LM2623 General-Purpose, Gated-Oscillator-Based DC-DC Boost Converter

1 Features
- Good Efficiency Over a Very Wide Load Range
- Very Low Output Voltage Ripple
- Up to 2-MHz Switching Frequency
- 0.8-V to 14-V Operating Voltage
- 1.1-V Start-up Voltage
- 1.24-V to 14-V Adjustable Output Voltage
- Up to 2-A Load Current at Low Output Voltages
- 0.17-Ω Internal MOSFET
- Up to 90% Regulator Efficiency
- 80-µA Typical Operating Current (Into V_{DD} Pin of Supply)
- < 2.5-µA Ensured Supply Current In Shutdown
- Small 8-Pin VSSOP Package (Half the Footprint of Standard 8-Pin SOIC Package); 1.09-mm Package Height
- 4-mm × 4-mm Thermally Enhanced WSON Package Option

2 Applications
- Cameras, Pagers and Cell Phones
- PDAs, Palmtop Computers, GPS devices
- White LED Drive, TFT, or Scanned LCDs
- Flash Memory Programming
- Hand-Held Instruments
- 1, 2, 3, or 4 Cell Alkaline Systems
- 1, 2, or 3 Cell Lithium-ion Systems

3 Description
The LM2623 is a high-efficiency, general-purpose, step-up DC-DC switching regulator for battery-powered and low input voltage systems. It accepts an input voltage between 0.8 V and 14 V and converts it into a regulated output voltage between 1.24 V and 14 V. Efficiencies up to 90% are achievable with the LM2623.

In order to adapt to a number of applications, the LM2623 allows the designer to vary the output voltage, the operating frequency (300 kHz to 2 MHz) and duty cycle (17% to 90%) to optimize the part's performance. The selected values can be fixed or can vary with battery voltage or input to output voltage ratio. The LM2623 uses a very simple, on/off regulation mode to produce good efficiency and stable operation over a wide operating range. It normally regulates by skipping switching cycles when it reaches the regulation limit (Pulse Frequency Modulation).

Note: See Non-Linear Effect and Choosing The Correct C3 Capacitor so that any challenges with designing with this part can be taken into account before a board design/layout is finalized.

For alternative solutions, See Also: LM2700, LM2622, LM2731, LM2733, and LM2621.

Device Information(1)

<table>
<thead>
<tr>
<th>PART NUMBER</th>
<th>PACKAGE</th>
<th>BODY SIZE (NOM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM2623</td>
<td>WSON (14)</td>
<td>4.00 mm × 4.00 mm</td>
</tr>
<tr>
<td></td>
<td>VSSOP (8)</td>
<td>3.00 mm × 3.00 mm</td>
</tr>
</tbody>
</table>

(1) For all available packages, see the orderable addendum at the end of the data sheet.

An IMPORTANT NOTICE at the end of this data sheet addresses availability, warranty, changes, use in safety-critical applications, intellectual property matters and other important disclaimers. PRODUCTION DATA.
Table of Contents

1 Features ............................................................... 1
2 Applications .......................................................... 1
3 Description ............................................................. 1
4 Revision History ...................................................... 2
5 Pin Configuration And Functions ................................. 3
6 Specifications .......................................................... 4
   6.1 Absolute Maximum Ratings .................................... 4
   6.2 ESD Ratings ........................................................ 4
   6.3 Recommended Operating Conditions ....................... 4
   6.4 Thermal Information ............................................ 4
   6.5 Electrical Characteristics ..................................... 5
   6.6 Typical Characteristics ....................................... 5
7 Detailed Description .................................................. 7
   7.1 Overview .......................................................... 7
   7.2 Functional Block Diagram ..................................... 7
   7.3 Feature Description ............................................ 7
   7.4 Device Functional Modes ...................................... 9
8 Applications And Implementation .................................. 10
   8.1 Application Information ....................................... 10
   8.2 Typical Application ............................................ 10
9 Power Supply Recommendations ..................................... 12
10 Layout ................................................................... 12
   10.1 Layout Guidelines ............................................. 12
   10.2 Layout Example ................................................ 13
   10.3 WSON Package Devices ..................................... 13
11 Device And Documentation Support ............................... 14
   11.1 Device Support ................................................ 14
   11.2 Documentation Support ..................................... 14
   11.3 Receiving Notification of Documentation Updates .......... 14
   11.4 Community Resources ....................................... 14
   11.5 Trademarks ...................................................... 14
   11.6 Electrostatic Discharge Caution ............................ 14
   11.7 Glossary ........................................................ 14
12 Mechanical, Packaging, And Orderable Information ........ 14

