Latest System Technologies for Railway Electric Cars

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OVERVIEW: Changes in society confront railroads today with challenging issues: how to reduce their environmental impact, reduce their life-cycle costs, and adapt to a shrinking pool of skilled labor that is projected in the years ahead. Hitachi is in the forefront in addressing these issues with its next-generation A-train aluminum railcar system that is quieter inside, performs better in navigating curves, and provides passengers with a more relaxed and comfortable ride than ever before. The new Series N700 Shinkansen (bullet train) significantly reduces travel times and has been made more environmentally-friendly with a newly designed aerodynamic nose shape and vibration control technology. The N700 also features a new hybrid drive system that was moved quickly into production for its beneficial effects in mitigating environmental impact. It is also significantly lighter and more compact than previous drive systems thanks to advances in control technology, traction inverter, and other circuit technologies. In the area of train control, Hitachi has developed an ATC (automatic train control) system that now, for the first time in Japan, has been used in a subway train. Supporting safe and reliable subway operations, the system deals squarely with the demographic dilemma of a falling birthrate coupled with an increasing elderly population while holding down running costs.*

INTRODUCTION

AGAINST the backdrop of environmental challenges and a declining birth rate coupled with an increasingly elderly population, railroads must take the initiative in reducing their environmental impact, in minimizing life-cycle costs, and in preparing for a shrinking pool of skilled workers in the years ahead. Yet at the same time, we are seeing a leveling off of demand for rail travel in Japan, so we must strive for a better quality rail travel experience in order to retain riders and attract new passengers.

Hitachi is in the forefront of these quality enhancement efforts with the development of its next-generation A-train aluminum railcar system that reconciles a major advance in quality with lower costs. Assembled in a modular fashion using FSW (friction stir welding) and other revolutionary manufacturing methods, A-train cars have a high-precision, high-quality aluminum double carbody that is sleeker in appearance than conventional trains. Hitachi is continuing to improve and refine this A-train model.

* The A in A-train stands for a number of concepts and features characterizing the new system, all starting with the letter A: advanced, amenity, ability and aluminum.

Meanwhile, the fundamental needs of the Shinkansen (bullet train)—the mainstay mode of inter-city travel in Japan—are to simultaneously reduce travel times, achieve closer harmony with the environment, and to provide a comfortable riding experience. Here again, drawing on its expertise in various simulation and mechatronics technologies, Hitachi has been in the lead in coming up effective solutions for reducing exterior noise and improving the comfort of riding the Shinkansen.

Turning to the Shinkansen's drive system, Hitachi reengineered a hybrid drive system that is environmentally-friendly in that it conserves energy, and in the process devised more compact inverter circuits, leading-edge control technologies, and a host of other innovations.

Finally, in a ground-breaking development in the area of train operating systems, Hitachi developed an automatic operation system that was installed, for the first time in Japan, in a subway train. Essentially a compilation of Hitachi's rail technology know-how and expertise, this well demonstrates Hitachi's commitment to the industry and its ability to come up with creative solutions for railroad operating

Fig. 1—Train Systems that Incorporate Hitachi's Leading-edge Technologies.
Hitachi's advanced railway systems, found in all kinds of trains from the Shinkansen to subways, are contributing to the future of the rail industry.

