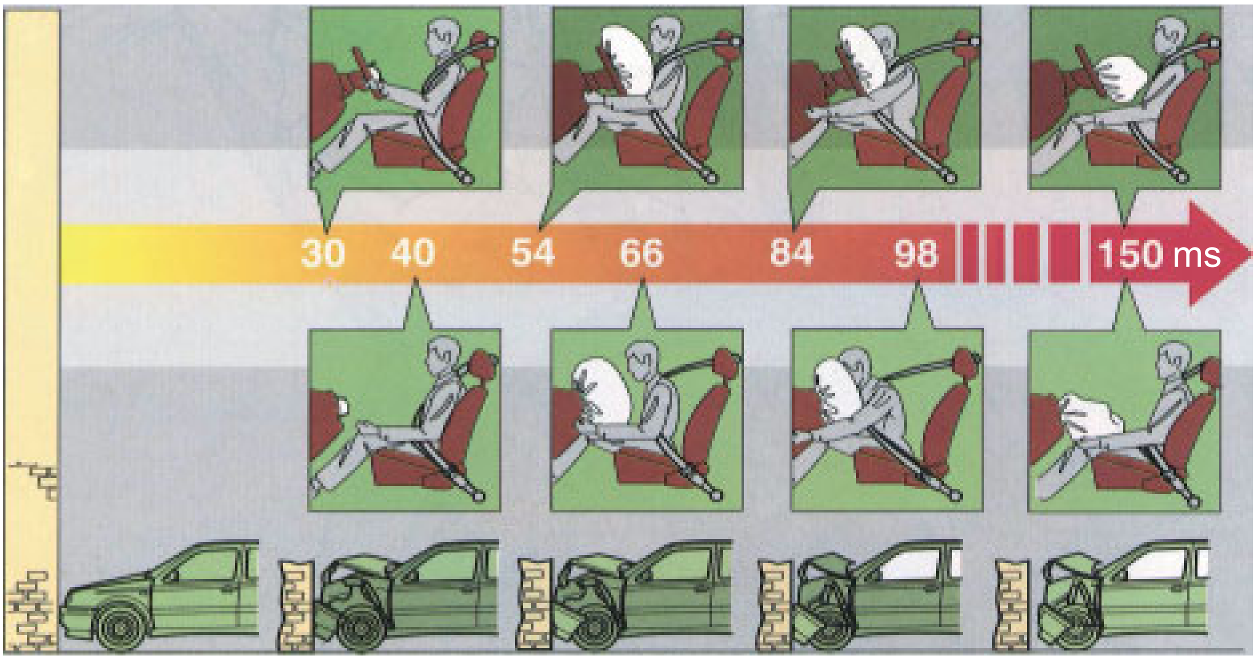

Figure 1.1: Time Plot of Airbag Activation in a Crash [3]

1.2 Airbag Control Systems

1.2.1 Airbag Control Unit

The core component of up-to-date airbag control systems is the airbag control unit (ACU) as shown in figure 1.2. Its main functions are detection of a crash (or a roll-over), activation of adequate protection means, disconnection of the battery from the on-board voltage supply infrastructure and, eventually, transmission of an emergency call in the so-called *post-crash phase* shortly after the collision.

The major electronic components inside the ACU are a microcontroller (*main-μC*) with operating system, deployment algorithms, diagnosis routines etc., and a redundant, second microcontroller (*safety-μC*) for sensor signal processing

Figure 1.2: ACU (left) and Crash Sensors (right: g-Sat, p-Sat) [3]

and deployment decision. Internal acceleration sensors yield measurements on vehicle dynamics, which are used to validate external crash sensor information. To assure autarkic operation of the ACU, e.g. if the battery is damaged early during a severe front-crash, capacitors offer the necessary voltage supply, typically charged to enable 100 to 200 milliseconds of self-sustained operation. Activation of pyrotechnical devices is triggered by a current, that is generated by redundant firing stages inside the ACU. The connection to the in-car communication system is realized by a bus controller. Table 1.1 presents some typical settings for electronics of an airbag control unit. The values are real-life parameters for the ACU of an Audi A6 Limousine, as produced from 2004 to 2007 [4], [3].
Figure 1.3 gives an impression of the typical installation place of the ACU, which is on the gear-tunnel, near to the center of mass in the middle of the car. This placement is chosen for two main reasons. First of all, in case of a crash, the ACU must not be destroyed or disconnected from the contact before belt tensioners and airbags have been deployed. A centered installation of the ACU offers the best protection in terms of distance to possible sites of impact. Second, for reasons of functional safety, the severity of the impact and the acceleration of the vehicle is measured both by external satellite sensors and by internal sensors in the ACU. Installation near to the center of mass, thus near to the central rotation axes, yields the most accurate and trustworthy measurements.

