Development of Airbag System for Kei Cars

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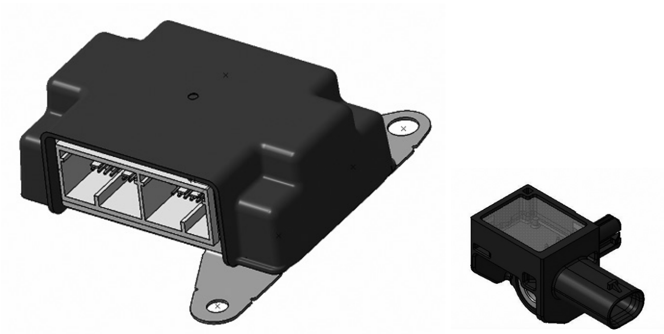


Abstract

Recently, kei cars have drawn attention in the car market in Japan due to economic efficiency. Thus, the safety technology against collisions and protection equipment for occupants in those cars are increasingly improved. FUJITSU TEN has developed and mass-produced airbag ECUs for ordinary-sized vehicles for more than 20 years. In order to meet the needs of a wider range of customers, this time, we developed a new platform for kei cars.

When making proposals to new customers, we need to propose an airbag system for an entire car, instead of ECUs as its part. Therefore, we had to develop a comprehensive technology including an impact determination technology and satellite sensors for the entire car.

This paper elaborates on some major points of our engineering development for kei cars.

1 Introduction

Recently, as the safety technology for collision prevention has improved and an increasing number of people are accustomed to wearing seat-belt, almost all recent vehicles are equipped with airbags and seat-belt pretensioner as standard equipment. Partly because of their effects, traffic accident fatalities have been decreasing since 1992 year after year, according to a survey by Ministry of Land, Infrastructure, Transport and Tourism (**Fig. 1**).

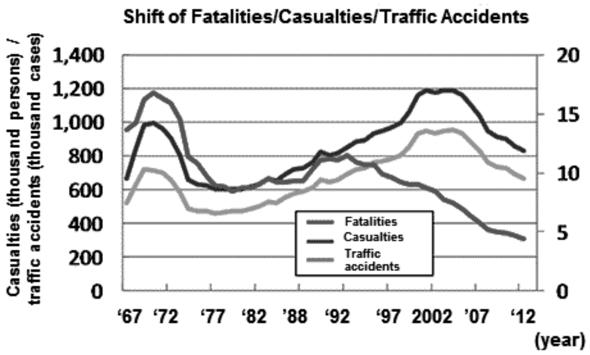


Fig.1 Traffic Accident Fatalities/Casualty (Japan)*(1)

Moreover, other countries (in Europe and the Unites States) have introduced stricter safety standards year by year to protect pedestrians and to prevent side collisions so that safety functions are sophisticated further by use of technologies to detect pedestrians and possible side collisions.

When taking a look at the car market in Japan, an increase of kei car sales is noteworthy. In addition to the advantages in fuel efficiency and economic efficiency, the so-called "smart stop" function and others are installed to kei cars. Thus, their values have been enhanced as a car. The airbags for driver's seat and the passenger's seat are standard equipment and now a percentage of installation of side airbags is growing.

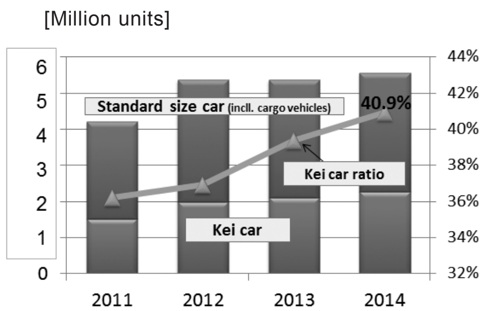


Fig.2 Units and Ratio*(2) of Kei Car Sales

2 Outline of Airbag System

An airbag ECU controls the driver airbag, passenger airbag, seat-belt pretensioner, side airbags and side curtain airbags. As shown in the configuration in **Fig. 3**, impacts from the front and the sides of the vehicle are detected by the airbag ECU equipped in the center of the vehicle as well as by the front and the side satellite sensors on the front and sides of the vehicle. The impacts are calculated by microprocessors in the airbag ECU and if a calculated value exceeds an impact threshold value that is set for each vehicle, the ECU triggers an ignition circuit. Thus, an electric current flows into an igniter to generate propellant to rapidly inflate the airbags.

