

Dual High Efficiency Synchronous MOSFET Driver

Check for Samples: **TPS51601A**

FEATURES

- **High Voltage Synchronous Buck Driver**
- **Integrated Boost Switch for Bootstrap Action**
- **Adaptive Dead Time Control and Shoot-through Protection**
- **0.4- Ω Sink Resistance for Low-side Drive**
- **1.0- Ω Source Resistance for High-side Drive**
- **SKIP Pin to Improve Light-Load Efficiency**
- **Adaptive Zero-Crossing Detection for Optimal Light-Load Efficiency**
- **8-Pin 3 mm \times 3 mm SON (DRB) Package**

DESCRIPTION

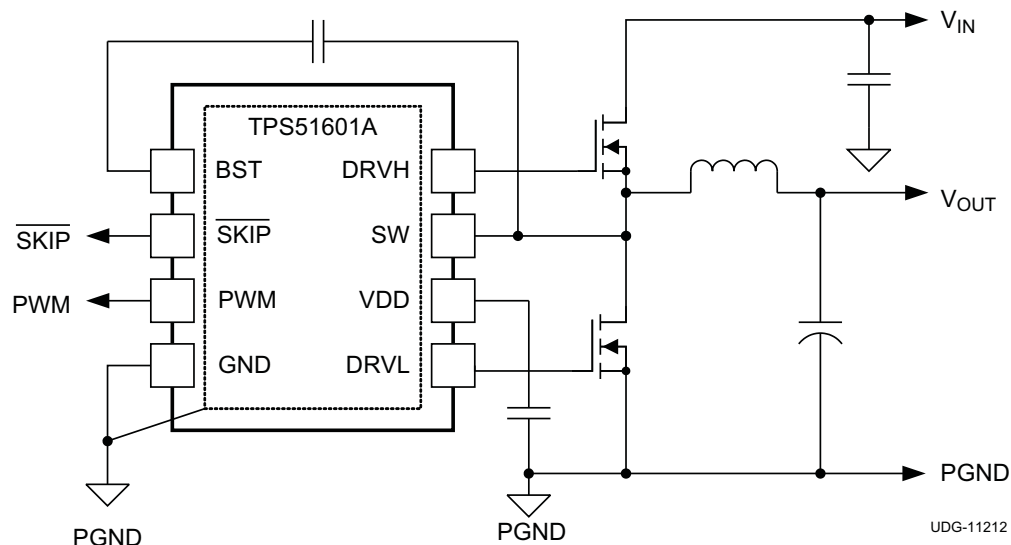
The TPS51601A is a synchronous buck MOSFET driver with integrated boost switch. This high-performance driver is capable of driving high-side and low-side side N-channel FETs with the highest speed and lowest switching loss. Adaptive dead-time control and shoot-through protection are included.

The TPS51601A is available in the space-saving 8-pin 3 mm × 3 mm SON package and operates between -40°C and 105°C.

APPLICATIONS

- **Mobile core regulator products**
- **High frequency DC-DC Converters**
- **High input voltage DC-DC converters**
- **Multiphase DC-DC converters**

SIMPLIFIED APPLICATION



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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of the Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

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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.

ORDERING INFORMATION⁽¹⁾⁽²⁾

T _A	PACKAGE	ORDERABLE NUMBER	PINS	TRANSPORT MEDIA	MINIMUM QUANTITY	ECO PLAN
-40°C to 105°C	Plastic Small Outline No-Lead (SON)	TPS51601ADRBT	8	Tape-and-reel (large)	250	Green (RoHS and no Sb/Br)
		TPS51601ADRBR		Tape-and-reel (small)	3000	

- (1) For the most current package and ordering information see the *Package Option Addendum* at the end of this document, or see the TI web site at www.ti.com.
- (2) Package drawings, thermal data, and symbolization are available at www.ti.com/packaging.

ABSOLUTE MAXIMUM RATINGS⁽¹⁾⁽²⁾⁽³⁾

		MIN	MAX	UNIT
Input voltage	VDD	-0.3	6	V
	PWM, $\overline{\text{SKIP}}$	-0.3	6	
Output voltages	BST to SW	-0.3	6	V
	DRVH to SW	-0.3	6	
	DRVL	-0.3	6	
	SW	-1	32	
Ground	GND	-0.3	0.3	V
Operating junction temperature, T _J		-40	125	°C
Storage temperature, T _{stg}		-55	150	°C

- (1) Stresses beyond those listed in this table may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated in the **RECOMMENDED OPERATING CONDITIONS** table is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) All voltage values are with respect to the network ground terminal unless otherwise noted.
- (3) Voltage values are with respect to the corresponding LL terminal.

THERMAL INFORMATION

THERMAL METRIC ⁽¹⁾		TPS51601	UNITS
		DRB	
		8 PINS	
θ_{JA}	Junction-to-ambient thermal resistance ⁽²⁾	42.6	°C/W
θ_{JCTop}	Junction-to-case (top) thermal resistance ⁽³⁾	3.0	
θ_{JB}	Junction-to-board thermal resistance ⁽⁴⁾	18.9	
Ψ_{JT}	Junction-to-top characterization parameter ⁽⁵⁾	62.1	
Ψ_{JB}	Junction-to-board characterization parameter ⁽⁶⁾	19.1	
θ_{JCbott}	Junction-to-case (bottom) thermal resistance ⁽⁷⁾	12.7	

- (1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](http://www.ti.com/lit/an/spra953).
- (2) The junction-to-ambient thermal resistance under natural convection is obtained in a simulation on a JEDEC-standard, high-K board, as specified in JESD51-7, in an environment described in JESD51-2a.
- (3) The junction-to-case (top) thermal resistance is obtained by simulating a cold plate test on the package top. No specific JEDEC-standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.
- (4) The junction-to-board thermal resistance is obtained by simulating in an environment with a ring cold plate fixture to control the PCB temperature, as described in JESD51-8.
- (5) The junction-to-top characterization parameter, Ψ_{JT} , estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA} , using a procedure described in JESD51-2a (sections 6 and 7).
- (6) The junction-to-board characterization parameter, Ψ_{JB} , estimates the junction temperature of a device in a real system and is extracted from the simulation data for obtaining θ_{JA} , using a procedure described in JESD51-2a (sections 6 and 7).
- (7) The junction-to-case (bottom) thermal resistance is obtained by simulating a cold plate test on the exposed (power) pad. No specific JEDEC standard test exists, but a close description can be found in the ANSI SEMI standard G30-88.

