TIOS102 and TIOS102x Digital Sensor Output Drivers with Integrated Surge Protection In Small Packages

1 Features

- Wide supply operation
  - 4.75-V to 36-V supply Voltage (TIOS102, TIOS1023)
  - 7-V to 36-V supply voltage (TIOS1025)
- PNP, NPN or push-pull configurable output
- Functional safety capable
  - Documentation available to aid in functional safety system design
- Pin-compatible with TIOS101(x) with improved performance
  - Low residual Voltage of 0.5 V (typical) at 200 mA
  - Active driver current limiting capability
  - Improved thermal performance of the package
  - Slower driver slew rates to reduce overshoots (max of 750 ns)
- Integrated protection features for robust systems
  - Configurable driver overcurrent limit (50 mA to 350 mA)
  - Active reverse polarity protection of up to 65 V on VCC, OUT and GND
  - Fault indicator for overcurrent, overtemperature and UVLO faults
  - Safe and fast demagnetization of large inductive loads
  - Extended ambient temperature operation: -40°C to 125°C
- Integrated EMC protection on VCC and OUT
  - ±8 kV IEC 61000-4-2 ESD contact discharge
  - ±4 kV IEC 61000-4-4 Electrical fast transient
  - ±1.2 kV/500 Ω IEC 61000-4-5 Surge
- Large capacitive load driving capability
- < 1.5-mA (typical) quiescent supply current (when driver is disabled)
- Integrated LDO options for up to 20 mA current
  - TIOS1023: 3.3-V LDO
  - TIOS1025: 5-V LDO
  - TIOS1023L (DSBGA): Selectable 3.3-V/5-V LDO output
- Small space-saving package options
  - 3 mm x 3 mm 10-pin VSON package (pin-compatible with TIOS101)
  - 2.45 mm x 1.7 mm DSBGA package

2 Applications

- Proximity Switches
- Capacitive and Inductive Sensors
- Actuators
- Digital Outputs

3 Description

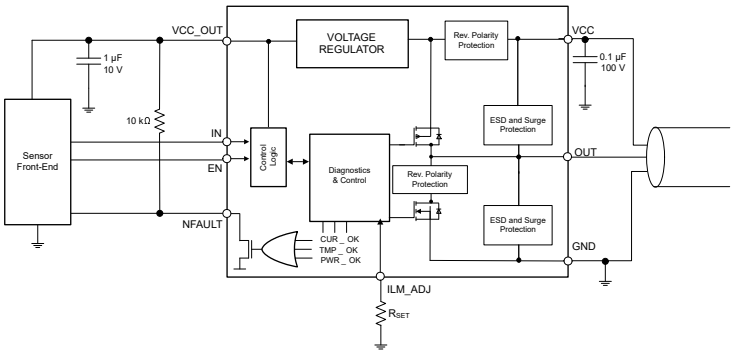
The TIOS102(x) devices are configurable as high-side, low-side or push-pull drivers. These devices are capable of withstanding up to 1.2 kV (500 Ω) of IEC 61000-4-5 surge and feature integrated reverse polarity protection.

A pin-programmable interface allows easy interfacing to the circuits. The output current limit can be configured using an external resistor. Fault reporting and internal protection functions are provided for undervoltage, overcurrent and overtemperature conditions.

Package Information

PART NUMBER	PACKAGE(1)	PACKAGE SIZE(2)
TIOS102	VSON (10)	3 mm x 3 mm
TIOS1023		
TIOS1025		
TIOS102	DSBGA (12)	2.45 mm x 1.7 mm
TIOS1023L		

(1) For all available devices, see the orderable addendum at the end of the data sheet.
(2) The package size (length × width) is a nominal value and includes pins, where applicable.



Typical Application Diagram

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.

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4 Revision History

Changes from Revision A (December 2022) to Revision B (June 2023)	Page
• Deleted the *Product Preview* note from the DSBGA package in the *Device Information* table	1
• Changed the Device Information table to *Package Information* table	1
• Changed the DRC package images	3
• Added the custom images for the YAH (DSBGA) 12-pin package	24

Changes from Revision * (February 2022) to Revision A (December 2022)	Page
• Changed the data sheet from *Advanced Information* to *Production* data for the VSON package	1

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5 Pin Configuration and Functions

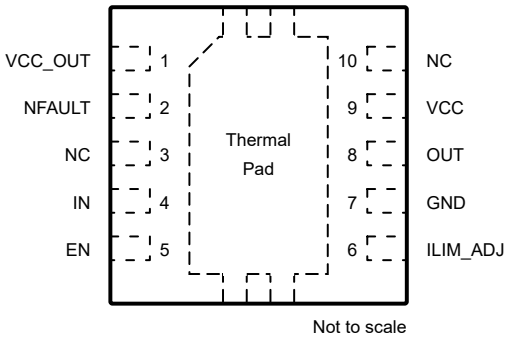

Figure 5-1. TIOS1023, TIOS1025 DRC, 10-Pin VSON (Top View)

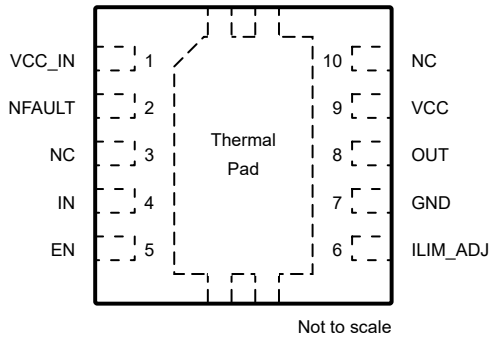

Figure 5-2. TIOS102 DRC, 10-Pin VSON (Top View)

Table 5-1. Pin Functions (VSON Package)

PIN NO	PIN NAME		Type	DESCRIPTION
	TIOS102	TIOS1023, TIOS1025		
1	VCC_IN	VCC_OUT	P	3.3-V or 5-V linear regulator output; external 3.3-V or 5-V logic supply input for option without LDO.
2	NFAULT	NFAULT	O	Fault indicator output signal to the microcontroller. Connect this pin via pull-up resistor to VCC_IN (TIOS102) or VCC_OUT (TIOS1023, TIOS1025)
3	NC	NC	-	Do not connect to GND. Leave floating
4	IN	IN	I	Transmit data input from the local controller. No effect if EN is low. Logic high sets low-side switch. Logic low sets high-side switch. Weak internal pull-up.
5	EN	EN	I	Driver enable input signal from the local controller. Logic low sets the OUT output at Hi-Z. Weak internal pull-down.
6	ILIM_ADJ	ILIM_ADJ	I	Input for current limit adjustment. Connect resistor R_{SET} between ILIM_ADJ and GND.
7	GND	GND	GND	Device ground connection
8	OUT	OUT	O	Driver output
9	VCC	VCC	P	Supply voltage (24 V nominal)
10	NC	NC	-	Do not connect to GND. Leave floating
	Thermal Pad	Thermal Pad	—	Connect to GND plane for optimal thermal and electrical performance

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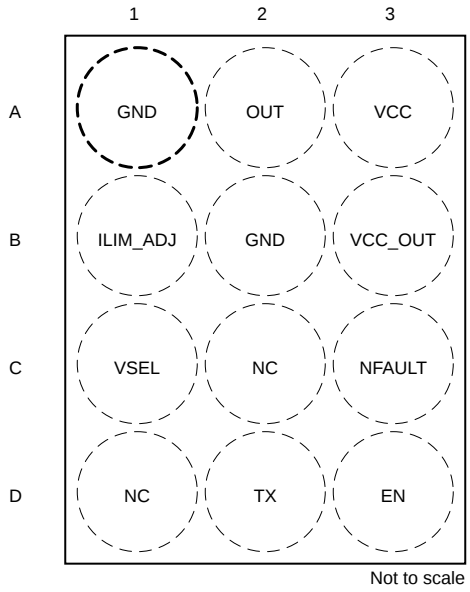

Figure 5-3. TIOS1023L YAH, 12-Pin DSBGA (Top View)

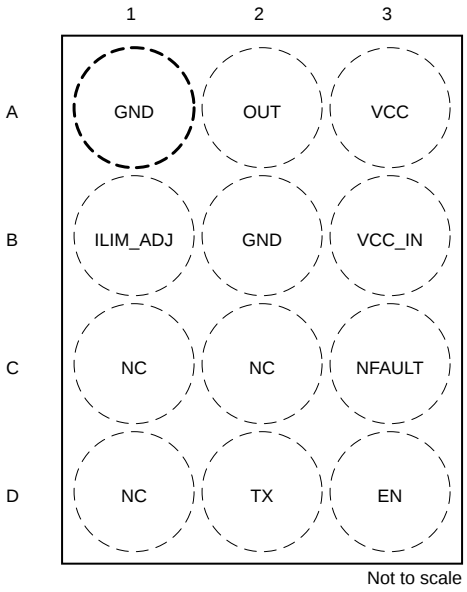

Figure 5-4. TIOS102 YAH, 12-Pin DSBGA (Top View)

Table 5-2. Pin Functions (DSBGA)

PIN NO	PIN NAME		Type	DESCRIPTION
	TIOS102	TIOS1023L		
B3	VCC_IN	VCC_OUT	P	3.3-V or 5-V linear regulator output; external 3.3-V or 5-V logic supply input for option without LDO.
C3	NFAULT	NFAULT	O	Fault indicator output signal to the microcontroller. Connect this pin via pull-up resistor to VCC_IN (TIOS102) or VCC_OUT (TIOS1023, TIOS1025)
D2	TX	TX	I	Transmit data input from the local controller. No effect if EN is low. Logic high sets low-side switch. Logic low sets high-side switch. Weak internal pull-up.
D3	EN	EN	I	Driver enable input signal from the local controller. Logic low sets the OUT output at Hi-Z. Weak internal pull-down.
B1	ILIM_ADJ	ILIM_ADJ	I	Input for current limit adjustment. Connect resistor R_{SET} between ILIM_ADJ and GND.
A1, B2	GND	GND	GND	Device ground connection
A2	OUT	OUT	O	Switch output
A3	VCC	VCC	P	Supply voltage (24 V nominal)
D1, C2	NC	NC	-	Leave floating. Do not connect.
C1	NC	VSEL	I	TIOS102: Leave floating. Do not connect TIOS1023L: VSEL: Connect to GND for 5V LDO output. Please leave this pin floating for 3.3V LDO output

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6 Specifications

6.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Supply voltage	Steady state voltage for VCC and OUT	–65	65	V
	Transient pulse width < 100 µs for VCC and OUT	–70	70	V
Voltage difference	$\lvert V_{(VCC)} - V_{(OUT)} \rvert$		65	V
Logic supply voltage (TIOS102)	VCC_IN	–0.3	6	V
Input logic voltage	IN, EN, VSEL, ILIM_ADJ	–0.3	min(VCC_IN +0.3, 6)	V
Output current	NFAULT	–5	5	mA
Storage temperature, T_{stg}		-55	170	°C

(1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute maximum ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If briefly operating outside the *Recommended Operating Conditions* but within the Absolute Maximum Ratings, the device may not sustain damage, but it may not be fully functional. Operating the device in this manner may affect device reliability, functionality, performance, and shorten the device lifetime. All voltages are with reference to the GND pin, unless otherwise specified.