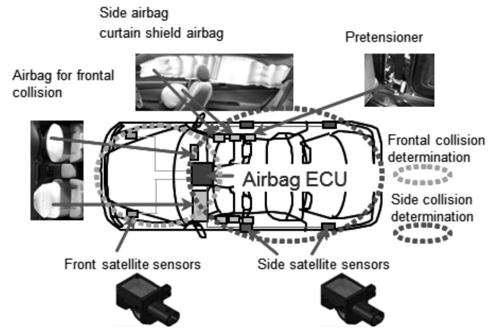


Fig.3 Example of Airbag System Configuration

3 History of Airbag ECU Development in FUJITSU TEN

FUJITSU TEN began delivery of airbag EUCs (only for 1 channel for the driver airbag) to Toyota Motor Corporation from 1993 when the demand of airbags was still low and they were still expensive. Now, more than 3 million ECUs are manufactured every year in our five plants in Japan, Europe, the North America, China and the ASEAN region.

We have developed to increase channels of the airbags in response to the safety standard (laws and regulations) against impact in countries. In order to meet the needs of a broader base of customers, we developed a new airbag system for kei cars. In addition to a new airbag ECU, review of feasibility of airbag installation in kei cars and satellite sensors were included in this development because we were requested by a new customer to make a proposal of the entire airbag system.

Chapter 4 and the subsequent chapters elaborate on the technology that we worked on for kei cars.

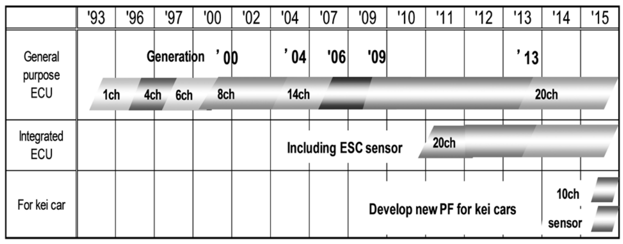


Fig.4 History of Airbag Development of FUJITSU TEN

∗(1) "1. Koutsu-jiko no Genjyou" [homepage on the Internet]. Japan: Ministry of Land, Infrastructure, Transport and Tourism. [cited December 17, 2015]. Available from: http://www.mlit.go.jp/road/road/traffic/sesaku/genjyo.html

∗(2) Data from "Kei-Yonrinsha Hanbai Daisu no Nenbetsu/Shashubetsu Suii" [homepage on the Internet]. Japan: JAPAN LIGHT MOTOR VEHICLE AND MOTORCYCLE ASSOCIATION. [cited December 17, 2015]. Available from: https://www.zenkeijikyo.or.jp/statistics/index.html and from "Shinsha-Nenbetsu Hanbai Daisu" [homepage on the Internet]. Japan: JAPAN AUTOMOBILE DEALERS ASSOCIATION. [cited December 17, 2015]. Available from: http://www.jada.or.jp/contents/data/type/type00.html

4 Purpose and Target Setting of Development

Since the airbag system to be developed was for kei cars smaller than standard size cars in size (**Fig. 5**), we set the points (1) and (2) below as the development targets.

(1) Establishment of impact determination technology

For kei cars in which occupants are seated closer to the front edge as compared to standard size cars, airbags must deploy in a shorter time from an impact. Therefore, kei cars should be equipped with sensors that can detect the impact earlier. Thus, we had to establish an algorithm for earlier determination of impacts.

Target: shorter impact determination time -25%

(2) Development of a compact and lightweight device

Since fuel efficiency is an important factor for kei cars so that we set targets of size and weight as below to contribute to reduction in weight of vehicle and a wider choice of locations to install the ECU and the sensors.

Weight: ECU -50% / Satellite sensor -30%
Size: ECU -30% / Satellite sensor -40%
*Targets as compared to devices for standard size cars.

