

Precision Adjustable Current -Limited Power Switch

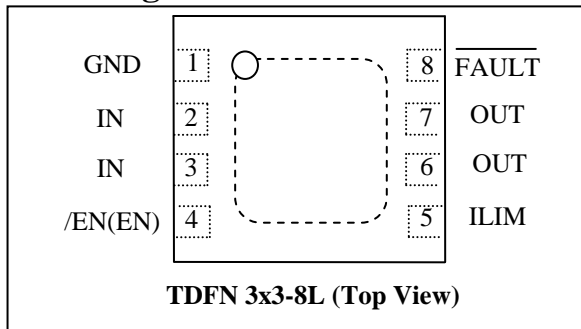
Features

- Meets USB Current-Limiting Requirement
- $\pm 6.5\%$ Current-Limit Accuracy at 4.0A
- Adjustable Current Limit, 500mA-5A (typ.)
- Fast Over-current Response - 3.5 μ S (typ.)
- 22m Ω High-Side MOSFET
- Operating Range: 2.5 V to 5.5V
- 2- μ A Maximum Standby Supply Current
- Built-in Soft-Start
- 15 kV / 8 kV System-Level ESD Capable
- Device Package: TDFN 3x3-8L
- UL Listed - File No. E341484
- CB Certified

Applications

- USB Ports/Hubs
- Digital TV
- Set-Top Boxes
- VOIP Phones

Pin Configuration



Pin Description

Pin No.	Pin Name		Type	Description
	PI5PD2556	PI5PD2557		
1	GND		-	Ground.
2, 3	IN		I	Power input voltage.
4	/EN	EN	I	Enable input, logic low turns on power switch for PI5PD2556, logic high turns on power switch for PI5PD2557.
5	ILIM		I	External resistor used to set current-limit threshold; recommended $20\text{ k}\Omega \leq R_{ILIM} \leq 187\text{ k}\Omega$.
6, 7	OUT		O	Power switch output for channel two
8	/FAULT		O	Active-low open-drain output, asserted during over-current or over-temperature condition or reverse voltage occurs

Description

The PI5PD2556/2557 series is single-channel power-distribution switch intended for applications where precision current limiting is required or heavy capacitive loads and short circuits are encountered. These devices offer a programmable current-limit threshold between 500 mA and 5A (typ) per channel via an external resistor. The power-switch rise and fall times are controlled to minimize current surges during turn on/off.

Each channel of the PI5PD2556/2557 devices limits the output current to a safe level by switching into a constant-current mode when the output load exceeds the current-limit threshold.

Typical Application Circuit

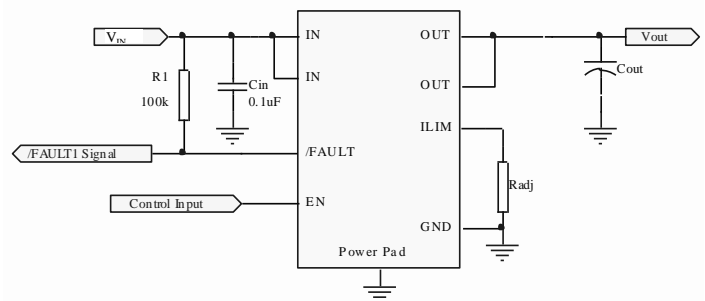


Figure 1 Typical Application Circuit

Maximum Ratings

Storage Temperature.....	-65°C to +150°C
Supply Voltage to Ground Potential.....	-0.5V to +6.0V
DC Input Voltage.....	-0.5V to $V_{DD}+0.5V$
Voltage range from IN to OUT.....	-0.5V to +6.0V
Control Input Voltage (VIN).....	-0.5V to +6.0V
Continuous total power dissipation ⁽¹⁾	2400mW
Continuous FAULT sink current.....	25mA
Power Dissipation.....	0.5W
ESD: HBM Mode.....	4000V
CDM Mode.....	500V
ESD-system level (contact/air).....	8kV/15kV

Note:

1. Stresses greater than those listed under MAXIMUM RATINGS may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

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

Recommended operation conditions

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IN}	Input Voltage	-	2.5	-	5.5	V
V_{EN}	Input Voltage	PI5PD2556	0	-	5.5	V
$V_{/EN}$		PI5PD2557	0	-	5.5	
V_{IH}	High-level input voltage on EN	-	1.1	-	-	V
V_{IL}	Low-level input voltage on EN	-	-	-	0.66	V
I_{OUT}	Continuous output current per channel, OUT	-	0	-	5	A
I_{FAULT}	Continuous /FAULT sink current	-	-	-	10	mA
R_{ILM}	Recommended resistor limit range	-	20	-	187	kΩ
T_A	Operating Temperature Range	-	-40	-	85	°C

DC Electrical Characteristics

$V_{I(IN)} = 5.0V$; $T_A = -40\text{ }^\circ\text{C}$ to $+85\text{ }^\circ\text{C}$; unless otherwise specified.

