Development of Low-Cost Standard Air Bag ECU

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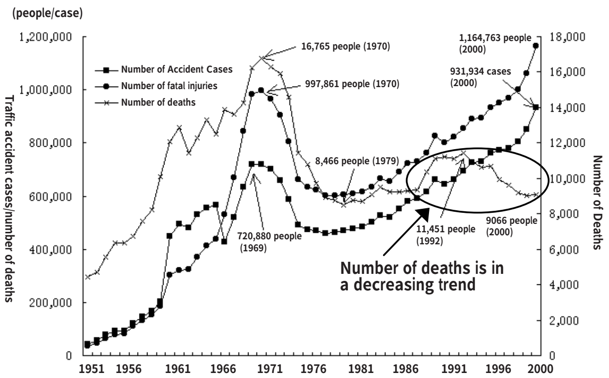
Abstract

Due to the rise in consciousness concerning automobile safety in recent years, almost all vehicles in Japan are now equipped with a system for controlling a 4-item set of occupant protection devices, consisting of Air Bags and seat belt pre-tensioners for both the driver seat and passenger seat ("4 channel system" below). And such systems are now expanding into the Chinese and other Asian markets. Fujitsu Ten is engaged in developing not only an advanced Air Bag ECU, but also a low-cost high-quality 4-channel Air Bag ECU to meet needs of the expanding market in the future. In order to win over the competition in such markets, we have set up collaborations with automobile manufacturers to enhance our development capabilities and design efficiency, and have started activities to develop "an Air Bag ECU with a world wide competitive edge". This paper presents the first results of such activities; the low-cost standard Air Bag ECU that was put into mass production in 2000.

1 Introduction

Heightened consciousness concerning automobile safety in recent years has led to improved collision safety technology for automobiles, to wearing of seatbelts becoming an established practice, and to almost all vehicles in Japan now being equipped with Air Bags and seat belt pre-tensioners*1 for both the driver seat and passenger seat. As a result the number of road accident deaths is on a decreasing trend, even though the number of accident casualties has risen due to the increase in automobile utilization itself (Figure 1).

Air Bag systems are being expanded to provide protection for side collisions and for passengers' heads, though currently this is limited to certain vehicle types only; in the USA deliberations are proceeding for enactment of legislation and regulations concerning advanced Air Bags whose activation will have less effects on the passengers. Air Bags are set to become more sophisticated in the future and demand for Air Bag systems is on an increasing trend in China and other Asian countries as their markets expand.



Note: 1. Data from Police department materials.
2. Cases after 1966 does not include accidents with inanimate objects.
3. Cases up to 1971 does not include Okinawa.

Fig.1 Trends of casualties in traffic accidents

Our company began supplying Air Bag ECUs to Toyota Motors in 1993, when Air Bag systems were a high-price optional item in low demand. Currently we are engaged in developing sophisticated Air Bag ECUs, focussing on development of a low-cost high-quality 4-channel Air Bag ECU to meet the needs of a market that is set to expand in the future. In order to win out in the competition in such a market we have entered into cooperation with automobile manufacturers to enhance our development capability and design efficiency, launching development activities for "an Air Bag ECU that can compete on a world scale". This paper presents the "first fruit" of such activities, the low-cost standard Air Bag ECU that was put into mass production in 2000.

2 Overview of Air Bag system

The newly-developed ECU is for control of the Driver and Passenger Seat Air Bags and pre-tensioners. As can be seen from the configuration shown in Figure 2, impacts are sensed from the front via the Air Bag ECU, which is deployed in a central forward location within the vehicle interior, and a front sensor located at the front end of the vehicle. Computation of such sensing is performed by a microcomputer within the Air Bag ECU; if the impact exceeds an impact criterion level set for the particular vehicle, the firing circuits are turned on to make current flow to the firing device ("squib" below), which ignites the gas generating agent, whereupon high pressure gas is generated and instantly inflates the Air Bags.

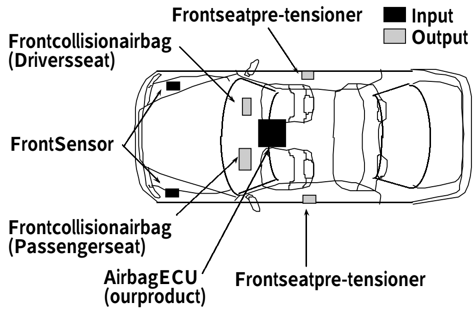


Fig.2 Structure of Air Bag system

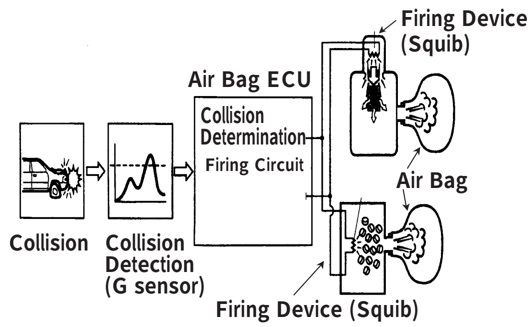


Fig.3 Deployment process of an Air Bag system

3 Development objectives

(1) Development of integrated ASIC

Reduce the number of components of the integrated ASIC via large-scale function incorporation, thus realizing cost cutting.

