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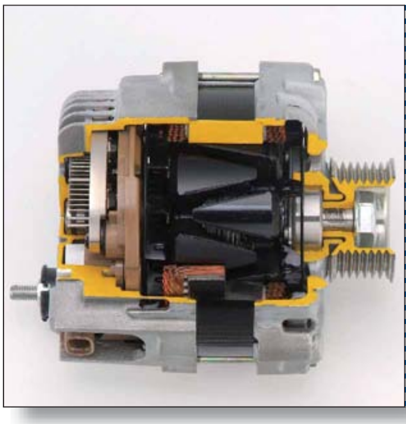
ADVANCE

Advanced Technologies for New Modern Automobile Lifestyle



MITSUBISHI ELECTRIC
Changes for the Better

Mar. 2008 / Vol. 121

MITSUBISHI ELECTRIC ADVANCE

Advanced Technologies for New Modern Automobile Lifestyle

Cover Story

Automobile technologies have been continuously developed in wider fields. These include technologies which consider environmental issues and fuel consumption as typically represented by the increase in the number of hybrid automobiles newly developed, digital technologies which have been increasingly incorporated in consumer-electronics products, and technologies to support social infrastructure as represented by ETC systems.

Photos show the representative Mitsubishi Electric products of the respective fields. Photos at the upper left and lower right show the alternator and electric power steering in the field of environmental technologies, while photos at the upper right and lower left show the navigation system in the field of information and entertainment technologies and the ETC in the field of technologies to support social infrastructure.

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Overview

Author: *Atsushi Ueda**

Contribution to the Special Issue on Advanced Technologies for New Modern Automobile Lifestyle

In the global auto industry today, major developed markets such as Japan, the U.S. and Europe are unlikely to grow significantly, whereas sales volumes are rising, albeit not steadily, in the emerging markets of Brazil, Russia, India, and China (BRICs). Automobiles are facing difficult times with challenges such as global warming, higher crude oil prices, and traffic accidents. Against this backdrop, technological developments for better fuel consumption and conservation of natural resources, as well as safety and security, are becoming increasingly important for the whole auto industry. Mitsubishi Electric is working hard to develop and use state-of-the-art technologies and new products.

Automobiles in the 21st century must be in harmony with the environment, people-friendly, and enjoyable. Future development efforts must encompass diverse, sophisticated research and development based on not only downsizing and light-weight design techniques and advanced electronics control techniques, but also communications and information technologies. Mitsubishi Electric will use and integrate these to successfully develop “advanced technologies for a new modern automobile lifestyle,” and thus, we will continue to contribute to the development of society through creating a new automobile culture in the 21st century.

* *Senior Executive Officer, Group President, Automotive Equipment Group*

New Generation (9G) Alternator

Authors: *Wakaki Miyaji** and *Atsushi Oohashi**

1. Introduction

To meet the demands of major automobile manufacturers for high-performance products, we have developed a new generation (9G) alternator with higher output and efficiency without sacrificing quietness, by using state-of-the-art manufacturing technologies for improving the fill factor of the stator coil for which conventional methods had reached their limit, This report introduces technological aspects of the stator used for the new generation (9G) alternator.

2. Trends of Alternators

Alternators for automobiles in general are driven via belt by engines for AC generation, and the current thus generated is converted into DC by built-in rectifiers to provide electric power to the various electric loads on the vehicle and also to recharge its battery. Recently, electric loads on automobiles have increased further as the number of electronics-based systems have increased to meet demands related to the environment, safety and security, and information and entertainment.

As for environmental needs, after the Kyoto Protocol, which was adopted at the Third Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP3) in 1997, announced legally binding reduction targets for greenhouse gas emissions for respective advanced nations, controls on automobile fuel consumption have been tightened worldwide in order to reduce CO_2 emissions. (1) In order to satisfy these regulations on improving fuel economy, the electrical loads on automobiles, directly or indirectly have rapidly increased. As a result, technological requirements for alternators have become much more complicated.

3. Challenges for Alternators

The recent technological challenges for alternators are described below. The development themes listed below are trade-offs to each other yet must be solved simultaneously.

(1) High outputs for increased electrical loads

As mechanical engine accessories are increasingly motorized to improve fuel economy, the output of alternators will need to be increased by 30 amperes by the year 2015.

(2) High power generation efficiency

Even if mechanical engine accessories are motorized, its merits would be offset if alternator power generation efficiency were low, because driving torque will increase for higher output.

(3) Compact and light-weight

The high outputs of alternators must be attained without increasing the size of alternators, due to vehicle requirement for weight reduction and limited underhood space.

(4) Quietness

Quietness of each engine part is strongly required in order to increase product value of the vehicle. Therefore, power generation noise, which tends to increase when alternator output is enhanced, must be lowered.

4. Technological Features of New Generation (9G) Alternator

4.1 Outline of new generation (9G) alternator

We have solved the above problems and completed the development of the new generation (9G) alternator (Fig. 1) by simultaneously improving the fill factor of the stator coils and increasing both the cooling performance and noise suppression required for increased output levels. The technological features are described below.

Fig. 1 9G Alternator

(1) Output current: Increased by 54% (against the conventional model 6GA)
(2) Power generation efficiency: Increased by 12% (against the conventional model 6GA)
(3) Electromagnetic noise: Reduced by 10 dB (against the conventional model 6GA)

4.2 Improvement of stator fill factor

The factor that most influences the power genera-

*Himeji Works

tion efficiency of an alternator is the copper loss of the stator. With the conventional model 6GA series, the copper loss accounts for approximately 67% of the total loss under full load and temperature saturated condition. One effective way to reduce the copper loss of a stator is to increase the cross section area of the coil by making the most of the available stator coil winding space, that is to say, increasing coil fill factor (∑ copper wire cross-section/stator coil winding space). For example, Mitsubishi developed and commercially produced the 8GM alternator with higher fill factor by applying coil forming only to the portion to be inside the slots of the stator core, whereas no coil forming was conducted on 6GA stator.

However, the scope for improving the fill factor by this method is limited since the copper wires in the conventional models must be inserted axially into the stator core in the manufacturing process.

Meanwhile in 1993, we developed a stator structure called "Poki-Poki motor", and this structure has since been employed in various information devices, factory automation equipment, electric home appliances, automobile devices, and elevators. This original technology of Mitsubishi can improve the fill factor without sacrificing productivity. [2]

Under these circumstances, we have developed a new stator manufacturing method that combines the conventional 8GM technology (partial coil forming for copper lines in the slot) with the Poki-Poki motor technology. The stator cores, which are ring-shaped in conventional models, are now flat bands. Furthermore, band shaped strands of continuous copper wires, to which coil forming is conducted, are inserted into the opening of the slot (see Figs. 2 and 3). This method has dramatically improved the fill factor of the stator coil (Fig. 4) and reduced the coil resistance remarkably by reducing the height of the coil end.

Fig. 2 9G Stator

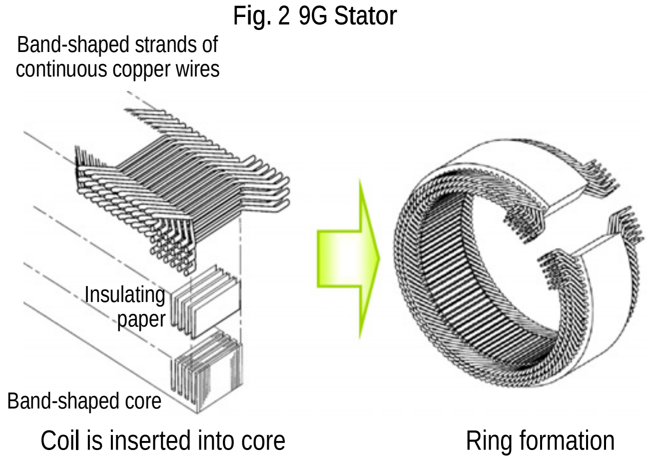


Fig. 3 Manufacturing method of 9G stator

4.3 Improved cooling performance

Higher output without changing the size of an alternator increases the temperature of the alternator components. When designing the alternator, it is desir-

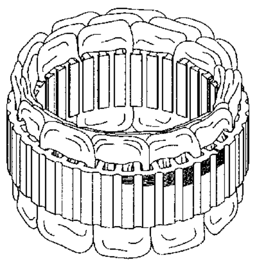
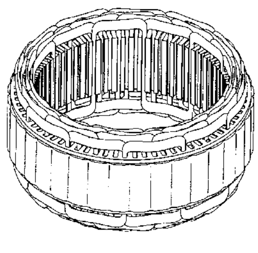
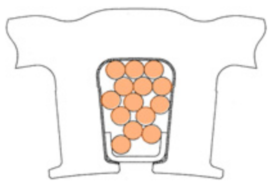
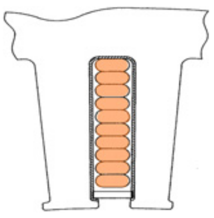
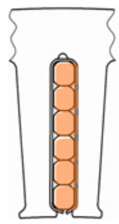
	Conventional models		New generation model
	6GA	8GM	9G
Appearance			
Slot cross section	 Fill factor: 60%	 Fill factor: 72%	 Fill factor: 85%

Fig. 4 Comparison of stator structure

able to improve the cooling performance as far as is practical, to minimize the use of heat-resistant parts that increase material costs. Figure 5 shows the improved heat transfer performance of the bracket as an example of the cooling performance improvements we have incorporated in the new 9G alternators.

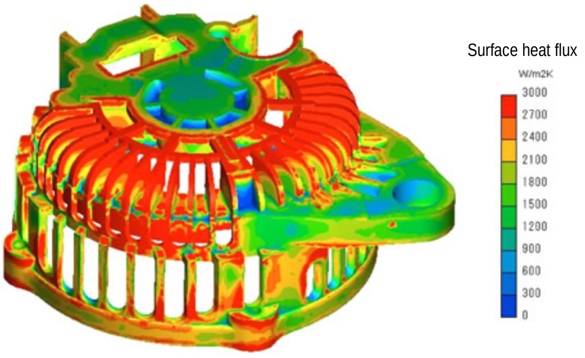


Fig. 5 Case example of heat transfer analysis

5. Conclusion

This report has introduced stator manufacturing technology that remarkably improves the fill factor, and design technology for the cooling mechanism on the basis of thermo-fluid analysis. These technologies have contributed to the successful development of alternators that feature high output, high efficiency, compact size, reduced weight, and low noise. We will continue to develop technologies for higher outputs and efficiencies.

References:

(1) Data from the web page of the Ministry of Environment (published information)

(2) N. Miyake: New Motor Manufacturing Technologies, Mitsubishi Denki Giho, 76, No. 6, pp. 426-430 (2002)

Development of the GMR (Giant Magnetoresistance) Revolution Sensor

Authors: *Yuji Kawano** and *Hiroshi Sakanoue**

1. Introduction

Improved fuel efficiency of automobiles is becoming increasingly important for environmental reasons, and so complex fuel injection control, ignition timing control, and shift transmission control are needed. In addition, new systems to support early ignition during start-up and to stop idling will play important roles.

Revolution sensors for automobiles are used to detect the operation of the engine or transmission based on the revolution of gears, and to control the engine and transmission. To attain detailed control of the mechanisms, the angle of revolution must be detected very accurately. To develop a new system, detection of revolution conditions (such as the stop position and revolution direction) should be also incorporated.