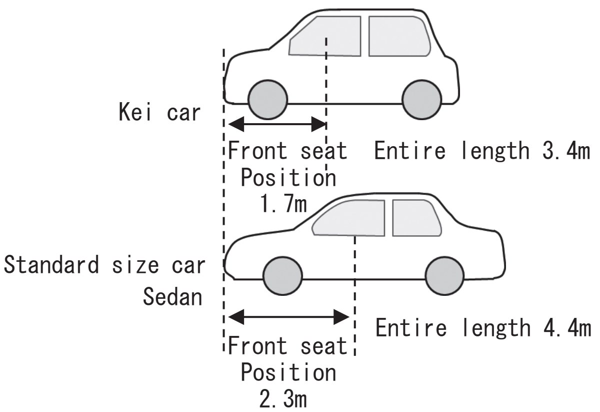


Fig.5 Difference between Kei Car and ordinary-sized vehicles

5 Details of Technology Development

5.1 Establishment of Impact Determination Technology

(1) Necessity of early detection for kei cars

Airbags in kei cars need to be deployed earlier as compared to standard size cars, due to their body structure.

The structure will be explained below, taking frontal impact as an example. As compared to the standard size car, the kei car has a shorter crushable zone that reduces impact at the time of a collision. Therefore, its front side member and other frames that prevent deformation of its cabin are generally harder. Thus, since deceleration in the cabin at the time of the collision is greater as compared to the standard size car, the driver is moved fast toward the steering wheel due to inertia (**Fig. 6**).

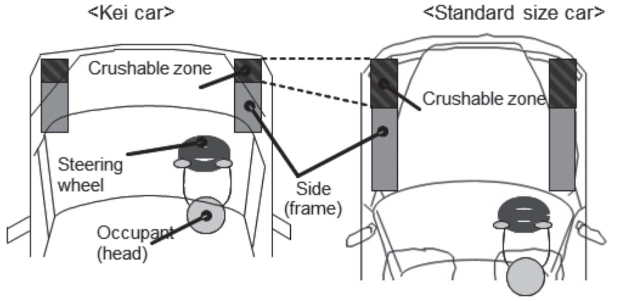


Fig.6 Structure Comparison between Kei Car and ordinary-sized vehicles against Frontal impact

(2) Review of optimal installation positions for sensors against frontal impact

We studied optimal positions for satellite sensors and the airbag ECU to be installed to a kei car for effective detection of an impact at the time of collision, as a first approach to shorten a time to determine a collision.

In order to detect a frontal impact, it is advantageous that the front satellite sensors are mounted on the radiator support that will be near the impact from a colliding object and that the airbag ECU including a sensor is mounted in a center floor tunnel that excellently transmits the impact. We studied their optimal installation positions in a kei car and reached the conclusion that their optimal positions were similar to those in a standard size car. Thus, we determined that we could shorten little detection time through optimization of the positions of the sensors and the ECU.

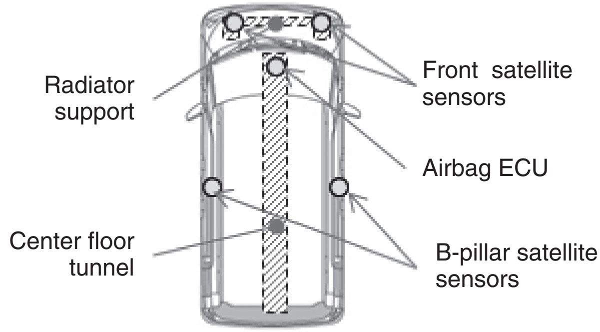


Fig.7 Installation Diagram of Airbag ECU and Satellite Sensors

(3) Algorithm to determine frontal impact

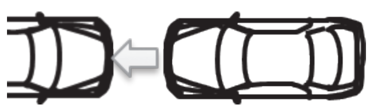


Fig.8 Figure of Frontal impact

Since it was difficult to realize earlier detection of an impact by optimizing the installation positions of the airbag ECU and the front satellite sensors, as described above, efficient computing and determination of detected impact waveform are key to the earlier collision detection.

Therefore, we developed a collision determination algorithm that can capture features of kei cars.

In the case of a frontal collision, a vehicle receives an impact on the left and right front side frames so that greater acceleration is generated in the cabin of the kei car than in the cabin of the standard size car.

We analyzed frequency components of the waveform of the impact force to find that the waveform includes high frequencies of 50Hz or higher more than the standard size car does (**Fig. 9**), partly because the frames of the kei car are harder than the ones of the standard size car.

