ULTRA-LOW POWER, LOW INPUT VOLTAGE, CURRENT-LIMITED LOAD SWITCH WITH SHUT-OFF, AUTO-RESTART, AND OVER-CURRENT CONDITION TIME-OUT

Check for Samples: TPS22946

FEATURES

- **Ultra-Low Quiescent Current 1 μA (typ) at V_{IN} = 1.8 V**
- **Input Voltage Range: 1.62 V to 5.5 V**
- **Low ON-Resistance**
  - **r_{ON} = 300 mΩ at V_{IN} = 5.5 V**
  - **r_{ON} = 400 mΩ at V_{IN} = 3.3 V**
  - **r_{ON} = 500 mΩ at V_{IN} = 2.5 V**
  - **r_{ON} = 600 mΩ at V_{IN} = 1.8 V**
- **Selectable Minimum Current Limit: 155 mA, 70 mA, or 30 mA**
- **Integrated Inrush Current Timeout (8 ms)**
- **Shutdown Current: < 1 μA**
- **Thermal Shutdown**
- **Fault Blanking**
- **Auto Restart**
- **Over-Current Condition Timeout (Automatic Disable for Permanent Over-Current)**
- **1.8-V Compatible Control Input**
- **ESD Performance Tested Per JESD 22**
  - **6000-V Human-Body Model (A114-B, Class II)**
- **Tiny WCSP Package 1.4mm x 0.9 mm (YZP)**

APPLICATIONS

- **Fingerprint Module Protection**
- **Portable Consumer Electronics**
- **Mobile Phones**
- **Smartphone**
- **Notebooks**
- **GPS Devices**

DESCRIPTION

The TPS22946 is an ultra-low power load switch that provides protection to systems and loads in high-current conditions. The device contains a 300-mΩ current-limited P-channel MOSFET that can operate over an input voltage range of 1.62 V to 5.5 V. The switch is controlled by an on/off input (ON), which is capable of interfacing directly with low-voltage control signals. The TPS22946 includes thermal shutdown protection that prevents damage to the device when a continuous over-current condition causes excessive heating by turning off the switch.

When the switch current reaches the maximum limit, the TPS22946 operates in a constant-current mode to prohibit excessive currents from causing damage. The current limit can be selected using the CL input: a high CL input sets the current limit to 155 mA, a low CL input sets the current limit to 70 mA, and a floating CL input sets the current limit to 30 mA.

If the constant current condition still persists after 10 ms, the switch is turned off and the fault signal pin (OC) is pulled low. The TPS22946 has an auto-restart feature which turns the switch on again after 70 ms if the ON pin is still active. If the TPS22946 remains in an over-current condition for 5 seconds, the device shuts off until it is turned back on by setting the ON control signal off and then on again.

If the device is used to protect an LDO, the inrush current required by the LDO at startup can, in some cases, exceed the current limit and initiate a blanking (current limiting) condition. TPS22946 provides allowance for this scenario during startup of the LDO by temporarily increasing the current limit to 435-mA for 8-ms after the load switch is enabled.

The TPS22946 is available in space-saving 6-terminal WCSP (YZP) package. It is characterized for operation over the free-air temperature range of –40°C to 85°C.

Table 1. FEATURE LIST

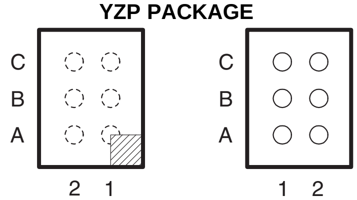
	r_{ON} (TYP) AT 5.5 V	CURRENT LIMIT	INTEGRATED INRUSH CURRENT TIMEOUT	CURRENT LIMIT BLANKING TIME	AUTO-RESTART TIME	OVER-CURRENT TIMEOUT	ENABLE
TPS22946	300 mΩ	30 mA, 70 mA, or 155 mA	Yes	10 ms	70 ms	6 s	Active high

ORDERING INFORMATION(1)

T_A	PACKAGE(2)		ORDERABLE PART NUMBER	TOP-SIDE MARKING(3)
–40°C to 85°C	WCSP – YZP (0.5-mm pitch)	Reel of 3000	TPS22946YZPR	_ _ 5 H _

(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.
(3) The actual top-side marking has two preceding characters to denote year, month and one following character to designate the wafer fab/assembly site. Pin 1 identifier indicates solder-bump composition (1 = SnPb, • = Pb-free).

YZP PACKAGE



Laser Marking View   Bump View

TERMINALS ASSIGNMENTS

C	ON	OC
B	CL	GND
A	V_{IN}	V_{OUT}
	2	**1**

TERMINAL FUNCTIONS

TERMINAL		TYPE	DESCRIPTION
NO.	NAME		
A1	V_{OUT}	O	Output of the power switch
B1	GND	–	Ground
C1	OC	O	Over-current output flag. Active-low open-drain output that indicates an over-current, supply under-voltage, or over-temperature state.
C2	ON	I	On/off control input
B2	CL	I	Current limit selection. CL high is 155-mA current limit, CL low is 70-mA current limit, and CL floating is 30-mA current limit.
A2	V_{IN}	I	Supply. Input to the power switch and the supply voltage for the device

Functional Block Diagram

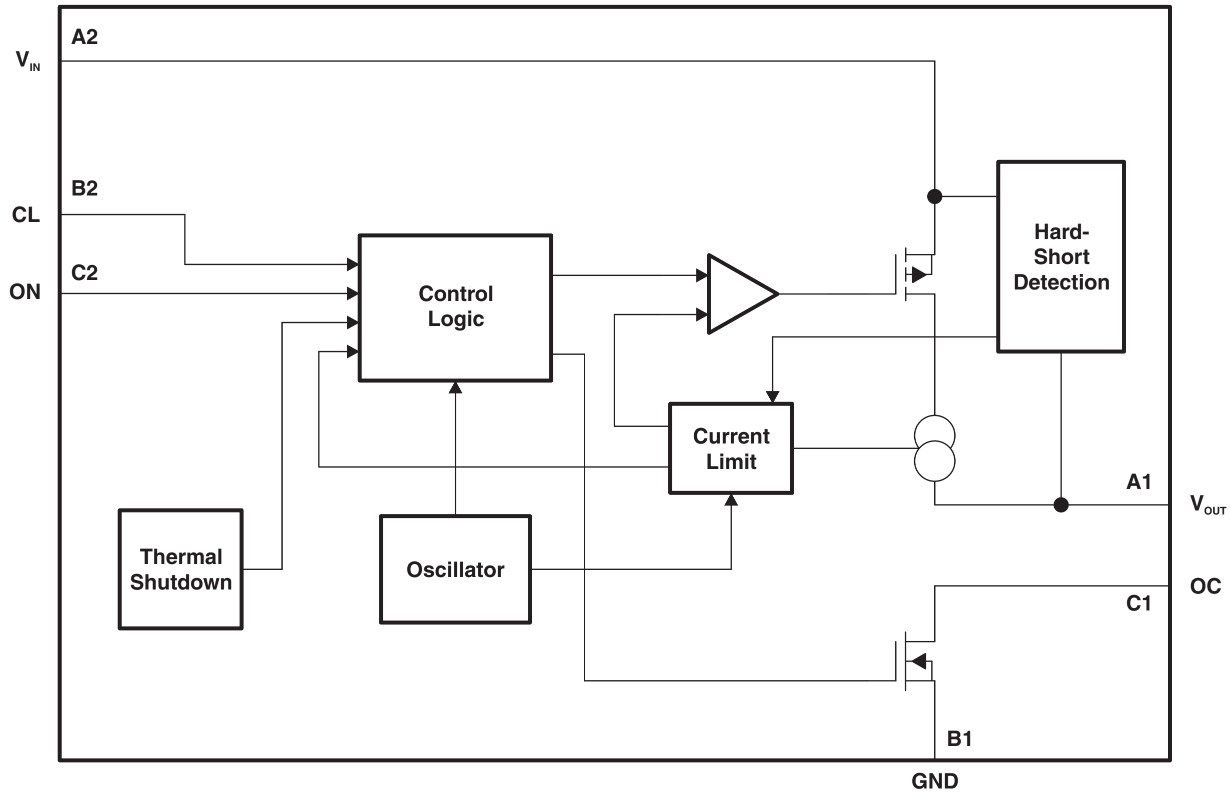


Table 2. FUNCTION TABLE

ON	CL	TPS22946
L	x	V_{IN} to V_{OUT} switch is off (open)
H	x	V_{IN} to V_{OUT} switch is on (closed)
x	H (1)	Current limit set to 155 mA
x	L (1)	Current limit set to 70 mA
x	Float (2)	Current limit set to 30 mA