(2) Development of standard casing

Improve ease of installation by unifying the shape of

*1: System for improving the securing of passengers during a collision by pre-tensioning the seatbelts.

the case to where the ECU is mounted in the vehicle. And reduce the number of types of case, thus realizing cost-cutting.

(3) Improvement of manufacture inspection processes

Improve product quality via improvement of detection ability in manufacture inspection procedures. Also shorten operation cycle times, thereby reducing manufacture costs.

4 Newly-developed technology

4.1 Development of integrated ASIC

1) Basic configuration of Air Bag ECU

The Air Bag ECU is basically composed of an electronic acceleration sensor that detects impacts ("G sensor" below); circuits for signal input from the front sensor, which senses collision at the front of the vehicle; a microcomputer that makes decisions on the severity of impacts; and firing circuits for the squib. Extremely high reliability is required of the Air Bag ECU since its non-operation or malfunction during an accident would leave passengers unprotected. Accordingly it is provided with the following functions in addition to those mentioned above, in order to secure reliability.

①Self-diagnosis function

The Air Bag ECU is a piece of equipment that will operate only one time -- or not at all -- in the lifetime of a vehicle, but it must operate properly that one time if an accident occurs. This makes it extremely important to have a self-diagnosis function ("SDF" below") that can diagnose whether the ECU and the system are ready to operate normally. Our SDF is able to constantly check this.

②Backup power function

A backup power function is provided that provides backup power for Air Bag control during a fixed time period in the event that the battery is broken or broken connections occur in its harness during an accident, cutting off power input.

③Safing function

This function prevents malfunction by compensating for weakness regarding electrical noise in the electronic circuits, with a combination of electronic circuits and mechanical safing sensors.

2) Incorporation of functions in integrated ASIC

The main functions of the Air Bag ECU and the controlling circuits correspond in the manner shown in Table 1. The integrated ASIC was integrated with these control circuits, in sections that were technically possible to incorporate and which offered major cost cutting effects through reduction of their number (hence number of components). The configuration is shown in Figure 4.

Table 1 Main functions and control circuits of Air Bag ECU

Air Bag ECU Main Functions	Control Circuit
①Drivers Seat, Passenger air bag and pre-tensioner control.	・firing Circuit ・Backup Power ・G sensor ・Safing sensor ・Micro computer(Collision Determination)
②Self diagnosis function	・Self diagnosis circuit ・Warning indicator lighting circuit
③Service feature	・Communication interface circuit
④Air bag disposal process function when disposing of the vehicle.	・Communication interface circuit
⑤Fuel cut off during collision	・Output circuit

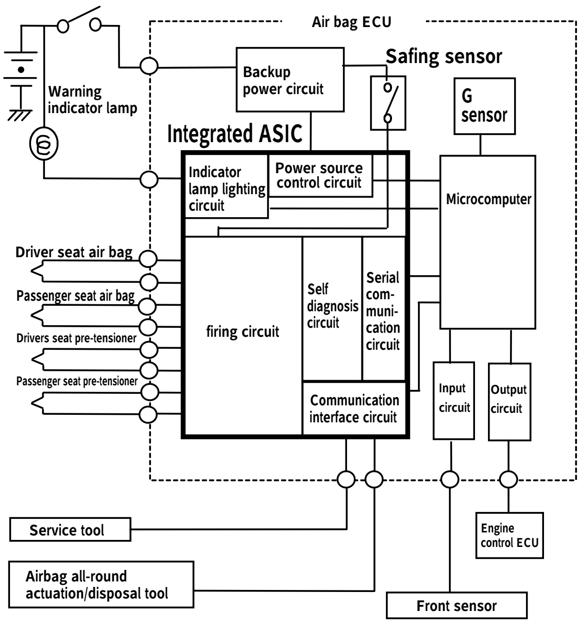


Fig.4 Structure of Air Bag ECU

3) Cost cutting effect through reduction in number of components

Integration of these circuits into the integrated ASIC reduced the number of components by 25%. This enabled what was traditionally a 2-piece product (one for either side) to be installed as a single piece one, permitting improvements in productivity and product quality as well as a 20% decrease in component materials costs. (Figure 5)

In the next round of ECU development we expect to achieve further reductions of 20% in the number of components and 10% in component material costs compared

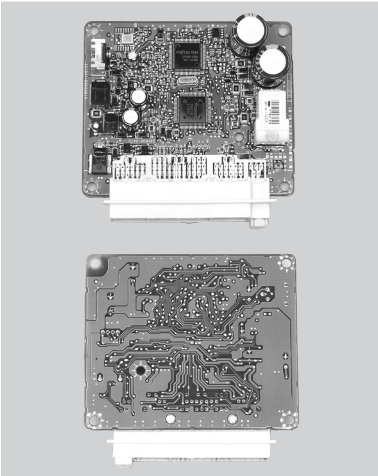


Fig.5 Newly developed printed circuit board for an Air Bag ECU

to the currently-developed product, by further function incorporation into the integrated ASIC and slimming-down of the circuit configuration via a revision of the design specifications. (Figure 6, 7)

