Mass Production of Electric Control Units for Electric Power Steering Systems

Demand has risen for electric power steering (EPS) systems, which utilize an electric motor for their operation, accompanying improvements in fuel efficiency and the overall computerization of automotive vehicles. An EPS is equipped with an electric control unit (ECU) that calculates the appropriate assistance power for steering and supplies the required electric power to the motor.

A line for the mass production of ECUs for EPS systems has been built at Toshiba Information Equipment (Hangzhou) Co., Ltd. (TIH), and production and shipment commenced in January 2014.

Because the ECU of an EPS system is classified as a critical safety part, which must have high safety and reliability, measures have been established to ensure high quality in the production line at TIH. These measures include thorough supplier management, prevention of the outflow of defective products, statistical process control to prevent defects in each process, a traceability system to record process information and verification results, and training in quality manufacturing.

A key feature of the ECUs produced at TIH is the adoption of a bare chip surface packaging structure consisting of a field-effect transistor (FET) and copper connector, thereby achieving both miniaturization and cost reduction. Toshiba is the first in the industry to realize this technology(*). These units also provide a fail-safe mechanism without the need for a redundant processor structure through the use of a microprocessor that provides enhanced functional safety.

(*) As of December 2014 (as researched by Toshiba)

ECU for EPS systems

Production line for ECUs for EPS systems

Propulsion System Consisting of Permanent Magnet Synchronous Motors and Traction Inverters Incorporating SiC Diodes for Series 1000 EMUs of Tokyo Metro Co., Ltd.

Toshiba has delivered a propulsion system, consisting of totally enclosed permanent magnet synchronous motors (PMSMs) and variable-voltage variable-frequency (VVVF) traction inverters incorporating silicon carbide (SiC) diodes, for the third-generation Series 1000 electric multiple units (EMUs) of Tokyo Metro Co., Ltd. This is the world's first propulsion system that employs VVVF traction inverters incorporating SiC diodes to drive PMSMs(*).

A new control scheme suitable for SiC diodes has been applied and the designs of the PMSMs and filter reactor have been improved for increased efficiency.

Our in-house test results show that our propulsion system achieves a reduction of 3.9% in tractive power consumption and an increase of 3.0% in regenerative power. We will further verify the energy-saving capacity of the system in the commercial operation of the third-generation Series 1000 EMUs.

Part of this system's development was carried out under the "Research and Development of High Efficiency, Compact Inverter System Technology with High Voltage SiC Power Devices" supported by the Innovative Energy Conservation Technology Development Project of the New Energy and Industrial Technology Development Organization (NEDO).

(*) As of September 2014 (as researched by Toshiba)

Series 1000 EMU of Tokyo Metro Co., Ltd.

SiC VVVF traction inverter

PMSM

Permanent Magnet Synchronous Motor Propulsion System for C151 Series Trains of SMRT Corporation Ltd., Singapore

The permanent magnet synchronous motor (PMSM), which employs permanent magnets in the rotor, is a highly efficient traction motor that can serve as one of the key components in realizing an energy-saving propulsion system for rolling stock.

Toshiba embarked on the development of a totally enclosed, self-cooled type PMSM at an early stage and commercialized a propulsion system using this PMSM. Since then, we have recorded many achievements in the Japanese railway market.

In the summer of 2013, we were awarded a contract by SMRT Corporation Ltd. (SMRT), a railway operator in Singapore, for a PMSM propulsion system to refurbish the existing DC motor systems of 66 C151 series train sets (396 cars). This is the first deployment of our highly efficient PMSM propulsion system outside Japan.

The salient features of the PMSM propulsion system are as follows:

- energy-saving performance due to the highly efficient traction motor with a rated efficiency of 97%
- easy maintenance achieved by the totally enclosed main motor
- low noise, with ventilation noise reduced by about 12 dBA.

The testing of cars equipped with our system is being conducted smoothly on SMRT's testing track and the main line.

C151 series train refurbished with PMSMs undergoing testing

Permanent Magnet Synchronous Motor Incorporating SmCo Magnet for 305 Series EMUs of Kyushu Railway Company

Kyushu Railway Company has introduced the new 305 series EMUs as a replacement for the 103 series EMUs running on the Chikuhi Line. The 305 series are the first mass-produced EMUs within the JR Group to incorporate a permanent magnet synchronous motor (PMSM) in the main circuit system.

Samarium cobalt (SmCo) magnets serve as the permanent magnets in this highly energy-saving and maintenance-free enclosed type PMSM. These SmCo magnets, which are being utilized for the first time to drive railway vehicles(*), are free of rare-earth elements, which are vulnerable to supply risk. The magnet was developed by Toshiba, and Toshiba Materials Co., Ltd. took charge of its mass production.

