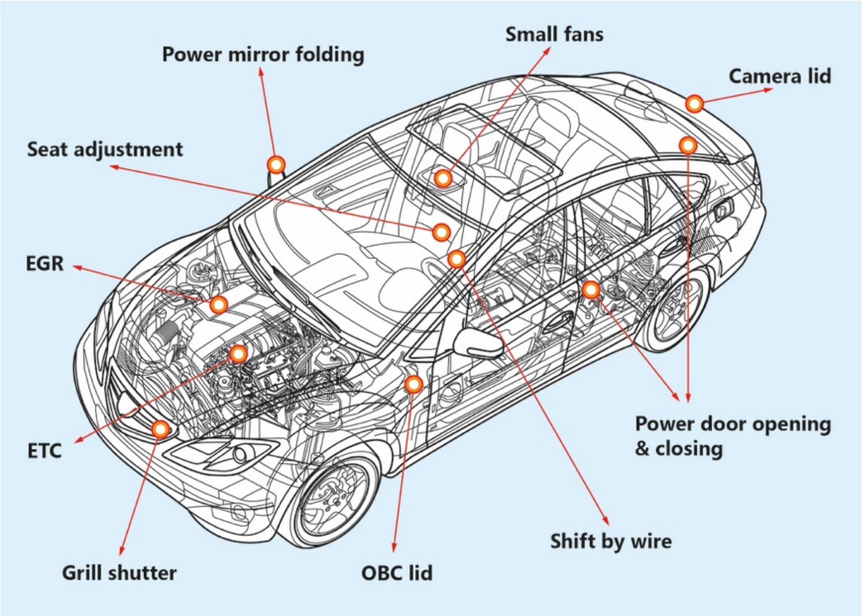
Efficient implementation DC motor control of up to 10 A in automotive applications

Full diagnostic overview and SPI control for automotive H-bridge DC motor applications

Introduction

The automobile is a fixed element of our transportation choices and some of the big names in motoring have been around for more than 100 years. While cars have been inextricably linked to combustion engines for the vast majority of that time, today's generation of drivers will think nothing of a vehicle being powered by an electric motor coupled to a battery. While electric propulsion for vehicles is nothing new (many in the UK think back fondly to the battery-powered 'floats' delivering milk, whirring through their streets), the technology that enables them to work is substantially different. Without vast amounts of software and powerful processors, this new generation of electric vehicles would, quite simply, not move. To lend an air of the futuristic to these hybrid and fully-electric cars, as well as to appeal to the touchscreen, smartphone-connected generation, they are packed with as many electrically assisted gadgets as possible. Furthermore, for those internal combustion engines that remain, the focus is on improving efficiency, requiring even more computing power and motor-driven actuators to provide the precision control needed.

Much has been made of brushless DC (BLDC) motor technology and many battery-powered consumer devices benefit from the substantial increase in performance that can be achieved, both in power and battery life. The automobile industry has also often turned to this technology but the fine balance between function, energy efficiency achieved, and system cost means that the classic brushed DC motor is still finding its way into a wide array of applications. In turn, the automotive industry is continuously searching for improvements in DC motor control silicon solutions. The requirements vary widely, but common demands include energy efficiency, minimal heat dissipation requirements, and more intelligence that enables the electronic control units (ECU) to interrogate status, functionality and, when required, perform a 'limp home' capability if a critical failure should occur.



Where brushed motors are still in use

While many of us would probably like to exit our vehicles through gull-wing doors that have whirred open upon arrival at our destination, many of the powered comfort luxuries are much simpler. Door mirrors and their folding mechanism are one example that fail to benefit from the move to brushless motor technology. They typically are used for a short period once per journey (if at all) and DC motors fit the bill perfectly. The same price/efficiency evaluation also applies to other comfort features, such as automated fuel flap or charging socket openers, and the reverse parking camera that is set into the trunk door emblem (figure 1).

DC motors, for the same reason of irregular use, are the device of choice under the hood of the vehicle too. Grill shutters, which control incoming air flow and allow the engine to warm more quickly to achieve most efficient operation, is such an application. They also feature in a range of other actuators.