4 Revision History
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision H (November 2014) to Revision I Page

• Changed Handling Ratings table to ESD Ratings to comply with current format .......................... 4
• Moved Storage temperature spec to Abs Max table ......................................................................... 4
• Added separate row for SW pin HBM ESD rating ........................................................................... 4
• Added condition to Recommended Operating Conditions table .................................................. 4
• Changed Updated RθJA value for NHE package from "40 – 56" to "46.5°C/W and DGK package from "240" to 152.5°C/W; added additional thermal information.................................................. 4

Changes from Revision G (December 2005) to Revision H Page

• Added Device Information and Handling Rating tables, Feature Description, Device Functional Modes, Application and Implementation, Power Supply Recommendations, Layout, Device and Documentation Support, and Mechanical, Packaging, and Orderable Information sections; moved some curves to Application Curves section .......... 1
## 5 Pin Configuration And Functions

### NHE Package
14-Pin WSON
Top View

### DGK Package
8-Pin VSSOP
Top View

### Pin Functions

<table>
<thead>
<tr>
<th>PIN</th>
<th>TYPE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSON</td>
<td>VSSOP</td>
<td>NAME</td>
</tr>
<tr>
<td>1</td>
<td>—</td>
<td>NC</td>
</tr>
<tr>
<td>2, 3</td>
<td>1</td>
<td>PGND</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>EN</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>FREQ</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>FB</td>
</tr>
<tr>
<td>7</td>
<td>—</td>
<td>NC</td>
</tr>
<tr>
<td>8</td>
<td>—</td>
<td>NC</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>SGND</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>VDD</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>BOOT</td>
</tr>
<tr>
<td>12, 13</td>
<td>8</td>
<td>SW</td>
</tr>
<tr>
<td>14</td>
<td>—</td>
<td>NC</td>
</tr>
<tr>
<td>DAP</td>
<td>—</td>
<td>DAP</td>
</tr>
</tbody>
</table>
6 Specifications

6.1 Absolute Maximum Ratings\(^{(1)(2)}\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW pin voltage</td>
<td>−0.5</td>
<td>14.5</td>
<td>V</td>
</tr>
<tr>
<td>BOOT, V(_{DD}), EN and FB pins</td>
<td>−0.5</td>
<td>10</td>
<td>V</td>
</tr>
<tr>
<td>FREQ pin</td>
<td>100</td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>(T_{\text{Jmax}})(^{(3)})</td>
<td>150</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Lead temp. (soldering, 5 sec)</td>
<td>260</td>
<td></td>
<td>°C</td>
</tr>
<tr>
<td>Power dissipation ((T_{A}=25^\circ\text{C}))(^{(3)})</td>
<td>500</td>
<td></td>
<td>mW</td>
</tr>
<tr>
<td>Storage temperature, (T_{\text{stg}})</td>
<td>−65</td>
<td>150</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) If Military/Aerospace specified devices are required, contact the Texas Instruments Sales Office/ Distributors for availability and specifications.

(3) The maximum power dissipation must be derated at elevated temperatures and is dictated by \(P_{\text{Dmax}} = \frac{(T_{\text{Jmax}} - T_{A})}{R_{\theta JA}}\) or the number given in the Absolute Maximum Ratings, whichever is lower.

6.2 ESD Ratings

<table>
<thead>
<tr>
<th>ESD Discharge</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(^{(1)})</td>
<td>±2000</td>
<td>V</td>
</tr>
<tr>
<td>All pins except SW pin</td>
<td>±1000</td>
<td>V</td>
</tr>
<tr>
<td>SW pin (VSSOP package pin 8) (WSON package pin 12 and pin 13)</td>
<td>±500</td>
<td></td>
</tr>
<tr>
<td>Charged-device model (CDM), per JEDEC specification JESD22-C101(^{(2)})</td>
<td>All pins</td>
<td>±500</td>
</tr>
</tbody>
</table>

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.

(2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

6.3 Recommended Operating Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MIN</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{\text{DD}}) pin</td>
<td>3</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>FB, EN pins</td>
<td>0</td>
<td>(V_{\text{DD}})</td>
<td></td>
</tr>
<tr>
<td>BOOT pin</td>
<td>0</td>
<td>10</td>
<td>V</td>
</tr>
<tr>
<td>Ambient temperature ((T_{A}))</td>
<td>−40</td>
<td>85</td>
<td>°C</td>
</tr>
</tbody>
</table>