Sym	Description	Test Conditions ⁽¹⁾	Min	Typ	Max	Unit	
Power Switch							
$R_{DS(on)}$	Static drain-source on-state resistance	-	-	22	35	m Ω	
t_r	Rise time, output	$V_{I(IN)} = 5.0V$	1	2	4	ms	
		$V_{I(IN)} = 2.5V$	0.5	1	3		
t_f	Fall time, output	$V_{I(IN)} = 5.0V$	0.3	0.5	1.0		
		$V_{I(IN)} = 2.5V$	0.2	0.4	0.6		
Enable EN							
V_{IH}	High-level input voltage	$2.5\text{ V} \leq V_{I(IN)} \leq 5.5\text{ V}$	1.1	-	-	V	
V_{IL}	Low-level input voltage	$2.5\text{ V} \leq V_{I(IN)} \leq 5.5\text{ V}$	-	-	0.6		
t_{on}	Turn on time	$C_L = 1\mu F, R_L = 100\Omega$	-	-	5	ms	
t_{off}	Turn off time		-	-	2		
Current Limit							
I_{OS}	Current-limit threshold @ $V_{OUT} = V_{IN} * 0.8$	$R_{ILIM} = 27.4\text{ k}\Omega$	3750	4040	4260	mA	
		$R_{ILIM} = 61.9\text{ k}\Omega$	1590	1785	1960		
		$R_{ILIM} = 100\text{ k}\Omega$	935	1100	1260		
I_{OC_TRIP}	Overcurrent trip threshold	$V_{IN} = 5\text{ V}$, current ramp ($\leq 100\text{ A/s}$) on OUT $R_{ILIM} = 27.4\text{ k}\Omega$	3800	4500	5000		
		$V_{IN} = 5\text{ V}$, current ramp ($\leq 100\text{ A/s}$) on OUT $R_{ILIM} = 100\text{ k}\Omega$	950	1250	1500		
t_{IOS}	Response time to short circuit	$V_{IN} = 5.0V$	-	3.5	-		μs
Supply Current							
I_{STB}	Input supply current at output disable	No load on OUT, $V_{EN} = \text{disable}$ $T_A = 25\text{ }^\circ\text{C}$	-	0.1	2	μA	
I_{SS}	Input supply current at output enable	No load on OUT, $V_{EN} = 5.0V$, $T_A = 25\text{ }^\circ\text{C}$	$R_{ILIM} = 24.9\text{ k}\Omega$	-	95		120
		$R_{ILIM} = 100\text{ k}\Omega$	-	85	110		
I_{REV}	Reverse Leakage Current	$V_{OUTx} = 5.5V, V_{IN} = 0V, T_A = 25\text{ }^\circ\text{C}$	-	0.01	1.0		
Under Voltage Lockout							
UVLO	Low-level input voltage	V_{IN} Rising	-	2.35	2.45	V	
	Hysteresis for low-level input voltage	$T_A = 25\text{ }^\circ\text{C}$	-	35	-	mV	
/FAULT FLAG							
V_{OL}	Output low voltage	$I_{FAULT} = 1\text{ mA}$	-	-	180	mV	
I_{OFF}	Off-state leakage	$V_{FAULT} = 5.5V$	-	-	1	μA	
T_D	/FAULT deglitch	FAULT assertion or de-assertion due to over-current condition	4	9	15	ms	
Thermal Shutdown							
OTSD2	Thermal shutdown threshold	-	-	155	-	$^\circ\text{C}$	
OTSD	Thermal shutdown threshold in current-limit	-	-	135	-		
	Hysteresis	-	-	20	-		

Note:

Pulse-testing techniques maintain junction temperature close to ambient temperature; thermal effects must be taken into account separately.

