TOSHIBA

Configuring the Features of Smart Gate Drivers

Introduction

Driving the gates of IGBTs, Si MOSFETs and SiC MOSFETs correctly in high-frequency switching applications like EV-charging is vital for high efficiency and reliability. Integrated smart gate drivers make this easy and include a Miller clamp and overcurrent detection using a 'DESAT' feature. These are discussed in this white paper.

Preventing false turn on

While IGBTs and Si/SiC MOSFETs are nominally off at VGS = 0, their gate is often driven to a negative voltage for the OFF state, to typically -7V for IGBTs and sometimes -5V for MOSFETs.
The reason for a negative gate drive is to prevent injected current into the gate from the non-linear Miller capacitance, between collector/drain and gate. This occurs as the device switches off, and high dV/dt at the collector/drain pushes current through the device to the gate. Any series resistance in the gate drive drops voltage from this current in a direction to turn the device on. Figure 1 illustrates the effect, which the negative drive voltage helps to avoid.

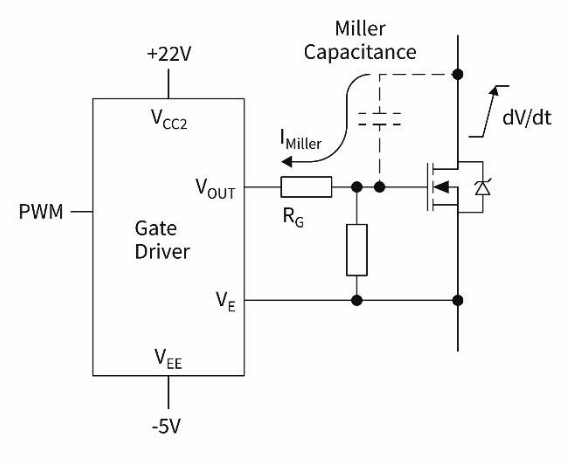

Figure 1: A negative gate voltage drive helps to avoid false turn on from Miller capacitance effects.

An alternative is to introduce a Miller clamp – a separate MOSFET that shorts gate to emitter/source after the main drive signal has transitioned below a pre-determined level. Figure 2 shows the arrangement. R_G sets the OFF-transition switching speed and R_{CLAMP} need to be a much lower value, effectively clamping the voltage to near zero. The drive to the Miller clamp transistor must be carefully timed with the PWM OFF-signal to be effective. After the collector/drain has stabilised at its OFF-state voltage, the Miller clamp transistor can be switched off, and the timing is not critical as long as it is off before the next ON-state drive. If the gate negative drive voltage can be reduced or eliminated by using a Miller clamp circuit, complexity of the required power supply is reduced, and some valuable gate drive power is saved.

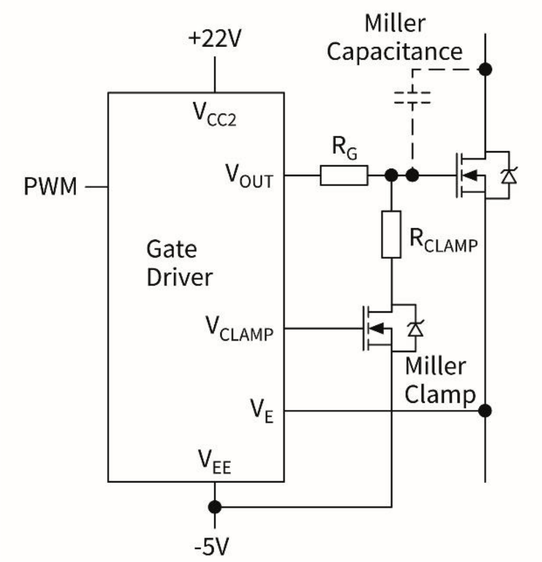

Figure 2: A separate Miller clamp transistor prevents spurious turn-on

Drivers can detect and protect against power device overload with DESAT detection

Inadequate drive or an overload can cause power device failure, and in both cases, this is practically caused by the IGBT or MOSFET, silicon or silicon carbide type, coming out of saturation, dropping excess voltage and failing from over-dissipation. The driver can detect this condition by monitoring the collector/drain voltage of the device - if it is above a set voltage threshold when, and only when, the gate is demanding an ON-state, this can be interpreted as a fault and the driver will then immediately force the device off. The technique is known as de-saturation detection or DESAT. The reaction time must be very rapid, as modern power devices are rated to withstand conditions such as short circuits for only a few microseconds at best. However, the actual transition time from on to off is best done 'softly' to avoid high di/dt causing other malfunctions from parasitic capacitance and inductance in the circuit. Ideally, this soft transition should be easily controllable for different operating conditions.