(1) Resistance to VCC or GND < 100 Ω
(2) Load on CL: C < 100 pF, R > 10 MΩ

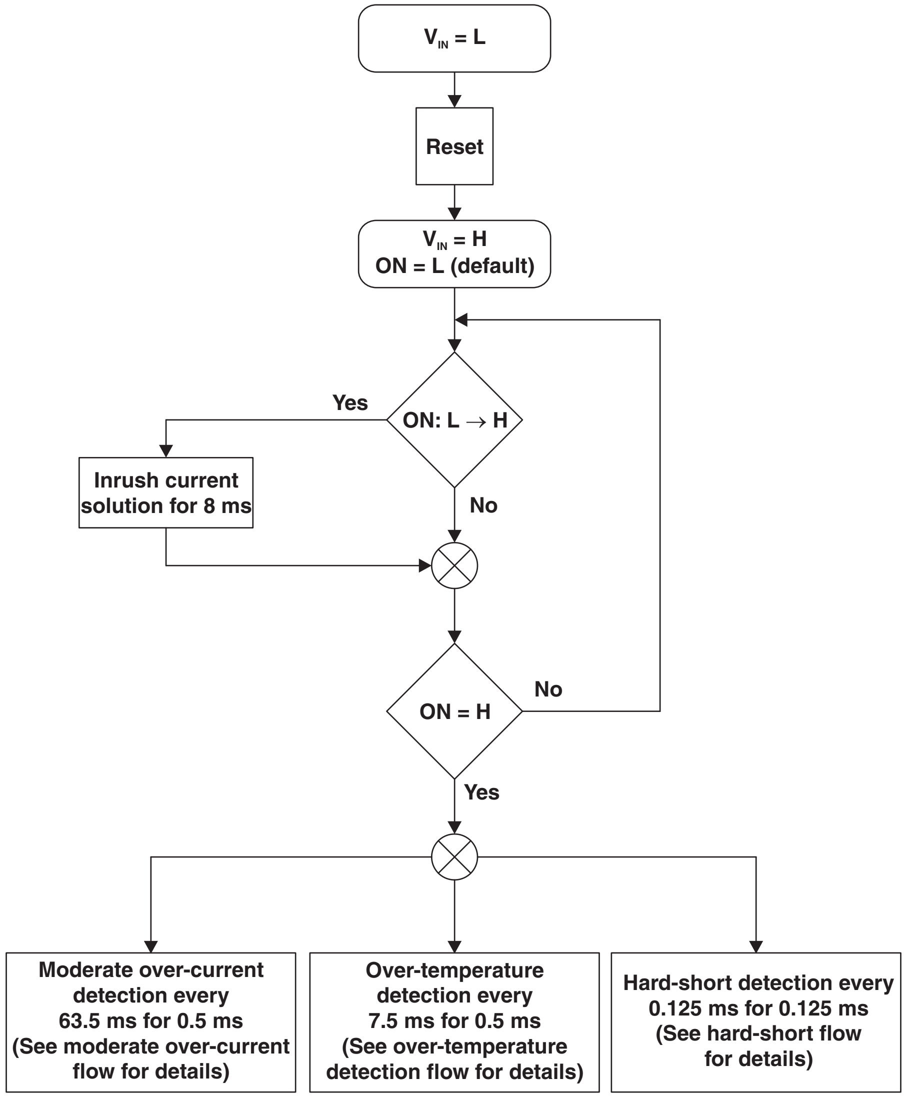


Figure 1. Functional Flow Diagram

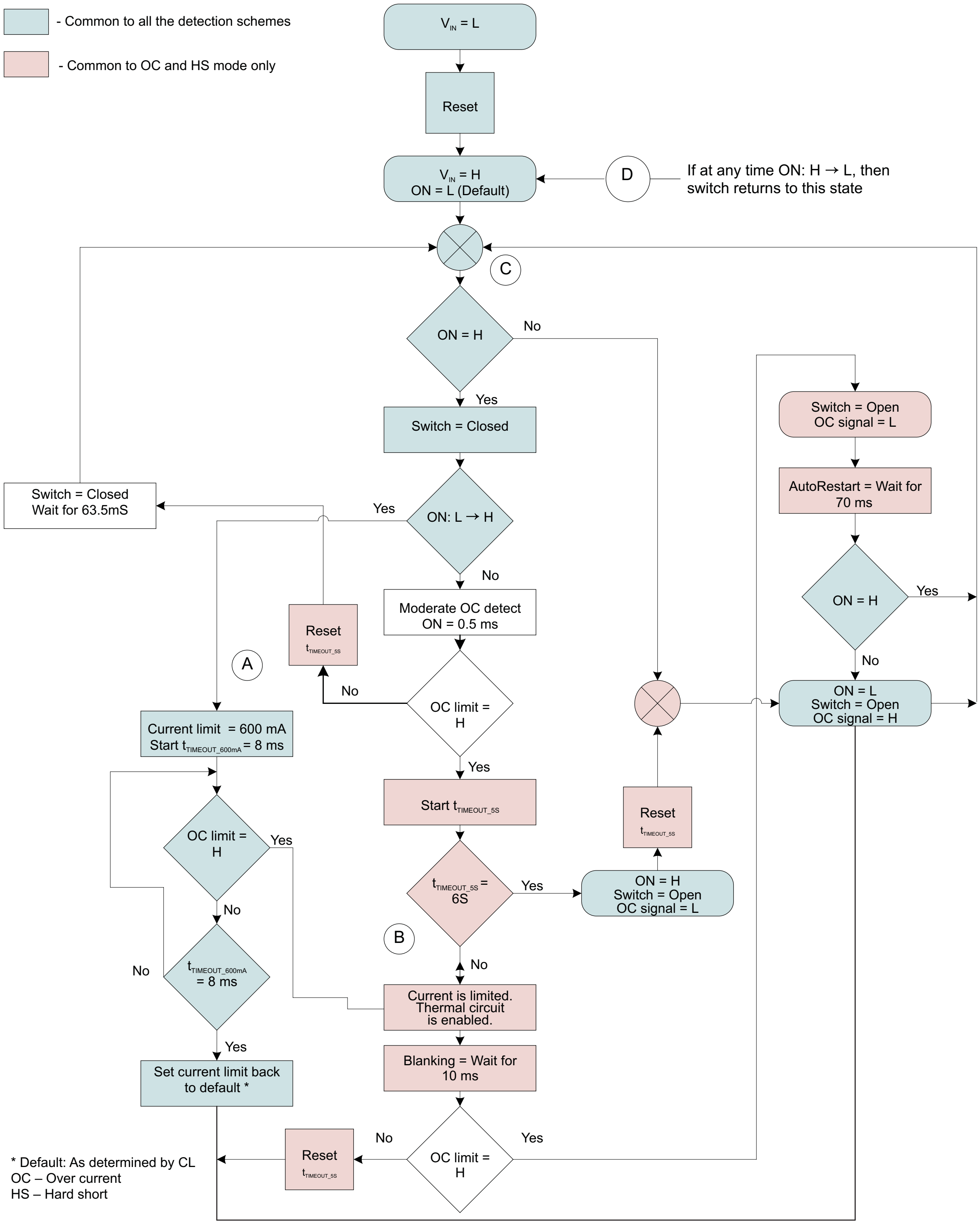


Figure 2. Moderate Over-Current Detection Flow Diagram

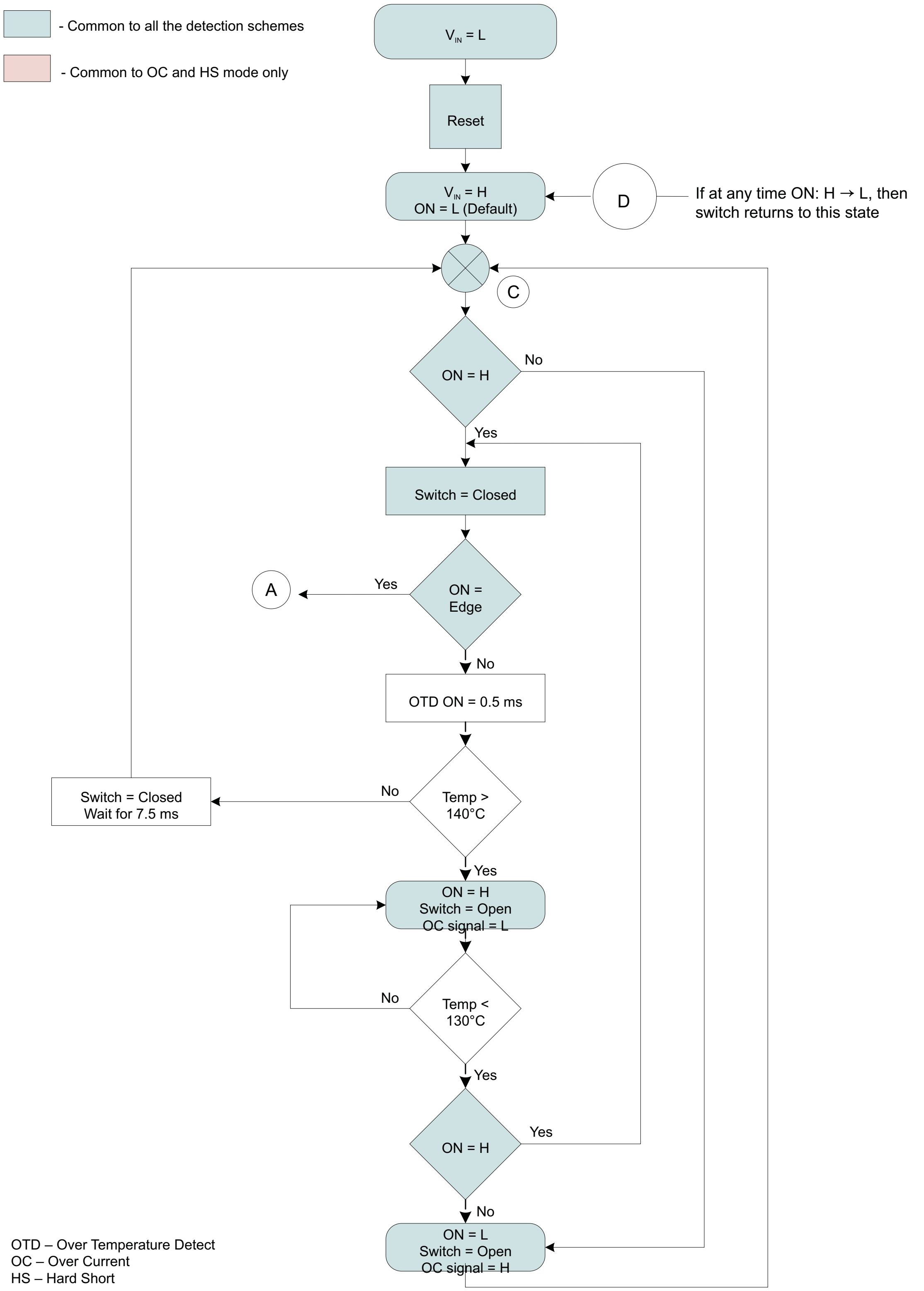


Figure 3. Over-Temperature Detection Flow Diagram

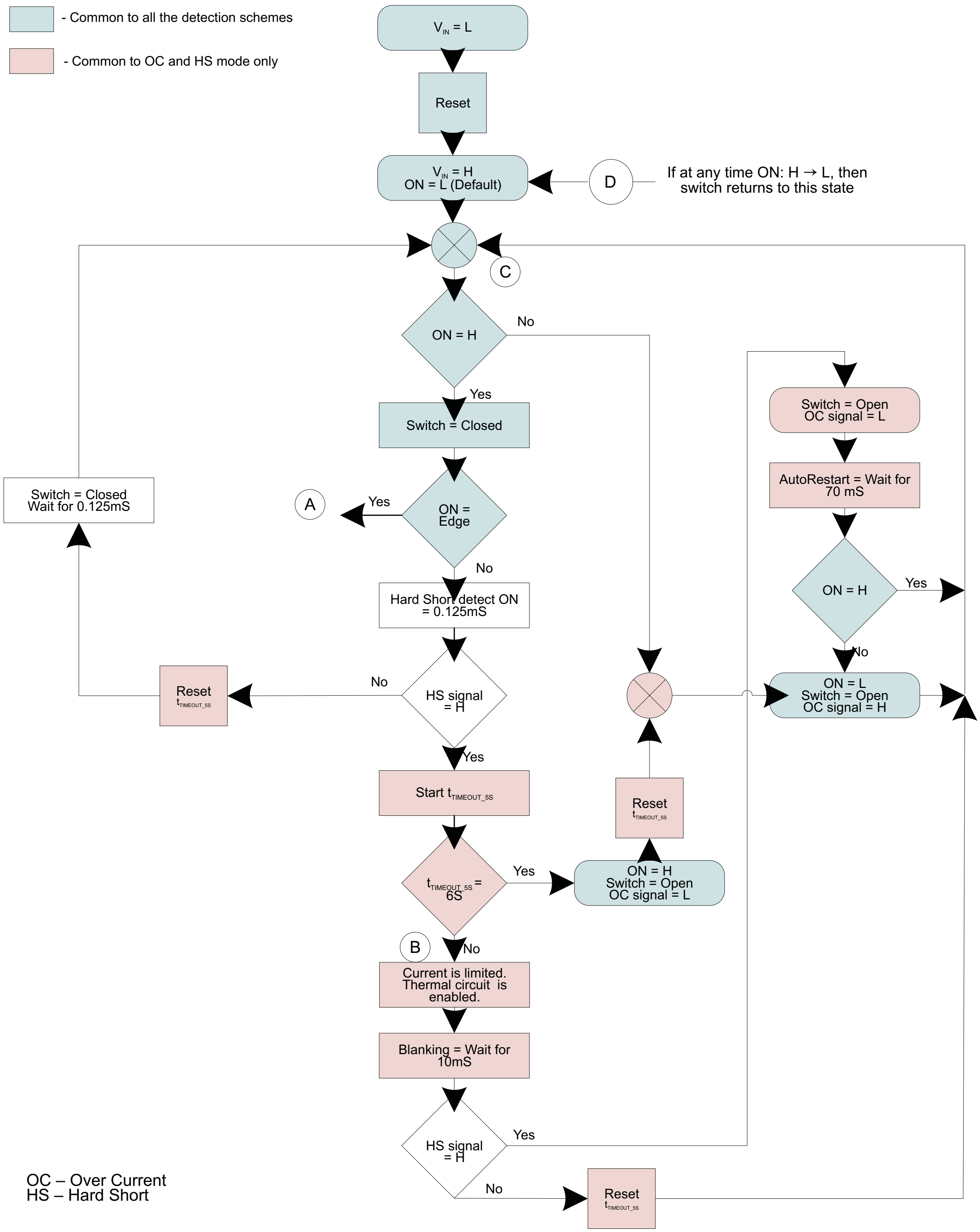


Figure 4. Hard Short-Circuit Detection Flow Diagram

ABSOLUTE MAXIMUM RATINGS

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

V_I	Input voltage	VIN, VOUT, ON, CL	–0.3 V to 6 V
T_J	Operating junction temperature range		–40°C to 125°C
T_{stg}	Storage temperature range		–65°C to 150°C
ESD	Electrostatic discharge protection	Human-body model (HBM)	6000 V

DISSIPATION RATINGS(1)

BOARD	PACKAGE	$R_{\theta JC}$	$R_{\theta JA}$	DERATING FACTOR ABOVE TA = 25°C	T_A < 25°C	T_A = 70°C	T_A = 85°C
High-K(1)	YZP	17.6°C/W	123.36°C/W	-8.1063 mW/°C	810.63 mW	445.84 mW	324.25 mW

(1) The JEDEC high-K (2s2p) board used to derive this data was a 3-in x 3-in, multilayer board with 1-ounce internal power and ground planes and 2-ounce copper traces on top and bottom of the board.

RECOMMENDED OPERATING CONDITIONS

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

			MIN	MAX	UNIT
V_{IN}	Input voltage		1.62	5.5	V
V_{ON}	ON pin voltage		0	5.5	V
V_{CL}	CL pin voltage		0	V_{IN}	V
V_{OUT}	OUT pin voltage		0	V_{IN}	V
T_A	Ambient free-air temperature		-40	85	°C
t_{CLSET}	CL pin setting time		8		ms
C_{IN}	Input capacitor		1 (1)		μF
V_{IH}	ON low-level input voltage	V_{IN} = 1.8 V	1.1	5.5	V
		V_{IN} = 2.5 V	1.2	5.5	
		V_{IN} = 3.3 V	1.3	5.5	
		V_{IN} = 5.5 V	1.4	5.5	
V_{IL}	ON high-level input voltage	V_{IN} = 1.8 V		0.4	V
		V_{IN} = 2.5 V		0.4	
		V_{IN} = 3.3 V		0.5	
		V_{IN} = 5.5 V		0.6	
V_{IH}	CL low-level input voltage	V_{IN} = 1.62 V to 5.5 V, I_{IH} = 55 μA	0.7 V_{IN}	V_{IN}	V
V_{IL}	CL high-level input voltage	V_{IN} = 1.62 V to 5.5 V, I_{IL} = 55 μA	GND	0.3 V_{IN}	V

(1) See the Application Information section of this data sheet.

ELECTRICAL CHARACTERISTICS

V_{IN} = 1.62 V to 5.5 V, TYP values at T_A = 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		T_A (1)	MIN	TYP	MAX	UNIT
I_{IN}	Average quiescent current	I_{OUT} = 0 mA, V_{IN} = 4.5 V to 5.5 V		Full range		1.5	5	µA
		I_{OUT} = 0 mA, V_{IN} = 3.0 V to 3.6 V				1.3	4	
		I_{OUT} = 0 mA, V_{IN} = 1.62 V to 1.98 V				1	3	
$I_{IN(OFF)}$	OFF state supply current	V_{ON} = 0 V	V_{IN} = 3.6 V, V_{OUT} open	Full range		0.1	1	µA
$I_{OUT(LEAKAGE)}$	OFF state switch current	V_{ON} = 0 V	V_{IN} = 3.6 V, V_{OUT} short to GND	Full range		0.1	1.1	µA
