Development of the electronic "Safing" system for airbag ECUs

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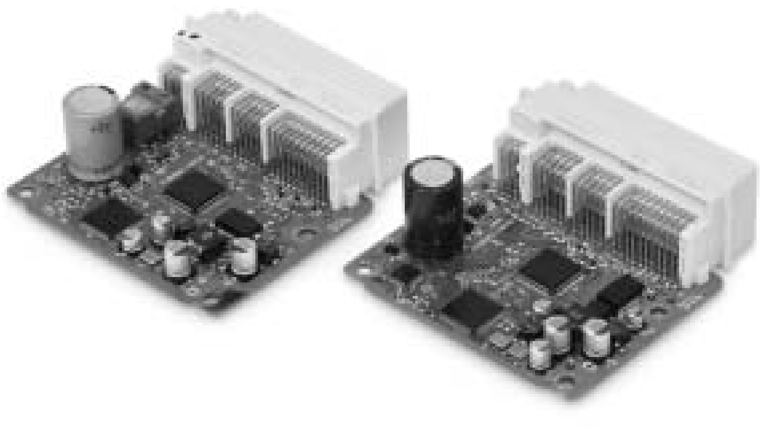


Abstract

With the recent increase in automotive safety consciousness, 4 channel airbag systems that cover the driver and passenger seats with seatbelt pretentioners have become standard equipment. To reduce car accident injuries and fatalities, the trend towards the standardization of side airbags and curtain airbags is accelerating.

In response to these demands, high-functionality and large scale cost reduction are required. However, as airbag systems are important safety devices for automobiles, reliability requirements are very strict. Thus, a big issue has been the establishment of high functionality and cost reductions while maintaining conventionally high levels of reliability.

In this paper, the development of the electronic "Safing" system is introduced as one of the key factors for cost reduction technology, which achieves the high level of reliability of conventional systems.

1 Introduction

With the recent increase in automotive safety consciousness, driver and passenger seats with seatbelt pretentioners have become standard equipment in virtually all vehicles in conjunction with improvements in collision safety technology and awareness of the importance of fastening seatbelts. As a result, there is now a trend toward reduced fatalities due to accidents (Fig. 1).

Beginning with the introduction of pedestrian head protection, and offset front collision, the Ministry of Land, Infrastructure and Transportation has set a target of reduced damage from vehicle compartment equipment, and a reduction of 1,200 fatalities from the current level by 2010.

Further, in China, where the number of vehicles sold has rapidly increased, traffic accident fatalities are increasing yearly, exceeding 100,000 people since FY 2001. As in Europe, the Chinese government is pursuing the application of head-on collision standards, and the introduction of European side collision standards is under discussion.

In terms of measures by automobile manufacturers in this situation regarding collision safety, system standardization is progressing, including multi-stage control airbags for reducing damage from airbag systems, as well as side collision and head protection, provided in some vehicle types.

As a background of standardization, multi-stage airbags for reducing fatalities among children and women, and head protection, in accordance with the increase in vehicles such as SUV and 1 BOX, in which side collision occur at a higher position are considered.

Further, the introduction of new systems is under discussion, including rollover and pedestrian protection.

In future, there will be a trend towards high functionality of airbag systems in developed countries, and equipment standardization in developing countries, and therefore demand for airbag systems are expected to increase. Conversely, system cost reductions have become essential.

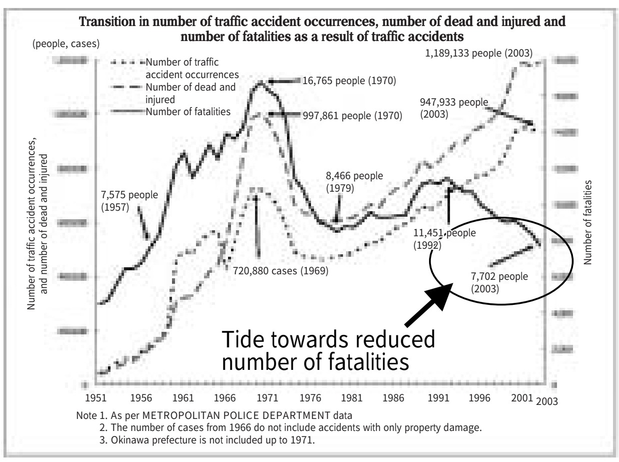


Fig.1 Transition in the number of injuries and fatalities from traffic accidents

2 History of airbag ECU(Electronic Control Unit) development at our company

Delivery of airbag ECU (driver seat air bags only with 1 channel design) to Toyota Motor Corporation began in 1993, a year in which airbag systems were set as a high-cost option with little demand. Currently, 1,200,000 units are produced annually, primarily ECU for 4 channel systems that cover driver and passenger seats with pretensioner controls.

In terms of technical cooperation during this period, cooperative development was pursued with Siemens from 1993 to 1999, and with Toyota Motor Corporation in 2000 (Fig. 2).

Regarding the 2004 models, in addition to conventional 4 channel systems, other systems have been developed in cooperation with Toyota Motor Corporation. There are 8 channel standard designs, including driver seat and passenger seat multi-stage control airbags, and knee-airbag units for controlling movement of passengers during collisions. There are also high functionality 14 channel designs for side collisions. airbags (side airbags, curtain shield airbags), and rear pretensioners.

In this paper, 2004 model airbag ECU "Safing" systems technology is introduced, which aims at higher functionality and cost reductions over conventional ECU.