Mitsubishi has applied a GMR element, which is a high-quality magneto-electric transducer element (to convert magnetic field strength to voltage), to revolution sensors for automobiles for the first time in the world and is now manufacturing the sensors (standard type sensors) commercially [1]. We have also developed and mass-produced sensors that can detect the stop positions of rotation (stop position detection sensors) and sensors that can detect the revolution direction (reverse revolution detection sensors).

This report introduces the line-up of GMR revolution sensors and discusses their technological features.

2. Revolution Sensors for Automobiles

Figure 1 shows the detection system of a typical revolution sensor for automobiles. The system consists of a gear wheel mounted on an axis of revolution (engine crank shaft, for example) and a revolution sensor installed end to end with the gear wheel. The revolution sensor contains a magneto-electric transducer element and a magnet. As the magnetic field formed by the magnet and the gear wheel, which is made of a soft magnetic material, changes as the wheel rotates, the element detects the changes.

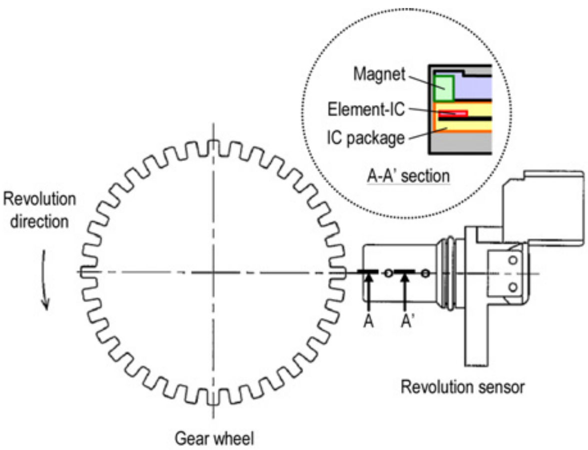


Fig. 1 Revolution sensor detection system for automobiles

3. GMR Revolution Sensor

3.1 Features

To achieve sensors of high accuracy, it is important to obtain signals with a high signal to noise (S/N) ratio. Table 1 shows the performance of the magneto-electric transducer elements used for revolution sensors for automobiles. The sensitivity and the MR ratio of the GMR element are respectively more than 10 times higher than the sensitivity of a Hall element and the MR ratio of a ferromagnetic MR element. In short, a large signal amplitude can be obtained with the GMR element in practical magnetic fields, thus realizing high S/N ratios.

Table 1 Performance of magneto-electric transducer elements

	GMR	Hall	(Anisotropic) MR
NR ratio	Good ≥30%	Good ∞	Fair 2-3%
Sensitivity	good 25 μV/V/(A/m)	poor 0.1 μV/V/(A/m)	good 25 μV/V/(A/m)
Temperature coefficient of resistance	good -1000 ppm/°C	poor -5000 ppm/°C	good -3500 ppm/°C
Thermal stability	good	fair	good
Integration with IC	good	good	good

3.2 Mechanism of detection

Figure 2 shows the MR curve of the GMR element. The magnet inside the sensor generates a bias field in the GMR element. As a tooth of the gear wheel comes close to the element, the magnetic field applied to the element expands, thus reducing the electric resistance of the element.

3.3 Block diagram

Figure 3 shows the basic block diagram of the GMR revolution sensor. The GMR elements constitute

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a Wheatstone bridge. The midpoint voltage level of the bridge is amplified by the differential amplifier and output as a digital signal via the comparator.

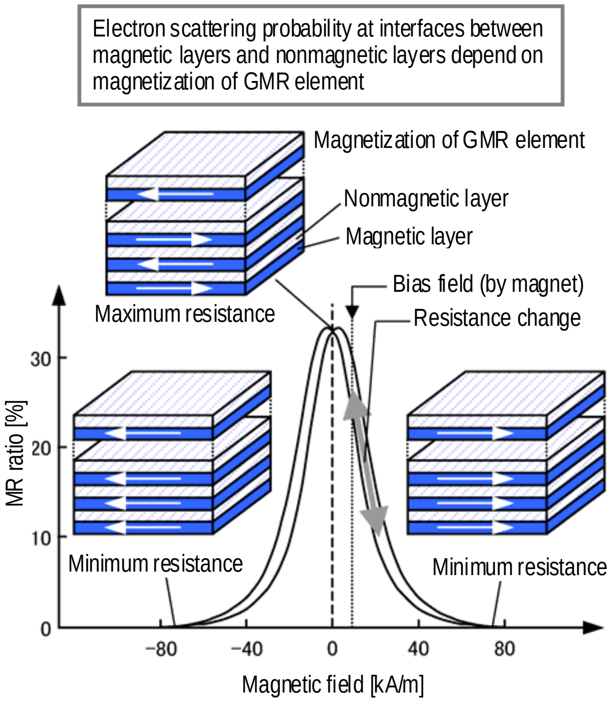
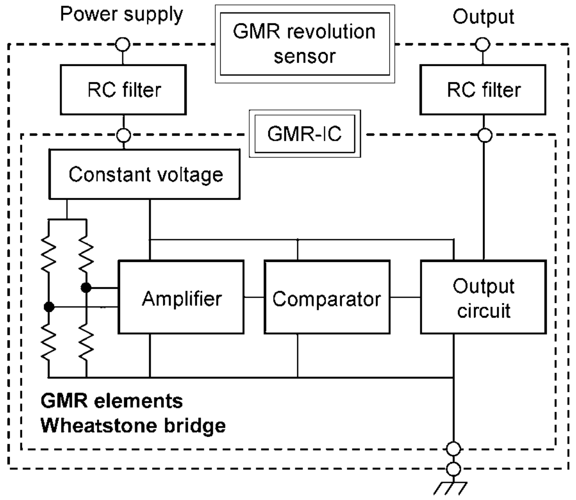


Fig. 2 MR curve of a GMR element

4. Line-up and Features of GMR Revolution Sensor

Figure 4 shows the line-up of the GMR revolution sensors.



Reverse revolution detection sensor consists of two series of circuits "Bridge – Amplifier – Comparator" and logic circuit before output circuit.

Fig. 3 Block diagram of the GMR revolution sensor

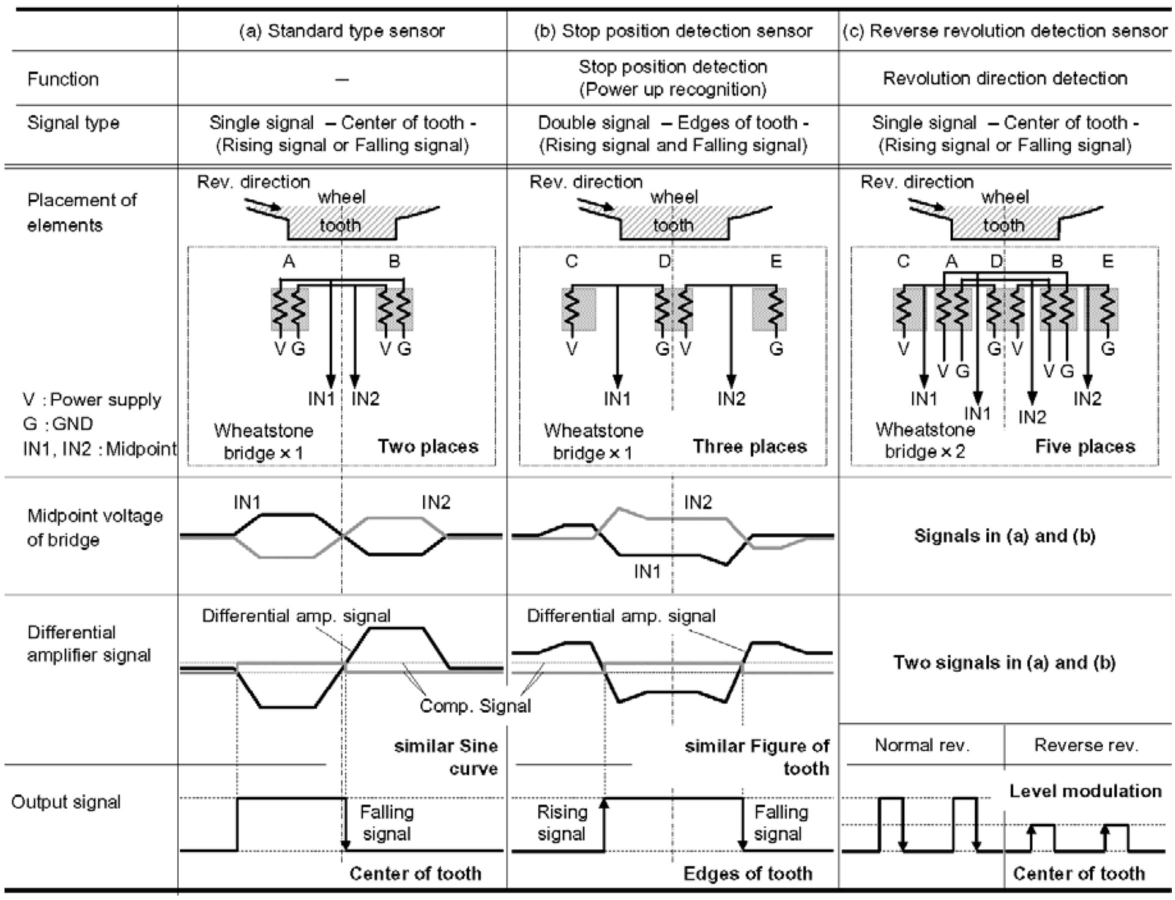


Fig. 4 Line-up and features of the GMR revolution sensor

4.1 Standard type sensor

Figure 4(a) shows the placement of elements and signal form of a standard type sensor. Elements are placed in two positions on the IC and constitute a Wheatstone bridge. When, as a result of gear wheel revolution, magnetic field is applied to the region A and then the region B shown in the figure, for example, the signal for the midpoint voltage level of a Wheatstone bridge, after the differential amplifier (differential amp. signal), changes similarly to a sine curve with the peak level located near two edges of the tooth; consequently, the edge signal[*1] (falling signal shown in the figure) as an output signal from the comparator is output near the center of the tooth. High-accuracy detection results from properly placing the GMR elements of high output to form a Wheatstone bridge.

4.2 Stop position detection sensor

Figure 4(b) shows the placement of elements and signal form of a stop position detection sensor. Elements are placed in three positions on the IC and constitute a Wheatstone bridge. When, as a result of gear wheel revolution, magnetic field is applied to region C, region D and then the region E shown in the figure in this order, for example, the signal for the midpoint voltage level of a Wheatstone bridge, after the differential amplifier (differential amp. signal), changes similar to the shape of the tooth; consequently, the edge signals (rising signal and falling signal shown in the figure) as output signals from the comparator are output near both edges of the tooth. For the signal form similar to the shape of the tooth, the voltage level is output in accordance with the shape, either a tooth or a slot, even when the gear wheel has stopped.