Table 1.1: Typical Configuration of Airbag Control Unit

Parameter	Setting	Comment
ACU Vendor	SiemensVDO	now ContiVDO
Main-μC	STMicroelectronics ST10	16-bit controller
Safety-μC	STMicroelectronics ST7	8-bit controller
Clocking Main-μC	32 MHz	–
Clocking Safety-μC	16 MHz	–
EEPROM	2 kByte	–
RAM	8 kByte	–
ROM	128 kByte	blockwise flashable
Energy Autarky	min. 150 ms	via capacitor charge
Internal Sensors	g_x, g_y	$\pm$ 50 g, Piezo-electric
Main Contact	75 Pins	Sumitomo dual-lock

1.2.2 Crash Sensors

Crash sensors are the central measurement components for detection of an impact. In general, crash sensors of an airbag control system can be categorized in:

- External crash sensors in the front part of the vehicle (cf. figures 1.2 and 1.3). These so-called *up-front* sensors are micromechanic devices which measure an acceleration based on Piezo-electric effects. In a front crash scenario, the up-front sensors are closest to the place of impact, thus they detect the collision first and send the digitalized measurement values to the ACU. Typical detection ranges are $\pm$200 g.
- External crash sensors on the sides of the vehicle. With the development of side- and window-airbags, additional measurement devices for detection of a side impact became necessary. As shown in figure 1.3, sensors are installed in the front doors and on the vehicle body close behind the rear doors. The devices in the doors are typically pressure sensors, which are equipped with a membrane to measure the increase in pressure inside the door in case of an impact, for example in ranges from 50 to 116 kPa. The side sensors on the vehicle body are using the same measurement principle as the up-front sensors, namely Piezo-electric elements for detection of accelerations of $\pm$200 g.

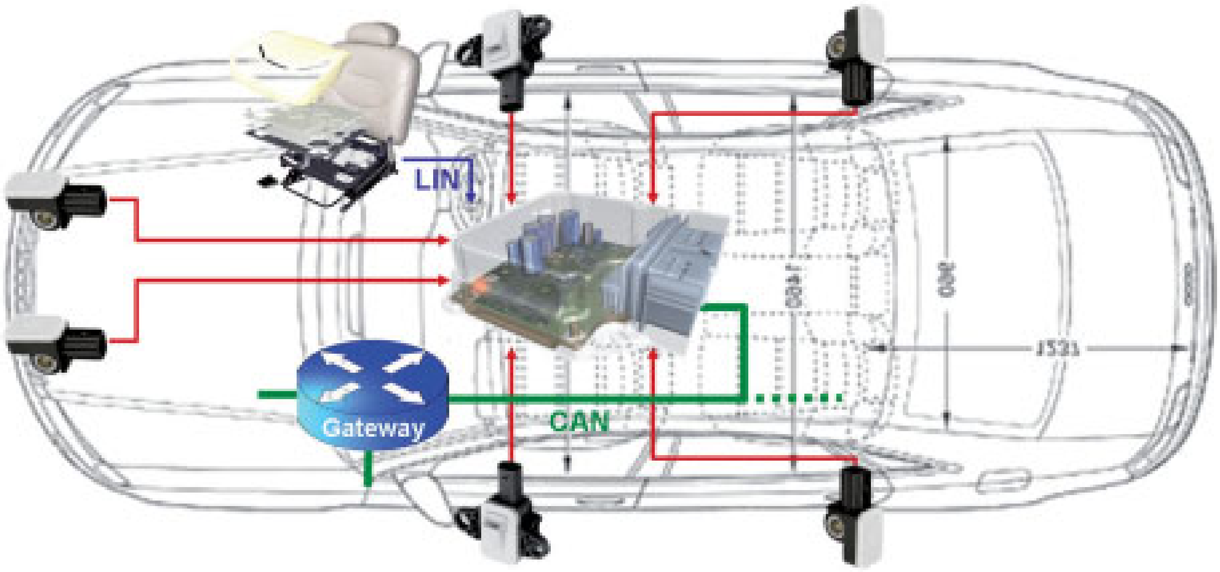

Figure 1.3: Placement and Interconnection of Passive Safety Electronics

- Internal crash sensors on the board of the ACU. For validation of signals from external up-front and side sensors, acceleration-based sensors are used. As the impulse of the impact is much lower in the middle of the car than at the damaged outer parts of the vehicle body, a significantly lower detection area of ±50 g is sufficient for internal devices. For detection of dangerous side-slip or roll-over situations, yaw-rate sensors are employed, i.e. combined acceleration sensors for x-, y- and z-direction or liquid-filled sensors with a movable gas-bubble.

