TLV3012-Q1 Low Power Comparator With Integrated Voltage Reference

1 Features

- Qualified for automotive applications
- AEC-Q100 qualified with the following results:
  - Device temperature grade 1: –40°C to +125°C ambient operating temperature range
  - Device HBM ESD classification level 2
  - Device CDM ESD classification level C6
- Low quiescent current = 5 μA (Max)
- Integrated voltage reference = 1.242 V
- Input common-mode range = 200 mV beyond rails
- Voltage reference initial accuracy = 1%
- Push-pull output
- Low supply voltage = 1.8 V to 5.5 V

2 Applications

- Lane departure warning
- Cluster
- Toll tag
- Asset tracking
- Battery management systems

3 Description

The TLV3012-Q1 device is a push-pull output comparator. The device features an uncommitted on-chip voltage reference and has a 5-μA (max) quiescent current, an input common-mode range 200 mV beyond the supply rails, and single-supply operation from 1.8 V to 5.5 V. The integrated 1.242-V series voltage reference offers low 100-ppm/°C (maximum) drift, is stable with up to 10-nF capacitive load, and can provide up to 0.5 mA (typical) of output current.

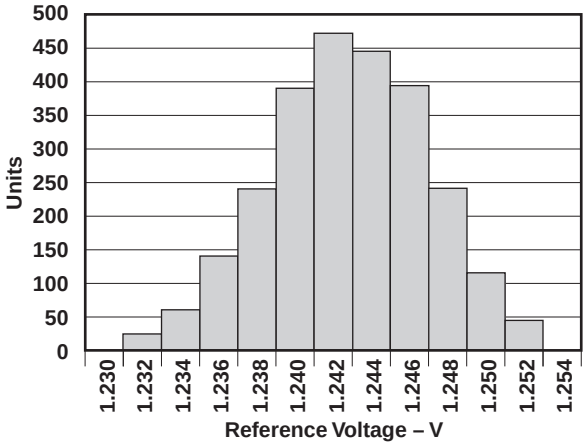
The TLV3012-Q1 device is available in the SOT (DCK) package. The device is specified for the temperature range of –40°C to +125°C.

Device Information(1)

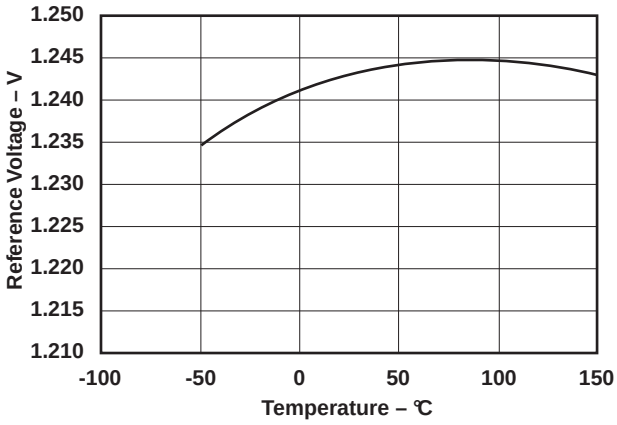
PART NUMBER	PACKAGE	BODY SIZE (NOM)
TLV3012-Q1	SOT (6)	2.00 mm × 1.25 mm

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

Reference Voltage Distribution



Reference Voltage vs Temperature



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4 Revision History

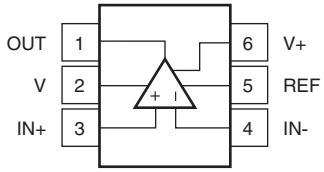
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (March 2011) to Revision A **Page**

- Added the HBM and CDM ESD ratings and classification levels. Also added the AEC-Q100 device temperature grade ... 1
- Changed the *Applications* list ... 1
- Added *Pin Configuration and Functions* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section ... 1
- Deleted the TLV3011-Q1 device from the data sheet and removed *A* from the TLV3012-Q1 part number ... 1
- Deleted the *Package Ordering Information* section ... 3
- Moved the switching characteristics from the *Electrical Characteristics* table to the *Switching Characteristics* table ... 5

5 Pin Configuration and Functions

DCK Package
6-Pin SOT
Top View



Pin Functions

PIN		I/O/P	DESCRIPTION
NO.	NAME		
1	OUT	O	Comparator output
2	V–	P	Negative (lowest) power supply
3	IN+	I	Non-inverting comparator input
4	IN–	I	Inverting comparator input
5	REF	P	Reference output
6	V+	P	Positive (highest) power supply

6 Specifications

6.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted)(1).

			MIN	MAX	UNIT
	Supply voltage			7	V
	Signal input pins	Voltage(2)	–0.5	(V+) +0.5	V
		Current(2)		±10	mA
	Output short circuit(3)		Continuos		
	Operating temperature		–40	125	°C
T_J	Junction temperature			150	°C
T_{stg}	Storage temperature		–65	150	°C

(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) All voltage values are with respect to the network ground pin.
(3) Short circuit to ground

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per AEC Q100-002(1)	±2000	V
		Charged-device model (CDM), per AEC Q100-011	±1000	

(1) AEC Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specification.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	MAX	UNIT
Supply Voltage	(V+) – (V–)	1.8	5.5	V
Ambient Temperature	T_A	–40	125	°C

6.4 Thermal Information

THERMAL METRIC(1)		TLV3012-Q1 DCK (SOT) 6 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	168.5	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	66.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	68.9	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.6	°C/W
ψ_{JB}	Junction-to-board characterization parameter	67.6	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	—	°C/W