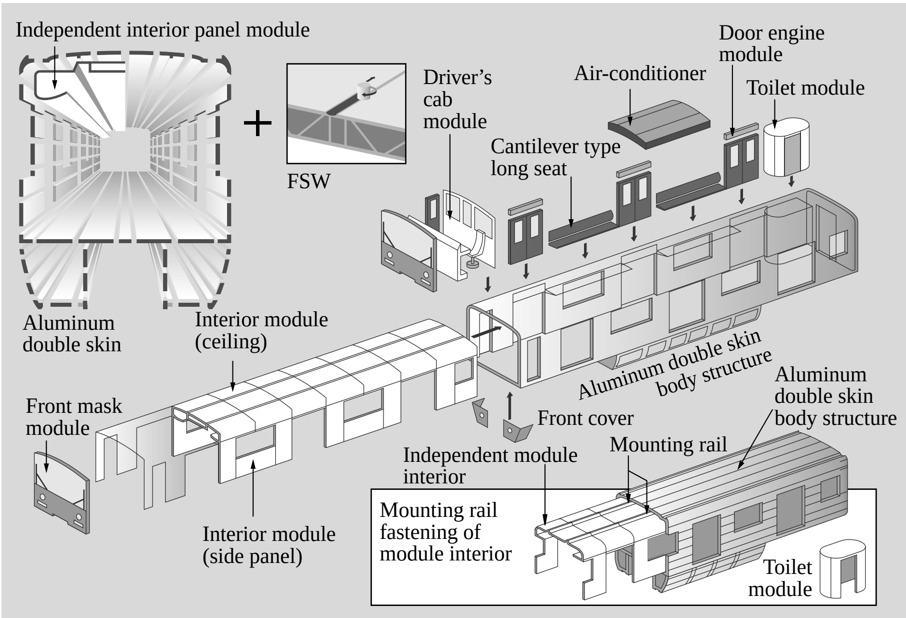

Fig. 2—A-train Basic Structure.
Independent interior panel module is fastened to the extrusion single-unit mounting rail in an aluminum double-skin body structure.

companies. In this article we will briefly survey Hitachi's solutions and contributions to these various new railroad systems.

EVOLVING A-TRAIN

Hitachi's next-generation A-train aluminum railcar system represents a fundamental reassessment of materials, structure, and manufacturing methods to develop a new kind of rolling stock that meets the needs of today to reduce environmental impact, minimize life-cycle costs, and are adapted to the projected shrinking pool of skilled labor (see Fig. 2). From 2003 to the present, the new A-train cars have been put into service on the Metropolitan Intercity Railway

Company's Tsukuba Express TX-2000 Series, Fukuoka City Transportation Bureau's Nanakuma Line Subway's Series 3000 trains, East Japan Railway Company's Sotobo and Uchibo Lines' Series E257 express trains, Tokyo Metro Company's Tozai Line Series 05 trains, TOYO RAPID RAILWAY CO., LTD.'s Tozai Line mutual trackage Series 2000 trains, TOBU RAILWAY CO., LTD.'s Tojo Line Series 50000 trains, and elsewhere. A-train rolling stock are being used on all kinds of trains ranging from commuter trains to special express trains, and the family is steadily increasing.

With a keen eye on the ever-changing business environment affecting the rail industry and operators, Hitachi continues to grapple with ways of improving the quality while pushing down the costs of its A-train system.

A-train passenger compartments were designed with passenger comfort in mind. The inside temperature is optimized for human comfort no matter what the outside conditions, and inside is whisper quiet even when the train is moving at top speed. The roof structure contains high-performance heat and sound insulation layers, but in the A-train cars these materials have been integrated in such a way that the roof structure is only 80% the thickness of conventional cars, which permits a noticeably more spacious interior in the A-train cars. Moreover, many of the features and subsystems that used to be implemented as functionally separate modules—the air conditioning ducts, baggage racks, fluorescent lamp assemblies, and wiring racks—are now organically connected as a consolidated set of components providing various different functions.

These are just some of the ways that we continue to refine and upgrade the quality of the A-train railcar system, making it such a valuable contribution and tool to the industry and railway operators.

HIGH-SPEED SHINKANSEN RAILCAR TECHNOLOGY

It has been some 40 years since the first Series 0 Shinkansen trains began operating at 210 km/h, and now the new Series N700 Tokaido and Sanyo Shinkansen trains will operate at maximum line speeds of up to 300 km/h on some sections. Even as the speeds have continued to increase over this period, the Shinkansen has also become increasingly eco-friendly, energy efficient, and comfortable inside. The prototype 16-car Series N700 Shinkansen, a compilation of many improvements and significant advances, made its debut in April 2005 (see Fig. 3). Here we will highlight some of most significant high-speed rail technologies that have been incorporated in the Series N700.

Fig. 3—View of Series N700 Shinkansen.
The Series N700 Shinkansen incorporates many of the latest technologies enabling faster speed, better rider comfort, and improved eco-friendliness.

Tilting System

In order to reduce the travel times between stations, the Shinkansen must
(1) increase its maximum line speeds,
(2) improve acceleration performance, and
(3) improve its ability to run through curves without slowing down.