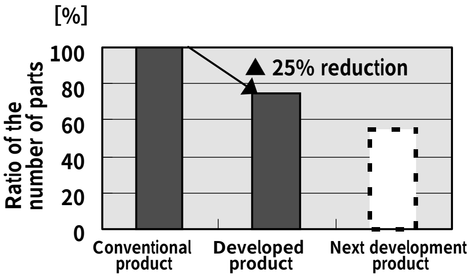


Fig.6 Comparison of number of components with conventional equipment

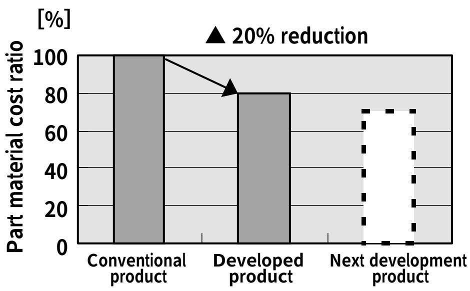


Fig.7 Comparison of component material cost with conventional equipment

4) Circuits built into the integrated ASIC

①Firing circuits

In order to control each squib independently, a transistor for supplying the firing energy (power MOSFET) is built in upstream (a) and downstream (a') of each squib. (Figure 8)

The configuration is such that firing current will flow when the upstream and downstream transistors and the safing sensors are actuated.

For the upstream transistors, the design is such that constant current control and firing duration control is

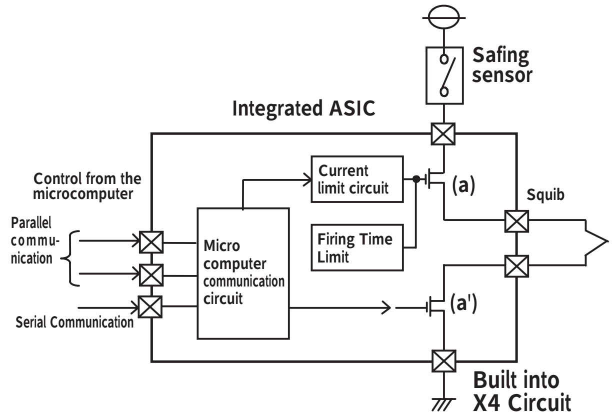


Fig.8 Firing circuits

implemented, so that no more than the necessary energy is consumed; this takes provides for suppression of ASIC heat-up and for backup capability save during a collision. Further, firing control by the microcomputer is configured so that it will not come on unless both serial communication and parallel communication are activated (AND condition), thus making the system even more fail-safe with regard to malfunction.

②Self-diagnosis circuits and warning indicator lighting circuits

Circuits that perform constant self-monitoring/diagnosis of the firing circuits' condition, and circuits for lighting of the warning indicator, which alerts the user if a failure is judged to have occurred, are built into the ASIC. The SDF is able to diagnose failures internal and external to the ASIC. Here as an example we describe the circuits for detecting external failure in the form of squib open/short circuit or squib short to power/ground.

A squib open/short circuit fault is detected when the voltage that is generated when current is passed to the squib. Since the resistances of the squib and of the

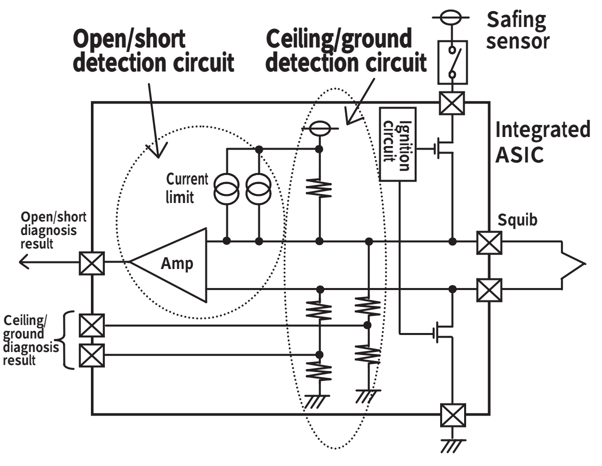


Fig.9 Self-diagnosis circuits

wire harness are low and furthermore are close values, a high-precision current is required in order to detect squib failure. Therefore a high-precision constant current is provided inside the ASIC as a power source, and the voltage difference produced in the squib by the precision current is amplified by a differential amplifier to facilitate diagnosis. (Figure 9)

A short to power or ground in the squib line is diagnosed by means of a resistance that is connected to the squib line from the power source inside the ASIC; this sets the squib line to a particular voltage, and if a short to power or ground occurs it is diagnosed from the resulting change in voltage. (Figure 9)

If the microcomputer judges a fault to have occurred from the results of the diagnosis, it turns on the warning indicator drive circuits, to light the warning indicator (located inside the vehicle's speedometer).

The ASIC also possesses an ECU protection function that disables the indicator if an indicator circuit is in a shorted condition or the line is shorted to power and continues for a particular duration (this is sensed by the voltage monitoring circuits), in order to protect the ECU (refer to Fig. 10).