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

6.4 Thermal Information

<table>
<thead>
<tr>
<th>Thermal Metric</th>
<th>LM2623 NHE (WSON)</th>
<th>DGK (VSSOP)</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction-to-ambient thermal resistance</td>
<td>46.5</td>
<td>152.5</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-case (top) thermal resistance</td>
<td>37.7</td>
<td>53.9</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-board thermal resistance</td>
<td>23.6</td>
<td>73.2</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-top characterization parameter</td>
<td>0.4</td>
<td>5.5</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-board characterization parameter</td>
<td>23.8</td>
<td>72.0</td>
<td>°C/W</td>
</tr>
<tr>
<td>Junction-to-case (bottom) thermal resistance</td>
<td>4.6</td>
<td>N/A</td>
<td>°C/W</td>
</tr>
</tbody>
</table>

(1) For more information about traditional and new thermal metrics, see the Semiconductor and IC Package Thermal Metrics application report.
6.5 Electrical Characteristics

Limits apply for $T_J = 25^\circ C$ and $V_{DD} = V_{OUT} = 3.3 \, \text{V}$, unless otherwise specified.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITION</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DD,ST}$</td>
<td>Start-up supply voltage 25°C $I_{LOAD} = 0 , \text{mA}$&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>1.1</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$V_{IN,OP}$</td>
<td>Minimum operating supply voltage (once started) $I_{LOAD} = 0 , \text{mA}$</td>
<td>0.65</td>
<td>0.8</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$V_{FB}$</td>
<td>FB pin voltage $-40^\circ C$ to 85$^\circ C$</td>
<td>1.24</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$V_{OUT,max}$</td>
<td>Maximum output voltage</td>
<td>14</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Efficiency $V_{IN} = 3.6 , \text{V}; V_{OUT} = 5 , \text{V};$</td>
<td>87%</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>$V_{IN} = 2.5 , \text{V}; V_{OUT} = 3.3 , \text{V};$</td>
<td>87%</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>D</td>
<td>Switch duty cycle</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_D$</td>
<td>Operating quiescent current&lt;sup&gt;(2)&lt;/sup&gt; $FB , \text{Pin} &gt; 1.3 , \text{V}; EN , \text{Pin at} V_{DD}$</td>
<td>80</td>
<td></td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td></td>
<td>$FB , \text{Pin} &gt; 1.3 , \text{V}; EN , \text{Pin at} V_{DD, -40^\circ C}$ to $85^\circ C$</td>
<td>110</td>
<td></td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td>$I_S$</td>
<td>Shutdown quiescent current&lt;sup&gt;(3)&lt;/sup&gt; $V_{DD, BOOT}$ and SW Pins at 5 $\text{V}; EN , \text{Pin} &lt; 200 , \text{mV}$</td>
<td>0.01</td>
<td></td>
<td>2.5</td>
<td>$\mu A$</td>
</tr>
<tr>
<td></td>
<td>$V_{DD, BOOT}$ and SW Pins at 5 $\text{V}; EN , \text{Pin} &lt; 200 , \text{mV, -40^\circ C}$ to $85^\circ C$</td>
<td></td>
<td></td>
<td></td>
<td>$\mu A$</td>
</tr>
<tr>
<td>$I_{CL}$</td>
<td>Switch peak current limit LM2623A</td>
<td>2.2</td>
<td>2.85</td>
<td></td>
<td>$A$</td>
</tr>
<tr>
<td></td>
<td>Switch peak current limit LM2623</td>
<td>1.2</td>
<td></td>
<td></td>
<td>$A$</td>
</tr>
<tr>
<td>$R_{DS,ON}$</td>
<td>MOSFET switch on resistance $-40^\circ C$ to $85^\circ C$</td>
<td>0.17</td>
<td>0.26</td>
<td></td>
<td>$\Omega$</td>
</tr>
</tbody>
</table>

**ENABLE SECTION**

| $V_{EN,LO}$          | EN pin voltage low<sup>(4)</sup> $-40^\circ C$ to $85^\circ C$ | 0.15 $V_{DD}$ |      |      | V    |
| $V_{EN,HI}$          | EN pin voltage high<sup>(4)</sup> $-40^\circ C$ to $85^\circ C$ | 0.7 $V_{DD}$  |      |      | V    |

(1) $V_{DD}$ tied to BOOT and EN pins. Frequency pin tied to $V_{DD}$ through 121-K$\Omega$ resistor. $V_{DD,ST} = V_{DD}$ when start-up occurs. $V_{IN}$ is $V_{DD} + D1$ voltage (usually 10 mV to 50 mV at start-up).

(2) This is the current into the $V_{DD}$ pin.

(3) This is the total current into pins $V_{DD, BOOT, SW,}$ and FREQ.