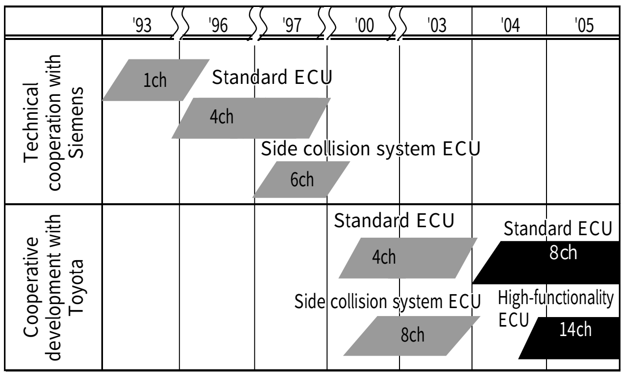


Fig.2 Development history of airbag ECU

3 Overview of airbag systems

3.1 Airbag system structure

The ECU developed in 2004 implements control for front impact multi-stage airbags for driver and passenger seats, pretensioners, side airbags and curtain shield airbags. As shown in the structure in Fig. 3, collisions from the front and side are detected from airbag ECU located at the front center of the vehicle compartment, and by front satellite and side satellite sensors, positioned at vehicle front and sides respectively. These are processed by ECU internal microprocessors (hereinafter called microprocessors), and the firing circuit turns ON when collision determination values, set for each type of vehicle, are exceeded. In this way, current flows to the firing device (hereinafter the squib) shown in Fig. 4, and the airbags are deployed.

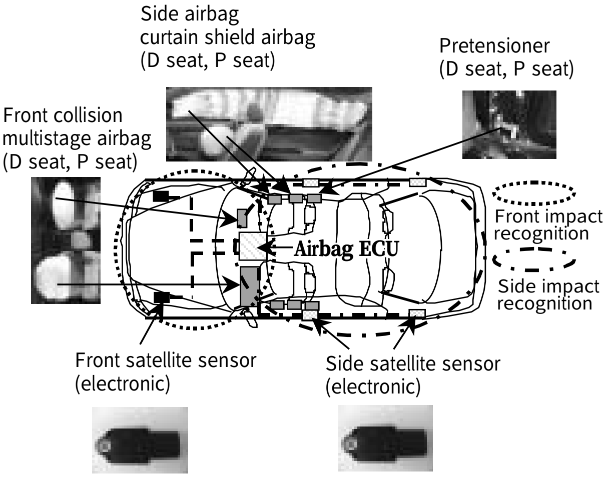


Fig.3 Airbag system structure

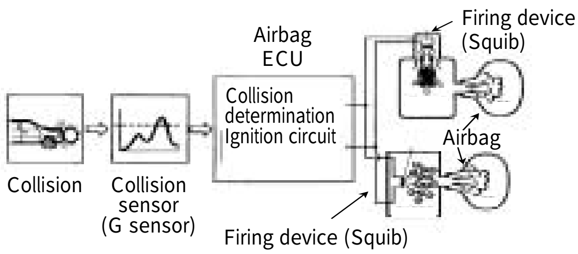


Fig.4 Deployment process of the airbag system

3.2 Role of the Safing system

The airbag system is structured with a safing sensor in series with firing circuit transistors, to ensure operational reliability, enabling breakage of the current circuit in case of incorrect operation due to malfunction or electrical noise.

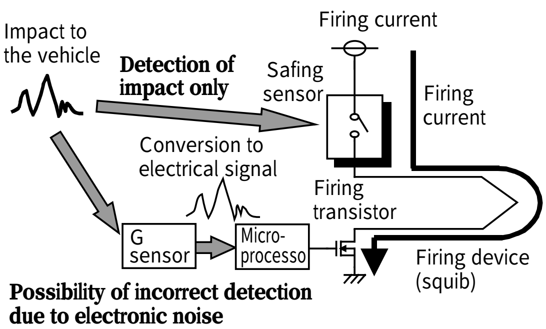


Fig.5 Role of the safing system

3.3 Technological changes in the safing system

In terms of the airbag ECU safing system, as shown in Fig. 6, conventionally (1993 to 2003), a mechanical contact safing system was adopted, enabling the firing of current to the squib. However, for future standard ECU and high-functionality ECU, in order to achieve a smaller size cost reductions, and high functionality, development is necessary of trigger sensor safing systems and fully electronic safing systems.

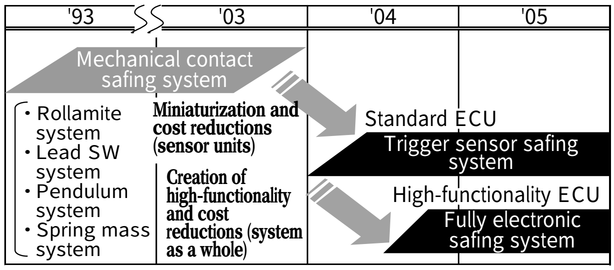


Fig.6 Technological changes in the safing system

4 Objectives of the developed system

The objectives of development of the abovementioned safing system are as shown below.

1) Trigger sensor safing system [Standard ECU (6 channels)]

In contrast to conventional mechanical contact sensors, enabling the firing of current to the squib, sensor size and cost reductions are achieved by setting only impact detection functionality, with no firing current flow.

2) Fully electronic safing system [high functionality ECU (14 ch)]

By adopting electronic sensors, the intent is to improve collision discrimination performance due to the increase of impact detection analysis functionality in comparison with mechanical sensors, and to heighten functionality of the entire system by enabling omni directionality (forward/back, left/right) of impact detection. Further, with side collision airbag systems, the intent is to enable reductions in the number of sensors in comparison with mechanical sensors, which are only capable of detection in a single direction, thus reducing costs of the entire system. This is accomplished by installation of electronic sensors, capable of left/right side impact detection, in the airbag ECU, as shown in Fig. 7.