Operation of the 305 series EMUs on the Chikuhi Line (in mutual operation with the Fukuoka Municipal Subway Kuko Line) commenced in stages beginning in February 2015. Kyushu Railway Company completed the commercial introduction of all six train sets as scheduled in March 2015.

(*) As of September 2014 (as researched by Toshiba)

PMSM for 305 series EMUs of Kyushu Railway Company

3.3 kV SiC Hybrid IGBT for Vehicle Controller in 3000 Series EMUs of Nishi-Nippon Railroad Co., Ltd.

The silicon carbide (SiC) power device offers better performance than a silicon power device, including low switching loss, high reaction speed, and high-temperature operation. It is therefore considered to be indispensable for realization of the next-generation power converter.

Toshiba has developed a 3.3 kV SiC hybrid insulated gate bipolar transistor (IGBT) for DC 1 500 V overhead lines and applied it to the vehicle controller device in the 3000 series EMUs of Nishi-Nippon Railroad Co., Ltd. The low switching loss characteristics of the SiC hybrid IGBT improve the inverter output current and carrier frequency of the pulse width modulation (PWM) control while maintaining the cooling performance of the previous inverter unit.

We have performed a verification test by installing SiC hybrid IGBTs in 3000 series EMUs and confirmed that they realize an energy saving of about 5% compared with EMUs equipped with a conventional power device.

Inverter unit equipped with 3.3 kV SiC hybrid IGBTs for 3000 series EMUs of Nishi-Nippon Railroad Co., Ltd.

SCiB™ Battery System for Rolling Stock

In recent years, a hybrid shunting locomotive and an electro-drive operation method that does not require a feeding system have been developed to reduce the total energy consumption of rolling stock systems.

Toshiba has developed a traction battery system for these purposes using its SCiB™ lithium (Li)-ion battery, which employs a lithium titanate (LTO) anode. LTO gives the SCiB™ battery various advantages. First, LTO achieves fast Li-ion migration, which allows high-speed charging and discharging of the battery. Second, long battery life is assured because only small amounts of metal are deposited on the LTO anode. Third, the battery can be charged and discharged even at temperatures as low as -30°C. Fourth, the use of LTO makes the battery highly safe. In the event of a short circuit, LTO emits Li ions and exhibits an insulative property. This property serves to significantly lower the short circuit temperature, limiting the emission of heat.

The structure of the SCiB™ traction battery system has also been designed so that it can be installed either under the floor or on the roof of rolling stock.

Toshiba continues to provide innovative railway solutions with smart battery systems that ensure both safety and a long life.

Traction battery system for rolling stock using SCiB™ Li-ion battery

Introduction of Electric Bus System at Toshiba Fuchu Complex

Toshiba has built an electric bus system for picking up and sending off visitors at the Fuchu Complex.

This electric bus system incorporates the high-performance SCiB™ Li-ion battery and an application using a new technology created for the bus. The bus system is also utilized to demonstrate the performance of these devices.

The electric bus application provides an in-vehicle display system. This allows the bus to connect to the Internet at any time via ground-side equipment to exchange various types of information, and shows information for the passengers on the display.

The bus also has a satellite positioning system using the Quasi-Zenith Satellite System (QZSS), which accurately shows the position of the bus on a large-screen monitor at the guest center of the Fuchu Complex. By associating bus operations with future evolutions in the QZSS system, we expect to be able to pinpoint the position of the bus to within an accuracy of several centimeters, which will be useful in understanding traffic conditions.

Electric bus introduced at Fuchu Complex

Commencement of Operation of Automated Mail Sorting System at Singapore Post Limited

Toshiba has supplied its TT-1600 automated mail sorting system to Singapore Post Limited. Installation of the system began in March 2014, and it commenced operation in November of the same year. This system made it possible to automatically sort most of the mail items processed by Singapore Post.

The system is an integrated mail sorting system that performs the tasks essential for mail processing and related operations. It consists of conventional letter sorting machines; flat item and packet sorters; a unified optical character recognition and video coding system (OCRV) incorporating an optical character reader (OCR), barcode reader, and video coding system (VCS); and an information technology (IT) system for operation planning and management.

Each of these devices offers not only a high throughput and OCR read rate, but also excellent environmental performance such as space saving, low noise, and low power consumption. In addition, a high level of operational efficiency is achieved by centralized control of the data from the different devices by the IT system.