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

6.5 Electrical Characteristics

V_S = 1.8 V to 5.5 V, at T_A = 25°C, V_{OUT} = V_S, unless otherwise noted

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
V_{OS}	Input offset voltage	V_{CM} = 0 V, I_O = 0 V		0.5	15	mV
dV_{OS}/dT	Input offset voltage vs temperature	T_A = –40°C to +125°C		±12		µV/°C
PSRR	Power supply rejection ratio	V_S = 1.8 V to 5.5 V		100	1000	µV/V
INPUT BIAS CURRENT						
I_B	Input bias current	V_{CM} = V_S/2		±10		pA
I_{OS}	Input offset current	V_{CM} = V_S/2		±10		pA
INPUT VOLTAGE RANGE						
V_{CM}	Common-mode voltage range		(V–) – 0.2		(V+) + 0.2	V
CMRR	Common-mode rejection ratio	V_{CM} = –0.2 V to (V+) – 1.5 V	60	74		dB
		V_{CM} = –0.2 V to (V+) + 0.2 V	54	62		
INPUT IMPEDANCE						
	Common mode			10^{13} ‖ 2		Ω ‖ pF
	Differential			10^{13} ‖ 4		Ω ‖ pF
OUTPUT						
V_{OL}	Voltage output low from rail	V_S = 5 V, I_{OUT} = –5 mA		160	200	mV
V_{OH}	Voltage output high from rail	V_S = 5 V, I_{OUT} = 5 mA		90	200	mV
	Short-circuit current			See Typical Characteristics		
VOLTAGE REFERENCE						
V_{OUT}	Output voltage		1.208	1.242	1.276	V
	Initial accuracy				±1%	
dV_{OUT}/d_T	Temperature drift	–40°C ≤ T_A ≤ 125°C		40	100	ppm/°C
dV_{OUT}/dI_{LOAD}	Load regulation, sourcing	0 mA < I_{SOURCE} ≤ 0.5 mA		0.36	1	mV/mA
	Load regulation, sinking	0 mA < I_{SINK} ≤ 0.5 mA		6.6		
I_{LOAD}	Output current			0.5		mA
dV_{OUT}/dV_{IN}	Line regulation	1.8 V ≤ V_{IN} ≤ 5.5 V		10	100	µV/V
NOISE						
	Reference voltage noise	f = 0.1 Hz to 10 Hz		0.2		mV_{PP}
POWER SUPPLY						
V_S	Specified voltage		1.8		5.5	V
	Operating voltage range		1.8		5.5	V
I_Q	Quiescent current	V_S = 5 V, V_O = High		2.8	5	µA
TEMPERATURE						
	Operating range		–40		125	°C
	Storage range		–65		150	°C

6.6 Switching Characteristics

over operating free-air temperature range (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
	Propagation delay time, low to high	f = 10 kHz, V_{STEP} = 1 V, input overdrive = 10 mV		12		µs
		f = 10 kHz, V_{STEP} = 1 V, input overdrive = 100 mV		6		
	Propagation delay time, high to low	f = 10 kHz, V_{STEP} = 1 V, input overdrive = 10 mV		13.5		µs
		f = 10 kHz, V_{STEP} = 1 V, input overdrive = 100 mV		6.5		
t_r	Rise time	C_L = 10 pF		100		ns
t_f	Fall time	C_L = 10 pF		100		ns

7 Typical Characteristics

At T_A = 25°C, V_S = 1.8 V to 5.5 V, and Input Overdrive = 100 mV, unless otherwise noted.

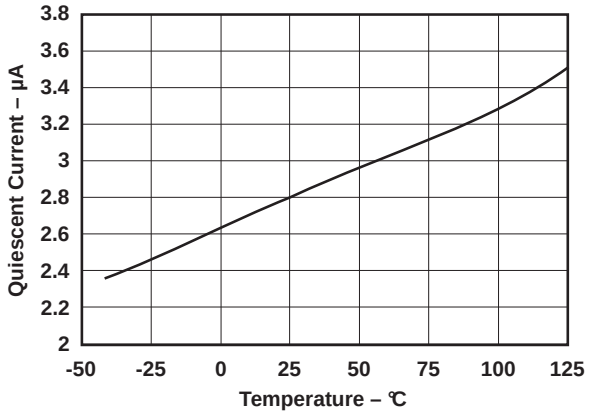


Figure 1. Quiescent Current vs Temperature

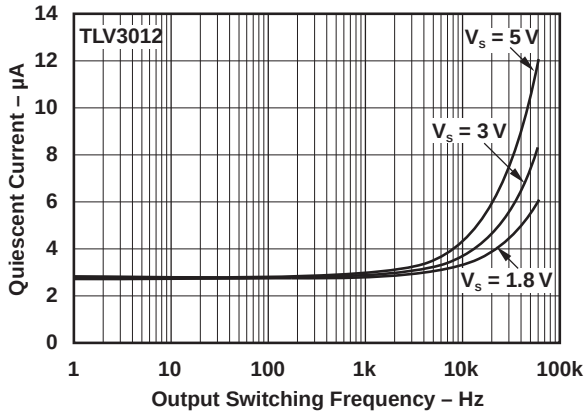


Figure 2. Quiescent Current vs Output Switching Frequency

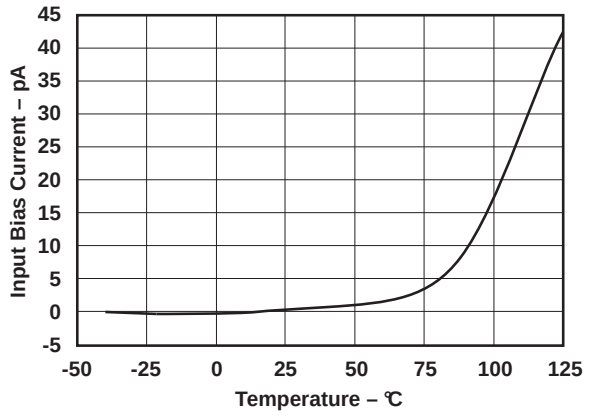


Figure 3. Input Bias Current vs Temperature

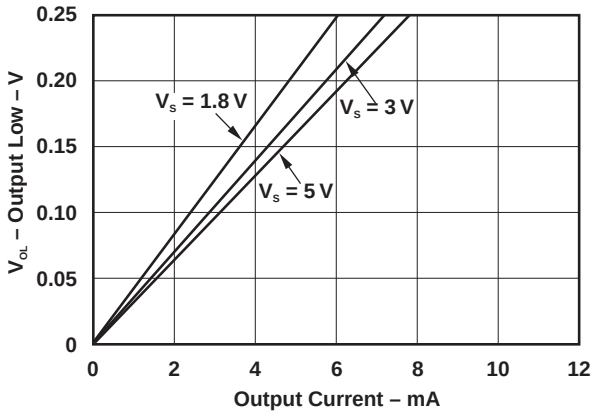


Figure 4. Output Low vs Output Current

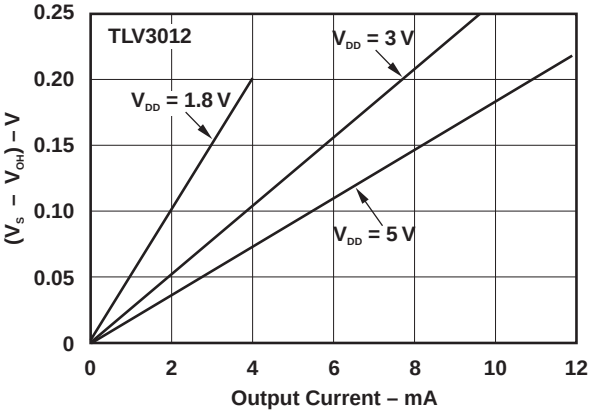


Figure 5. Output High vs Output Current

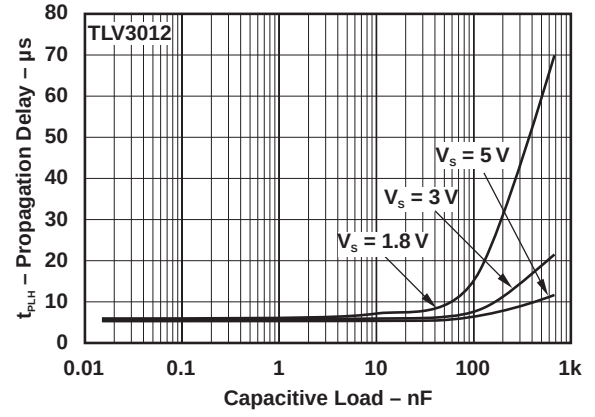


Figure 6. Propagation Delay (t_{PLH}) vs Capacitive Load

Typical Characteristics (continued)

At T_A = 25°C, V_S = 1.8 V to 5.5 V, and Input Overdrive = 100 mV, unless otherwise noted.