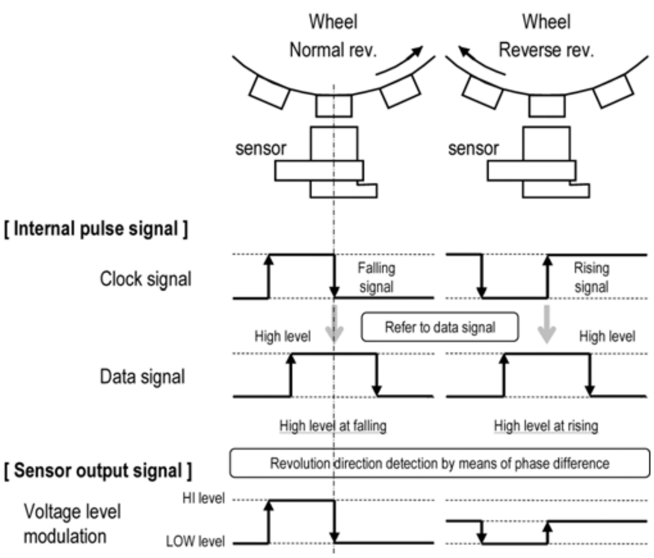


Figure 5 Principle of revolution direction detection

4.3 Reverse revolution detection sensor

Figure 5 shows the principle of revolution direction detection. Two types of signals are required for detecting the revolution direction of a gear wheel. A data signal (reference signal for revolution direction) is detected with the timing of the clock signal and checked, to finally determine the revolution direction (normal or reverse) by the logic circuit. So, these signals are required to have phase differences. The standard type sensor signals (center of a tooth) and the stop position detection sensor signals (edges of a tooth) theoretically have phase differences, and so are suitable for detecting revolution direction.

Figure 4(c) shows the placement of elements and signal form of a reverse revolution detection sensor. Elements are placed in five positions on the IC and constitute two Wheatstone bridges. Region A and region B constitute the standard type sensor element, while regions C, D, and E constitute the stop position detection sensor element. Two types of elements are incorporated in the reverse revolution detection sensor.

The direction of revolution is judged by the logic circuit as mentioned above by means of two signals from the two Wheatstone bridges. The output signals represent the direction of revolution by changing the HI level and/or LOW level in accordance with the direction of revolution (level modulation). With the newly developed sensor, an edge signal is output near the center of a tooth, and so is highly compatible with the standard type sensor, allowing for both high accuracy and revolution direction detection.

We have created highly accurate GMR revolution sensors and improved the related functions. We will modify these sensors for wide application to assist the development of highly efficient and low fuel-consumption power trains.

Reference:

(1) Motohisa Taguchi, et al.: GMR Revolution Sensors for Automobiles, SAE2000-01-0540

[*1] Position signal used for control

Third-Generation Fuel Pump Module for Medium & Large-sized Motorcycles

Authors: *Hiroshi Yoshioka** and *Kazuyuki Yamamoto***

As the number of electronically-controlled products complying with exhaust gas regulations installed on medium and large-sized motorcycles increases, the total weight of the motorcycles has increased and the balance between discharging and charging has deteriorated. To solve this problem, we developed the Third-Generation Fuel Pump Module which is compact, light weight, and low in power consumption by downsizing the components of the T35 fuel pump and its housing module.

1. Features of T35 Fuel Pump and Development Means

A fuel pump consists of a pump part equipped with an impeller for suction and pressure feeding of fuel, a motor part equipped with a rotor and a magnet for driving the impeller, and a power supply part for supplying power to the rotor (Fig. 1). The T35 fuel pump features the following improvements over conventional fuel pumps.

(1) The components of the fuel pump have been optimized and the total length of the rotor that constitutes the motor in particular has been shortened, resulting in a compact and light model, with both volume and mass approximately 40% less than conventional models.

(2) With the structure of the rotor core modified, the packing factor of the winding is improved and the current consumption has been reduced by 35%.

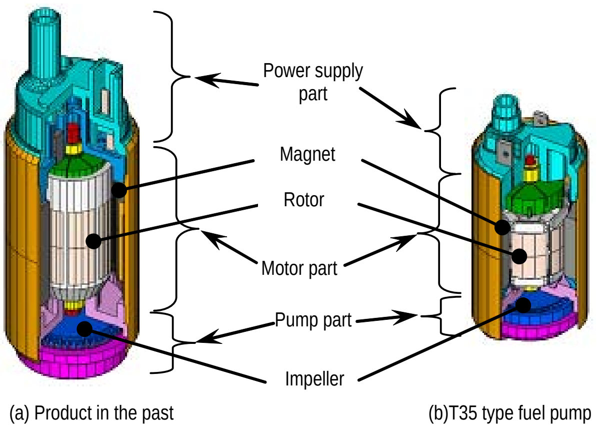


Fig. 1 Main body of the fuel pump

These achievements have been attained as follows. The winding method for the rotor has been changed from the conventional distributed winding to concentrated winding to reduce the total length of the rotor (Fig. 2). In the conventional distributed winding method, a coil was wound across different teeth and four layers were stacked one on top of the other, so the end-winding was high and the total length of the rotor was very long. However, with the concentrated winding method, coil winding is made for each tooth without interfering with the winding on another tooth, resulting in a low end-winding.

For the rotor core of the motor, a sliding tooth division core structure has replaced the conventional integrated core (Fig. 3). With the conventional integrated core, the coil was wound via a gap between teeth. Using the sliding tooth division core structure, each tooth can be taken out for aligned coil winding. As a result, the coil winding characteristic, which has long been a technological challenge, has been improved and the packing factor has also been increased. With the combination of the sliding tooth division core structure and a powerful magnet, the new fuel pump offers improved motor efficiency and low current consumption.

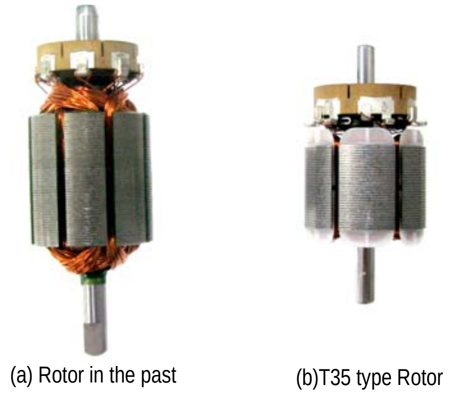


Fig.2 Rotor winding

Fig.3 Sliding tooth division core structure and concentrated winding

2. Features of Fuel Pump Module and Development Means

A fuel pump module consists of fuel system components, such as a fuel pump, a suction filter, a high-pressure side filter, and a pressure regulator, and an installation bracket to support and mount these components on the fuel tank. For motorcycle-specific needs of rapid acceleration or deceleration and right or left turning, the fuel accumulation part is installed near the suction filter so that fuel suction operates reliably even when little fuel remains. A metallic material is used for the plate of the installation bracket which serves as the cover of the fuel tank installation hole, thus increasing the breaking load and preventing fuel leakage (Fig. 4).

The Third-Generation Fuel Pump Module for Medium & Large-sized Motorcycles (Fig. 4(b)) is 30% smaller in volume than the conventional model thanks to the use of a smaller T35 fuel pump. In addition, the weight has been reduced by 30% from the conventional model by changing the material from metal to resin, without sacrificing safety.

These achievements have been attained as follows. The T35 fuel pump having a short total length is incorporated in the Third-Generation Fuel Pump Module. As a result, the cup-shaped part for fuel accumulation provided on the metal plate in the conventional model has been eliminated, so there is no protrusion at the bottom of the fuel tank. Furthermore, the fuel accumulation part, which is made of metal in conventional models, has been changed to a resin part, to reduce weight. The fuel accumulation part has been designed to support the structure of the T35 fuel pump and reduce the outer diameter of the fuel pump module. In addition, this fuel accumulation part in the new module can hold 100% of the surplus fuel unconsumed in the engine after discharging from the fuel pump and discharged from the pressure regulator, and the fuel accumulated in the fuel accumulator part is fed to the suction filter without fail. As a result, motorcycle riders no longer need be concerned about an insufficient flow of fuel when changing the position of their machines (Fig. 5).

The filtering material of the suction filter has also been changed for improved performance; the clogging-induced service life of the high-pressure side filter in the downstream has been improved. In addition, the effective filtration area of the high-pressure side filter is optimized and its dimensions effectively reduced (Fig. 6).

Thanks to the above development techniques, the

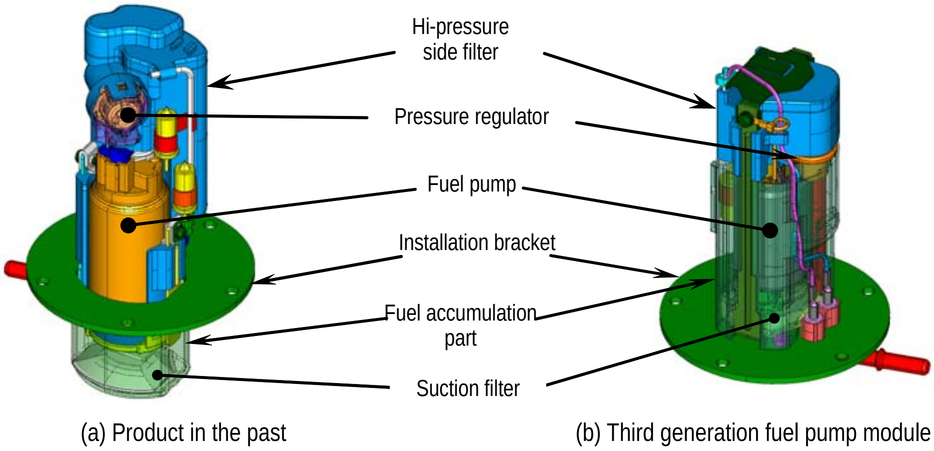


Fig.4 Fuel pump module

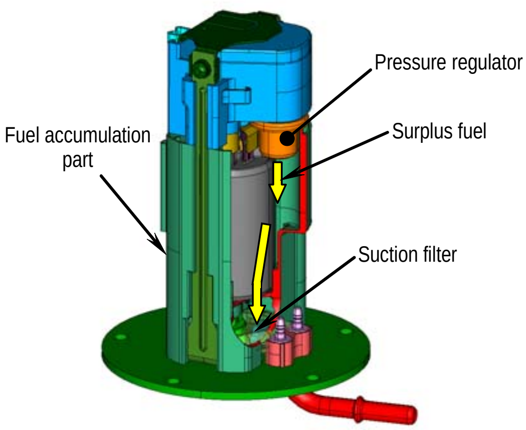


Fig.5 Structure of the fuel accumulation part

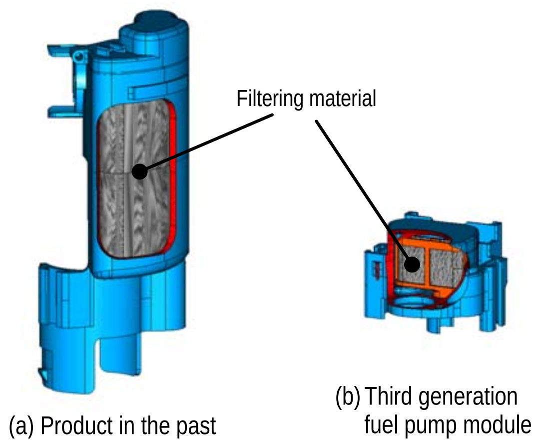


Fig.6 Miniaturization of the high-pressure side filter

Third-Generation Fuel Pump Module for Medium & Large-sized Motorcycles has a low height and weight, and so can be applied to a wide range of motorcycles, including design-conscious American type motorcycles equipped with low-profile fuel tanks and super-sports type motorcycles requiring a high power-to-weight ratio (Fig. 7).

In future, we will work on further reducing the size, weight, and power consumption to contribute to the advancement of motorcycles.