RECOMMENDED OPERATING CONDITIONS

		MIN	TYP	MAX	UNIT
Input voltages	VDD	4.5		5.5	V
	PWM, $\overline{\text{SKIP}}$	-0.1		5.5	
Output voltages	BST to SW	-0.1		5.5	V
	DRVH to SW	-0.1		5.5	
	DRVL	-0.1		5.5	
	SW	-1		30	
Ground	GND	-0.1		0.1	V
Operating junction temperature, T_J		-40		105	°C

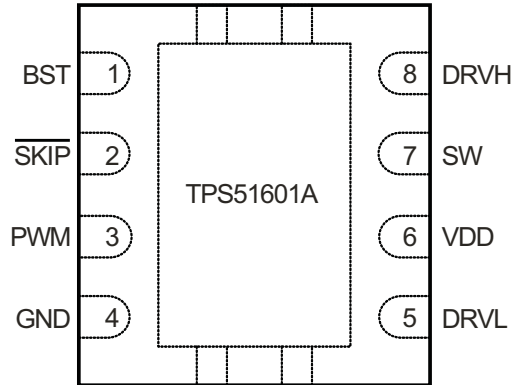
ELECTRICAL CHARACTERISTICS

over operating free-air temperature range, $V_{DD} = 5.0\text{ V}$ (unless otherwise noted)

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
SUPPLY, UNDERVOLTAGE LOCKOUT						
I _{VDD}	VDD bias current	PWM = HI		160	220	μA
		PWM = LO		500		
		PWM = float		50		
V _{UVLO(h)}	VDD UVLO 'OK' threshold		3.5	3.7	3.9	V
V _{UVLO(l)}	VDD UVLO fault threshold		3.3	3.5	3.7	V
V _{UVLO(hys)}	VDD UVLO hysteresis			0.2		V
PWM INPUT						
V _{IH(pwm)}	HIGH-level PWM input		4.0			V
V _{IL(pwm)}	LOW-level PWM input				0.7	V
R _{VDD-PWM}	VDD-to-PWM resistance			30		kΩ
R _{PWM-GND}	PWM-to-GND resistance			20		kΩ
V _{PWM(tri)}	PWM tri-state voltage	PWM floating	1.5		2.5	V
SKIP INPUT						
V _{IH(skip)}	HIGH-level $\overline{\text{SKIP}}$ input logic		2.2			V
V _{IL($\overline{\text{skip}}$)}	LOW-level $\overline{\text{SKIP}}$ input logic				0.7	V
I _{L$\overline{\text{SKIP}}$-GND}	$\overline{\text{SKIP}}$ -to-GND leakage	V $\overline{\text{SKIP}}$ = 5 V			2	μA
GATE DRIVE OUTPUT						
R _{DRVH}	DRVH on resistance	Source resistance, (V _{BST} – V _{LL}) = 5 V, HIGH-state (V _{BST} – V _{DRVH}) = 0.1 V		1.0	2.5	Ω
		Sink resistance, (V _{BST} – V _{LL}) = 5 V, LOW-state (V _{DRVH} – V _{LL}) = 0.1 V		0.5	1.5	
R _{DRVL}	DRVL on resistance	Source resistance, (V _{VDD} – GND) = 5 V, HIGH-state, V _{VDD} – V _{DRVL}) = 0.1V		0.8	1.5	Ω
		Sink resistance, V _{VDD} – GND = 5 V LOW-state, V _{DRVL} – GND = 0.1 V		0.4	1.0	
TIMING CHARACTERISTICS						
t _{DRVH}	DRVH transition time	DRVH rising, C _{DRVH} = 3.3 nF		15	35	ns
		DRVH falling, C _{DRVH} = 3.3 nF		10	35	
t _{DRVL}	DRVL transition time	DRVL rising, C _{DRVL} = 3.3 nF		15	35	ns
		DRVL, falling, C _{DRVL} = 3.3 nF		10	35	
t _{NONOVL P}	Driver non-overlap time	DRVH LOW to DRVL HIGH	5	20		ns
		DRVL LOW to DRVH HIGH	5	20		
t _{DLY(rise)}	PWM rising to drive output delay	DCM mode: PWM rising to DRVH rising		25		ns
		CCM mode: PWM rising to DRVL falling		25		
t _{DLY(fall)}	PWM falling to drive output delay	PWM falling to DRVH falling		25		ns
t _{DLY1}	3-state propagation delay to LOW	PWM floating to PWM LOW		40		ns
t _{DLY2}	3-state propagation delay to HIGH	PWM floating ti PWM HIGH		50		ns
t _{TS(hold)}	3-state hold-off time	PWM entering tri-state from HIGH or LOW		150		ns
t _{$\overline{\text{SKIP}}$(pdh)}	$\overline{\text{SKIP}}$ LOW-to-HIGH propagation delay			15		ns
t _{$\overline{\text{SKIP}}$(pdl)}	$\overline{\text{SKIP}}$ HIGH-to-LOW propagation delay			15		ns
t _{DRVH(min)}	Minimum DRVH width				80	ns
t _{DRVL(min)}	Minimum DRVL width	Minimum DRVL width before Zero-crossing can turn OFF DRVL		400	500	ns
BOOT-STRAP SWITCH (BST)						
R _{BST}	BST switch on-resistance	I _{BST} = 10 mA	4	10	20	Ω
I _{BST(leak)}	BST switch leakage current	V _{BST} = 34 V, V _{SW} = 28 V			2	μA

