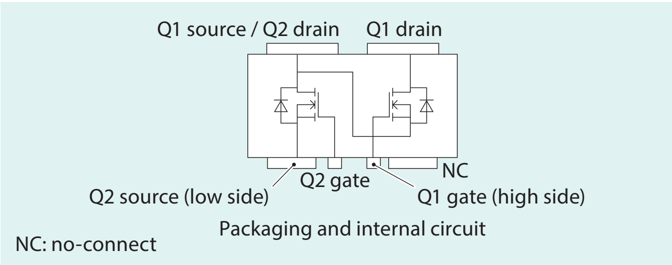
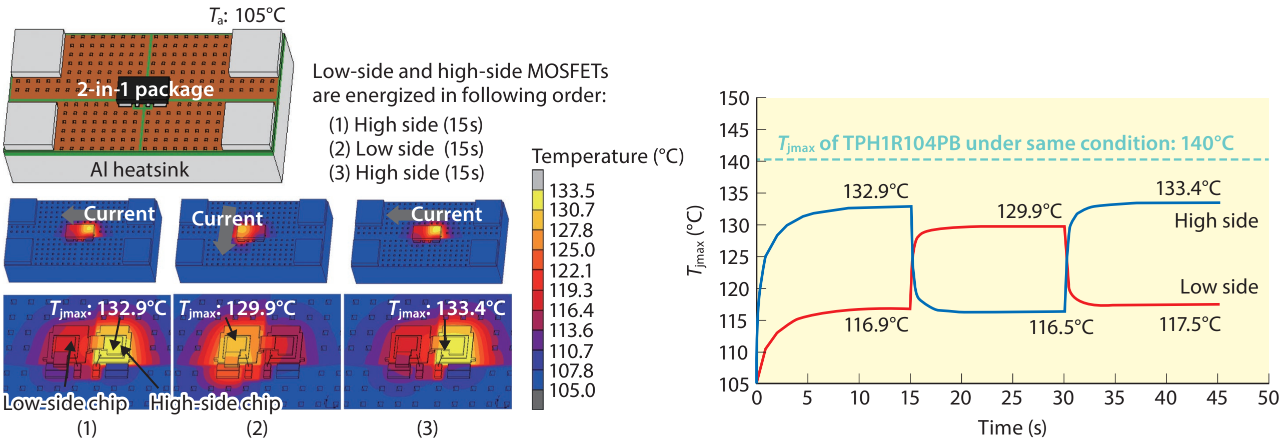
4. Electronic Devices and Storage

4.1 Two-in-One Power MOSFET with Reduced Mounting Area Contributing to More Compact In-Vehicle Electronic Equipment



Equivalent circuit diagram and pin configuration of the 2-in-1 power MOSFET under development



Thermal simulation results

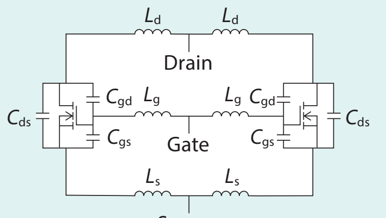
Vehicle electrification is accelerating worldwide to comply with environmental regulations. Although power metal-oxide semiconductor field-effect transistors (MOSFETs) are required to support high-current, high-power motors to enhance electric vehicle performance, there are space constraints for electronic control units (ECUs). Demand is therefore growing for compact surface-mount devices (SMDs) with high current density.

With this in mind, Toshiba Electronic Devices & Storage Corporation has developed a 2-in-1 surface-mount power MOSFET that consists of two chips in the same package. It provides improved heat dissipation and is housed in a package with a smaller footprint than the total footprint of two packages containing a single MOSFET. For a half-bridge circuit, using the new 2-in-1 MOSFET results in a 41% reduction in circuit footprint compared to when using two conventional single (1-in-1) MOSFETs. Internal copper connectors pass high current between two chips. The internal half-bridge configuration and the adjacent gate terminals of two chips also simplify inverter design.

Because power MOSFETs generate heat during operation, thermal considerations are crucial for high-density applications. In addition to reduced on-resistance to minimize conduction loss, we have improved the thermal performance of the 2-in-1 MOSFET by using a thick copper leadframe. In simulations under electric power steering (EPS) stall conditions, the maximum junction temperature (T_{jmax}) of the new 2-in-1 MOSFET remained equal to (140°C) or lower than that of the 1-in-1 MOSFET in the SOP Advance (WF (Wettable Flank)) package (TPH1R104PB) with equivalent on-resistance.