Fig.7 Third generation fuel pump module for middle & large-sized motorcycles

Torque Controlled Active Steering for Electric Power Steering

Authors: *Hideyuki Tanaka** and *Takanori Matsunaga**

1. Introduction

The market for electric power steering systems (EPS) that help drivers to steer is expanding. This report introduces a new assist torque control method that can stabilize vehicles on a slippery road such as a snow-covered road, to improve the performance of the EPS.

2. Characteristics of Slippery Road Surfaces

Vehicle stability decreases on a slippery road (called a low-μ road hereafter), and may lead to spinning off the road. As shown in Fig. 1, the cornering force increases in proportion to the slip angle when the wheel slip angle is small (a). However, as the slip angle increases, the rate of increase of cornering force decreases and finally the cornering force saturates (b). On the other hand, lower road surface μ tends to lower the rate of increase of cornering force and the slip angle at which the cornering force saturates (c).

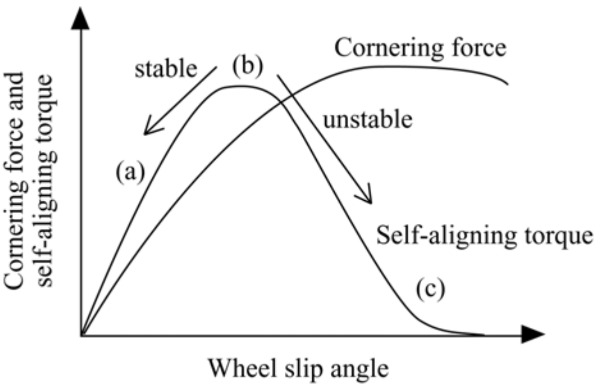


Fig. 1 Cornering force and self-aligning torque

The self-aligning torque also tends to increase linearly when the wheel slip angle is small. However, the self-aligning torque saturates at a smaller slip angle than that at which the cornering force saturates, and decreases further after reaching that point.

It is also known that the vehicle stability on a low-μ road is lower than that on a dry asphalt road (called a high-μ road hereafter). This matches the phenomenon of reduced maneuverability including driver performance on low-μ roads, indicating that vehicle stability and maneuverability are correlated.

3. Linear Analysis of Vehicles Equipped with EPS

This section discusses the linear analysis of the self-aligning torque feedback controller. Equations (1) through (3) shown below are dynamic equations of a vehicle equipped with EPS and Fig. 2 shows the model representation.

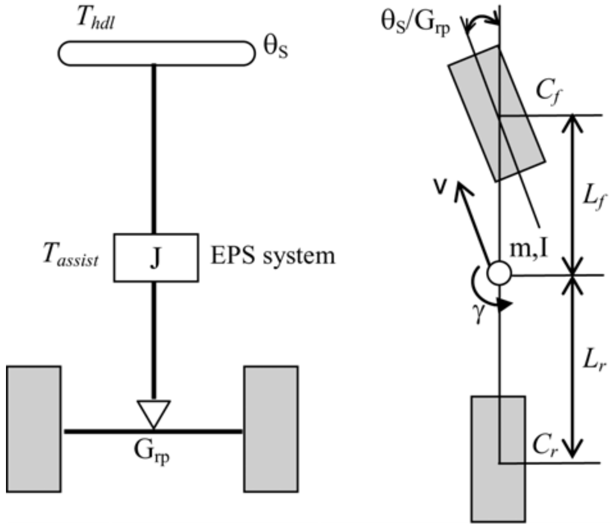


Fig. 2 Model of the vehicle and the steering system

$$J\ddot{\theta}_S + c\dot{\theta}_S = T_{assist} + T_{hdl} - \frac{\xi}{G_{rp}} C_f \left(\frac{\theta_S}{G_{rp}} - \frac{L_f}{V}\gamma - \beta \right) \quad (1)$$

$$mV\dot{\beta} = -2(C_f + C_r)\beta + \left\{ -mV - \frac{2}{V}(L_f C_f - L_r C_r) \right\}\gamma + 2Cf\frac{\theta_S}{G_{rp}} \quad (2)$$

$$I\dot{\gamma} = -2(L_f C_f - L_r C_r)\beta - \frac{2(L_f^2 C_f + L_r^2 C_r)}{V}\gamma + 2L_f C_f \frac{\theta_S}{G_{rp}} \quad (3)$$

T_{assist} by the controller mentioned above is defined by:

$$T_{assist} = -\alpha_1 \frac{\xi}{G_{rp}} C_f \left(\frac{\theta_S}{G_{rp}} - \frac{L_f}{V}\gamma - \beta \right) \quad (4)$$

Figure 3 shows the results of linear analysis of differential equations (1) through (4). According to the results, the pole position expands toward the negative direction compared to the pole position of a system without any control; hence, the vehicle stability has been improved by the controller.

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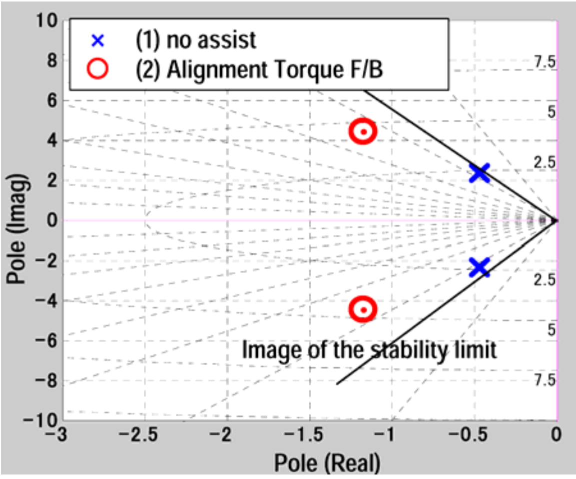


Fig. 3 Pole analysis of dynamics (Low μ)

4. Control Strategy and Self-Aligning Torque Estimator

We have built an EPS controller in accordance with the following strategies for assisting the maneuvering speed of the driver by adding steering return torque by means of self-aligning torque.

(1) Vehicle stability shall be improved by assisting the steering wheel torque even on a low-μ road.
(2) The controller configuration shall be built without adding new sensors.
(3) No other EPS compensation function shall be affected.

Figure 4 shows the block diagram of our newly developed controller. First, the self-aligning torque is estimated from the steering torque supplied by the driver and the assist torque of EPS. Then, the steering return torque is assisted based on the estimated value of the self-aligning torque.

The self-aligning torque estimator obtains the estimated value of the self-aligning torque by eliminating nonlinear elements such as friction torque and the like by using a filter in accordance with the vehicle state values. Figure 5 shows the self-alignment torque values estimated by the estimator, confirming the accuracy of the values from low to high frequencies.

5. On-vehicle Test Results

We conducted slalom testing on a snow-covered testing road using an actual car to evaluate the maneuverability including driver performance and vehicle stability.

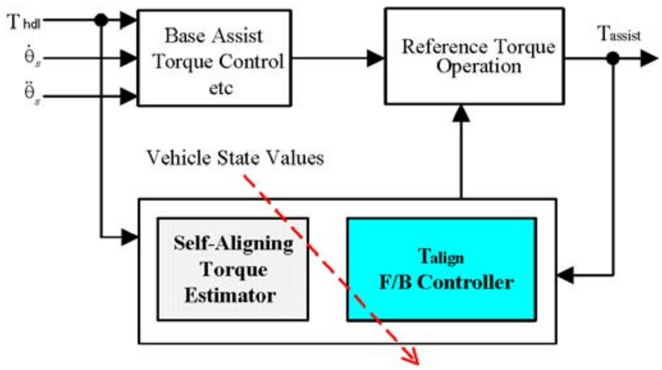


Fig. 4 Block diagram of the new controller

5. On-vehicle Test Results

We conducted slalom testing on a snow-covered testing road using an actual car to evaluate the maneuverability including driver performance and vehicle stability.

Figure 6 shows that the delay time during steering wheel return is improved by approximately 0.5 seconds by using the control algorithm of this paper, compared to the conventional control, and that the vehicle instability due to the delay in return was reduced. In short, the algorithm improves maneuverability including driver performance and vehicle stability.

We will continue to develop EPS technologies to improve value-added mechanisms, which will not only help EPS as actuators but also significantly contribute to vehicle stability.

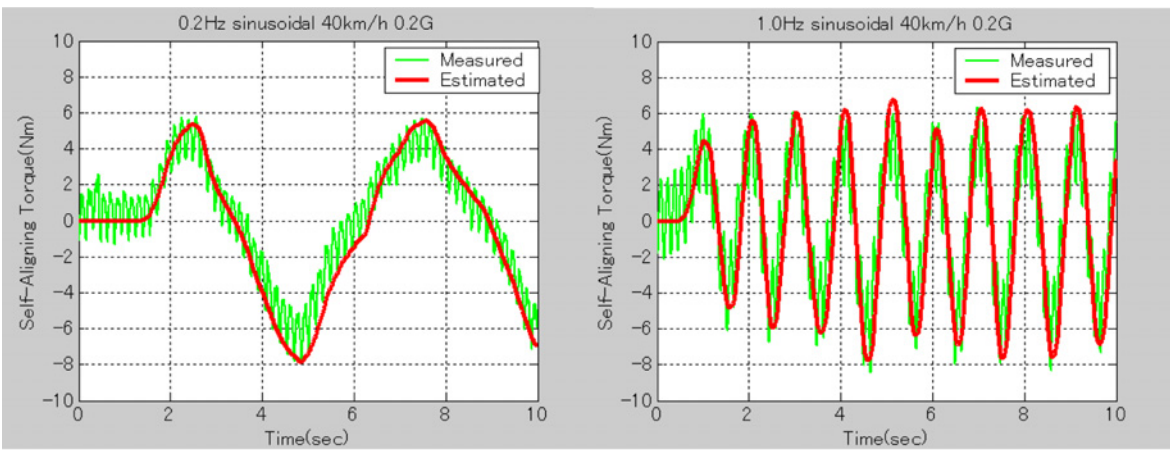


Fig. 5 Estimation results of the self-aligning torque

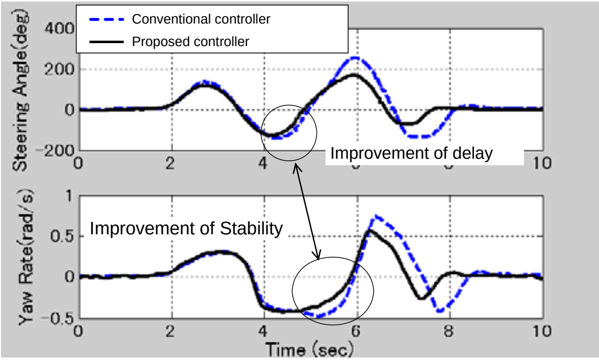


Fig. 6 Test of slalom steering

Reference:

(1) Tanaka H. et al., Torque Controlled Active Steering for EPS, In Proc. International Symposium on Advanced Vehicle Control, 501-506, 2004

Electronic Ballast for Mercury-Free Xenon Lamps

Authors: *Hiroyuki Hasebe** and *Naoto Maruo***

1. Introduction

Bulbs of xenon head lamps most widely used today contain a trace amount of mercury. Getting rid of mercury from the bulbs is required for environmental reasons. The electrical characteristics of mercury-free bulbs are different from those of conventional bulbs especially in terms of luminous efficiency during run-up period and rated current in the stable state. This report discusses the development of an electronic control unit (electronic ballast) that drives a mercury-free bulb.