DEVICE INFORMATION

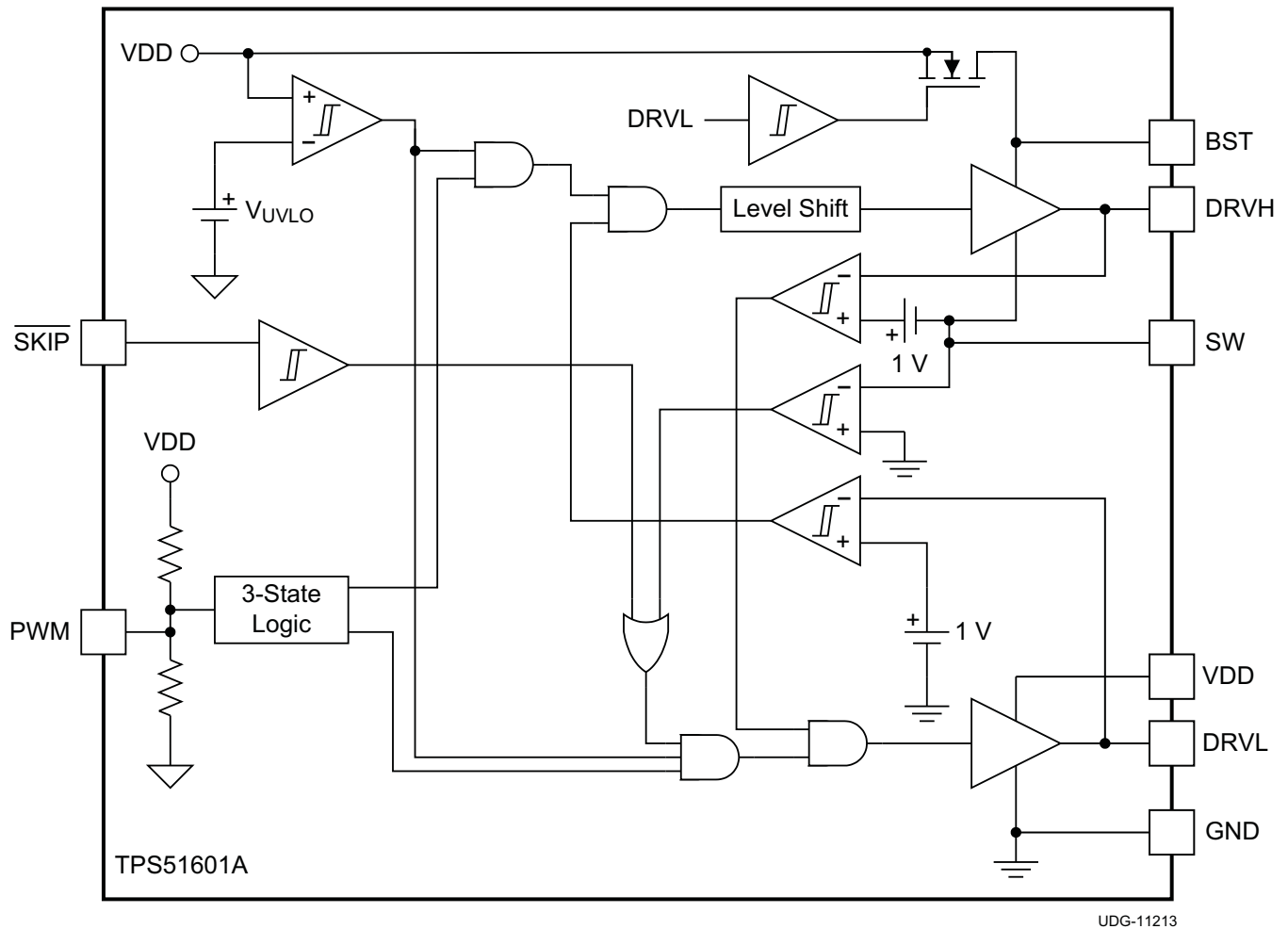
**QFN (DRB) PACKAGE
8 PINS
(TOP VIEW)**



PIN FUNCTIONS

PIN NAME	I/O	DESCRIPTION
BST	I	High-side, N-channel FET bootstrap voltage input, supply for high-side driver
DRVH	O	High-side, N-channel FET gate drive output.
DRVL	O	Low-side, synchronous N-channel FET gate drive output
GND	–	Low-side, synchronous N-channel FET gate drive return and device ground.
PWM	I	PWM input. This defines the on-time for the high-side FET of the converter. Input is coming from PWM controller. A 3-state voltage on this pin turns OFF both the high-side (DRVH) and low-side drivers (DRVL)
PwrPAD	–	Thermal pad. This is a non-electrical pad and is recommended to be connected to GND.
SKIP	I	If SKIP is LOW, then the inductor current zero-crossing is active and DRVL turns off when inductor current goes to zero. (discontinuous conduction mode active) If SKIP is HIGH, then the DRVL stays HIGH as long as PWM stays LOW. (forced continuous conduction mode)
SW	I/O	High-side N-channel FET gate drive return. Also used as input for sensing inductor current for zero-crossing.
VDD	I	5-V power supply input for the device.

