

# Low Drop-Out (LDO) Regulator IC

## 1. Introduction

Low Drop-Out (LDO) regulators are highly accurate power supply ICs which are typically under 500mA, and frequently used in a wide range of electronic devices.

Small mobile devices like smartphones and tablets not only try to achieve lower power consumption, but from the system standpoint, a well regulated power supply is also necessary. Also, a range of different power supplies are needed to ensure that the device performance throughout the system is optimized. To meet these needs, an IC with various sorts of power supply ICs combined into 1 large IC (Power Management IC; PM-IC) is used to fill this requirement. However, as technological advances in smartphones and tablets, they have become increasingly complex, so the number of PM-IC channels and its power supply quality may be unable to meet some customer requirements. As such, LDO regulators become an important supplement to the PM-IC.

The highly accurate and stable power supply characteristics of LDO regulators are also used in standard electronic devices. This is especially to ensure analog circuits work exactly as they are designed. The quality of the power supply for the circuit as an important parameter can be easily covered by LDO regulators.

LDO is a simple solution to obtain a highly accurate power supply circuit, but in order to get the best performance, careful layout and design is necessary. This application note will explain the LDO regulator and its basic circuitry followed by precautions to take note of during usage. We hope that you will find it useful in your circuit design.

**2. Basics of Power Supply IC**

LDO regulator IC is a series type power supply IC.

Power supply ICs are generally divided into 3 types, namely Series Regulators, Shunt Regulators, and Switching Regulators. Series type and Shunt type are also known as Linear Regulators. Each of the regulators have their own strong and weak points, and to understand LDO regulators thoroughly, each regulators will be briefly introduced.

●Series Regulator

Series regulator basic circuitry is shown in Fig.1.

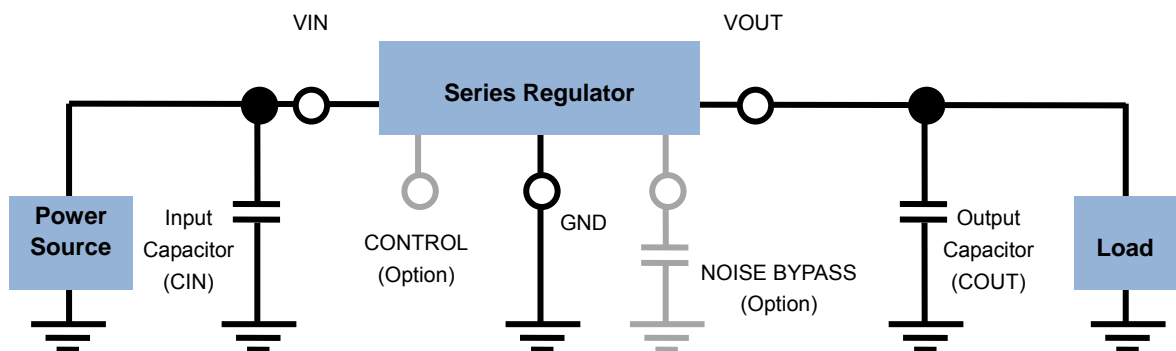


Fig.1 Example of Basic circuitry of Series Regulators

Series regulators are connected serially between the power source and the load, to remove irregularities in the power source and thus provide a stable voltage to the load. Essentially, the Series Regulator consists of 3 pins, the Input Pin (VIN), the Output Pin (VOUT) and the GND Pin, thus it is also known as the 3 pin regulator. Recently, Control Pins (CONTROL, Shutdown Pin) to turn the regulator ON/OFF, and Noise Pins (NOISE BYPASS) for connecting additional capacitors to reduce the noise at the output have also been introduced. For more precise control of the power supply, control pins have become an essential feature.

For stable operation of the Series Regulator at VIN and VOUT, input capacitors (CIN) and output capacitors (COUT) are required at the respective pins. The capacitance for CIN and COUT play an important part, so it will be further explained later.

In a circuit, the series regulator can only be used to provide reduced voltage of the power source to the load. Also, the load current has to pass through the internal transistor, so it is not efficient to use the regulator for large currents.

### •Shunt Regulator

Shunt regulator basic circuitry is shown in Fig.2.