(4) When the EN pin is below $V_{EN,LO}$ the regulator is shut down; when it is above $V_{EN,HI}$ the regulator is operating.

6.6 Typical Characteristics

![Figure 1. Efficiency vs Supply Voltage](image1)

![Figure 2. $V_{FB}$ vs Temperature](image2)

Copyright © 2004–2017, Texas Instruments Incorporated

Submit Documentation Feedback
Typical Characteristics (continued)

Figure 3. Frequency vs $V_{IN}$

Figure 4. Maximum Start-Up Voltage vs Temperature

Figure 5. Typical $R_{DS(ON)}$ vs Temperature

Figure 6. Typical Current Limit vs Temperature

Figure 7. Output Voltage vs Supply Voltage
7 Detailed Description

7.1 Overview

The LM2623 is designed to provide step-up DC-DC voltage regulation in battery-powered and low-input voltage systems. It combines a step-up switching regulator, N-channel power MOSFET, built-in current limit, thermal limit, and voltage reference in a single 8-pin VSSOP package. The switching DC-DC regulator boosts an input voltage between 0.8 V and 14 V to a regulated output voltage between 1.24 V and 14 V. The LM2623 starts from a low 1.1 V input and remains operational down to below 0.8 V.

This device is optimized for use in cellular phones and other applications requiring a small size, low profile, as well as low quiescent current for maximum battery life during stand-by and shutdown. A high-efficiency gated-oscillator topology offers an output of up to 2 A at low output voltages.

Additional features include a built-in peak switch current limit, and thermal protection circuitry.

7.2 Functional Block Diagram

7.3 Feature Description

7.3.1 Gated Oscillator Control Scheme.

The on/off regulation mode of the LM2623, along with its ultra-low quiescent current, results in good efficiency over a very wide load range. The internal oscillator frequency can be programmed using an external resistor to be constant or vary with the battery voltage. Adding a capacitor to program the frequency allows the designer to adjust the duty cycle and optimize it for the application. Adding a resistor in addition to the capacitor allows the duty cycle to dynamically compensate for changes to the input/output voltage ratio. We call this a Ratio Adaptive Gated Oscillator circuit. See the Typical Application for sample application circuits. Using the correct RC components to adjust the oscillator allows the part to run with low ripple and high efficiency over a wide range of loads and input/output voltages.
Feature Description (continued)

7.3.2 Cycle-To-Cycle PFM
When the load doesn't vary over a wide range (like zero to full load), ratio adaptive circuit techniques can be used to achieve cycle to cycle PFM regulation and lower ripple (or smaller output capacitors). The key to success here is matching the duty cycle of the circuit closely to what is required by the input to output voltage ratio. This ratio then needs to be dynamically adjusted for input voltage changes (usually caused by batteries running down). The chosen ratio should allow most of the energy in each switching cycle to be delivered to the load and only a small amount to be stored. When the regulation limit is reached, the overshoot will be small and the system will settle at an equilibrium point where it adjusts the off time in each switching cycle to meet the current requirements of the load. The off time adjustment is done by exceeding the regulation limit during each switching cycle and waiting until the voltage drops below the limit again to start the next switching cycle. The current in the coil never goes to zero like it frequently does in the hysteretic operating mode of circuits with wide load variations or duty cycles that aren't matched to the input/output voltage ratio. Optimizing the duty cycle for a given set of input/output voltages conditions can be done by using the circuit values in the Application Notes.

7.3.3 Shutdown
The LM2623 features a shutdown mode that reduces the quiescent current to less than an ensured 2.5 µA over temperature. This extends the life of the battery in battery powered applications. During shutdown, all feedback and control circuitry is turned off. The regulator's output voltage drops to one diode drop below the input voltage. Entry into the shutdown mode is controlled by the active-low logic input pin EN (pin-2). When the logic input to this pin is pulled below 0.15 V_{DD}, the device goes into shutdown mode. The logic input to this pin should be above 0.7 V_{DD} for the device to work in normal stepup mode.