Parameter Measurement information

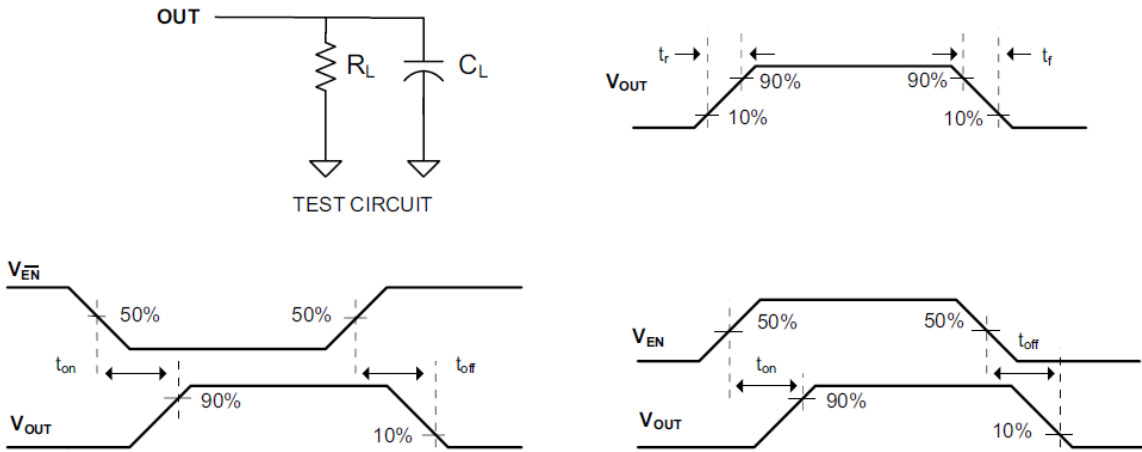


Figure 2 Test Circuit and Voltage Waveforms

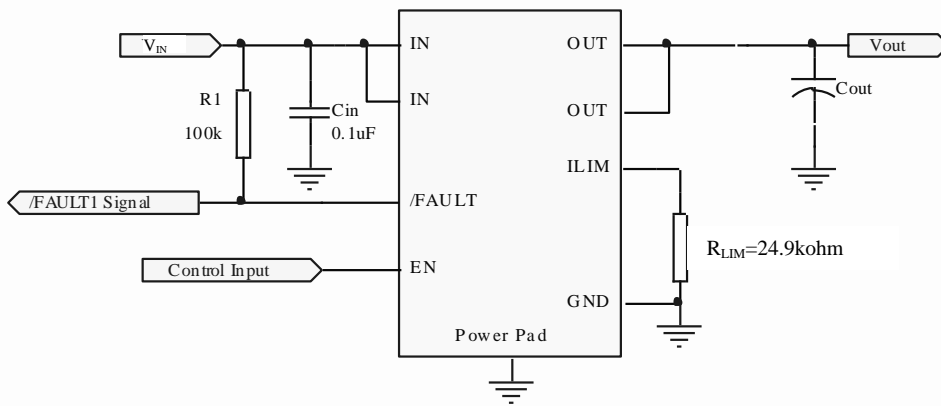


Figure 3 Typical Characteristics Reference Schematic

Typical characteristic

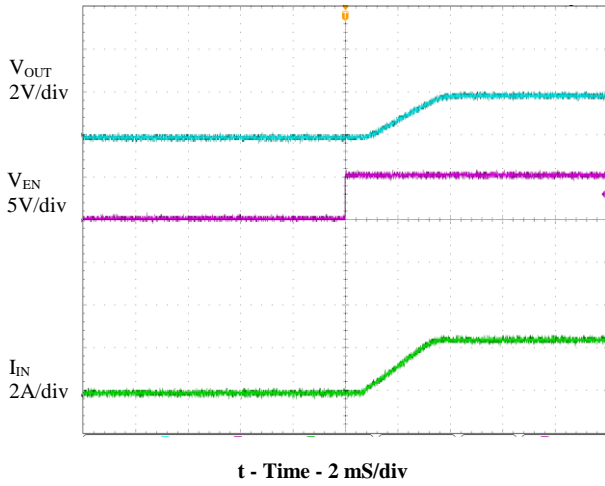


Figure 3 Turn-on Delay and Rise Time

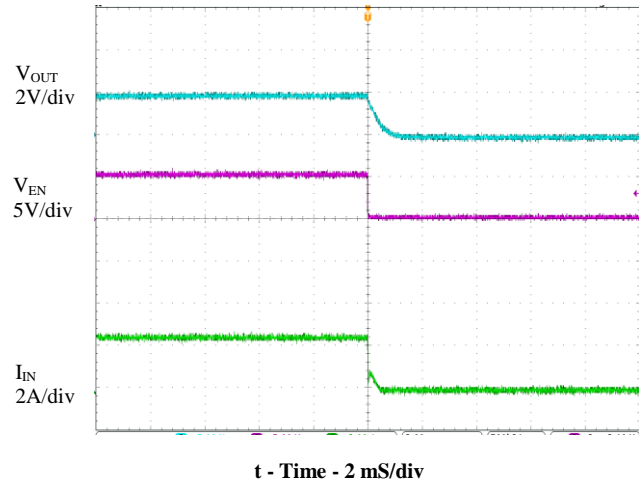


Figure 4 Turn-off Delay and Fall Time

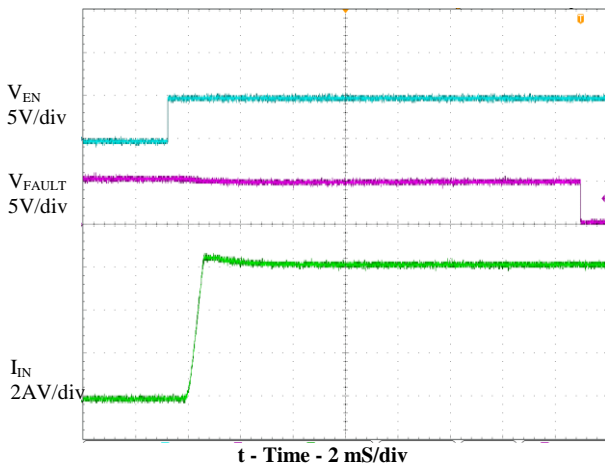


Figure 5 Device Enabled into Short-Circuit

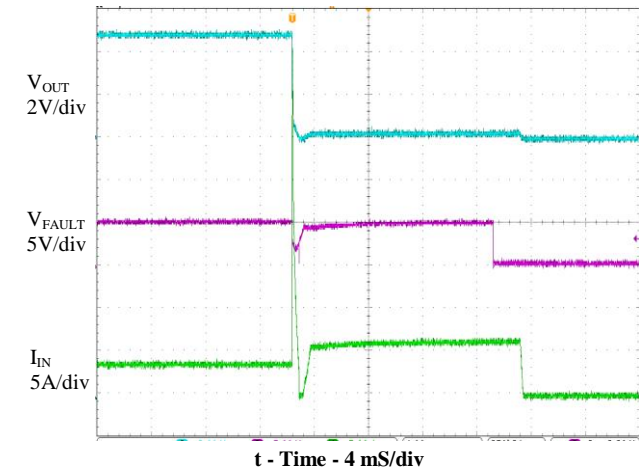


Figure 6 Full-Load to Short-Circuit Transient Response

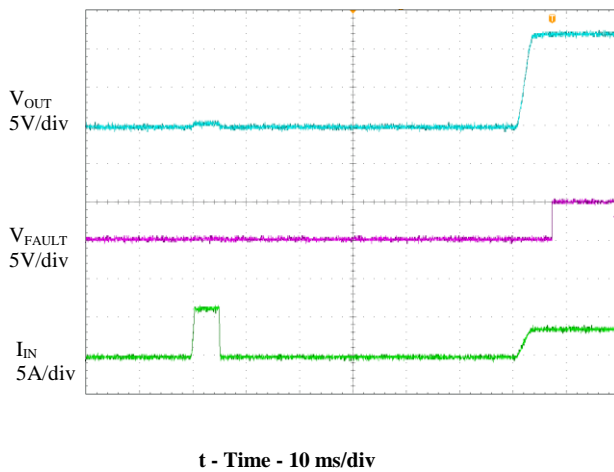


Figure 7 Short-Circuit to Full-Load Recovery Response

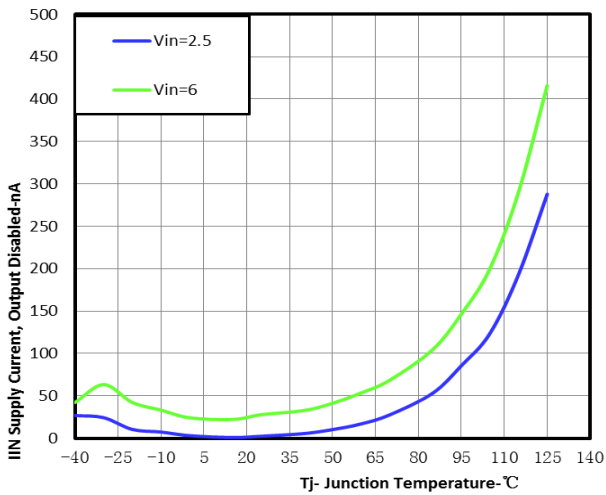


Figure 8 I_{IN} & Junction Temperature, Output Disabled

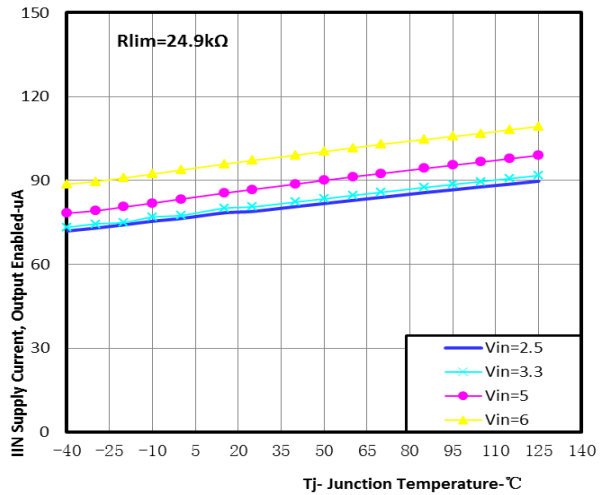


Figure 9 I_{IN} & Junction Temperature, Output Enabled

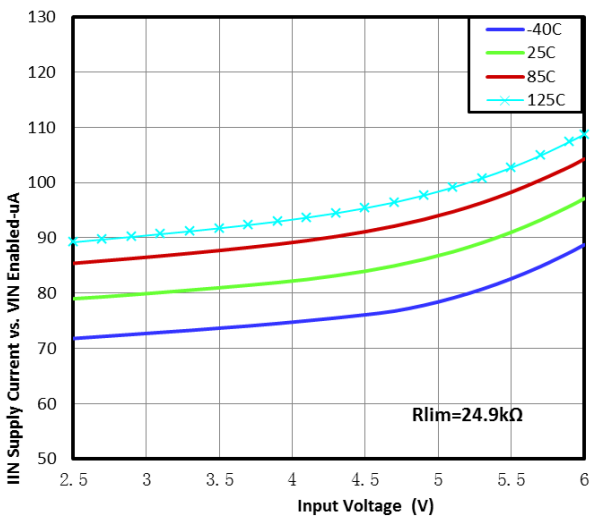


Figure 10 I_{IN} & V_{IN} Supply Voltage