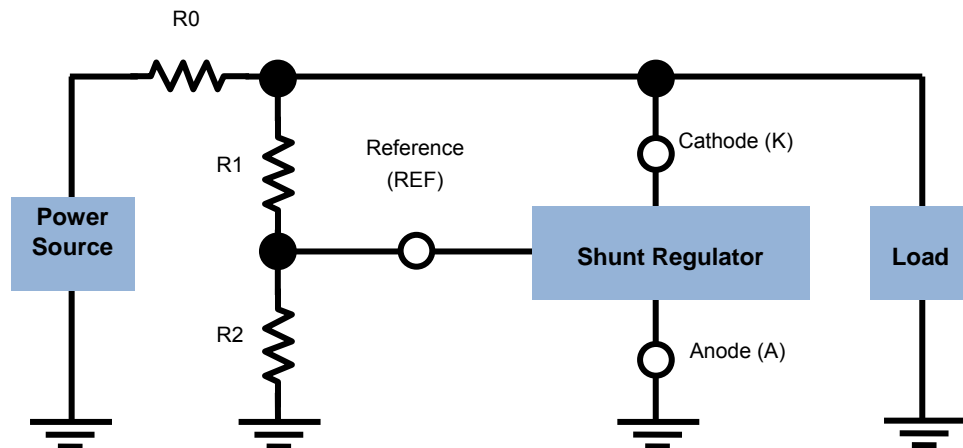


Fig.2 Example of Basic circuitry of Shunt Regulators

Shunt regulators, as the name implies, control the voltage at the load by dividing (Shunt) the current which flows to the load. The voltage of the supply is measured by the external resistors, and the output voltage is then kept constant by adjustments within the shunt regulator. The output voltage is then adjusted by changing the external resistors.

Structurally, the voltage at the load is limited by the amount of current which can be allowed to flow between the cathode and anode of the regulator. Also, to ensure stability, a constant current has to flow between the cathode and anode, even under no load or light load conditions so it is not very efficient. However, this highly accurate regulator is commonly used for producing reference voltages.

### •Switching Regulator

Switching regulators are divided into insulating type (AC-DC convertor) and non-insulating type (DC-DC converter), but in order to compare with linear regulators, only DC-DC converter ICs will be explained. As the name suggests, by switching the input ON/OFF continuously, the IC changes the voltage level and smoothens the output, and unlike the linear regulator, decreasing the voltage (step-down) and increasing the voltage (step-up) are both possible.

It can handle large currents without much heat dissipation and is also highly efficient, but the switching operation results in EMI (electronic-magnetic interference). Improvements have also been made to the switching function to increase the efficiency during light load, so it is a high performance power supply IC. However the cost of a switching regulator is generally higher than the linear regulator.

This concludes the introduction the 3 types of power supplies. Understanding each product's advantage and disadvantage is key to choosing a suitable power supply for a electronic circuit. Generally, considering the balance between cost/IC size and performance, for loads of 500mA and under, series regulator should be the easiest to implement.

### 3. LDO regulator electrical characteristics and usage precautions

Under this chapter, usage precautions for the LDO regulator and understanding how to read the datasheet will be explained. TCR2EN series will be used to help explain the electrical characteristics

●Electrical Characteristics

The electrical characteristics of Toshiba’s TCR2EN series is unless specified, measured based on the conditions shown in Fig.3 below. This will ensure the most stable operation. In actual usage, the regulator can be used in various conditions other than that shown below, that could result in large changes in electrical characteristics. The impact to each characteristic will be elaborated below.

Toshiba TCR2EN series standard measurement conditions:  
 $V_{IN} = V_{OUT} + 1V$ ,  $I_{OUT} = 50mA$ ,  $C_{IN} = 0.1\mu F$ ,  $C_{OUT} = 1.0\mu F$ ,  $T_j = 25^\circ C$

Fig.3 Toshiba’s TCR2EN series standard measurement conditions

1) Output voltage <Symbol:  $V_{OUT}$ >

As a power supply IC, the output voltage characteristics of an LDO regulator is the most important. On a LDO regulator’s datasheet, the specification linked with output voltage is output voltage accuracy. This output voltage is essentially available in steps of 0.1V. As for TCR2EN series, it has a selectable lineup ranging from 1.0V to 3.6V. The output voltage specification for TCR2EN series is as shown in Fig.4.

| Characteristics         | Symbol    | Test Condition   | Min                 | Typ. | Max | Unit |    |
|-------------------------|-----------|------------------|---------------------|------|-----|------|----|
| Output voltage accuracy | $V_{OUT}$ | $I_{OUT} = 50mA$ |                     |      |     |      |    |
|                         |           |                  | $V_{OUT} < 1.8V$    | -18  | —   | +18  | mV |
|                         |           |                  | $1.8V \leq V_{OUT}$ | -1.0 | —   | +1.0 | %  |

Fig.4 Output voltage specification for Toshiba TCR2EN series

Output voltage accuracy differs with output voltage ranges as seen in Fig.4. For output voltages above 1.8V, the accuracy is within  $\pm 1.0\%$ , for output voltages below 1.8V, the accuracy will be guaranteed within  $\pm 18mV$  regardless of the output voltage.