Many DC motor applications are also considered to be safety relevant, such as electronic throttle control (ETC) and shift-by-wire solutions. They may also be part of high-temperature systems such as the exhaust gas recirculation (EGR). This places additional requirements on the suppliers of silicon devices, one of which is the respective AEC-Q100 Grade certification, as well as the ability to perform automated optical inspection (AOI) of the package when soldered to the board for the purpose of quality checking.

An automotive silicon partner

Toshiba has long been involved in electronics for the automotive industry. Highly integrated bipolar technology formed the basis for many of the early solutions designed for the car of the mid-70s, such as wiper motor control, meter cluster systems, and electronic fuel injectors. Since the mid-80s, Toshiba have developed improvements in silicon process with their BiCMOS technology. This delivers the benefits of bipolar's high precision, coupled with the high-density, logic, and non-volatile memory that

CMOS offers, on a single chip. Today's automotive solutions from Toshiba make use of the most recent process technology: BiCD. This adds the high-power capability of LDMOS in a 0.13 µm process supporting voltages of up to 96 V and improves on the breakdown voltages such devices can withstand.

The result is a range of devices that are robust and provide a wide range of integrated.

Partitioning DC motor control

System architects are spoilt for choice when it comes to DC motor solutions. The motor itself needs to be connected to an H-bridge circuit (for bi-direction control). On the other side there is typically a microcontroller (MCU). This communicates with other devices on the automotive network via CAN or LIN, implements any safety features, and is responsible for handling a wide range of diagnostic functions. The input for these functions come from the diagnostic capabilities in the pre-driver, which boosts the relatively low output current of the MCU to drive the switches of the H-bridge. Its sits between the MCU and the H-bridge and can provide insight into the health and status of the drive implementation. These are even more essential today as drivers expect issues to be flagged up, and vehicle service centres need to build a clear picture of which ECU in the vehicle may have failed or be operating sub-optimally. Furthermore, they are a critical element in the implementation of the safety functions of motor-powered applications, such as the comfort features of an electric seat, detecting dangers such as pinching.

The portioning of this system varies. The simplest approach is to source the three elements separately, but this of course demands that there is enough surface area on the printed circuit board (PCB) for the devices (figure 2). There is also something to be said for keeping the number of devices in use to a minimum, as the lower the component count, the lower the likelihood of a failure. In recent years there has been a trend to integrate the pre-driver with the MCU. The challenge here is that much of the development in the automotive industry benefits significantly from reuse. By locking the pre-driver in with the MCU, developers may be forced to go through significant code development and certification. The same would apply if all three elements were integrated into a single chip.

Instead, the preferred path for many automotive system architects is to use solutions that combine the H-bridge with the pre-driver. This allows the MCU, its software, and related interfacing hardware to be largely retained. Only the code associated with the control of the integrated pre-driver/H-bridge needs to be updated.

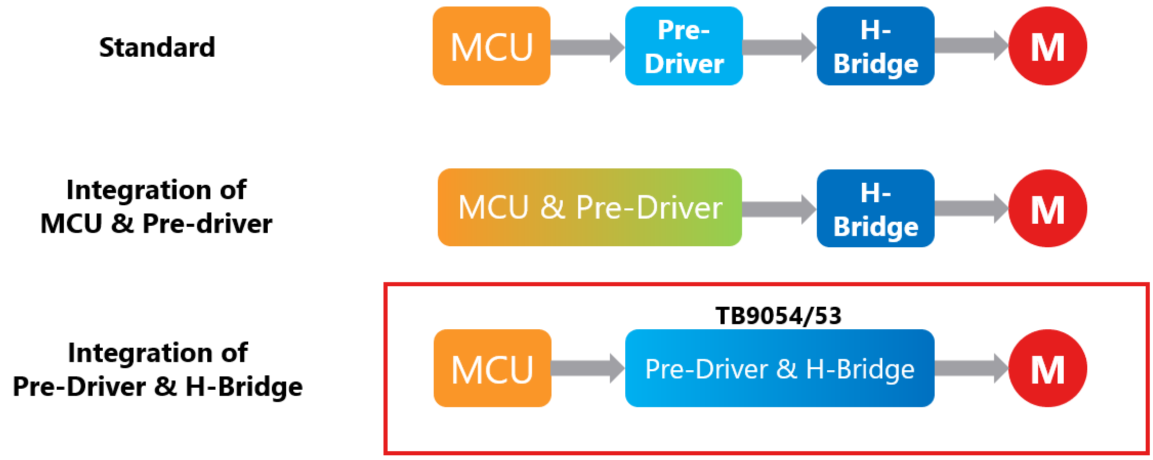


Figure 2: Integration of DC motors silicon solutions makes most sense between the pre-driver and H-bridge, leaving the MCU choice open.