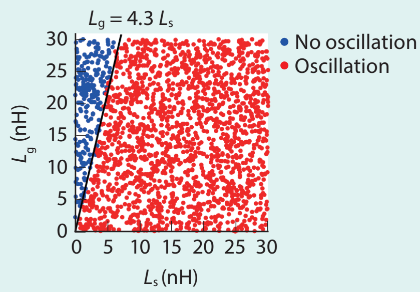
Vehicle electrification is expected to continue, increasing the importance of automotive power MOSFETs. We will offer MOSFETs in alignment with ECU trends to support the advancement of the automotive industry.

4.2 Approach to Mitigating Parasitic Oscillation Between Parallel-Connected Chips in SiC Power Modules

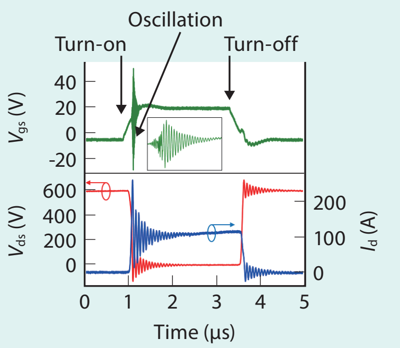


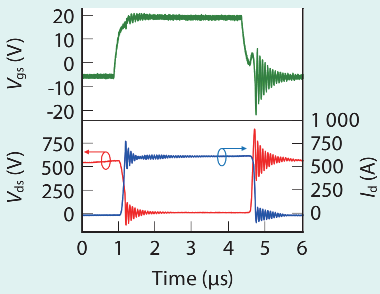
L_d: drain-to-drain inductance C_{ds}: drain-to-source capacitance
C_{gd}: gate-to-drain capacitance C_{gs}: gate-to-source capacitance

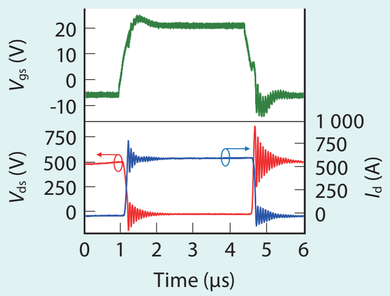
Equivalent circuit of two MOSFETs connected in parallel



Simulation-based oscillation condition in two parallel MOSFETs with zero gate resistance







Measurement conditions		Module A	Module B	Module C
Internal chip gate resistance (Ω)		12	30	12
L_g/L_s (simulation-based)		2.10	2.10	3.86
I_d = 100 A	Turn-on losses (mJ)	1.78	2.94	1.80
	Turn-off losses (mJ)	1.68	2.14	1.61
I_d = 600 A	Turn-on losses (mJ)	N/A	6.69	4.89
	Turn-off losses (mJ)	N/A	29.26	24.66

V_{gs}: gate-to-source voltage V_{ds}: drain-to-source voltage I_d: drain current

Prototype module switching waveforms and switching losses

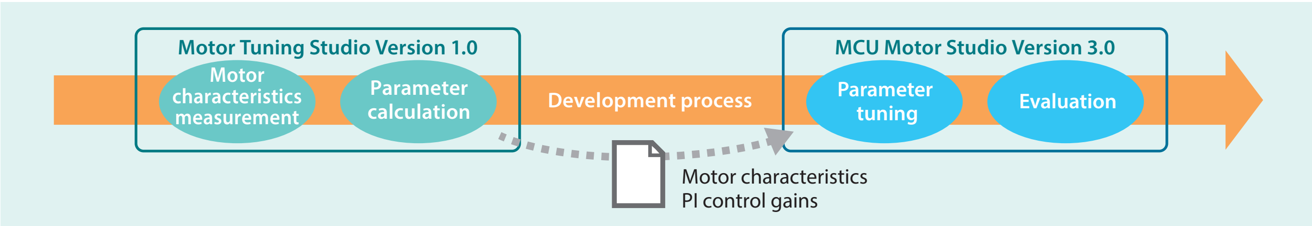
Carbon neutrality initiatives are driving demand for technologies that improve energy efficiency in many areas, including renewables, railways, and industrial equipment. In these sectors, the application of power modules built around silicon carbide (SiC) MOSFETs is seen as a solution that supports high-speed switching at high voltages and high currents.

In the case of power modules, higher switching frequencies result in higher ratios of switching loss to total loss, so it is important to reduce switching loss. Connecting multiple chips in parallel in power modules to accommodate high current can form oscillation circuits due to wiring inductance between chips and parasitic capacitance. This reduces module reliability if not countered, which is usually achieved by increasing gate resistance. However, this approach slows switching speed, resulting in a trade-off with switching losses.