6.2 ESD Ratings

				VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	All pins	±4000	V
$V_{(ESD)}$	Electrostatic discharge	Charged Device Model (CDM), per ANSI/ESDA/JEDEC JS-002 (2)	All pins	±750	V

(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 ESD Ratings - IEC Specifications

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	IEC 61000-4-2 ESD (Contact Discharge), VCC, OUT and GND (1)	±8,000	V
	Electrostatic discharge	IEC 61000-4-5, 1.2 µs/50 µs Surge with 500 Ω in series, VCC, OUT and GND (1)	±1,200	
	Electrostatic discharge	IEC 61000-4-4 EFT (Fast transient or burst), VCC, OUT and GND (1)	±4,000	

(1) Minimum 100-nF capacitor is required between VCC and GND. Minimum 1-µF capacitor is required between VCC_IN/VCC_OUT and GND.

6.4 Recommended Operating Conditions

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

			MIN	NOM	MAX	UNIT
$V_{(VCC)}$	Supply voltage	TIOS102,TIOS1023, TIO1023L (3.3V output)	4.75	24	36	V
		TIOS1025, TIOS1023L (5V output)	7	24	36	V
$V_{(VCC_IN)}$	Logic level input voltage (TIOS102 only)	3.3 V configuration	3	3.3	3.6	V
		5 V configuration	4.5	5	5.5	V
R_{SET}	External resistor for CQ current limit		0		110	kΩ
$1/t_{BIT}$	Data rate (Communication mode)				250	kbps
$I_{(VCC_OUT)}$	LDO output current (TIOS1023,TIOS1023L, TIOS1025 only)				20	mA
T_A	Operating ambient temperature		–40		125	°C
T_J	Junction temperature				150	°C

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6.5 Thermal Information

THERMAL METRIC (1)		TIOS102, TIOS1023, TIOS1025	TIOS102, TIOS1023L	UNIT
		DRC (10 Pins)	YAH (12 Pins)	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	45.9	79.3	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	45.9	0.3	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	17.9	19.5	°C/W
ψ_{JT}	Junction-to-top characterization parameter	0.7	0.1	°C/W
ψ_{JB}	Junction-to-board characterization parameter	17.8	19.4	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	4.7	N/A	°C/W

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

6.6 Electrical Characteristics

over operating free-air temperature range (unless otherwise noted). Typical values are at V_{VCC} = 24 V, V_{VCC_IN} = 3.3 V, V_{VCC_OUT} = 3.3 V and T_A = 25 °C unless otherwise specified.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
POWER SUPPLIES (VCC)							
$I_{(VCC)}$	Quiescent supply current	EN = LOW, no load			1	1.5	mA
		EN = HIGH, no load			2.1	2.95	mA
LOGIC-LEVEL INPUTS (EN, IN, VSEL)							
V_{IL}	Input logic low voltage					0.8	V
V_{IH}	Input logic high voltage			2			V
R_{PD}	Pull-down (EN) resistance				100		kΩ
R_{PU}	Pull-up (IN) resistance				200		kΩ
R_{PU}	Pull-up (VSEL) resistance				1000		kΩ
CONTROL OUTPUTS (NFAULT)							
V_{OL}	Output logic low voltage	I_O = 4 mA				0.5	V
I_{OZ}	Output high impedance leakage	Output in Hi-Z, V_O = 0 V or VCC_IN/OUT		–1		1	µA
DRIVER OUTPUT (OUT)							
$R_{DS(ON)}$	High-side driver on-resistance				2.5	4.5	Ω
$V_{DS(ON)}$	High-side driver residual voltage	I = 200 mA			0.5	0.9	V
		I = 100 mA			0.25	0.5	V
$R_{DS(ON)}$	Low-side driver on-resistance				2.5	4.5	Ω
$V_{DS(ON)}$	Low-side driver residual voltage	I = 200 mA			0.5	0.9	V
		I = 100 mA			0.25	0.5	V
I_{PD}	OUT pull-down current	EN = LOW, IN = LOW, $R_{SET:}$ >= 10 kΩ	0 ≤ $V_{(OUT)}$ ≤ ($V_{(VCC)}$ - 0.1) V	40	50	80	µA
I_{PU}	OUT pull-up current	EN = LOW, IN = HIGH		40	50	80	µA
$I_{O(LIM)}$	Driver output current limit	R_{SET} = 10 kΩ; V(OUT) = ($V_{(VCC)}$-3) V or 3 V		300	350	400	mA
		R_{SET} = 110 kΩ; V(OUT) = ($V_{(VCC)}$-3) V or 3 V		35	50	70	mA
		R_{SET} = 0 to 5 kΩ; (3) V(OUT) = ($V_{(VCC)}$-3) V or 3 V T_J < $T_{(SDN)}$ or t < 200 µs		500			mA
		(Fast-detect mode) R_{SET} = OPEN(1) V(OUT) = ($V_{(VCC)}$-3) V or 3 V		260	330	400	mA

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6.6 Electrical Characteristics (continued)

over operating free-air temperature range (unless otherwise noted). Typical values are at V_{VCC} = 24 V, V_{VCC_IN} = 3.3 V, V_{VCC_OUT} = 3.3 V and T_A = 25 °C unless otherwise specified.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
PROTECTION CIRCUITS							
$V_{(UVLO)}$	VCC under voltage lockout	VCC falling; NFAULT = Hi-Z	TIOS102 and 3.3V LDO version	4.2	4.4		V
$V_{(UVLO)}$	VCC under voltage lockout	VCC rising; NFAULT = Hi-Z			4.6	4.75	V
$V_{(UVLO)}$	VCC under voltage lockout	VCC falling; NFAULT = Hi-Z	TIOS1025	6	6.3		V
		VCC rising; NFAULT = Hi-Z			6.5	6.8	V
$V_{(UVLO,HYS)}$	VCC under voltage lockout hysteresis	Rising to falling threshold	Rising to falling threshold	200			mV
$V_{(UVLO_IN)}$	VCC_IN under voltage lockout (No LDO option)	VCC_IN falling; NFAULT = Hi-Z			2.3		V
		VCC_IN rising; NFAULT = LOW			2.5		V
$V_{(UVLO_IN,HYS)}$	VCC_IN under voltage hysteresis (No LDO option)	Rising to falling threshold			190		mV
$T_{(WRN)}$	Thermal warning	Die temperature T_J		125			°C
$T_{(SDN)}$	Thermal shutdown			150	160		°C
$T_{(HYS)}$	Hysteresis for thermal shutdown and warning thresholds				14		°C
I_{REV}	Leakage current in reverse polarity	EN=LOW, IN=x; $V_{(OUT)} < V_{(GND)}$ or $V_{(OUT)} > V_{(VCC)}$, up to |36 V|				60	µA
		EN=LOW, IN=x; $V_{(OUT)} < V_{(GND)}$ or $V_{(OUT)} > V_{(VCC)}$, up to |55 V|				110	µA
		EN = HIGH, IN = LOW; $V_{(OUT\ to\ VCC)}$ = 3 V				640	µA
		EN = HIGH, IN = HIGH; $V_{(OUT\ to\ GND)}$ = -3 V				10	µA
LINEAR REGULATOR (LDO)							
$V_{(VCC_OUT)}$	Voltage regulator output	5 V LDO version		4.75	5	5.25	V
		3.3 V LDO version		3.13	3.3	3.46	V
$V_{(DROP)}$	Voltage regulator drop-out voltage ($V_{(VCC)} – V_{(VCC_OUT)}$)	I_{CC} = 20 mA load current	5 V LDO			1.9	V
			3.3 V LDO			1.4	V
REG	Line regulation ($dV_{(VCC_OUT)}$/ dV(VCC))	$I_{(VCC_OUT)}$ = 1 mA				1.7	mV/V
L_{REG}	Load regulation ($dV_{(VCC_OUT)}$/ $V_{(VCC_OUT)}$)	$V_{(VCC)}$ = 24 V, $I_{(VCC_OUT)}$ = 100 µA to 20 mA				1%	
PSSR	Power Supply Rejection Ratio	100 kHz, $I_{(VCC_OUT)}$ = 20 mA			40		dB

(1) Current fault indication will be active. Current fault auto recovery will be de-activated.
(2) If operating continuously with this current limit, ensure that the current through the device does not cause the T_J to be greater than $T_{(SDN)}$ for a given ambient temperature and thermal property of the system. For pulse durations t < 200 µs, the device can source or sink current of at least 500 mA across the recommended operating conditions.

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6.7 Switching Characteristics

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

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
DRIVER						
t_{PLH}, t_{PHL}	Driver propagation delay	See Figure 7-3 R_L = 2 kΩ C_L = 5 nF $R_{(SET)}$ = 10 kΩ		600	1200	ns
$t_{P(skew)}$	Driver propagation delay skew. $\lvert t_{PLH} - t_{PHL} \rvert$			75		ns
t_{PZH}, t_{PZL}	Driver enable delay				4	µs
t_{PHZ}, t_{PLZ}	Driver disable delay				4	µs
t_r, t_f	Driver output rise, fall time		200		700	ns
$\lvert t_r - t_f \rvert$	Difference in rise and fall time			50		ns
t_{SC}	Current fault blanking time		175	200		µs
t_{pSC}	Current fault indication delay				280	µs
t_{SCEN}	Current fault driver re-enable wait time			15		ms
$t_{(UVLO)}$	OUT re-enable delay after UVLO (1)	$V_{(UVLO)}$ rising threshold crossing time to CQ enable time	10	30	50	ms

(1) CQ output remains Hi-Z for this time

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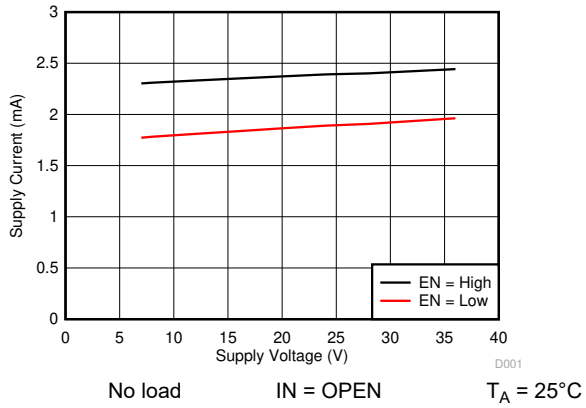
6.8 Typical Characteristics



