# Cruise Control ECU Adopting Combined ASIC

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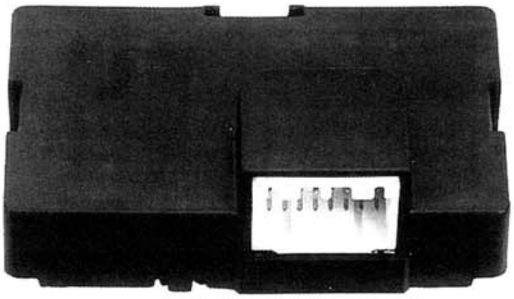
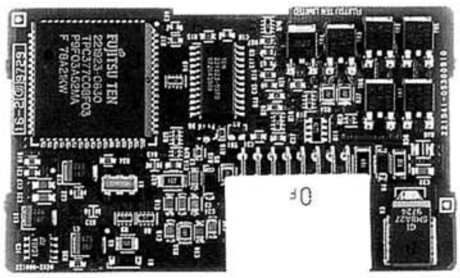




Changes in the global market have led to significant drop in the prices of electronic parts for automobiles. This development has prompted more car manufacturers to move their production operations overseas. As a result, demand for parts procurements has grown at the local level, at the overseas plants of car manufacturers. This is demand that electronic parts manufacturers need to accommodate as local suppliers. Under these circumstances, to meet the needs of our customers, we have been producing the cruise control ECU in the United States since 1997.

Of course, supplying our customers with a lower-priced product was not the sole target of our efforts in the development of the cruise control ECU. A more streamlined production process was another of our key aims. Streamlined production was afforded by the development of an ASIC combining more than one application. We developed an ASIC implementing most cruise control functions. This ASIC includes a microprocessor, an analog-to-digital converter, a voltage regulator and power drivers. Adopting this ASIC to the ECU allowed us to significantly reduce the number of electrical components and achieve a simplified design. We designed the printed circuit board so that it would require only one side reflow soldering process (enabling us to reduce the number of components) and implemented heat bending, with the result that we were able to shorten the assembly line time. Additionally, as for chassis assembly technology eliminated screws from the ECU. We also adopted a chassis assembly technology that eliminated the need for screws in the ECU.

This paper describes the features of our cruise control ECU and the key technologies used in its production.

## 1. Introduction

A cruise control system, when switched on by the driver, can maintain a preset vehicle speed when the accelerator is released. It is expected to contribute to reduced driver fatigue on long drives on the freeway.

The recent slump in the domestic economy and the yen's appreciation have led to sharp reductions in the prices of vehicle electronic parts. In addition, an increasing number of domestic automobile manufacturers are shifting their factories overseas and engaging in automobile parts procurement on a global scale for optimal parts procurement. Interest has therefore grown in procuring automobile parts locally.

In the late '80s, to improve the control of our electronic control units (ECUs) for cruise control, we shifted from analog electronic components to four-bit microprocessors, and then to eight-bit microprocessors. In the early '90s, we reduced the cost of our ECUs. To start production of electronic cruise control units at our factory in the United States in fiscal '97, we developed an electronic cruise control unit that could be produced easily with existing facilities. This unit was developed based on Application Specific Integrated Circuit (ASIC) technology implementing a microprocessor, power supply, and output driver on a single chip[1], where the ASIC uses several combined applications.

This article describes the control logic, circuit configuration, mounting form, and housing structure of the electronic cruise control unit we began mass producing in early 1997.

## 2. Overview of cruise control systems

### 2.1 System configuration

Figure 1 is a block diagram of a cruise control system. When the driver operates the control, release, or any other switch, the electronic cruise control unit, mounted in the passenger compartment, receives a signal from the switch and drives an actuator installed in the engine compartment in accordance with the switch signal and the pulse received from the vehicle speed sensor. The actuator opens and closes the engine throttle valve via a link. Figure 2 shows the switches for the cruise control system, and Figure 3, a DC motor-driven actuator[2),3)]. Unlike conventional cruise control systems, in which a potentiometer is provided for the actuator, our cruise control system does not use a potentiometer (dotted portion in Figure 1). Chapter 4 describes how the system is affected by the elimination of potentiometer signals and how this effect is accommodated using the control logic.