7.3.4 Internal Current Limit And Thermal Protection
An internal cycle-by-cycle current limit serves as a protection feature. This is set high enough (2.85 A typical, approximately 4 A maximum) so as not to come into effect during normal operating conditions. An internal thermal protection circuit disables the MOSFET power switch when the junction temperature (T_J) exceeds about 160°C. The switch is re-enabled when T_J drops below approximately 135°C.
7.4 Device Functional Modes

7.4.1 Pulse Frequency Modulation (Pfm)

Pulse Frequency Modulation is typically accomplished by switching continuously until the voltage limit is reached and skipping cycles after that to just maintain it. This results in a somewhat hysteretic mode of operation. The coil stores more energy each cycle as the current ramps up to high levels. When the voltage limit is reached, the system usually overshoots to a higher voltage than required, due to the stored energy in the coil (see Figure 8). The system will also undershoot somewhat when it starts switching again because it has depleted all the stored energy in the coil and needs to store more energy to reach equilibrium with the load. Larger output capacitors and smaller inductors reduce the ripple in these situations. The frequency being filtered, however, is not the basic switching frequency. It is a lower frequency determined by the load, the input/output voltage and the circuit parameters. This mode of operation is useful in situations where the load variation is significant. Power managed computer systems, for instance, may vary from zero to full load while the system is on and this is usually the preferred regulation mode for such systems.

7.4.2 Low Voltage Start-Up

The LM2623 can start up from voltages as low as 1.1 V. On start-up, the control circuitry switches the N-channel MOSFET continuously until the output reaches 3 V. After this output voltage is reached, the normal step-up regulator feedback and gated oscillator control scheme take over. Once the device is in regulation, it can operate down to below 0.8 V input, since the internal power for the IC can be boot-strapped from the output using the \( V_{DD} \) pin.
8 Applications And Implementation

NOTE
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information
The LM2623 features a shutdown mode, entry into the shutdown mode is controlled by the active-low logic input pin EN (pin 2). When the logic input to this pin is pulled below 0.15 \( V_{DD} \), the device goes into shutdown mode. The logic input to this pin should be above 0.7 \( V_{DD} \) for the device to work in normal start-up mode.

8.2 Typical Application

8.2.1 Design Requirements
The LM2623 allows the designer to vary output voltage, operating frequency and duty cycle to optimize the part performance, please read Detailed Design Procedure for details.

8.2.2 Detailed Design Procedure

8.2.2.1 Non-Linear Effect
The LM2623 is very similar to the LM2621. The LM2623 is based on the LM2621, except for the fact that the LM2623 takes advantage of a non-linear effect that allows for the duty cycle to be programmable. The C3 capacitor is used to dump charge on the FREQ pin in order to manipulate the duty cycle of the internal oscillator. The part is being tricked to behave in a certain manner, in the effort to make this Pulse Frequency Modulated (PFM) boost switching regulator behave as a Pulse Width Modulated (PWM) boost switching regulator.

8.2.2.2 Choosing The Correct C3 Capacitor
The C3 capacitor allows for the duty cycle of the internal oscillator to be programmable. Choosing the correct C3 capacitor to get the appropriate duty cycle for a particular application circuit is a trial and error process. The non-linear effect that C3 produces is dependent on the input voltage and output voltage values. The correct C3 capacitor for particular input and output voltage values cannot be calculated. Choosing the correct C3 capacitance is best done by trial and error, in conjunction with the checking of the inductor peak current to make sure your not too close to the current limit of the device. As the C3 capacitor value increases, so does the duty cycle. And conversely as the C3 capacitor value decreases, the duty cycle decreases. An incorrect choice of the C3 capacitor can result in the part prematurely tripping the current limit and/or double pulsing, which could lead to the output voltage not being stable.
Typical Application (continued)

8.2.2.3 Setting The Output Voltage

The output voltage of the step-up regulator can be set by connecting a feedback resistive divider made of \(R_{F1}\) and \(R_{F2}\). The resistor values are selected as follows:

\[
R_{F1} = R_{F2} \times \left(\frac{V_{OUT}}{1.24} - 1\right)
\]

A value of 50k to 100k is suggested for \(R_{F2}\). Then, \(R_{F1}\) can be selected using Equation 1.

8.2.2.4 \(V_{DD}\) Supply

The \(V_{DD}\) supply must be between 3 V to 5 V for the LM2623. This voltage can be bootstrapped from a much lower input voltage by simply connecting the \(V_{DD}\) pin to \(V_{OUT}\). In the event that the \(V_{DD}\) supply voltage is not a low ripple voltage source (less than 200 millivolts), it may be advisable to use an RC filter to clean it up. Excessive ripple on \(V_{DD}\) may reduce the efficiency.

8.2.2.5 Setting The Switching Frequency

The switching frequency of the oscillator is selected by choosing an external resistor (R3) connected between \(V_{IN}\) and the FREQ pin. See Figure 3 in the Typical Characteristics section of the data sheet for choosing the R3 value to achieve the desired switching frequency. A high switching frequency allows the use of very small surface mount inductors and capacitors and results in a very small solution size. A switching frequency between 300 kHz and 2 MHz is recommended.