No load IN = OPEN T_A = 25°C

Figure 6-1. Supply Current vs Supply Voltage

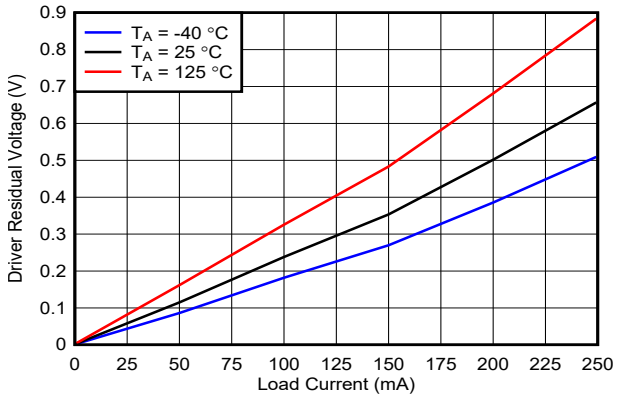


Figure 6-2. Residual Voltage vs Load Current: High Side

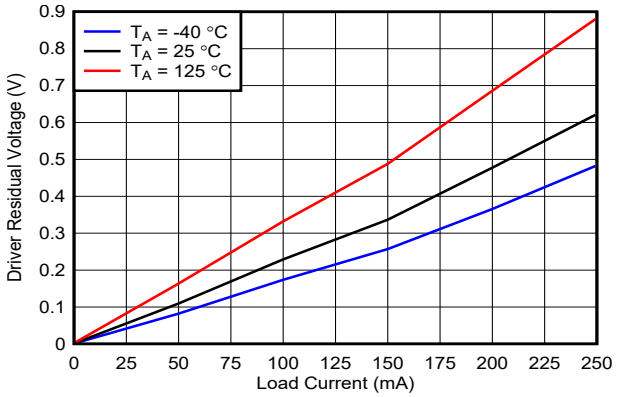


Figure 6-3. Residual Voltage vs Load Current: Low Side

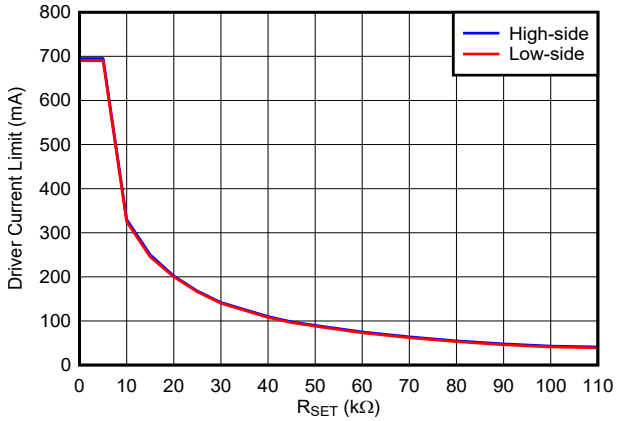
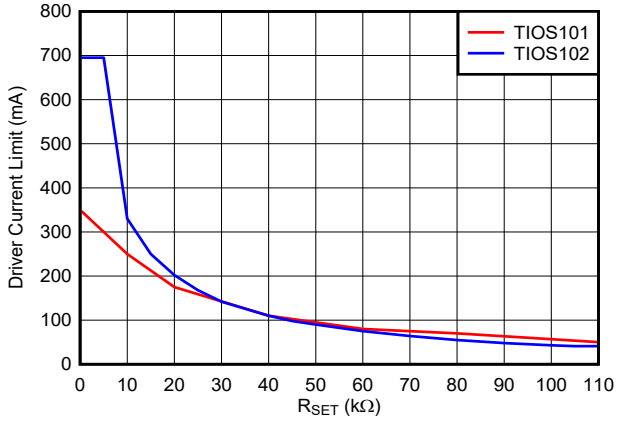


Figure 6-4. Current Limit vs R_{SET}



T_A = 25°C

Figure 6-5. Current Limit vs R_{SET} : TIOS102(x) vs TIOS101(x)

7 Parameter Measurement Information

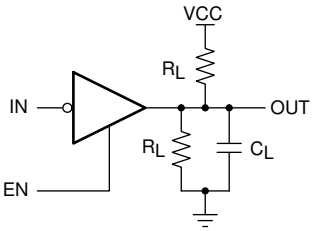


Figure 7-1. Test Circuit for Driver Switching

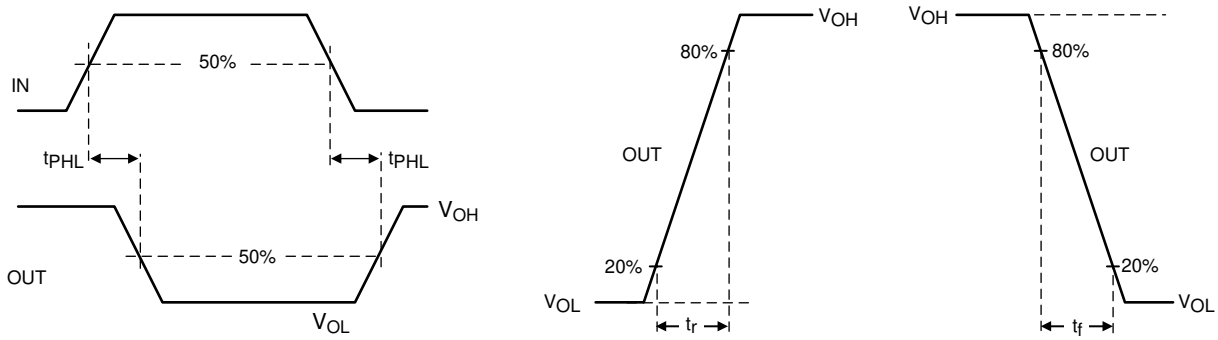


Figure 7-2. Waveforms for Driver Output Switching Measurements

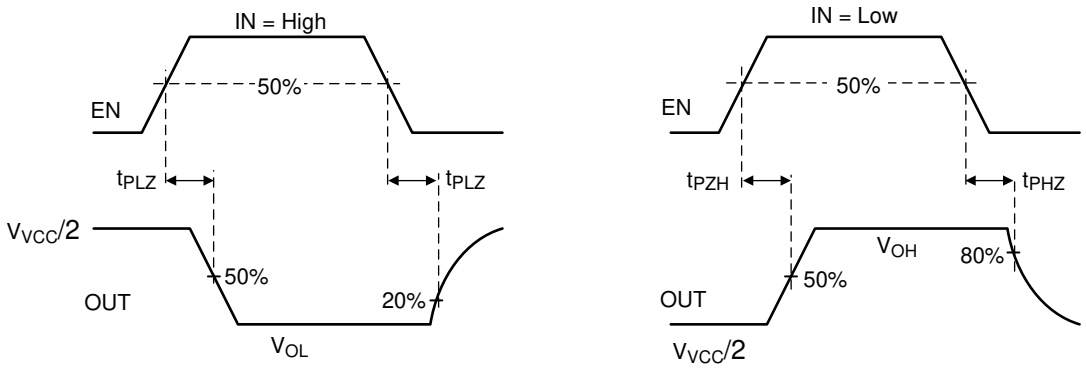


Figure 7-3. Waveforms for Driver Enable or Disable Time Measurements

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8 Detailed Description

8.1 Overview

Figure 8-1 shows that the device driver output (OUT) can be used in a push-pull, high-side, or low-side configuration using the enable (EN) and transmit data (IN) input pins. OUT can drive resistive, large capacitive or large inductive loads.

TIOS102 and TIOS102x devices have integrated IEC 61000-4-4/5 EFT and surge protection. In addition, tolerance to ±65-V transients enables flexibility to choose from a wider range of TVS diodes if an application requires higher levels of protection. These integrated robustness features will simplify the system-level design by reducing the external protection circuitry.

These devices implement protection features for over-current, over-voltage and over-temperature conditions. The devices also provide a current-limit setting of the driver output current using an external resistor.

The TIOS102x devices derive the low voltage supply from the typical 24 V industrial supply via an internal linear regulator to provide power to the local controller and sensor circuitry.

8.2 Functional Block Diagrams

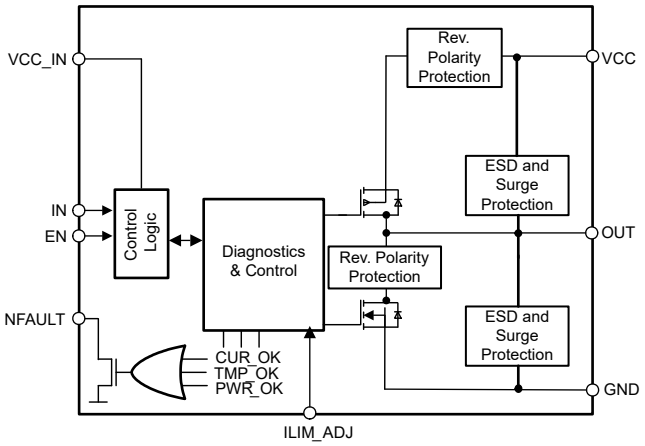

Figure 8-1. Block Diagram, TIOS102

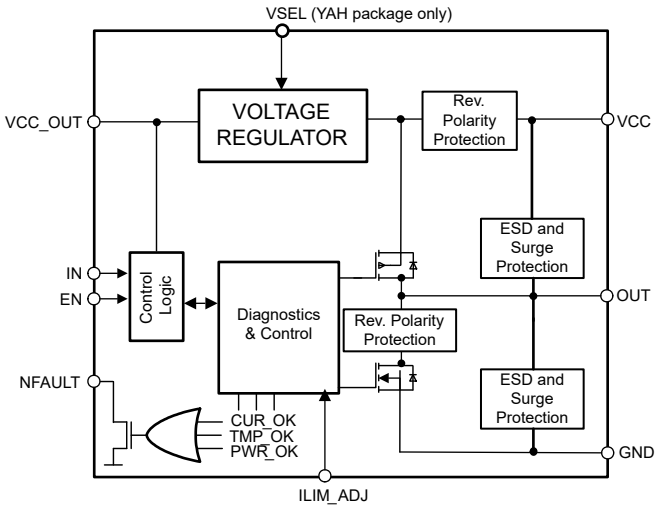

Figure 8-2. Block Diagram, TIOS102x

8.3 Feature Description

8.3.1 Current Limit Configuration

The output current can be configured with an external resistor on ILIM_ADJ pin. The highest current limit setting with an external resistor of 10 kΩ specifies a minimum of 300 mA over the operating temperature and voltage range.

Output disable due to current fault and current fault auto recovery features can be disabled by floating ILIM_ADJ pin. However, the current fault indication is still active in this configuration. This feature is useful when driving large capacitance.

When the ILIM_ADJ pin is shorted to ground, the TIOS102(x) is configured to source or sink a minimum of 500 mA. In this mode, current fault indication is disabled. Output Disable and Auto Recovery feature is also disabled in this mode. The driver is disabled if the power dissipation in the device causes the junction temperature to reach $T_{(SDN)}$.

Table 8-1. Current Limitation

ILIM_ADJ Pin Condition	OUT Current Limit (Min.)	NFAULT Indication Due to Current Fault	Output Disable and Auto Recovery
R_{SET} resistor to GND (R_{SET}: 10 kΩ to 110 kΩ)	Variable (35 mA to 300 mA)	Yes	Yes
Connected to GND (R_{SET} 0 to 5 kΩ)	500 mA	No	No
OPEN	260 mA	Yes	No

8.3.2 Current Fault Detection, Indication and Auto Recovery

If the output current at OUT exceeds the internally set current limit $I_{O(LIM)}$ for a duration longer than t_{SC}, the NFAULT pin is driven logic low to indicate a fault condition. The output is turned off, but the LDO continues to function. The output periodically retries to check if the output is still in the over current condition. In this mode, the output is switched on for t_{SC} in t_{SCEN} intervals. Current fault auto recovery mode can be disabled by setting ILIM_ADJ = OPEN or GND. See Table 8-3. Toggling EN will clear NFAULT.