TT-1600 automated mail sorting system for Singapore Post Limited

New EG-7000 Automatic Ticket Gate for Shinkansen Stations with Improved Passenger Friendliness and Enhanced Usability for Station Personnel

High-performance automatic ticket gates at Shinkansen stations handle several types of tickets and smart cards simultaneously, including fare tickets, limited express tickets, and seat reservation tickets, as well as smart cards for Shinkansen and conventional railway lines.

Toshiba has developed the new EG-7000 automatic ticket gate for Shinkansen stations that incorporates improvements in terms of not only processing performance but also passenger friendliness and usability for station personnel.

The main features of the new automatic ticket gate are as follows:

- User-friendly design for passengers
  The new ticket gate has a streamlined shape, a slim body 20 mm thinner than the previous model, and a ticket outlet sign that signals passengers not to forget to take their ticket after passing through the gate.
- New mechanism to improve usability for station personnel
  A temporary ticket holding unit enables station personnel to easily find a ticket that is stuck inside the machine.

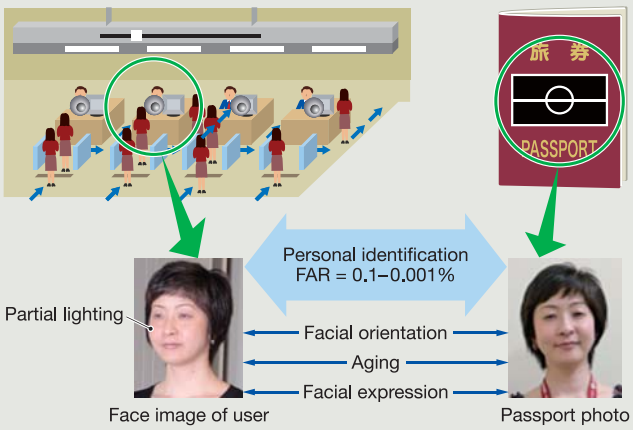
Newly developed EG-7000 automatic ticket gate for Shinkansen stations

Improvement of Face Recognition Accuracy

Toshiba has accumulated 20 years of experience in face recognition technology and has utilized it since 1999 for PC logins as well as for access control at consumer and government sites.

The access control system for consumer use achieved a false rejection rate (FRR) of 1% at a false acceptance rate (FAR) of 0.1%. Subsequently, we developed applications for government use that achieve higher query precision for facial images through enhancement of performance by making more robust facial identification possible regardless of facial orientations and lighting conditions. The performance of our highly accurate face query algorithms has been verified by the U.S. National Institute of Standards and Technology (NIST) in Face Recognition Vendor Test (FRVT) 2013.

For immigration use, however, the precision of one-to-one matching between an ID picture and the facial image of the person presenting the ID should be evaluated at a minimum FAR of 0.001%. In order to meet this requirement and expand the areas of application, we are making efforts to improve its robustness against facial aging, lighting conditions, and facial expressions by using machine learning.



Items for improvement of accuracy of immigration application

Unified Controller nv Series "type2 light" small- to medium-scale controller

Toshiba has added the "type2 light" model to its range of Unified Controller nv series products. The type2 light is a distributed control system (DCS) type controller intended for small- to medium-scale systems.

The main features are as follows:

- Compact DCS
  To facilitate setting up of the system configuration by users, we selected standard functions for the DCS and combined them into one small module with a width of 70 mm. The module contains two network functions (interfaces for remote input/output (I/O) and for an information system), as well as duplex-redundant functions.
- Connection between latest and existing systems, and between systems of other vendors
  In order to connect the latest system with existing systems, the type2 light has been designed to support the latest TC-net I/O series as well as the previous I/O series; namely, the intelligent I/O series. Furthermore, the type2 light is designed to support several types of industrial fieldbus networks so as to connect to existing systems of other vendors.
- Continuous operation (reliability)
  The type2 light is designed to offer high reliability in order to ensure continuous operation and improve productivity. The user can operate the system in a duplex-mode configuration. The type2 light also has a self-diagnosis function run by software and a hardware-assisted error check and correct (ECC) function for automatic memory correction.

Unified Controller nv series type2 light small- to medium-scale controller

LF471 Electromagnetic Flowmeter with Extremely Small-Diameter Measuring Pipe for Marine SCR Systems

Marine vessels equipped with diesel engines having an output exceeding 130 kW that are constructed from 2016 onwards are required to have a selective catalytic reduction (SCR) system in accordance with the International Maritime Organization (IMO) regulations for the reduction of nitrogen oxides (NO_x) in exhaust gases, when navigating in designated regions of the sea.

In SCR systems, a urea solution is used as a reducing agent to remove NO_x gases. To manage the volume of urea solution, an electromagnetic flowmeter for extremely small-diameter pipes is essential.

