Engine Management System for Compliance with Different Environmental Standards

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OVERVIEW: The remainder of this decade will see a tightening of automotive environmental standards around the world. The situation is becoming more diverse, including the international standardization of driving test modes, tighter rules on particulates for gasoline-powered vehicles, and CO_2 incentives. Hitachi Automotive Systems, Ltd. is developing engine management systems to suit different needs. Systems for reducing CO_2 emissions include engine downsizing systems, engine control systems that allow higher compression ratios, and stop & start systems that extend the length of time the engine is stopped. Remarkable advances are also being made in the fuel injectors, variable valve mechanisms, starters, controllers, and other components used in these systems.

INTRODUCTION

ENVIRONMENTAL standards covering carbon dioxide (CO_2) and exhaust emissions are set to be tightened over the remainder of this decade. In addition to the convergence of regulatory levels, there is also a trend toward the standardization of things like driving test modes and CO_2 incentives. To comply with these new standards, engine management systems need to be developed based on conditions and perspectives different from those in the past.

This article describes advances in engine management systems that comply with environmental standards from around the world.

GLOBAL ENVIRONMENTAL STANDARDS AND SYSTEMS FOR COMPLYING WITH THEM

Fig. 1 shows an overview of the changes in global automotive environmental standards and the development of engine management systems. While Europe has been taking the lead in CO_2 standards, it is anticipated that North America, too, will adopt equally stringent rules. Also under consideration is the standardization of the different driving mode stipulations that have applied in Japan, the USA, and Europe [Worldwide Harmonized Light Duty Driving Test Cycle (WLTC)], and of the modes that are based on actual driving conditions [Real Driving Emission (RDE)]. Another possibility is greater use of compressed natural gas (CNG) in different parts of the world after 2020, prompted by the production of shale gas, particularly in North America.

Particulate number/particulate matter (PN/PM) standards for exhaust emissions are also becoming tighter. Europe is leading the world in this area, with the Euro 6c standard for PN being particularly stringent. As the standards will also cover direct injection of gasoline (DIG) engines, complying with these rules is an urgent task.

The figure also shows work on engine management system development. Hitachi sees the development of highly efficient engine systems and engine management systems as central to this work.

In the area of emissions reduction, there is an urgent need for ways of improving PN/PM performance in highly efficient DIG engines, as described above. Hitachi has succeeded in adopting higher compression ratios to improve efficiency through better anti-knock performance using pistons and DIG, and is working on the development of engine downsizing systems based on DIG and the associated high boosting technology. The key features include a wide dynamic range of DIG that supports high boosting and a cooled exhaust gas recirculation (EGR) control technique for anti-knock. Developments aimed at the future implementation of lean-burn combustion and homogeneous charge compression ignition (HCCI) are also in progress.

In the area of energy management, meanwhile, progress is being made on the adoption of electric drive systems and the variable control of pumps that reduce friction in auxiliary systems. Hitachi is also developing technology for the regeneration of energy to charge the battery during deceleration that works