2) Input voltage <Symbol :  $V_{IN}$ >

Input voltage is the acceptable voltage range for the LDO regulator’s input. For the minimum specification, if there are no exceptions stated, the input voltage is the voltage that will allow the output current ( $I_{OUT}$ ) to flow under standard test conditions. Also, for large current flow, there is a need to increase the input voltage, which will be explained in the next section.

3) Drop-out voltage <Symbol: VIN-VOUT>

Drop-out voltage is the minimum voltage above output voltage that will allow the specified current to flow in a steady state. For Toshiba’s TCR2EN series, this is shown in Fig.5.

| Characteristics  | Symbol   | Test Condition        | Min | Typ. | Max | Unit |
|------------------|----------|-----------------------|-----|------|-----|------|
| Drop-out voltage | VIN-VOUT | IOUT = 150mA (Note 2) | —   | 160  | 210 | mV   |

(Note 2)  $2.5V \leq VOUT$

Fig.5 Toshiba’s TCR2EN series Drop-out voltage specifications

Toshiba’s TCR2EN series can drive up to 200mA of output current. The specification test conditions are based assuming the actual usage is around 25% lower at 150mA, Even if the load current changes, if peak current is kept below, the specified 210mV above the corresponding output voltage is necessary at the input (eg. VIN more than 2.71V is required for VOUT=2.5V). In other words, the minimum input voltage is the drop-out voltage added to the output voltage. This means that the minimum input voltage used should change according to the output voltage. Take note that the specifications provided on the datasheet is only for the measurement conditions stated.

As drop-out voltage is dependent on output voltage, the note for Fig.5’s specification table states that the specification shown is only applicable for VOUT above 2.5V. For Toshiba’s TCR2EN series, there is a separate specification table which provides more specific specifications for the drop-out voltage at each output voltage. This is shown in Fig.6.

| Output Voltage | Symbol   | Test Condition | Min | Typ. | Max | Unit |
|----------------|----------|----------------|-----|------|-----|------|
| VOUT = 1.2V    | VIN-VOUT | IOUT = 150mA   | —   | 360  | 550 | mV   |
| VOUT = 1.8V    |          |                | —   | 210  | 290 |      |
| VOUT = 2.5V    |          |                | —   | 160  | 210 |      |
| VOUT = 3.0V    |          |                | —   | 130  | 180 |      |

Fig.6 Toshiba’s TCR2EN series List of Drop-out voltage specifications

Essentially, the lower the output voltage, the higher the input voltage is required to drive the same amount of current. For LDO regulators, the input voltage is also the power supply voltage, which means that the voltage used has to be sufficiently high for stable operation of the IC.

As such, Toshiba’s TCR2EN series has a standard measurement condition of VIN = VOUT + 1V, a 1V margin. If using an input voltage below this condition, please consider a margin on top of the VIN-VOUT specifications given above. Also, the accuracy of the input voltage to the LDO regulator should also be given proper consideration.

4) Line Regulation <Symbol : Reg-line>

The characteristic is the variation in the output voltage given the variations in input voltage (power supply voltage) and a given output current (load current). As the LDO regulator can maintain a steady output current despite variations in input voltage, this should not be a problem.

5) Load Regulation, Load Transient Response <Symbol : Reg-load,  $\Delta V_{out}$ >

Load regulation is the variations in the output voltage with changes in the load current under steady operating conditions. Variations in the load current has a large impact on the output voltage stability so let's take a closer look.

For smartphones and recent mobile phones, as the main power supply is a Li-Ion rechargeable battery with only 1 cell, lower voltages are used to power devices within the phone, thus optimising the power management is required. On the other hand, high speed mobile communication, WiFi and other high speed signals have gradually increased in speed so high speed operation is necessary. Lastly, as battery capacity is limited, lower power consumption is necessary.