FUNCTIONAL BLOCK DIAGRAM



TYPICAL CHARACTERISTICS

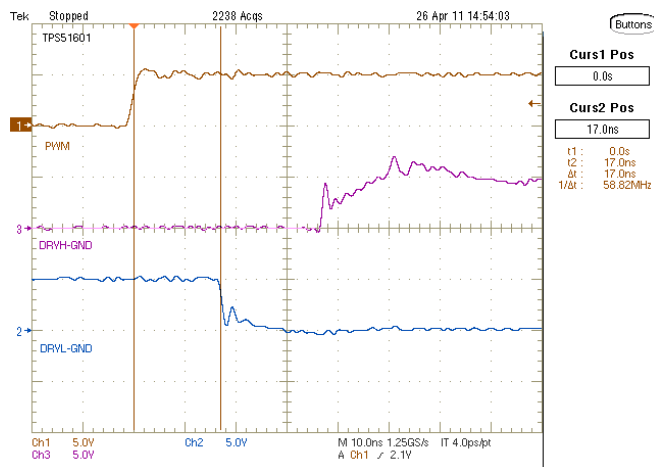


Figure 1. PWM Rising to DRV_L Falling

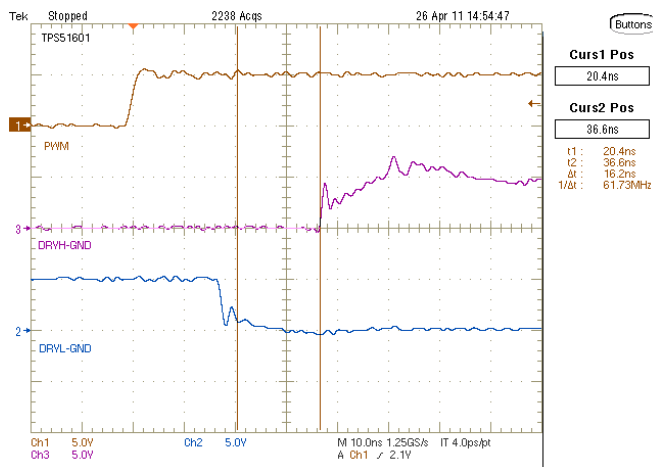


Figure 2. DRV_L Falling to DRVH rising

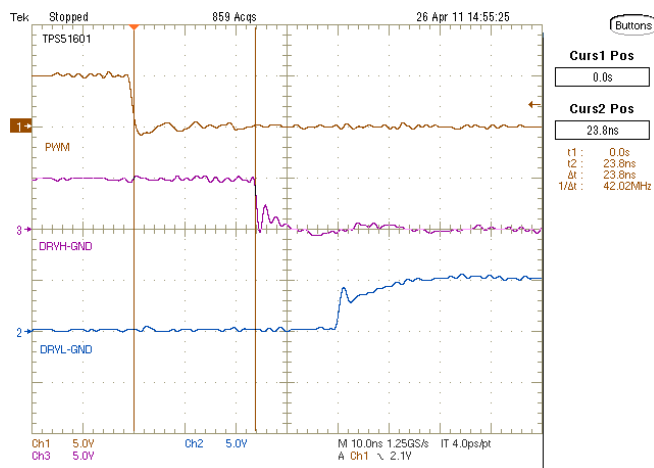


Figure 3. PWM Falling to DRVH Falling

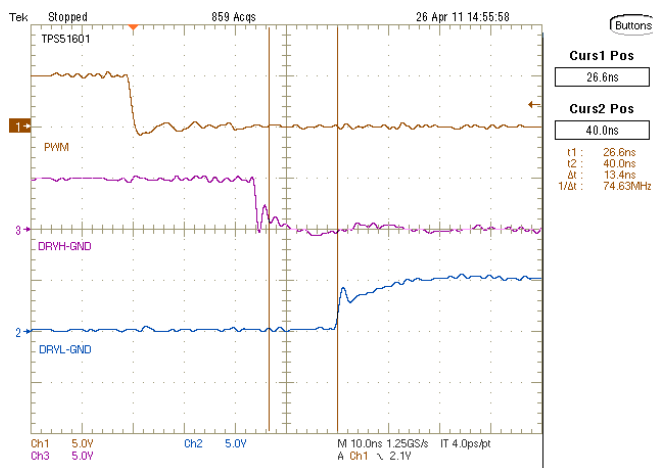


Figure 4. SW-Node Falling to DRV_L Rising

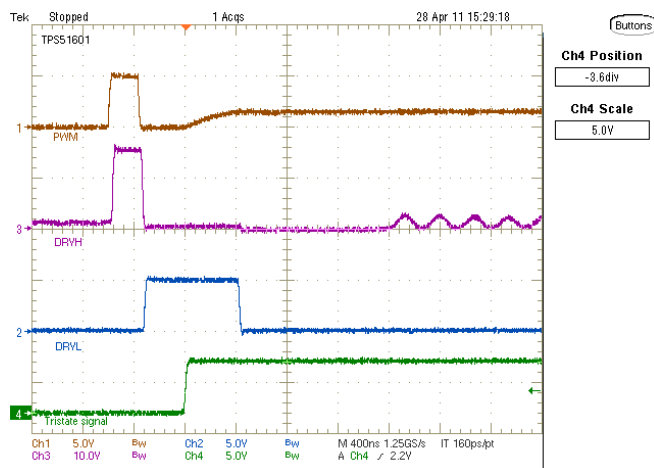


Figure 5. 3-State Entry on DRV_L

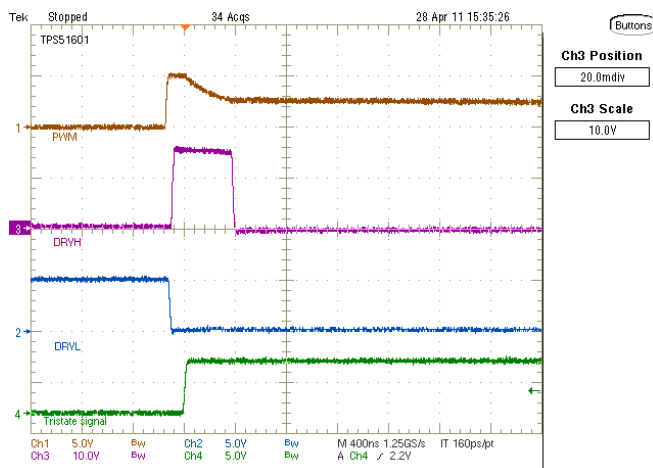


Figure 6. 3-State Entry on DRVH

TYPICAL CHARACTERISTICS (continued)