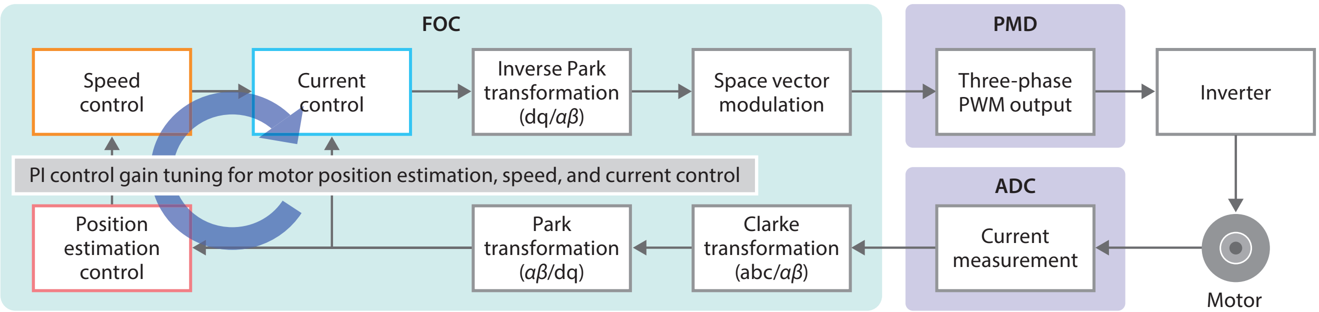
The Toshiba Group has developed technology to mitigate parasitic oscillation during wiring layout. This was accomplished by analyzing simulations using an equivalent circuit model of the power module to determine theoretical oscillation conditions. The results show that parasitic oscillation occurs when L_g/L_s, the ratio of gate-to-gate inductance (L_g) to source-to-source inductance (L_s) of parallel chips, is below a certain value. As increasing L_g/L_s is an effective means of mitigating parasitic oscillation, we fabricated prototype modules with different L_g/L_s values and measured switching performance. This confirmed that increasing L_g/L_s mitigated oscillation, even with a 60% lower gate resistance than that required by the alternative approach of increasing gate resistance.

Applying this technology to power modules in development can make them less likely to cause parasitic oscillation, even with minimal gate resistance. The new technology therefore helps in the development of power modules with low power loss and highly reliable switching operation.

4.3 Release of Motor Tuning Studio Version 1.0 and MCU Motor Studio Version 3.0



Development process using Motor Tuning Studio Version 1.0 and MCU Motor Studio Version 3.0



PMD: programmable motor driver PWM: pulse-width modulation ADC: analog-to-digital converter

FOC PI gain tuning

Toshiba Electronic Devices & Storage Corporation jointly developed MCU Motor Studio Version 3.0 and Motor Tuning Studio Version 1.0 with Corporate Laboratory of Toshiba Corporation, which were released in March 2024. MCU Motor Studio Version 3.0, an enhanced version of MCU Motor Studio, a motor control software development kit released in 2022, now incorporates new motor position estimation control technology. Motor Tuning Studio Version 1.0 is a tool for calculating motor parameters automatically.

Although field-oriented control (FOC) is a highly efficient motor control technique, a drawback is its difficulty in tuning the proportional-integral (PI) control gain for motor position estimation control. PI control is also used for motor speed and current control. Time and experience are required to tune the three PI control gains because they interfere with one another.