Large and sharp rise occurs in the waveform by computing the detected impact force so as to extract high frequency components, and thus early detection can be materialized. Hence, we designed an airbag ECU with high cut-off frequency set to a low-pass filter for computing the acceleration.

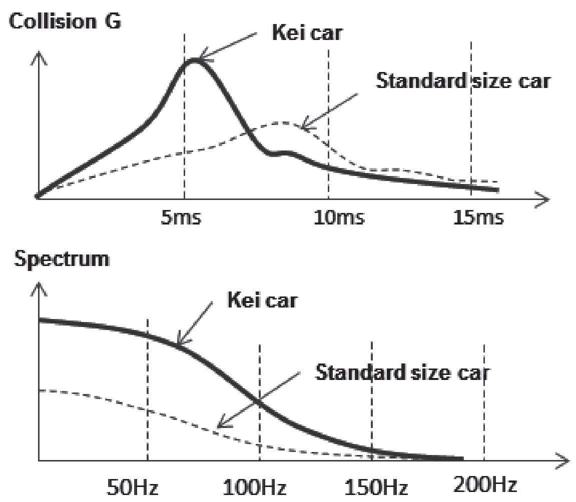


Fig.9 Comparison of Frequency Components at Frontal Impact (Time until Ignition is Determined)

(4) Algorithm to determine overlap frontal impact

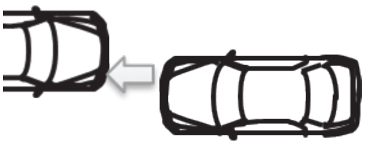


Fig.10 Figure of Overlap Frontal Impact

In the case of overlap frontal impact, being different from the frontal impact in (3), only one side frame of a vehicle receives an impact so that its front portion is easily deformed and small acceleration is generated in the cabin.

The conventional technology determines an overlap frontal impact by lowering the threshold of the airbag ECU for deploying the airbag when the front satellite sensor detects large impact acceleration. However, since the airbag in the kei car needs to be deployed earlier, the threshold should be set to an extremely low value. Therefore, we needed to develop a new reliable logic that can ensure impact determination performance.

We focused on sharp rise of waveform unique to the overlap frontal impact. It is characterized by a large change in acceleration in the early stage of the collision (**Fig. 10**). We designed the algorithm to detect a degree of the change rate by calculation using differential logic.

Differential logic = Integral value B – Integral value A

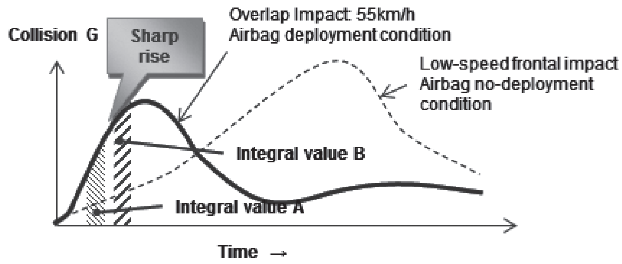


Fig.11 Overlap Frontal impact Waveform Generated Based on Differential Algorithm

We achieved a 30% reduction in time required to determine an impact by optimizing the installation positions of the sensors and ECU described in (2) and by using algorithms to determine the impact explained in (3) and (4).

(5) Review of optimal installation positions of sensors against side impact

As for a side impact, we realized earlier detection by changing installation positions of the B-pillar satellite sensors (**Fig. 12**) from the inner reinforcement to the outer reinforcement in order to place those sensors closer to the impact.

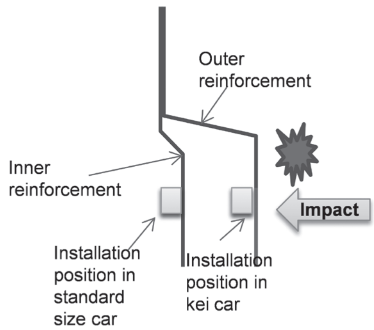


Fig.12 Installation Position of B-Pillar Satellite Sensor

5.2 Establishment of Compact and Light-weight Device Technology

We carried out the following technology development for the satellite sensors and the air-bag ECU to widen the choice of installation locations in the kei car and to reduce the overall weight of the car.