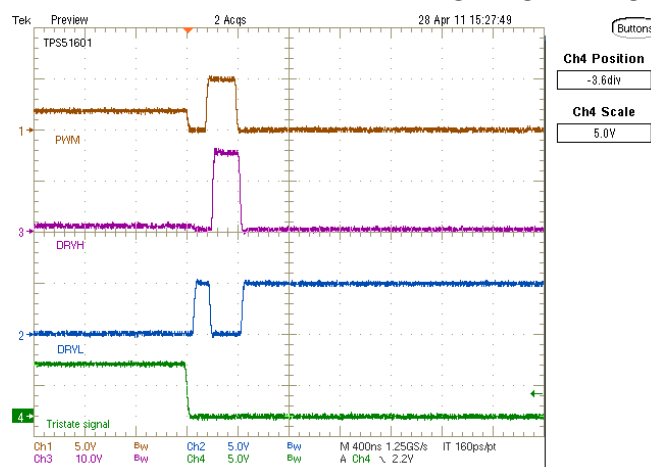


Figure 7. 3-State Exit on DRV_L

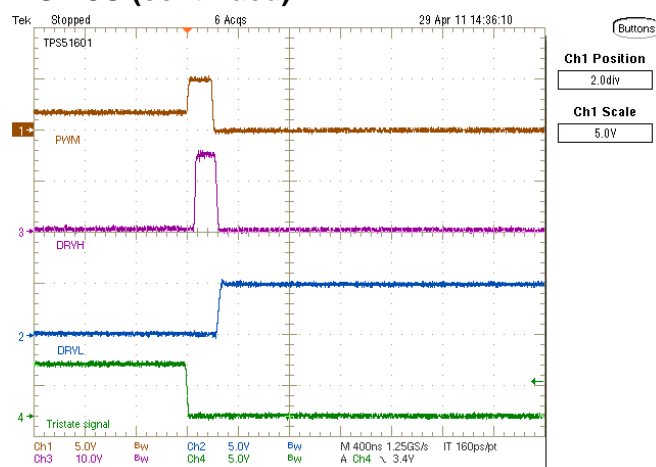


Figure 8. 3-State Exit on DRV_H

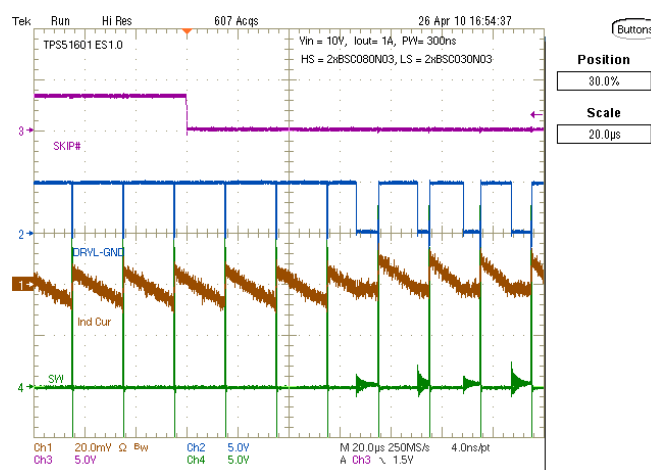


Figure 9. FCCM Exit and SKIP Mode Entry

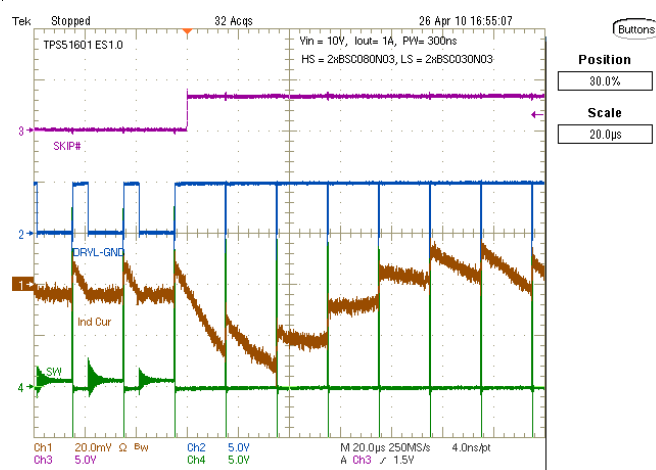


Figure 10. SKIP Mode Exit and FCCM Entry

TYPICAL CHARACTERISTICS

For Figure 11 through Figure 16 high-side FET used is CSD17302Q5A and low-side FET used is CSD17303Q5.