2. Xenon Head Lamp and Mercury-Free Bulb

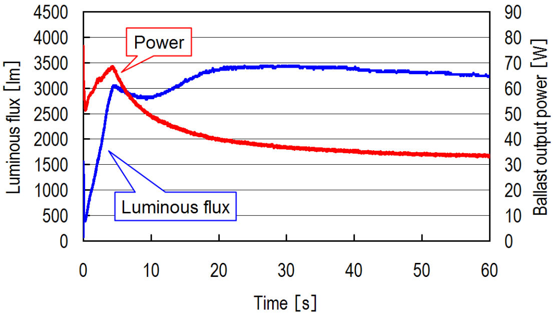
A xenon head lamp has twice the luminance of a conventional halogen lamp, four times the service life, and yet consumes just two-thirds of the power, so it has increasingly been used to improve driving safety at night. Mitsubishi Electric has developed and manufactured electronic ballasts that drive the xenon bulbs used as the light source of xenon headlamps and the products are shipped not only in Japan but also to markets in Europe and North America.

The bulbs of today's mainstream xenon lamps contain a trace amount of mercury for emitting visible light and holding the valve voltage at a high level. However, mercury is one of the substances prohibited in principle in the European End of Life Vehicle Directive, and its use in xenon bulbs is exceptionally permitted since it is technically difficult to replace it with another substance. Nevertheless, as xenon systems will eventually have to be mercury free, bulb manufacturers have continued work on developing mercury-free bulbs.

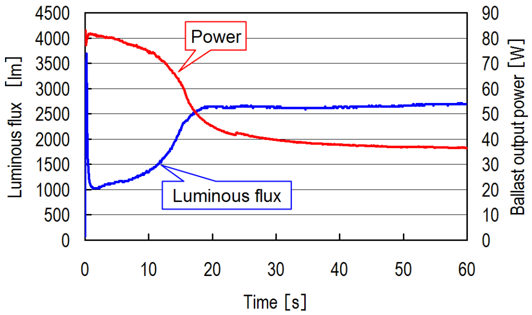
Although one newly selected material for mercury-free bulbs improves the bulb voltage, it does not perform the same as the conventional material. Table 1 and Fig. 1 show the differences in the run-up power and rated bulb current between the bulbs.

Table 1 Comparison between a conventional bulb and the mercury-free bulb

	Conventional bulb	Mercury free bulb
Run-up power	70 W	75 W
Steady state power	35 W	35 W
Rating bulb voltage	85 V	42 V
Rating bulb current	0.41 A	0.83 A



(a) Conventional bulb



(b) Mercury free bulb

Fig. 1 Comparison of luminous run-up characteristics

3. Ballast for Xenon Headlamp

The xenon system at the heart of the xenon headlamp consists of a bulb, an igniter, and ballast. Of these components, the ballast has the following functions.

(1) The ballast converts the battery voltage (rated level: 12V) into the voltage level required for the bulb (400V for open circuit voltage and rated 42V for stable state).

(2) The ballast supplies 1 kV power for ignition trigger.

(3) The ballast supplies a high power (75W) for quick luminous run-up while the luminous efficiency of the bulb is low during run-up. After the period, the ballast decreases the output power gradually to the rated power output of 35 W so that the brightness does not change suddenly as the luminous efficiency of the bulb grows.

Since the electrical characteristics of mercury-free bulbs are greatly different from those of the conventional bulbs as described above, conventional ballasts cannot drive mercury-free bulbs. Mitsubishi started shipping ballasts for mercury-free bulbs to European markets in 2007.

The delay in luminous run-up during lamp run-up of

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a mercury-free bulb is partly compensated by an increase in initial power to the bulb and by an extension of the power supply time on the ballast. However, for the ballast itself, the power loss with regard to the input/output current increases. In addition, even in the stable state, the rated bulb current required to output the same power is double that of the conventional valve, because the rated bulb voltage of a mercury-free bulb is almost half that of a conventional bulb. Thus, the increased output current increases the power loss, which must be controlled properly because it raises the temperature of the ballast and lowers the reliability during operation.

Also, reduction in ballast size is another issue required for installation on vehicles (headlamps)

To develop ballasts for mercury-free bulbs, we aimed to reduce the power loss and product dimensions to equivalent levels of the conventional types or less.

4. Technological Components of Ballasts for Mercury-Free Bulbs

First, we changed the DC/DC converter from a single system to a dual system. With this modification, the current per diode remains at the same level as the conventional ballasts even when the output current during stable illumination of a mercury-free bulb is doubled, thus suppressing an increase in forward power loss (forward voltage × current) per diode. In addition, the phase of the dual system is shifted 180° (Fig. 2) to control output/input ripples, thus improving the circuit efficiency.

Next, we replaced the drive-frequency fixed hard switching method of the conventional ballasts by the zero voltage switching (ZVS) method that reduces switching loss, and we used a newly developed application specific integrated circuit (ASIC) to drive the ZVS. The ASIC is equipped with an internal power supply circuit and power control circuit that are made of discrete devices in the conventional ballasts, thus successfully limiting the increase in number of component devices and product size.

Thirdly, the DC/DC converter operates at high frequency and the transformer and smoothing capacitor have been made smaller. With the conventional hard switching method it was difficult to employ high-frequency operation because a high-frequency DC/DC converter increases the switching loss. However, with the new model, the ZVS method allows high-frequency operation without affecting the efficiency.

Lastly, we used an insulated gate bipolar transistor (IGBT) for the inverter element that changes the polarity of the output current. IGBT is characterized by the on-state voltage decreases and the on-state power loss decreases with increasing temperature. Furthermore, since the on-state power loss is proportional to the current, IGBT is more effective than MOS FET in reducing the on-state power loss in a high-current mode. (The on-sate power loss with MOS FET in the conventional method was proportional to the square of the current.)

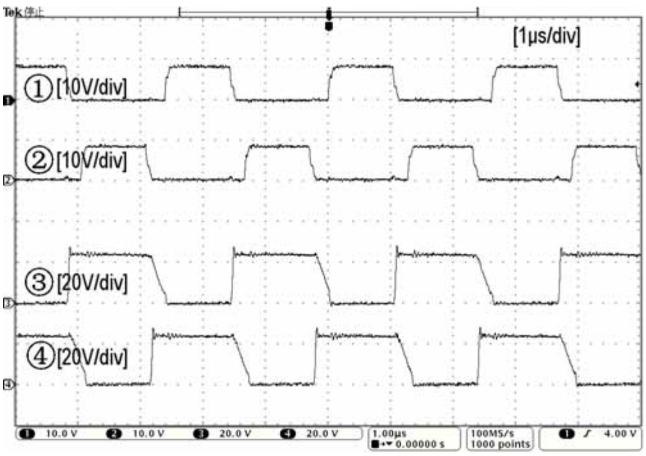
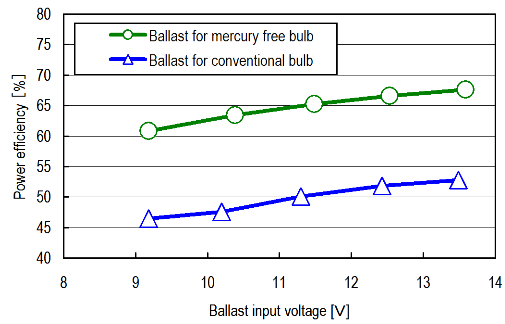


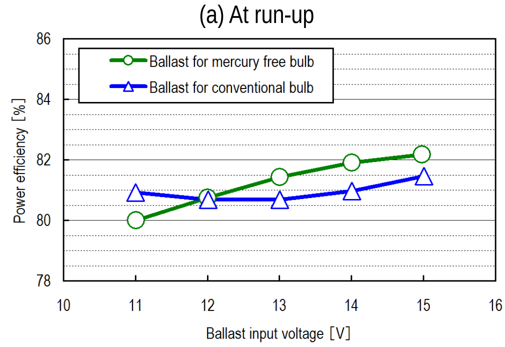
Fig. 2 FET gate voltage waveforms (①②) and drain voltage waveforms (③④) at ZVS

5. Efficiency and Size of Mitsubishi Ballast

The ballast efficiency (bulb input power/ballast input power, Fig. 3(a)) during high power output at run-up has been improved by approximately 20 points against the conventional type, and yet the ballast efficiency during stable illumination (Fig. 3(b)) remains almost the same as the conventional type.



(a) At run-up



(b) At steady state lighting

Fig. 3 Comparison of ballast power efficiency

Table 2 Comparison of ballasts for a conventional bulb and the mercury-free bulb

	Ballast for conventional bulb	Ballast for mercury free bulb
Volume	175 cm^3	140 cm^3
Weight	250 g	175 g

Furthermore, as shown in Table 2, the ballast size has been reduced by approximately 20% and the weight by approximately 30% compared with the conventional type.

Fig. 4 Ballast for a conventional bulb (left) and ballast for the mercury-free bulb (right)

6. Conclusion

Increased use of mercury-free type bulbs and stricter regulations on mercury use (exclusion of xenon bulbs from the exception list) are expected as environmental awareness and technological achievements progress.

We will gather the findings gained through developing the ballasts for mercury-free bulbs as discussed here, work together with bulb manufacturers, and promptly develop products. We will continue to provide the markets with products that meet the needs of automobile manufacturers and contribute to society.

DSRC On-board Unit for Multiple Services

Authors: *Mamoru TakiKita** and *Yukio Goto***

1. Introduction

The 5.8-GHz band DSRC (Dedicated Short Range Communication) system applied to ETC (Electronic Toll Collection) in 2001 has been studied for various advanced applications and services in both the public and private sector, resulting in the launch of pilot programs and experimental operations. We have developed a DSRC on-board unit conforming to the Standard Specification for ITS On-Board Unit which can support various types of services.

2. Specifications

Figure 1 shows the appearance of the DSRC on-board unit and its switch unit. Table 1 shows the specifications. The radio specifications conform to the DSRC Communication Standard [1].

Fig. 1 Exterior of the DSRC on-board unit

Table 1 Specifications of the DSRC on-board unit

Item	Specification
Uplink Carrier Frequency	5815-5845 MHz
Downlink Carrier Frequency	5775-5805 MHz
Modulation Method	ASK, π/4 shift QPSK
Transmit Power	10 mW
Reception sensitivity	-60.5 dBm e.i.r.p.
Size (W × H × D)	93 × 28 × 136 mm
Power Consumption	DC12V, 0.5A
Interface	RS-232C, USB, CAN

ASK: Amplitude Shift Keying
QPSK: Quadrature Phase Shift Keying

3. Features

(1) The on-board unit has been certified for EMV Level 1[*1]. Standard IC credit cards can be used.

(2) A voice processing circuit is built into the on-board unit. The unit alone can transmit speech data. Repeated reproduction and output stop can be controlled from the switch unit.

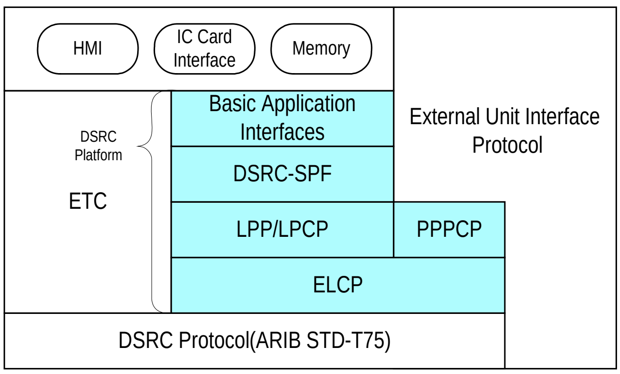
(3) An RS-232C interface having the same communication protocol as the ETC on-board unit, CAN (Controller Area network) interface, and USB (Universal Serial Bus) interface for connection to the Internet are provided as external device connection interfaces. Car navigation systems can be easily connected to the unit.