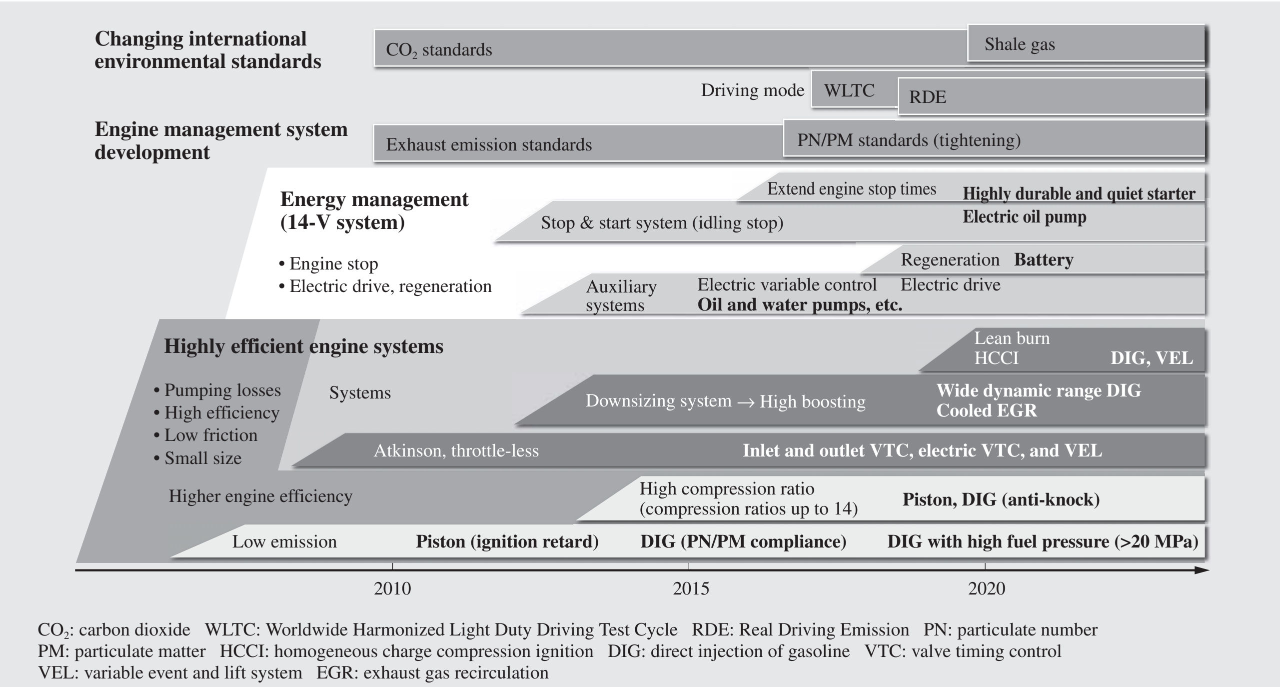


Fig. 1—Development of Engine Management Systems to Reduce CO_2 Emissions.
In addition to regulatory requirements, there is a trend toward the globalization of driving test modes and CO_2 incentives. The strengthening of PN/PM standards has added urgency to the development of systems that can comply with these rules. Hitachi is developing systems for reducing CO_2 emissions that are based on engine efficiency improvements and energy management.

with electric drive systems. Greater use is being made of idling stop, and future systems will extend the length of time the engine is able to stop.

DEVELOPMENT OF ENGINE SYSTEMS FOR REDUCING CO_2 EMISSIONS

This section describes the development of systems for highly efficient engines and energy management. Hitachi develops DIG systems that work with high boosting and high compression ratios and feature reduced PN/PM levels and improved anti-knock performance (see Fig. 2). The former uses a quick-response multiple injection technique that injects fuel up to five different times during each intake stroke to achieve a homogenous air-fuel mixture in the combustion chamber. The key technologies for this are injectors with a wide dynamic range and the drive circuits and electronic control units (ECUs). These technologies are combined with a short penetration spray and higher fuel pressures (20 MPa, currently 15 MPa) to comply with the tighter standards.

Cooled EGR and a piston cooling system are used to improve anti-knock performance. To measure the large pulse flow that results from EGR, a bi-directional type of silicon (Si) mass air flow sensor (MAFS) is used together with an inlet pipe pressure sensor to perform precise measurement of the EGR ratio. Also, precise control of the amount of EGR is achieved by using quick-response electric valve timing control (VTC) and an electrically controlled throttle body.

Hitachi also supplies a small ignition coil with high energy output that improves combustion strength when using EGR. Piston cooling for better anti-knock performance is achieved by incorporating cooling channels into the pistons and using a variable-capacity oil pump to control cooling based on operating conditions.

Fig. 3 shows a stop & start system for energy management and technologies for use with electric drive systems. To reduce CO_2 emissions by stopping the engine for a longer time, the idling stop system has been enhanced to create a system that can also stop the engine during deceleration and normal driving. To avoid discontinuity when restarting the stopped engine, Hitachi has developed a starter with high durability, quiet operation, and improved meshing performance. Because battery management is required if stopping the engine for a longer time, Hitachi has responded by developing a regenerative battery system that supports electric drive of equipment together with state-of-charge (SOC) control.