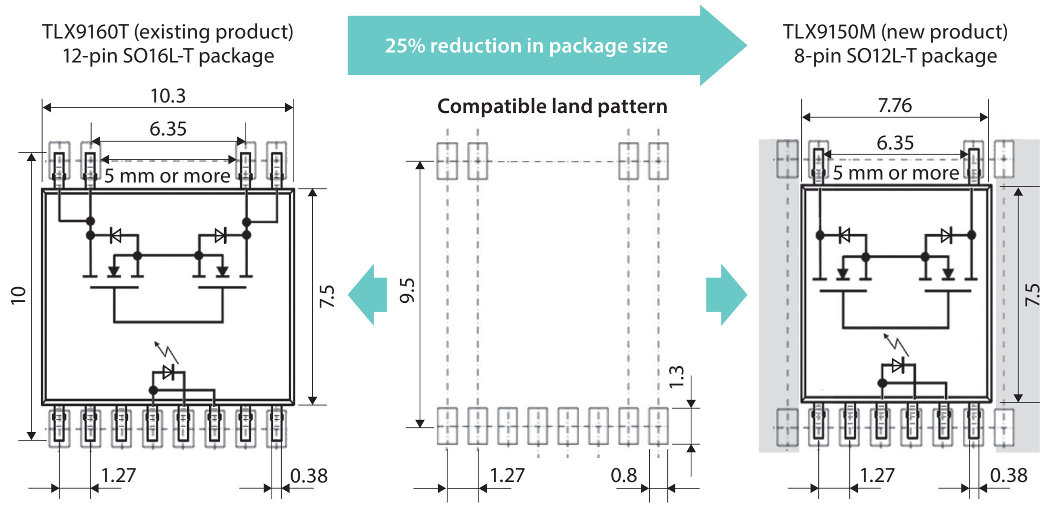
Motor Tuning Studio Version 1.0 automatically measures the characteristics of the motor to be controlled and calculates the optimal PI control gains accordingly. This technology eliminates the need for the complicated initial tuning process and allows users to begin FOC evaluations immediately. Furthermore, the automatically calculated parameters can be exported to MCU Motor Studio Version 3.0.

MCU Motor Studio Version 3.0 incorporates a new motor position estimation control technique based on a magnetic flux observer. This technique, which does not use PI control, is free from the mutual interference of PI control gains and makes tuning easier compared to conventional techniques.

Motor Tuning Studio Version 1.0 and MCU Motor Studio Version 3.0 facilitate FOC parameter tuning and provide an environment for facilitating FOC evaluation using our microcontroller unit (MCU).

We will continue to research even more accurate parameter tuning technology using artificial intelligence (AI) in collaboration with Corporate Laboratory of Toshiba Corporation.

4.4 High-Voltage Solid-State Relay Contributing to Reduction in Size of Vehicle Battery Management Systems



Comparison of conventional and new package external dimensions

Parameter	TLX9160T	New Product TLX9150M
Package	SO16L-T (12-pin)	New Package
Storage temperature	-55 to 150°C	-55 to 150°C
Operating temperature	-40 to 125°C	-40 to 125°C
V_{off} (T_a=25°C)	1 500 V, bidirectional	900 V, bidirectional
Operating voltage (T_a=25°C)	1 000 V	900 V
CTI	>600 (Material Group 1)	>600 (Material Group 1)
Pin-to-pin creepage distance* (secondary side)	5 mm or more for 1 000 V	4.5 mm or more for 900 V

* Creepage distance as specified in Table F.4 of the International Electrotechnical Commission (IEC) 60664-1 standard for an operating voltage of 1 000 V, a comparative tracking index (CTI) of >600, and a pollution degree of 2

V_{off}: Voltage that can be applied between relay output terminals in the off state

Rated specifications of conventional and new photorelay products

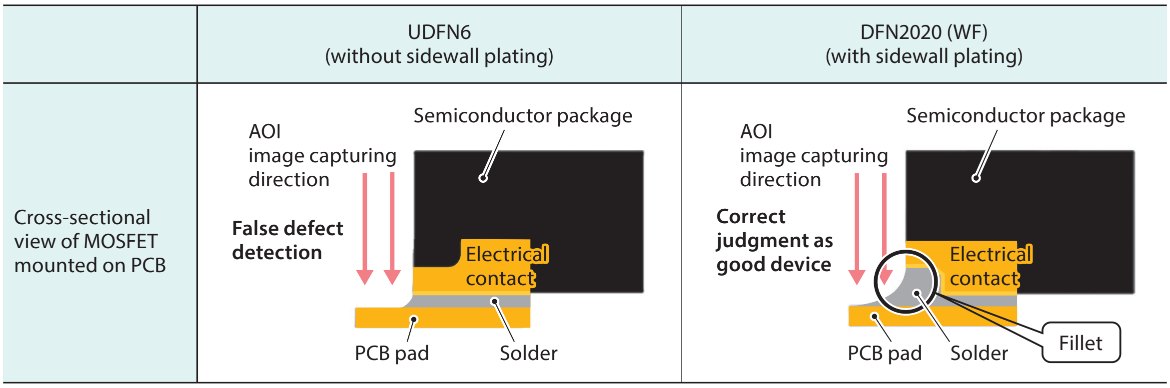
Electric vehicles are equipped with a battery management system (BMS) to use on-board batteries efficiently, and there is a need to increase the withstand voltage and reduce the size of solid-state relays for BMS applications.