Monitoring the collector or drain of a high voltage device switching at tens of kHz is not easy, but a practical circuit to do this is shown in Figure 3 with a 'smart' gate driver that also includes the Miller clamp MOSFET. Here, diode D_{DESAT} is forward biased when the power transistor is saturated, pulling the DESAT monitor signal low. This can be compared with the PWM drive demand and with $V_{DESAT,max}$ which is for TLP5214A 6,5V, to evaluate whether the device has responded correctly. Clearly the timing of the measurement is important, and the current-voltage (I-V) behaviour of the power device must be known. The diode must be rated for the full DC bus voltage with some margin, which could be 1000V or more in some systems. Forward current rating can be low however, as it only passes I_{CHG} when forward biased. High voltage diodes do typically have a high forward voltage drop, which must be factored in. The diode must also be fast-acting to be effective, with very low capacitance and reverse recovery charge. These characteristics are difficult to achieve in combination, so series diodes are sometimes seen, to achieve the total voltage rating. This also has the advantage of dividing down the diode capacitance, but the disadvantage is higher forward voltage drop and a consequently higher threshold of DESAT detection, which may not be within the range of the controller. Voltage sharing can also be an issue and the diodes must have substantial derating to be reliable. Silicon carbide (SiC) diodes are an alternative to silicon fast epitaxial types, but the forward voltage drop is considerably higher.

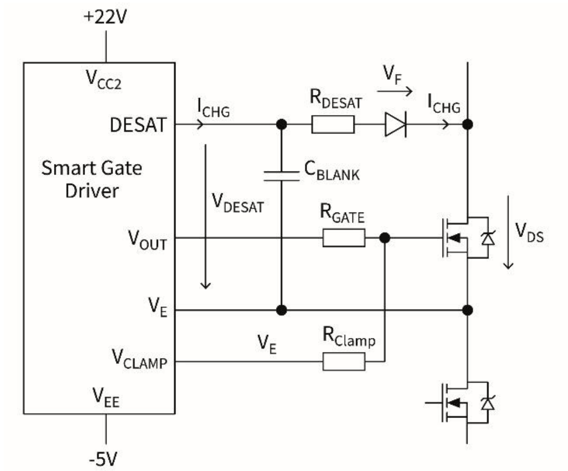

Figure 3: A practical DESAT detection arrangement using a smart gate driver with integrated Miller clamp MOSFET

Power converters are noisy, so protection of the DESAT input of the gatedriver is normally required in the form of clamp diodes. A zener diode typically clamps the positive voltage to a safe value and a low forward drop Schottky diode clamps the voltage below ground. Both diodes need to be added externally to the gate driver.

As an example, values for R_{DESAT} and C_{BLANK} should be calculated for Toshiba smart gate driver TLP5214A and SiC MOSFET TW070J120B: First of all, the maximum allowed VDS voltage should be extracted from the ID - VDS curve (Figure 4) from the datasheet of TW070J120B.
In Figure 4 a normal operating point with a current of 20A and V_{DS} = 1.1V can be seen (marked in green) The maximum allowed current is 40A with a corresponding V_{DS} of 2.35V(marked in red in Figure 4).