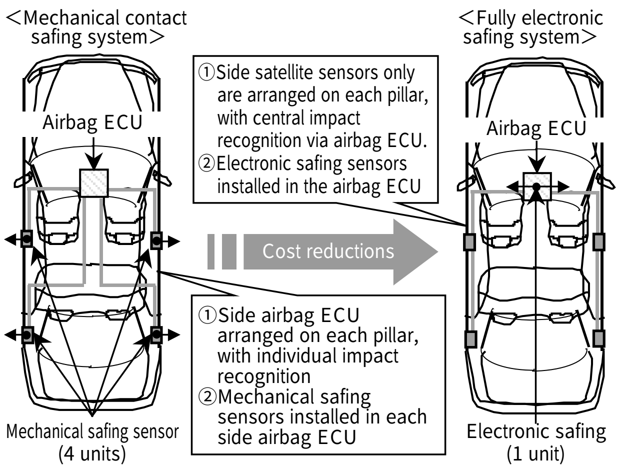


Fig.7 Side impact air bag system

The next section provides an explanation of measures involved in current development.

5 Technical development details

5.1 Airbag fail safe design concept

> **[Hard duplex system structure]**
> A redundant system structure is implemented between differing devices, eliminating the primary cause of incorrect operation (incorrect airbag deployment).

In order to prevent the primary cause of incorrect operation, breakage of the firing current has been designed by making the collision detectors, firing determination and firing drive completely independent circuits. To give an example, the design is such that the firing circuit will not operate if the safing sensor is not ON, even if the G sensor malfunctions and firing determination is output.

5.2 Trigger sensor safing system technology

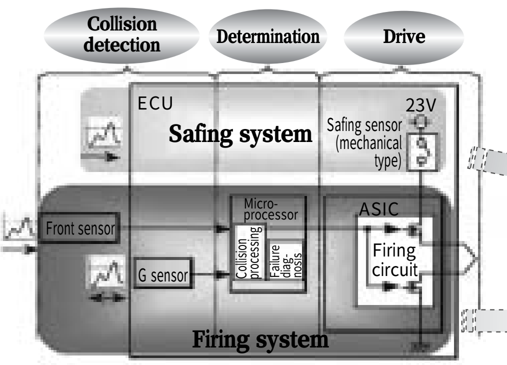
An explanation is now provided of safing technology which retains the design concept above while achieving size and cost reductions. In order to ensure equivalent failsafe performance to that of conventional models, a structure is adopted with hard duplexing preserved for each circuit stage as shown in Table 1.Further, by moving from a completely mechanical safing system to a combination of mechanical and electronic circuitry, measures are taken via filter circuitry to avoid sensitivity when electrical noise resistance becomes degraded.

An explanation of the technology of individual elements is given on the next page.

Table 1 Comparison with conventional safing system and 2004 trigger sensor safing system

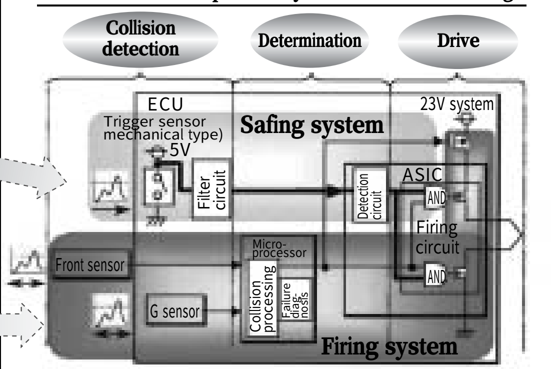
Hardware duplex system structure

Structure of conventional safing system



2004 Trigger sensor Safing system structure

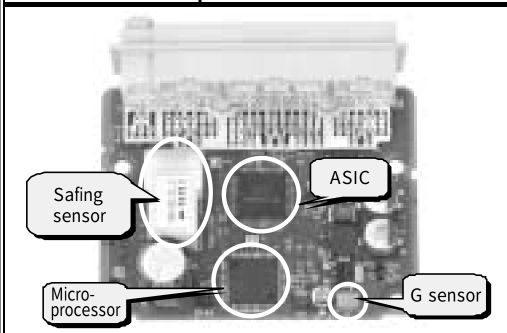
Formulated with independent systems at each circuit stage