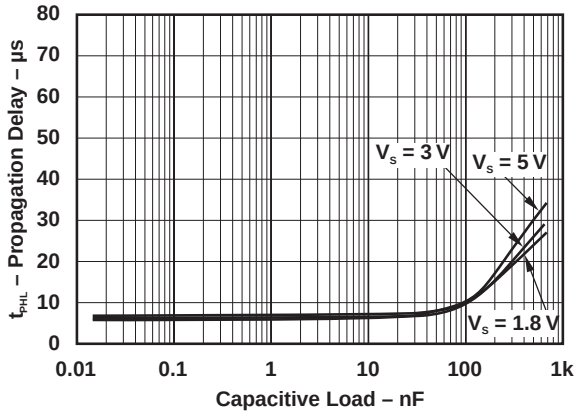


Figure 7. Propagation Delay (t_{PHL}) vs Capacitive Load

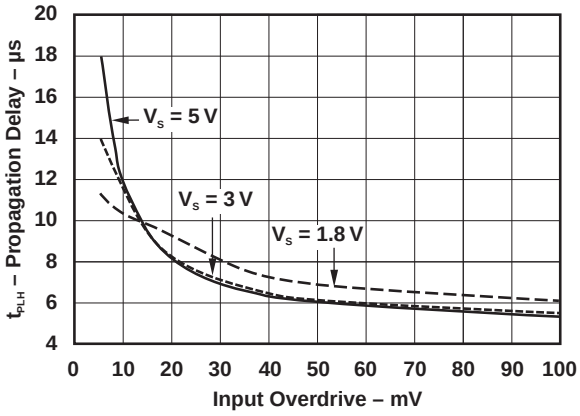


Figure 8. Propagation Delay (t_{PLH}) vs Input Overdrive

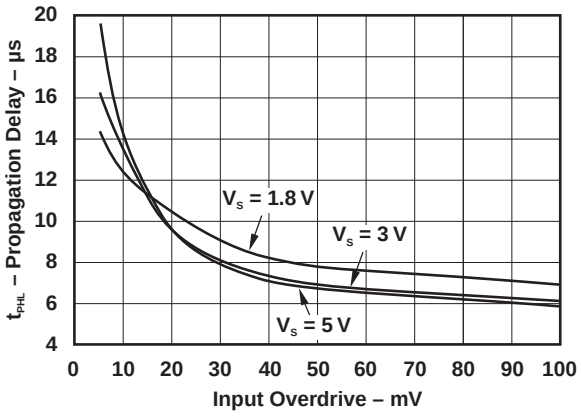


Figure 9. Propagation Delay (t_{PHL}) vs Input Overdrive

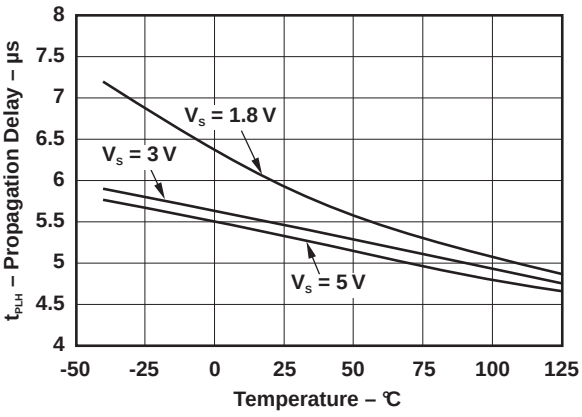


Figure 10. Propagation Delay (t_{PLH}) vs Temperature

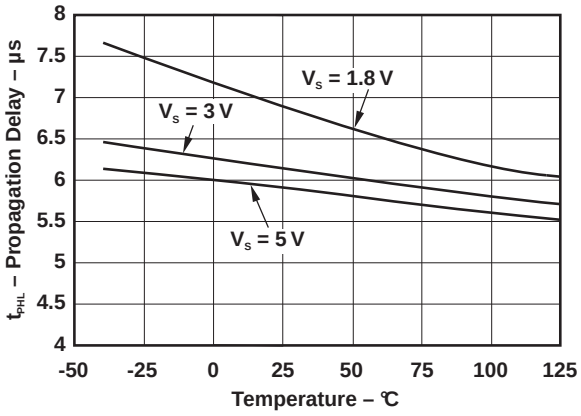


Figure 11. Propagation Delay (t_{PHL}) vs Temperature

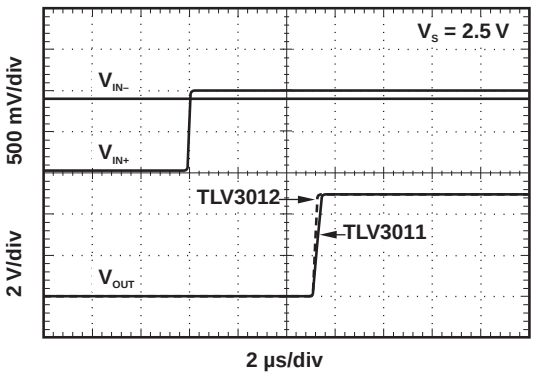


Figure 12. Propagation Delay (t_{PLH})

Typical Characteristics (continued)

At T_A = 25°C, V_S = 1.8 V to 5.5 V, and Input Overdrive = 100 mV, unless otherwise noted.