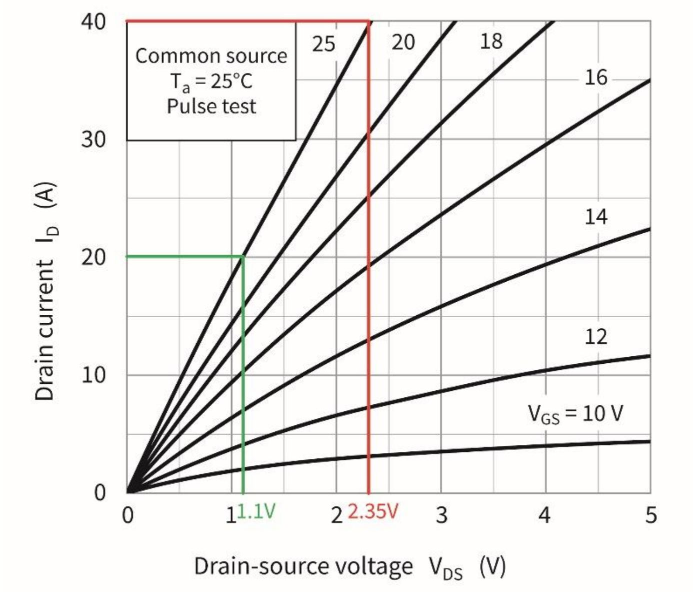

Figure 4: Transfer characteristics of Toshiba TW070J120B SiC MOSFET

Now the formulas for R_{DESAT} and C_{BLANK} should be derived.

Calculation of R_{DESAT}:

$V_{DESAT,max} = R_{DESAT} \cdot I_{CHG} + n \cdot V_F + V_{DS,SAT}$	(1)
$R_{DESAT} = \dfrac{V_{DESAT,max} - n \cdot V_F - V_{DS,SAT}}{I_{CHG}}$	(2)

With the given values:

$V_{DESAT,max}$ = 6.5V (from the data sheet)

I_{CHG} = 250µA (from the data sheet)

$V_{DS,SAT}$ = 2.35V (from Figure 4)

n = 2

V_F = 1.4V (for CRF03A as an example)

$R_{DESAT} = \dfrac{6.5V - 2.7V - 2.3V}{250\mu A} = 5.4k\Omega$	(3)

Calculation of C_{BLANK}:

$C = \dfrac{Q}{V} = I \cdot \dfrac{t}{V}$	(4)

With a short circuit withstand time between 2µs and 4µs and the given values above, C_{BLANK} can be calculated as:

$C_{BLANK} = \dfrac{t_{BLANK} \cdot I_{CHG}}{V_{DESAT(max)}}$	(5)
$C_{BLANK} = \dfrac{2\mu s \cdot 240\mu A}{6.5V} = 74pF$	(6a)
$C_{BLANK} = \dfrac{4\mu s \cdot 240\mu A}{6.5V} = 148pF$	(6b)

C_{BLANK} should be in a range of 74pF and 148pF

Figure 5 shows on the left-hand side normal operation and on the right-hand side operation with a short circuit applied and the action of DESAT protection.