Each external sensor is connected to the ACU by a dedicated wire. The analogue measurement samples are digitalized by an application-specific integrated circuit (ASIC) in the sensor and, together with sensor status information, periodically transfered to the ACU. Widespread up-to-date protocols for sensor data transmission are the Peripheral Acceleration Sensor 4 (PAS-4) protocol from Bosch for acceleration sensors or, for pressure sensors, the PEGASUS protocol from SiemensVDO/ContiVDO. Here, Manchester-coded data words of 10 - 12 bits length are transfered over a twisted-pair current interface, typically every 250 μs, i.e. with 4 kHz clocking. The Peripheral Sensor Interface 5 (PSI 5) is supposed to be the upcoming standard for communication between crash sensors and ACU [46], the launch is planned for 2010.

1.2.3 Airbags and Belt Tensioners

The actual protection for occupants is achieved by appropriate activation of protection means in a crash, namely the airbags and the pyrotechnical belt tensioners as depicted in figure 1.4. An airbag is a textile cushion with a volume from about 15 liters (side-airbag) to more than 100 liters (front-airbag passenger side). To match the timing constraints of only a few ten milliseconds for opening the airbag completely, pyrotechnical processes are employed to generate the adequate amount of gas and to inflate the cushion. The same holds for the pyrotechnical belt tensioners, which have to reach force-levels of about 4 kN for tightening the passenger in the seat and thus to suppress a forward movement against the steering wheel or the dashboard. Upon detection of a collision with a certain severity, the ACU sends a *firing current* to the relevant protection devices. For example, in a front-crash with a speed of at least 26 km/h, the front-airbags and the belt tensioners for driver and front passenger are activated. The firing current triggers Natriumazid pallets in the airbag module to oxidate and to generate Nitrogen, which inflates the cushion. In the belt tensioner, Nitrocellulose is fired and the resulting portion of gas rewinds the belt mechanics via iron bowls.

Figure 1.4: Side-Airbags, Front-Airbags and Belt Tensioner [50]

1.2.4 Functional Safety of the Airbag Control System

Even though airbags and belt tensioners yield reasonable protection for occupants in a crash, an unmotivated deployment of these pyrotechnical devices in a non-crash driving situation remarks a serious threat for the passengers. Thus, considerable effort is spent to avoid misuse scenarios. First and foremost, the ACU relies on both external and internal sensor measurements for crash detection. In figure 1.5, this concept of *plausibility* is indicated by the green-colored external and internal sensors serving as combined input to the ACU, where each sensor type can be used to validate the measurements of its counterpart. For instance, if a defective upfront sensor generates corrupted data reporting a front-crash, the ACU will detect its malfunction by validation of external sensor data with internal measurements.

The second important concept for functional safety of the airbag control system is the *redundancy* in the dual controller layout of the ACU (colored in blue in figure 1.5). Main- and safety-μC monitor the correct operation of each other by hardware and/or software watchdog mechanisms and evaluate sensor data redundantly. Only a timely- and event-correlated firing decision of both microcontrollers – indicated by the logical "AND" in figure 1.5 – will activate any firing stages. This concept prevents the system from erroneous processing of correct (external and/or internal) sensor data if one of the controllers comes into a malfunctional operation mode.

The third strategy which contributes to safe and reliable system operation is the *safing* concept. The main-μC evaluates sensor data from external and internal sensors permanently. Thus, the measured values show a certain plot over the time axis, resembling the currently measured acceleration or pressure. In case of a collision, sensor data values are expected to deviate from normal measurements significantly in terms of an instantaneous, steep increase of measurements due to the impact. Within the safing concepts, thresholds are implemented, which the sensor data must exceed with a specified increase or for a certain time interval before any pyrotechnical means are activated. This prevents from undesired deployments, caused by steep but rather short peeks in acceleration of the whole vehicle body, e.g. on rough roads, or by longer but rather low impulses, for example from low-speed contact with the bumper of another vehicle while parking.

1.3 Future Vehicle Safety Approaches

The passive safety systems for occupant protection are nowadays on a high level of effectiveness and functional safety. Thus, vehicle safety strategies based solely on passive airbag control systems and stiff vehicle bodies will hardly lead to significant improvements in this field. As a consequence, lots of effort is spent on novel developments for a further reduction of road traffic fatalities.