r_{ON}	ON-state resistance	I_{OUT} = -100 mA	V_{IN} = 5.5 V	25°C		0.3	0.4	Ω
				Full range			0.45	
			V_{IN} = 3.3 V	25°C		0.4	0.5	
				Full range			0.55	
			V_{IN} = 2.5 V	25°C		0.5	0.6	
				Full range			0.65	
			V_{IN} = 1.8 V	25°C		0.6	0.8	
				Full range			0.85	
			V_{IN} = 1.62 V	25°C		0.7	0.9	
				Full range			1	
I_{ON}	ON input leakage current	V_{ON} = V_{IN} or GND		Full range			1	µA
I_{LIM}	Current limit	V_{IN} = 1.8 V, V_{OUT} = 1.5 V, CL = GND		Full range	70	85	120	mA
		V_{IN} = 3.3 V, V_{OUT} = 3.0 V, CL = GND		Full range	60	80	115	
		V_{IN} = 1.8 V, V_{OUT} = 1.5 V, CL = VIN		Full range	155	175	235	
		V_{IN} = 3.3 V, V_{OUT} = 3.0 V, CL = VIN		Full range	135	165	230	
		V_{IN} = 1.8 V, V_{OUT} = 1.5 V, CL floating		Full range	30	45	60	
		V_{IN} = 3.3 V, V_{OUT} = 3.0 V, CL floating		Full range	28	40	60	
I_{limit_inrush}	Inrush current limit	R_l = 1 Ω, V_{IN} = 3.3 V, V_{OUT} = 2.3 V		Full range	375	435	685	mA
	Thermal shutdown (2)	Shutdown threshold		Full range		135		°C
		Return from shutdown				125		
		Hysteresis				10		
V_{OL}	OC output logic low voltage	V_{IN} = 5 V, I_{SINK} = 10 mA		Full range		0.1	0.2	V
		V_{IN} = 1.8 V, I_{SINK} = 10 mA				0.1	0.3	
I_{OH}	OC output high leakage current	V_{IN} = 5 V, Switch ON		Full range			1	µA

(1) Full range T_A = –40°C to 85°C
(2) See the Application Information section of this data sheet.

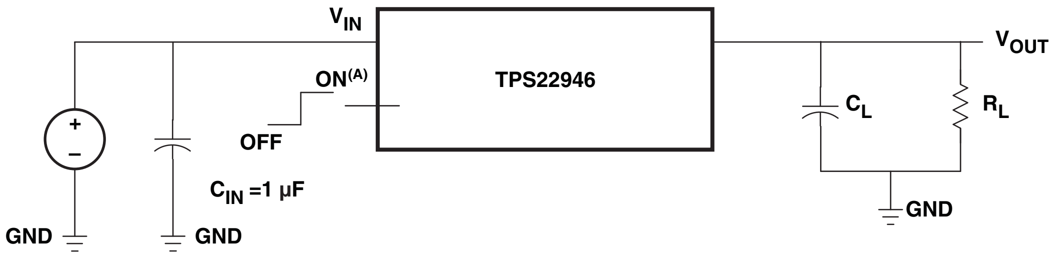
SWITCHING CHARACTERISTICS

V_{IN} = 1.8 V, R_L = 50 Ω, CL = 1 μF, T_A = –40°C to 85°C, TYP values at T_A = 25°C (unless otherwise noted)

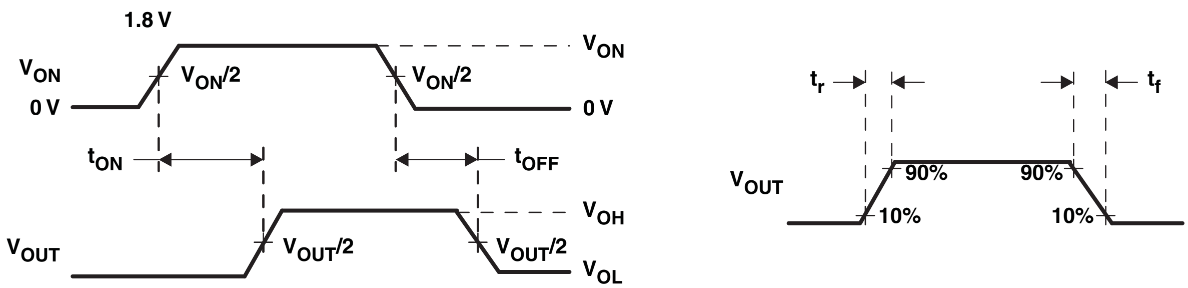
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
t_{PWRON}	Power-ON time	R_L = 50 Ω, C_L = 1 μF		192		μs
t_{PWROFF}	Power-OFF time	R_L = 50 Ω, C_L = 1 μF		0.55		μs
t_{ON}	Turn-ON time	R_L = 50 Ω, C_L = 1 μF		125		μs
t_{OFF}	Turn-OFF time	R_L = 50 Ω, C_L = 1 μF		115		μs
t_R	V_{OUT} rise time	R_L = 50 Ω, C_L = 1 μF		35		μs
t_F	V_{OUT} fall time	R_L = 50 Ω, C_L = 1 μF		120		μs
t_{BLANK}	Over-current blanking time		7	10	15	ms
t_{RSTART}	Auto-restart time		50	70	95	ms
$t_{TIMEOUT}$	Over-current detection timeout(1)	V_{IN} = V_{ON} = 3.3 V, hard short(2)		6000		ms
t_{OVRTMP}	Over-temperature detection maximum response time			7.7		ms
t_{MODOC}	Moderate over-current detection maximum response time	V_{IN} = V_{ON} = 1.8 V, Moderate over-current condition(3)		63.5		ms
		V_{IN} = V_{ON} = 3.3 V, Moderate over-current condition(3)		65.5		
$t_{HARDSHORT}$	Hard-short detection maximum response time	V_{IN} = V_{ON} = 1.8 V, hard short(2)		270		μs
		V_{IN} = V_{ON} = 3.3 V, hard short(2)		295		