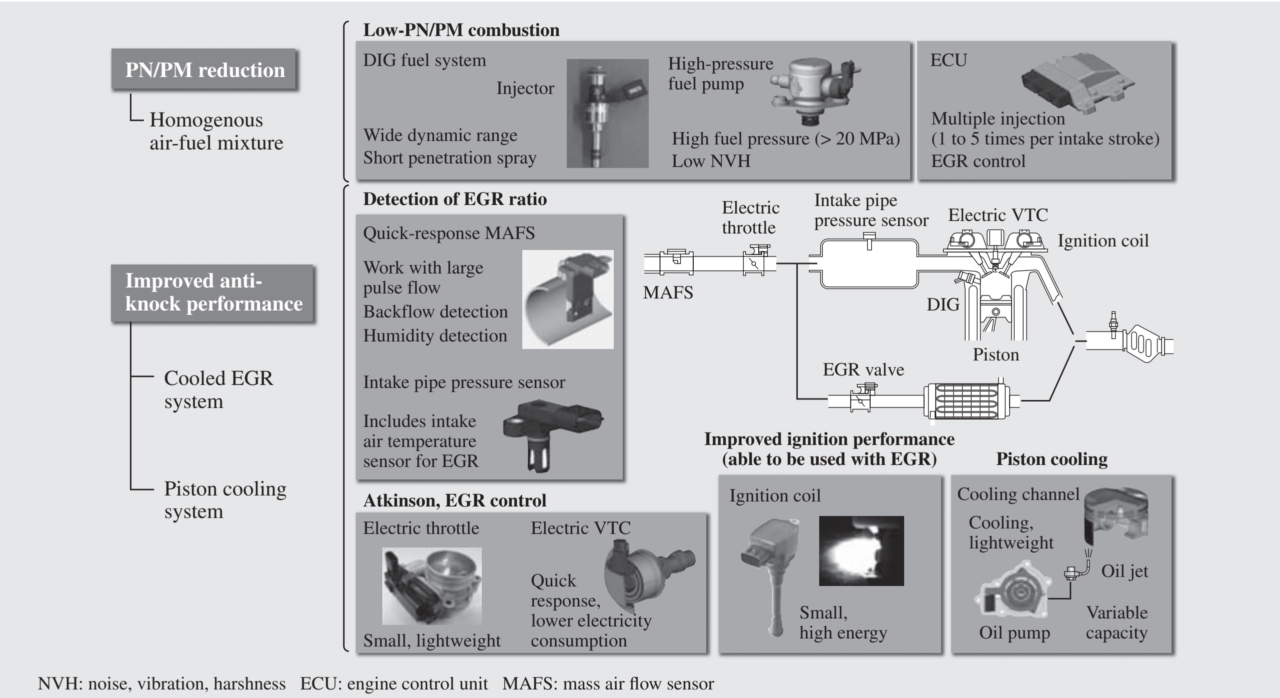


Fig. 2—DIG System for Compliance with Different Environment Standards.
The DIG system features use of high boosting for engine downsizing and to reduce PN/PM, and anti-knock technologies that work with high compression ratios.

NEXT GENERATION OF COMPONENTS

DIG Injector and Drive Control

This section describes DIG fuel systems, electric VTC, and starters for stop & start operation. These are key next-generation components.

Fig. 4 shows a DIG injector that complies with PN/PM standards, and its associated benefits. Achieving a homogenous air-fuel mixture and preventing the adhesion of fuel to the combustion chamber walls are key factors in reducing PN/PM levels. Accordingly, Hitachi has improved the multi-hole nozzles and shortened the spray penetration depth. The low-PN spray has a significantly shorter penetration depth for producing a highly homogeneous spray.