This ability to navigate curves at high speed is especially critical on the connection between Tokyo and Shin-Osaka that has many curve sections, and for the first time on the Shinkansen, a tilting system has been adopted.

There are various ways that a tilting system could be implemented. The idea for the N700 Shinkansen was to use air-suspension pressuring to slightly elevate the outside rail when the train rounds the curve. While this was simple enough and was effective in suppressing the increasing mass, it took too long to respond from when a train was detected and was at first considered unsuitable for high-speed Shinkansen trains traveling at 270 km/h (75 m/s).

Eventually a way was found to use the tilting with air-suspension pressuring by combining it with a new ATC (automatic train control) system and train control and communication network that delivers precise speed and train position data in real time (see Fig. 4).

More Comfortable Ride

In order to reduce the travel time between stations, the emphasis on the Sanyo Shinkansen was simply to increase the maximum line speed, while the concern

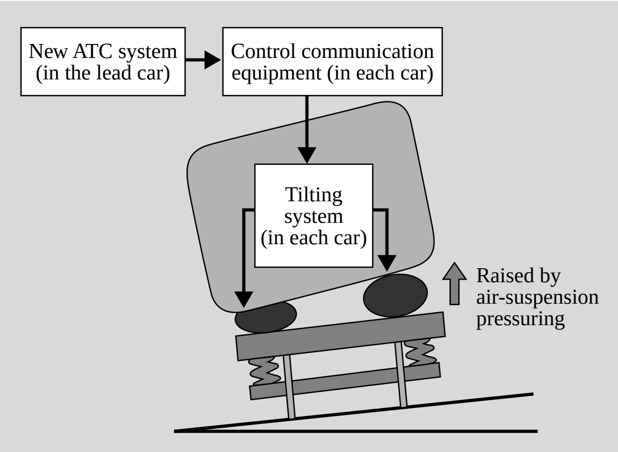

Fig.4—Schematic of Tilting System.
When navigating curves, the air suspension pressuring system tilts the cars toward the inside of the curve at an angle of 1 degree. A new ATC system detects location and speed information, which is conveyed to the tilting system over train control and communication network.

on the Tokaido Shinkansen with its many curve sections was to increase the speed of the train while navigating around curves. This meant that a range of technologies were introduced on the N700 to ensure that the comfort of the ride and the degree of quietness inside the passenger cars were not adversely affected by the increasing speed of the trains.

High-performance semi-active vibration control devices that had only been installed on some of the Series 700 Shinkansen cars—leading cars, cars with pantographs, and first-class cars—were installed on all the cars in the N700, and the new devices featuring single-step control are much more precise in dealing with car swaying than the previous 5-step control devices. In addition, problematic left-right acceleration when navigating around curves was reduced by the tilting system described earlier, and front-rear acceleration was reduced by smooth braking with a continuous speed profile employing a new-type ATC device.

To ensure passengers enjoy a quiet ride, a number of new technologies were introduced to exclude noise penetrating from outside (transmitted noise) and propagated vibrations from under-floor equipment and from the drive system (solid-borne noise). Transmitted noise was effectively suppressed in passenger compartments by more extensive use of the A-train double-skin body structure with its excellent sound insulation qualities, and noise protection in the deck areas was provided by installing for the first time a new-type hood that entirely covers the vestibule space between cars. The solid-borne noise was suppressed by damping drive system vibrations with a low-noise single ring and by installing special sound-insulated flooring that blocks vibrations and noise from the under-floor equipment.

Energy-saving Initiatives for Environmental-friendliness

Shinkansen trains travel as such high speeds that inevitably they must confront a number of environmental issues. Specifically, the new Series N700 trains must address the new aerodynamic phenomena arising from the faster maximum line speeds and faster speeds that the Shinkansen navigates curves. The most problematic issues that had to be addressed were micro-pressure waves in tunnel sections and exterior noise.