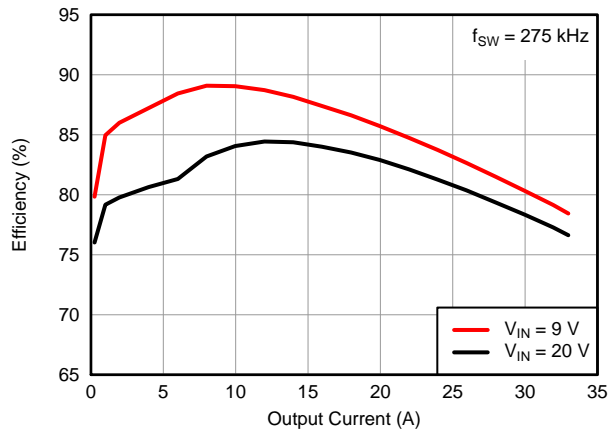


Figure 11. Efficiency vs. Output Current

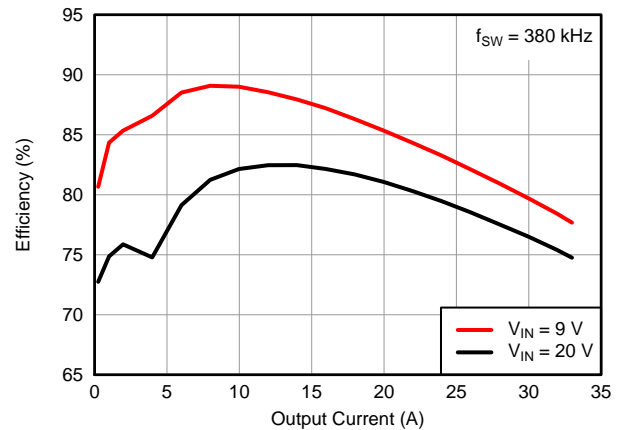


Figure 12. Efficiency vs. Output Current

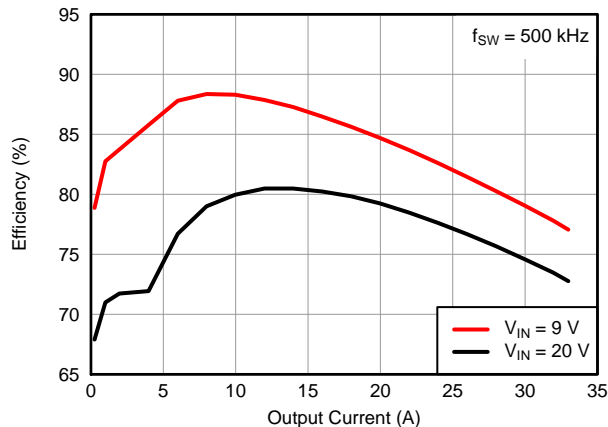


Figure 13. Efficiency vs. Output Current

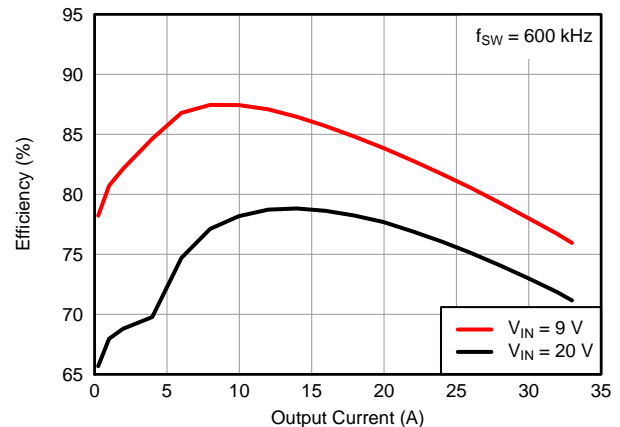


Figure 14. Efficiency vs. Output Current

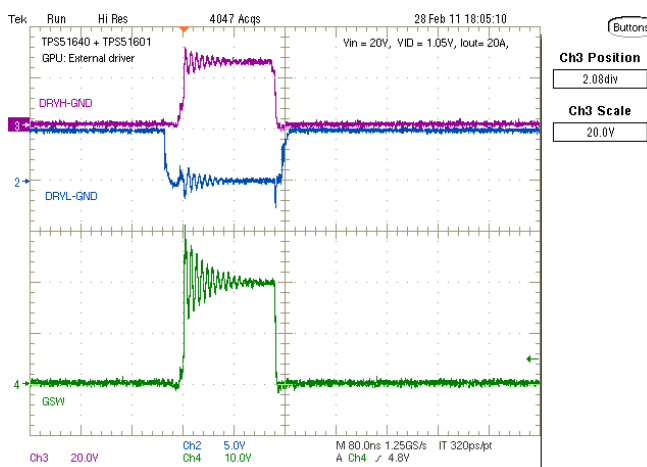


Figure 15. Gate Driver Waveforms Using TPS51640 Controller and TPS51601A Driver at $V_{IN} = 9\text{ V}$

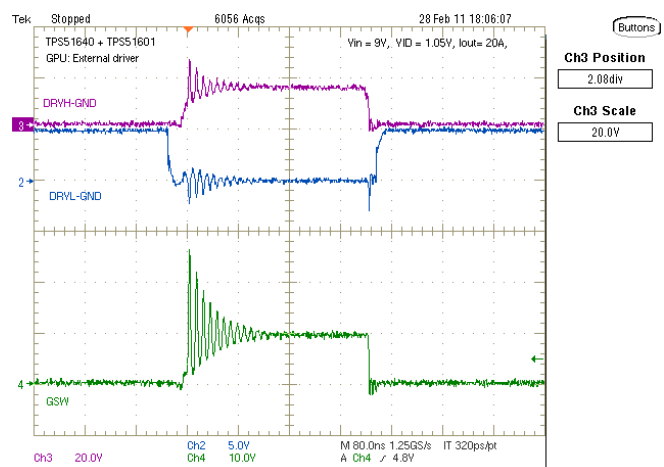


Figure 16. Gate Driver Waveforms Using TPS51640 Controller and TPS51601A Driver at $V_{IN} = 20\text{ V}$

DETAILED DESCRIPTION

UVLO

The TPS51601A includes an undervoltage lockout circuit that disables the driver and external power FETs in an OFF state when the input supply voltage, (V_{DD}) is insufficient to drive external power FET reliably. During the power-up sequence, both gate drive outputs remain low until the VDD voltage reaches UVLO-H threshold, typically 3.7 V. Once the UVLO threshold is reached, the condition of the gate drive outputs is defined by the input PWM and SKIP signals. During the power-down sequence, the UVLO threshold is set lower, typically 3.5 V.

PWM Input

Once the input supply voltage is above the UVLO threshold, the gate drive outputs are defined by the PWM input and $\overline{\text{SKIP}}$ input. Prior to PWM going HIGH, both the gate drive outputs, (DRVH and DRVL) are held LOW. The DRVL is LOW until the first PWM HIGH pulse to support pre-biased start-up. Once PWM goes HIGH for the first time, DRVH goes HIGH. Then, when PWM goes LOW, DRVH goes LOW first. After the non-overlap time, DRVL goes HIGH.

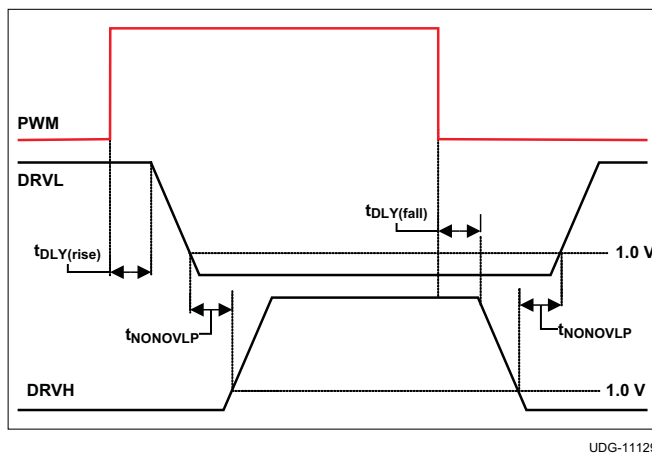


Figure 17. Continuous Conduction Mode Waveforms

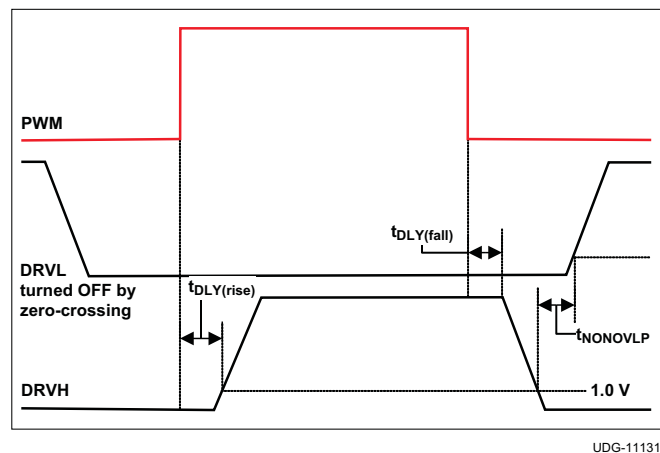


Figure 18. Discontinuous Conduction Mode Waveforms

SKIP/FCCM Mode Operation

The TPS51601A can be configured in two ways. When used as the external driver for Phase 1, this pin connects to the corresponding SKIP pin of the PWM controller. The SKIP pin is active low signal. This means when SKIP is low, then the zero crossing detection circuit of the driver is active. When $\overline{\text{SKIP}}$ is high, the zero-crossing detector is disabled and the converter operates in forced continuous conduction mode (FCCM).