[Satellite sensor]
(1) Performance of impact transmission via one connected point
(2) Waterproof performance

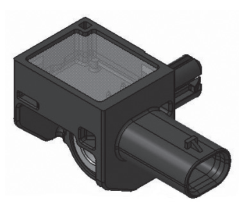


Fig.13 Appearance of Satellite Sensor

[Airbag ECU]

(1) Plastic case and performance of impact transmission

(2) Switched-mode power supply for higher frequency and noise control performance

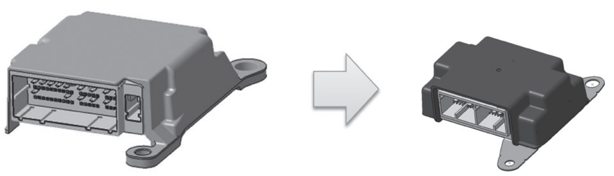


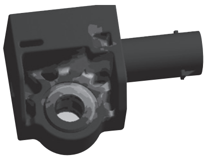
Fig.14 Case Shape Comparison

[Satellite sensor]

(1) Performance of impact transmission via one connected point

The case of the airbag sensor is not only for fixing the sensor to the vehicle but is also an important functional part that transmits an impact to the built-in G-sensor at a time of a collision (hereinafter performance of impact transmission). Our challenge was to ensure the performance of impact transmission via only one screw fixing the case to the vehicle at one point.

Since the case is cantilevered by one point fixation, we discussed its structure, checking resonation of the structure by simulation. Especially for a side impact that requires an earlier response, due to fast ignition request, as compared to the G-sensor in the ECU, we set 400 Hz or more as the requirement of resonation of the structure.



CAE	Actual device
1225 Hz	1390 Hz

Fig.15 Analyzed Model and Results

Moreover, brokerage of the portion fixed to the vehicle is fatal so that strength of the portion was ensured by molding a metal collar (external diameter of ϕ12 mm and length of 10 mm) inserted into the case. We selected a G-sensor that can endure a maximum impact of 200 G as the built-in G-sensor because it is located closer to the impact than the ECU.

(2) Waterproof performance

The satellite sensors need to be waterproof because they may be installed in the engine compartment. Considering situations in which the vehicle is placed, "high-pressure washing," "being watered," and "chemical resistance (battery liquid, etc.)" are added to the test conditions.

Some among the waterproof structures are "sealing by potting material" and "welding the case with the lid." We selected the waterproof structure sealed by a potting material, from the viewpoints of performance (that satisfies the test conditions) and cost.

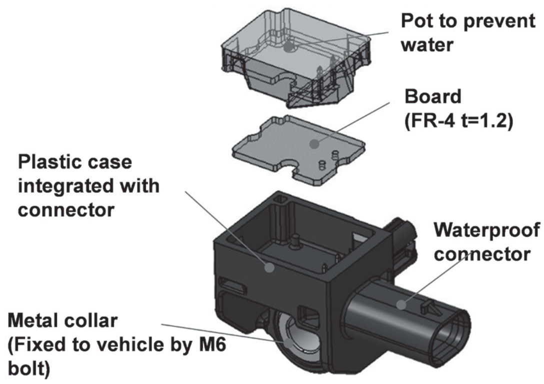


Fig.16 Satellite Sensor Configuration

Details of the developed satellite sensors are shown below (**Table 1**). As shown in the table, targets described in (1) and (2) are achieved.

Table 1 Satellite Sensor Design Spec

		Necessary spec.	Actual design
Resonance of structure		400Hz or greater	1390Hz
Breakage strength of portion fixed to vehicle		250N or greater	1500N or grater
G-sensor IC	Output G-range	200G or more	240G
	Resolution	0.5G or less	0.5G
	Filter	300Hz to 500Hz	400Hz
Waterproof performance		Watering test (IPX5) High-pressure washing test	Passed the tests
Chemical resistance		JASO D14-2 (diluted sulfuric acid, etc.)	Passed the test

[Airbag ECU]

(1) Plastice case and performance of impact transmission

In order to ensure the performance of impact transmission, we conventionally adopted an aluminum die-casting case. We studied adoption of a plastic case for weight reduction (by 30%) of the airbag system and established necessary technologies in this development. The points below are keys to the technology development for both of the weight reduction and the performance of impact transmission.