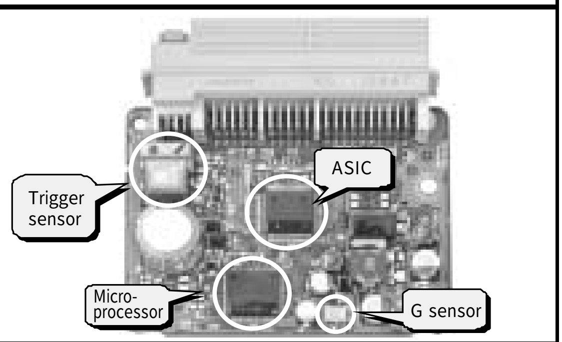


Failsafe design for primary causes factors

Required failsafe performance	Conventional Design	2004 Model design
①No incorrect operation due to primary malfunction	Incorrect operation does not occur unless there is an ON malfunction in both the firing determination systems of the mechanical safing sensors and electronic G sensor	○ It is structured as conventionally with a hardware duplex system. However, as the safing signal system and firing signal system are mixed in 1 chip on the ASIC, consideration is given to separation of logic parts in the ASIC layout design. Further, MOSFET is arranged upstream of the ASIC, providing an even more reliable structure for preventing incorrect operation.
②No incorrect operation due to microprocessor runaway	As the safing sensor is completely independent of the microprocessor system circuit, there is no incorrect operation, even with microprocessor failure or runaway.	○ The safing determination system is completely built-in to the ASIC, and is completely independent of the microprocessor system. There is no incorrect operation even with microprocessor runaway.
③No incorrect operation due to noise (Radio waves, static electricity, etc.)	There is no incorrect operation, because even if the electronic circuits operate incorrectly, there are mechanical safing sensors placed in series with the firing current circuit.	○ Electrical noise resistance of the safing sensors equivalent to that for the mechanical type. The ASIC determination circuit retains equivalent electrical noise resistance performance, with a filter + multiple time determinations.

ECU circuit board





5.2.1 Trigger sensor

In contrast to conventional mechanical contact sensors, enabling a squib firing current, by changing to a trigger sensor which only functions for impact detection, with no firing current flow, sensor size and cost reductions are achieved. These details are explained below.

1) Impact detection method

To begin, an explanation is given of the principle of impact detection methods for mechanical triggers. As shown in Fig. 8, when an impact is applied to the sensor, a weight affixed to the front edge by springs moves to the end edge. The principle involves contact between a contact affixed to the weight, and a terminal, as a result of the weight's movement. This contact switches the contact condition from OPEN to CLOSED, and detects the impact.

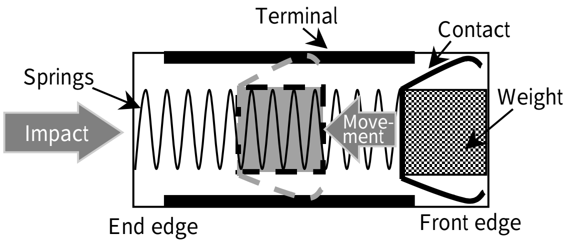


Fig.8 Principle of impact detection

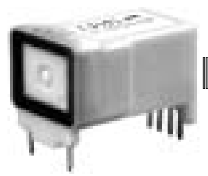
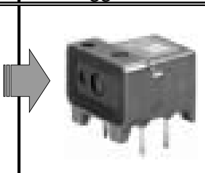
2) Merits of trigger sensors

In the case of mechanical contact sensors with firing current flow, the weight movement stroke is necessary, as the sensor's ON period must overlap with main determination for current to flow to the squib and the airbag to deploy. As a result, the total length of the sensor must be longer. In contrast, with trigger sensors, as the ON period is maintained by an external circuit, it is possible to reduce the total length of the sensor.

3) Features of trigger sensors

Points of change in structure from mechanical contact sensors are shown in Table 2.

Table 2 Points of structural change with trigger sensors

Items	Mechanical contact sensor	Trigger sensor
Appearance	 [27×17×20(mm)]	 [16.4×16.2×14(mm)]
Pass-through current	14A	10mA
Weight retention method	Sliding axes + peripheral retention	Peripheral retention
Weight materials	Metal + coating [4.9g]	Resin + metal powder [1.5g]
Contact affixing method	Press fit and crimp	Hot upset
Weight impact absorption rubber	With	Without
Contact pressure	118mN	49mN

The goals of the respective structural changes are shown below.

①Weight retention method: Size reductions are implemented in the width and height direction by deleting sliding axes.

②Weight materials: Parts unit costs are reduced by changing from metal weight to resin weight, achieving product cost reductions. (Metallic powder is used for weight adjustment)

③Contact affixing method: cost reductions are achieved through simplification of the production process, by changing from press fit and crimp to hot upset

④Weight impact absorption rubber: Cost reductions are achieved for the longitudinal direction, by deleting impact absorption rubber installed at the end edge.

⑤Contact pressure: By reducing contact pressure, weight sliding degradation is compensated by weight reductions in accordance with size reduction.

4) Technical issues accompanying structural changes

Primary technical issues accompanying structural changes are as shown below.

Issue 1: Weight sliding performance

During a vehicular collision, impact is applied to the sensor from three directions (forward/back, left/right, up/down). However, with peripheral retention only via deleting the sliding axis, weight sliding performance becomes a concern.

Issue 2: Contact bounce

①Contact bounce becomes a concern due to the increase in impact during the weight's end edge impact, by deleting weight impact absorption rubber.

②Contact bounce becomes a concern during the weight's end edge impact, and during contact between the contact and terminal, in accordance with contact pressure reductions.

5) Countermeasures for technical issues

Countermeasure 1: Adoption of sliding grade resin materials

Weight sliding performance is improved by using sliding grade materials for the weight resin materials and peripheral housing resin materials. Further, verification of effectiveness for sliding grade products has been implemented, via conformity inspection of simulation impact detection periods, and actual impact detection periods, via actual vehicle collision tests and lab bench inclined vibration tests. A sliding performance level equivalent to that of mechanical contact sensors has been obtained.

Countermeasure 2: Adoption of integrated circuits

As improvements to the sensor unit's contact bounce is difficult because of the achievement of size and cost reductions, measures have been adopted to eliminate the influence of contact bounce by using filter circuits outside the sensor. Further, results have been obtained showing no problems with the adoption of integrated circuits, based on verification in actual vehicle worst-case tests that there is no detection with impacts other than during a collision, from the influence of the filter circuits.

Through the abovementioned countermeasures, trigger sensors have been developed enabling the achievement of size and cost reductions.