8.3.3 Thermal Warning, Thermal Shutdown

If the die temperature exceeds $T_{(WRN)}$, the NFAULT flag is held low indicating a potential over temperature problem. When the T_J exceeds $T_{(SDN)}$, The output is disabled but the LDO remains operational. As soon as the temperature drops below the temperature threshold (and after $T_{(HYS)}$), the internal circuit re-enables the driver, subject to the state of the EN and IN pins.

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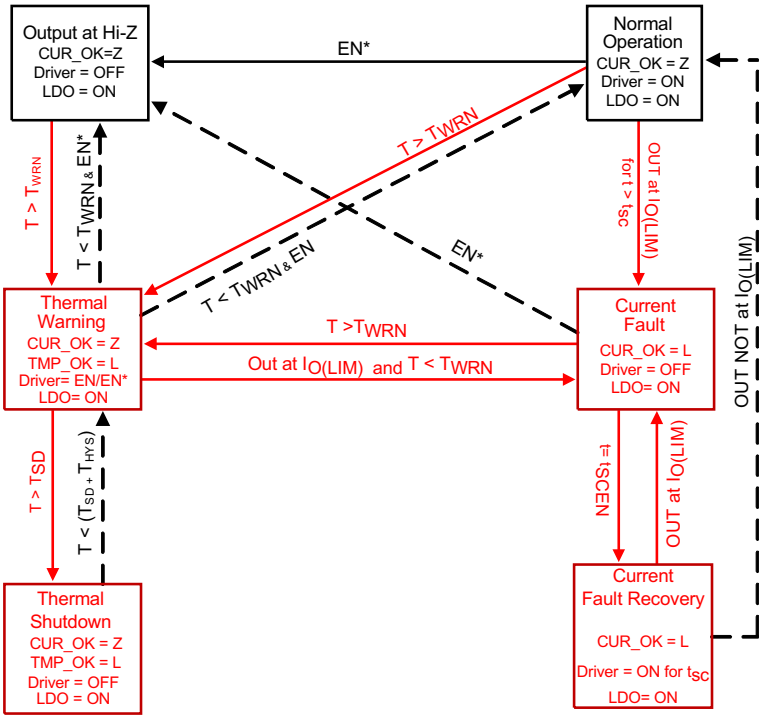
8.3.4 Fault Reporting (NFAULT)

NFAULT is driven low if either a current fault condition is detected, die temperature has exceeded $T_{(WRN)}$ or supply has dropped below the UVLO threshold. NFAULT returns to high-impedance as soon as all three fault conditions clear.



NFAULT = [CUR_OK && PWR_OK && TMP_OK]

Figure 8-3. Device State Diagram

8.3.5 Device Function Tables

Table 8-2. Driver Function

EN	IN	OUT	COMMENT
L / Open	X	Hi-Z	Device is in ready-to-receive state
H	L	H	OUT is sourcing current (high-side drive)
H	H / Open	L	OUT is sinking current (low-side drive)

Table 8-3. Current Limit Indicator Function ($t > t_{SC}$)

EN	IN	OUT CURRENT	NFAULT	COMMENT
H	H / Open	$\lvert I_{(OUT)} \rvert > I_{O(LIM)}$	L	OUT current exceeds the set limit for over t_{SC}
		$\lvert I_{(OUT)} \rvert < I_{O(LIM)}$	Z	Normal operation
H	L	$\lvert I_{(OUT)} \rvert > I_{O(LIM)}$	L	OUT current exceeds the set limit for over t_{SC}
		$\lvert I_{(OUT)} \rvert < I_{O(LIM)}$	Z	Normal operation
L / Open	X	X	Z	Driver is disabled, current limit indicator is inactive

8.3.6 The Integrated Voltage Regulator (LDO)

The TIOS1023 and TIOS1025 each have an integrated linear voltage regulator (LDO) which can supply power to external components. The voltage regulator is specified for VCC voltages in the range of 7 V to 36 V (TIOS1025) or in the range of 5 V to 36 V (TIOS102, TIOS1023) with respect to GND. The LDO is capable of delivering up to 20 mA. The LDO output is current limited to 35-mA to limit the inrush current onto VCC_OUT decoupling capacitors during initial power up.

In the DSBGA (YAH) package, TIOS1023L offers pin-configurable LDO output via VSEL pin. When VSEL is connected to GND, VCC_OUT is configured to provide a 5-V output. When VSEL is left floating, VCC_OUT provides a 3.3-V output.

Table 8-4. LDO Output Configuration via VSEL pin (YAH Package)

VSEL pin connection	VCC_OUT
GND	5 V
Floating	3.3 V

The LDO is designed to be stable with standard ceramic capacitors with values of 1 µF or larger at the output. X5R- and X7R-type capacitors are best because they have minimal variation in value and ESR over temperature. Maximum ESR should be less than 1 Ω. With tolerance and dc bias effects, the minimum capacitance to ensure stability is 1 µF.

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8.3.7 Reverse Polarity Protection

Reverse polarity protection circuitry protects the devices against accidental reverse polarity connections to the VCC, OUT and GND pins. The maximum voltage between any of the pins may not exceed 65 V DC at any time.

Figure 8-4 and Figure 8-5 shows all the possible connection combinations.

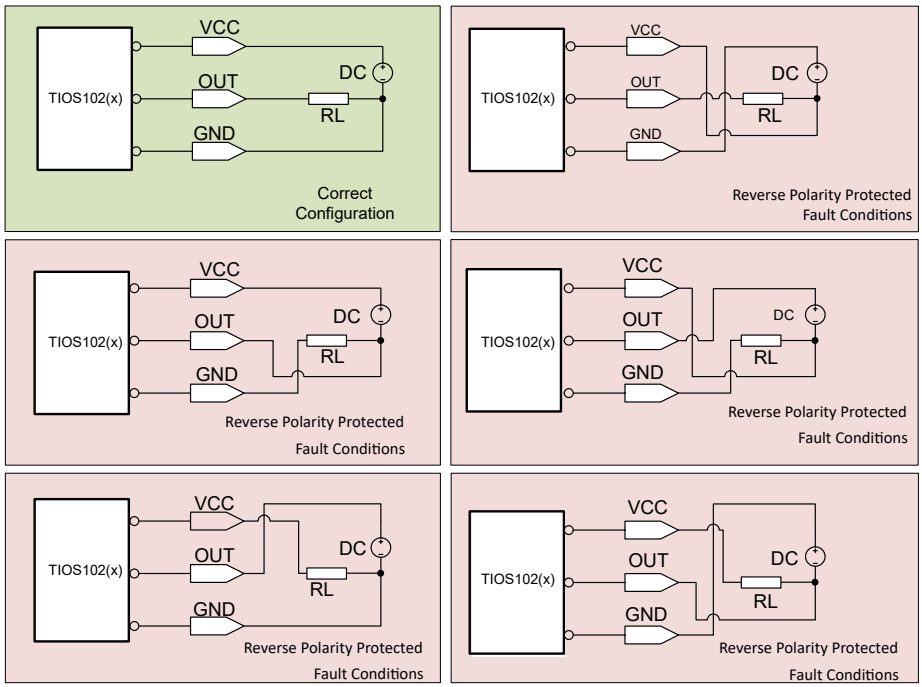

Figure 8-4. High-Side Driver Configuration

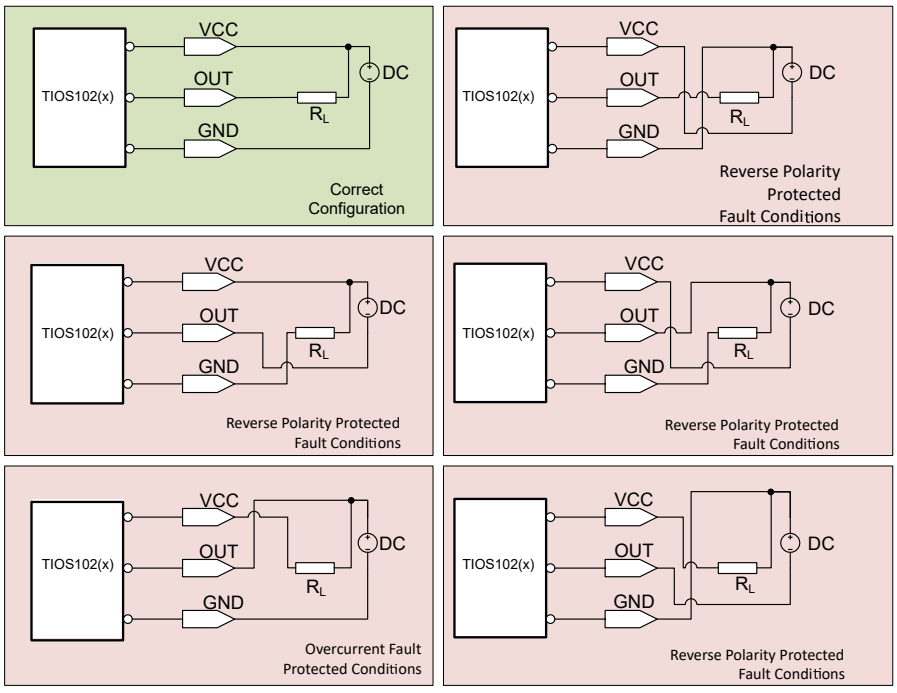

Figure 8-5. Low-Side Driver Configuration

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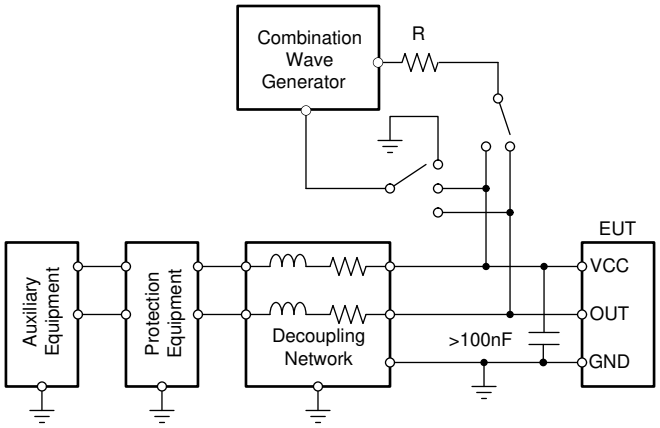
8.3.8 Integrated Surge Protection and Transient Waveform Tolerance

The VCC and OUT pins of the device are capable of withstanding up to 1.2 kV of 1.2/50 – 8/20 µs IEC 61000-4-5 surge with a source impedance of 500 Ω. The surge testing should be performed with a minimum 100 nF supply decoupling capacitor between VCC and GND, and 1 µF between VCC_IN/OUT and GND.

External TVS diodes may be required for higher transient protection levels. The system designer should ensure that the maximum clamping voltage of the external diodes should be < 65 V at the desired current level. The device is capable of withstanding up to ±65-V transient pulses < 100 µs.