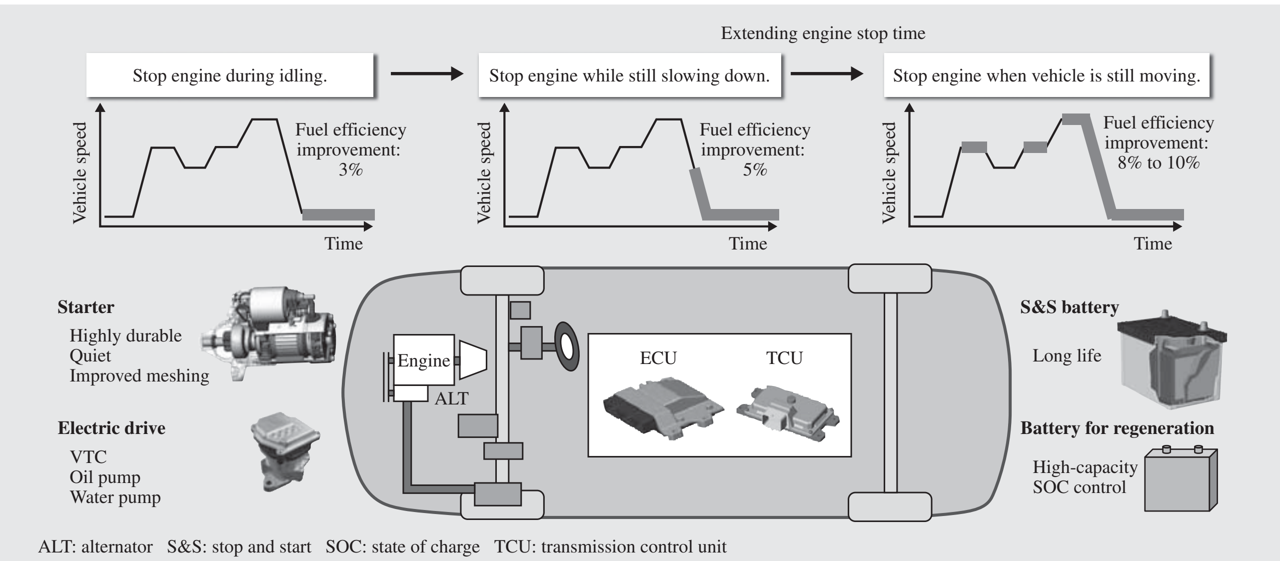


Fig. 3—Stop & Start System and Electric Drive System.
The stop & start system extends the engine stop time to include times when the vehicle is still moving. Used together with electric drive for control equipment and a battery management system, CO_2 emissions are reduced under real-world driving conditions.

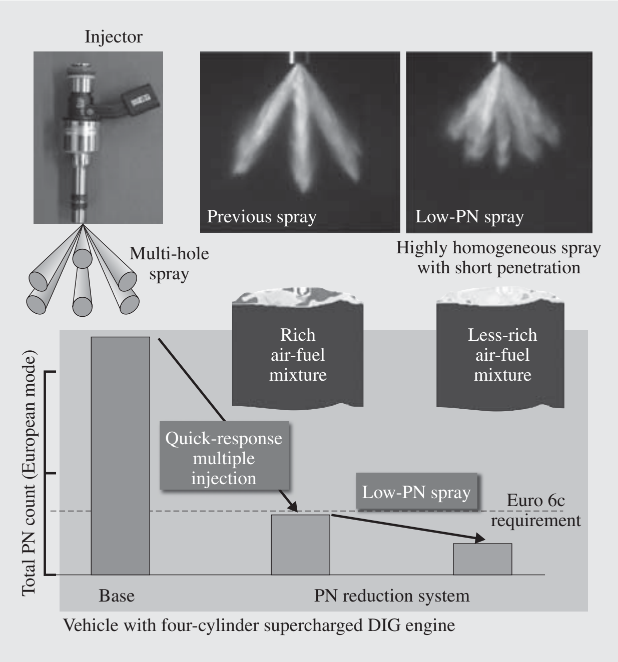


Fig. 4—DIG Injector for Complying with PN/PM Standards and its Benefits.
The figure shows an overview of a DIG system that achieves Euro 6c compliance through the use of quick-response multiple injection and a low-PN spray.