5.2.2 Trigger sensor detection interface

1) Interface configuration

A configuration has been developed such that trigger sensor ON is detected via filter circuits and ON detection circuits built into the ASIC, with latching for a certain fixed period.

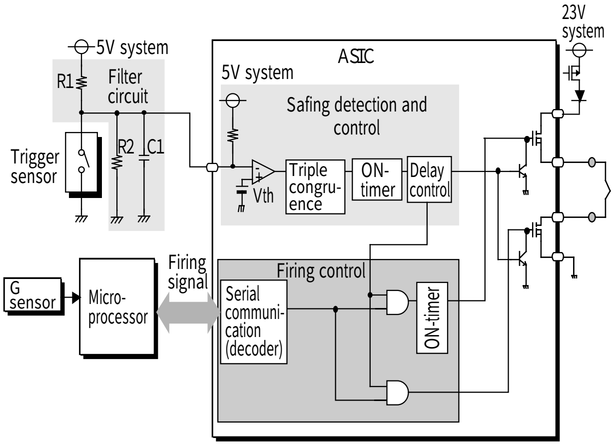


Fig.9 System diagram for the trigger sensor detection interface

2) Electrical noise resistant design of the ON detection circuit, and the latch function

As a design consideration to avoid incorrect operation due to electrical noise, the ASIC ON detection circuit has been designed with triple sampling, and no confirmation without continuous congruency determination.

Further, by enabling initial stage and 2nd stage delayed control, as with airbag multi-stage deployment control, it functions to latch the safing determination during a certain fixed period.

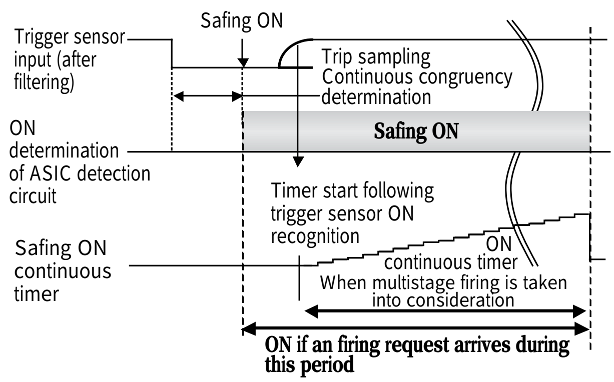


Fig.10 Control timing chart for ASIC detection circuit

3) ON bounce countermeasures via filter circuits

As indicated on the previous page, the trigger sensor has greater contact bounce than conventional sensors. As a result, when this phenomenon occurs it is possible that the triple sampling continuous congruency condition for the ASIC detection circuitry may not occur. To prevent this, values of components for filter circuits have been optimized to keep the system on when a bounce occurs. (ON requirement concept)

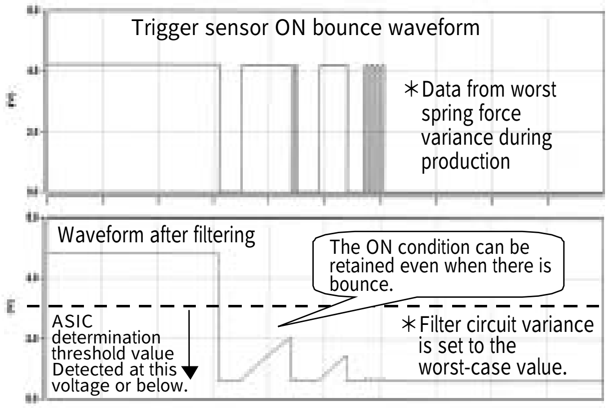


Fig.11 Simulation result for filter circuit to ON bounce signal

4) Electrical noise resistance countermeasures via filter circuits

Consideration must also be given to design conditions to avoid late ON occurrence, as well as incorrect operation due to electrical noise.

In terms of OFF requirements, electrical noise levels entering the ECU are quantitatively measured, and filter circuit constants are set such that even when this electrical noise enters, an ON determination is not made. Electrical noise countermeasures are thereby implemented in conjunction with the continuous congruency condition of the triple sampling. (OFF requirement concept)

As shown above, it is designed so that both ON and OFF requirements are satisfied.