As such in mobile devices, fine-tuning power management is necessary. This does not only apply to the on/off of power supply, but also in order to increase control speed, the sudden change in consumption current in devices occurs frequently.

The important characteristic for selection for mobile devices is then load regulation, selection by load transient response is also suitable. Both are caused by variations in output current, but load regulation is under steady load condition and load transient response is the peak transient response under sudden changes in current. Fig.7 shows the characteristics curve.

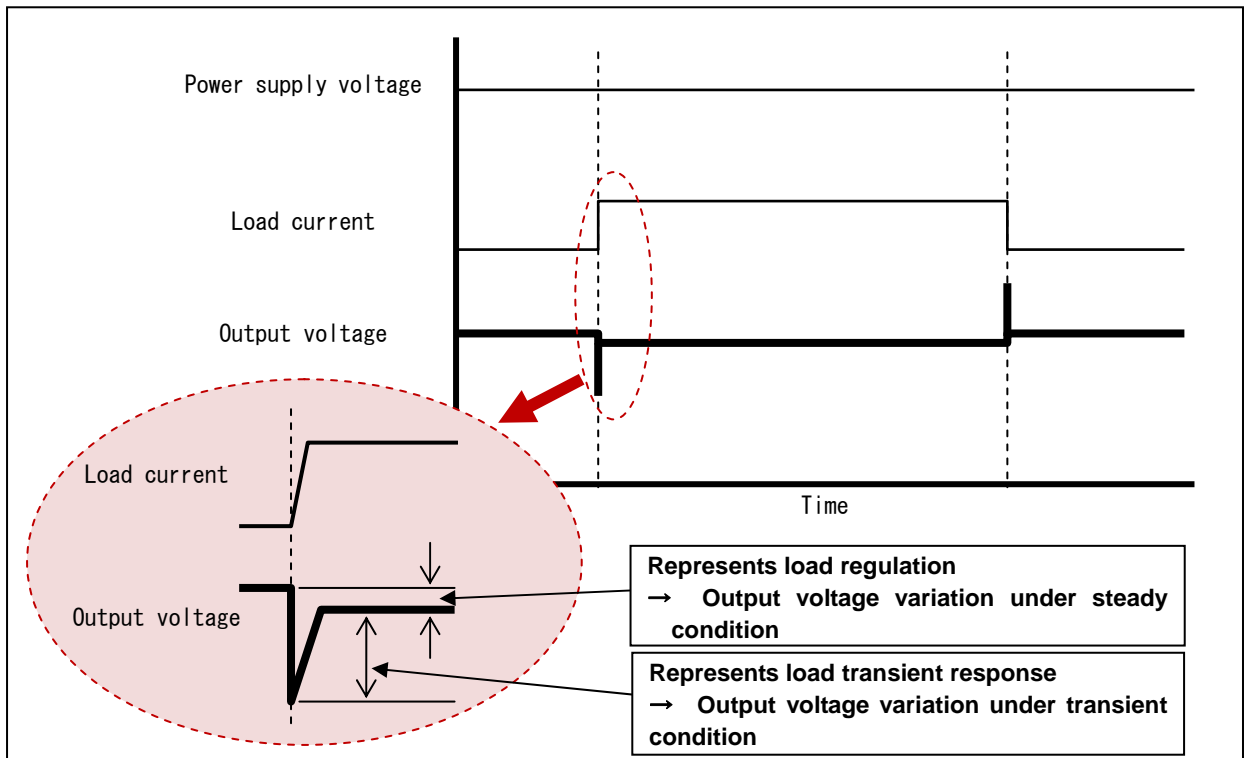


Fig.7 Load regulation and load transient response

Let's first look at it under steady condition. As the output current increases, the ON resistance of the MOSFET used as the output transistor of the LDO regulator will increase, so the output voltage will correspondingly decrease. It is thus necessary to determine the minimum voltage needed for the LDO regulator to provide power supply to the system and check with the load regulation specification given in the datasheet.

Let's then take a look under transient condition. The LDO regulator will keep the output voltage from dropping even when there are sudden or big increases in load current, but the output voltage will not be able to keep up if the load current changes too quickly, which results in a voltage drop. This is known as a load transient response. Also, as there are sudden changes in current, a charged output capacitor will discharge to try to maintain the output voltage, also contributing to the load transient response, so choosing a suitable capacitance is also very important. Essentially, when a big capacitance is chosen, load transient response improves, but at the expense of switch on speed of the LDO regulator which will decrease, and is thus unsuitable for systems with strict requirements on switching speeds.