The micro-pressure waves are caused by pressure waves that form when a fast-moving train enters a tunnel. As it propagates through the tunnel, the pressure wave exerts fluctuating pressure on the train, and as the wave is reflected at the exit from the tunnel, a portion is emitted that makes a loud boom. The most effective way to mitigate these micro-pressure waves in tunnels is to adopt a constant, graduated rate of change of the cross section of the front or the nose of the train. Essentially, this meant extending the length of the nose, but this could adversely affect the number of riders or reduce the equipment carrying capacity of the train. The solution was to use the latest GA (genetic algorithm) analysis technology that is normally used in the development of aircraft wings. This resulted in the development of a longer tapered nose dubbed the aero double-wing that optimizes the aerodynamic performance of the N700 when traveling at 300 km/h, and extends the nose of the N700 to 10.7 m compared with 9.2 m for the Series 700 Shinkansen. Exterior noise was further reduced by adopting a new-type of hood that entirely covers the vestibule spaces between cars to smooth out the exterior of the train, and by further muffling the under-floor equipment.

Various methods were also adopted to mitigate the environmental effects of faster train speeds. Although the train mass of the N700 cars increased with the introduction of the body tilting system and other features, the N700 rolling stock is nevertheless lighter in weight than the Series 700 cars thanks to painstaking efforts to reduce the weight of every component of the cars and the introduction of an advanced control and communication system that substantially reduced the amount of on-board wiring. The running resistance was also markedly reduced by optimizing the nose shape of the leading car and by installing the streamlined hoods covering the spaces between cars mentioned earlier.

The N700 not only saves energy by reducing the frequency of accelerations and decelerations on curve sections, it also achieves significant energy conservation by replacing the traditional friction-based trailer brakes on the 700 cars with regenerative brakes on 14 of the N700 cars. Regenerative brakes allow the vehicle to recapture part of the kinetic energy that is otherwise lost to heat on other trains, which is supplied to the overhead wire from the pantograph. Braking is accomplished by switching motors to act as generators that convert motion into electricity instead of electricity into motion. Use of regenerative brakes saves approximately 10% of the power consumed by the Series 700 cars.

TRAIN MAIN CIRCUIT SYSTEM TECHNOLOGIES

Train Main Circuit System Needs

Fig. 5 shows a summary overview of the principle needs for train main circuit systems and the latest technological solutions for addressing those needs. To address energy conservation, maintainability, and eco-friendliness, Hitachi has focused on:

(1) Practical implementation of a hybrid drive system that improves rail motor maintainability and conserves energy.

(2) More advanced low-loss, low-noise main circuit and gate-drive technology to reduce the size and weight of main circuit systems.

(3) Cooling technology that utilizes air flow caused by running wind and is both more compact and quieter.

(4) Enhanced speed sensorless vector control technology that supports better adhesion coupled with improved maintainability and energy efficiency.

Hybrid Drive System

With the goal of reducing the environmental impact of diesel engine rail motors as the power source and reducing life-cycle costs, we developed a practical hybrid drive engine that not only improves maintainability but also adopts a energy storage technology that is expected to save considerable energy. Fig. 6 shows a schematic overview of system equipment. AC (alternating current) power generated by the engine is converted to VVVF (variable voltage, variable frequency) by the main converter, which drives an induction motor. A secondary battery (i.e. a storage

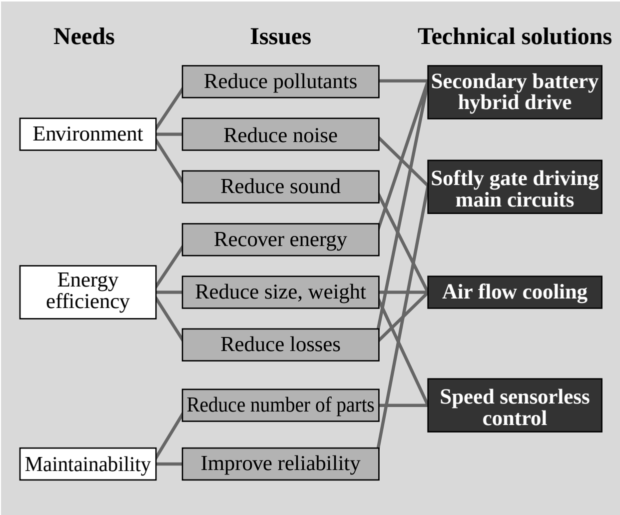

Fig. 5—Train Main Circuit System: Needs and Technical Solutions.
Hitachi develops new railway systems to address needs for energy conservation, maintainability, and eco-friendliness.