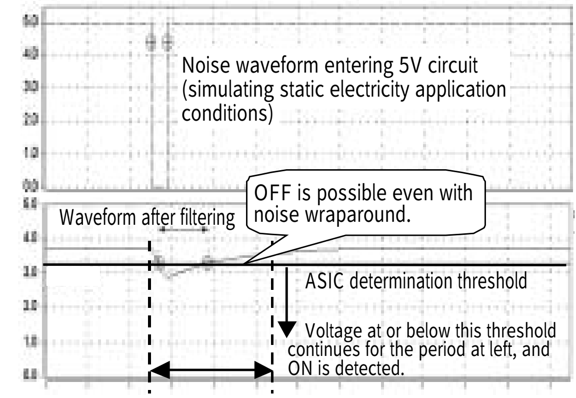


Fig.12 Simulation result for filter circuit to electric noise signal

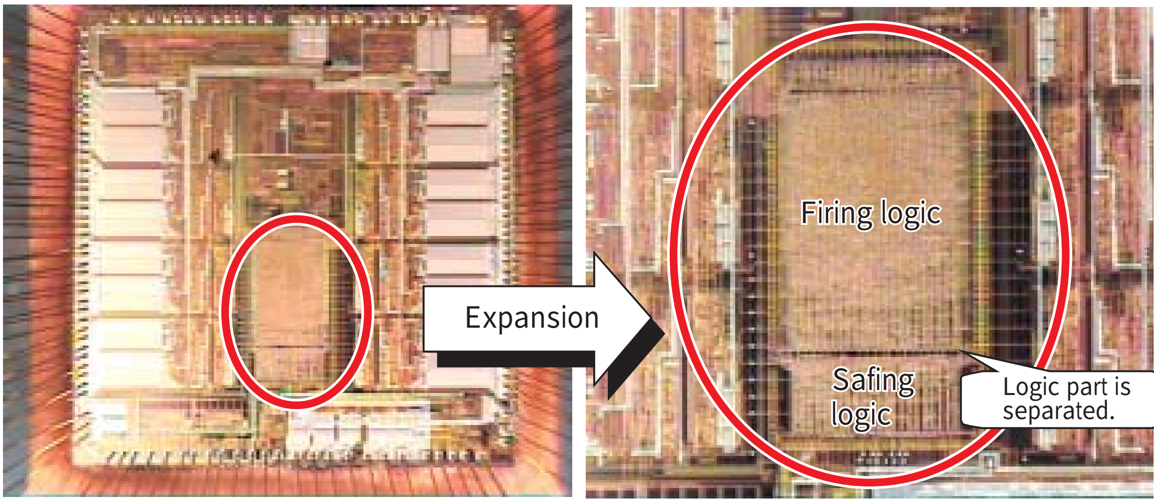


Fig.13 Individual logic circuit layout in the ASIC

5.2.3 Other failsafe designs

1) Design concept for ASIC chip layout

The firing circuit and safing circuit are completely separated up to detection and determination. However, at the drive point, they are integrated into a single chip. Thus the chip layout is designed with the firing system logic part and the saving logic part separated.

Normally, in CMOS logic layout design, circuits are groups in the same region with automatic layout wiring, achieving a design with best surface area efficiency. However, with this design, there are many places where the safing system lines and firing system lines intersect, and there is thus the possibility that a single adherence by foreign matter could set both safing and firing to ON. To improve the failsafe performance, layout is designed to preserve a separation of the 2 parts even though surface area is increased somewhat.

2) Firing upstream MOSFET arrangement

Consideration is given in layout design to an ASIC internal malfunction. However, as there is a single chip, it is not possible to carry out separation with completely difference devices. Thus a MOSFET is arranged upstream of the ASIC firing circuit, in order to ensure an even more redundant structure.

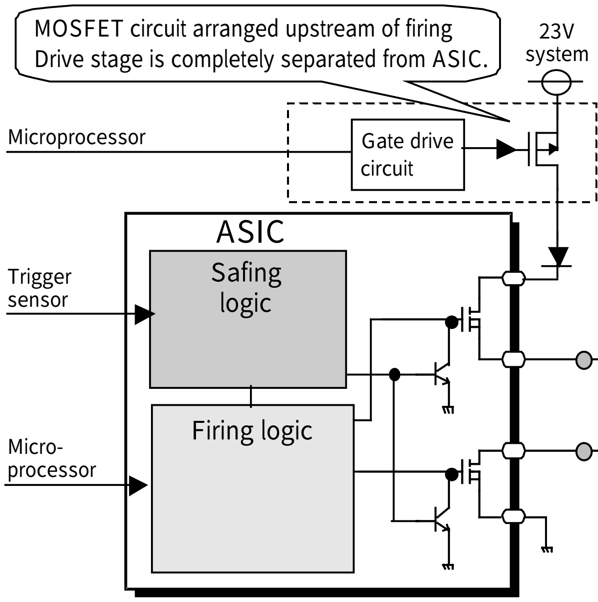


Fig.14 Location of the upstream MOSFET to fire squib

5.3 Fully electronic safing system technology

5.3.1 CPU system concept

1) System structure

For high functionality response, is it necessary to enable forward/rear and left/right detection. To enable this, a structure is adopted utilizing electronic 2-axis G sensors. A dual CPU structure has been adopted, setting the processing of the determination of G sensor analogue output, and the diagnosis functions as a separate sub microprocessor from the microprocessor performing firing determination. (Table 3)

2) Microprocessor issues and the necessity of dual CPUs

In systematically structuring a redundant system, with respect to the microprocessor concept, multistaging was implemented for processes up to watchdog monitoring and the issuance of firing request commands. Consideration is thus given so that firing mode will not easily occur due to microprocessor overdrive.

However, at the current technological level, verification cannot be predictably made that operation mode will reliably not occur with microprocessor runaway from a primary cause when firing and safing determination is implemented via a single microprocessor. Accordingly, a dual-microprocessor structure was deemed necessary, in order to maintain the high level of quality of the conventional ECU .

3) Failsafe design with dual CPU structure

The following failsafe design has been implemented in order to preserve the design concept explained in 4.1.

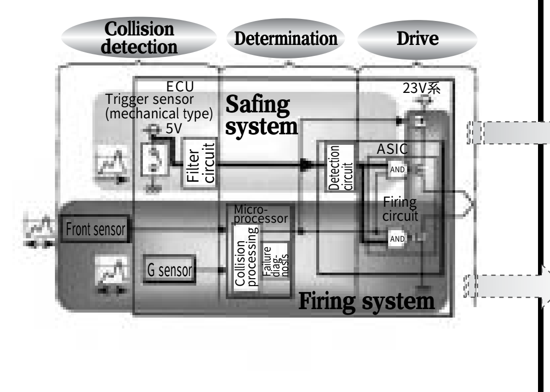
①It should be structured such that the microprocessor cannot participate in the sub microprocessor determination.