(1) See the *Automatic Disable in Case of Permanent Over Current* section in *Application Information*.
(2) Hard short check is performed at the output voltage of the switch. Hard short condition is active when V_{OUT} < 2/3 V_{IN}. Please refer to application information.
(3) If the current going through the switch is above I_{LIM}, then the moderate over-current condition is activated

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT



t_{ON}/t_{OFF} WAVEFORMS

Figure 5. Test Circuit and t_{ON}/t_{OFF} Waveforms

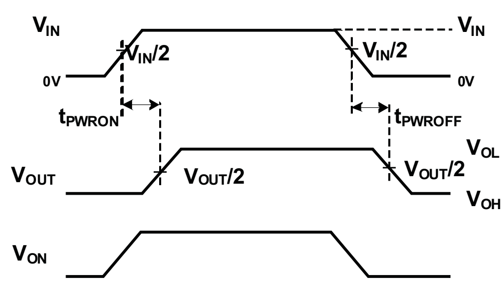


Figure 6. t_{PWRON}/t_{PWROFF} Waveforms

TYPICAL CHARACTERISTICS

ON RESISTANCE
vs
INPUT VOLTAGE

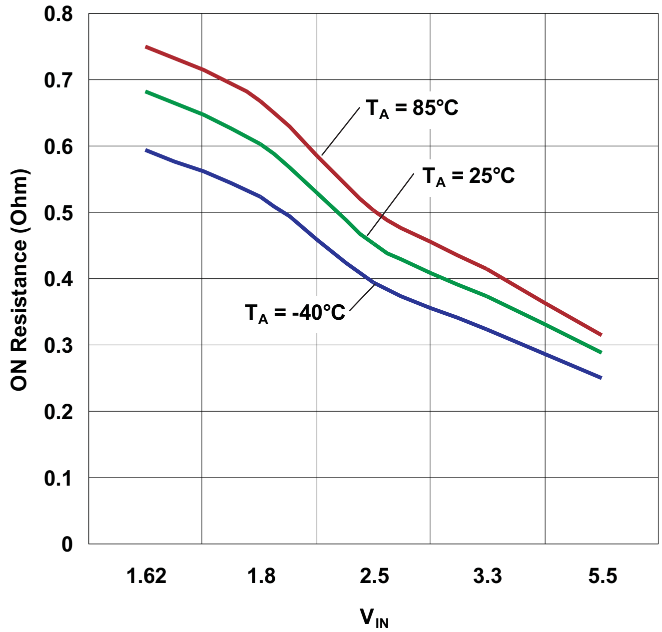


Figure 7.

ON RESISTANCE
vs
TEMPERATURE

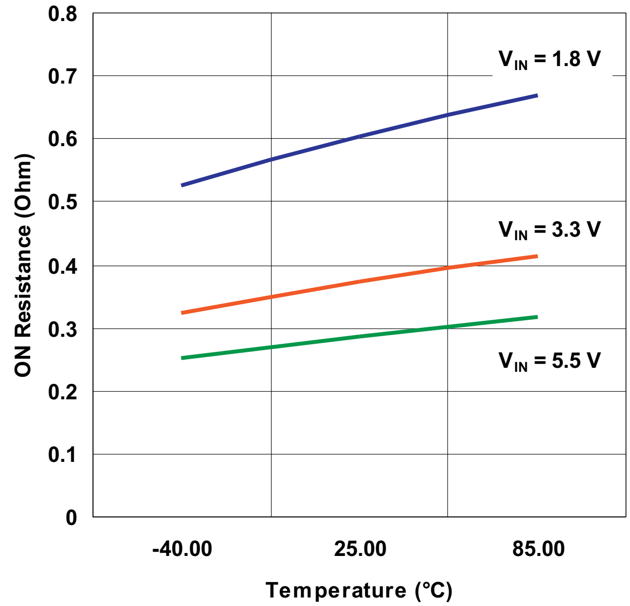


Figure 8.

INPUT CURRENT (QUIESCENT)
vs
TEMPERATURE

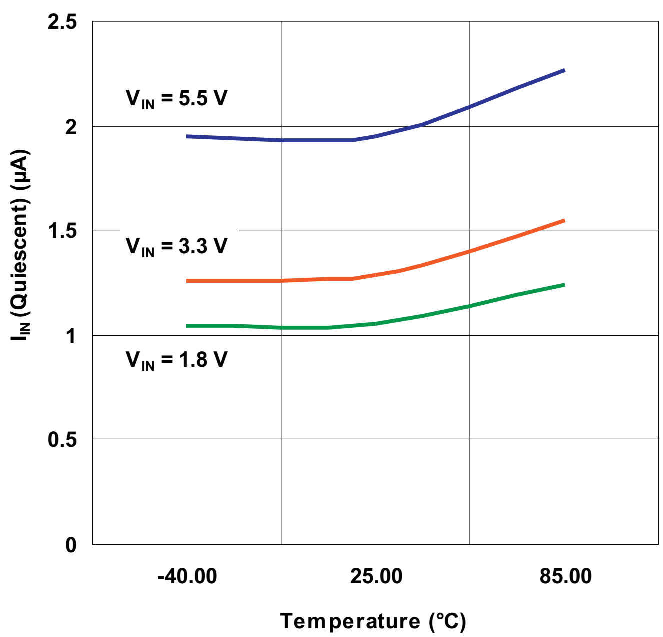


Figure 9.

INPUT CURRENT (LEAKAGE)
vs
TEMPERATURE

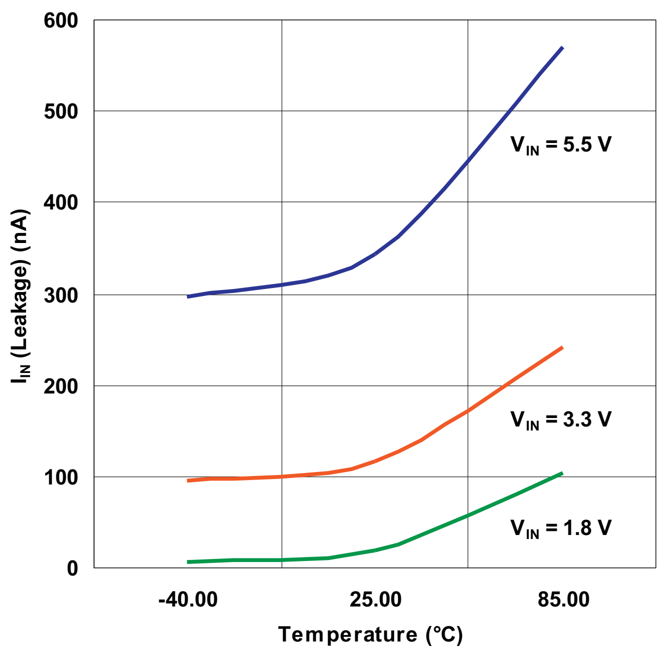


Figure 10.

TYPICAL CHARACTERISTICS (continued)

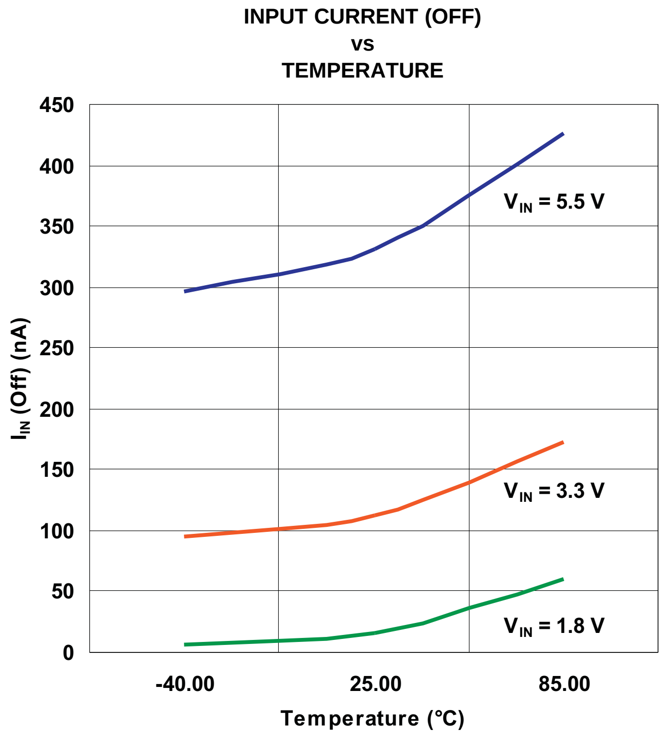


Figure 11.

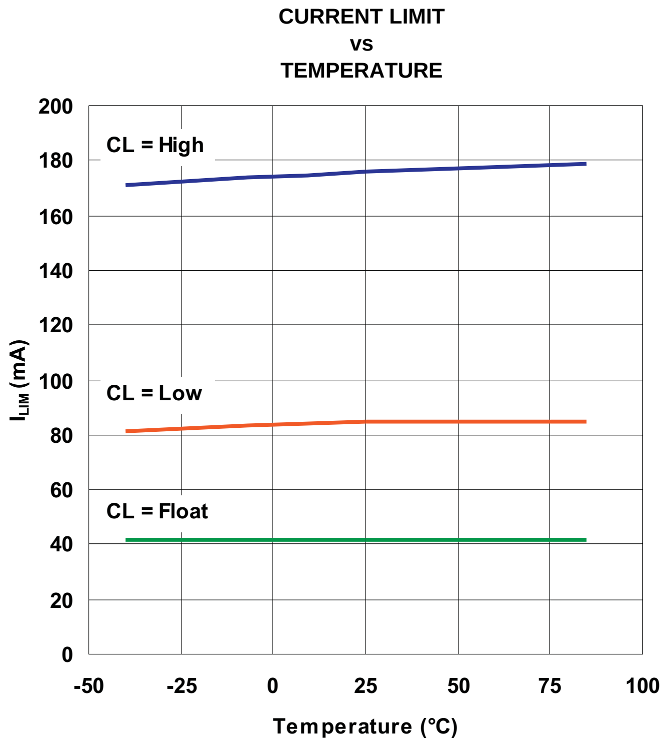


Figure 12.