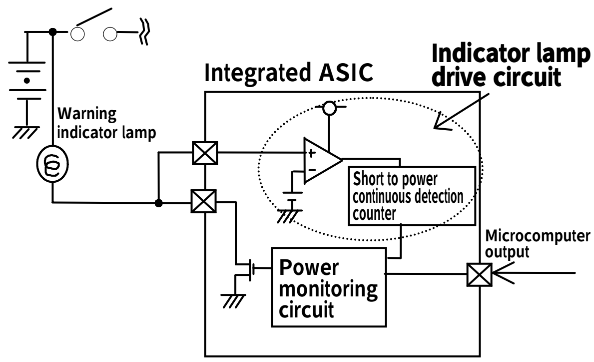


Fig.10 Warning lamp lighting circuits

③Communication interface circuits

If a trouble occurs with the ECU, the dealer will use a service tool to read out the diagnosis results from the ECU and carry out troubleshooting based on the results.

And when the vehicle is disposed of the disposal company will connect up an all-round actuation/disposal

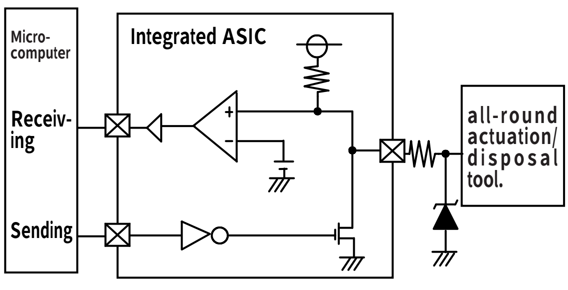


Fig.11 Communication interface circuits

tool to the ECU and use it to implement disposal treatment of the Air Bags. The ASIC has built-in 2-way serial communication interface circuits for communicating with these tools. (Figure 11)

④Circuits to accommodate development to more sophisticated Air Bag ECU

To accommodate a system that will control side air bags and curtain air bags, an extension of the firing circuits and circuits for receiving signals from the side sensors*2 (for sensing side collisions) will be required. Accordingly the ASIC has built-in circuits intended to serve such purposes with ease and at low-cost.

a) Configuration of firing control circuit extension

The configuration decided on connects up 2 ring-form serial communication lines for the ASIC, thus permitting batch control of up to 8 channels by the microcomputer. (Figure 12)

This will enable control of side and curtain Air Bags for the driver and passenger seats, in addition to the regular Air Bags and pre-tensioners for those seats.

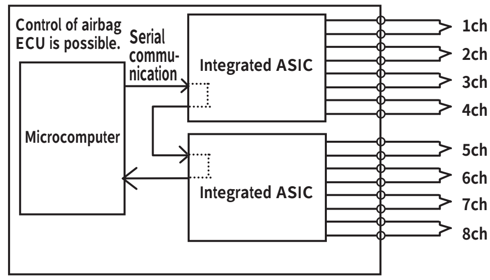


Fig.12 Configuration of ignition control circuit expansion

b) Communication interface circuits for satellite sensors

Communication with the satellite sensors is to be current communication type, which sends signals via switching of the current between high and low levels. Since attaching such communication circuits to the ASIC exterior would increase the number of components and the cost, 2 communication channels to accommodate B pillar satellite sensors on either side of the vehicle have been built into the ASIC.

4.2 Development of standard case

4.2.1 Configuration of Air Bag ECU

The Air Bag ECU is composed of 2 extremely simple items, a die-cast aluminum case that houses the circuit boards and a bracket of steel plate that fastens the case to the vehicle. And in order to fulfil its special role of detecting collision of the vehicle, the Air Bag ECU is

*2:Sensors are installed on the B-pillars of the vehicle to detect side collisions.

provided with the following 2 features. (Figure 13)

①Assured transmission of impacts to G sensor

The construction must be such that impacts during a collision are transmitted faithfully to the sensors inside the body, without increase or diminution.

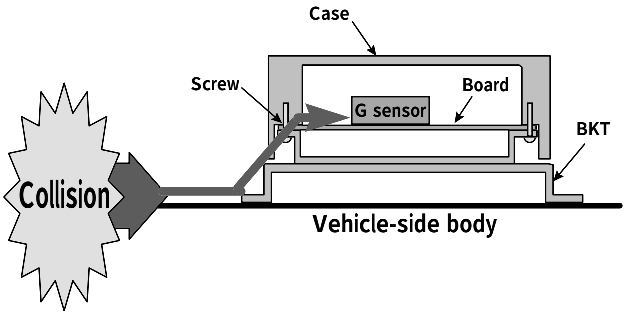


Fig.13 Impact transmission routes

② Protection of circuit boards during collision

The ECU must be protected so that when a collision is sensed, it continues functioning until current is passed to the firing circuits.

4.2.2 Problems with conventional construction

Conventional Air Bag ECU bracket had the following problems.

①Many Variations

There were different mounting screw positions and case size specifications for each different vehicle type.

②Heavy weight

Each Air Bag ECU weighed 700 to 800 grams, with the bracket accounting for over 50% of the weight.

③High cost

The ECUs were designed for high resonance frequencies and low resonance gain, in order to lessen the effects of vehicle vibration. This made them complex objects with duplex and triplex reinforcement via beads and flanges, etc., which raised the cost of the bracket.

④Installation difficulty

The screw direction differed widely among the ECUs, so that it took time to install the ECU in the vehicle assembly line.