Adaptive Zero-Crossing

The TPS51601A has an adaptive zero-crossing detector. Zero crossing accuracy is detected by checking the switch-node voltage at an appropriate time after the low-side FET is turned OFF by DRVL going low. Then the zero-crossing comparator offset is updated based on previous result. After several zero-crossing events, the comparator offset is optimized to give the best efficiency.

Adaptive Dead-Time Control (Anti-Cross Conduction)

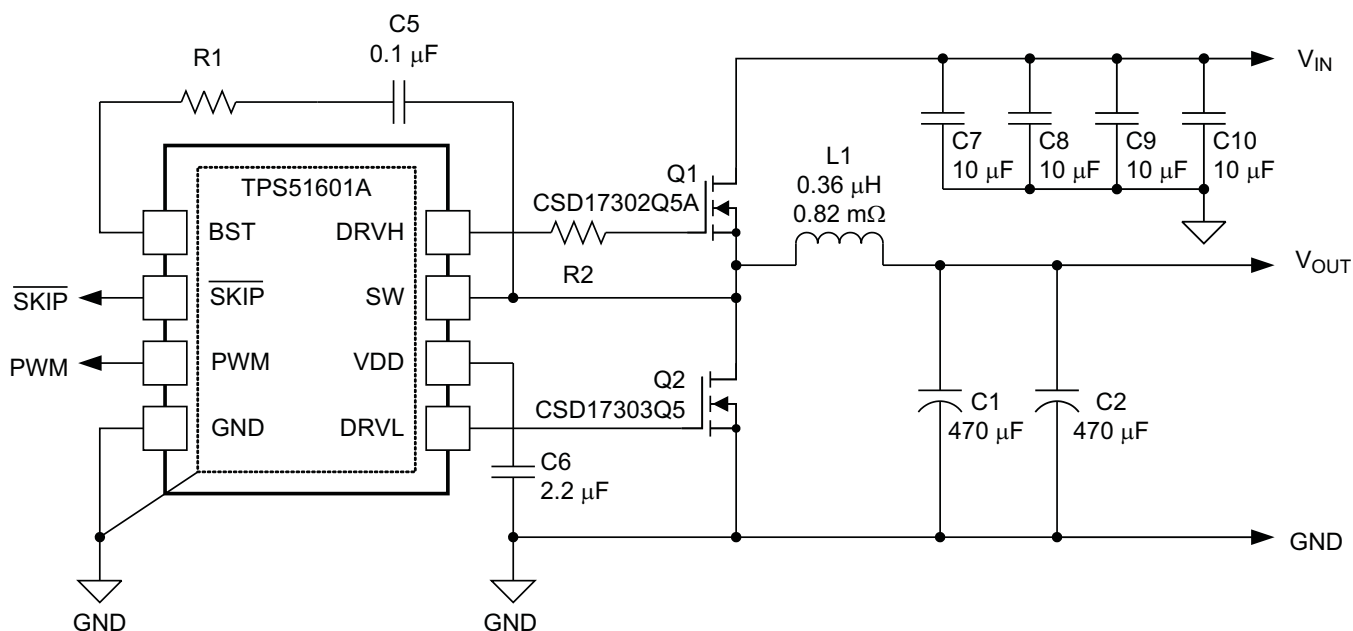
The TPS51601A has an adaptive dead-time control logic to minimize the non-overlap time between DRVH and DRVL signals. The internal signal to the low-side driver goes HIGH only when the DRVH-SW voltage goes below approximately 1 V and DRVH goes below approximately 1 V to ensure the high-side MOSFET has turned OFF. Additional driver delays ensure that there is some non-overlap time between DRVH falling edge and DRVL rising edge. Similarly, the internal signal to the DRVH goes high only after DRVL-GND goes below 1 V.

Integrated Boost-Switch

To maintain a BST-SW voltage close to VDD (to get lower conduction losses on the high-side FET), the conventional diode from VDD to BST is replaced by a FET which is gated by DRVH signal.

APPLICATION INFORMATION

Figure 19 shows a typical application. Resistors R1 and R2 can be used if necessary to reduce the switch-node ringing.



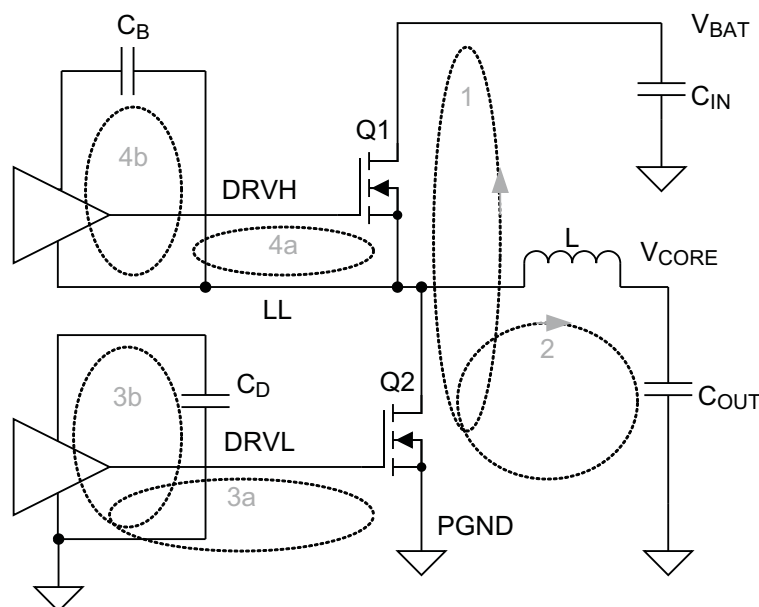
UDG-11214

Figure 19. Typical Application

PCB Layout Guidelines

Figure 20 shows the primary current loops in each phase, numbered in order of importance. The most important loop to minimize the area of is Loop 1, the path from the input capacitor through the high-side and low-side FETs, and back to the capacitor through ground. Loop 2 is from the inductor through the output capacitor, ground and Q2. The layout of the low side gate drive (loops 3a and 3b) is important. The guidelines for gate drive layout are:

- Make the low-side gate drive as short as possible (1 inch or less preferred).
- Make the DRVH width to length ratio of 1:10, wider (1:5) if possible.
- If changing layers is necessary, use at least two vias.
- Decouple VDD to GND (C_D in Figure 20) with at ceramic capacitor with a value of least a 2.2- μ F.