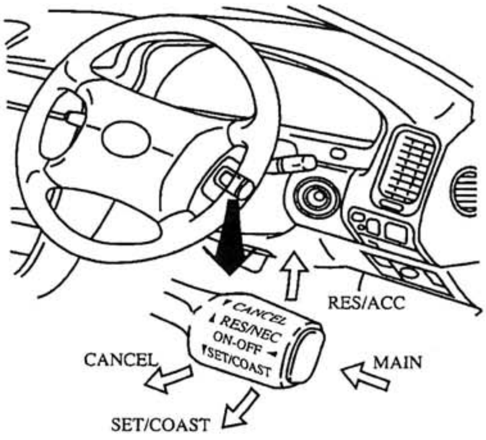
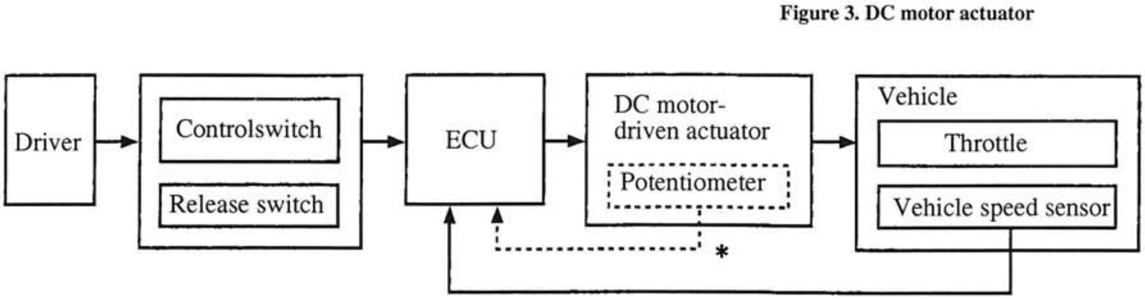



**Figure 2. Control switch**

**Figure 3. DC motor actuator**




* The dotted portion is not used in the newly developed cruise control system.

**Figure 1. Configuration of cruise control system**

## 2.2 System functions

The following paragraphs describe the basic functions of the cruise control system.

① Set function: Starts constant-speed cruise control for the current vehicle speed when the driver operates the SET/COAST switch.

② Cancel function: Cancels constant-speed cruise when the driver operates the CANCEL switch or steps on the brake pedal, for example, because the traffic ahead is slowing down owing to a buildup of road congestion, decreasing the distance between the vehicle and that traffic.

③ Resume function: Resumes constant-speed cruise control for the previous vehicle speed, when the driver operates the RES/ACC switch, for example, because the vehicle's distance from the traffic ahead has increased sufficiently.

④ Override function: Enables the driver to increase the vehicle speed, for example, to pass slower vehicles, and resumes constant-speed cruise control for the previous vehicle speed when the accelerator is released.

⑤ Accelerate function: Increases the vehicle speed under cruise control while the RES/ACC switch is being operated.

⑥ Tap-up function: Increases the vehicle speed under cruise control by about 1.5 km/h each time the RES/ACC switch is operated momentarily.

⑦ Coast function: Decreases the vehicle speed while the SET/COAST switch is being operated.

⑧ Tap-down function: Decreases the vehicle speed under cruise control by about 1.5 km/h each time the SET/COAST switch is operated momentarily.

## 3. Features of the newly developed electronic cruise control unit

Figure 4 compares the newly developed electronic cruise control unit with its predecessor.

To satisfy demand for lower prices and to create a structure enabling an optimum procurement environment, we, together with our customers, configured a new electronic cruise control system, reviewed inputs and outputs for the system, and designed new control logic circuits. As a