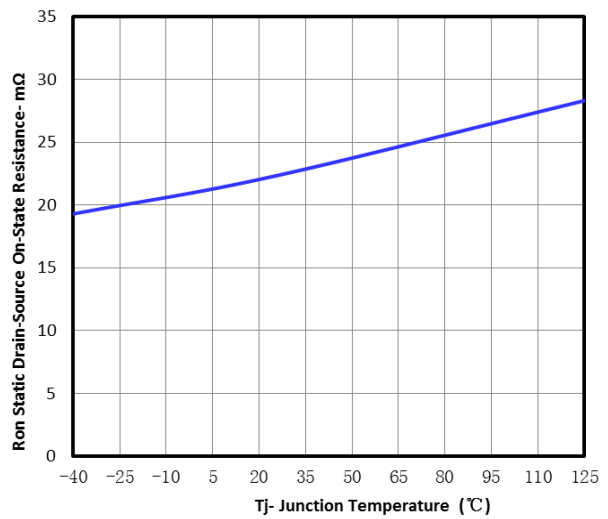


Figure 11 MOSFET R_{on} & Junction Temperature

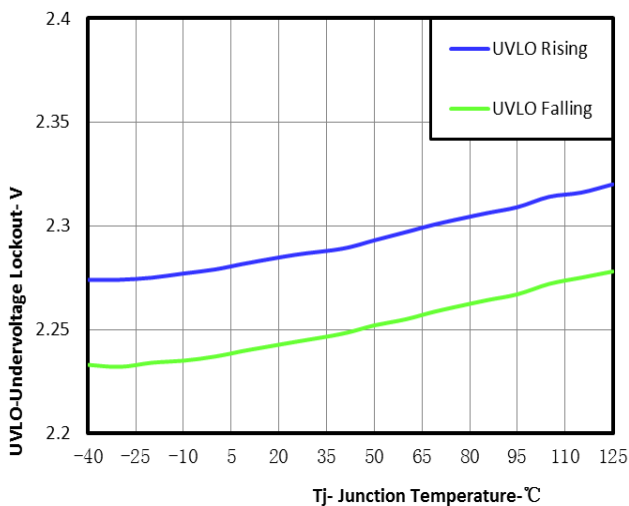


Figure 12 UVLO – Under voltage Lockout – V

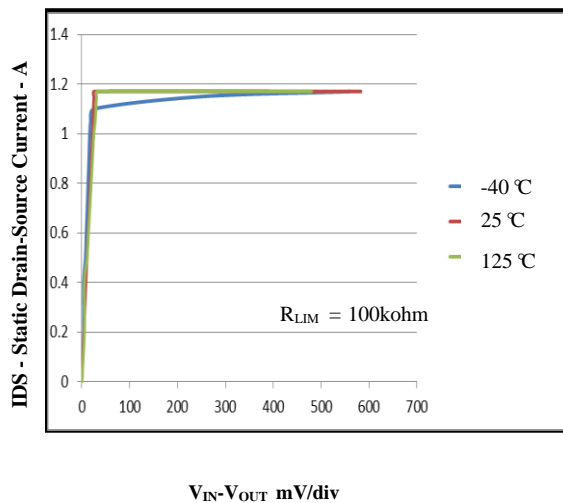


Figure 13 Switch Current Vs. Drain-Source Voltage Across

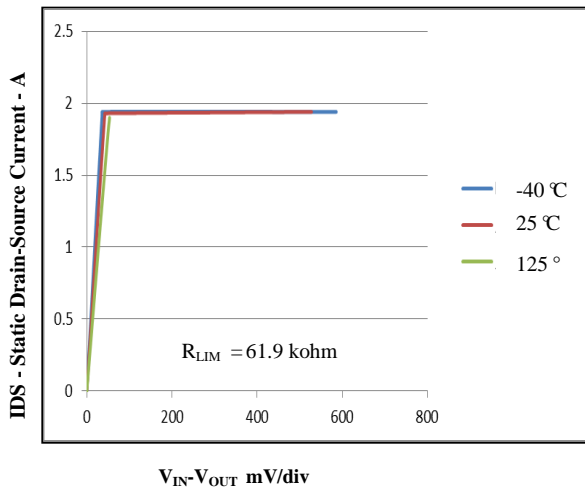


Figure 14 Switch Current Vs. Drain-Source Voltage Across

Functional Block Diagram

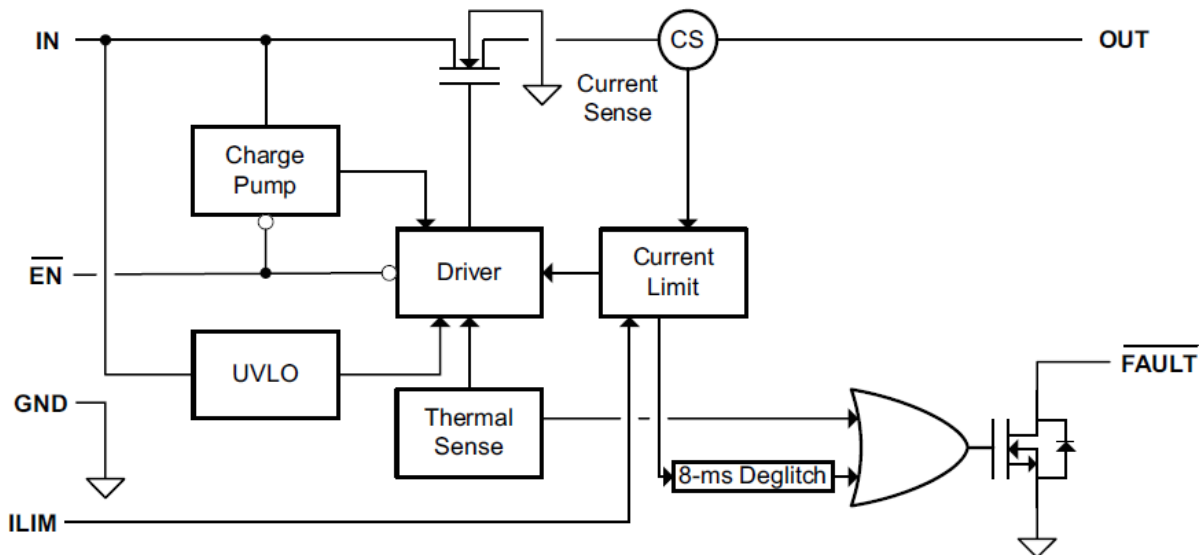


Figure 15 Functional Block Diagram

Functional Description

Overview

The PI5PD2556/2557 is a single-channel, current-limited power-distribution switch using N-channel MOSFETs for applications where short circuits or heavy capacitive loads will be encountered. This device allows the user to program the current-limit threshold between 500 mA and 5.0 A (typ) via an external resistor. This device incorporates an internal charge pump and gate drive circuitry necessary to drive the N-channel MOSFETs. The charge pump supplies power to the driver circuit for each channel and provides the necessary voltage to pull the gate of the MOSFET above the source. The charge pump operates from input voltages as low as 2.5 V and requires little supply current. The driver controls the gate voltage of the power switch. The driver incorporates circuitry that controls the rise and fall times of the output voltage to limit large current and voltage surges and provides built-in soft-start functionality. The PI5PD2556/2557 limits the output current to the programmed current-limit threshold IOS during an over-current or short-circuit event by reducing the charge pump voltage driving the N-channel MOSFET and operating it in the linear range of operation. The result of limiting the output current to IOS reduces the output voltage at OUT because the N-channel MOSFET is no longer fully enhanced.

Over-current Conditions

When an over-current condition is detected, the device maintains a constant output current and reduces the output voltage accordingly.