4. DSRC Communication Platform

To support various types of DSRC-based services with a single on-board unit, a DSRC communication platform equipped with functions common to the services is necessary. This DSRC platform is designed for both fast connection in short range communication system and common usage such as Internet connections.

4.1 Protocol configuration

The DSRC-based services are designed on the premise of coexistence with ETC units. This on-board unit has the DSRC communication platform on the DSRC protocol[1] in the same way as the ETC (Fig. 2). The DSRC communication platform of this on-board unit consists of ELCP (External Link Control Protocol), which expands the functions of the DSRC protocol and executes common processing, LPP (Local Port Protocol) and LPCP (Local Port Control Protocol), which are local protocols[2] for DSRC, DSRC-SPF (DSRC Security Platform) for common security, DSRC Basic Application



HMI: Human Machine Interface

Fig. 2 Protocol stack in the DSRC on-board unit

*1 IC card standard specification for credit cards established by Europay, MasterCard, and Visa.

*Automotive Electronics Development Center **Advanced Technology R&D Center

Interfaces[3] to enable the DSRC-based services, and PPPCP (Point-to-Point Protocol Control Protocol)[2] for Internet communication.

The DSRC communication platform is designed on the basis of the fast connection concept characteristic to DSRC communication and similarity to Internet standards. For functionality, LPP/LPCP are equivalent to TCP/UDP, DSRC-SPF to SSL (Secure Socket Layer), and DSRC Basic Application Interfaces to FTP (File Transfer Protocol) and SNMP (Simple Network Management Protocol). These are standardized by a DSRC association and Mitsubishi Electric participated in the standardization phase, including contribution of providing technical support.

This on-board unit is equipped with an interface protocol for hooking up with external devices having a similar structure as the DSRC communication platform, thus allowing various devices such as car navigation systems and the like to be connected to this on-board unit.

4.2 Local Port Protocol

LPP/LPCP help optimize the resources of the on-board unit by providing the following for charging, making payments, and services while driving and providing common functions required for high-order applications:

(1) Fast connection and application identification on the basis of the port No.
(2) High-reliability communication by request response and retry functions
(3) Large-capacity communication by division and assembly of communication messages

4.3 DSRC Basic Application Interfaces

The on-board unit comes with six basic applications[3] in a full-function mode. The respective applications provided on the unit have the following features.

(1) OBU (On Board Unit) Identification Communication Application: The identification data registered in the on-board unit are held securely and output to the road-side systems.
(2) OBU Basic Indication Application: The results of service transactions are notified with functions such as speech and car navigation combined.
(3) OBU Indication and Response Application: The intention of the driver is checked by functions such as switches and car navigation combined.
(4) IC Card Access Application: Command send/receive operation with the IC card is performed in accordance with the IC card interface EMV level 1 specification.
(5) OBU Memory Access Application: The on-board unit memory control can be operated from the car navigation system by the external unit interface protocol.
(6) Push Type Information Delivery Application: Fast and large-capacity data transmission is attained by using a large-capacity double buffer. Arbitrary registration of application types and contents types to be received can be made.

5. Examples of Services

Various types of ITS services can be delivered by this on-board unit, such as ETC, sound guidance, payment of parking fees, provision of traffic information and collection of traffic-congestion information on the road, and connection to Internet information sources. The on-board unit is expected to be widely used as an on-board communication unit for services to improve road traffic safety, including a safe driving support system which is expected to be introduced after pilot tests in the future.

References:

(1) Dedicated Short-Range Communication System, ARIB STD-T75, Association of Radio Industries and Businesses.
(2) DSRC Application Sub-Layer, ARIB STD-T88, Association of Radio Industries and Businesses.
(3) Guideline for DSRC Basic Application Interfaces, ITS FORUM RC-004, ITS Info-communications Forum.

Progress of Car Navigation in Combination with In-Car Peripherals

Authors: *Hideo Watanabe** and *Tatsuya Mitsugi**

1. Introduction

Car navigation systems have been developed to assist driving by giving directions to the driver. In recent years, the systems have been developed in combination with electronic apparatuses such as rear-view cameras and entertainment devices such as digital video systems.

This report discusses the challenges for developing car navigation systems focusing on their combined use with such external devices.

2. Car Navigation Systems and Connection of Devices

Today's car navigation systems contain fast, high-performance arithmetic devices, large-capacity memory, and large display screens, so they can also serve as an on-screen display of the rear-view camera or front-view camera and a HFT (hands free telephone) unit that allows telephone-answering while driving. Furthermore, car navigation systems are increasingly being used as entertainment equipment other than for assisting driving, such as for displaying TV or DVD images, and for storing and playing back music data. Such functions are provided not by the car navigation system alone; they are presented to users by the car navigation system in combination with dedicated devices. The functionality of such services is being improved through combined configurations. Some examples of the functions available through combining a car navigation system and external devices are described below (Fig. 1). Note that some of the external devices, which are now considered independent external de-

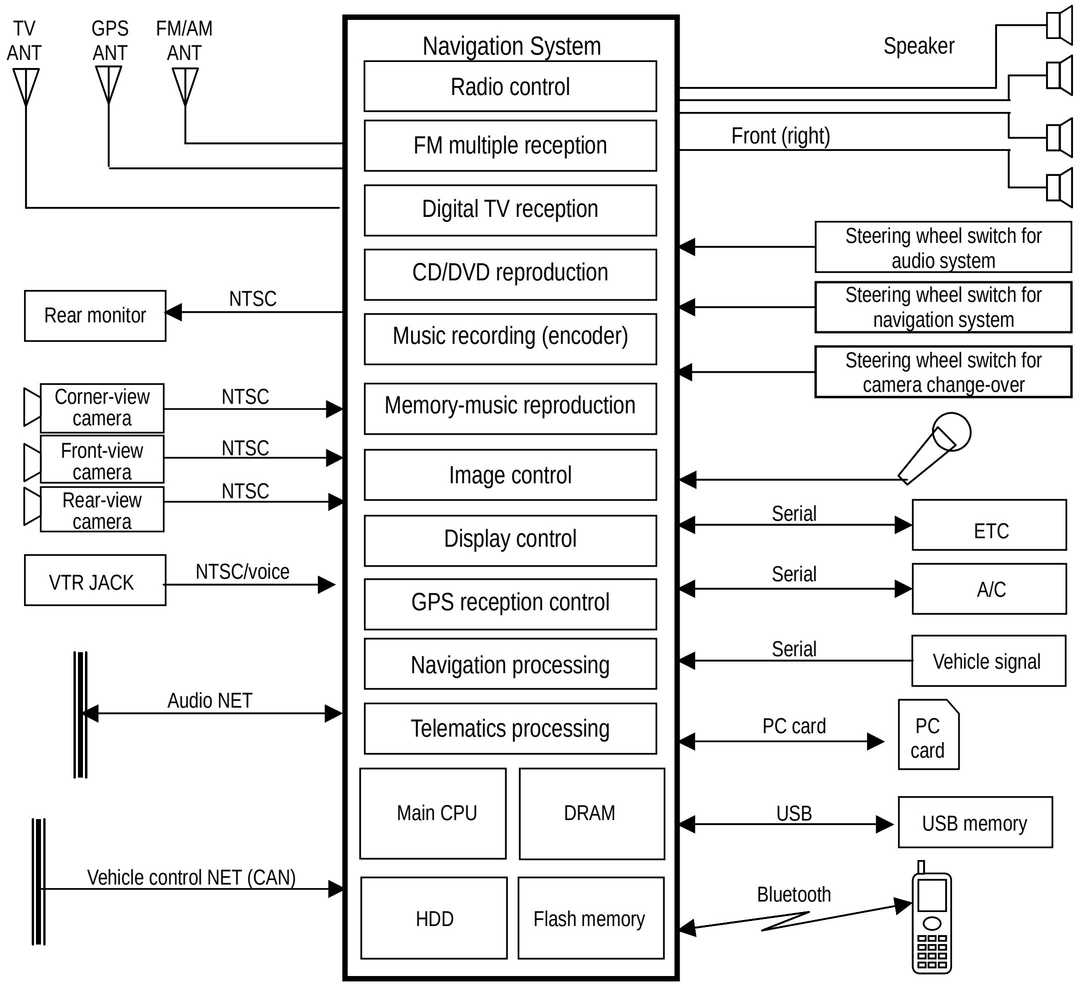


Fig. 1 Block diagram of a car navigation system and peripherals

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vices, may be incorporated into the car navigation systems as component elements as the devices will become smaller or integrated into chips in the future.

3. Combination with Cellular Phones

The functions of the on-board unit related with cellular phones are: the HFT function, data communication function, and address book management function. An outline and the development challenges of the HFT function are discussed below.

The HFT function was incorporated for hands-free cellular phones without having to hold the phone while driving for safety reasons. In the case of a general manufacturer's car navigation system added as an extra, the speech button is usually installed on the steering wheel, to allow the driver to start to talk without taking his/her hands off the wheel.

The driver can hear the voice of the caller output through an on-board speaker. However, the voice is also input back to the microphone to collect the driver's voice. Noises inside and outside of the car also enter the microphone. In short, the caller can hear the driver's voice, and the echoed voice of the caller overlapped with noises, and sometimes the driver's voice is inaudible (Fig. 2). To solve such problems, a noise canceller or echo canceller must be included in the system.

Unnecessary components such as noises and echoes vary with road conditions, vehicle environment, and the characteristics of the microphone or speaker, so tuning must be conducted for each car to remove such components. Also, the unnecessary components may vary with the conditions of the cellular phone system, and are thus very hard to completely eliminate.

For problems that depend on cellular phone conditions, differences in sound volume or performance of HFT support functions as well as the elements mentioned above can also affect the normal operation of the unit. Checking and adjusting system performance takes enormous time and effort.

4. Combination with Music Players

Today's drivers want to enjoy music output from state-of-the-art audio devices, including memory audio players such as USB (Universal Serial Bus) audio units, iPod (registered trademark of Apple U.S.A.) systems, and other portable music players. In conventional methods, the output from the headphone socket of a portable audio system was input to the on-board audio device via external input terminals (AUX), requiring the driver to operate the portable audio system itself to select the music. However, there is demand to hand the switching function to the car navigation system. To control an iPod from an external system, for example, the iPod control process must be uploaded to the car navigation system by using a special interface library provided by Apple. For a USB memory connection, a special control process complying with the USB interface specification must be implemented.

5. Challenges Related with the Increase of Devices Connected to Car Navigation Systems

As described above, an interface is required for each device to be connected as the number of external devices increases. Sometimes the specifications of devices cannot be clearly disclosed in accordance with the External Device Connection Interface Specification. In such cases the interface between the devices must be developed by actual connection followed by actual adjustment, which requires much time and effort.