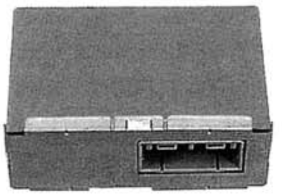
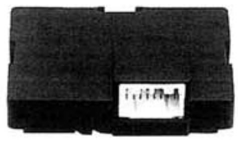
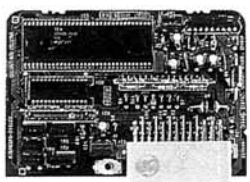
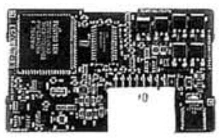
| | Predecessor | Newly developed electroniccruise control unit |
|---|---|---|
| Device |  |  |
| Printed-circuit board |  |  |
| Size | 110 × 80 × 32 (mm) | 110 × 60 × 20 (mm) |
| Volume | 280cc | 120cc |
| Weight | 200g | 80g |
| Number of components | 150 | 70 |
| Number of connector pins | 26 | 16 |
| Mounting method | Double-sided PC board, double-surface mounting, flow soldering | Double-sided PC board, single-surface mounting, flow soldering |
| Housing structure | Aluminum die-casting case, bolt-fixed | Resin case, fixed by heat bending |

**Figure 4. Comparison between newly developed electronic cruise control unit and its predecessor**

result, we succeeded in reducing the size of the connector for the newly developed electronic cruise control unit by using a smaller number of connector pins. Furthermore, by using an ASIC that uses several combined applications, we have succeeded in significantly cutting down on the number of components in the electronic cruise control unit. Using less and smaller components has enabled us to lower our printed-circuit board area requirements and halve the volume and weight of the electronic cruise control unit, as compared with its predecessor.

Using less components has led to a simplified component mounting process, because all of the components (except the connector) can be mounted on a single surface of the printed-circuit board and reflow-soldered. Moreover, the reduction of the printed-circuit board in size has made it possible to mount it in the housing simply by heat bending. Automated assembly is thereby facilitated because no nuts or bolts are required to assemble the electronic cruise control unit.

By applying these methods, we have succeeded in developing an electronic cruise control unit that can be manufactured easily at low cost.

Chapters 4, 5, and 6 respectively provide detailed descriptions of the new control logic, the ASIC using combined applications, and the mounting and structure designs.

## 4. Control withoutusing potentiometer signals

This chapter explains the effect the elimination of potentiometer signals from the actuator has on the cruise control system and what control method is used to maintain the same performance as that available with conventional cruise control systems.

### 4.1 Conventional control method

Conventional cruise control systems use PID control, which is a combination of proportional and integral control based on differences between targeted and actual vehicle speeds and differential control based on the acceleration/deceleration applied to the vehicle. Figure 5 is a block diagram of a conventional cruise control system. The requirements of a control method for cruise control systems include small undershoot and overshoot (immediately after control is engaged), quick response (to promptly enter a stable state), and a propensity to be less prone to self-sustained oscillation[4].

### 4.2 Functions of the potentiometer signal

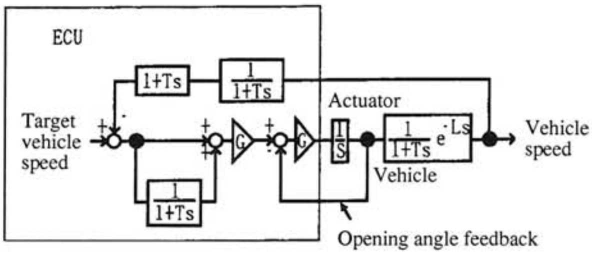



**Figure 5. Block diagram of conventional system**

The actuator is driven by a built-in DC motor. The DC motor generates a higher torque than that available with a stepping motor, but is outperformed in terms of positional control. Even if the electronic cruise control unit provides the DC motor with the same drive as that provided to the stepping motor, the amount of movement of the actuator varies with the battery voltage, ambient temperature, and actuator load. A potentiometer signal is used to feed back the actuator arm opening angle to compensate for the DC motor's low positional controllability. The feedback cancels off a delay in actuator motion, thus decreasing the system's phase delay. Eliminating the potentiometer signal from the conventional control method would allow a system phase delay to occur, thus slowing the system's response. Contrarily, self-sustained would be more likely to occur if system gain were increased to prevent phase delay. In any case, the driver would likely not feel very secure with the system.

### 4.3 Control methods used in the newly developed electronic cruise control unit

The newly developed electronic cruise control unit uses two basic control methods that assure a high response, while avoiding the self-sustained oscillation described above.