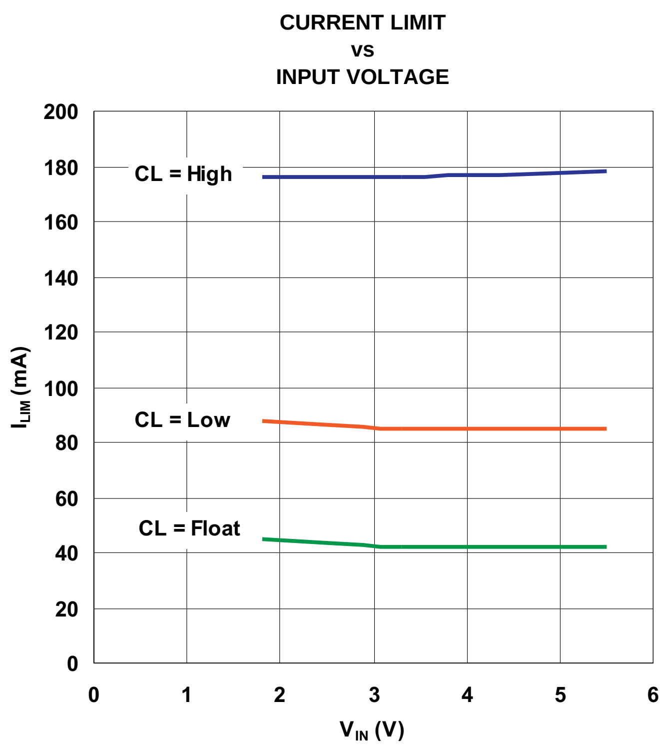


Figure 13.

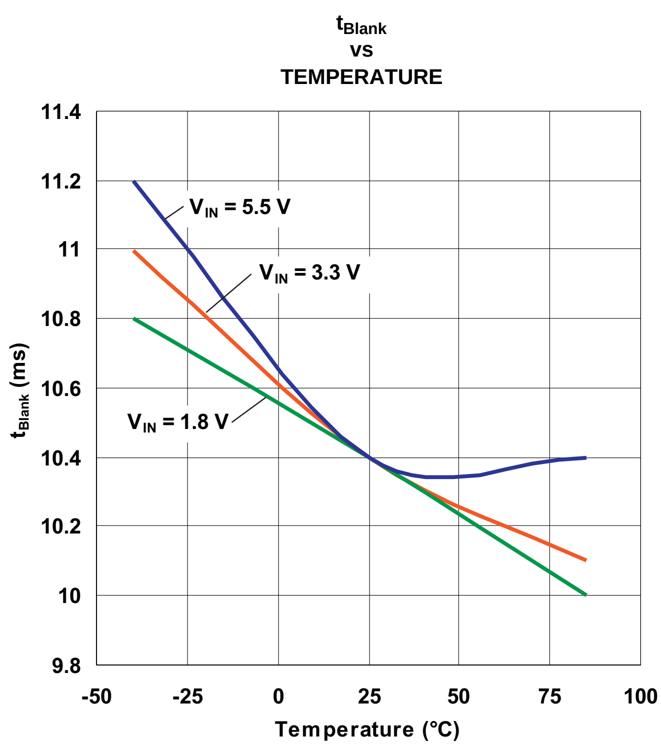


Figure 14.

TYPICAL CHARACTERISTICS (continued)

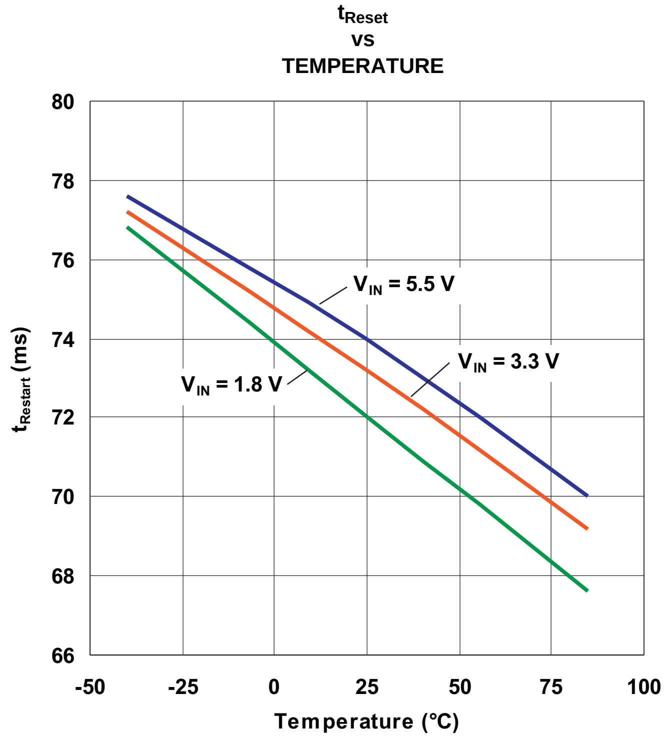


Figure 15.

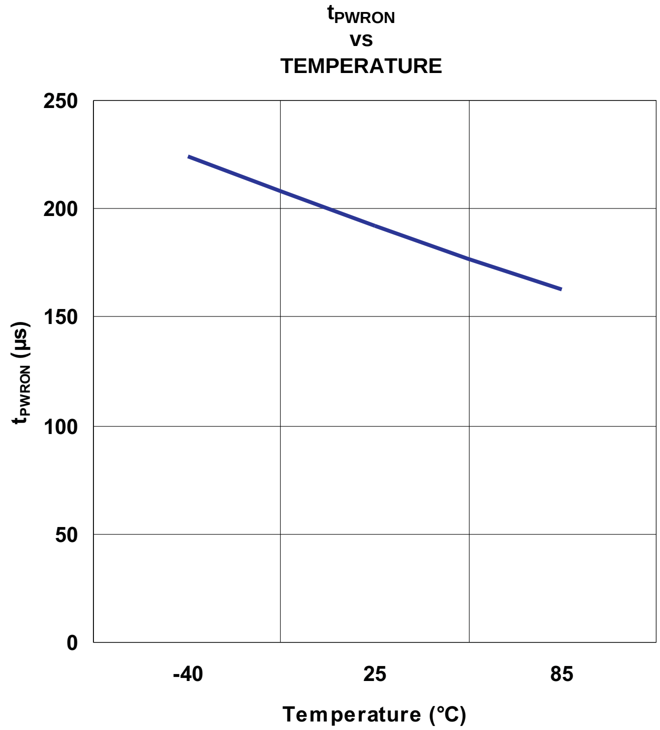


Figure 16.

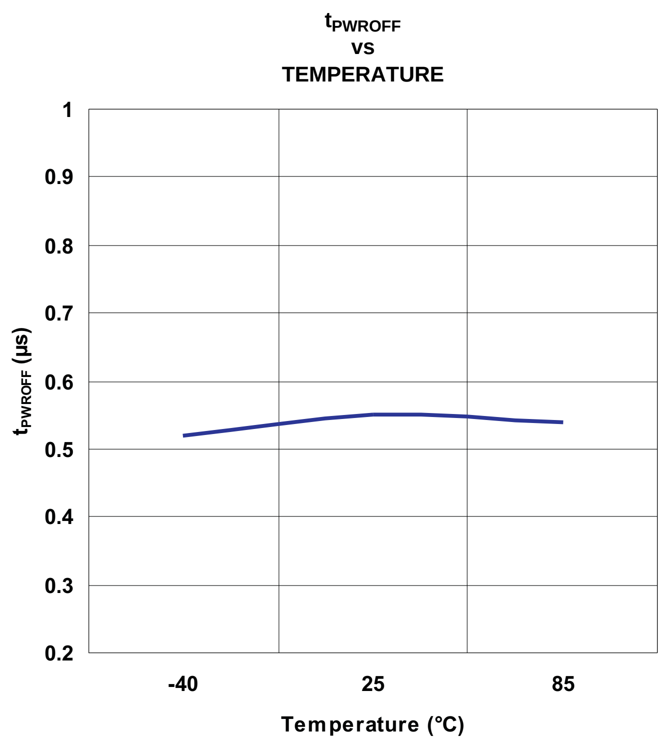


Figure 17.

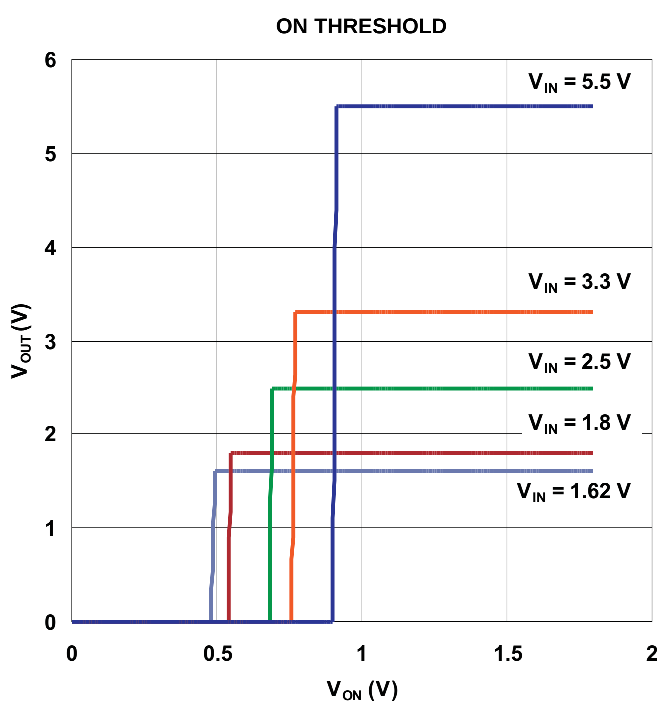


Figure 18.