Further space-saving benefits can be attained when this approach is expanded to include two H-bridges and pre-drivers in a single device (figure 3).

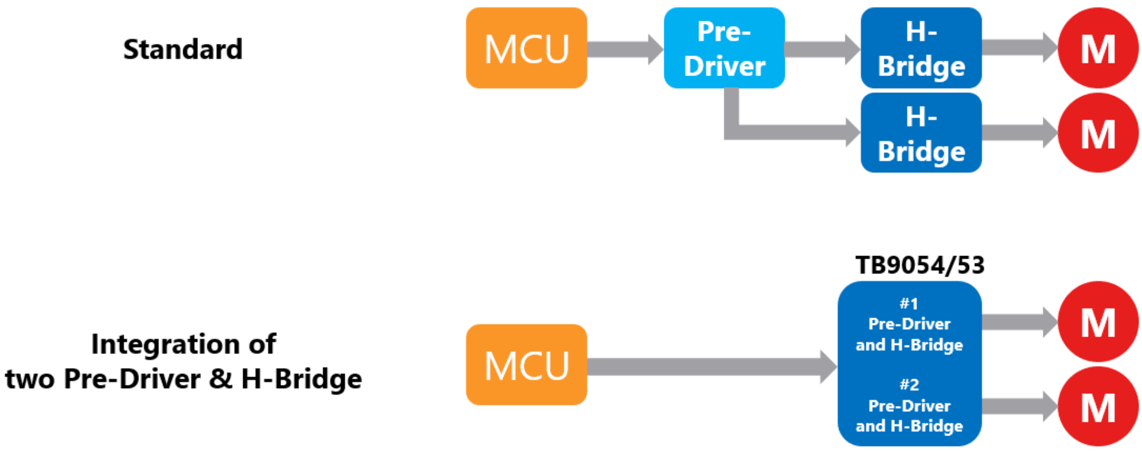


Figure 3: A dual H-bridge with integrated drivers saves space and simplifies circuit design where multiple DC motors are in use.

Highly integrated H-bridge with pre-driver

The latest devices developed for brushed DC motor control applications in the vehicle are the dual-channel TB9053FTG and TB9054FTG. These two products are the same in all but their packaging: the TB9053FTG comes with a thermally enhanced package that integrates an additional metal plate between the die and the exposed PAD (ePAD) of the package in order to provide an even lower R_{th} (thermal resistance) of just 0.67°C/W. This simplifies the thermal design of the system, enabling elements of the thermal resistance chain to be implemented simply from the copper of the PCB.

Inside the device, the H-bridge switch is made up of two N-channel DMOS H-bridges. These support the control of up to two 5 A motors (SMALL mode) or, when operated in parallel, a single 10 A motor (LARGE mode). This low switch resistance of the BiCD process not only limits the heat generated in operation, which also simplifies heat dissipation concepts, it has also enabled the device to be very compact (figure 4). The TB9054FNG is offered in a 40-pin QFN package that is just 6 × 6 mm in dimension with a 0.5 mm pin pitch and that also features fully wettable flanks. This makes this AEC-Q100 device suitable for AOI processes.