One of the basic control methods estimates the state of control and load from the vehicle speed, the acceleration being applied to the vehicle, and the amount of drive output to the actuator, and adjusts the gain in accordance with the estimates. The other basic control method applies feed-forward control positively when changing the target vehicle speed. Namely, increasing the gain only on a transient band can assure a high stability while maintaining quick response similar to that available with conventional control methods. Figure 6 is a block diagram of the newly developed cruise control system. Figure 7 shows the control performance delivered when the tap-up function is engaged on a climbing lane to explain how effective the new control methods are.

The response of a cruise control system is slow if it does not use the control method developed for climbing lanes, because the system maintains a low control gain over the entire range to suppress self-sustained oscillation. It therefore takes much time for the electronic cruise control

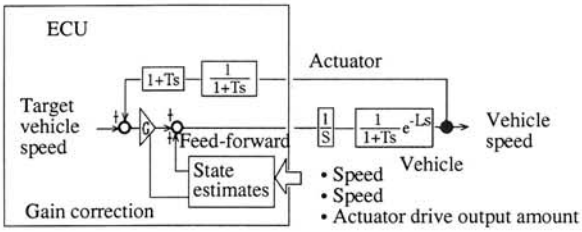



**Figure 6. Block diagram of developed system.**

unit to settle on the desired vehicle speed. Moreover, its overshoot becomes large, giving the driver an unpleasant feeling. On the contrary, if the system uses the newly developed control method, it puts feed-forward control into effect immediately after the tap-up function is used, and also feed-forward control and variable control into effect after the vehicle speed is increased, thereby maintaining quick response and enabling the system to promptly settle on the desired vehicle speed. Furthermore, comfortable control is achieved through small undershoot.

## 5. Circuit configuration of the new development

### 5.1 Electronic cruise control unit circuit configuration

The electronic cruise control unit consists of an 8-bit microprocessor for performing calculation related to control, a voltage regulator circuit for converting 12 V supplied from the battery to 5 V, an input circuit for converting signals from the outside of the cruise control unit into a form that can be handled by the microprocessor, an output circuit for converting signals output from the microprocessor into a signal for driving the actuator, and a fail-safe circuit for monitoring these signals to verify that the system is running normally. In conventional electronic cruise control units, these circuits are configured as separate parts. On the contrary, all circuits (except for the fail-safe circuit) of the newly developed electronic cruise control unit are incorporated into a single chip, which is encapsulated in a PLCC package. We developed this ASIC jointly with Texas Instruments Japan, Ltd. Figures 8 and 9 respectively show the circuit configurations of the conventional and newly developed circuits.

### 5.2 Overview of the ASIC

#### 5.2.1 Functions of the ASIC

The microprocessor part of the ASIC is provided with 8 Kbytes of ROM and 256 bytes of RAM as well as resource functions such as an AD converter and serial communications interface. The 5 V voltage regulator circuit incorporates a boost transistor to enable the supply of up to 75 mA. The circuit also incorporates eight interface circuits that can receive the voltage of 12-V batteries, and serial resistors inserted there protect the circuit from high voltage. Included are such output circuits as a low-side driver circuit to enable powering of the 1.5 W lamps directly from the IC and a high-side predriver circuit to enable the stepping up of the voltage for the gate of an N-channel MOS transistor. The use of the high-side predriver