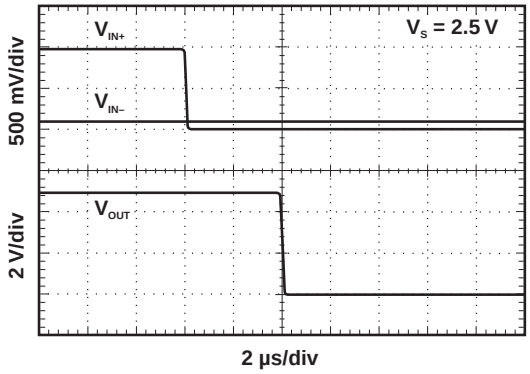


Figure 13. Propagation Delay (t_{PHL})

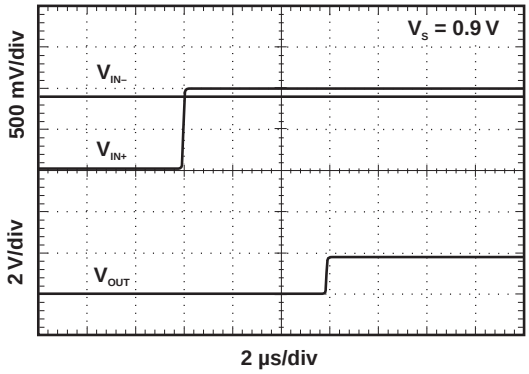


Figure 14. Propagation Delay (t_{PLH})

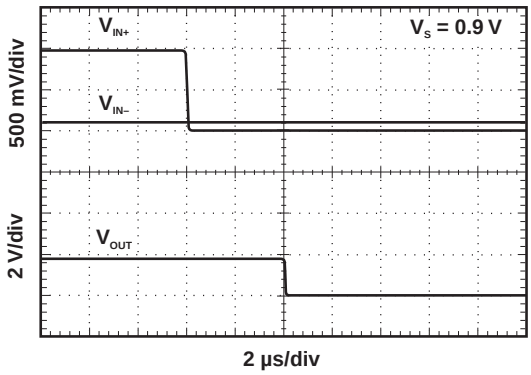


Figure 15. Propagation Delay (t_{PHL})

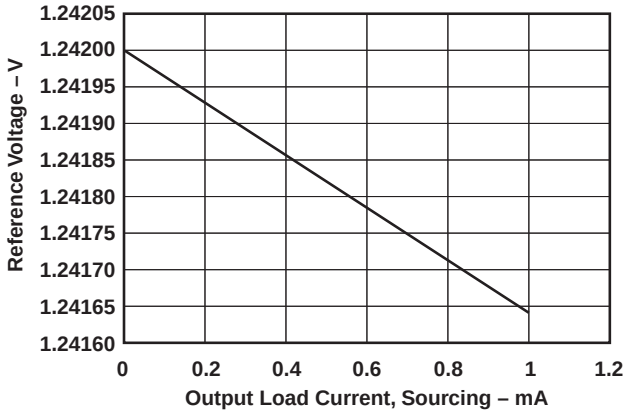


Figure 16. Reference Voltage vs Output Load Current (Sourcing)

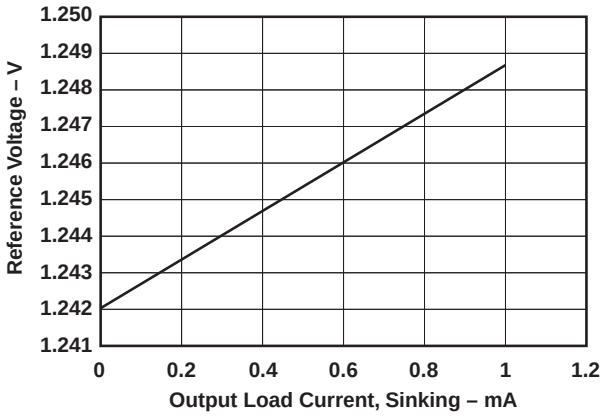


Figure 17. Reference Voltage vs Output Load Current (Sinking)

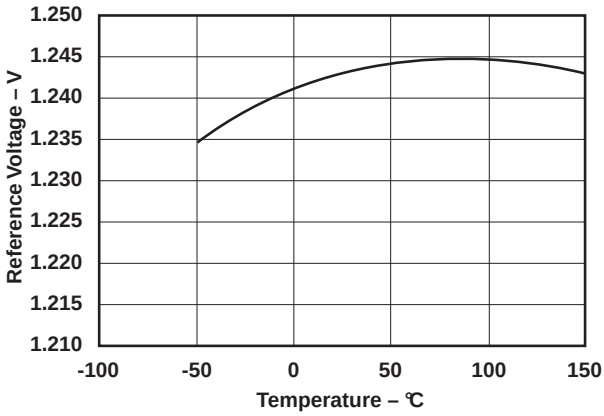


Figure 18. Reference Voltage vs Temperature

Typical Characteristics (continued)

At T_A = 25°C, V_S = 1.8 V to 5.5 V, and Input Overdrive = 100 mV, unless otherwise noted.

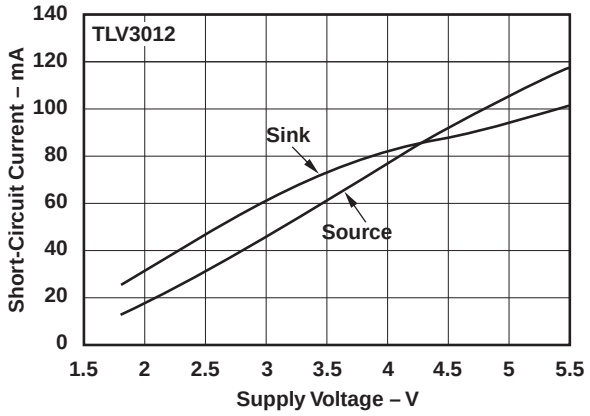


Figure 19. Short-Circuit Current vs Supply Voltage

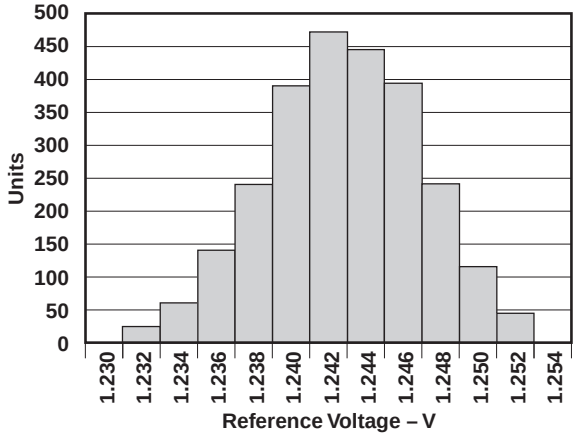


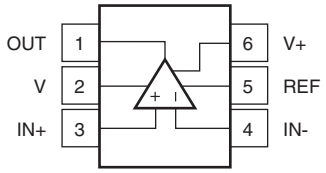
Figure 20. Reference Voltage Distribution

8 Detailed Description

8.1 Overview

The TLV3012-Q1 is a MicroPower comparator with an integrated reference that is well suited for compact, low-current, precision voltage detection applications. With a high-accuracy, internal reference of 1.242 V and 5 uA of quiescent current, the TLV3012-Q1 enables power conscious systems to monitor and respond quickly to fault conditions.