①To ensure 200 Hz or greater resonance of the case by using metal members for the structure to impact transmission to surely transmit frequency components of 100Hz or less necessary to determine an impact

②To select a sensor that can response to high frequencies of 200 Hz or greater, as the built-in G- sensor

③To attenuate resonance of the case by digital filter in the microcomputer to remove an influence on impact determination

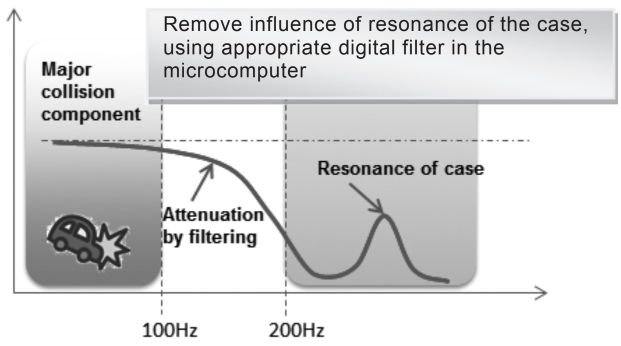


Fig.17 Relationship among Impact, Case Resonance and Filter

The developed case includes a plastic upper case. We designed the case such that the impact is transmitted from the portion fixed to the vehicle to the bracket and then to the G-sensor via the PWB, bypassing the plastic case (**Fig. 18**). This structure has no influence of plastic deterioration on the impact transmission.

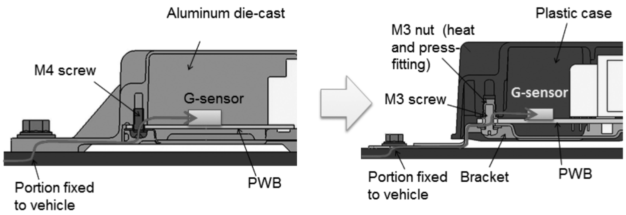
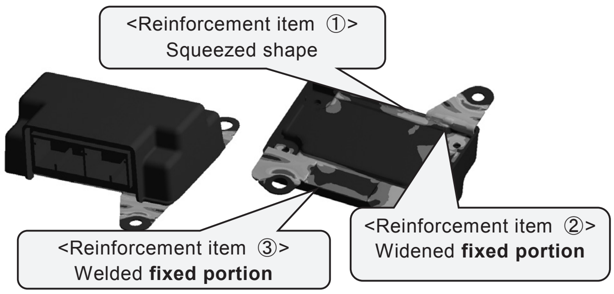


Fig.18 Impact Transmission in Resin Structure

The thickness of the brackt is 0.8 mm to reduce the weight. We ran simulation to make sure to satisfy the resonance of 200 Hz or greater by adding the reiforcement items ①, ② and ③ (**Fig. 19**).



CAE	Actual device
279.6 Hz	280.2 Hz

Fig.19 Resonance Results of Resin Structure

Due to the efforts mentioned above, the performance of impact transmission can be ensured, even using the plastic case.

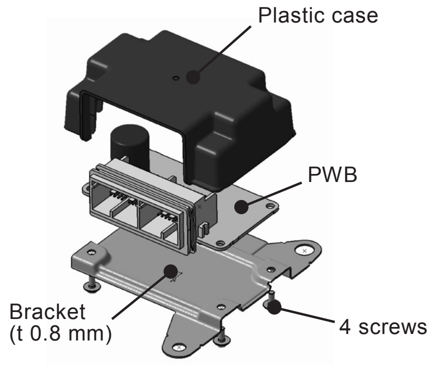


Fig.20 Shape of Completed ECU Case for Kei Cars

(2) Switched-mode power supply for higher frequency and noise control performance

The power supply circuit accounts for a large portion of the PWB surface on which devices are mounted. Therefore, focusing on the power supply circuit, we reduced the size of the airbag ECU. **Fig. 21** illustrates a typical power supply configuration. We adopted the high-frequency switched mode for all of the power supply circuits ① to ④ below to reduce sizes of the peripheral circuit components. The switching frequency increased twentyfold so that the inductance values and capacities were reduced to one-twentieth, which lead to reduction in sizes of the components.