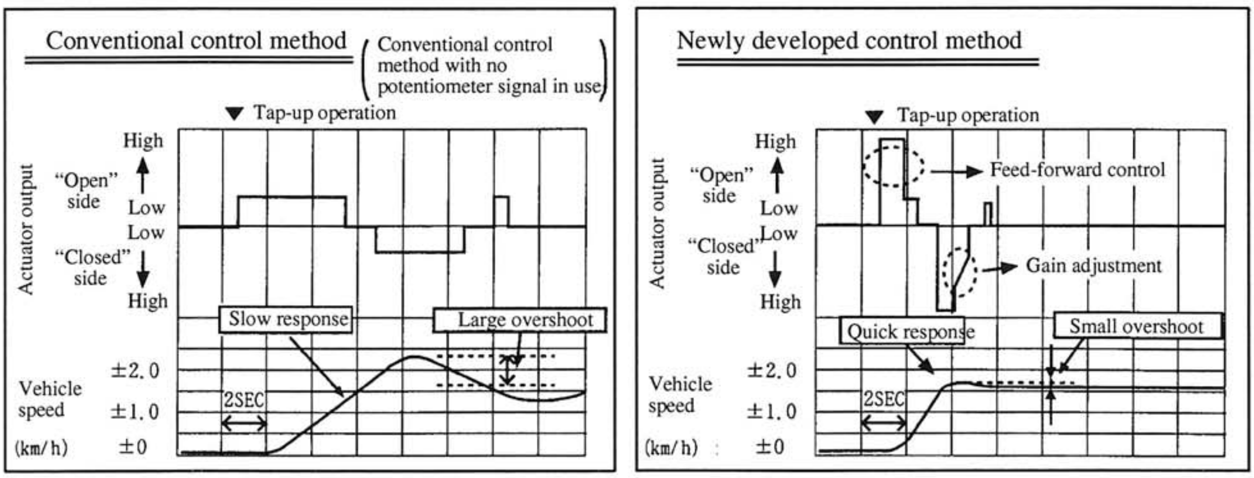



**Figure 7. Control performance when climbing roads with steep grades when tap up is operated**

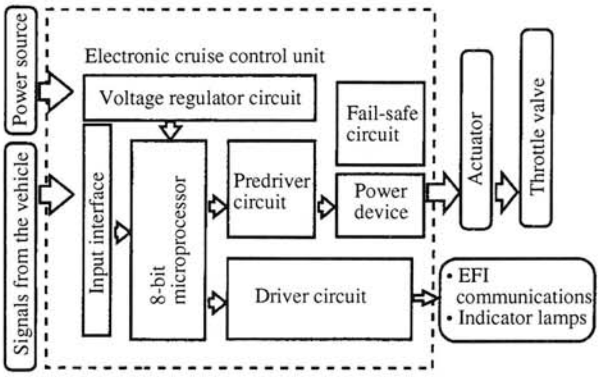



**Figure 8. Circuit diagram of conventional electronic cruise control unit**

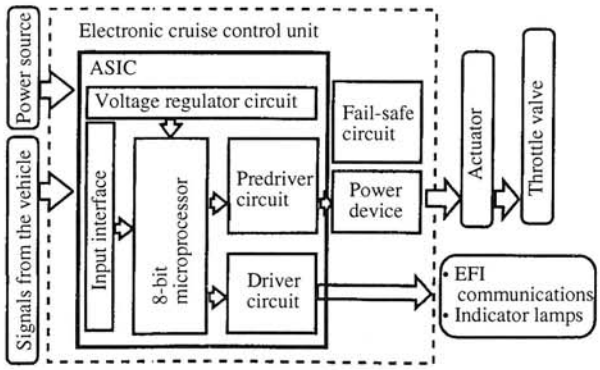



**Figure 9. Circuit diagram of developed electronic cruise control unit**

enables driving the actuator with a low-priced N-channel MOS transistor instead of a P-channel MOS transistor.

### 5.2.2 ASIC production process

We planned and carried out the development of a system configuration and a production process concurrently. The most important purpose behind the use of the ASIC is to reduce the number of required components, because the reduction can help reduce the size and weight of the electronic cruise control unit and simplify the parts mounting process. Another important purpose behind using this IC is to curtail the required development time, thereby making it possible to put the product on the market earlier. To minimize the number of required components, we tried maximizing the number of circuit blocks to be implemented as an IC. As a result, we have successfully implemented on a single chip all of the circuit blocks (except for the fail-safe circuit). It became necessary for this single chip to incorporate:

① Microprocessor (operating on 5 V)
② Voltage regulator circuit (operating on 12 V)
③ Input/output interface circuit (operating on 12 V)
④ Output interface (operating on 12 V)
⑤ FET predriver (operating on 12 V and including a charge pump)
⑥ AD converter (operating on 5 V)

We therefore decided to adopt combined CMOS/DMOS technology and develop the single-chip ASIC conjunctionaly with Texas Instruments Japan. This company, having put combined CMOS/DMOS processes on the market at a relatively early stage, offers a cornucopia of actual circuit libraries. Figure 10 is a photograph of the IC we developed jointly with Texas Instruments. Figure 11 lists the absolute maximum ratings of this IC.