8.2 Functional Block Diagram



8.3 Feature Description

The TLV3012-Q1 is comprised of a rail-to-rail input comparator with a push-pull output stage and a voltage reference that is externally available.

8.4 Device Functional Modes

The TLV3012-Q1 requires an operating voltage between 1.8 V and 5.5 V for the comparator output to reflect the voltage applied to the inputs. Similarly, the reference output (REF) will also be valid over the same operating voltage range.

9 Application 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.

9.1 Application Information

The TLV3012-Q1 comparator with on-chip 1.242-V series reference has a push-pull output stage that features no shoot-through current.

A typical supply current of 2.8 μA and small packaging combine with 1.8-V supply requirements to make the TLV3012-Q1 device optimal for battery and portable designs.

Figure 21 shows the typical connections for the TLV3012-Q1 device.

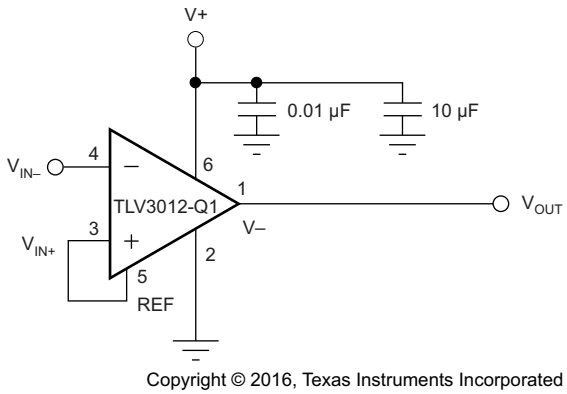


Figure 21. Basic Connections of the TLV3012-Q1

9.1.1 External Hysteresis

Comparator inputs have no noise immunity within the range of specified offset voltage (±12 mV). For noisy input signals, the comparator output may display multiple switching as input signals move through the switching threshold. The typical comparator threshold of the TLV3012-Q1 device is ±0.5 mV. To prevent multiple switching within the comparator threshold of the TLV3012-Q1 device, external hysteresis may be added by connecting a small amount of feedback to the positive input. Figure 22 shows a typical topology used to introduce hysteresis, described by Equation 1.

$$V_{HYST} = \frac{V+ \times R1}{R1 + R2} \quad (1)$$

Application Information (continued)

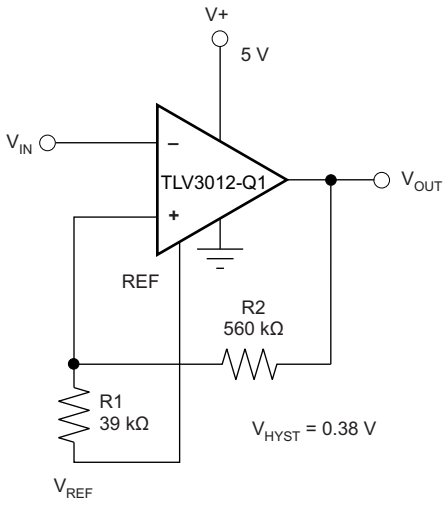


Figure 22. Adding Hysteresis

The V_{HYST} voltage sets the value of the transition voltage required to switch the comparator output by increasing the threshold region, thereby reducing sensitivity to noise.

9.2 Typical Application

9.2.1 Under-Voltage Detection

Under-voltage detection is frequently required to alert the system that a battery voltage has dropped below the usable voltage level. Figure 23 shows a simple under-voltage detection circuit using the TLV3012-Q1 which is configured as a non-inverting comparator with the integrated 1.242 V reference is externally connected to the inverting input pin (IN-).

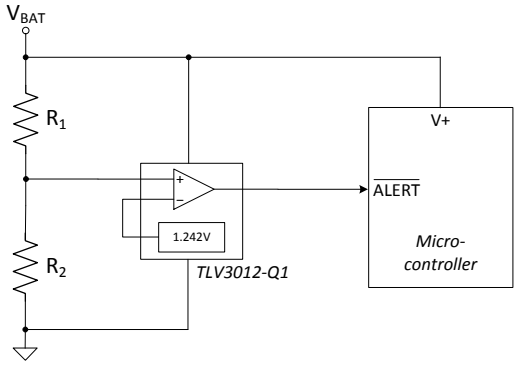


Figure 23. Under-Voltage Detection

9.2.1.1 Design Requirements

For this design, follow these design requirements:

- Operate from power supply that powers the microcontroller.
- Under-voltage alert is active low.
- Logic low output when V_{BAT} is less than 2.0V.

Typical Application (continued)

9.2.1.2 Detailed Design Procedure

Configure the circuit as shown in Figure 23. Connect (V+) to V_{BAT} which also powers the microcontroller. Resistors R_1 and R_2 create the under-voltage alert level of 2.0 V. When the battery voltage sags down to 2.0 V, the resistor divider voltage crosses V_{REF}, the 1.242 V reference threshold of the TLV3012-Q1. This causes the comparator output to transition from a logic high to a logic low. The push-pull output of the TLV3012-Q1 is selected since the comparator operating voltage is shared with the microcontroller which is receiving the under-voltage alert signal.

Equation 2 is derived from the analysis of Figure 23.

$$V_{REF} = \frac{R_2}{R_1 + R_2} \times V_{BAT} \tag{2}$$

where

- R_1 and R_2 are the resistor values for the resistor divider connected to IN+
- V_{BAT} is the voltage source that is being monitored for an undervoltage condition.
- V_{REF} is the falling edge threshold where the comparator output changes state from high to low

Rearranging Equation 2 and solving for R_1 yields Equation 3.

$$R_1 = \frac{(V_{BAT} - V_{REF})}{V_{REF}} \times R_2 \tag{3}$$

For the specific undervoltage detection of 2.0 V using the TLV3012-Q1, the following results are calculated.

$$R_1 = \frac{(2.0 - 1.242)}{1.242} \times 1M = 610\ k\Omega \tag{4}$$

where

- R_2 is set to 1 MΩ
- V_{BAT} is set to 2.0 V
- V_{REF} is set to1.242 V

Choose R_{TOTAL} (R_1 + R_2) such that the current through the divider is at least 100 times higher than the input bias current (I_{BIAS}). The resistors can have high values to minimize current consumption in the circuit without adding significant error to the resistive divider.