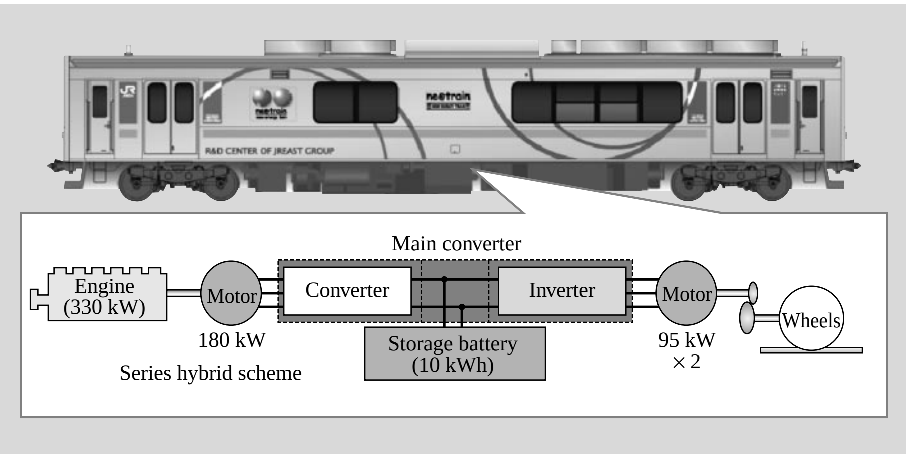

Fig. 6—Schematic Overview of Hybrid Drive System.
Engine output is converted to electrical energy and a series hybrid scheme is adopted in which just the motor drives the wheels.

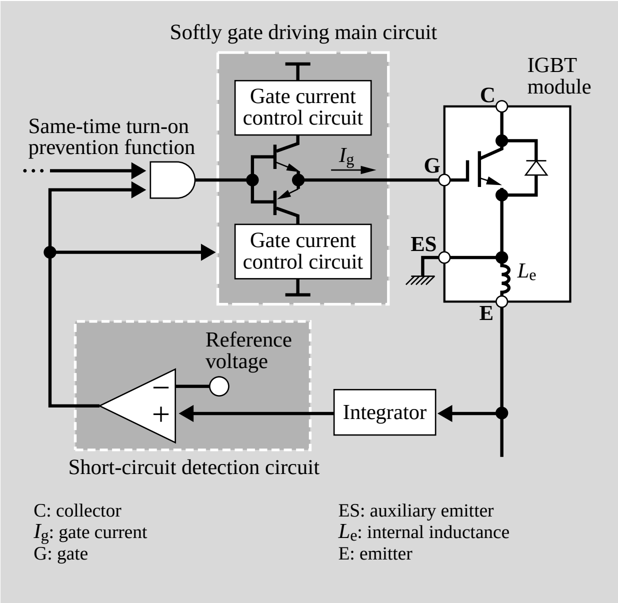

Fig. 7—System Configuration of Low-loss Low-noise Smart Main Circuit System.
A low-noise main circuit drive is implemented with softly gate control, and reliability is enhanced by same-time turn-on action between upper and lower switching elements that prevents short-circuits in the upper and lower switching elements.

battery) is installed in the converter's intermediate DC (direct current) section, and the charging and discharging of the batteries is controlled by the output balance between the converter and inverter. Note in this system that the engine shares much in common with conventional rail motors and the converter and other electrical components share similar technology with inverter trains. This means we can continue using the same maintenance technology in these areas while eliminating a number of mechanical parts—including the transmission and reversing gear—and reducing maintenance costs.

Low-loss Low-noise Main Circuit Technology

A smart inverter system was developed that not only minimizes IGBT (insulated gate bipolar transistor) inverter generation losses but also incorporates main circuit and gate control technology that effectively suppresses adverse effects on the signal system (see Fig. 7). We also reduced the size and weight of circuitry by reducing the number of circuit elements, incorporated a softly gate driving technology that was well adapted for the snubberless main circuit, and added maintenance functions that enhanced already high reliability. These measures had a number of beneficial effects:

(1) By implementing the main circuit with a soft switching IGBT module and 100-nH class super-low-impedance device, losses and noise of both the voltage change factor and current change factor are reduced by the gate control.