**Figure 10. External view of the ASIC**

| Item | Rating | Unit |
|---|---|---|
| Supply voltage | -1.0 to 40 | V |
| High-side predriver output voltage | -0.3 to 41.5 | V |
| Low-side driver output voltage | -0.3 to 60 | V |
| Low-side driver output current | 500 (DC) | mA |
| Input interface voltage | -0.5 to 40 | V |
| General-purpose I/O port voltage | -0.5 to 6 | V |
| Guaranteed operating temperature range | -40 to 105 | °C |

**Figure 11. Absolute maximum rating of the ASIC**

Since the beginning of its development planning stage, it took us about seven months to complete the development of engineering samples for this IC. This period amounts to half the time that would normally be required to develop a fully customized IC. We were able to halve the development period because we used existing circuit modules, or circuit blocks. Three different chip types were developed during this development period: Masked microprocessor, EPROM (OTP)-based microprocessor, and evaluation ICE chips.

Vehicle ECUs are required to be resistant to extraneous electromagnetic radiation. The development process used for the IC we developed is designed for on-board use, but is not up to our requirements. We therefore made improvements to the following:

① ESD resistance:
Resistance to malfunction/breakdown due to static electricity

② EMS performance:
Immunity to extraneous electromagnetic radiation

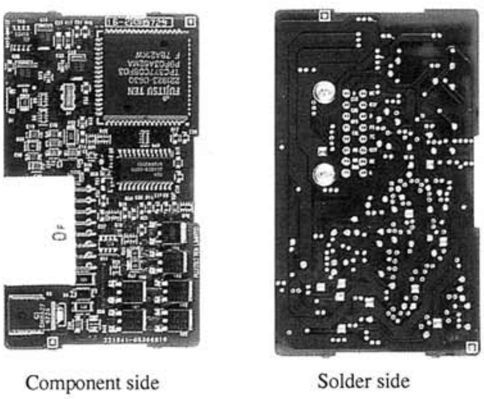
③ EMI:
Reduction of influence by internal electromagnetic radiation to the outside

The ESD resistance was enhanced by 25 kV on an ECU level by improving the layout of circuit components on the chip and the protection element. The EMS performance was improved by 200 V/m after preliminary surveys and circuit reviews. The EMI was reduced sufficiently by optimizing the clock driver and the circuit layout through preliminary examination. For the fail-safe circuit, its pin arrangement was optimized by performing FMEA in a manner similar to that applied to other LSI chips.

## 6. Mountingmethod and structure design

### 6.1 Mounting method design

In the newly developed electronic cruise control unit, all components except for the connectors are surface-mounted on a single side of a circuit board, thereby enabling cuts in the cost of production through reductions in the size of the product and a streamlined production process. Figure 12 shows how the components are mounted on the circuit board. To be more specific, !!(1)!! the size of the board has been reduced by 40%, and !!(2)!! the amount of time used in the soldering process for the board has been shortened by 50%.



Component side　　Solder side

**Figure 12. Printed circuit board**

The following sections describe the superior features of this mounting method and what areas we examined before deciding to employ it.

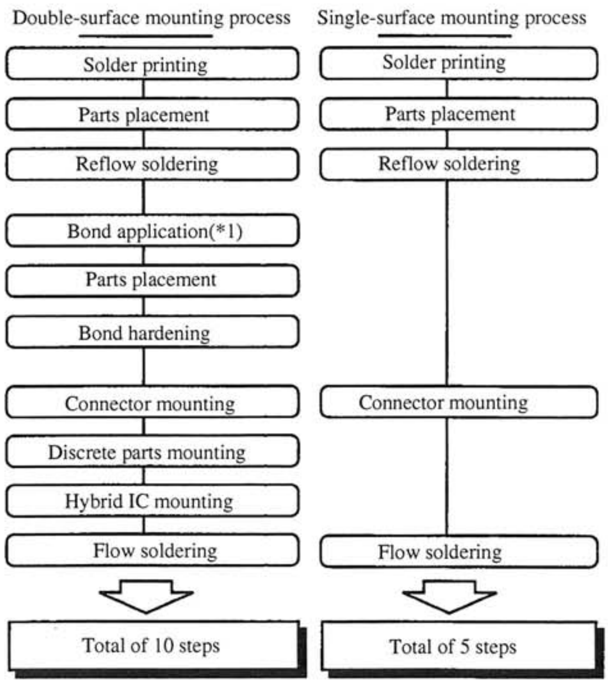
#### 6.1.1 Advantages of reflow soldering