Typical Application (continued)

9.2.1.3 Application Curves

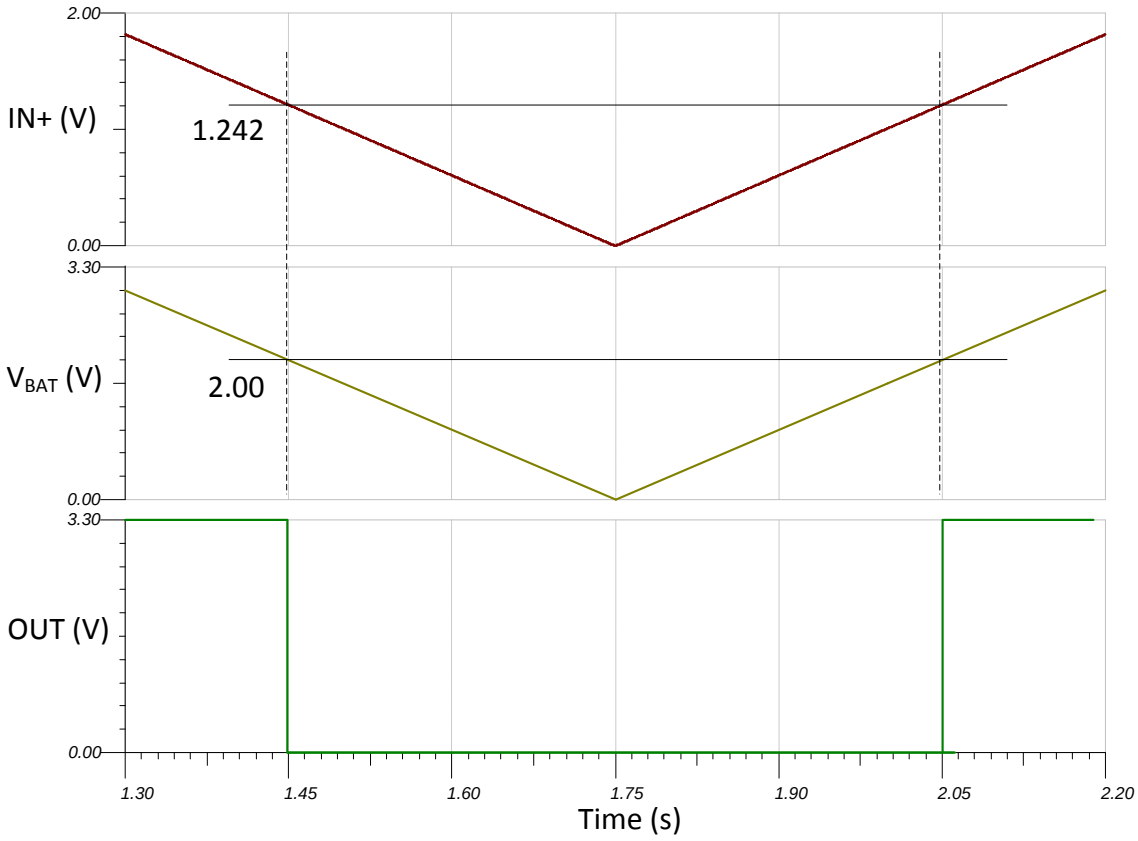


Figure 24.

9.3 System Examples

9.3.1 Power-On Reset

The reset circuit shown in Figure 25 provides a time-delayed release of reset to the MSP430™ microcontroller. Operation of the circuit is based on a stabilization time constant of the supply voltage, rather than on a predetermined voltage value. The negative input is a reference voltage created by the internal voltage reference. The positive input is an RC circuit that provides a power-up delay. When power is applied, the output of the comparator is low, holding the processor in the reset condition. Only after allowing time for the supply voltage to stabilize does the positive input of the comparator become higher than the negative input, resulting in a high output state, releasing the processor for operation. The stabilization time required for the supply voltage is adjustable by the selection of the RC component values. Use of a lower-valued resistor in this portion of the circuit does not increase current consumption, because no current flows through the RC circuit after the supply has stabilized.

System Examples (continued)

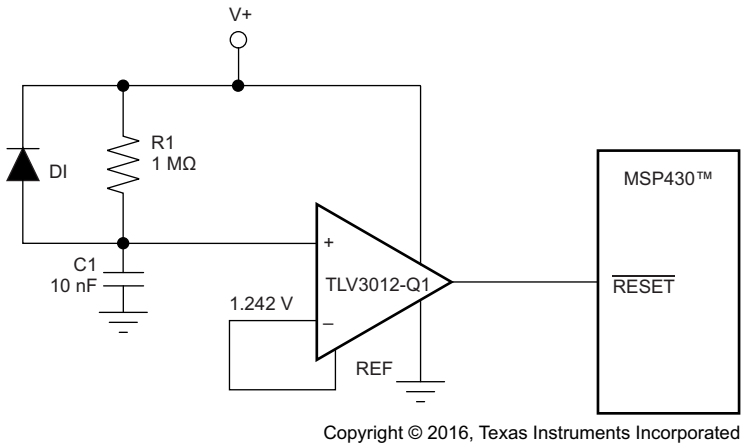


Figure 25. TLV3012-Q1 Configured as Power-Up Reset Circuit for the MSP430™ Microcontroller

The reset delay needed depends on the power-up characteristics of the system power supply. R_1 and C_1 are selected to allow enough time for the power supply to stabilize. D_1 provides rapid reset if power is lost. In this example, the $R_1 \times C_1$ time constant is 10 ms.

9.3.2 Relaxation Oscillator

The TLV3012-Q1 device can be configured as a relaxation oscillator to provide a simple and inexpensive clock output (see Figure 26). The capacitor is charged at a rate of T = 0.69RC and discharges at a rate of 0.69RC. Therefore, the period is T = 1.38RC. R_1 may be a different value than R_2.

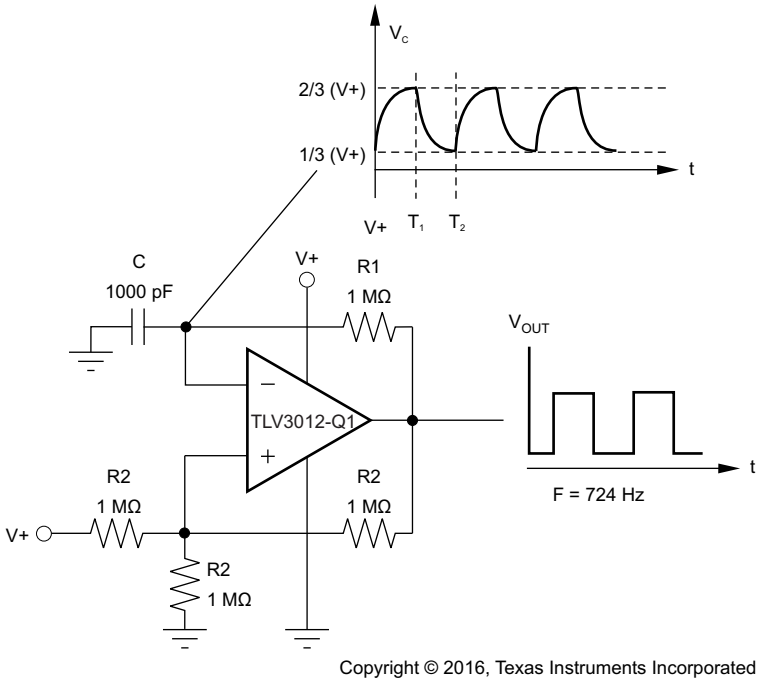


Figure 26. TLV3012-Q1 Configured as Relaxation Oscillator

10 Power Supply Recommendations

The TLV3012-Q1 has a recommended operating voltage range (V_S) of 1.8 V to 5.5 V. V_S is defined as (V+) – (V-). Therefore, the supply voltages used to create V_S can be single-ended or bipolar. For example, single-ended supply voltages of 5 V and 0 V and bipolar supply voltages of +2.5 V and –2.5 V create comparable operating voltages for V_S. However, when bipolar supply voltages are used, it is important to realize that the reference (REF) and logic low level of the comparator output is referenced to (V-). Output capacitive loading and output toggle rate will cause the average supply current to rise over the quiescent current in the EC Table.