APPLICATION INFORMATION

On/Off Control

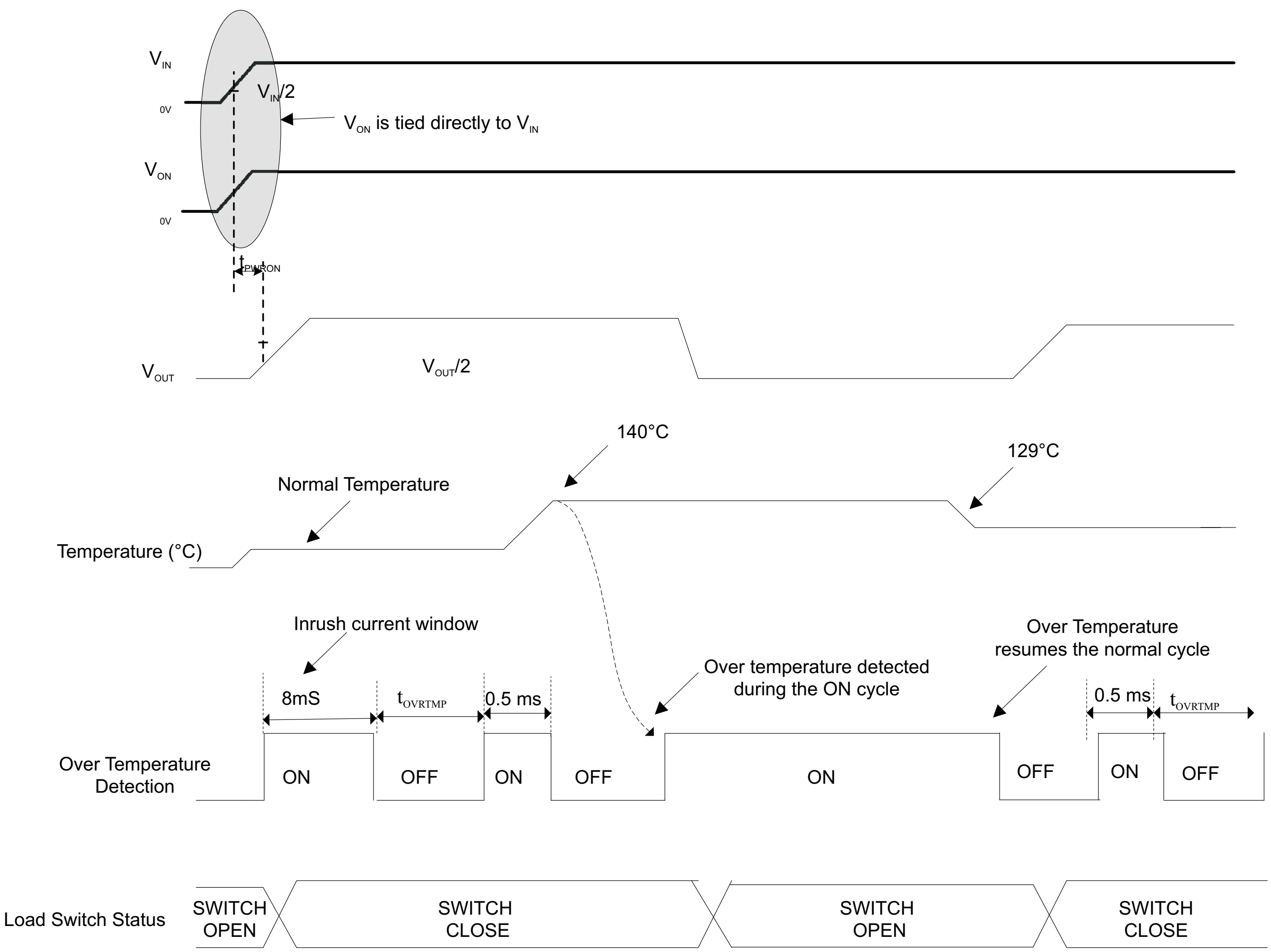
The ON pin controls the state of the switch. Activating ON continuously holds the switch in the on state so long as there is no fault. A junction temperature in excess of 150°C overrides the ON control to turn off the switch. ON is active HIGH and has a low threshold making it capable of interfacing with low voltage signals. When the MOSFET is off, the body diode is disabled so no current can flow through it from the input to the output, however it does not prevent reverse current flowing.

Detection Schemes

Over-Temperature Detection

The thermal shutdown detection circuit is active every 8mS for a period of 0.5mS. The thermal shutdown protects the part from internally or externally generated excessive temperatures. During an over-temperature condition the switch is turned-off (Open). The switch automatically turns-on (closes) again if temperature of the die drops below the threshold temperature while the part is still enabled.

In addition, if an over-current fault condition is detected due to a moderate over-current or a hard-short, the thermal shutdown is activated immediately and stays on continuously for the duration of blanking (see Figure 3).



NOTE: Case where the temperature causes the over-temperature detection circuit to trip before the other detection schemes.

Figure 26. Over-Temperature Detection

Hard-Short Detection

The hard short detection circuit is active every 250 µs for a period of 125 µs A comparator monitors the output voltage, V_{OUT}. A hard short is detected when V_{OUT} is lower than 2/3 V_{IN}. The switch then goes into current-limiting mode.

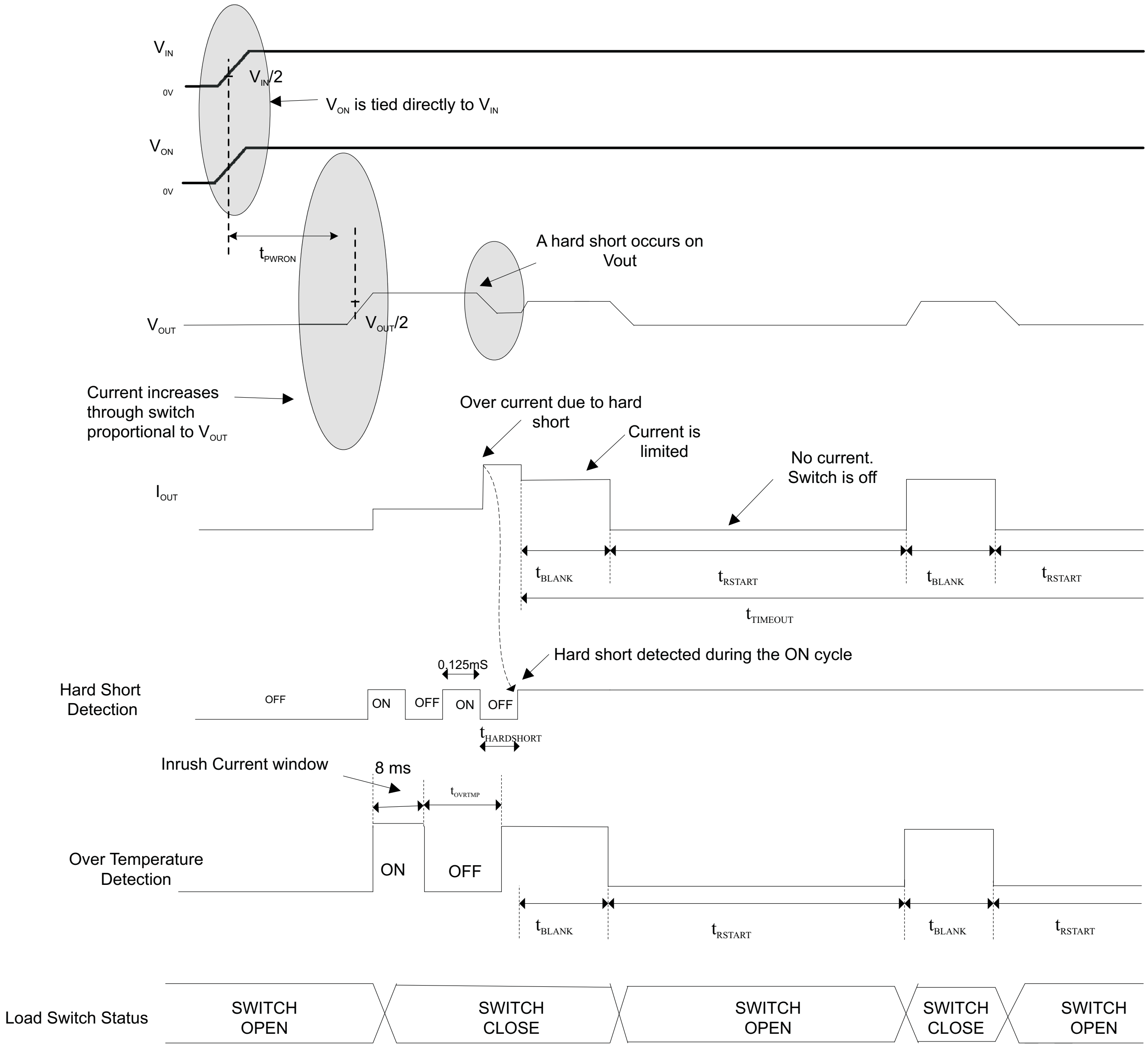
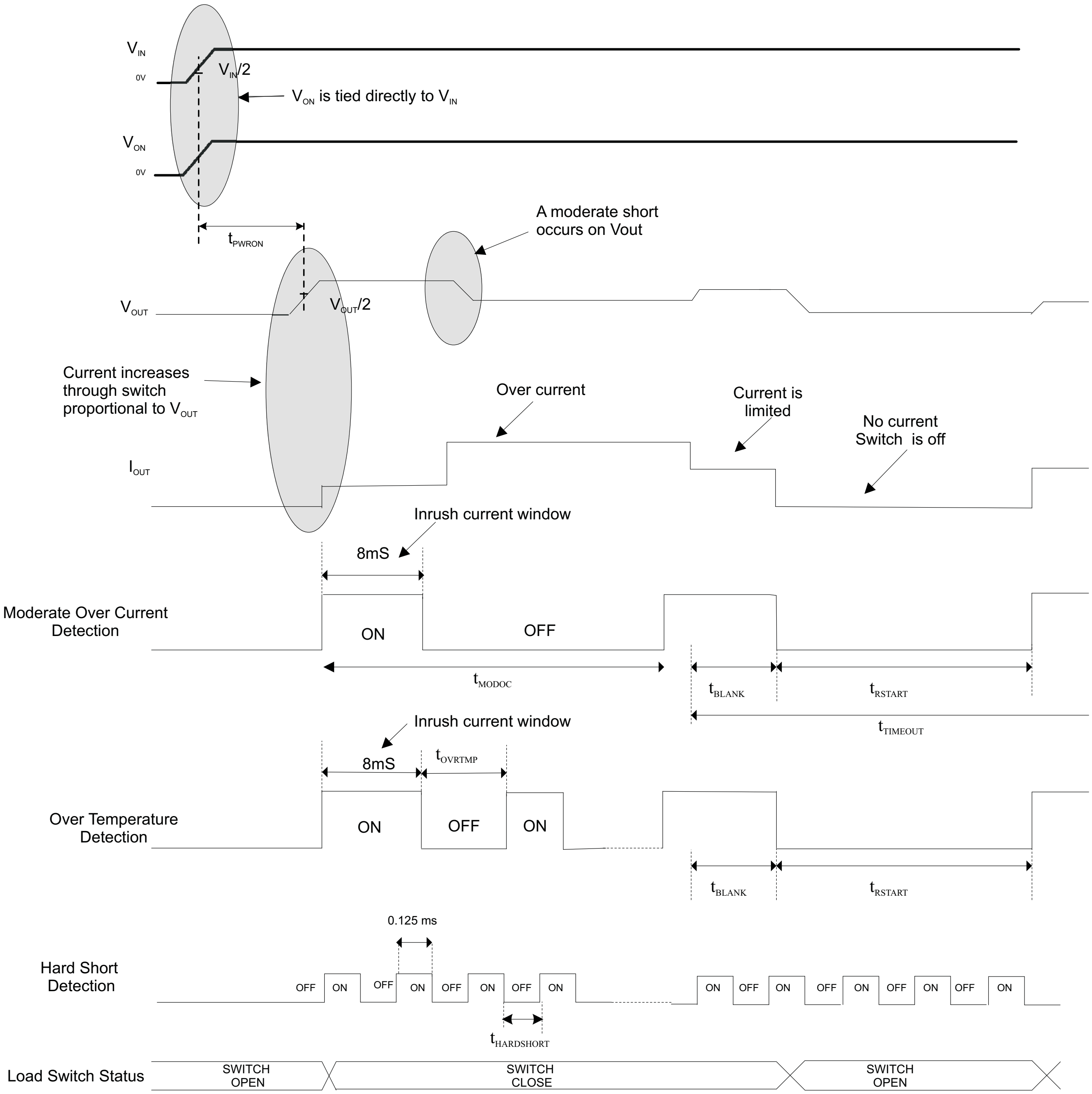


Figure 27. Hard-Short Detection

Moderate Over-Current Detection

The moderate over-current detection circuit is active every 64 ms for a period of 0.5 ms. A moderate over-current condition is triggered when the output current of the switch exceeds the current limit value and is not yet into hard short condition. The switch then goes into current-limiting mode.