Single-surface reflow soldering has the following advantages over double-surface reflow soldering:

(1) The soldering process can be halved, leading to efficient facility use.
As a specific example, Figure 13 compares the two method mounting types.
In single-surface mounting, neither surface-mountable devices nor discrete parts are mounted on the solder side of the circuit board. Accordingly, the mounting process was halved as compared with double-surface mounting, eliminating a need to expand production facilities.

(2) The soldering land size and parts-to-parts space can be reduced. In addition, the use of small parts such as chip resistor arrays allow for the reduction of the size of the circuit board.

(3) A solder printing method can be used to perform quantitative management of soldering quality, making it easier to shift production overseas.




*1 Bond is applied to fix chip parts.

**Figure 13. Comparison of soldering processes**

## 6.2 Structure design

Figure 14 shows the housing of the product. This is a two-piece structure designed for easy assembly. The two pieces are assembled by heat bending. Unlike conventional aluminum impact molding, heat bending does not require the use of screws and is suitable for assembly automation, leading to a reduction in the required assembly labor-hours. Moreover, heat bending assures easy assembly because of eased dimension tolerances at engaged parts, compared with resin tab-based fitting.

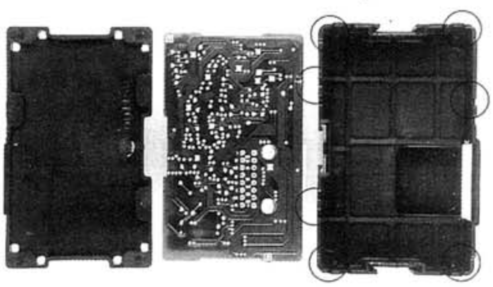



**Figure 14. Chassis structure**

The following section introduces the heat bending technology, which is a key to success in developing the structure of the new electronic cruise control unit.

### 6.2.1 Heat bending

Heat bending is a technology by which resin tabs are softened and bent by pressure and heat to fasten resin-made components, as shown in Figures 15 and 16. Other manufacturers are using this technology for the casing of components such as the throttle positioning sensor. To apply this technology to our product, we executed the following developments:

### 6.2.2 Selection of a material for the case

How reliably this process works varies with the material and heat bending conditions selected for a case to be made.

First of all, we carried out basic studies concerning the items listed in Figure 17 and, as a result, found out that PP is better suited to heat bending and priced lower than other types of materials. It is also sufficiently resistant to heat as it is molded into a case. We therefore decided to use this resin for the case of the cruise control unit.

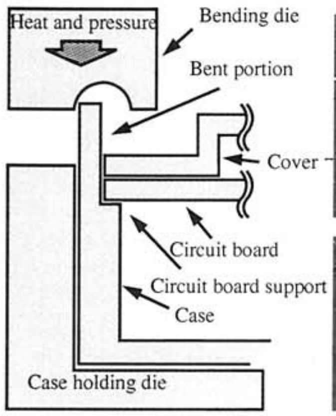



**Figure 15. Cross section of heat bending portion**

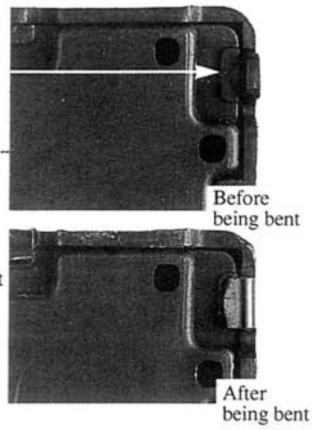



**Figure 16. Heat bending portion**

### 6.2.3 Study of bending conditions

The controlling factors in heat bending are heat, pressure, and time. First, we examined the interrelationships between the molding die temperature and bending time. Figure 18 shows the results of the examination. The results of the examination revealed that bends are most stable at a point near the heat distortion temperature of the resin, and a temperature range between the heat distortion temperature and +15°C above it is an effective region for heat bending. Second, we examined which molding die pressure can reduce the required heat bending time most effectively under the stable molding die conditions. Figure 19 shows the result. In this way, we were able to determine the optimum conditions for reliable heat bending within the minimum amount of time.