When a car navigation system is to be connected with several devices at the same time, technologies related with the specifications of the interface between the devices and device characteristics must be developed as discussed above. However, physically speaking, many signal lines are also necessary as shown in Fig. 1. As a result, the rear face of the car navigation system is packed with many connectors and connecting all of them in a conventional manner becomes physically difficult. So many signal lines is a challenge for not

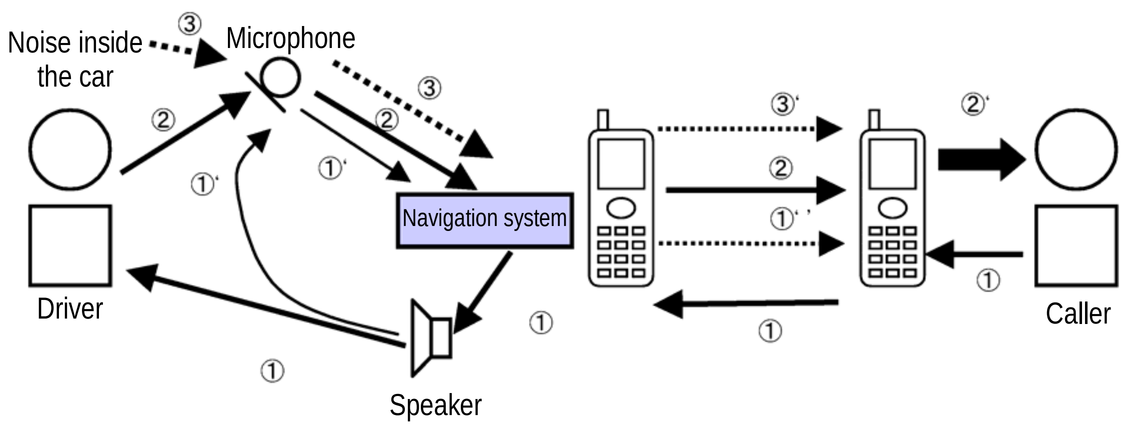


Fig. 2 Noise and echo cancelling

only the car navigation system itself, but also for the whole vehicle due to wiring space, wiring work, and arrangement cost. To solve this problem, high-speed networks such as MOST (Media Oriented Systems Transport) and IEEE 1394 have been proposed for reducing the number of signal lines on board and realizing high-speed data exchange. In Europe in particular, the MOST method has been employed in some applications; however, manufacturers are still studying the feasibility. As a car navigation system manufacturer, we must develop elemental technologies while closely monitoring vehicle development trends.

6. Conclusion

Car navigation was developed to help drivers drive their cars without concerns about losing their way in new places. Safe driving assistance and entertainment functions will need to be improved in the future, and car navigation systems will need to be combined with various devices. Since connecting external devices to the car navigation systems requires work that may not be worthwhile, device interfaces should be standardized and a reference model developed for verifying actual systems.

Advanced Concept of User Interface for On-board Information Systems

Authors: *Tsutomu Matsubara** and *Masami Aikawa**

1. Abstract

On-board information systems are increasingly used in combination with large-capacity HDD units and portable music players as the volume of various data handled is increasing: not only map data but also images, music, and general data such as telephone information. Drivers and passengers increasingly wish to enjoy entertainment such as music and video in the car.

However, as data volumes have increased and device operating procedures have become more complicated, there have been complaints about the difficulty of operating devices or unsatisfactory image quality.

Manufacturers must solve these problems and create a safe and comfortable on-board environment.

Mitsubishi Electric has therefore developed a user-centered control interface that helps drivers and passengers operate on-board information systems easily and safely through the optimum combination of operating devices (control devices) and sound/image devices.

The typical features provided by this control interface are:

(1) Optimal interface for customized contents and operating environment based on passenger identification
(2) Safe and reliable operating interface that allows the driver to safely choose data from a huge selection, even while driving
(3) LCD touch-screen interface for simplified operation from the front passenger seat
(4) Personal audio system and simplified music search function
(5) Highly-legible display interface that can display map information or meters at the optimum ratio in accordance with the operation status of the vehicle (running/stop)

2. Introduction

The increased volume of contents such as images and music and the complexity of operating devices due to many switches and the like to allow each passenger to control such devices, are major challenges for the development of on-board information systems. A safe and comfortable on-board environment that solves these challenges is needed.

We have developed the industry's most advanced control interface (design specifications related with operability) for safer and more comfortable operation of on-board information systems by optimally combining the operation devices and sound or image devices.

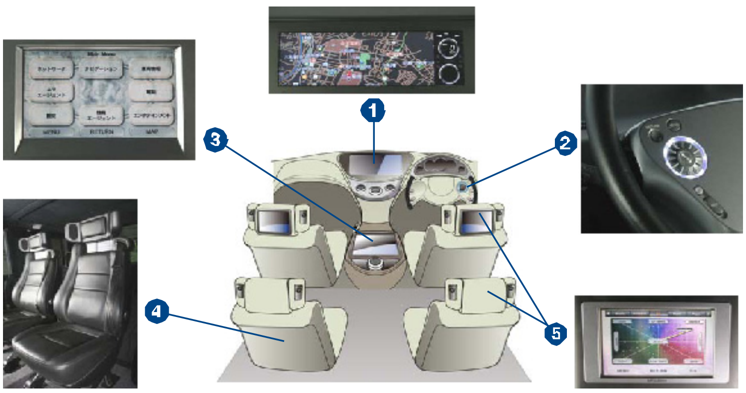
This report discusses the features and outline of these user-centered interfaces.

3. Contents of Development

3.1 Provision of optimum contents to individual passengers by passenger identification

Noncontact passenger identification to identify passengers in the respective seats can be made when each passenger with an IC tag, which is built into their cellular phone or key-less entry system, gets into the vehicle.

After authentication the individual personal meter is



Additional suggestions
① Passenger identification system that can provide optimum contents to the respective passengers
② Safe and easy-to-use operating interface remote control installed on the steering wheel
③ LCD touch-screen that allows the passenger beside the driver to operate the system easily while looking at the screen
④ Personal audio system and simplified music search screen
⑤ Wide LCD display screen with improved legibility in accordance with the operation status of the vehicle

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displayed automatically with driver's preferences (Fig. 1), music contents, and telephone directory data.

This system to automatically set up devices for different users as soon as a user sits in a particular seat can be applied to various devices in the future.

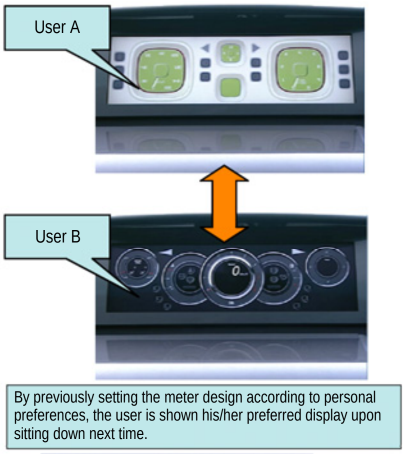

Fig. 1 Design interface meter adapts to the user

3.2 Safe and reliable control interface by remote control on steering wheel and talkback function

Equipped with a remote control on the steering wheel (Fig. 2) and talkback (audio response) function for safety, the driver can operate the on-board information system safely through a click-feel on the fingers and audio guidance without having to keep looking at the screen.

Fig. 2 Steering-wheel mounted remote control

A typical application is a surrounding area search while driving. When the driver wishes to stop at a particular place, the driver can operate the remote control on the steering wheel to call up the surrounding facility menu and select a menu item by using the rotating dial and talkback (audio response) function. The candidate facilities are displayed in a spiral pattern with the cursor position on the map as the center. The driver can search the facilities outward by rotating the dial.

Thus, with the audio guidance and a quick glance for checking, the interface is safe for the driver to operate, minimizing the need to look at the screen.

3.3 LCD touch-screen interface easily accessed from the front passenger's seat

An LCD touch-screen that can be operated while looking at it is located at the most convenient location for the passenger sitting in the front passenger seat (Fig. 3). Our newly developed interface provides each individual passenger with the optimum control method.

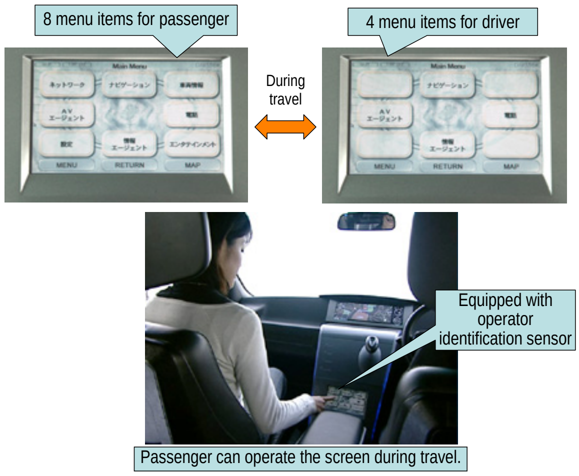

Fig. 3 LCD touch screens

Since it is dangerous for the driver to keep looking at the screen while driving, the current systems restrict the operation of the screen by the driver while driving. This means that a passenger seated beside the driver cannot operate the screen.

We have developed a touch-screen display which can be actuated only by the passenger seated beside the driver. With this display, the passenger can always operate all the menu items, while only limited menu items that do not affect safety can be operated by the driver.

With this display, both the operability for the passenger seated beside the driver and safety for the driver have been secured simultaneously.

This technology is expected to contribute to greater convenience and safety for both the passenger and driver in the future.

3.4 Development of personal audio systems

In order to be able to provide each passenger with their favorite music, we have created a personalized audio and image rendering system with a speaker and touch-screen display unit installed on the headrest of every seat (Fig. 4).

We have also developed a system for each passenger in a different seat in a vehicle to enjoy their preferred music and images which are output via individual speakers and display unit interlocked by IC tags (Fig. 5).

Fig. 4 Personal audio system

3.5 Wide screen for improved legibility of navigation map and the like

With 15-inch wide LCD screens installed (Fig. 6), the legibility of large-screen maps and entertainment quality of the system in a stopped car have been improved.

When map display is not necessary, the screen displays the meters fully. On the other hand, when map display is necessary the meters are displayed in a small screen and the map is displayed in the remaining larger space for improved legibility.

When the car is parked, images can be displayed full screen for enhanced entertainment.

3.6 Music search interface

An enormous amount of music data can be stored in today's hard disks, but this makes it difficult to search the music efficiently. To solve the problem, we have developed a music search function (Fig. 7) and automatic music recommendation system (Fig. 8). With the music search function, the tune components of music data such as genre and tempo are analyzed, and automatically classified and registered on the basis of lightness or darkness (horizontal axis) and fastness or slowness (vertical axis), so the driver can select the music. With the automatic music recommendation system, the most appropriate music contents are automatically recommended to the driver based on a combination of the driver's history and preference and external environment information, such as vehicle position, time, weather and road conditions (including traffic congestion, expressway and general road information) provided by the car navigation system. As a result, much quicker operation is possible.

4. Conclusion

IT technologies will increasingly be implemented on vehicles as information services are enhanced using IT communications such as music and video delivery as well as map-updating information, in addition to a huge volume of music and image data which drivers and passengers themselves upload to the system, as data capacities increase in the future.

An interface is needed to support various types of information, music, and images, while ensuring safe operation and providing a personalized environment for handling the increased amount of information available.

It is important to verify the types of input/output devices on actual operation environments (in vehicle compartments), accelerate R&D on control interfaces for such on-board environments, and improve the environment for safely and easily using on-board information systems.