8.2.2.6 Output Diode Selection

A Schottky diode should be used for the output diode. The forward current rating of the diode should be higher than the peak input current, and the reverse voltage rating must be higher than the output voltage. Do not use ordinary rectifier diodes, since slow switching speeds and long recovery times cause the efficiency and the load regulation to suffer.

8.2.3 Application Curves

![Figure 10. Efficiency vs Output Current](image1)

![Figure 11. Output Voltage vs Output Current](image2)
9 Power Supply Recommendations

The LM2623 can start up from voltages as low as 1.1 V. On start-up, the control circuitry switches the N-channel MOSFET continuously until the output reaches 3 V. After this output voltage is reached, the normal step-up regulator feedback and gated oscillator control scheme take over. Once the device is in regulation, it can operate down to below 0.8 V input, since the internal power for the IC can be boot-strapped from the output using the \( V_{DD} \) pin.

10 Layout

10.1 Layout Guidelines

The example layouts below follow proper layout guidelines and should be used as a guide for laying out the LM2623 circuit. The LM2623 inductive boost converter sees a high switched voltage at the SW pin, and a step current through the Schottky diode and output capacitor each switching cycle. The high switching voltage can create interference into nearby nodes due to electric field coupling (\( I = C \times dV/dt \)). The large step current through the diode and the output capacitor can cause a large voltage spike at the SW and BOOST pins due to parasitic inductance in the step current conducting path (\( V = L \times di/dt \)). Board layout guidelines are geared towards minimizing this electric field coupling and conducted noise.

**Boost Output Capacitor Placement**, **Schottky Diode Placement**, and **Boost Input / \( V_{DD} \) Capacitor Placement** detail the main (layout sensitive) areas of the LM2623 inductive boost converter in order of decreasing importance:

10.1.1 Boost Output Capacitor Placement

Because the output capacitor is in the path of the inductor current discharge path, it will see a high-current step from 0 to \( I_{PEAK} \) each time the switch turns off and the Schottky diode turns on. Any inductance along this series path from the diodes cathode, through \( C_{OUT} \), and back into the LM2623 GND pin will contribute to voltage spikes at SW. These spikes can potentially over-voltage the SW and BOOST pins, or feed through to GND. To avoid this, \( C_{OUT}^+ \) must be connected as close as possible to the cathode of the Schottky diode, and \( C_{OUT}^- \) must be connected as close as possible to the LM2623 GND bumps. The best placement for \( C_{OUT} \) is on the same layer as the LM2623 to avoid any vias that can add excessive series inductance.

10.1.2 Schottky Diode Placement

In the LM2623 device boost circuit the Schottky diode is in the path of the inductor current discharge. As a result the Schottky diode sees a high-current step from 0 to \( I_{PEAK} \) each time the switch turns off, and the diode turns on. Any inductance in series with the diode will cause a voltage spike at SW. This can potentially over-voltage the SW pin, or feed through to \( VOUT \) and through the output capacitor, into GND. Connecting the anode of the diode as close as possible to the SW pin, and connecting the cathode of the diode as close as possible to \( C_{OUT}^+ \), will reduce the inductance (\( L_{P_{-}} \)) and minimize these voltage spikes.

10.1.3 Boost Input / \( V_{DD} \) Capacitor Placement

The LM2623 input capacitor filters the inductor current ripple and the internal MOSFET driver currents. The inductor current ripple can add input voltage ripple due to any series resistance in the input power path. The MOSFET driver currents can add voltage spikes on the input due to the inductance in series with the \( VIN/V_{DD} \) and the input capacitor. Close placement of the input capacitor to the \( V_{DD} \) pin and to the GND pin is critical since any series inductance between \( VIN/V_{DD} \) and \( C_{IN}^+ \) or \( C_{IN}^- \) and GND can create voltage spikes that could appear on the \( VIN/VDD \) supply line and GND.
10.2 Layout Example

10.3 WSON Package Devices

The LM2623 is offered in the 14-lead WSON surface mount package to allow for increased power dissipation compared to the VSSOP-8. For details of the thermal performance as well as mounting and soldering specifications, refer to Application Note AN-1187 Leadless Leadframe Package (LLP) (SNOA401).
11 Device And Documentation Support

11.1 Device Support

11.1.1 Third-Party Products Disclaimer

TI’S PUBLICATION OF INFORMATION REGARDING THIRD-PARTY PRODUCTS OR SERVICES DOES NOT
CONSTITUTE AN ENDORSEMENT REGARDING THE SUITABILITY OF SUCH PRODUCTS OR SERVICES
OR A WARRANTY, REPRESENTATION OR ENDORSEMENT OF SUCH PRODUCTS OR SERVICES, EITHER
ALONE OR IN COMBINATION WITH ANY TI PRODUCT OR SERVICE.