| Material | | PP | PPE | ABS | PBT |
|---|---|---|---|---|---|
| Heat resistance/heat distortion temperature | | ○ 135°C | ○ 120°C | △ 100°C | ◎ 200°C |
| Molding properties for case forming | | ○ | ◎ | ◎ | ○ |
| Heat bending properties | Shape of bent portion | ◎ | △ | △ | ○ |
| | State of heat distortion | ◎ | ○ | △ | ○ |
| | Mold shift | ○ | ○ | × | ○ |
| | Reliability | ◎ | △ | – | ○ |
| Overall evaluation | | ◎ | △ | × | ○ |

**Figure 17. Comparison of chassis materials**

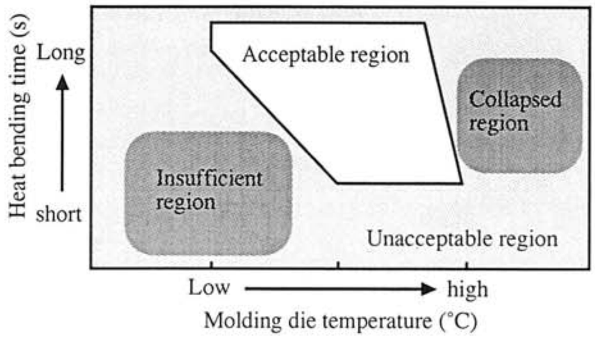



**Figure 18. Correlation between metal mold and bending temperatures**

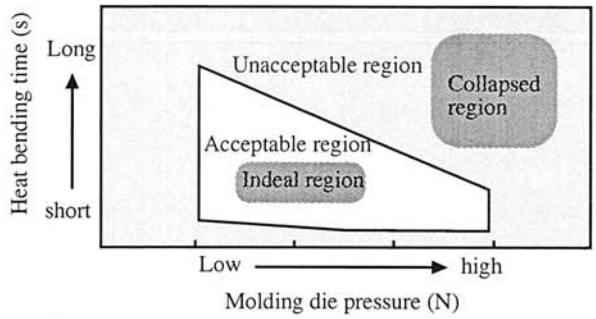



**Figure 19. Correlation between bending pressure and bending time**

## 7. Conclusion

We plan to develop electronic cruise control units with value-added functions, such as an electronic cruise control unit with a built-in actuator, using the ASIC to apply the fruits of our efforts to commercial products. We are also developing a reflow soldering technology for connectors. With this technology, we will be able to implement 100% reflow soldering in the manufacture of electronic cruise control units (including connectors).

In the future, we expect that an increasing number of manufacturers will shift their vehicle ECU production facilities to overseas locations. To cope with this trend, it is necessary to develop products that can be manufactured anywhere so that the needs of the customer can be met promptly. So, it will be important to design optimum circuits and select optimum materials so that production processes can be efficient.

Finally, we are deeply grateful to people at Toyota Motor Corp. who provided us with guidance on the development of new cruise control logic.

## References

(1) Teratani, et al., "The Current and Future States of Cruise Control Systems," Motor Technologies, Vol. 46, No. 2 (1992)

(2) Harada, "Cruise Control," TOYOTA Technical Reviews, Vol. 43, No. 1 (May, 1993)

(3) Murata, et al., "Cruise Control Systems and Small-Sized Electronic Control Units," Fujitsu TEN Technical Reviews, Vol. 11, No. 3 (1993)

(4) Takahashi, et al., "Fuzzy-Logic Cruise Control," Fujitsu TEN Technical Reviews, Vol. 19, No. 1 (1991)

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