4.2.3 Development of standard ECU case

Development of a standard ECU case began with simplifying the bracket shape so as to cut the cost and improve development efficiency. But subsequently it became clear that integrating the case with the bracket would achieve lower costs and reduce weight, while this reduced weight would raise the resonance frequency, thus making it possible to reduce the orders in the G sensor's low-pass filter. Therefore the steel-plate bracket was abandoned and a case integrated with bracket was made standard for the Toyota Group. (Figure 14)

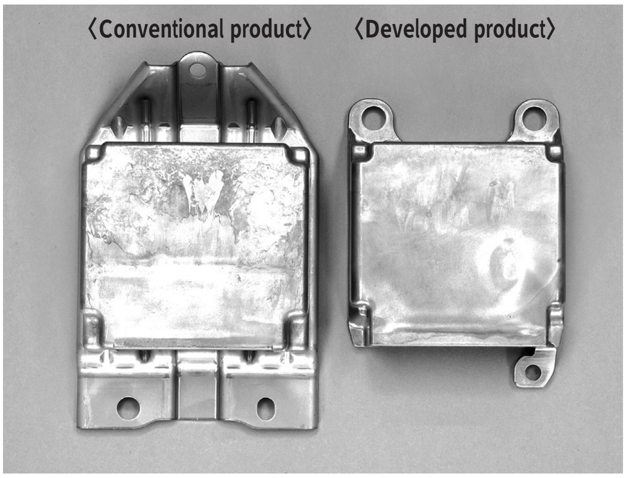


Fig.14 Conventional product and product under development

①Shape of item fitted to vehicle

Initially in the development we considered fastening the item to the vehicle with 4 screws, but to improve the ease of installation we switched to considering 3-screw fastening (3-point support). This 3-point support was made possible by rectifying the effects of the reduction in the number of screws on the resonance characteristics, by means of resonance evaluation, real-vehicle collision tests and structural simulations of the ECU. Further, we surveyed the body shape and accommodation of harness etc., for various vehicle types / models, and based on the results designed a case with standard installation shape, made of die-cast aluminum and compatible with all vehicles.

②Design concepts of the integrated case and bracket

The integrated case and bracket aims to reduce the weight of the ECU by changing the material of the bracket from the conventional plate metal to die-cast aluminum, and to raise the resonance frequency. In order to enhance these effects, a point of installation to the vehicle was selected so that the distance from the vehicle installation position and the board installation positions would be the smallest. Also, in order to configure it so that it can withstand shocks and warpage of the vehicle during a collision, the shock applied to the vehicle installation position was estimated from previous crash testing results, and by designing a case which would not be destroyed under those loads, a structure was developed that can be applied to any vehicle. For when the warpage of the vehicle is very severe, the connection from the bracket and case section was made thinner, so that only the bracket will warp, thus controlling the warpage of the case and thereby protecting the circuit board. In addition, in event that the bracket breaks, a case design was developed so that the section of the bracket below the circuit board would break first (Figure 15), so that the metal fragments from the case does not fall on top of the board and cause a short circuit.

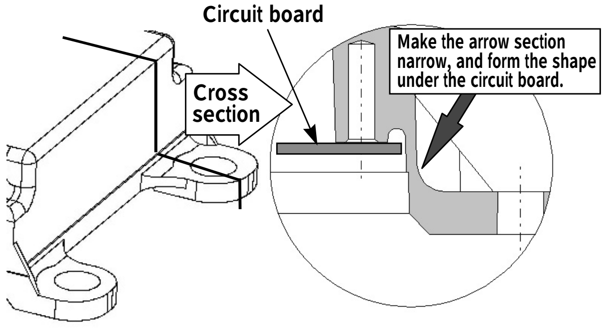


Fig.15 Structure for deforming the BKT under the circuit board

4.2.4 Employment of taptight screws

Employment of taptight screws was examined, since these could reduce the tap machining of the case and thereby cut the cost of manufacturing. Taptight screws are a type of tapping screw which forms a female thread itself as it is being screwed in, and are used with die-cast aluminum / zinc or similar products. They have the merit of providing high connection reliability, since they are less likely to become loosened. (Figure 16)

Fig.16 Conventional screw and self-tapping screw (taptite)

However taptight screws have differing screw axial force characteristics relative to tightening torque, depending on the dimensions and surface conditions of their pre-hole. Because of this they require that the necessary axial force be determined, and need to be designed with optimal values for meshing allowance and tightening torque. In the present research we investigated non-uniformity in the factors in Table 2 and determined the minimum necessary taptight screw axial force for maintaining the characteristics of impact transmission to the G sensors on the printed boards, using the condition "obtain the axial force that will prevent the circuit boards from moving laterally out of position due to the G acting on the ECU during a collision". Thus we derived the range of values within which the parameters for taptight screws for Air Bag ECUs should be set. (Figure 17)

Table 2 Parameters and applications for the taptite tightnening method

	Factors of Non-uniformity	Range
1	Screw bottom hole size tolerance	±0.03
2	Screw bottom hole surface hardness	Hv80~Hv120
3	Screw bottom hole surface roughness	Drill Work-Reamer Work
4	Screw outer diameter size difference	±0.05
5	Screw tightening torque non-uniformity	±10%