To meet these requirements, Toshiba Electronic Devices & Storage Corporation has developed the TLX9150M, a high-voltage automotive photorelay that is 25% smaller than conventional products. Because the size of the internal MOSFET chip must be reduced to achieve a smaller photorelay package, we adopted a multi-stage guard ring (GR) structure for MOSFET termination that helps reduce electric fields in high-voltage products and optimizes the electric field strength distribution. The multi-stage GR structure also helps improve device reliability. We have confirmed that the TLX9150M withstands high-temperature, high-humidity reverse bias tests up to 1 000 hours at 85°C and 85% humidity.

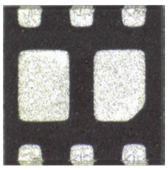
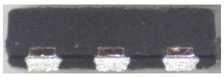
4. Electronic Devices and Storage

We also optimized the size of the die mount pads in a leadframe and positional relationships to maintain or reduce the stress applied to the new package in comparison with conventional packages. The TLX9150M passes up to 1 000 cycles of a temperature cycling test with a temperature range of -55°C to 150°C. The TLX9150M is also compliant with AEC-Q101, a reliability standard developed by the Automotive Electronics Council.

4.5 DFN2020 (WF) Small-Signal Package for Automotive Applications Compatible with Automated Optical Inspection



Differences in fillet formation on packages with and without flank plating

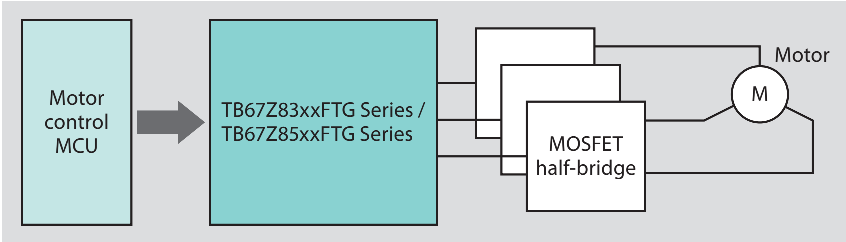
Top view	Bottom view	Side view
		

DFN2020 (WF) exterior view

To accurately inspect printed circuit boards (PCBs) for in-vehicle electronic equipment via automated optical inspection (AOI), ensuring the visibility of each semiconductor device is necessary to detect any mounting defects. However, many automotive semiconductor devices are housed in packages with electrical contacts on the bottom to reduce the mounting area and weight and improve heat dissipation. Because an AOI system can only capture images from a top-down perspective, solder fillets formed on the package edge can result in incorrect pass/fail determination.

To solve this issue, Toshiba Electronic Devices & Storage Corporation has developed a small DFN2020 (WF) package for automotive MOSFETs with a WF structure based on the UDFN6 package for consumer MOSFETs currently in production. The DFN2020 (WF) allows stable solder fillet formation on the package side, enabling top-view inspection. To apply tin (Sn) plating to the sidewall of the DFN2020 (WF) and form a WF structure, we optimized the step-cut dicing process (i.e., the process of separating dies from a wafer in two steps) by selecting dicing tape and the method of attaching dicing tape to the leadframe.

4.6 Gate Driver ICs for Wide Range of Applications



Example of motor control subsystem block diagram

Part number	Regulator voltage	Current-sense amplifier	Interface	Package
TB67Z830HFTG	3.3 V	0 ch	Hardware	P-VQFN32-0505-0.50-007
TB67Z830SFTG			SPI	
TB67Z833HFTG		3 ch	Hardware	P-WQFN40-0606-0.50-003
TB67Z833SFTG			SPI	
TB67Z850HFTG	5 V	0 ch	Hardware	P-VQFN32-0505-0.50-007
TB67Z850SFTG			SPI	
TB67Z853HFTG		3 ch	Hardware	P-WQFN40-0606-0.50-003
TB67Z853SFTG			SPI	

SPI: Serial Peripheral Interface

Gate driver IC lineup

Brushless DC motors are increasingly being adopted in various fields because of advantages such as high efficiency, low noise, and long service life. Consequently, demand for gate driver integrated circuits (ICs) that control power devices for motor drive is also growing.