The PI5PD2556/2557 thermal cycles if an overload condition is present long enough to activate thermal limiting in any of the above cases. The device turns off when the junction temperature exceeds 135 °C (min) while in current limit. The device remains off until the junction temperature cools 20 °C (typ) and then restarts. The PI5PD2556/2557 cycles on/off until the overload is removed.

/FAULT Response

The FAULT open-drain outputs are asserted (active low) during an over-current or over-temperature condition. The PI5PD2556/2557 asserts the FAULTx signal until the fault condition is removed and the device resumes normal operation. The PI5PD2556/2557 is designed to eliminate false FAULT reporting by using an internal delay "deglitch" circuit (9-ms typ) for over-current conditions without the need for external circuitry. This ensures that FAULT is not accidentally asserted due to normal operation such as starting into a heavy capacitive load. The deglitch circuitry delays entering and leaving current-limited induced fault conditions. The FAULT signal is not deglitched when the MOSFET is disabled due to an over-temperature condition but is deglitched after the device has cooled and begins to turn on. This unidirectional deglitch prevents FAULT oscillation during an over-temperature event.

Under-voltage Lockout (UVLO)

The under-voltage lockout (UVLO) circuit disables the power switch until the input voltage reaches the UVLO turn-on threshold. Built-in hysteresis prevents unwanted on/off cycling due to input voltage droop during turn on.

Enable (EN OR /EN)

The logic enables control the power switches and device supply current. The supply current is reduced to less than 2-μA when a logic high is present on /EN or when a logic low is present on EN. A logic low input on /EN or a logic high input on EN enables the driver, control circuits, and power switches. The enable inputs are compatible with both TTL and CMOS logic levels.

Thermal Sense

The PI5PD2556/2557 self protects by using two independent thermal sensing circuits that monitor the operating temperature of the power switch and disable operation if the temperature exceeds recommended operating conditions. The PI5PD2556/2557 operates in constant-current mode during an over-current condition, which increases the voltage drop across the power switch. The power dissipation in the package is proportional to the voltage drop across the power switch, which increases the junction temperature during an over-current condition. The first thermal sensor (OTSD) turns off the power switch when the die temperature exceeds 135 °C (min) and the chip is in current limit. Hysteresis is built into the thermal sensor, and the switch turns on after the device has cooled approximately 20 °C.

The PI5PD2556/2557 also has a second ambient thermal sensor (OTSD2). The ambient thermal sensor turns off power switch when the die temperature exceeds 155 °C (min) regardless of whether the power switch are in current limit and will turn on the power switches after the device has cooled approximately 20 °C. The PI5PD2556/2557 continues to cycle off and on until the fault is removed.

Application Information

Input and Output Capacitance

Input and output capacitance improves the performance of the device; the actual capacitance should be optimized for the particular application. For all applications, a 0.1µF or greater ceramic bypass capacitor between IN and GND is recommended as close to the device as possible for local noise decoupling. This precaution reduces ringing on the input due to power-supply transients.

Additional input capacitance may be needed on the input to reduce voltage overshoot from exceeding the absolute-maximum voltage of the device during heavy transient conditions or output shorting. This is especially important during bench testing when long inductive cables are used to connect the evaluation board to the bench power supply. Normally suggested the distance between IC and DC supply source is less than 15cm.

Output capacitance also need to be close to IC as possible. When large transient currents are expected on the output, placing a high-value electrolytic capacitor on the output pin is recommended.

Programming the Current-Limit Threshold

The overcurrent threshold is user programmable via an external resistor. The PI5PD2556/57 uses an internal regulation loop to provide a regulated voltage on the ILIM pin. The current-limit threshold is proportional to the current sourced out of ILIM. The recommended 1% resistor range for RILIM is $20\text{ k}\Omega \leq R_{ILIM} \leq 187\text{ k}\Omega$ to ensure stability of the internal regulation loop. Many applications require that the minimum current limit is above a certain current level or that the maximum current limit is below a certain current level, so it is important to consider the tolerance of the overcurrent threshold when selecting a value for RILIM. The following equations approximate the resulting overcurrent threshold for a given external resistor value @ILIM). Consult the Electrical Characteristics table for specific current limit settings. The traces routing the RILIM resistor to the PI5PD2556/57 should be as short as possible to reduce parasitic effects on the current-limit accuracy.