1.2/50 - 80/20 µs CWG
R = 500 Ω

Figure 8-6. Surge Test Setup

8.3.9 Power Up Sequence

VCC_IN and VCC domains can be powered up in any sequence. In the event of VCC is powered and VCC_IN is not, the OUT pin remains in high impedance.

8.3.10 Undervoltage Lock-Out (UVLO)

The device enters UVLO if the VCC voltage falls below $V_{(UVLO)}$. (For the device without the integrated LDO, the device monitors VCC_IN in addition to VCC. UVLO happens if either supply falls below the threshold.)

As soon as the supply falls below $V_{(UVLO)}$), NFAULT is pulled low, the LDO is turned off and the OUT output is disabled (Hi-Z). Receiver performance is not specified in this mode.

When the supply rises above $V_{(UVLO)}$, NFAULT returns to Hi-Z (given no other fault conditions present) and the LDO will be enabled immediately. The OUT output will be turned on after $T_{(UVLO)}$ delay.

8.4 Device Functional Modes

These devices can operate in three different modes.

8.4.1 NPN Configuration (N-Switch Mode)

Set IN pin high (or open) and use EN pin as control for realizing the function of an N-switch (low-side configuration) on OUT.

8.4.2 PNP Configuration (P-Switch Mode)

Set IN pin low and use EN pin as control for realizing the function of a P-switch (high-side configuration) on OUT.

8.4.3 Push-Pull Mode

Set EN pin high and toggle IN as control for realizing the function of a push-pull output on OUT. Table 8-5, Table 8-6, and Table 8-7 summarize the pin configurations to accomplish the functional modes.

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Table 8-5. NPN Mode

EN	IN	OUT
L / Open	H / Open	Hi-Z
H	H / Open	N-Switch

Table 8-6. PNP Mode

EN	IN	OUT
L / Open	L	Hi-Z
H	L	P-Switch

Table 8-7. Push-Pull Mode

EN	IN	OUT
L / Open	X	Hi-Z
H	H / Open	N-Switch
H	L	P-Switch

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9 Application Information Disclaimer

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, as well as validating and testing their design implementation to confirm system functionality.

9.1 Application Information

TIOS102 and TIOS102x are robust 24-V digital drivers for industrial sensors.

9.2 Typical Application

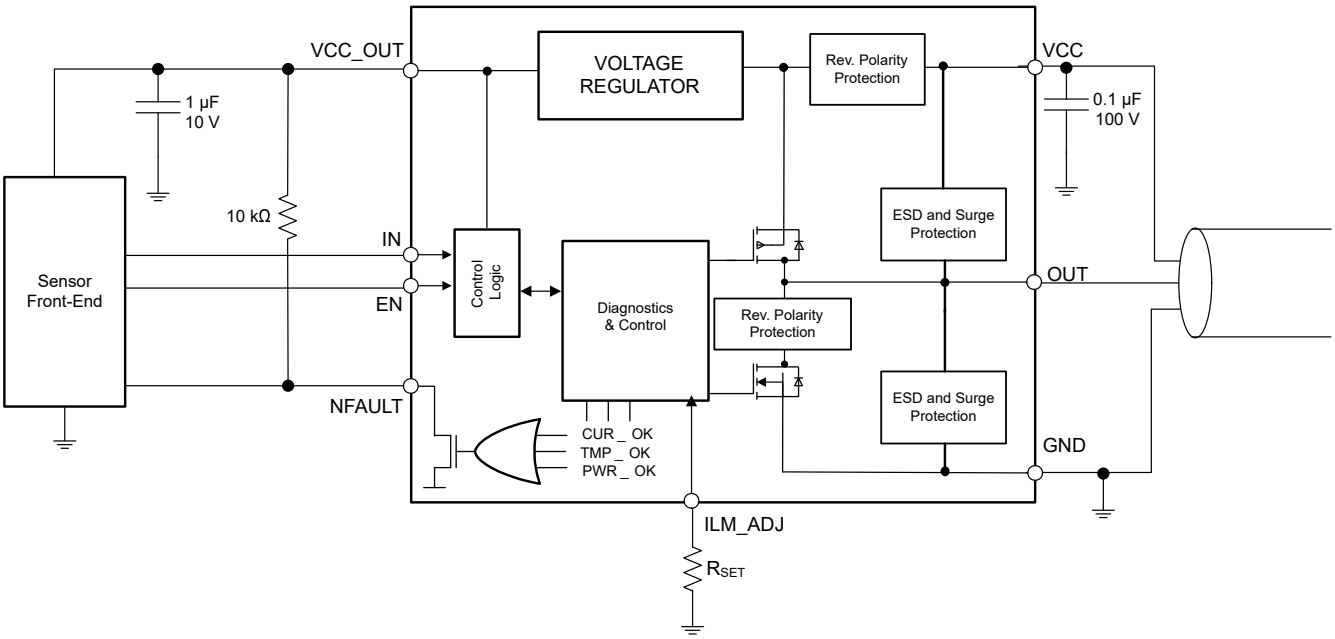

Figure 9-1. Typical Application Schematic

9.2.1 Design Requirements

Table 9-1 shows recommended components for a typical system design.

Table 9-1. Design Parameters

PARAMETERS	Design Requirement	TIOS102(x) Specification
Input voltage range (VCC)	24 V, 30 V (max)	7 V to 36 V (TIOS1025)
Output current (OUT)	200 mA	Choose 250 mA limit with R_{SET} = 27 kΩ
Output voltage (VCC_OUT), Pick TIOS1025	5 V	Choose TIOS1025; VCC_OUT = 5 V
Maximum LDO output current ($I_{VCC(OUT)}$)	5 mA	I_{VCC_OUT}: Up to 20 mA
Pull-up resistors for NFAULT	10 kΩ	10 kΩ
VCC decoupling capacitor	0.1 µF / 100 V	0.1 µF / 100 V
LDO output capacitor	1 µF / 10 V	1 µF / 10 V
Maximum Ambient Temperature, T_A	105°C	TIOS102(x) can support up to T_A of 125 °C if T_J < $T_{(SDN)}$

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9.2.2 Detailed Design Procedure

9.2.2.1 Maximum Junction Temperature Check

For a 200 mA current limit:

- Choose driver output current limit, $I_{O(LIM)}$ = 250 mA (allowing for current limit tolerance); R_{SET} = 27 kΩ
- The maximum voltage drop across the high-side switch at 250 mA current is $V_{DS(ON)}$ = 1.1 V.

This causes a power consumption of:

$$PD_{OP} = V_{DS(ON)} \times I_{O(LIM)} = 1.1\,V \times 250\,mA = 275\,mW \quad (1)$$

For a 5 mA LDO current output,

$$PD_{LDO} = \left(V_{L+} - V_{VCC_{OUT}}\right) \times I_{VCC_OUT} = (30 - 5)V \times 5\,mA = 125\,mW \quad (2)$$

Total power dissipation,

$$PD = PD_{LDO} + PD_{OP} = 275\,mW + 125\,mW = 400\,mW \quad (3)$$

Multiply this value with the Junction-to-ambient thermal resistance of θ_{JA} = 45.9 °C/W (taken from the *Thermal Information table* table) to receive the difference between junction temperature, T_J, and ambient temperature, T_A:

$$\Delta T = T_J - T_A = PD \times \theta_{JA} = 400\,mW \times 45.9\,{}^{\circ C}/_{W} = 18.36\,{}^{\circ}C \quad (4)$$

Add this value to the maximum ambient temperature of T_A = 105°C to receive the final junction temperature:

$$T_J = T_A + \Delta T = T_A + PD \times \theta_{JA} = 105\,{}^{\circ}C + 400\,mW \times 45.9\,{}^{\circ C}/_{W} = 105\,{}^{\circ}C + 18.36\,{}^{\circ}C = 123.36\,{}^{\circ}C \quad (5)$$

As long as T_J is below the recommended maximum value of 150°C, no thermal shutdown will occur. However, the junction temperature is closer to T_{WRN} and thermal warning may be generated if the junction temperature rises above T_{WRN}.

Note that the modeling of the complete system may be necessary to predict junction temperature in smaller PCBs and/or enclosures without air flow.

9.2.2.2 Driving Capacitive Loads

These devices are capable of driving capacitive loads on the OUT output. Assuming a pure capacitive load without series/parallel resistance, the maximum capacitance that can be charged without triggering current fault can be calculated as:

$$C_{LOAD} = \frac{[I_{O(LIM)} \text{ x } t_{SC}]}{V_{(VCC)}} \quad (6)$$

To drive higher capacitive loads and avoid overcurrent condition disabling the driver, it is recommended to leave ILIM_ADJ pin floating. With ILIM_ADJ floating, TIOS102(x) indicates overcurrent fault without blanking time delay (t_{SC}) but does not disable the driver. Another approach is to drive high capacitive loads with a series resistor between the output and the load to avoid overcurrent condition. Capacitive loads can be connected to GND or VCC

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9.2.2.3 Driving Inductive Loads

The TIOS102(x) family is capable of magnetizing and demagnetizing large inductive loads. These devices contain internal circuitry that enables fast demagnetization when configured as either P-switch or N-switch mode.

In P-switch configuration, the load inductor L is magnetized when the OUT pin is driven high. When the PNP is turned off, there is a significant amount of negative inductive kick back at the OUT pin. This voltage is clamped internally at about -15 V.

Similarly, in N-switch configuration, the load inductor L is magnetized when the OUT pin is driven low. When the NPN is turned off, there is a significant amount of positive inductive kick back at the OUT pin. This voltage is clamped internally at about 15 V.

The equivalent protection circuits are shown in Figure 9-2 and Figure 9-3. The minimum value of the resistive load R can be calculated as:

$$R = \frac{V_{(VCC)}}{I_{O(LIM)}} \quad (7)$$

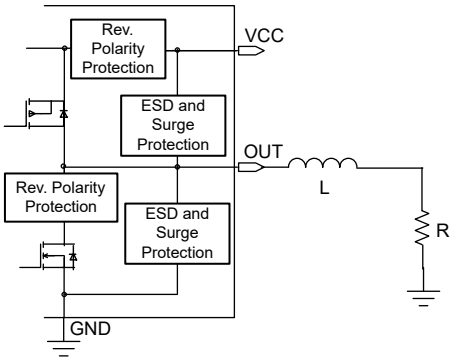

Figure 9-2. PNP Mode

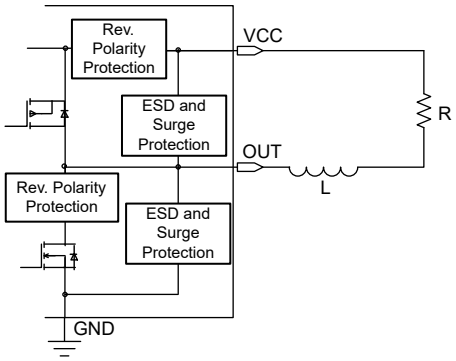

Figure 9-3. NPN Mode

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9.2.3 Application Curves

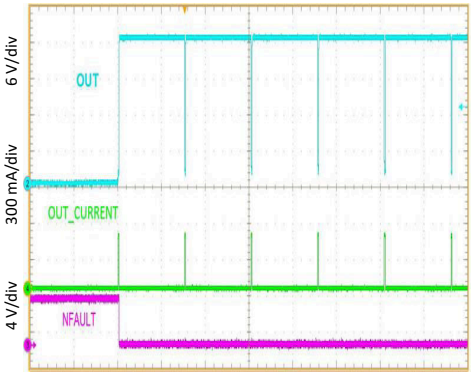


Figure 9-4. OUT In Current Fault Auto Recovery, Low Side Mode

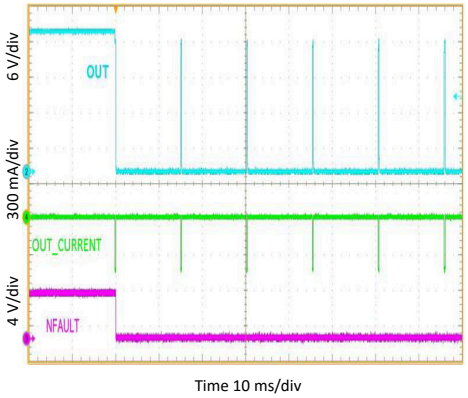
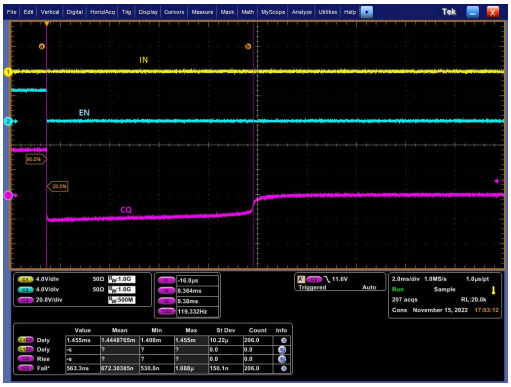


Figure 9-5. OUT In Current Fault Auto Recovery, High Side Mode

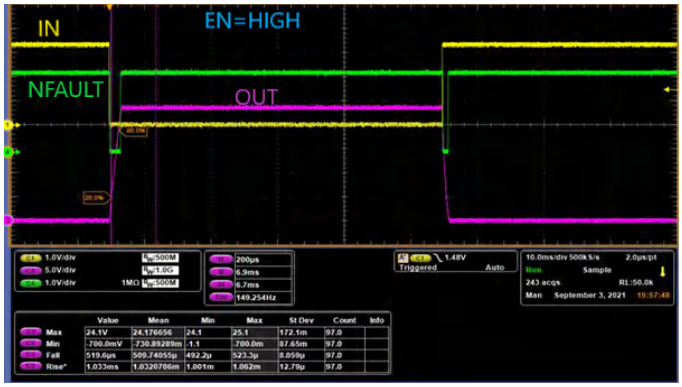


VCC = 36 V L = 1.5 H R_L = 360 Ω
R_{SET} = 10 kΩ T_A = 25 °C

Figure 9-6. OUT Driving Inductive Load, High Side Mode (PNP)

VCC = 36 V L = 1.5 H R_L = 360 Ω
R_{SET} = 10 kΩ TA = 25 °C

Figure 9-7. OUT Driving Inductive Load, Low Side Mode (NPN)



NFAULT indicated for the duration of charging and discharging of the capacitor but driver is not disabled when ILIM_ADJ is floating.
VCC = 24 V C_L = 20 uF R_L = 100 Ω R_{SET} = 1 MΩ (ILIM_ADJ Floating) T_A = 25 °C

Figure 9-8. OUT Driving Capacitive Load, Push-Pull Mode

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10 Power Supply Recommendations

The TIOS102 and TIOS102x are designed to operate from a 24-V nominal supply at VCC, but can operate from supply voltage range of 7 V to 36 V (TIOS1025) or 4.75 V to 36 V (TIOS102, TIOS1023). This supply should be buffered with at least a 100-nF/100-V capacitor.

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11 Layout

11.1 Layout Guidelines

- Use of a 4-layer board is recommended for good heat conduction. Use layer 1 (top layer) for control signals, layer 2 as GND, layer 3 for the 24-V supply plane (VCC), and layer 4 for the regulated output supply (VCC_IN/OUT).
- Connect the thermal pad to GND with maximum amount of thermal vias for best thermal performance.
- Use entire planes for VCC, VCC_IN/OUT and GND to assure minimum inductance.
- The VCC terminal must be decoupled to ground with a low-ESR ceramic decoupling capacitor with a minimum value of 100 nF. The capacitor must have a voltage rating of 50 V minimum (100 V depending on max sensor supply fault rating) and an X5R or X7R dielectric.
- • The optimum placement of the capacitor is closest to the VCC and GND terminals to reduce supply drops during large supply current loads. See Figure 11-1 for a PCB layout example.
- Connect all open-drain control outputs via 10 kΩ pull-up resistors to the VCC_IN/OUT plane to provide a defined voltage potential to the system controller inputs when the outputs are high-impedance.
- Connect the R_{SET} resistor between ILIM_ADJ and GND.
- Decouple the regulated output voltage at VCC_IN/OUT to ground with a low-ESR, 1 µF, ceramic decoupling capacitor. The capacitor should have a voltage rating of 10 V minimum and an X5R or X7R dielectric.

11.2 Layout Example

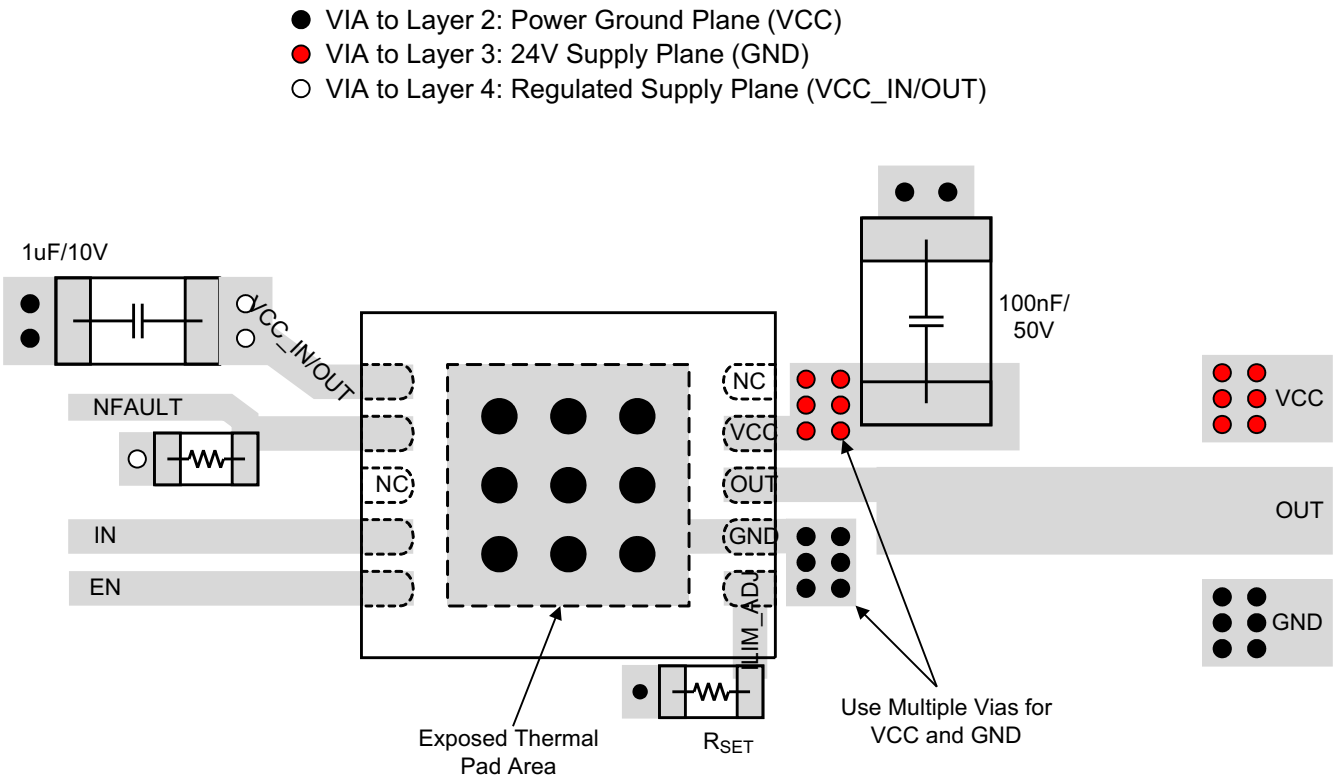

Figure 11-1. Layout Example

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. Click on *Subscribe to updates* 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 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is 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.

12.3 Trademarks

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All 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

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.

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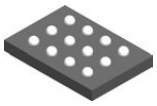
13.1 Mechanical Data