With this in mind, Toshiba Electronic Devices & Storage Corporation has developed and released the TB67Z83xxFTG and TB67Z85xxFTG series of gate driver ICs. Fabricated using a 0.13-µm analog IC process, these gate driver ICs feature a maximum withstand voltage of 96 V and a wide operating supply voltage range from 8 to 75 V. The supply voltage for external MOSFETs can be 6 to 75 V. The gate drive current for external MOSFETs is programmable between 10 mA to 1 A(*) (peak) when sourcing current, and between 20 mA to 2 A(*) (peak) when sinking current. The TB67Z83xxFTG and TB67Z85xxFTG series are therefore compatible with a wide range of applications with different voltage and current requirements, including power tools, industrial robots, and vacuum cleaners.

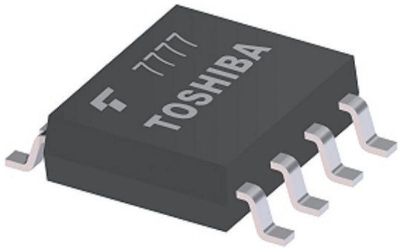
We can offer total motor drive solutions by combining these gate driver ICs with our motor control MCUs and MOSFETs.

(*) The gate drive current is constrained by operating conditions such as ambient temperature and power supply voltage.

4.7 Digital Isolators with High CMTI for Industrial Applications

Parameter	Competitor's product (example)	New products
Number of channels	Two forward channels or one forward and one reverse channel	
Maximum data transfer speed	150 Mbits/s	150 Mbits/s
CMTI	60 kV/μs (minimum)	100 kV/μs (minimum)

Main features of new digital isolator



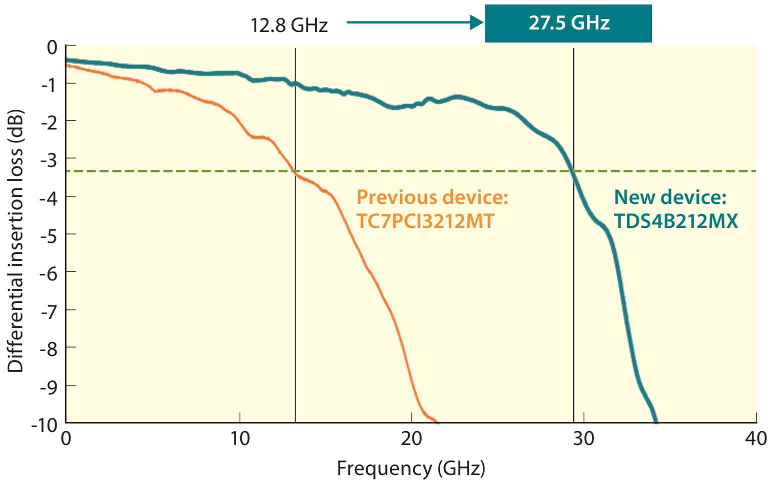
Package for new digital isolator (8-pin small-outline IC (SOIC) narrow-body package)

To achieve carbon neutrality, efforts are accelerating worldwide to reduce greenhouse gas emissions, driving the popularity of electric vehicles and renewable energy applications. These applications use electronic isolation devices to transfer signals across different voltage domains with minimal noise interference. High-voltage applications require isolation devices with high common-mode transient immunity (CMTI) to prevent malfunction due to high dV/dt noise during power semiconductor device switching.

With this in mind, Toshiba Electronic Devices & Storage Corporation has developed digital isolators using a proprietary magnetic coupling method to achieve a high CMTI of 100 kV/μs (minimum)[*], which help stabilize signal transmission and system operation and contributes to improving the safety of renewable energy and other industrial applications.

(*) Test conditions: V_I=V_{DD} / 0 V, V_{CM}=1 500 V, T_a=25°C

4.8 Bus Switch for High-Speed Digital Signals



Differential insertion loss and -3 dB bandwidth of new bus switch

The recent increase in data transfer speed between the components of PCs, servers, and semiconductor test systems is driving the need for bus switches with superior passband characteristics. Using a proprietary process, Toshiba Electronic Devices & Storage Corporation has developed and commercialized the TDS4A212MX 2:1 multiplexer (mux) switch and the TDS4B212MX 1:2 demultiplexer (demux) switch for high-speed digital signals.