11.2 Documentation Support

11.2.1 Related Documentation

For related documentation, see the following:

Application Note AN-1187 Leadless Leadframe Package (LLP)

11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper
right corner, click on Alert me to register and receive a weekly digest of any product information that has
changed. For change details, review the revision history included in any revised document.

11.4 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective
contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's Terms of
Use.

TI E2E™ Online Community  Ti's Engineer-to-Engineer (E2E) Community. Created to foster collaboration
among engineers. At e2e.ti.com, you can ask questions, share knowledge, explore ideas and help
solve problems with fellow engineers.

Design Support  Ti's Design Support Quickly find helpful E2E forums along with design support tools and
contact information for technical support.

11.5 Trademarks

E2E is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

11.6 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam
during storage or handling to prevent electrostatic damage to the MOS gates.

11.7 Glossary

SLYZ022 — Ti Glossary.
This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, And Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most
current data available for the designated devices. This data is subject to change without notice and revision of
this document. For browser-based versions of this data sheet, refer to the left-hand navigation.
### PACKAGING INFORMATION

<table>
<thead>
<tr>
<th>Orderable Device</th>
<th>Status (1)</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>Package Qty</th>
<th>Eco Plan (2)</th>
<th>Lead/Ball Finish</th>
<th>MSL Peak Temp (3)</th>
<th>Op Temp (°C)</th>
<th>Device Marking (4/5)</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM2623ALD/NOPB</td>
<td>ACTIVE</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>1000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 85</td>
<td>2623A</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623AMM</td>
<td>NRND</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>TBD</td>
<td>Call TI</td>
<td>Call TI</td>
<td>-40 to 85</td>
<td>S46A</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623AMM/NOPB</td>
<td>ACTIVE</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 85</td>
<td>S46A</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623AMMX/NOPB</td>
<td>ACTIVE</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>3500</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 85</td>
<td>S46A</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623LD/NOPB</td>
<td>ACTIVE</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>1000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 85</td>
<td>2623AB</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623LDX/NOPB</td>
<td>ACTIVE</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>4500</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-3-260C-168 HR</td>
<td>-40 to 85</td>
<td>2623AB</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623MM/NOPB</td>
<td>ACTIVE</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 85</td>
<td>S46B</td>
<td>Samples</td>
</tr>
<tr>
<td>LM2623MMX/NOPB</td>
<td>ACTIVE</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>3500</td>
<td>Green (RoHS &amp; no Sb/Br)</td>
<td>CU SN</td>
<td>Level-1-260C-UNLIM</td>
<td>-40 to 85</td>
<td>S46B</td>
<td>Samples</td>
</tr>
</tbody>
</table>

(1) The marketing status values are defined as follows:
- **ACTIVE**: Product device recommended for new designs.
- **LIFEBUY**: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
- **NRND**: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
- **PREVIEW**: Device has been announced but is not in production. Samples may or may not be available.
- **OBsolete**: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check [http://www.ti.com/productcontent](http://www.ti.com/productcontent) for the latest availability information and additional product content details.
- **TBD**: The Pb-Free/Green conversion plan has not been defined.
- **Pb-Free (RoHS)**: TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
- **Pb-Free (RoHS Exempt)**: This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
- **Green (RoHS & no Sb/Br)**: TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material).

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

**Important Information and Disclaimer:** The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.
### TAPE AND REEL INFORMATION

#### TAPE DIMENSIONS

| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W  | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

#### REEL DIMENSIONS

- Reel Diameter
- Reel Width (W1)

#### QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE

1. **Sprocket Holes**
2. **Pocket Quadrants**
3. **User Direction of Feed**

*All dimensions are nominal.*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Reel Diameter (mm)</th>
<th>Reel Width W1 (mm)</th>
<th>A0 (mm)</th>
<th>B0 (mm)</th>
<th>K0 (mm)</th>
<th>P1 (mm)</th>
<th>W (mm)</th>
<th>Pin 1 Quadrant</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM2623ALD/NOPB</td>
<td>WSON</td>
<td>NHE 14</td>
<td>1000</td>
<td>178.0</td>
<td>12.4</td>
<td>4.3</td>
<td>1.3</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623AMM</td>
<td>VSSOP</td>
<td>DGK 8</td>
<td>1000</td>
<td>178.0</td>
<td>12.4</td>
<td>5.3</td>
<td>1.4</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623AMM/NOPB</td>
<td>VSSOP</td>
<td>DGK 8</td>
<td>8</td>
<td>1000</td>
<td>178.0</td>
<td>5.3</td>
<td>1.4</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623AMMX/NOPB</td>
<td>VSSOP</td>
<td>DGK 8</td>
<td>8</td>
<td>3500</td>
<td>12.4</td>
<td>5.3</td>
<td>1.4</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623LD/NOPB</td>
<td>WSON</td>
<td>NHE 14</td>
<td>1000</td>
<td>178.0</td>
<td>12.4</td>
<td>4.3</td>
<td>1.3</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623LDX/NOPB</td>
<td>WSON</td>
<td>NHE 14</td>
<td>14</td>
<td>4500</td>
<td>12.4</td>
<td>4.3</td>
<td>1.3</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623MM/NOPB</td>
<td>VSSOP</td>
<td>DGK 8</td>
<td>8</td>
<td>1000</td>
<td>178.0</td>
<td>5.3</td>
<td>1.4</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LM2623MMX/NOPB</td>
<td>VSSOP</td>
<td>DGK 8</td>
<td>8</td>
<td>3500</td>
<td>12.4</td>
<td>5.3</td>
<td>1.4</td>
<td>8.0</td>
<td>12.0</td>
<td>Q1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal*

<table>
<thead>
<tr>
<th>Device</th>
<th>Package Type</th>
<th>Package Drawing</th>
<th>Pins</th>
<th>SPQ</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM2623ALD/NOPB</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>1000</td>
<td>210.0</td>
<td>185.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623AMM</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>210.0</td>
<td>185.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623AMM/NOPB</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>210.0</td>
<td>185.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623AMMX/NOPB</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>3500</td>
<td>367.0</td>
<td>367.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623LD/NOPB</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>1000</td>
<td>210.0</td>
<td>185.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623LDX/NOPB</td>
<td>WSON</td>
<td>NHE</td>
<td>14</td>
<td>4500</td>
<td>367.0</td>
<td>367.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623MM/NOPB</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>1000</td>
<td>210.0</td>
<td>185.0</td>
<td>35.0</td>
</tr>
<tr>
<td>LM2623MMX/NOPB</td>
<td>VSSOP</td>
<td>DGK</td>
<td>8</td>
<td>3500</td>
<td>367.0</td>
<td>367.0</td>
<td>35.0</td>
</tr>
</tbody>
</table>
NOTES:  
A. All linear dimensions are in millimeters.  
B. This drawing is subject to change without notice.  
   Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.  
   Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.  
E. Falls within JEDEC MO-187 variation AA, except interlead flash.
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.
Texas Instruments Incorporated (TI) reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete.

TI's published terms of sale for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm) apply to the sale of packaged integrated circuit products that TI has qualified and released to market. Additional terms may apply to the use or sale of other types of TI products and services.

Reproduction of significant portions of TI information in TI data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such reproduced documentation. Information of third parties may be subject to additional restrictions. Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and/or implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyers and others who are developing systems that incorporate TI products (collectively, “Designers”) understand and agree that Designers remain responsible for using their independent analysis, evaluation and judgment in designing their applications and that Designers have full and exclusive responsibility to assure the safety of Designers’ applications and compliance of their applications (and of all TI products used in or for Designers’ applications) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to their applications, Designer has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any applications that include TI products, Designer will thoroughly test such applications and the functionality of such TI products as used in such applications.

TI’s provision of technical, application or other design advice, quality characterization, reliability data or other services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, “TI Resources”) are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using TI Resources in any way, Designer (individually or, if Designer is acting on behalf of a company, Designer’s company) agrees to use any particular TI Resource solely for this purpose and subject to the terms of this Notice.

TI’s provision of TI Resources does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

Designer is authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY PATENT, COPYRIGHT, MASK WORK, TRADE SECRET, OTHER INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNER AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

Unless TI has explicitly designated an individual product as meeting the requirements of a particular industry standard (e.g., ISO/TS 16949 and ISO 26262), TI is not responsible for any failure to meet such industry standard requirements.

Where TI specifically promotes products as facilitating functional safety or as compliant with industry functional safety standards, such products are intended to help enable customers to design and create their own applications that meet applicable functional safety standards and requirements. Using products in an application does not by itself establish any safety features in the application. Designers must ensure compliance with safety-related requirements and standards applicable to their applications. Designers may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

TI may expressly designate certain products as completing a particular qualification (e.g., Q100, Military Grade, or Enhanced Product). Designers agree that it has the necessary expertise to select the product with the appropriate qualification designation for their applications and that proper product selection is at Designers’ own risk. Designers are solely responsible for compliance with all legal and regulatory requirements in connection with such selection.

Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer’s non-compliance with the terms and provisions of this Notice.