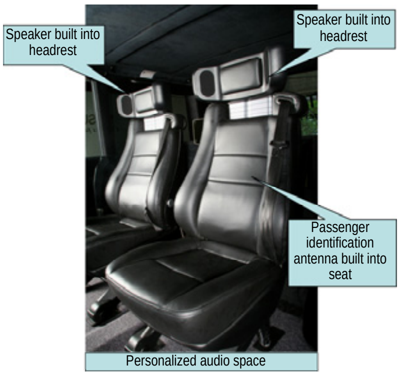

Fig. 5 Personal audio seats

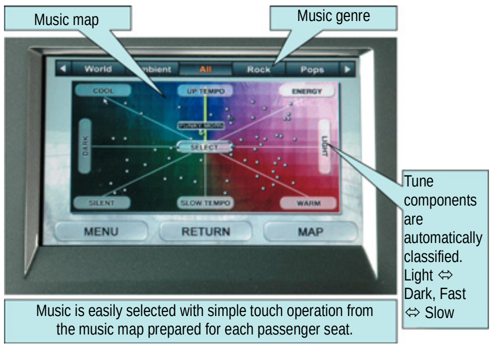

Fig. 7 Music search screen

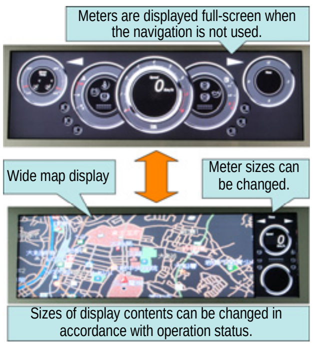

Fig. 6 Wide-screen display

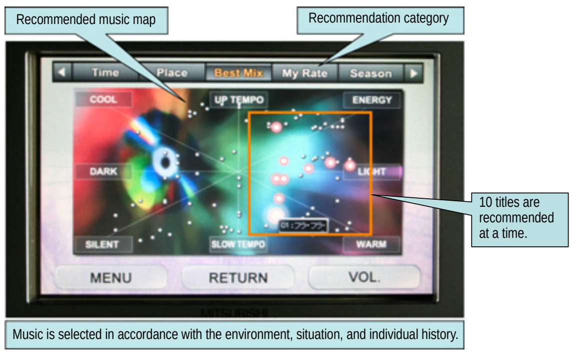

Fig. 8 Image type music recommendation screen

Application of UI Design Tool "NINA" to In-Car Infotainment Systems

Authors: *Akira Toyo-oka** and *Hiroki Konaka**

1. Introduction

The cost of UI (User Interface) software development continues to rise since embedded devices become more functional and UI designs become richer. We have been developing a UI design tool "NINA (Navigator for Interface of Application)" to improve the efficiency of UI development for such embedded devices, to overcome the problem of cost. This report discusses the application of NINA to the UI development for in-car infotainment systems and the results of evaluating its effectiveness.

2. UI Design Tool "NINA"

"NINA" is a UI design tool for embedded devices. Since embedded devices have smaller screens than those of PCs, they are generally operated by switching scenes in accordance with restricted operating procedures. NINA is based on the SCO (State Chart Object) concept which is suitable for UI modeling.

An SCO is a UI component which consists of more than one state, each corresponding to a scene, and transitions between states. In each SCO scene, in addition to basic UI components such as buttons and labels, other SCOs can be laid out as UI components. With the hierarchical nature of SCOs, all of the custom UI components and the UI of the applications can be designed in the same framework and used in combination. In addition, the reusability and maintainability of UI design are improved.

Figure 1 shows an example of hierarchical SCOs. SCO1 is placed as a custom UI component in the music playing scene of SCO2. If SCO1 is modified, the music playing scene of SCO2 which uses SCO1 reflects that particular modification.

3. Structure of NINA

NINA consists of several functional modules used on PC and a software module for the target device. Figure 2 shows the structure of NINA and the flow of UI development.

The chart editor is a tool to design the transitions between the UI scenes into a state diagram. The procedures in response to key events during device operation and other events generated in the device can be defined as event handlers.

The layout editor is a tool to prepare the layout of UI components in the scene for each SCO state. The scene layout is designed using basic UI components such as labels, buttons, images, and container panels, and other SCOs in combination.

The simulator is a tool to check the behavior of the UI, which has been designed with the chart editor and the layout editor, on a PC. The inspection is faster and more efficient on a PC than on the target device.

The code generator generates the source code in C++ language for the target device from the UI design data. The code thus generated neither has platform-dependency nor requires modification by the

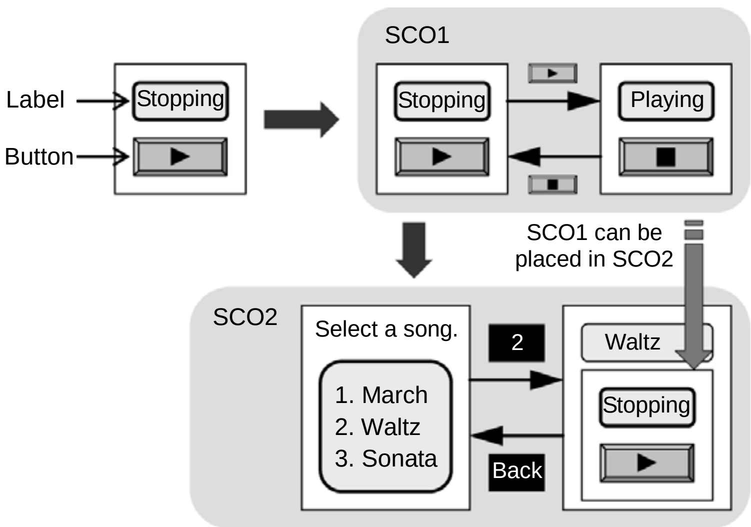

Fig. 1 Hierarchical use of SCOs

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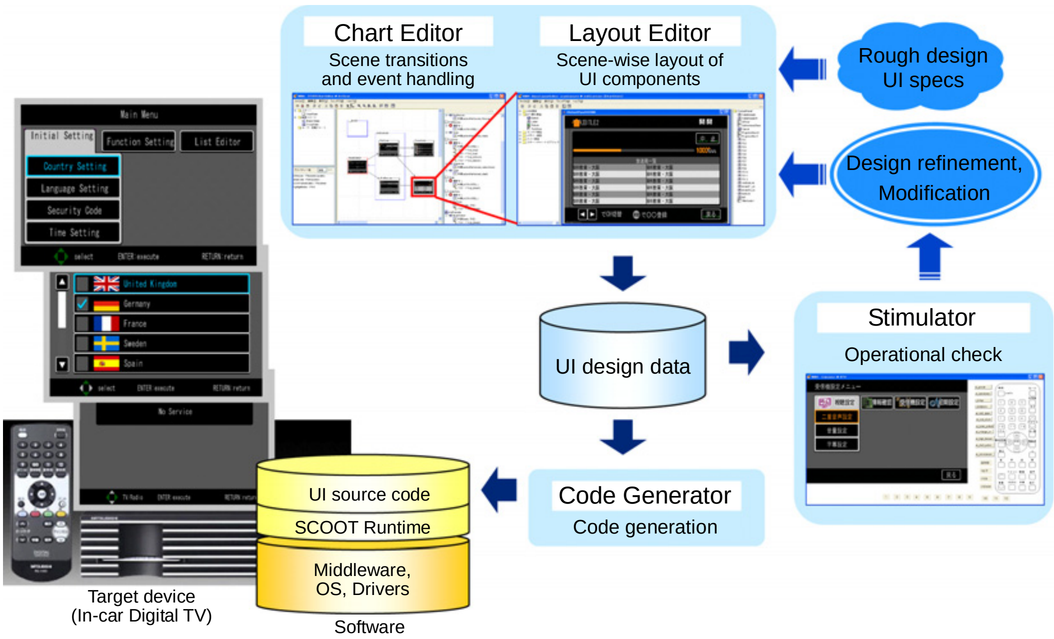
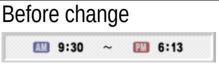
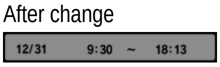


Fig. 2 The structure of NINA and the flow of UI development

Table 1 Modification tasks of UI design data

No.	Task	Scene image	Description of task
1	Change of hierarchical structure of the menu		The hierarchical structure of the menu, in which a sub-menu item is selected from the tab after selecting the category by the tab, is changed. - Development of menu based on old specification has been completed. The hierarchical structure of the menu in accordance with the new specification is changed. - The number of categories (4) remains unchanged. Each category name is changed. - The number of sub-menu items in each category is changed. - The total number of sub-menu items remains the same (items are exchanged among the categories).
2	Design of a new setting menu		A new setting menu which has the function of selecting one option out of two to four items is designed. - A similar setting menu has already been developed. Development of custom UI components such as a button with a check box has been completed.
3	Change of appearance of custom UI components	Before change  After change 	The time display method and the layout of the component to display program broadcasting time are changed. - Time display is changed from AM/PM display to 24-hour type display. - Date display is added. - The layout (display position and background) is changed.
4	Change of appearance and operating procedure of the TV program guide		A new appearance design is prepared for the TV program guide. In addition, the operating procedure is also changed to add new functionality. - Date display and a selection function are added. - A function that lists the currently broadcast programs on all channels is added.

programmer.

The SCOOT (SCO Oriented Technology) Runtime is a software module written in C++ language for running the source code generated by the code generator on the target device.

4. Application to In-car Infotainment Systems

We used NINA to develop the UI for in-car infotainment systems, which are digital TV prototypes for European markets in compliance with DVB-T (Digital Video Broadcasting-Terrestrial) and domestic digital TV products in compliance with ISDB-T (Integrated Services Digital Broadcasting-Terrestrial). The domestic digital TV products are available in the market as TU-100D (launched in December 2005) and TU-200D (launched in June 2007).

The conventional UI development was based on hand-coding by programmers using a stock UI toolkit. The problems of the conventional method and the effectiveness of NINA-based development are discussed below.

(1) In the conventional method, generation and layout of UI components, event handling procedures, and conversion of display data are combined in the same program. On the other hand, in NINA, those functions are divided by the tools, thus making the UI design more readable. Besides, the points of modification and the extent of the impact are made clear when changing the UI specifications.
(2) In the conventional method, operational checks of the UI were conducted on the target device, incurring overhead such as recompilation and downloading. With NINA, operational checks can be performed using the simulator, thus eliminating such overhead.
(3) In the conventional method, routine processes commonly used in UI program were hand-coded. With NINA, routine processes are already provided by the SCOOT Runtime, thus reducing development cost and preventing bugs.

5. Evaluation

We evaluated the conventional method and NINA by conducting the tasks shown in Table 1 to assess the development cost.

Table 2 compares the development cost between the conventional method and NINA. One person was in charge of the development of the conventional method and NINA respectively, and each person was skilled in the respective method. The development cost is shown in man-hours. The man-hour rate shows the value for NINA against 100 for the conventional method. For any type of task, development efficiency with NINA is higher than with the conventional method. The conventional method required more time than NINA for resetting UI component coordinates when changing the scene layout, modification of transition processing when changing scene transition, and functional checks on the target device. With NINA, each task can be completed while checking the results of modifications by using the layout editor, chart editor and simulator, resulting in a clear difference over the conventional method.

Table 2 Comparison of UI modification costs

No.	Task	Conventional method	NINA	Man-hour rate
1	Change of hierarchical structure of the menu	16h	4h	25%
2	Preparation of a new setting menu	16h	8h	50%
3	Change of appearance of custom UI components	6h	1h	17%
4	Change of appearance and operating procedure of the TV program guide	120h	48h	40%

6. Conclusion

We used the UI design tool “NINA” to develop UI for in-car infotainment systems. We confirmed that the cost of developing UI software for specification changes can be reduced to around 17% to 50%. We will continue to develop the technology described in this report for application to other derivational products in the future.

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