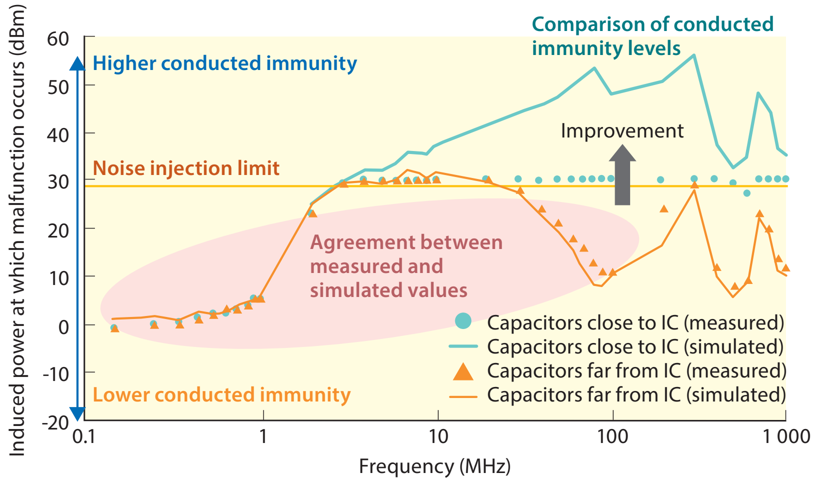
These bus switches provide a -3 dB bandwidth(*1) of 27.5 GHz, much wider than that of the previous TC7PCI3212MT mux/demux bus switch, achieving industry-leading passband characteristics(*2). Because of this remarkable improvement in bandwidth, the TDS4A212MX and TDS4B212MX support data transfer rates of up to 40 Gbit/s. The new bus switches are housed in the small XQFN16 package (typically measuring 2.4×1.6 mm) to save PCB space.

We will continue to develop bus switches that support even faster digital signals.

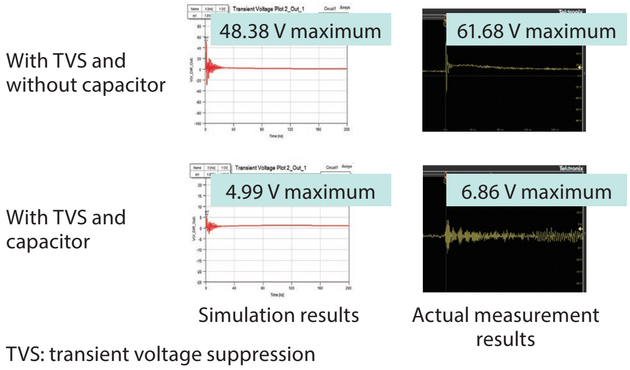
(*1) Frequency at which the signal power drops to half of its maximum value

(*2) As of October 2024 for 2:1 mux/1:2 demux bus switches (according to Toshiba Electronic Devices & Storage Corporation research)

4.9 Semiconductor EMC Simulation Model for System Verification



Comparison of measured and simulated power-line noise thresholds at which system failure is triggered depending on capacitance location



TVS: transient voltage suppression

Comparison of measured and simulated noise propagation caused by ESD

The progress of electronic devices for autonomous driving and connected cars is making it crucial to ensure electromagnetic compatibility (EMC) endurance for the development of ECUs. Because semiconductor devices with robust characteristics are required to improve EMC endurance, the importance of semiconductor EMC models is on the rise.

With this in mind, Toshiba Electronic Devices & Storage Corporation has developed an EMC model creation and simulation environment. Leveraging the new environment, we evaluated both conducted and electrostatic discharge (ESD) immunities of semiconductor devices, confirming that the simulated values closely match the measured values. The conducted immunity test confirmed that EMC endurance levels depend on the population and positions of capacitors on a PCB across the entire observed bandwidth. The ESD test indicated that adding capacitors helps reduce the ESD noise level. These results show that the new EMC models can be utilized to optimize PCB designs.

We will work toward the practical application of the new semiconductor EMC models and develop PCB optimization guidelines to contribute to streamlined ECU development.

4.10 MG11 Series 3.5-Inch HDDs for Data Centers with Maximum Storage Capacity of 24 TB Using Conventional Magnetic Recording

MG11 series 3.5-inch HDD for data centers

In recent years, the spread of generative AI, the expansion of social networking services (SNS), and the increased use of video streaming services have led to a dramatic increase in the amount of data handled by data centers. Because data centers prioritize large storage capacities and low costs over read speeds when selecting storage devices, hard disk drives (HDDs) still play an important role at these facilities.

Toshiba Electronic Devices & Storage Corporation has released the MG11 series of 3.5-inch HDDs for data centers, which provides a maximum storage capacity of 24 TB(*1) using conventional magnetic recording (CMR) technology. To increase the recording density, we leveraged second-generation flux-controlled, microwave-assisted magnetic recording (FC-MAMR) technology, optimized the flying height of the read/write heads, and improved servo control technology. Additionally, to reduce power consumption and increase data transfer speeds, we reduced the motor current, optimized servo control methods, and increased the buffer size using 1 GiB(*2) dynamic random-access memory (DRAM).