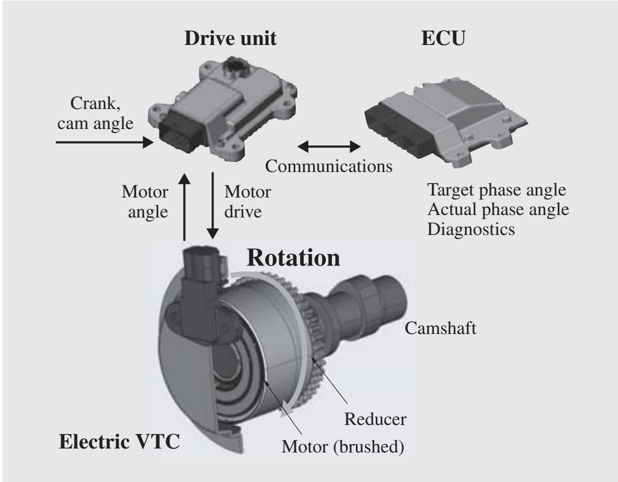


Fig. 5—Structure of Electric VTC System.
This compact electric VTC system combines a motor and reducer in a single package.

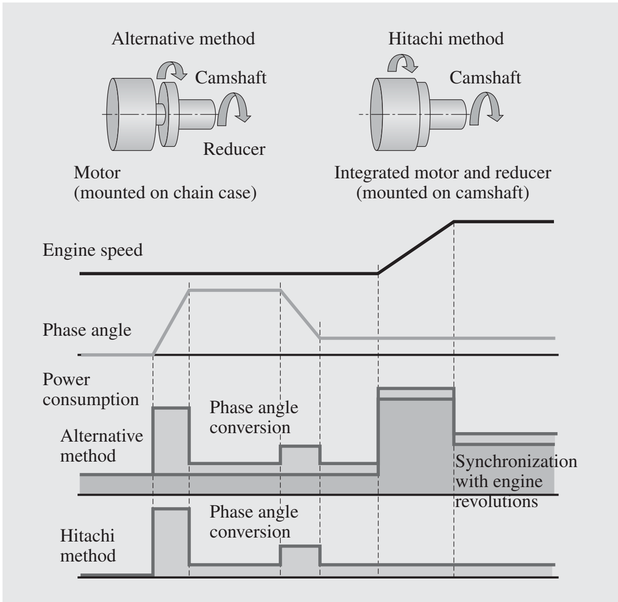


Fig. 6—VTC Power Consumption.
The new system reduces the power consumed during VTC control compared with the alternative method.

Fig. 4 also shows the reduction in PN level for a four-cylinder supercharged DIG engine measured using the European mode. Compliance with the Euro 6c PN standards can be achieved by using quick-response multiple injection that homogenizes the air-fuel mixture in combination with a low-PN spray. The simulation results for two air-fuel mixtures shown in Fig. 4 demonstrate the effect of the low-PN spray, with the reduction in spray penetration depth and greater homogeneity for a rich air-fuel mixture resulting in significantly lower PN levels.

Design and Operating Characteristics of Electric VTC

In electric VTC, a drive unit optimally controls an electric motor in accordance with phase control commands from the ECU (see Fig. 5). The direct current (DC) motor and reducer are integrated into a single unit that is attached to the camshaft. Because the motor rotates along with the camshaft, there is no need to synchronize rotation with the camshaft. Because motor drive is only used for VTC phase angle conversion, the system has lower electricity consumption and a quick response. The reduction of drive load permits the use of an inexpensive brushed motor. The components the reducer are arranged in the radial direction to reduce the total length. The unit also delivers high torque with low friction by transmitting torque via a roller.

Fig. 6 compares the operating characteristics of electric VTC with an alternative method. As other forms of VTC require attachment to the chain case mount, the motor needs to synchronize its rotation with the engine revolutions in addition to driving phase conversion. With the Hitachi system, in contrast, the drive operates during only phase conversion because the motor is attached to the camshaft, resulting in lower electricity consumption.