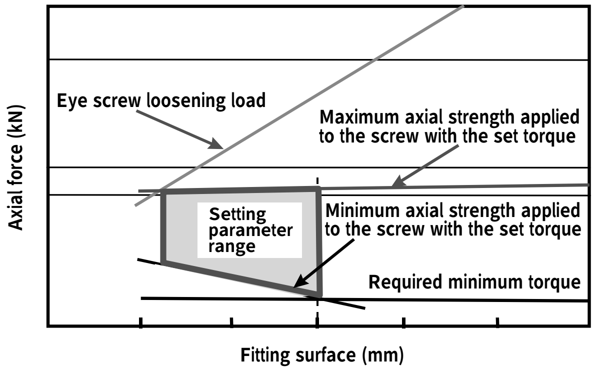


Fig.17 Application range of taptite

4.2.5 Effects of development of standard case

Getting rid of the steel-plate bracket made possible a reduction of around 51% in the ECU's weight compared to conventional items for the same vehicle type, as well as a major cost cut in the form of a 58% reduction in component costs. Further, the development of a standard case resulted in a single type of bracket as compared to the previous 6 types, thus improving the ECU's ease of installation to vehicles and enabling drastic reductions in design time and labor. (Figure 18, 19)

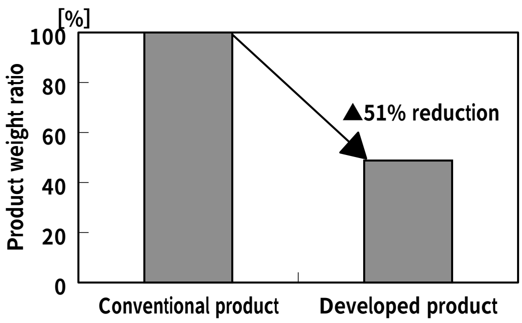


Fig.18 Comparison of product weight versus conventional equipment

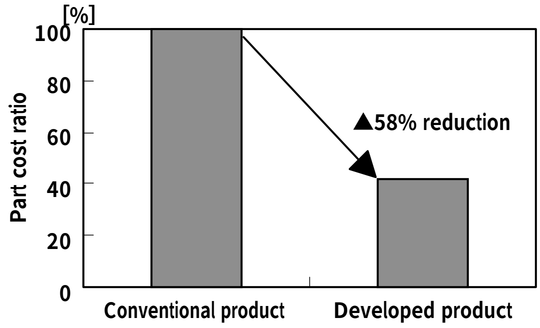


Fig.19 Comparison of parts cost with conventional items

4.3 Improvements in manufacture inspection processes

4.3.1 Problems in conventional inspection processes

Shortening the inspection time is a major task in reducing ECU manufacturing costs. Also, improving the error detection ability is critical for improvement of product quality. Therefore, we have listed the tasks necessary to achieve these goals, based on the conventional ECU inspection process. (Figure 20)

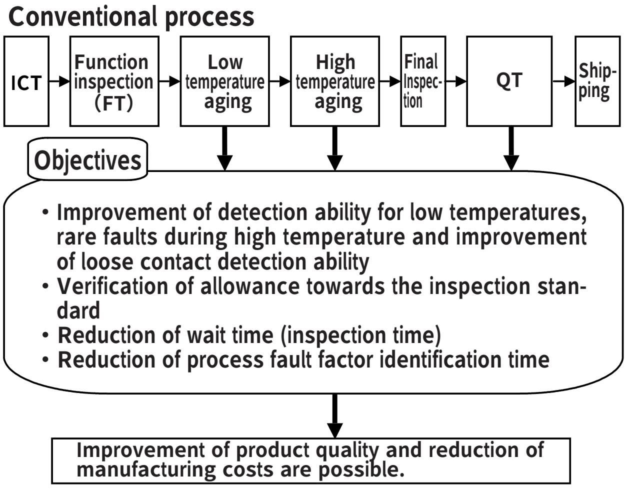


Fig.20 Inspection process improvement tasks

4.3.2 New manufacture inspection method

To resolve the above listed problems, we implemented a review of the inspection process in which the production outfits also participated. As a result, for those processes in which faults were detected via the ECU's self-diagnosis results, a change was made to detection of faults via reading out of A/D conversion values inside the microcomputer of the ECU, so as to better determine the situation in the ECU interior. (Figure 21)

As shown in Figure 22, the criterion levels for failure of the ECU's SDF were set with consideration for thermal characteristics and deterioration, so that the function will not detect failures due to temperature variation or secular change in the field environment. For the