Communication is implemented for communication of failure diagnosis results only between the sub microprocessors and the main microprocessor. However, there is no independence if settings are made such that there is an influence on sub microprocessor determination pro-

Table 3 Comparison with 2004 trigger sensor safing system and fully electronic safing system

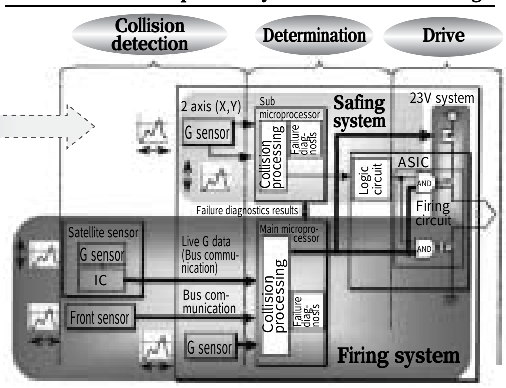
Hardware duplex system structure

2004 Trigger sensor Safing system structure



2004 Fully electronic Safing system structure

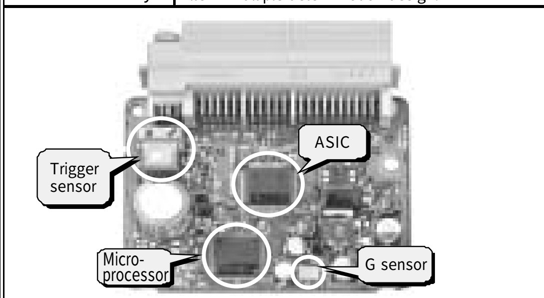
Formulated with independent systems at each circuit stage

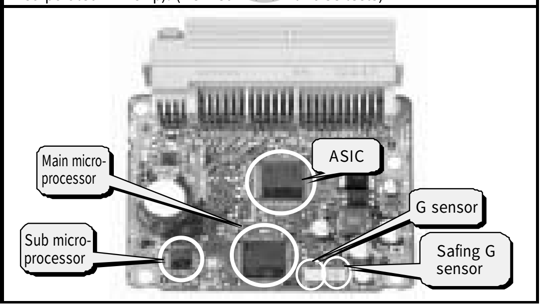


Failsafe design for primary causes factors

Required failsafe performance	2004 Trigger sensor safing system	2004 Fully electronic safing design
①No incorrect operation due to primary malfunction	It is structured as conventionally with a hardware duplex system. However, as the safing signal system and firing signal system are mixed in 1 chip on the ASIC, consideration is given to separation of logic parts in the ASIC layout design. Further, MOSFET is arranged upstream of the ASIC.	It is structured as conventionally with a hardware duplex system. There is separation with firing determination - main microprocessor, and safing determination - sub microprocessor by implementing a dual CPU structure. In addition, the structure is identical to that at left for ASIC and upstream MOSFET.
②No incorrect operation due to microprocessor runaway	The safing determination system is completely built-in to the ASIC, and is completely independent of the microprocessor system. There is no incorrect operation with microprocessor runaway.	The safing determination system is structure with a sub microprocessor, and is completely independent of the main microprocessor for the firing determination system. There is no incorrect operation with primary causes microprocessor runaway.
③No incorrect operation due to electrical noise (radio wave and static electricity	As conventionally, the safing sensor electrical noise resistance is equivalent to that for the mechanical type. The ASIC determination circuit retains equivalent electrical noise resistance performance, with a filter + multiple determination design.	The safing G sensor and firing determination G sensor are both electronic. However, replacement of mechanical type units has become possible due to dramatic improvements in electrical noise resistance performance, with improvements in the G sensor (reduction in gain via electrostatic capacity method, and sensor element + processing circuit incorporated in 1 chip). (Verified with limit noise tests)

ECU circuit board





cessing via this communication control. Thus the design is not such that sub microprocessor determination can be operated from the main microprocessor.

Further, in order to verify that even in failure mode, this type of influence cannot occur, FTA and FMEA is thoroughly implemented, completely eliminating any influence on determination processing.

②Failures occurring with sub microprocessors should all be capable of self diagnosis via the sub microprocessor.

If the main microprocessor is relied on for diagnosis of failures in the sub microprocessor system, and one envisions a state in which sub microprocessor failure cannot be detected due to main microprocessor runaway, there is the possibility of incorrect operation due to main microprocessor primary cause runaway, with the safing ON malfunction left undetected. To avoid this, sub microprocessor failure diagnosis must be fully implemented by the unit itself. A failsafe design has thus been implemented such that when the sub microprocessor malfunctions, it detects the fault itself, and can make a determination to stop itself.

5.3.2 Structure of the sub microprocessor

1) System structure

In terms of the structure of the sub microprocessor system, there are safing 2 axis G sensors (X axis and Y axis) which function as the input system. In the sub microprocessor, G sensor output is converted through A/D, 0G correction processing is performed and threshold comparison is made with the data after filtering processing, thus implementing safing determination. (Fig. 15)

Output when there has been a safing determination carries information specifying which channels should have safing ON, and this is transmitted to the ASIC as the ON command.

The ASIC receives this signal and the ASIC internal safing logic is turned ON.

Between the sub microprocessor and the main microprocessor, the main microprocessor is notified of the sub microprocessor diagnostic results. The watchdog clock is transmitted to the main computer, and this is monitored, thus implementing sub microprocessor runaway detection.

2) Safing ON control methods

In the same way as with the trigger sensor system, consideration has been given so as to be capable of latch control response, with attention to airbag multistage deployment.