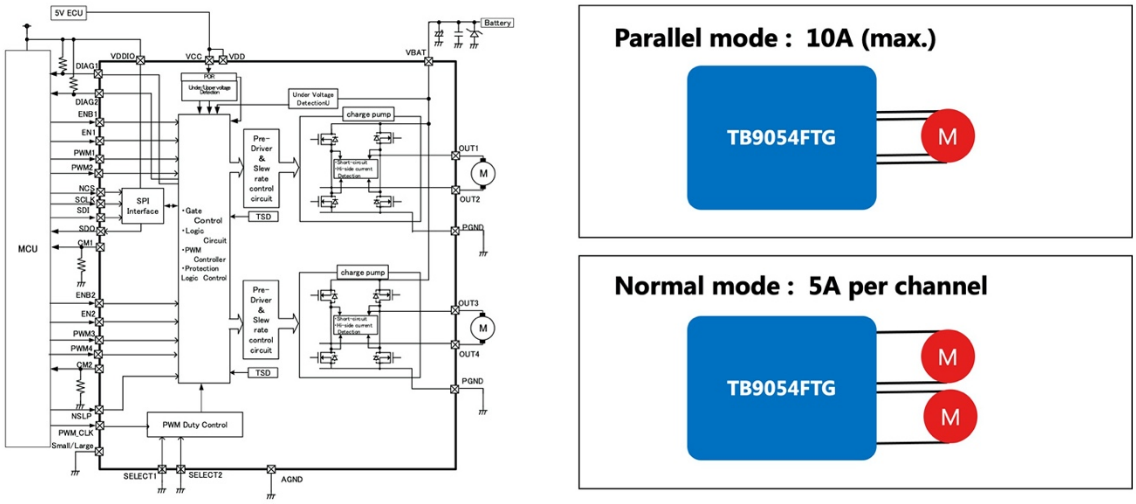


Figure 4: The TB905xFTG can handle up to 5 A per channel for two motors in SMALL mode, or up to 10 A in LARGE mode for a single motor.

Further simplifying the implementation are the integrated capacitors to feed the pre-driver charge pumps. This saves space on the board and reduces the pin count required. The charge pump design is such that a duty cycle of 100% can be assured.

As would be expected, the TB905xFTG supports two pulse-width modulated inputs per channel, one for the high-side and the other for the low-side. These can be operated at between 1 kHz and 20 kHz. Dead time is handled automatically within the device (figure 5). Like previous generation devices, the control of logic-input pins via the MCU can be used to define direction of rotation, engage the brake function, or enable or disable operation.

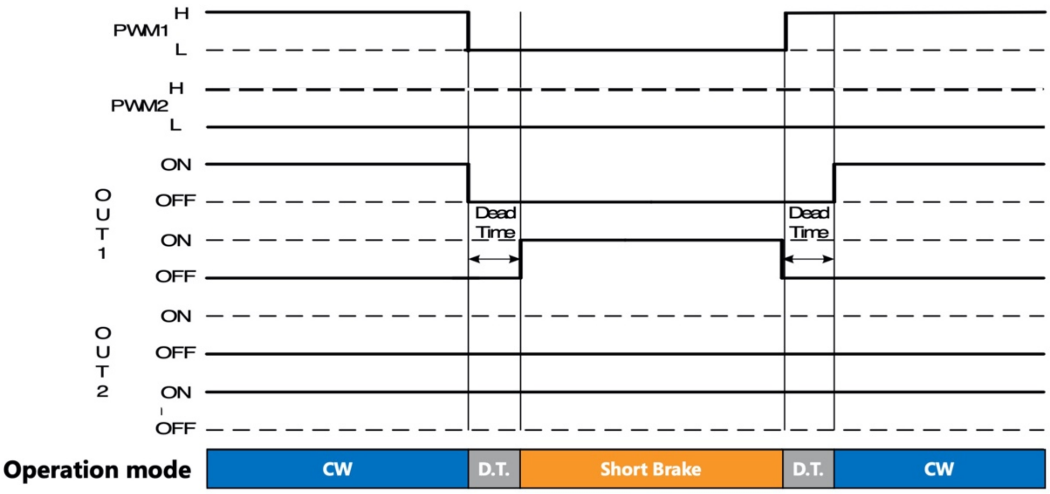


Figure 5: Dead time is inserted automatically.

Two diagnostic output pins provide feedback on the state of the device, including over-temperature, over-current, under-voltage on both V_{BAT} and V_{CC} (latched), and non-operational open load.

The device also features an SPI interface (figure 6). This provides a more granular configuration of the TB905xFTG as well as more insight into any failures. For example, the over-current threshold can be configured to between 4.6 A and 6.5 A in SMALL mode, or 9.2 A and 13.0 A in LARGE mode. This over-current protection cannot be switched off, operating instead as a chopper-type current-limit control. This is a safety feature that ensures a motor can be operated, even if it is causing an overload. The hysteresis in the current measurement is configurable between 0.25 A and 0.5 A in SMALL mode, or 0.5 A and 1.0 A in LARGE mode. Operation is ensured up to an ambient temperature of 125°C and a junction temperature of 150°C.