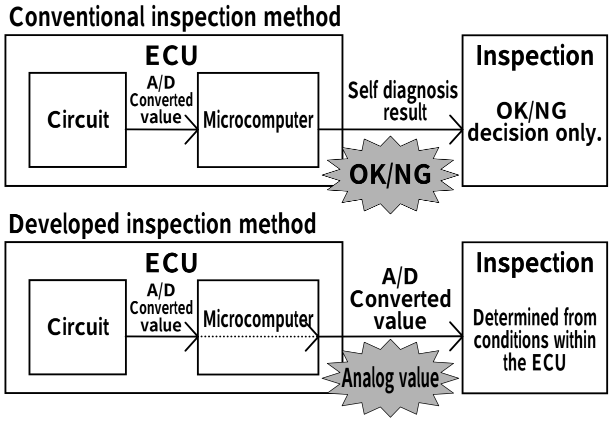


Fig.21 Production inspection methods

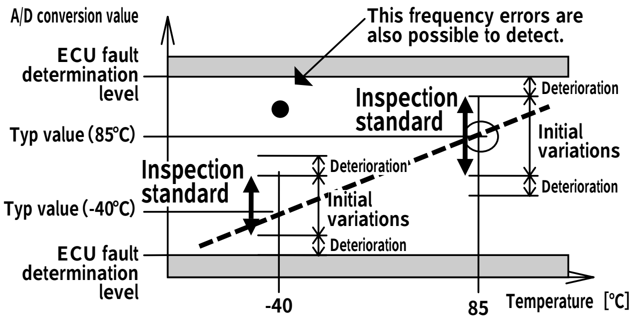


Fig.22 Inspection criteria for new inspection processes

inspection standards used for the manufacture inspections however, more stringent levels were set, taking account of initial non-uniformity of components and deterioration under various temperature conditions. This enables detection of faults in output characteristics, such as when they slightly exceed the initial non-uniformity range.

Further, inspection of the squib open / short failure detection circuits shown in Figure 23 checks the output characteristics for 2 different LOAD (resistance to be changed;2 point measurement). As shown in Figure 24, when the output characteristics are normal they are represented by a thick, unbroken straight line, while offset abnormality and non-linear output results in dashed line and dotted line waveforms respectively. This makes possible the detection of abnormality. And the system

*3:
- ICT: Checking, using an In-Circuit Tester, of whether the electrical characteristic values (R, L, C, etc.) of the elements in the assembled electronic circuit boards match the design values.
- FT: Checking of whether the functions and operations are normal.
- Aging: Inspection in which the product is left in an energized/activated state for a fixed time period, in order to stabilize the installed state and the characteristics, etc.
- Impact test: Test in which the ECU is subjected to impact and the firing performance under such is checked.
- QT (Quality Test): Final inspection of the finished product.

was enabled to detect the circuits' oscillation via the difference between the maximum and minimum A/D conversion values. (Figure 25)

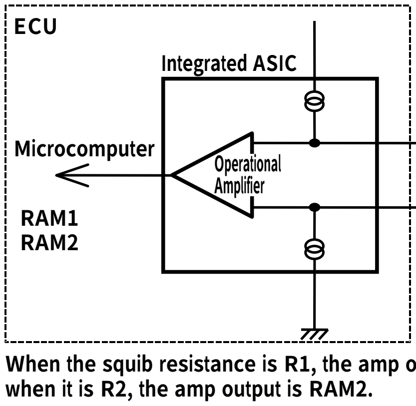


Fig.23 Inspection settings for squib open / short failure

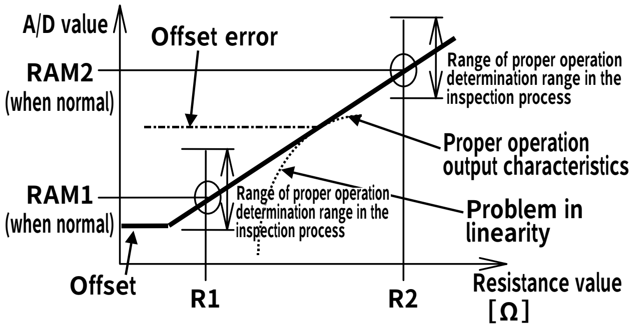


Fig.24 Failure detection method using 2 measuring points

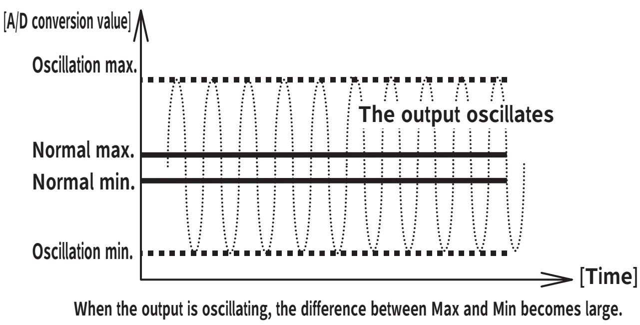


Fig.25 Detection of output oscillation

In order to realize this inspection process, software that can memorize the maximum and minimum A/D conversion values in its RAM, and permits reading out of such from the exterior via the above-mentioned communication interface function, was incorporated into the newly-developed ECU.