UDG-11040

Figure 20. Minimizing Current Loops

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)
TPS51601ADRBR	Active	Production	SON (DRB) 8	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A
TPS51601ADRBR.B	Active	Production	SON (DRB) 8	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A
TPS51601ADRBRG4	Active	Production	SON (DRB) 8	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A
TPS51601ADRBRG4.B	Active	Production	SON (DRB) 8	3000 LARGE T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A
TPS51601ADRBT	Active	Production	SON (DRB) 8	250 SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A
TPS51601ADRBT.B	Active	Production	SON (DRB) 8	250 SMALL T&R	Yes	NIPDAU	Level-2-260C-1 YEAR	-40 to 105	601A

(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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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



*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
TPS51601ADRBR	SON	DRB	8	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
TPS51601ADRBRG4	SON	DRB	8	3000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
TPS51601ADRBT	SON	DRB	8	250	180.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS51601ADRBR	SON	DRB	8	3000	346.0	346.0	33.0
TPS51601ADRBRG4	SON	DRB	8	3000	346.0	346.0	33.0
TPS51601ADRBT	SON	DRB	8	250	210.0	185.0	35.0

DRB 8

GENERIC PACKAGE VIEW

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4203482/L



VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD

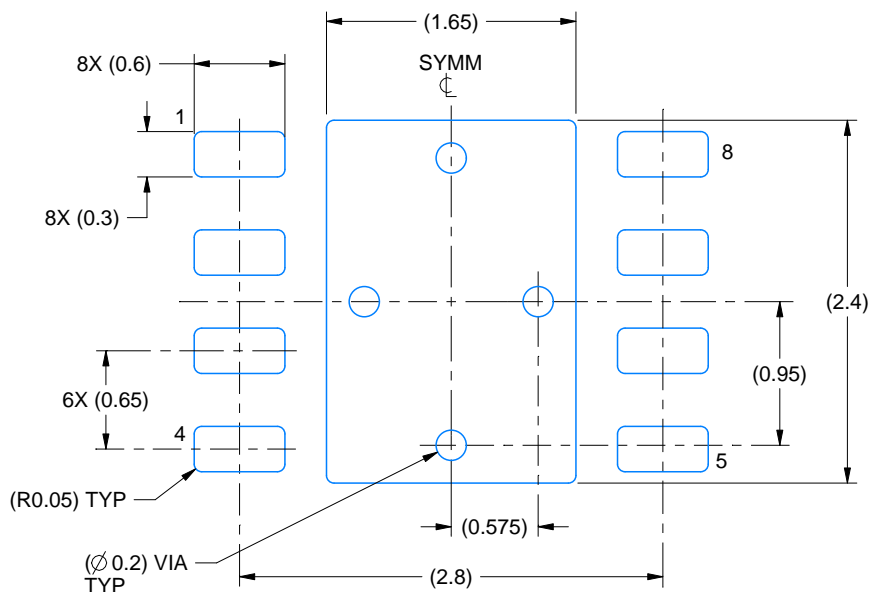


1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

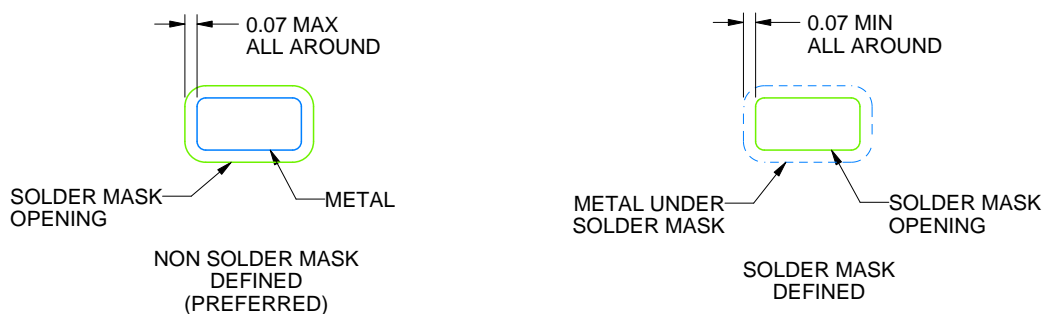
DRB0008B

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE
SCALE:20X



SOLDER MASK DETAILS

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NOTES: (continued)

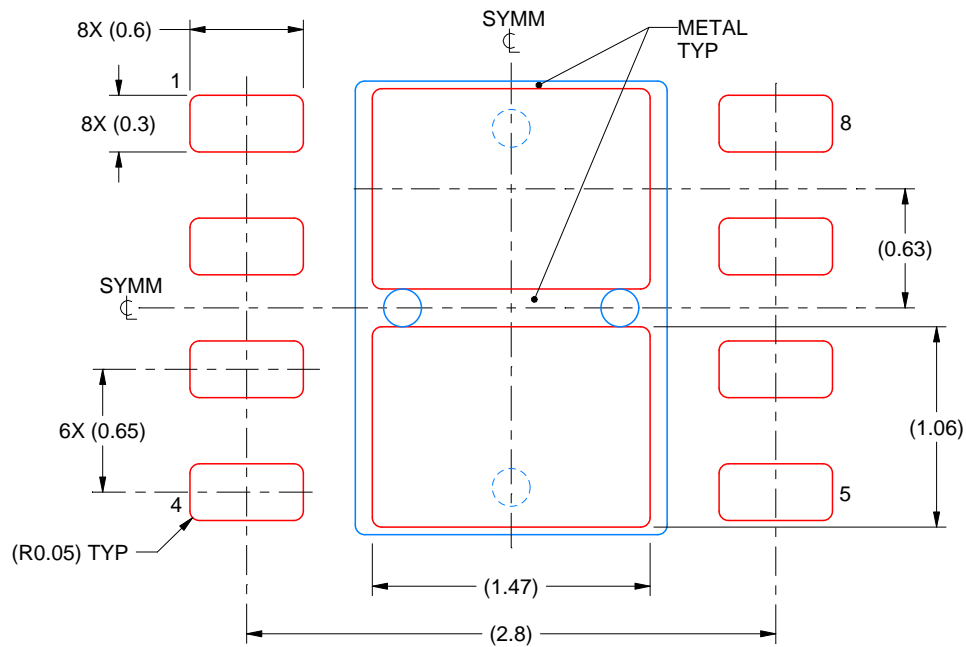
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/sluea271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

EXAMPLE STENCIL DESIGN

DRB0008B

VSON - 1 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD
81% 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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