Restart Control and Starter for Stop & Start System

Fig. 7 shows the stop & start system and its improvement. The previous system (a) stops the engine after the vehicle stops. The new system (b) stops the engine while the vehicle is still moving.

However, because the vehicle is still moving, it is possible that the driver may have a change of mind and accelerate again after the engine stops, at which point the engine revolutions will have slowed. To ensure that the engine restarts promptly in such cases, the system predicts the slowed engine speed and uses this to ensure that the meshing of the starter and engine can occur quickly. Also, by controlling the engine's fuel injection and ignition to ensure combustion occurs correctly on the first power stroke after meshing the starter, the engine revolutions can be increased quickly, with the characteristics shown in the Fig. 7 graph as (b)-1, and the vehicle can accelerate smoothly.

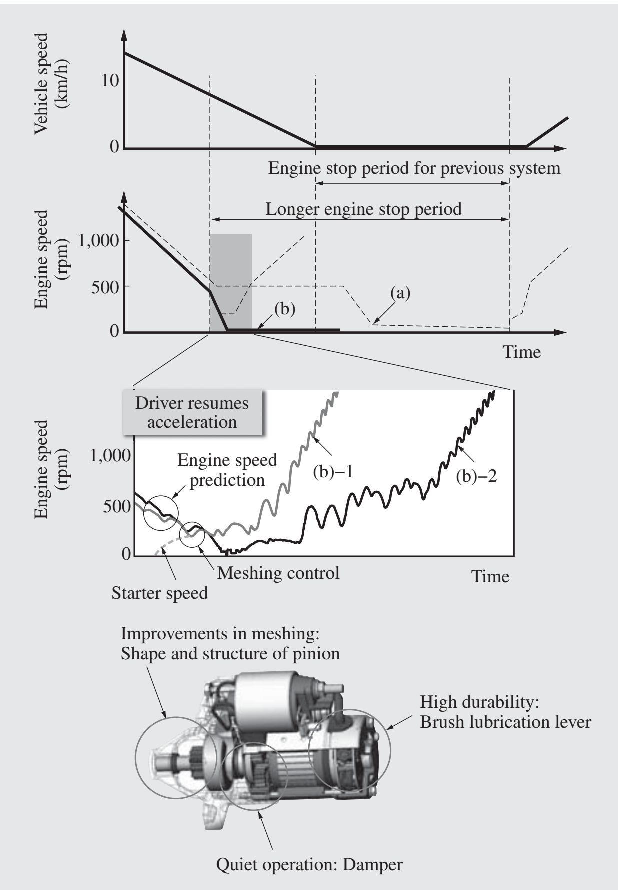


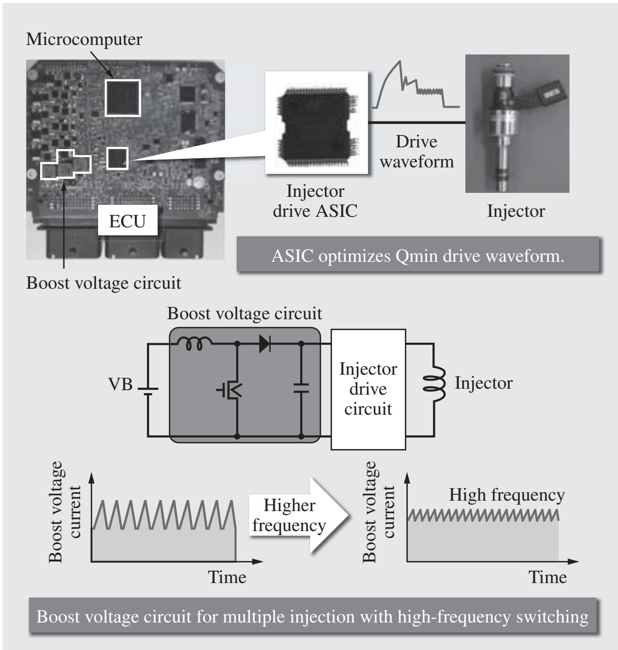
Fig. 7—Starter System Able to Deal with Change of Mind by Driver, and its Control.
By predicting engine speed, controlling starter meshing, and improving the starter, Hitachi has implemented a system that can respond smoothly when the driver changes their mind.