(2) Short-circuits are immediately detected without affecting main circuit noise, and without high-voltage detection, and the arm short-circuit protection function protects IGBT cut-off.

(3) Protection of same-time turn-on action between upper and lower switching elements effectively prevents short-circuits in the upper and lower switching elements at ignition.

More Compact and Lighter Weight Cooling System

In the past, high-capacity main circuit systems such as used in Shinkansen trains have relied extensively for cooling on high-performance boiling cooling systems. Taking full advantage of air flow was an essential key in developing an advanced next-generation cooling technology that combines smaller size and weight with reduced noise.

A notable feature of the structure that takes in cooling air from the side of the train is that it has a high degree of freedom as to placement of the radiator and the efficient way it takes in air flow. We are also making good progress in the development of a blowerless air flow cooling system that uses aluminum fins in the radiator and is installed below the surface of the floor. The primary goals of these projects are to devise a cooling system that makes less noise when the train is running at high speed and is quiet when the train is stopped in stations.

High-speed Sensorless Vector Control Technology

High expectations have emerged for high-speed sensorless control (i.e. control that eliminates the need for speed sensors) that promises better maintainability coupled with better durability against adverse environmental conditions. Hitachi has made good headway in the development of sensorless speed vector control providing much improved adhesion performance by eliminating delays in speed signal processing while at the same time conserving energy through improved voltage control (see Fig. 8). These improvements have had a number of beneficial effects:

(1) By performing speed estimation calculations using torque current control, slipping and skidding can be

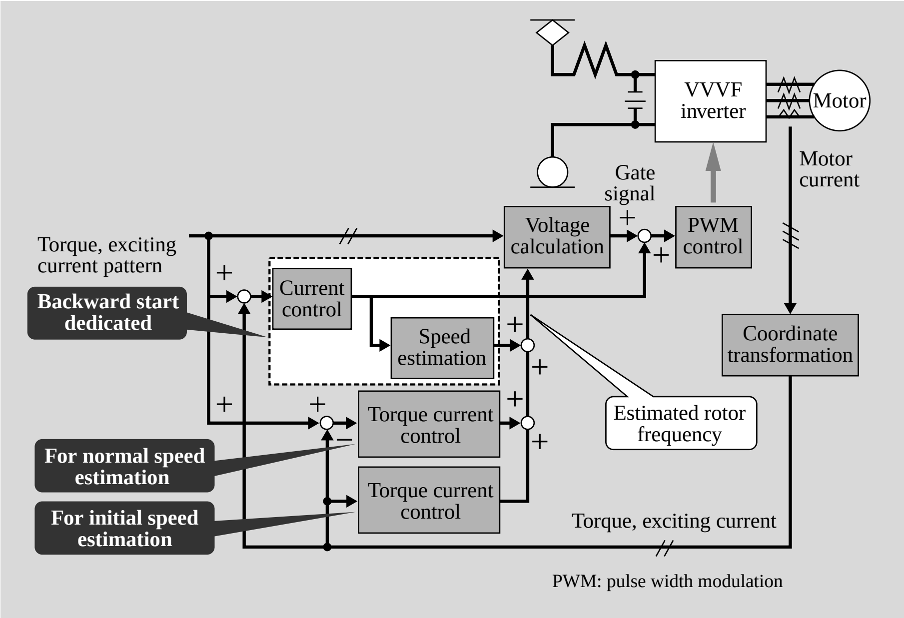

Fig. 8—Scheme for Enhancing Speed Sensorless Vector Control.
Adhesion performance is improved while energy is saved, and at the same time, initial speed estimates can be obtained faster and with greater precision by adding an initial speed estimation and backward start dedicated control unit.

detected immediately with a high degree of accuracy.
(2) Excellent robustness with respect to constant variables is achieved by adopting an exciting current feed-forward control scheme that works particularly well with motor constant variables.
(3) Initial speed estimates can be obtained even faster and with greater precision by adding an initial speed estimation and backward start dedicated control unit.