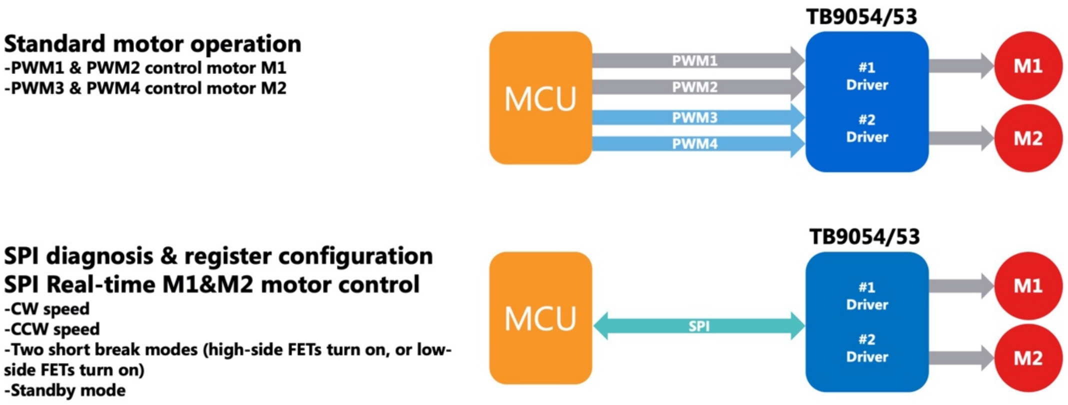


Figure 6: The use of the SPI interfaces reduces the number of MCU pins required, thanks to the internal oscillator and PWM blocks.

Furthermore, this device can also be used as part of a daisy-chained connection of devices if required. There is no limit imposed on the length of the chain but, if precise synchronisation in control of the motors is needed, the small delay through the SDO path needs to be considered (figure 7).

A unique aspect of the H-bridge is the integrated PWM controller and 16 MHz oscillator. In order to simplify the demands placed upon the selected MCU, the TB905xFTG can operate from source a single clock input and derive the PWM for each channel internally. The precise duty cycle with a resolution of 0.05% is then configured using the SPI interface. Should the external clock signal fail for any reason, the internal oscillator remains available as a fall-back option.