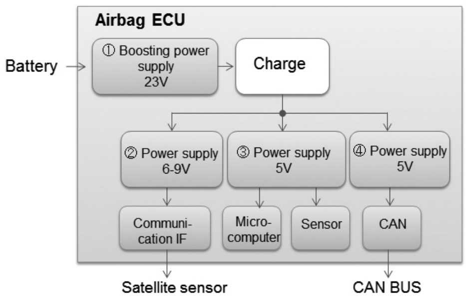


Fig.21 Typical Power Supply Configuration of Airbag ECU

Table 2 Approach to Downsized Power Supply

	Conventional	Developed device
①Boosting	Switched mode 23V, 100kHz	Same voltage Same mode 2MHz diffusion
②Power supply	Switched mode 7V, 100kHz	Switched mode 7V, 2MHz diffusion
③Power supply	linear mode Output 5V	Switched mode 5V, 2MHz diffusion
④Power supply	linear mode Output 5V	Integration of ③ and ④

On the other hand, as a result, noise emission increased to the outside of the ECU. Therefore, there was a concern of noise interference to vehicle-mounted devices, such as car radio. In order to reduce an influence on the car radio, we selected 2MHz as the switching frequency, excluding the bandwidth for AM radio (0.53MHz to 1.61MHz) and the bandwidth for FM radio (76MHz to

108MHz). Further, we included a frequency diffusion function in the power supply controller for noise reduction to control peak noise. As for the noise emission, results of evaluation with actual device satisfied the targets as shown in **Fig. 22**.

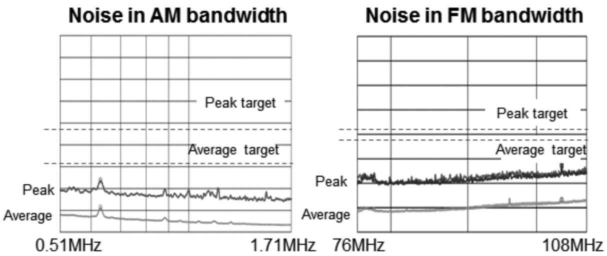


Fig.22 Noise Emission Level

Final results are shown in **Fig. 23**. We achieved a 69% reduction in size of the power supply circuit.

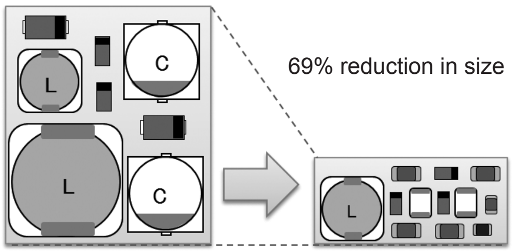


Fig.23 Downsizing by Smaller-sized Power Supply ECU

6 Results of Development

Actual results obtained by this development are shown in **Table 3**. The set targets are all achieved. We believe that we have developed the entire airbag system that we had to realize through this development.

Table 3 Results to Development Targets

		Target	Actual result (from 2010)
Time required to determine impact		-25%	-30%
ECU	Weight	-50%	-60% 122g
	Size	-30%	-45% L94×W84×H31.9
Sensor	Weight	-30%	-32% 18g
	Size	-40%	-49% 25×W28×H20.2 (excluding connectors)

7 Future Technology Development

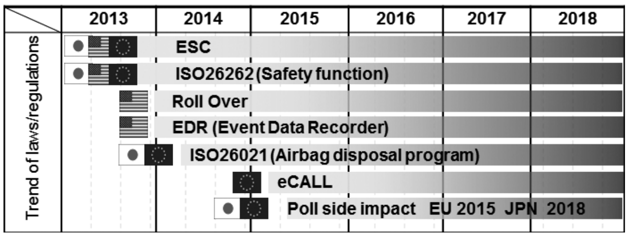


Fig.24 Trends of Laws and Regulations of Countries

We will make an effort to provide systems with more sophisticated functions, such as better impact detection, rollover function and ESC function, through our future technology development, in response to growing market needs for safety and trends of laws and regulations.

8 Conclusion

This development gave us an opportunity to contribute to a safer function at the time of collision and to reduction in traffic accident fatalities through our proposal to the kei car market that is a new market for us.

Here again, we would like to extend sincere appreciation to both internal and external people who provided warm cooperation to us for this development.

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