$$I_{OSmax}(\text{mA}) = \frac{99038V}{R_{ILIM}^{0.947}\text{k}\Omega}$$

$$I_{OSnom}(\text{mA}) = \frac{111704V}{R_{ILIM}^{1.0028}\text{k}\Omega}$$

$$I_{OSmin}(\text{mA}) = \frac{127981V}{R_{ILIM}^{1.0708}\text{k}\Omega}$$

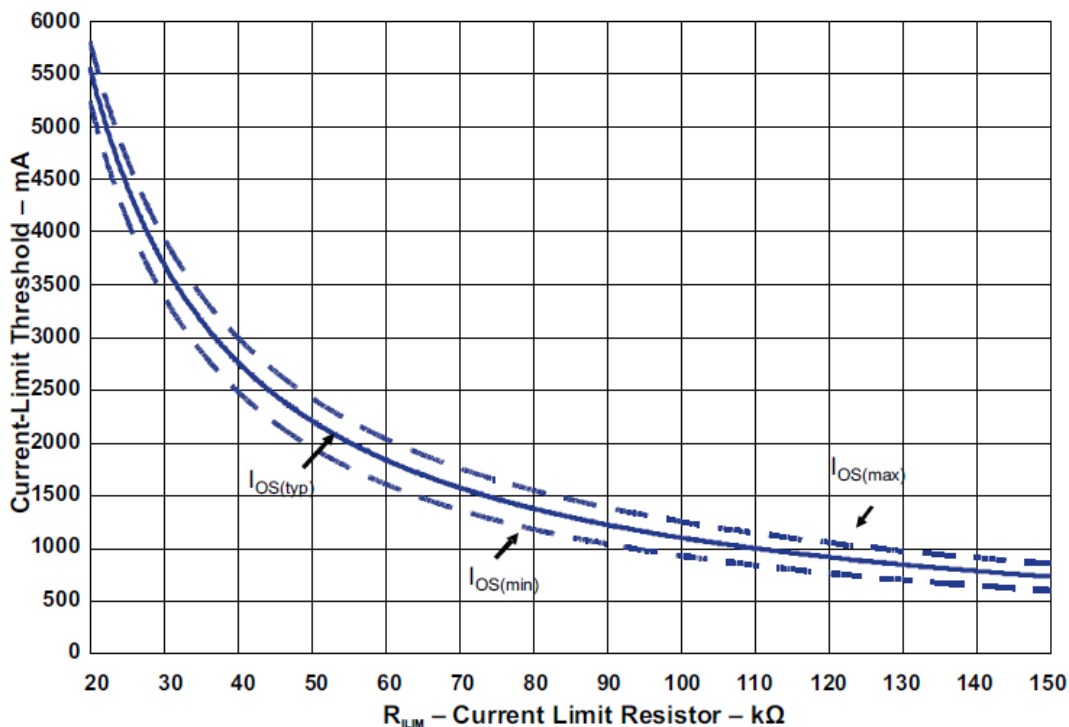


Figure 16 Current Limit Threshold & RILIM

Application 1: Designing above a Minimum Current Limit

Some applications require that current limiting cannot occur below a certain threshold. For this example, assume that 3 A must be delivered to the load so that the minimum desired current-limit threshold is 3000 mA. Use the IOS equations and Figure 7 to select RILIM.

$$I_{OSmin} (mA) = 3000mA$$

$$I_{OSmin} (mA) = \frac{127981V}{R_{ILIM}^{1.0708} k\Omega}$$

$$R_{ILIM} (k\Omega) = \left(\frac{127981V}{I_{OSmin} mA} \right)^{\frac{1}{1.0708}}$$

$$R_{ILIM} (k\Omega) = 33.3k\Omega$$

Select the closest 1% resistor less than the calculated value: RILIM = 33.2 k Ω . This sets the minimum current-limit threshold at 3000 mA . Use the IOS equations, Figure 7, and the previously calculated value for RILIM to calculate the maximum resulting current-limit threshold.

$$R_{ILIM} (k\Omega) = 33.2k\Omega$$

$$I_{OSmax} (mA) = \frac{99038V}{R_{ILIM}^{0.947} k\Omega}$$

$$I_{OSmax} (mA) = \frac{99038V}{33.2^{0.947} k\Omega}$$

$$I_{OSmax} (mA) = 3592mA$$

The resulting maximum current-limit threshold is 3592 mA with a 33.2 k Ω resistor.

Application 2: Designing Below a Maximum Current Limit

Some applications require that current limiting must occur below a certain threshold. For this example, assume that the desired upper current-limit threshold must be below 5000 mA to protect an up-stream power supply. Use the IOS equations and Figure 7 to select RILIM.

$$I_{OSmax} (mA) = 5000mA$$

$$I_{OSmax} (mA) = \frac{99038V}{R_{ILIM}^{0.947} k\Omega}$$

$$R_{ILIM} (k\Omega) = \left(\frac{99038V}{I_{OSmax} mA} \right)^{\frac{1}{0.947}}$$

$$R_{ILIM} (k\Omega) = 23.4k\Omega$$

Select the closest 1% resistor greater than the calculated value: RILIM = 23.7k Ω . This sets the maximum current-limit threshold at 5000 mA . Use the IOS equations, Figure 7, and the previously calculated value for RILIM to calculate the minimum resulting current-limit threshold.

$$R_{ILIM} (k\Omega) = 23.7k\Omega$$

$$I_{OSmin} (mA) = \frac{127981V}{R_{ILIM}^{1.0708} k\Omega}$$

$$I_{OSmin} (mA) = \frac{127981V}{23.7^{1.0708} k\Omega}$$

$$I_{OSmin} (mA) = 4316mA$$

The resulting minimum current-limit threshold is 4316 mA with a 23.7 k Ω resistor

Accounting For resistor Tolerance

The previous sections described the selection of RILIM given certain application requirements and the importance of understanding the current-limit threshold tolerance. The analysis focused only on the PI5PD2556/57 performance and assumed an exact resistor value. However, resistors sold in quantity are not exact and are bounded by an upper and lower tolerance centered around a nominal resistance. The additional RILIM resistance tolerance directly affects the current-limit threshold accuracy at a system level. The following table shows a process that accounts for worst-case resistor tolerance assuming 1% resistor values. Step one follows the selection process outlined in the application examples above. Step two determines the upper and lower resistance bounds of the selected resistor. Step three uses the upper and lower resistor bounds in the IOS equations to calculate the threshold limits. It is important to use tighter tolerance resistors, e.g. 0.5% or 0.1%, when precision current limiting is desired.