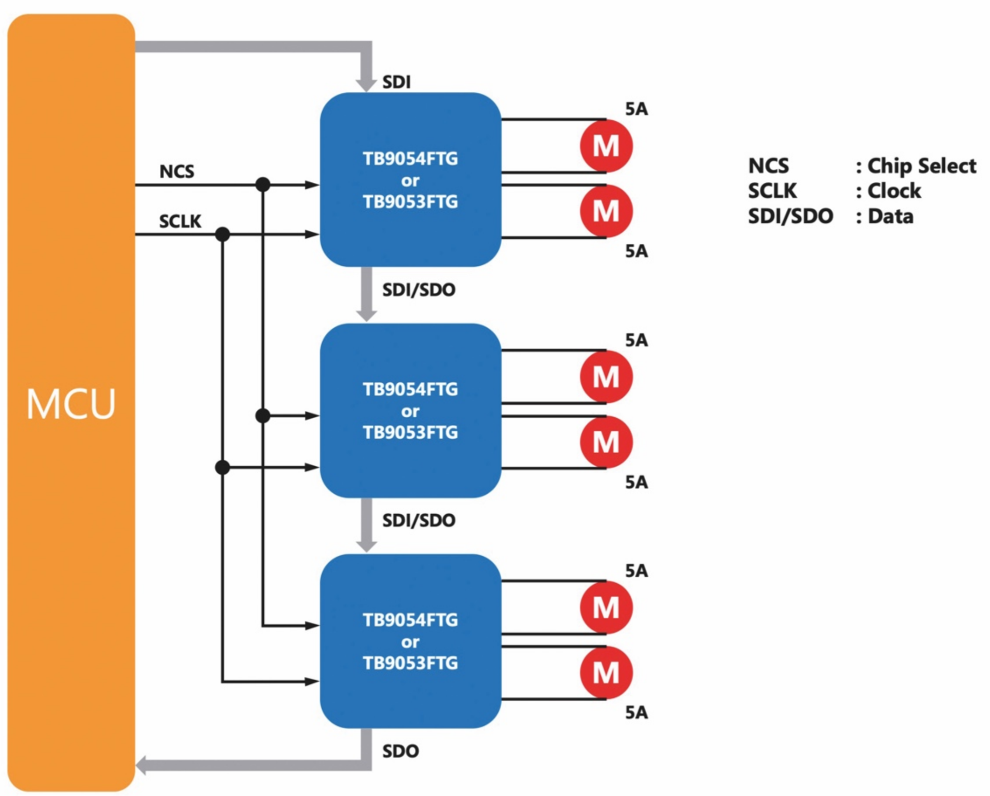


Figure 7: Multiple TB905xFTG devices can be daisy-chained, further reducing the need for pins from the MCU in more complex DC motor control applications.

One of the input pins can be used to place the device in its low-power sleep mode. It should be noted that there is some wake-up time associated with the wake-up due to the need to restart the pre-driver charge pumps. The internal oscillator, if used, also requires some time to stabilise.

Fulfilment of electromagnetic compatibility (EMC) requirements is often a challenge in such applications. The use of slew-rate control provides one approach to resolving this issue and can be configured between 1.09 and 26.25 V/µs in seven steps (figure 8). The default value is 17.5 V/µs, equivalent to a rise time of 0.8 µs at a 14 V V_{BAT}.

	Slow1	Slow2	Slow3	Slow4	No-SR*	Fast2	Fast1
Slew Rate [V/us]	1.09	2.19	4.38	8.75	17.5	21.88	26.25
Rising time [us] at VBAT=14V (for reference)	14.0	7.0	3.5	1.75	0.8	0.64	0.53

*No-SR : Not adjusted

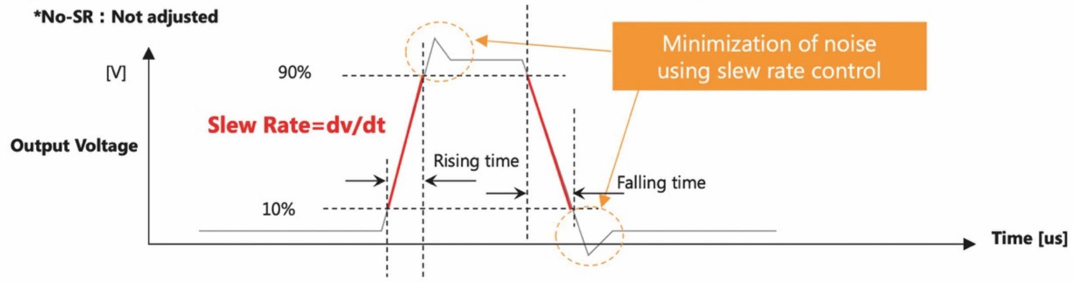


Figure 8: The TB905xFTG provides seven different levels of slew-rate control, something that can help with fulfilment of EMC requirements.

Summary

Brushed DC motors will remain with us in the field of automotive for some time to come as the electrical efficiencies provided by BLDC motors remain outweighed by the cost of the implementation in many applications. If fact, their use is likely to increase as powered features, such as charging port openers in electric vehicles and plug-in hybrids, are implemented to add to the futuristic flair of this new generation of vehicles with their innovative forms of propulsion. The integration of pre-driver with the H-bridge makes the most sense in such applications, allowing the MCU and its code to be reused in next-generation designs. Devices such as the TB905xFTG provide a high level of sophistication and, thanks to its SPI interface, a wide range of diagnostic and configuration options. In today's world of the connected car it is the ideal choice for automotive developers looking to be able to deliver high-quality, robust applications with a diagnosis-rich capability that improves the driver's motor-ownership experience.

Contact us to discuss incorporating our products and solutions into your design:
http://apps.toshiba.de/web/ContactUs/

toshiba.semicon-storage.com

Restrictions On Product Use

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as “TOSHIBA”.
Hardware, software and systems described in this document are collectively referred to as “Product”.

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA’s written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.
- PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE"). Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signalling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT. For details, please contact your TOSHIBA sales representative or contact as via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.