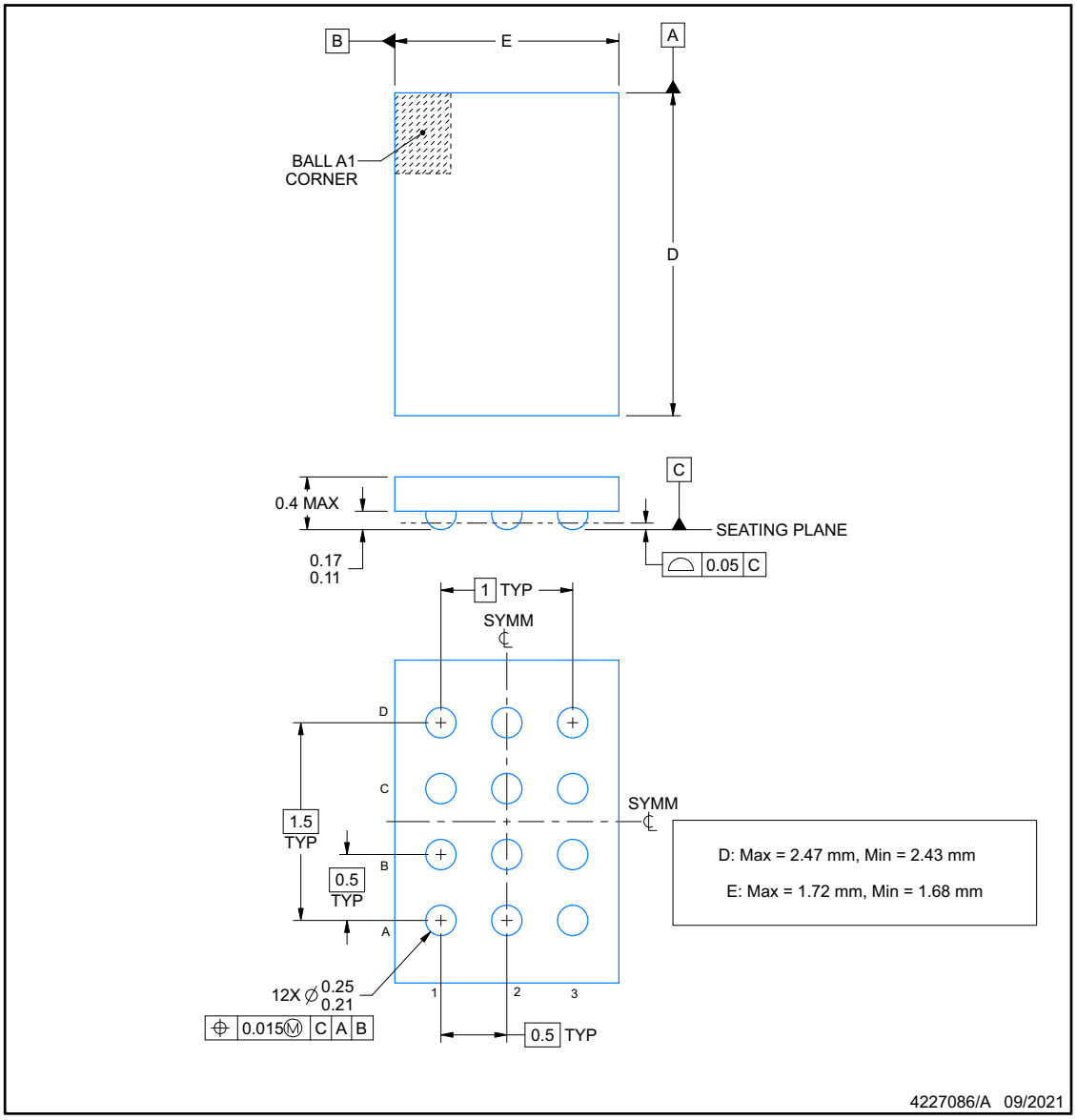


PACKAGE OUTLINE

YAH0012-C01

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

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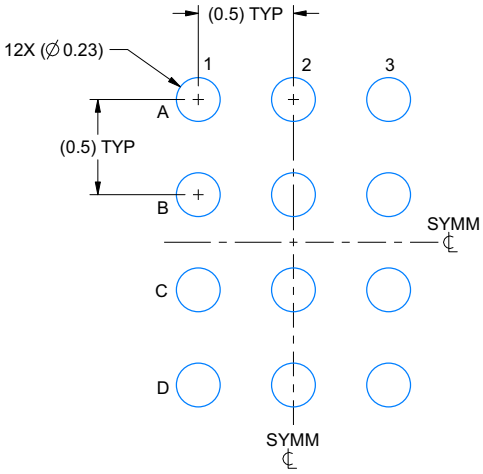
EXAMPLE BOARD LAYOUT

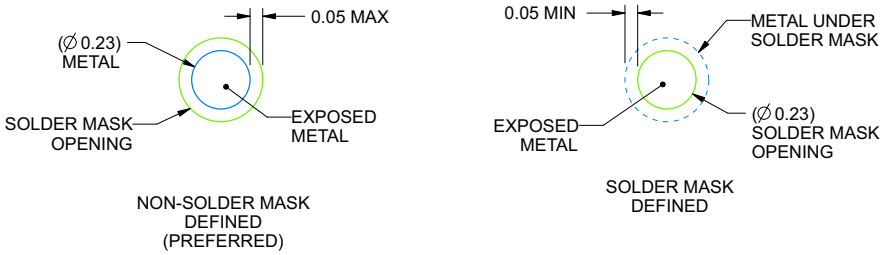
YAH0012-C01

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 30X



SOLDER MASK DETAILS
NOT TO SCALE

4227086/A 09/2021

NOTES: (continued)

3. Final dimensions may vary due to manufacturing tolerance considerations and also routing constraints.
   See Texas Instruments Literature No. SNVA009 (www.ti.com/lit/snva009).

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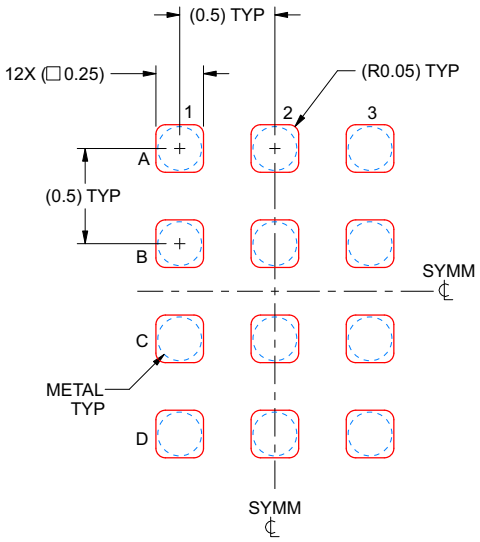
EXAMPLE STENCIL DESIGN

YAH0012-C01

DSBGA - 0.4 mm max height

DIE SIZE BALL GRID ARRAY



SOLDER PASTE EXAMPLE
BASED ON 0.075 mm THICK STENCIL
SCALE: 30X

4227086/A 09/2021

NOTES: (continued)

4. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release.

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PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
TIOS1023DRCR	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1023
TIOS1023DRCR.A	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1023
TIOS1023LYAHR	Active	Production	DSBGA (YAH) | 12	1500 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	T102L
TIOS1023LYAHR.A	Active	Production	DSBGA (YAH) | 12	1500 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	T102L
TIOS1025DRCR	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1025
TIOS1025DRCR.A	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1025
TIOS102DRCR	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	102
TIOS102DRCR.A	Active	Production	VSON (DRC) | 10	5000 | LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	102
TIOS102YAHR	Active	Production	DSBGA (YAH) | 12	1500 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	TS102
TIOS102YAHR.A	Active	Production	DSBGA (YAH) | 12	1500 | LARGE T&R	Yes	SNAGCU	Level-1-260C-UNLIM	-40 to 125	TS102

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts 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.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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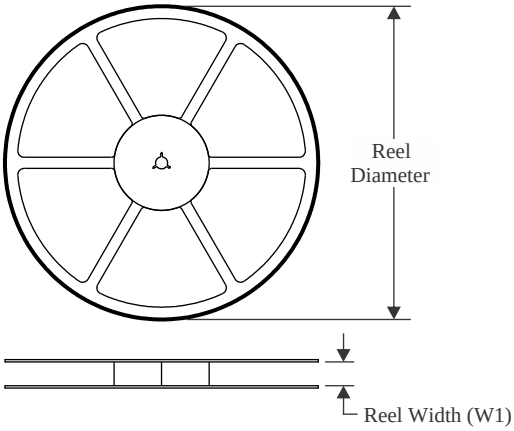
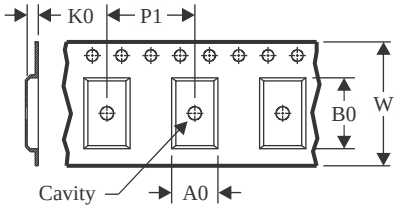
TAPE AND REEL INFORMATION

REEL DIMENSIONS

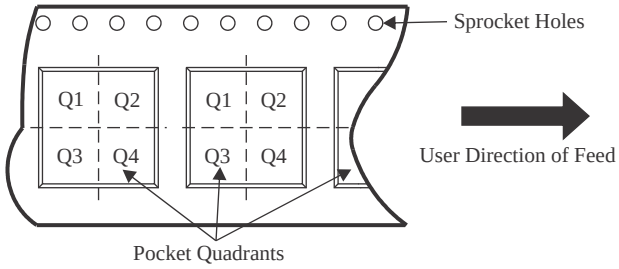


TAPE DIMENSIONS



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

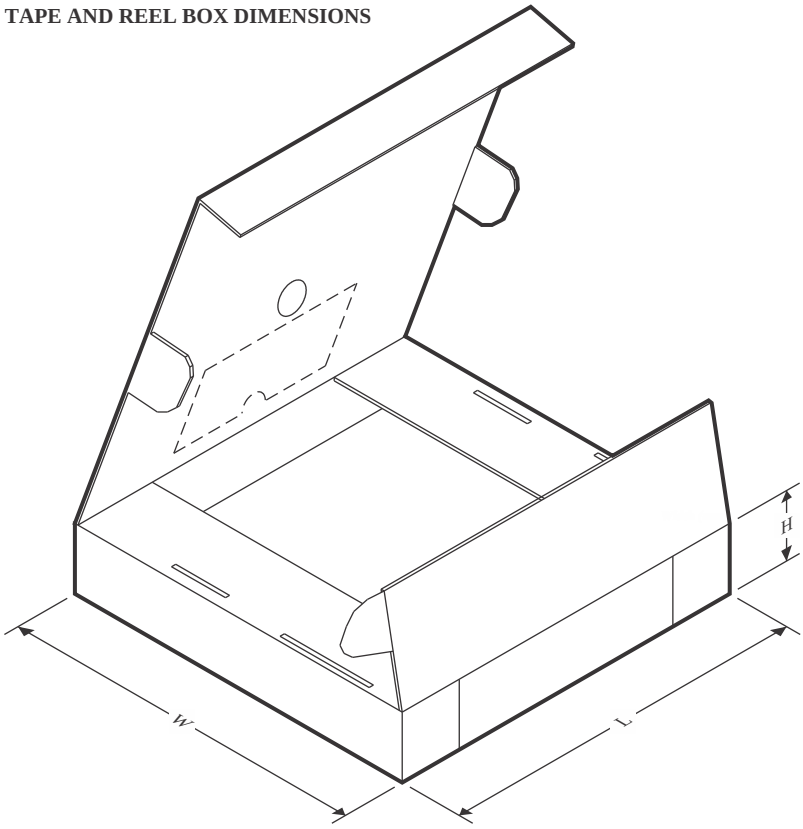
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
TIOS1023DRCR	VSON	DRC	10	5000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
TIOS1023LYAHR	DSBGA	YAH	12	1500	180.0	8.4	1.88	2.63	0.53	4.0	8.0	Q1
TIOS1025DRCR	VSON	DRC	10	5000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
TIOS102DRCR	VSON	DRC	10	5000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
TIOS102YAHR	DSBGA	YAH	12	1500	180.0	8.4	1.88	2.63	0.53	4.0	8.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TIOS1023DRCR	VSON	DRC	10	5000	367.0	367.0	35.0
TIOS1023LYAHR	DSBGA	YAH	12	1500	182.0	182.0	20.0
TIOS1025DRCR	VSON	DRC	10	5000	367.0	367.0	35.0
TIOS102DRCR	VSON	DRC	10	5000	367.0	367.0	35.0
TIOS102YAHR	DSBGA	YAH	12	1500	182.0	182.0	20.0