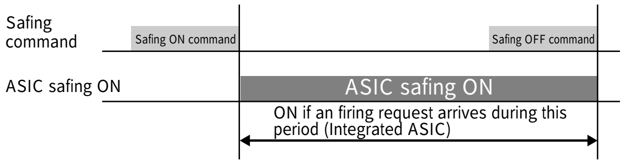


Fig.16 Control timing chart for fully electronic safing system

5.3.3 System extension performance

For safing communication as well as with the firing communication, flexibility is increased via serial communication in channel specification, enabling specification up to a maximum of 20 channels. The design makes increases possible, extending ASIC up to 2 units by connecting seri-

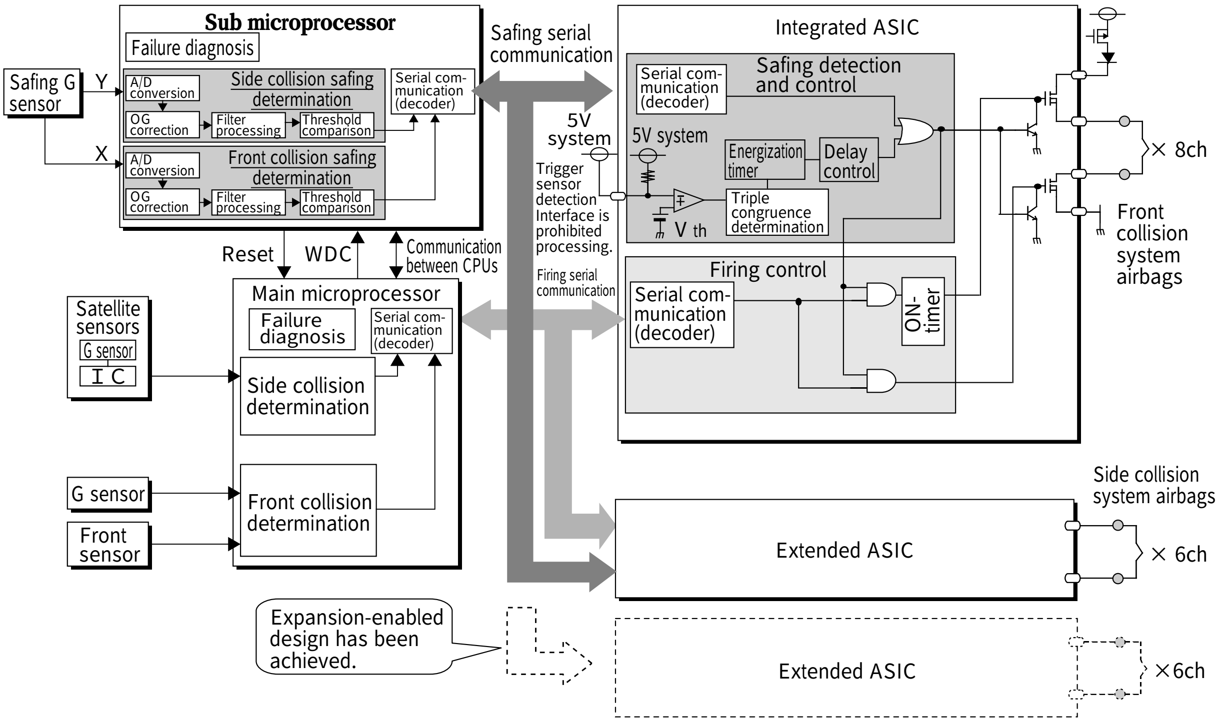


Fig.15 Dual CPU system diagram

al lines in parallel. In the 2004 model ECU design, up to 14 channel airbag control can be implemented because of the extension ASIC 1-unit structure. However, if necessary, it is possible to respond comparatively easily to channel increases.

6 Future safing system development

In terms of the future development process, as shown in Fig. 17, the safing structure for high-functionality systems will become high functionality compatible by adopting the highly flexible, fully electronic safing system currently developed as the basic platform. In future, once safing determinations are fixed as algorithms, even if flexibility is reduced, logic will be streamlined, and will be built in to ASIC, thus reducing costs. It is anticipated that this will become standard deployment.

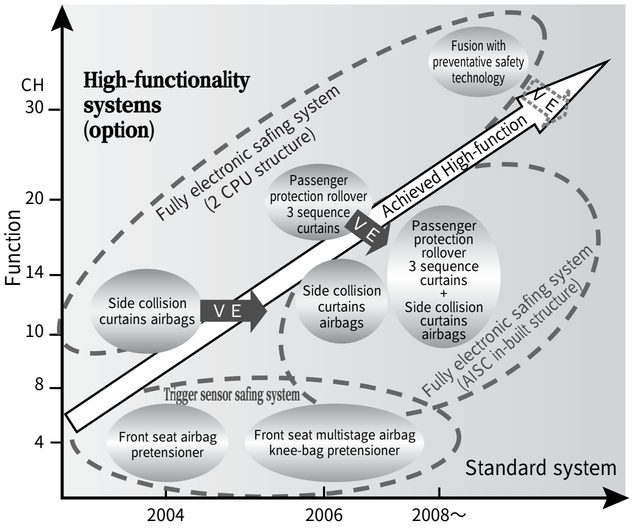


Fig.17 Trends in safety systems and electronic safing systems

7 Conclusion

With the current development, it has been possible not only to effect cost reductions, but to develop a system with consideration to subsequent high-functional response, while maintaining reliability.

In future, we will aim for even greater improvements in safety systems, pursuing development of systems integrating pedestrian protection and preventive safety technologies.

Finally, in development of this paper, I would like to express my heartfelt thanks to everyone involved for their cooperation and guidance.

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