NOTE: The over current does n't cause the temperature to go above 140°C here.

Figure 28. Moderate Over-Current Detection

Current Limiting Mode

When an over-current condition (moderate or a hard short) is detected, the TPS22946 operates in a constant-current mode to prohibit excessive currents from causing damage. TPS22946 has a current limit of 30 mA, 70 mA or 155 mA.

If the constant current condition still persists after 10ms, the device shuts off the switch and pulls the fault signal pin (OC) low. The TPS22946 has an auto-restart feature which turns the switch on again after 70 ms if the ON pin is still active.

Fault Reporting

When a moderate over-current, hard short or over-temperature condition is detected, OC is set active low to signal a fault condition. OC is an open-drain MOSFET and requires a pullup resistor between V_{IN} and OC. During shutdown, the pulldown on OC is disabled, reducing current draw from the supply.

Power-On / Power-Off Sequence

The device is enabled internally only once the hard-short detection circuit is enabled.

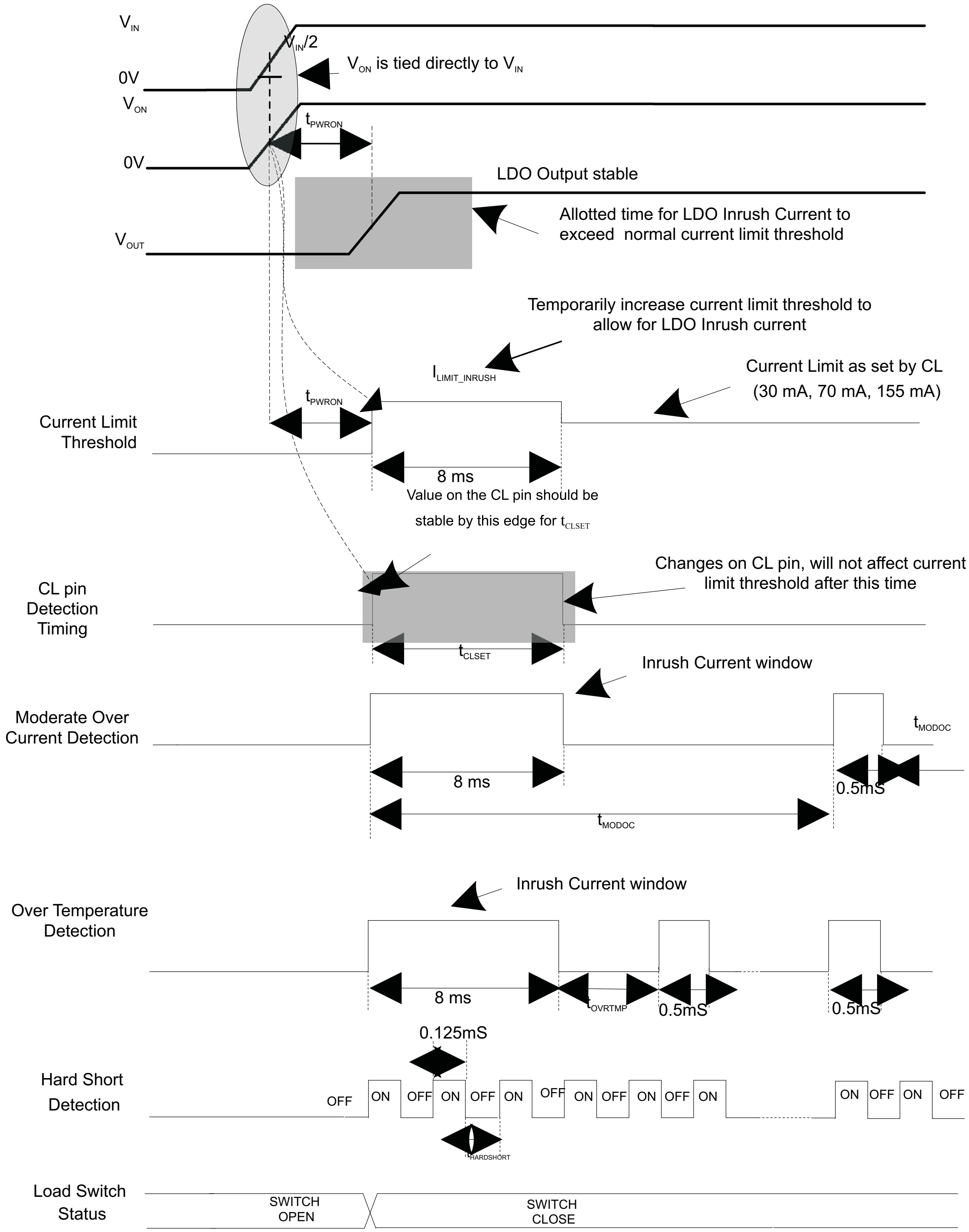


Figure 29. Power-On/Power-Off Sequence Timing

Automatic Disable in Case of Permanent Over Current

When the switch enters the current-limiting mode due to a hard short condition or a moderate over-current condition, TPS22946 goes through the 10-ms blanking state and the 70-ms auto restart state. If the hard-short condition or the moderate over-current condition persists after 5 s, the part shuts off regardless of the ON signal. The switch is turned on again after a power reset if the ON pin is HIGH.

Inrush Current Timeout Feature

The inrush current required by the LDO at startup can in some cases exceed the current limit and initiate a blanking (current limiting) condition. TPS22946 provides allowance for this scenario by temporarily increasing the current limit to 435 mA for 8 ms after the load switch is enabled. This timeout is initiated by the positive edge transition on the ON signal.