Due to the sudden drop of output voltage caused by the load transient response, the voltage provided by the LDO regulator might drop below the minimum required voltage, if this is not properly adjusted with system timings, it can result in system trouble. A common situation would be an idling LSI becoming active. If the output of the LDO regulator is shared among various devices, this could also result in the supply current gathering in a single device. When using LDO regulators in power supply designs, it is thus important to consider the load from number of devices, and the operating timing that each device requires from the system.

Also, it is not just the change in current when turning devices on and off, but it is also important to consider operating speed and pass through current when connecting logic LSIs as loads. As high speed logic LSIs are connected, supply current fluctuations occur at high frequency. Ripples and noise will then be observed at the output curve of the LDO regulator, but in this case, load transient response instead of ripples and noise is a more important issue. To improve load transient response, even if an LDO regulator has good transient response, it is also necessary to carefully consider input and output capacitors. Ripples and noise will be explained in the next section. Toshiba's TCR2EN series has good load regulation and load transient response characteristics. It operates well under various conditions using standard capacitors.

Also, there are cases when output voltage remains even when the power supply is turned off, which will cause problems to the system timing. When the power is turned off, the output capacitor used to stabilize the LDO regulator's output may not be fully discharged resulting in the above. Toshiba's TCR2EN series has an auto discharge function in response to customer's requirement. This will enable the output voltage to be tied to ground level at about the same time the LDO regulator is turned off.

6) Ripple rejection, output noise voltage <Symbol : R.R., VNO>

Ripple rejection is an important characteristic for LDO regulators. Ripples appear as fluctuations superimposed on the LDO regulator’s DC output. As LDO regulators are used to provide stable power supply, it is not acceptable to have ripples at the output. Even if the ripples occur at the input of the LDO regulator, a good regulator should be able to remove this disturbance. This ability is measured by its ripple rejection characteristic. A power supply with ripple rejection of 40dB and above can be used for most devices, but for devices with increasing needs for high precision, a pure DC power supply is much desired, and this is the reason why LDO regulators with high ripple rejection are selected.

On a LDO regulator’s datasheet, ripple rejection characteristic is given for only a selected frequency. However, in actual application, ripples with a range of different frequencies can be found at the input, so frequency response characteristics are also important. Fig.8 shows the ripple rejection ratio vs frequency characteristics (reference data) for Toshiba’s TCR2EN series.

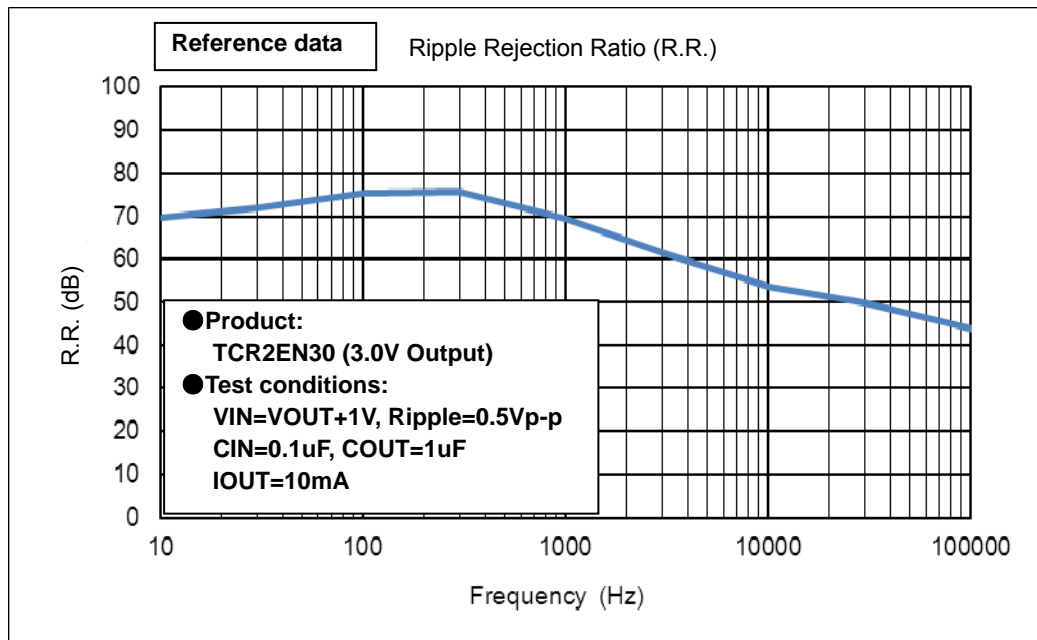


Fig.8 Toshiba’s TCR2EN series    Ripple Rejection Ratio vs. Frequency characteristics (reference data)