If the memorization of the A/D conversion values is implemented only in a special operation mode for inspection (inspection mode), then as shown in Figure 26, operation of two separate sets of software will be needed: that for normal operation and that for the inspection mode. Therefore in the newly-developed ECU no inspection mode is provided; instead memorization of the A/D conversion values is implemented continually. (Figure 26)

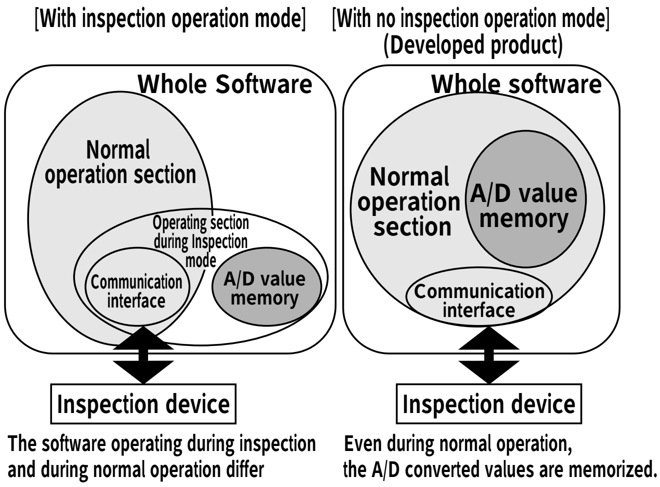


Fig.26 Configuration and operation of software

4.3.3 Effects of inspection process improvement

Adopting the manufacture inspection process described above brought the improvement effects presented below.

1) Improved trouble detection ability

①Detection of rare faults in product condition

Reading out the A/D conversion values during aging enables detection of rare faults that occur only with a temperature load, and detection of loose contact.

②Determination of margins relative to product specifications

From the A/D conversion values read out, it is possible to determine the margins relative to the product specifications. And by controlling the tendency of such, it is now possible to take preventive measures for troubles before they can occur.

2) Shortening of inspection duration's

Hitherto, in the aging and QT faults were detected via the ECU's self-diagnosis results, which meant it was necessary to wait the length of time it took to determine the faults from such results. In the newly-developed ECU however, the inspection takes the form of reading out the A/D conversion values, so that waiting time is reduced simply to the time it takes to implement A/D conversion several times. This enables a drastic reduction in the inspection duration. We also examined, via FMEA, whether it would be possible to replace the inspections entailing actual operation of equipment with equivalent inspections using A/D conversion values. As a result we were able to eliminate the FT process and cut the ICT items by one half, as shown in Figure 27.

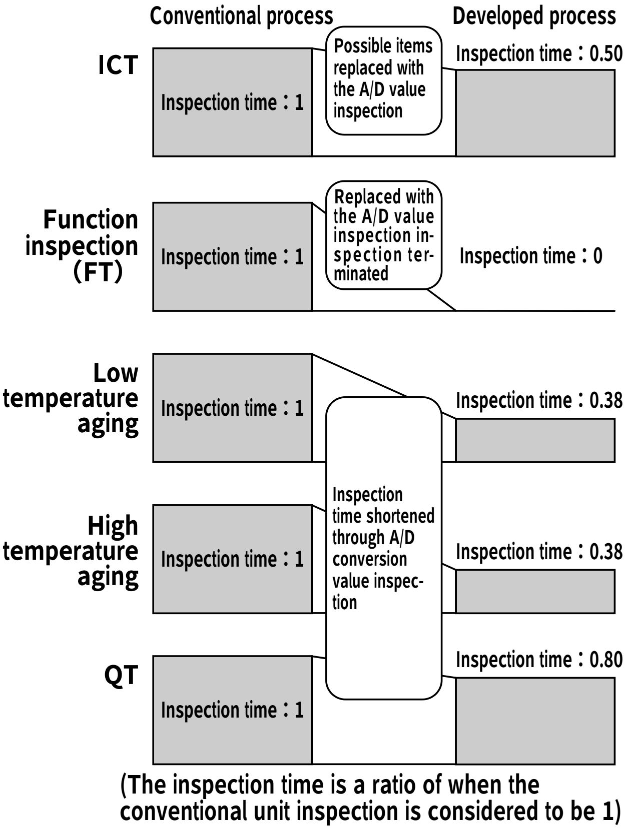


Fig.27 Improvement of inspection duration per individual process

3) Increased efficiency of trouble analysis

Hitherto when troubles were found in the inspection process, analysis to determine the trouble location was based on the fault codes output by the ECU. But since there were several possible causes for the same fault code, it took time to identify the fault location in this manner. In the newly-developed ECU however it is possible to identify the fault location using a combination of the fault codes and the maximum and minimum A/D conversion values, and this makes trouble location identification much easier than in the conventional products.

Further, the fact that it was now possible in the ECU development stage to determine fluctuation in the A/D conversion values during the tests meant that the design margins with regard to malfunction could be verified, which had the effect of improving design quality.

Thus, the present improvements in the manufacture inspection process have enabled an increase in trouble detection ability in the shipment inspection, and a shortening of the inspection process. This in turn has permitted improvement of the manufacturing quality of the Air Bag ECU and a reduction of its manufacture costs.

5 Conclusion

Bringing a low-cost, high-quality Air Bag ECU into mass production has made a great contribution to profit improvement via increased product development/design efficiency, standardization and cost cutting. We are currently continuing with efforts for further cost cutting and even higher quality and performance, with a view to full-fledged entry into the Chinese and other Asian markets. Finally we would like to express our thanks to all those within and outside the company who assisted in the present development.

Reference:

・ Fiscal 2001 White Paper on Traffic Safety

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