Responding to this need, Toshiba has optimized the materials and product specifications for a new electromagnetic flowmeter and developed the low-cost LF471 model.

LF471 electromagnetic flowmeter for marine SCR systems

To assure that the LF471 is compatible with SCR system requirements, it has been designed to provide (1) improved tolerance against electrical noise and vibration in marine vessel environments, (2) compact dimensions to allow installation even in narrow spaces, and (3) improved long-term zero-point stability. Furthermore, unlike other types of flowmeters such as Coriolis, orifice, and mechanical flowmeters, the LF471 causes minimal loss in liquid pressure because it does not obstruct the liquid flow in the pipe. It also requires little maintenance due to the absence of mechanical moving parts.

Solid-State Dual-Polarization Doppler Weather Radar for *Mirai* Oceanographic Research Vessel

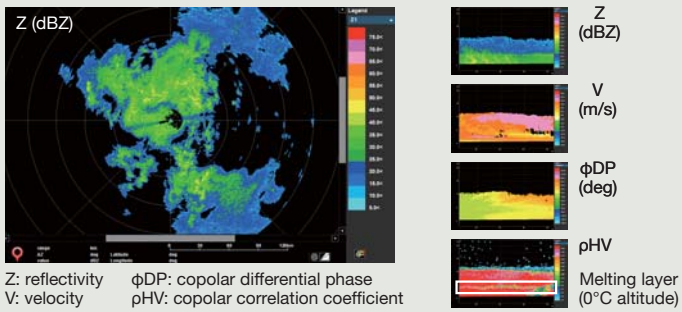
Toshiba has developed a solid-state dual-polarization Doppler weather radar for the *Mirai* oceanographic research vessel owned by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). It is the world's first C-band (5 GHz) dual-polarization Doppler weather radar equipped with a solid-state transmitter designed for use on marine vessels(*).

The main features of the new radar include motion control and rotation correction, which respectively assist in stabilizing the direction and plane of the antenna against ship motions. It also has the capability to correct Doppler velocity due to the vessel's movement. Because of the use of these techniques, the new radar provides observation performance equivalent to that of ground weather radars.

We commenced test operation of the radar in June 2014 and successfully observed the melting layer in rain clouds at near-zero temperature. As a result, we have confirmed the outstanding performance unique to dual-polarization observation. Several research voyages are planned, during which significant amounts of useful data are expected to be obtained for research on oceanic precipitation.

(*) As of November 2014 (as researched by Toshiba)

Solid-state dual-polarization Doppler weather radar installed on *Mirai* oceanographic research vessel



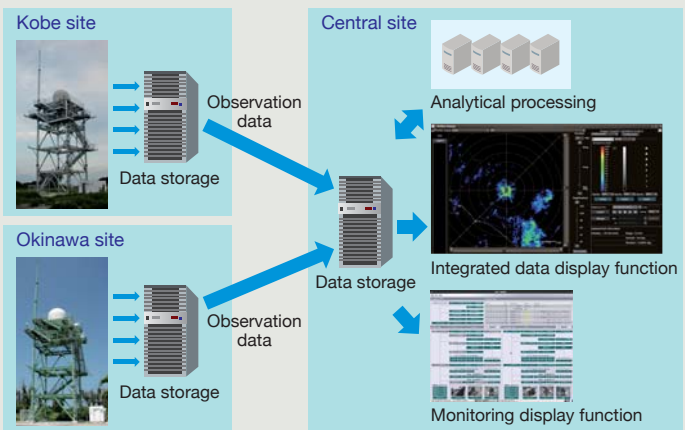
Examples of plan position indicator (PPI) and range height indicator (RHI) observation data

Sensor Fusion System for Comprehensive Observation of Weather Phenomena

Meteorological observations have recently come to play an increasingly important role in improving the operational efficiency of natural-energy electricity generation systems and reducing the damage caused by natural disasters.

In response to this trend, Toshiba has been developing sensor fusion systems for the centralized control of various meteorological sensors as well as for the comprehensive management of observation data.

In 2014, we delivered a phased-array weather radar and Doppler lidar fusion system to the National Institute of Information and Communications Technology (NICT). This sensor fusion system, installed at a central site in the Koganei district of Tokyo, manages various data obtained by phased-array weather radars, Doppler lidars, microwave radiometers, and other sensors at observation sites in Kobe and Okinawa.



Phased-array weather radar and Doppler lidar fusion system

The sensor fusion system at the central site is equipped with a large monitor display incorporating various functions including a quick-look function to access observation data using a Web browser and a function to simultaneously display combined data by overlaying multiple sensor data, in order to facilitate the effective analysis of observation data.