Table 1. Common RILIM Resistor Selections

Desired Nominal Current Limit (mA)	Ideal Resistor (kΩ)	Closest 1% Resistor (kΩ)	Resistor Tolerance		Actual Limits		
			1% Low (kΩ)	1% High(kΩ)	Ios Min (mA)	Ios Nor (mA)	Ios Max (mA)
750	146.9	147	145.5	148.5	605	749	886
1000	110.2	110	108.9	111.1	825	1002	1166
1250	88.2	88.7	87.8	89.6	1039	1244	1430
1500	73.6	73.2	72.5	73.9	1276	1508	1725
1750	63.1	63.4	62.8	64	1489	1742	1965
2000	55.2	54.9	54.4	55.4	1737	2012	2252
2250	49.1	48.7	48.2	49.2	1975	2269	2523

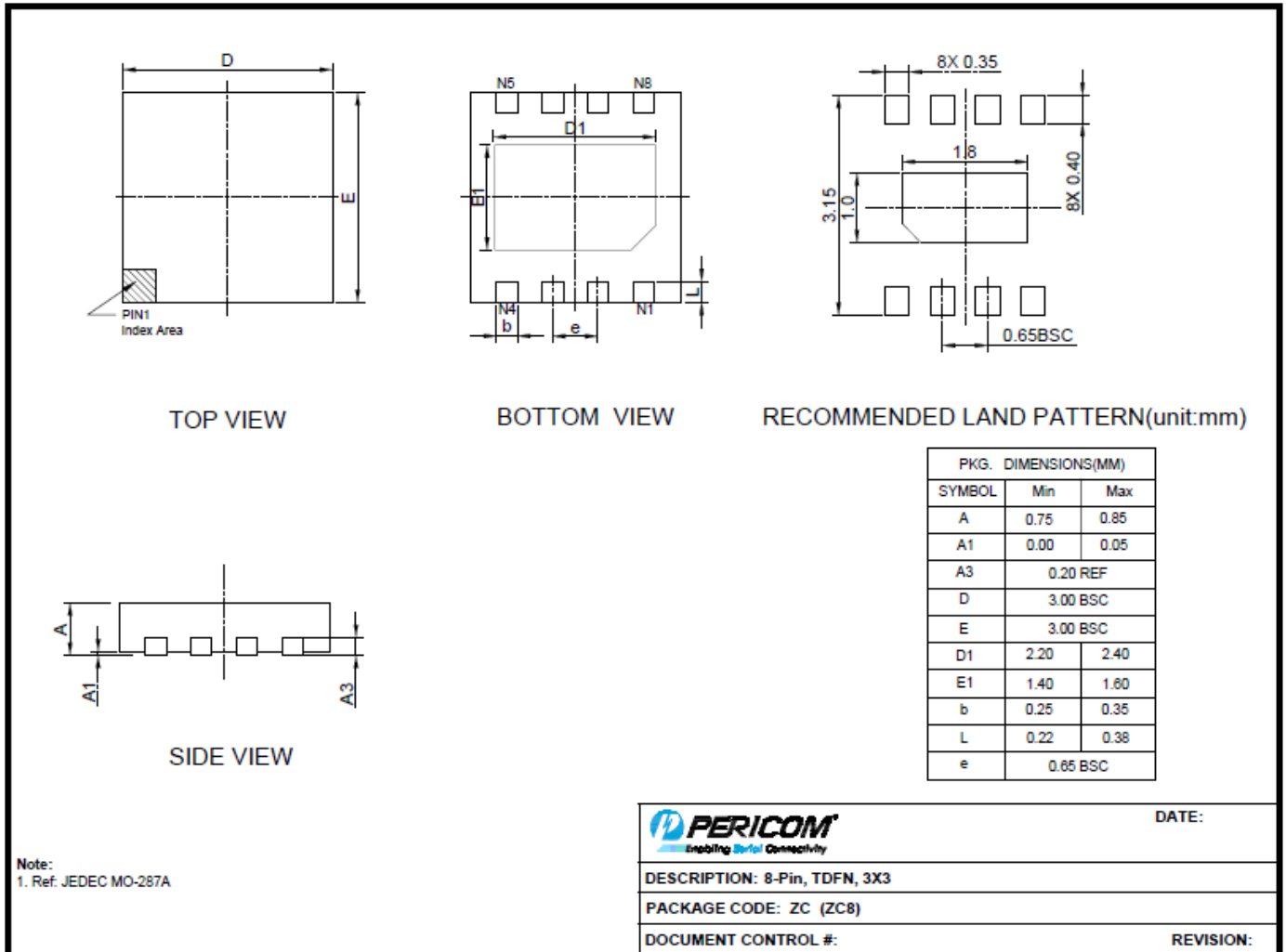


PI5PD2556/2557
Precision Adjustable
Current-Limited Power Switch

2500	44.2	44.2	43.8	44.6	2191	2501	2765
2750	40.2	40.2	39.8	40.6	2425	2750	3025
3000	36.9	36.5	36.1	36.9	2689	3030	3315
3250	34	34	33.7	34.3	2901	3253	3545
3500	31.6	31.6	31.3	31.9	3138	3501	3800
3750	29.5	29.4	29.1	29.7	3390	3764	4068
4000	27.7	27.4	27.1	27.7	3656	4039	4349
4250	26.0	26.1	25.8	26.4	3851	4241	4554
4500	24.6	24.9	24.7	25.1	4050	4446	4761
4750	23.3	23.2	23	23.4	4369	4773	5091
5000	22.1	22.1	21.9	22.3	4602	5011	5331
5250	21.1	21	20.8	21.2	4861	5274	5595
5500	20.1	20	19.8	20.2	5121	5539	5859

Mechanical Information

TDFN 3.0x3.0-8L



Ordering Information

Part No.	Package Code	Package
PI5PD2556ZCEX	ZC	Lead free and Green 8-pin TDFN3.0x3.0 Tape & reel
PI5PD2557ZCEX	ZC	Lead free and Green 8-pin TDFN3.0x3.0 Tape & reel

Note:

- E = Pb-free and Green
- Adding X Suffix= Tape/Reel

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