SIGNALING AND INFORMATION TECHNOLOGY

Signaling and Information System Requirements

The development of more people-oriented rail transport systems is critically important as needs continue to evolve: how to deal with improved operation-related security, the demographic dilemma of a declining birth rate coupled with increasing elderly population, reduced maintenance capabilities, and providing barrier-free access. Hitachi is committed to addressing these needs:
(1) In the area of automatic train operation, Hitachi has developed a driverless operation system that integrates a range of automation systems and technologies including procedures for dealing with emergency situations, and management of monitoring and other equipment.
(2) Hitachi has developed an integrated signal security system that features a shared fail-safe architecture for the digital ATC system, and a range of other signaling systems.
(3) Supported by high-speed large-capacity broadband transmission between on-board and track-side systems, an advanced train control and communication system has been developed that supports centralized management of information.

Driverless Operation System

Implementing driverless automatic operation on a train involves more than simply automating the navigation of the train per se, for it requires careful consideration of the security of passengers while ensuring their safety in the face of various abnormal events that might occur. The three basic requirements of an automatic operation system are
(1) to avoid stopping the train between stations,
(2) to do nothing that might arouse uneasiness among riders, and
(3) to assure operating safety.

Hitachi has developed a range of technologies to ensure that these requirements are met, including operating management systems, interlocking platform doors, ATC systems, train radio systems, train monitoring system series, and more.

Signaling System

A typical example of a signaling system is Hitachi's ATC system that provides continuous guide signals to the track circuit. There are in addition a host of other signaling systems in use that adopt quite different

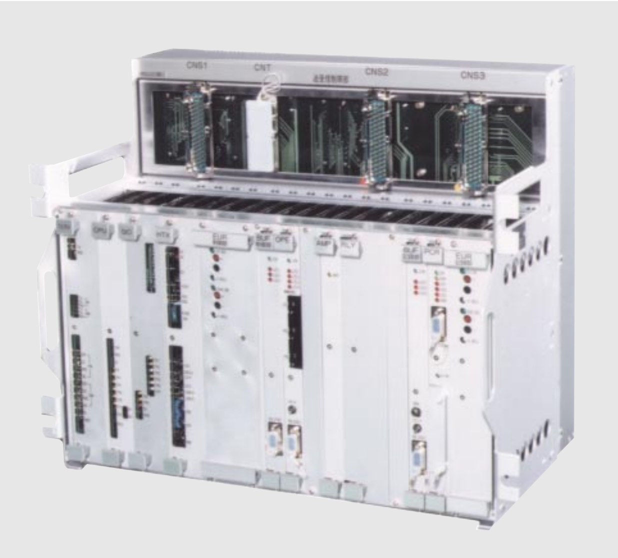

Fig. 9—Example of Fail-safe Arithmetic Unit.
An arithmetic circuit and redundant check function for ATC have been implemented as an LSI. Performing a microprocessor fail-safe check, the chip has been applied in the ATS-P system.

schemes and configurations including the ATS (automatic train stop) system, and the ATS-P (pattern-type ATS) system. Based on a fail-safe arithmetic unit that the company adopted in its digital ATC system, Hitachi has developed a range of on-board modular equipment and systems that use the same architecture. This ensures safety, compact implementation, excellent reliability, and interchangeability (see Fig. 9).

Train Information System

As a key technology for handling the enormous increasing volume of data involved in operating trains, Hitachi has developed a high-speed on-board data transmission system that integrates a shared interface control system, maintenance system, and service system, and many application systems are heavily reliant on the high-speed system. Representative examples include:

(1) Monitoring systems that monitor on-board equipment, collect maintenance data, and perform a variety of automatic checks.

(2) Communication system that relays control signals between equipment, and that reduces the amount of on-board wiring by transmitting monitoring signals in digital format.

(3) Information transmission systems that distributes multimedia data to and collects multimedia data from each car such as passenger information data and monitor video data.

CONCLUSIONS

This paper presented just a few of the railway and train related solutions that Hitachi has developed and made available to the rail industry and operators including the next-generation A-train aluminum railcar system, high-speed Shinkansen rolling stock, train main circuit systems, and signaling and information systems.

Railroads face an environment that is constantly changing. Hitachi has been in the forefront in developing innovative solutions that address these challenges faced by railway operators—the demographic dilemma of a declining birth rate coupled with an increasingly elderly population, global environmental issues, etc.—while continuing to develop technologies that support the unchanging requirements of safety and reliability.

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