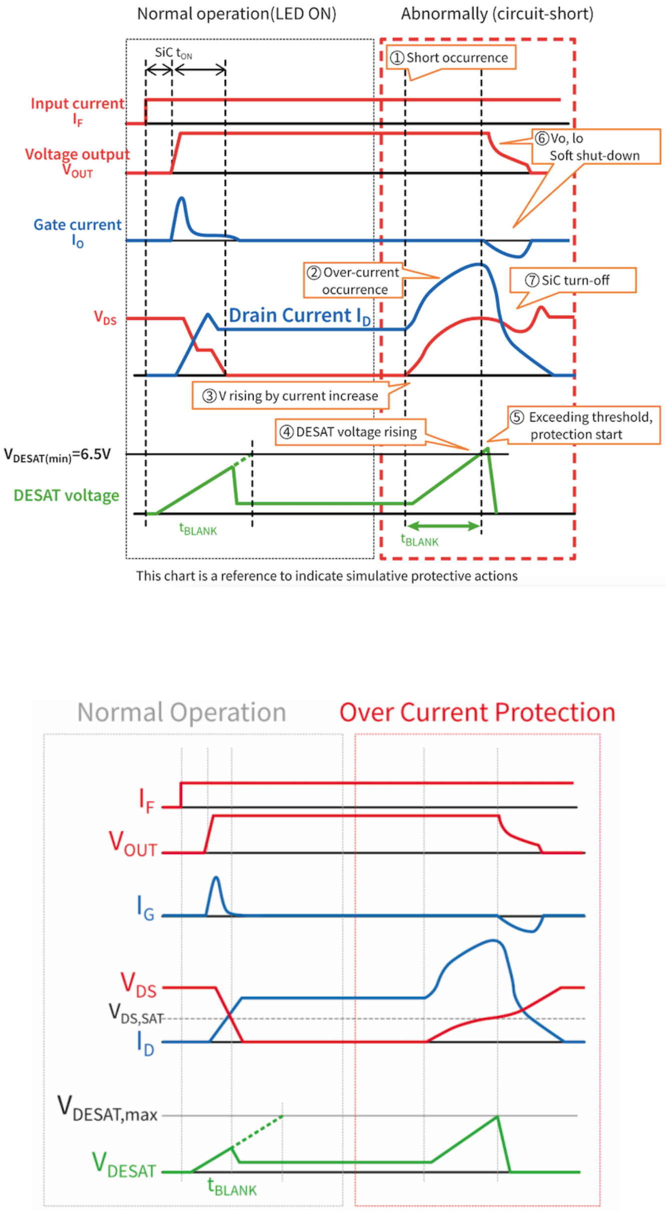

Figure 5a and b: Waveforms observed before and after a short circuit, showing action of DESAT protection

While initiating a soft shutdown of the driven IGBT or MOSFET, the DESAT monitor of the smart gate driver will also typically generate an isolated fault signal which is passed back to the controller. The controller then can re-try to drive the power switch on, after a programmed pause, with sufficient delay that if the short circuit persists, the average dissipation in the switch is not excessive.

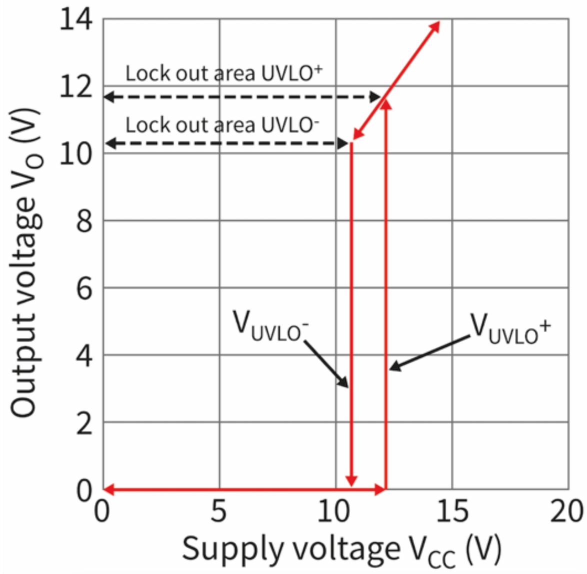

Figure 6: For the TLP5231 the opto-coupled fault signal can also indicate if a supply under-voltage lockout condition has occurred.

Integrated drivers are high performance

It is possible to design a gate driver with all of the features discussed with discrete components, but this is hardly economical in parts cost, design and assembly time and board area required. Integrated drivers are however available from Toshiba that make it easy to achieve a reliable, high-performance gate driver for all of the available switch technologies at any practical power level. The parts already hold safety certification, which can avoid the cost and delay of a user having to separately pay for certification of the safety barriers of a discrete design.

Comprehensive, high-performance integrated drivers are available

A range of integrated 'smart' gate drivers is available, and we will now look at some of the latest products. Types TLP5214 [1] and TLP5214A [2] are primarily intended for IGBT driving up to 50kHz and are in SO-16L packages with 8mm creepage and clearance. With appropriate choice of supply voltages, the parts can also be used to drive silicon or even SiC MOSFETs. Because of lower Gate capacitance and lower Gate charge for SiC MOSFETs PWM frequencies of up to 650kHz are possible. Isolation voltage rating is 5kVAC to meet UL 1577 and EN 60747 safety standards for 600VAC system voltages. The parts are able to supply +/-4A peak gate current, with propagation delays of less than 150ns and with a common-mode transient immunity of +/-35kV/µs. Isolation capacitance is 1pF typical. The full protection features discussed are incorporated including DESAT monitoring and shutdown, along with an internal Miller clamp. Under-voltage lock-out and fault reporting back to the controller is included. The TLP5214A version has the same base characteristics, but with longer DESAT blanking time and longer soft-duration shutdown time for systems with high peak loads and noise levels.