11 Layout

11.1 Layout Guidelines

To minimize supply noise, power supplies should be capacitively decoupled by a 0.1-μF ceramic capacitor. Comparators are sensitive to input noise and precautions such as proper grounding (use of ground plane), supply bypassing, and guarding of high-impedance nodes minimize the effects of noise and help to ensure specified performance.

11.2 Layout Example

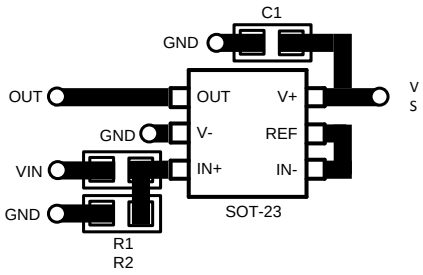


Figure 27. Layout Example

12 Device and Documentation Support

12.1 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.

12.2 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.

12.3 Trademarks

MSP430, E2E are trademarks of Texas Instruments.
All other trademarks are the property of their respective owners.

12.4 Electrostatic Discharge Caution

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

12.5 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

13 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

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV3012AQDCKRQ1	ACTIVE	SC70	DCK	6	3000	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	BPF	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

OTHER QUALIFIED VERSIONS OF TLV3012-Q1 :

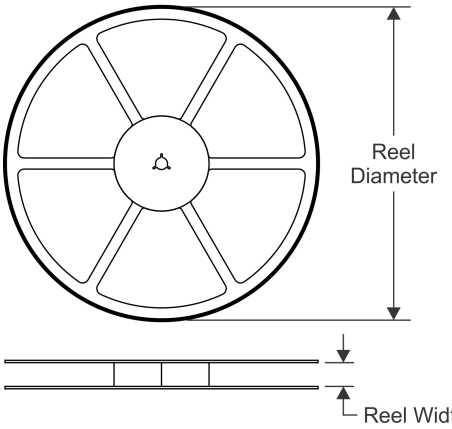
- Catalog: TLV3012

NOTE: Qualified Version Definitions:

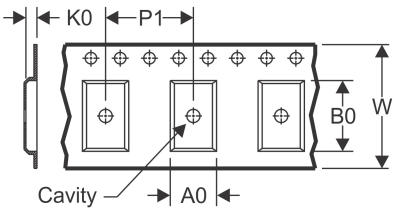
- Catalog - TI's standard catalog product

TAPE AND REEL INFORMATION

REEL DIMENSIONS

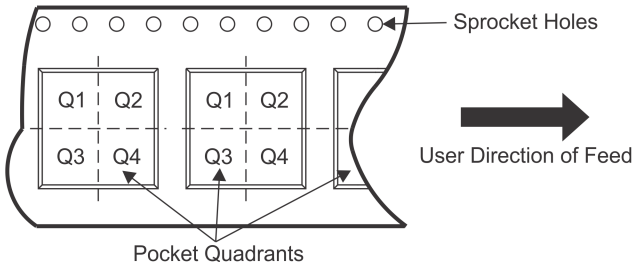


TAPE DIMENSIONS



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

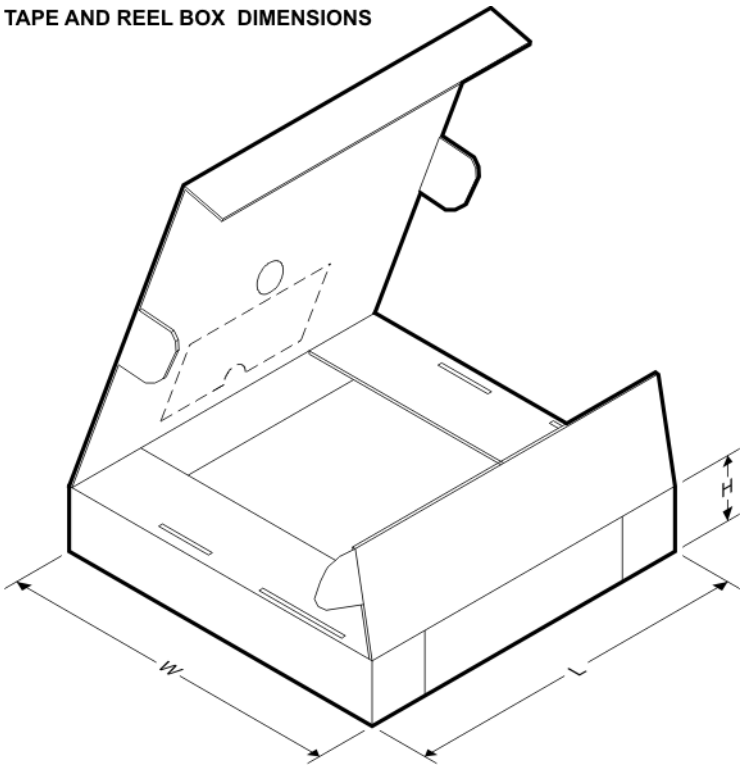
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TLV3012AQDCKRQ1	SC70	DCK	6	3000	179.0	8.4	2.2	2.5	1.2	4.0	8.0	Q3