Enhancements of the starter included improving the shape and structure of the pinion for better meshing performance and greater durability, and improving the brushes and adopting a lubrication lever to allow a faster drive speed. The starter was also made significantly quieter during starting (less cranking noise) by fitting a damper to internal parts subject to vibration.

IMPROVEMENTS TO CONTROLLER

Fig. 8 shows advanced ECU technology for next-generation engine management systems (DIG) and a DIG multiple injection function for compliance with Euro 6c standards. Because multiple injection requires that the injector be driven by short high-speed pulses, precise control of the drive waveform was achieved by using a newly developed application-specific integrated circuit (ASIC) for this purpose. To achieve multiple injection with short pulses, the lift behavior of the injector valves is controlled based on the number of injections and fuel pressure [drive with low minimum injection amount (Qmin)]. This results in both faster injector response and quick-response multiple injection.

While the DIG injector uses a boosted drive voltage (60 V), multiple injection requires a shorter boost



ASIC: application-specific integrated circuit
Qmin: minimum injection amount

Fig. 8—Injector Drive and Multiple Injection Support.
Quick-response multiple injection is achieved using a highly efficient boost voltage circuit, with a new ASIC that provides a smaller Qmin.

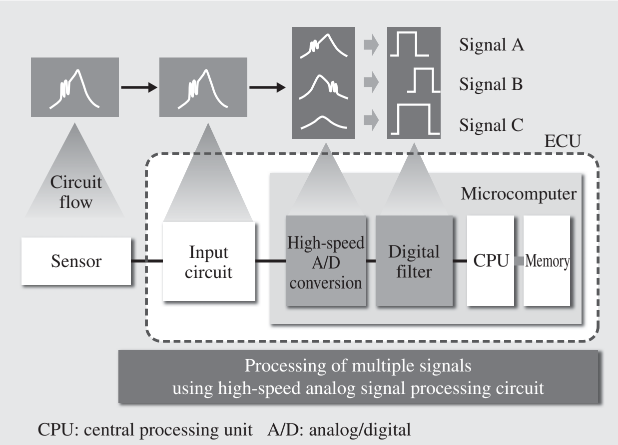


Fig. 9—Processing of Multiple Signals to Support Multi-function Sensing.
Processing of multiple signals is supported to allow more sophisticated sensing in the next generation of engine management systems.

voltage duration. To achieve this, the next generation of ECUs uses high-frequency switching to implement compact boost voltage circuits with quick response and high efficiency. This ECU technology can perform up to five quick-response multiple injections during each intake stroke.

More advanced engine systems require signal processing techniques that can work with multi-function sensing. Because of the need for sophisticated processing of ion current, knock sensor data (noise-tolerant), and other sensor signals (including from internal cylinder pressure sensors in the future), Hitachi has developed techniques for processing multiple signals using high-speed analog signal processing circuits (see Fig. 9). To ensure that they can process a number of signals without overloading the central processing unit (CPU), high-speed analog/digital (A/D) conversion and digital filter functions have been added to new microcomputers to increase A/D conversion speed. The digital filters provide greater flexibility for window and timing settings, and allow the desired signal processing to be implemented.

These advances in ECUs allow the performance of engine systems to be improved by supporting high-speed actuator drive and more sophisticated sensing.

CONCLUSIONS

This article has described the development of the next generation of engine management systems that comply with environmental standards from around the world.

Hitachi supplies advanced environmental systems by improving both components and control techniques.

REFERENCES

(1) M. Osuga et al., “Environmentally Friendly Engine Control Systems,” Hitachi Review **58**, pp. 313–318 (Dec. 2009).
(2) M. Osuga et al., “New Direct Fuel Injection Engine Control Systems for Meeting Future Fuel Economy Requirements and Emission Standards,” Hitachi Review **53**, pp. 193–199 (Nov. 2004).

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