The Toshiba TLP5212 part can also be used with IGBTs and MOSFETs with lower peak gate drive current requirements. The parts do not have rail-to-rail output voltages, to allow for backwards compatibility with other products. If TLP5214 parts, for example, were used to upgrade an existing product with non-rail-to-rail drivers, the applied voltages to the gate would be higher with less margin to the absolute maximum values with increased risk. Figure 6 shows the internal difference between the TLP5212 and TLP5214.

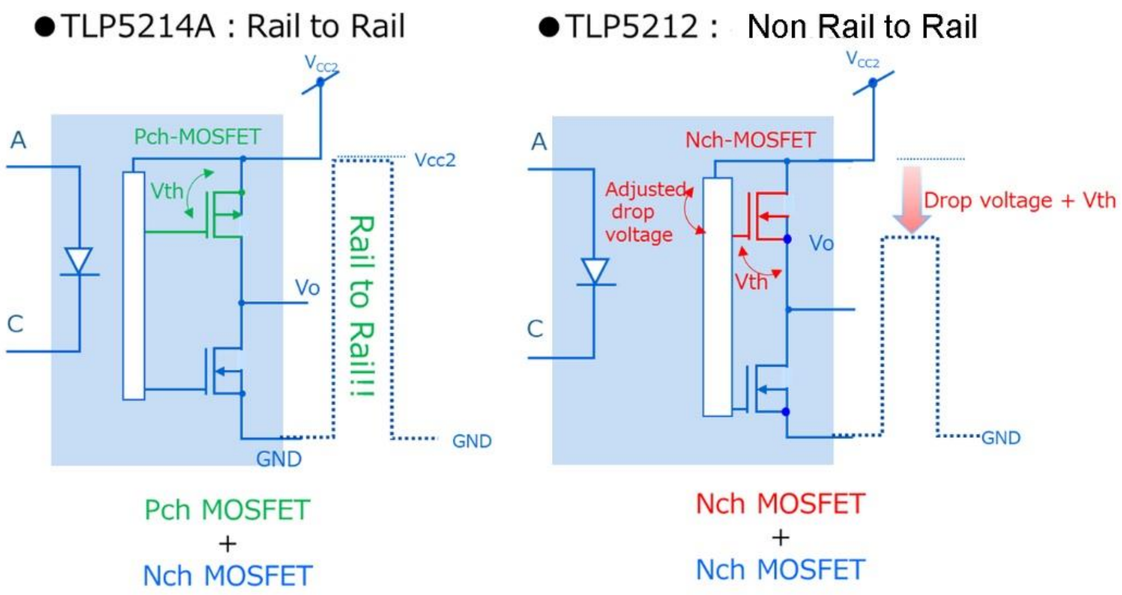

Figure 7: Toshiba TLP5212 gate driver has a non-rail-to-rail output swing, for backwards compatibility

Another Toshiba part, the TLP5231 is similar to the TLP5214 parts but is intended to be a pre-driver, followed by a buffer of a P- and N-channel MOSFET. These can be scaled for any desired power rating, and separate drive signals are made available for the two external MOSFET gates for maximum flexibility. Under-voltage lock-out is included, along with DESAT protection, with an externally adjustable soft shutdown time. In this part, a drive is provided to an externally fitted Miller clamp MOSFET. There are also detail differences in the propagation delay, DESAT thresholds and blanking charging current and timing. Table 1 summarises the performance of the parts described. Alternatively, the TLP5212 and TLP5214 could be used as pre-drivers.