The newly developed system is expected to contribute to the understanding and prediction of extreme weather phenomena such as localized torrential rainfall.

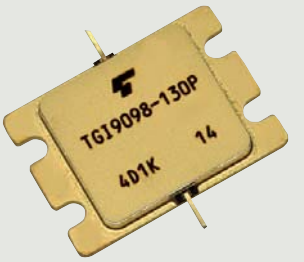
X-Band 130 W-Class GaN HEMT for SSPAs in Radar Systems

Weather radar and marine radar systems have employed travelling wave tube amplifiers (TWTAs) due to their ability to operate at high power. However, there has been strong demand to replace these TWTAs with solid-state power amplifiers (SSPAs), which are smaller and lighter and have a longer operating life. In order to enhance the output power of SSPAs, the gallium nitride (GaN) high electron mobility transistor (HEMT) employed in such amplifiers is required to have higher output power, higher gain, and higher power-added efficiency (PAE).

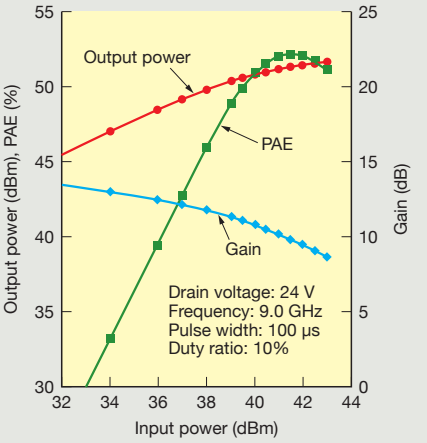
Toshiba has developed an X-band (8 to 12 GHz) 130 W-class GaN HEMT device. The following approaches were adopted to improve the performance of the GaN HEMT: (1) increase output power by suppressing current collapse, (2) increase gain by reducing capacitance between the gate and drain, and (3) increase PAE by controlling harmonic components.

Under pulsed operation at 9.0 GHz (duty ratio: 10%; pulse width: 100 µs), the newly developed GaN HEMT achieves an output power of 51.0 dBm, a gain of 10.5 dB, and a PAE of 52% at an input power of 40.5 dBm. Its saturated output power is 51.6 dBm (144 W). A PAE of more than 50% is obtained in the frequency range from 9.0 to 9.8 GHz (X-band radar bandwidth).

We are continuing to work toward the commercialization of the new device, which we expect to contribute to the progress of radar systems.



X-band 130 W-class GaN HEMT



Radio-frequency (RF) characteristics of GaN HEMT at 9.0 GHz

High-Performance Digital Signal Processor Board

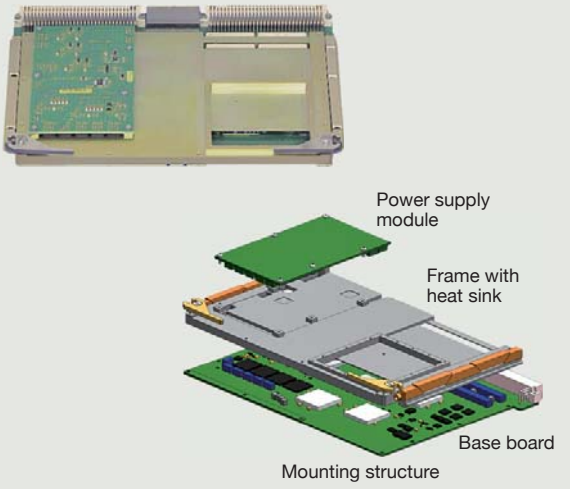
Various industrial computers are operating under severe environments, and the number of such computers is increasing every year. This situation has led to rising demand for not only improvements in the operational performance of industrial computers but also further reductions in their size and weight as well as their power consumption and cooling requirements.

To meet these needs, Toshiba has developed a high-performance digital signal processor (DSP) board that accelerates continuous real-time signal processing and memory throughput. As a result, the new DSP board has achieved a performance of 15 giga-floating-point operations per second (GFLOPS) as well as a low power consumption of 30 W in the operating temperature range of -40 to +71°C.

This board consists of a base circuit board equipped with processors, memories, and other integrated circuits (ICs), a frame with a heat sink, and a power supply module.

The new high-performance DSP board offers the following advantages:

- Both the continuous real-time signal processing performance and memory throughput of the industrial computer are enhanced.
- The size of the industrial computer can be further reduced.
- The environmental ruggedness of the industrial computer can be improved.



High-performance DSP board