(*1) Definition of capacity: Toshiba Electronic Devices & Storage Corporation defines a terabyte (TB) as 10^{12} (1 000 000 000 000) bytes.

(*2) Gi: gibi (2^{30})

4.11 Next-Generation Technologies to Realize 3.5-Inch HDDs with Storage Capacities Exceeding 30 TB

Prototype HDD featuring storage capacity exceeding 30 TB

With the spread of cloud services and data science, the amount of data being generated and stored is increasing exponentially. Therefore, data centers, which serve as centralized storage locations for these data, require high-capacity HDDs for efficient storage solutions.

Toshiba Electronic Devices & Storage Corporation has succeeded in achieving storage capacities of more than 30 TB[(∗1)] using two next-generation recording technologies: heat-assisted magnetic recording (HAMR) and microwave-assisted magnetic recording (MAMR).

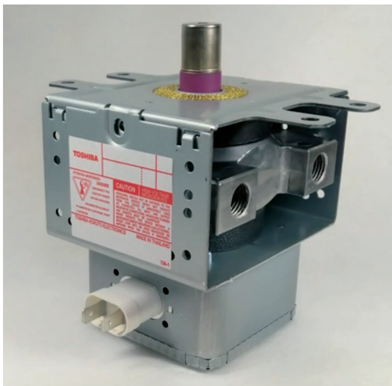
HAMR uses a near-field laser to heat the disk material locally to increase magnetic recording capabilities. We have now achieved a storage capacity of 32 TB with 10 platters by using HAMR in conjunction with shingled magnetic recording (SMR) technology.

In contrast, MAMR uses microwaves to enhance magnetic recording capabilities. We were the first in the industry to demonstrate its effectiveness[(∗2)], releasing the first-generation 24 TB MAMR HDDs in 2021 by using MAMR in conjunction with CMR technology. We have now achieved a storage capacity of 31 TB with 11 platters by using MAMR in conjunction with SMR technology and improving signal processing.

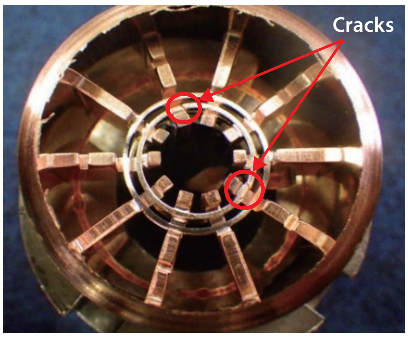
(∗1) Definition of capacity: Toshiba Electronic Devices & Storage Corporation defines a terabyte (TB) as 10^{12} (1 000 000 000 000) bytes.

(∗2) As of December 24, 2021 (according to Toshiba Electronic Devices & Storage Corporation research)

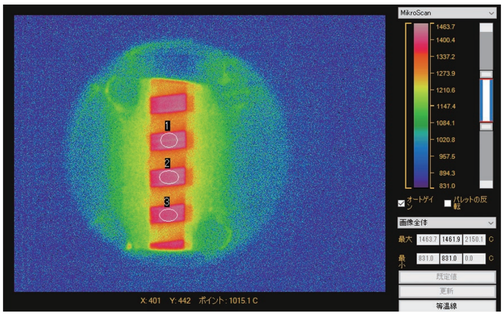
4.12 Development of Industrial Magnetrons Based on Consumer Technology: Reducing Development Time through Failure Analysis



Industrial water-cooled magnetron developed based on consumer tubes



Failure analysis of anode resonance section of magnetron after life testing



Measurement of cathode filament temperature during operation

Toshiba Hokuto Electronics Corporation has developed industrial magnetrons by leveraging technology cultivated through experience with consumer magnetrons. Because industrial magnetrons require better service life characteristics than consumer magnetrons, we conducted various life tests under industrial operating conditions for failure analysis. We identified two main causes of failure: cracks in the anode strap and degradation of the cathode filament.

Because we expected that increasing the size of the anode strap to improve its strength would result in a considerably longer development period, we alternatively utilized a material with higher tensile strength than that of the conventional strap material.

We found that higher than optimal temperatures cause degradation of the cathode filament. Therefore, we reduced the filament voltage to maintain the temperature at an appropriate level.

We succeeded in developing 1 300 W and 1 500 W industrial magnetrons without a longer development period.