GENERIC PACKAGE VIEW

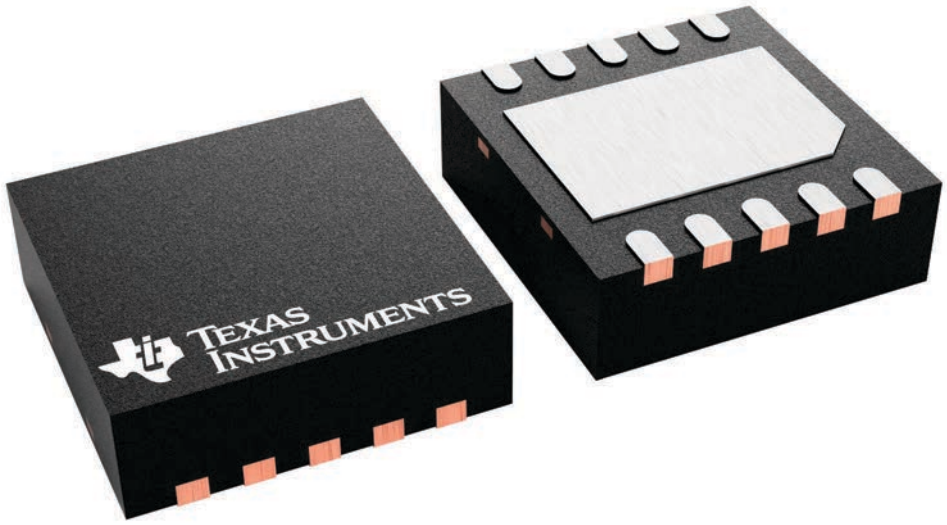
DRC 10

VSON - 1 mm max height

3 x 3, 0.5 mm pitch

PLASTIC SMALL OUTLINE - NO LEAD

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



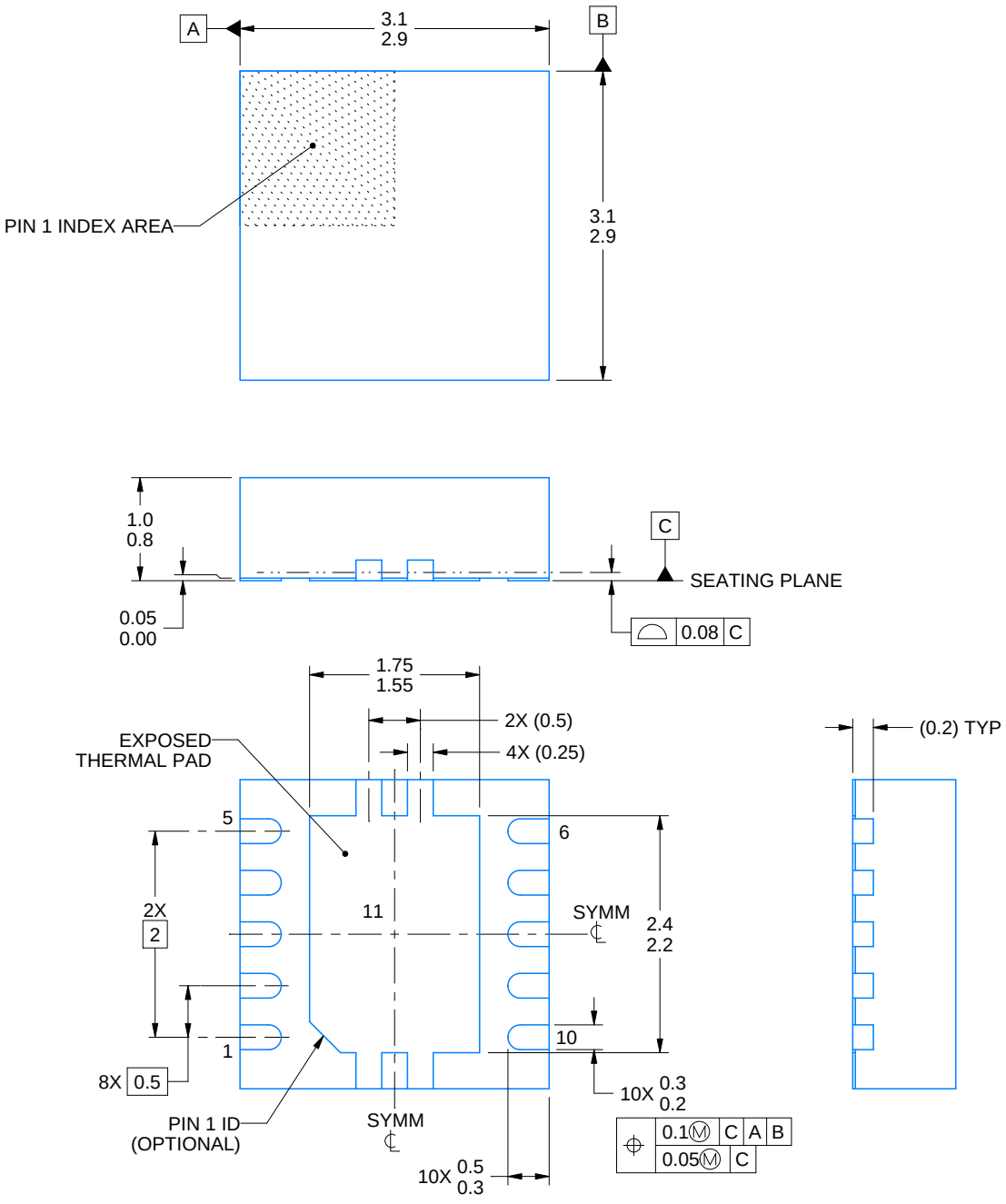
4226193/A

DRC0010V

PACKAGE OUTLINE

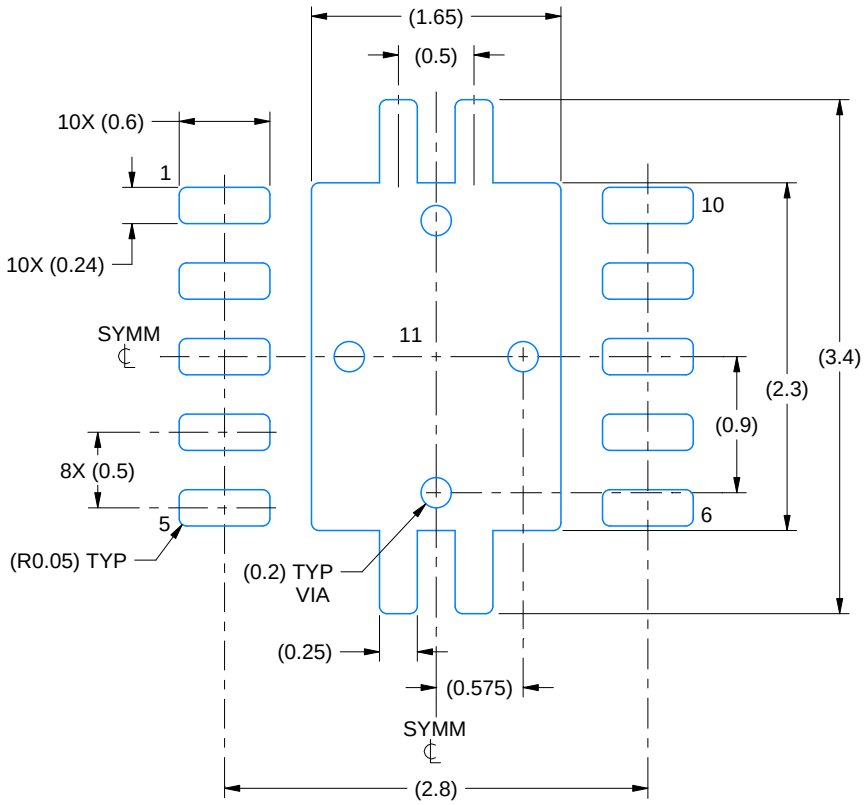
VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

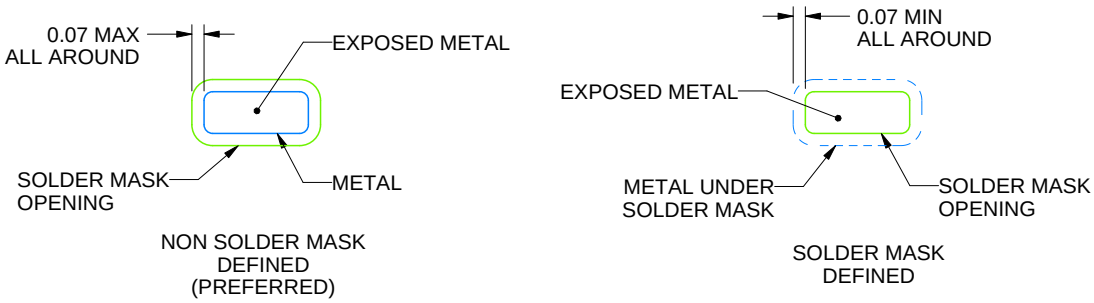


NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for optimal thermal and mechanical performance.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:20X



SOLDER MASK DETAILS

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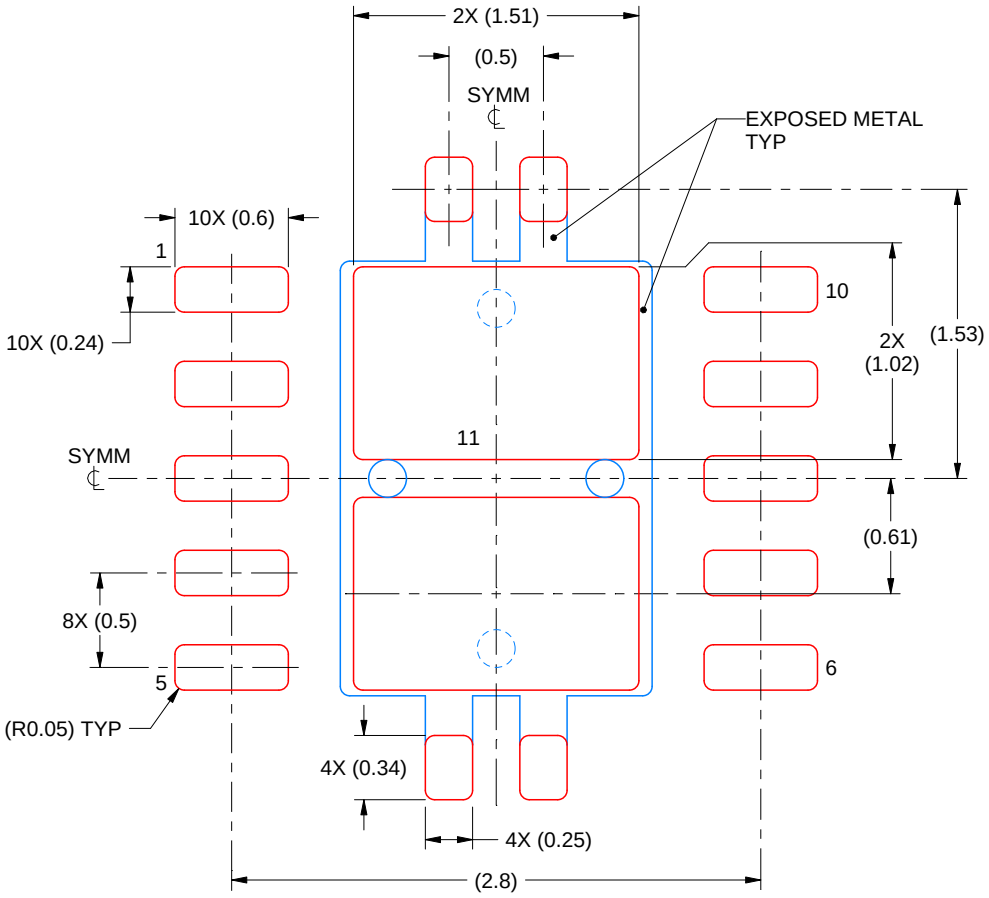
NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 11:
80% PRINTED SOLDER COVERAGE BY AREA
SCALE:25X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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