Toshiba’s TCR2EN series have a sufficient ripple rejection ratio of 73dB. Even at 100kHz, it has a ripple rejection ratio of about 45dB, which should not be a problem during use. Also note that above this frequency, the characteristics are influenced by the capacitance of the input capacitor used and not affected by the LDO regulator’s characteristics.

Output noise voltage is the noise voltage from the LDO regulator. It is hard to differentiate from ripples, but as a LDO regulator power supply for normal devices, Toshiba’s TCR2EN series has a noise voltage of about 35uVrms which is sufficient.



- LDO regulator usage considerations

### 1)Heat dissipation design

LDO regulator is a series type power supply IC. As such, the load current flows constantly between the input and output pins. Power is also used for the operation of the surrounding circuits. The power dissipation can be calculated as below.

$$\text{Power dissipation} = (V_{in} - V_{out}) \times I_{out} + (V_{in} \times I_B)$$

As it is clear from the above equation, the input-output voltage difference increases as low output voltage types are used, so careful considerations are necessary. Also, as input voltage increases, the consumption current of the LDO regulator cannot be ignored.

Especially for small mold package and BGA type LDO regulators, the package is small so heat is dissipated via the PCB land pattern, so proper design, for example having the GND pattern in multi-layer PCB lie directly underneath the LDO regulator is very important.

Proper derating of the maximum allowable power dissipation and operation temperature is necessary depending on the actual voltage, and current conditions used, and a safety margin should be allowed in the design.

### 2)Choosing input capacitors

For stable operation of the LDO regulator, input and output capacitors are necessary. Use for improving load transient response and ripple rejection ration has been explained, but the capacitance of input and output capacitors are also important for stable operation. Depending on situation, the recommended capacitances used for our test conditions in the datasheets are most suitable for stable operation. Also, only considering the stable operation of an LDO regulator, it would be advisable to increase the capacitance of input and output capacitors. However, the rise and fall time will become slower. Reducing the capacitance is not recommended but, if output current is small, input ripple is small, load current fluctuation is small, and the conditions are right, stable operation can also be achieved with small capacitors.

Also, please use input and output capacitors with low series resistance (ESR) as capacitors with large ESR will reduce the phase margin, leading to more instability. Note that even if ESR is small, large line capacitance due to long circuits have the same effect as using capacitors with large ESR. As such, input and output capacitors should be placed as close as possible to the LDO regulator to reduce line capacitances.

There are also capacitors which fluctuate with temperature. If the temperature environment is severe, it is advisable to consider the temperature characteristics of the capacitors during usage.

Whichever the case, it is always advisable to do evaluation under the expected use.

### 3)Overcurrent protection circuit

Overcurrent protection circuit is a circuit which protects the regulator and the connected load from situations when a short circuit occurs at the output pin. There are many different types of overcurrent protection circuits but the most commonly used circuit is the fold back circuit. This circuit does not immediately shut off the current, but gradually reduces both the current and voltage when specified current is exceeded. Reducing the voltage concurrently is the objective of the LDO regulator which helps reduce heat dissipation within the regulator.

The overcurrent protection circuit is not designed to keep current within the maximum allowable limits. So if the circuit is constantly in operation, problems with the heat dissipation design can occur as explained earlier.

## RESTRICTIONS ON PRODUCT USE

- Toshiba Corporation, and its subsidiaries and affiliates (collectively "TOSHIBA"), reserve the right to make changes to the information in this document, and related hardware, software and systems (collectively "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 creating and producing designs and using, 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 that 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 intended for use in general electronics applications (e.g., computers, personal equipment, office equipment, measuring equipment, industrial robots and home electronics appliances) or for specific applications as expressly stated in this document. Product is neither intended nor warranted for use in equipment 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 or serious public impact ("Unintended Use"). Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, devices related to electric power, and equipment used in finance-related fields. Do not use Product for Unintended Use unless specifically permitted in this document.
- 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 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.