<table>
<tr><th>Item</th><th>Symbol</th><th>TLP5212</th><th>TLP5214</th><th>TLP5214A</th><th>TLP5231
(Pre-driver)</th></tr>
<tr><td colspan="6">Power supply (Recommended conditions)</td></tr>
<tr><td>Total power supply voltage</td><td>V_{CC2}-V_{EE}</td><td colspan="3">15 to 30V</td><td>21.5 to 30V</td></tr>
<tr><td>Output negative voltage</td><td>V_E-V_{EE}</td><td colspan="3">-15 V to 0V</td><td>-15 to -6.6V</td></tr>
<tr><td>Output positive voltage</td><td>V_{CC2}-V_E</td><td colspan="3">15V to 30V – (V_E - V_{EE})</td><td>30V –
(VE - VEE)</td></tr>
<tr><td>Input positive voltage</td><td>V_{CC1}</td><td colspan="3">3.3 to 5.5V</td><td>3.3 to 5.5V</td></tr>
<tr><td colspan="6">Input / output characteristics</td></tr>
<tr><td>Threshold input current (maximum)</td><td>I_{FHL}</td><td colspan="3">6mA</td><td>3.5mA</td></tr>
<tr><td>Peak output current (maximum)</td><td>I_{OPH}/I_{OPL}</td><td>-2.5 / +2.5A</td><td colspan="2">-4.0 / +4.0A</td><td>-2.5 / +2.5A</td></tr>
<tr><td>Transmission delay time</td><td>t_{pLH}, t_{pHL}</td><td>100 to 250ns</td><td colspan="2">50 to 150ns</td><td>100 to 300ns</td></tr>
<tr><td>Delay propagation skew</td><td>t_{psk}</td><td>-150 to +150ns</td><td colspan="2">-80 to +80ns</td><td>-200 to +200ns</td></tr>
<tr><td colspan="6">DESAT characteristics</td></tr>
<tr><td>DESAT threshold</td><td>V_{DESAT}</td><td>6 to 7.5V</td><td>6 to 7.5V</td><td>5.9 to 7.5V</td><td>7.5 to 9.0V</td></tr>
<tr><td>Blanking charging current (standard)</td><td>I_{CHG}</td><td>-0.26mA</td><td colspan="2">-0.24mA</td><td>-0.54mA</td></tr>
<tr><td>DESAT blanking time (standard)</td><td>t_{DESAT} (LEB)</td><td>1.2μs</td><td>0.2μs</td><td>1.1μs</td><td>0.58μs</td></tr>
<tr><td>Soft shutdown time (standard)</td><td>t_{DESAT} (10%)</td><td>2μs</td><td>3.5μs</td><td>7.0μs</td><td>Adjustable with external MOS</td></tr>
<tr><td colspan="6">Miller clamp</td></tr>
<tr><td>Clamp terminal threshold (standard)</td><td>Vt_{Clanp}</td><td>2.25V</td><td>3.0V</td><td>2. 5V</td><td rowspan="2">None</td></tr>
<tr><td>Clamp "L" sink current (standard)</td><td>I_{CL}</td><td>2.4A</td><td>1.8A</td><td>1.8A</td></tr>
</table>

Table 1: Some integrated gate driver products available from Toshiba and their characteristics

Application notes for the parts discussed are available with more detailed information in references [1], [2] and [3]. The same pages will lead you to further information on related topics such as safety standards for photocouplers and using negative gate bias voltages.

Summary

The degree of integration now achieved in smart gate drivers allows designers to fit the parts as pre-certified and tested subsystems with performance that would be difficult to achieve with a discrete design. Comprehensive fault detection and reporting is built-in and as effectively a single part, reliability is extremely high. Toshiba has a wide range of suitable products available with comprehensive application documentation which can be viewed on their website[4]. Applications include motor control, EV charging, UPSs, inverters, servo drives, solar modules and much more.

References

[1] https://toshiba.semicon-storage.com/eu/semiconductor/product/isolators-solid-state-relays/detail.TLP5214.html

[2] https://toshiba.semicon-storage.com/eu/semiconductor/product/isolators-solid-state-relays/detail.TLP5214A.html

[3] https://toshiba.semicon-storage.com/eu/semiconductor/product/isolators-solid-state-relays/detail.TLP5231.html

[4] https://toshiba.semicon-storage.com/ap-en/semiconductor/product/isolators-solid-state-relays.html

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.**