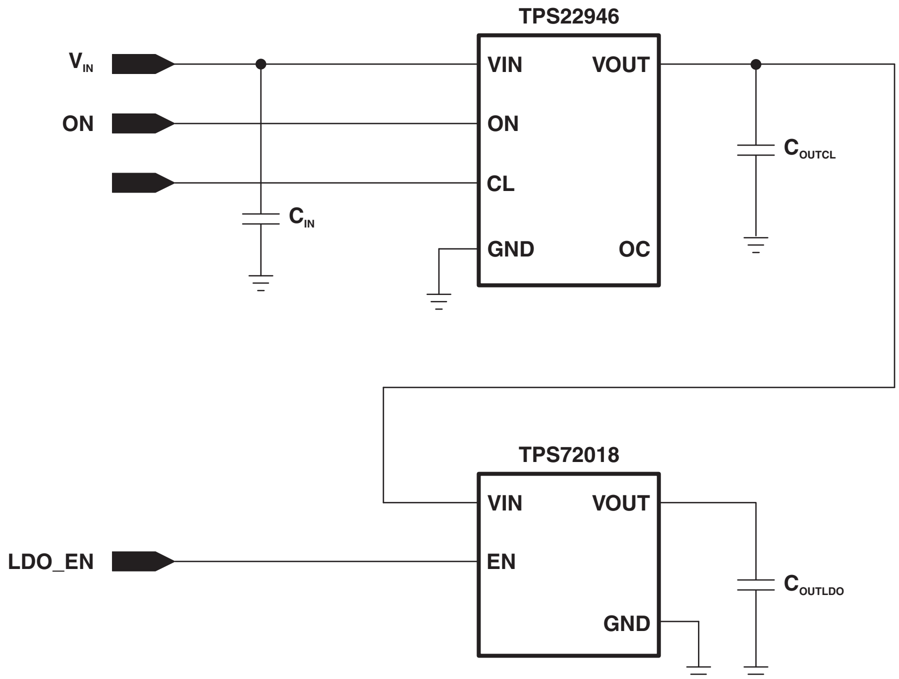


Figure 30. Inrush Current Timeout Circuit

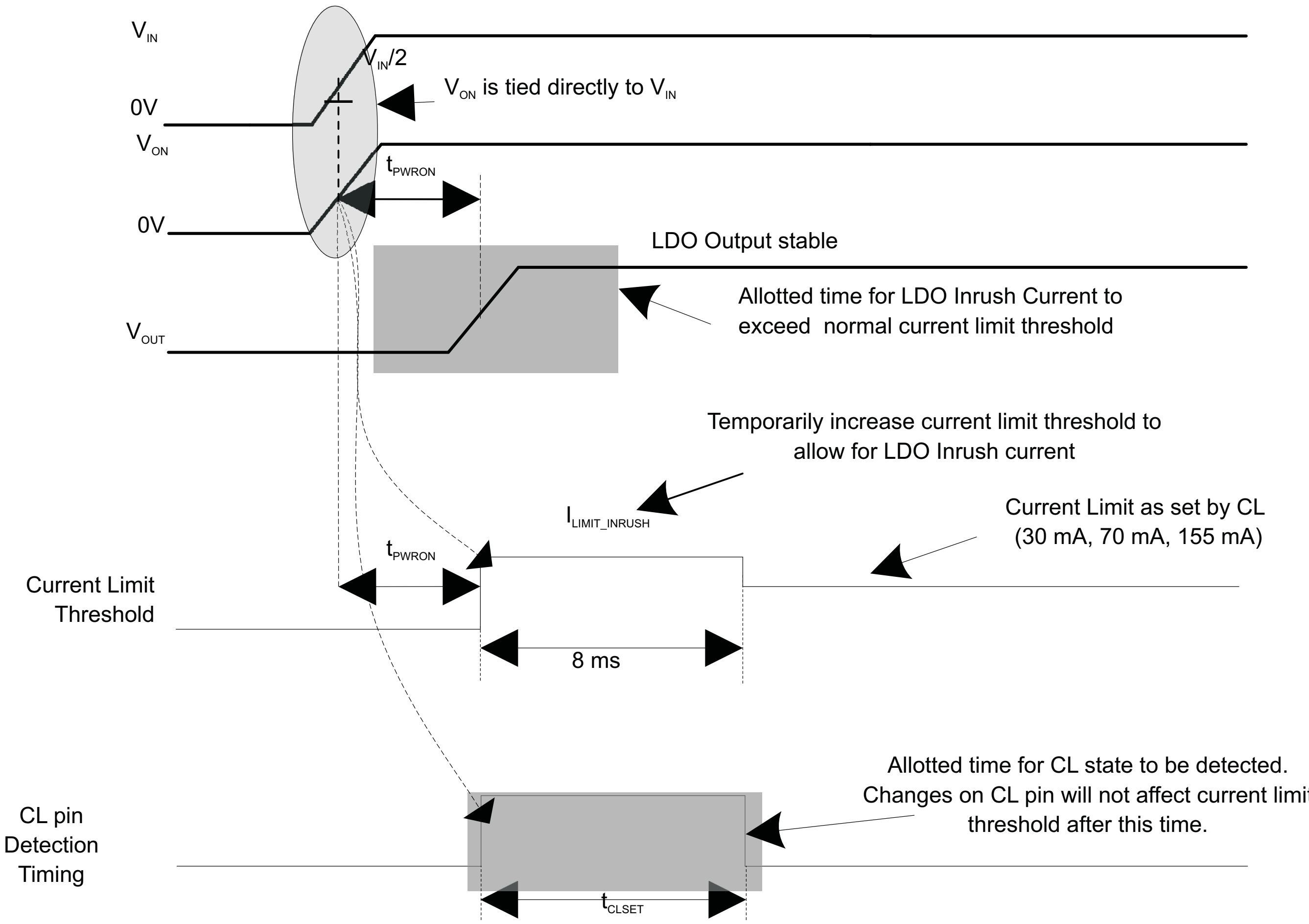


Figure 31. Inrush Current Timeout Timing

CL Control Pin

The TPS22946 supports three current limits: 30 mA, 70 mA, and 155 mA. The current limit selection is determined by the status of the digital input CL pin, as shown in Table 3. A high impedance, or floating, condition allows the CL pin to support a third state. The TPS22946 monitors the state of the CL pin during start-up from a disabled state, and upon start-up sets the current limit accordingly. When floating the CL pin, keep the total capacitance on the pin less than 100 pF and the resistive loading greater than 10 MΩ to ensure proper operation. Any changes to the state of the CL pin after the start-up operation has completed are ignored until the next start-up cycle.

The CL pin must be driven with logic levels referenced to VIN. The CL pin can be tied high or low on the printed wiring board (PWB) or driven by a general purpose I/O (GPIO), as long as the V_{IL} and V_{IH} recommended operating conditions are met.

Table 3. CL Control Pin

CL PIN STATUS	CURRENT LIMIT
Logic low(1)	70 mA
Float(2)	30 mA
Logic high(1)	155 mA

(1) Resistance to VCC or GND < 100 Ω
(2) Load on CL: C < 100 pF, R > 10 MΩ

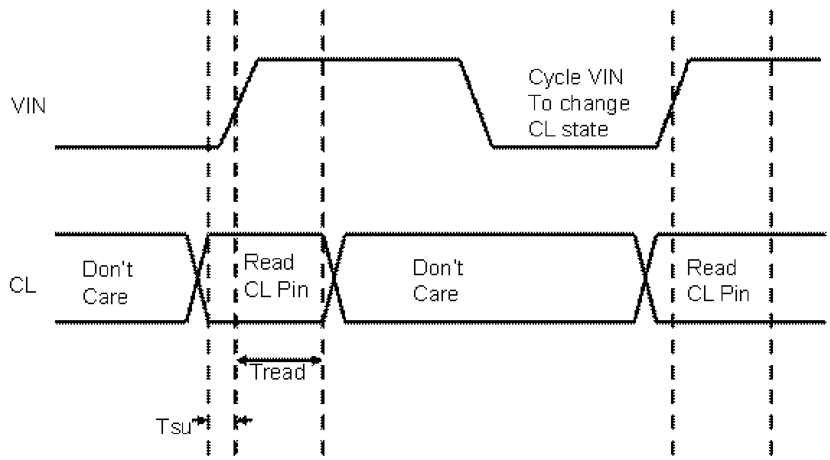


Figure 32. CL Pin Read Timing When cycling VIN (ON Pin Tied to VIN)

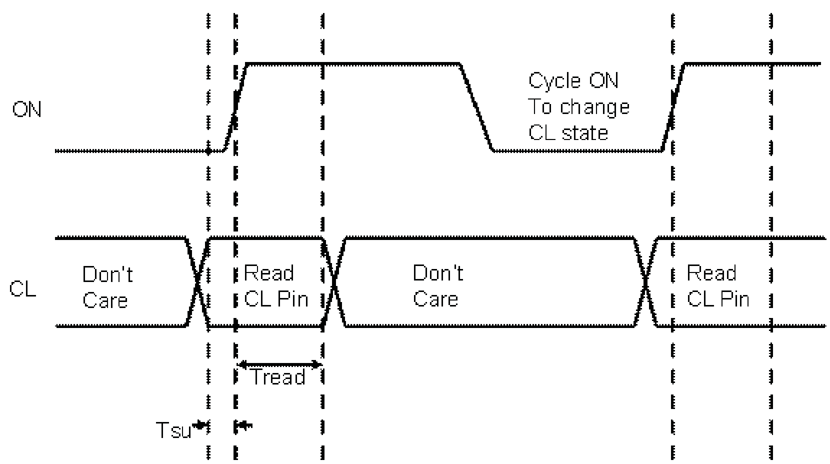


Figure 33. CL Pin Read Timing Cycling ON Pin (VIN High)

Over Temperature Protection

An over temperature condition occurs when the temperature of the part is greater than 140°C. The OC flag will go low to indicate a fault. If the over temperature condition persists for more than 6 seconds, the part times out and shuts OFF. The part has to be enabled by either toggling the ON pin or the VIN pin. If the temperature reduces below 130°C within 5 seconds, the part will start normal operation.

If the temperature is not constantly high above 140°C and is toggling between greater than 140°C and less than 130°C, the internal timeout timer keeps resetting. If this event occurs more than 32 times, it will cause the part to shut OFF. It can be enabled by toggling either the ON pin or the VIN pin.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
TPS22946YZPR	ACTIVE	DSBGA	YZP	6	3000	Green (RoHS & no Sb/Br)	SNAGCU	Level-1-260C-UNLIM

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

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

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

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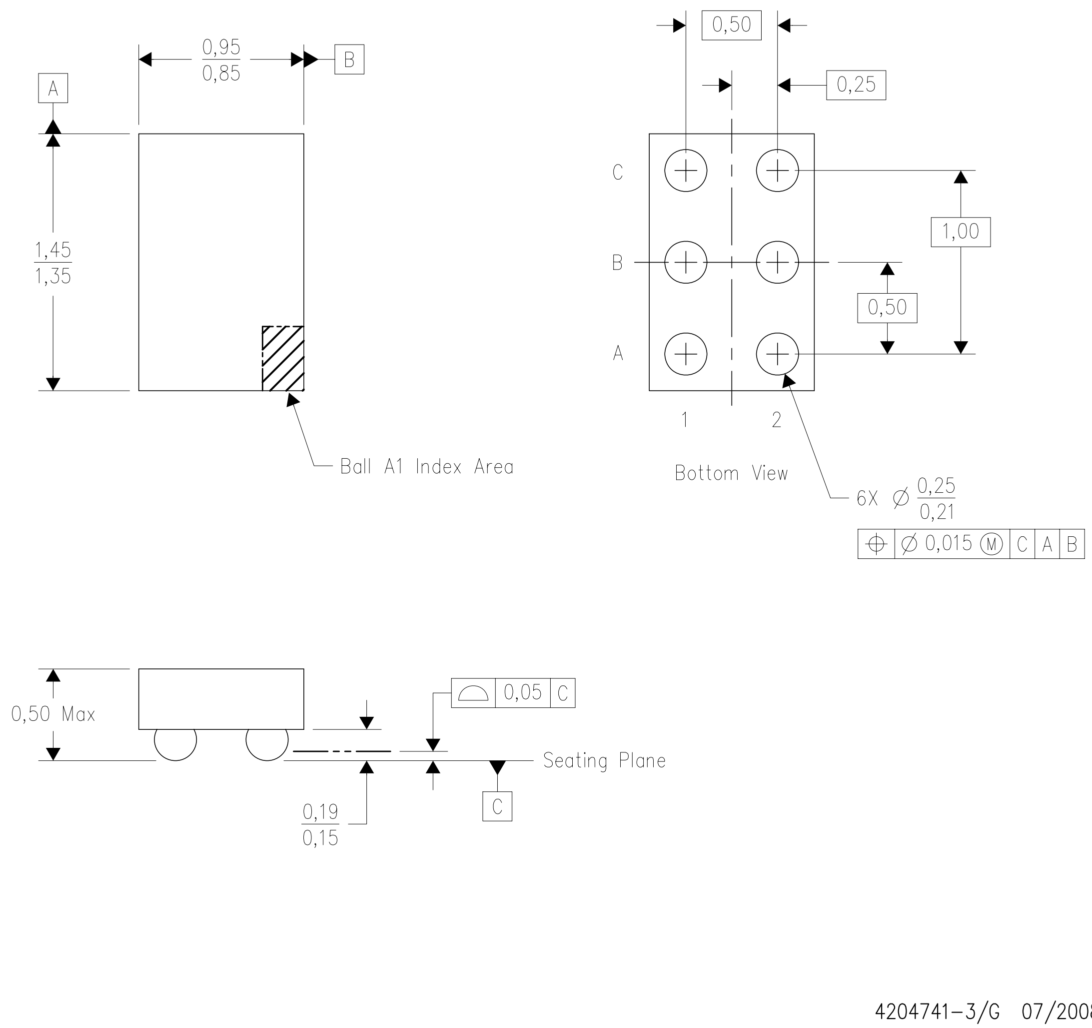
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

YZP (R–XBGA–N6) DIE–SIZE BALL GRID ARRAY



NOTES:
- A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
- B. This drawing is subject to change without notice.
- C. NanoFree™ package configuration.
- D. This package is lead–free. Refer to the 6 YEP package (drawing 4204725) for tin–lead (SnPb).

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