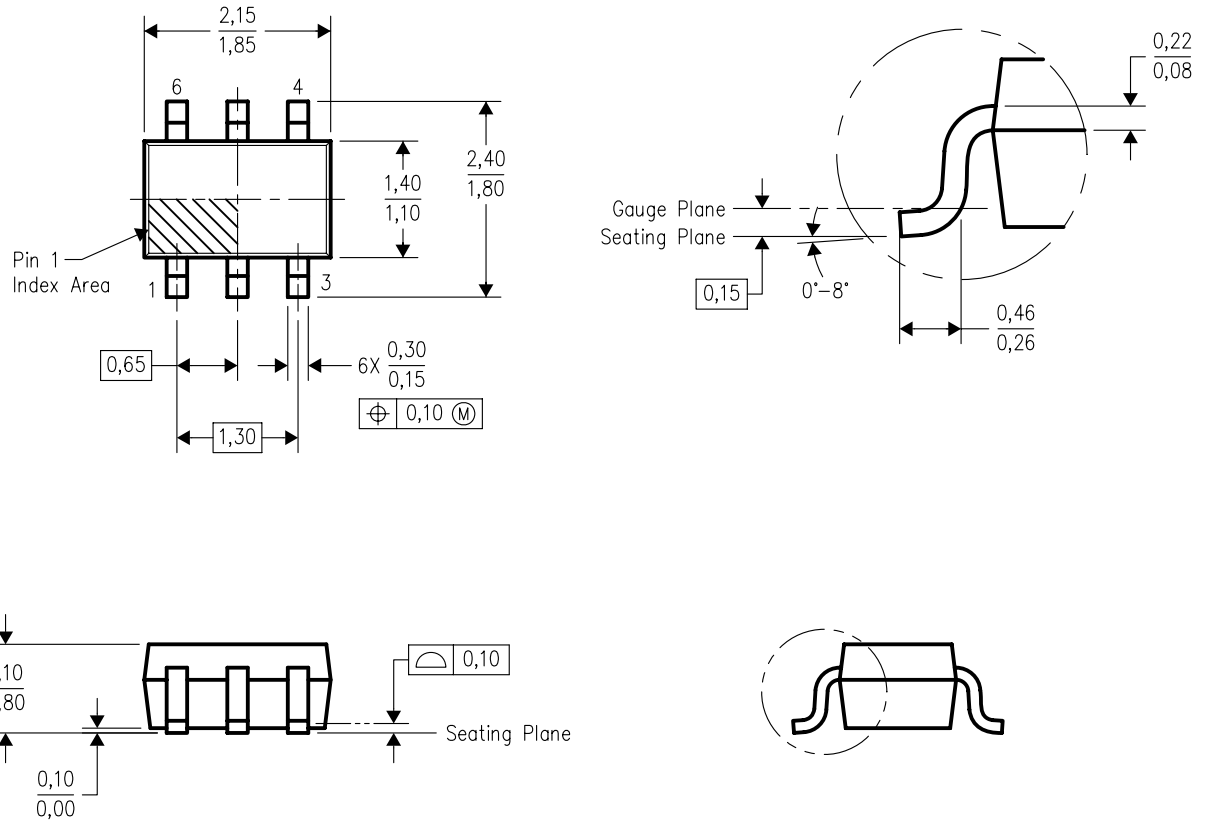
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TLV3012AQDCKRQ1	SC70	DCK	6	3000	200.0	183.0	25.0

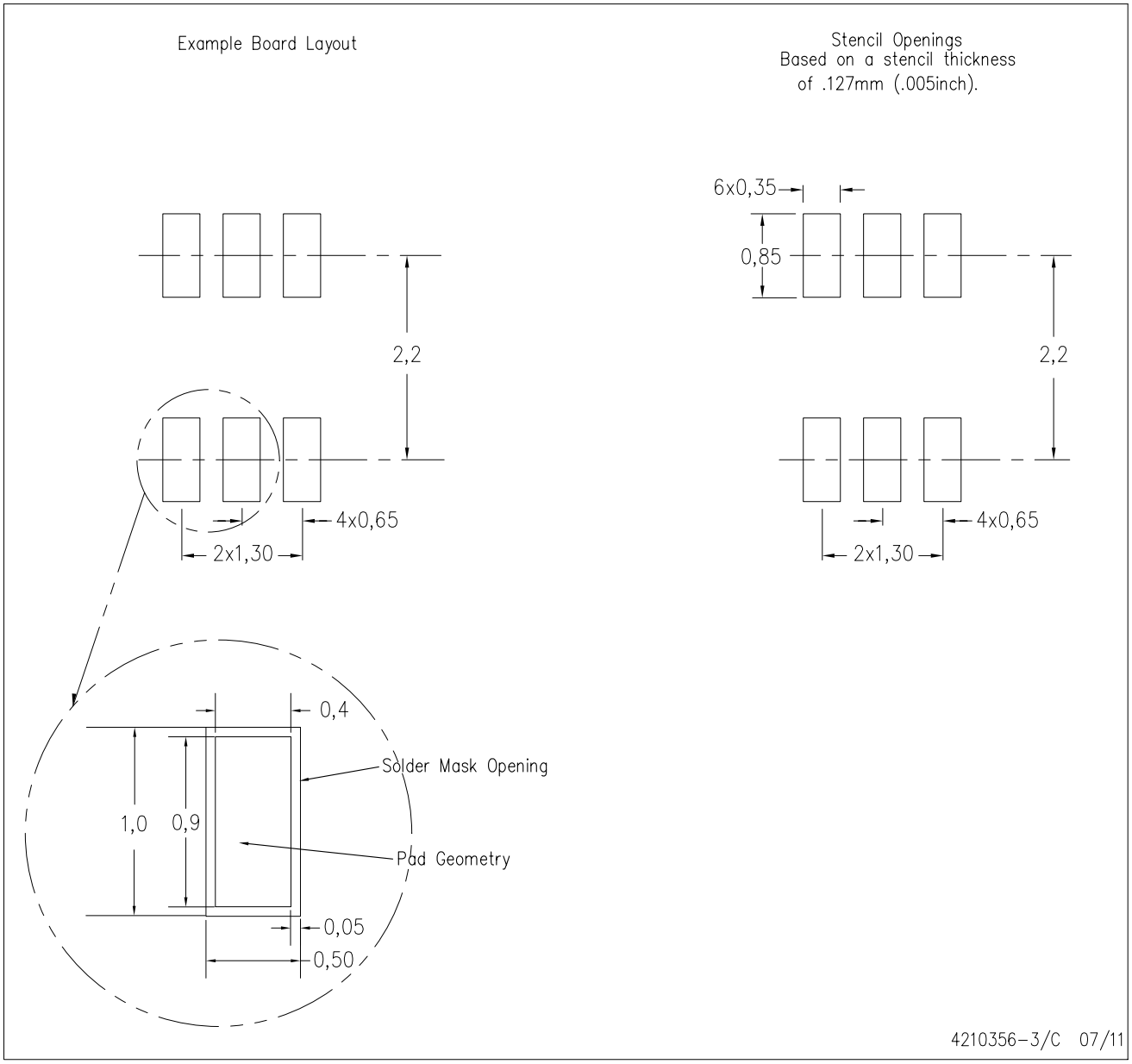
DCK (R–PDSO–G6) PLASTIC SMALL–OUTLINE PACKAGE



4093553–4/G 01/2007

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO–203 variation AB.

DCK (R–PDSO–G6) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC–7351 is recommended for alternate designs.
E. 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. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.

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