MPQ5873

36V, 3A, Single-Channel, 60mΩ, Smart High-Side Load Switch AEC-Q100 Qualified

DESCRIPTION

The MPQ5873 is a smart high-side load switch for nominal 3A loads. The device supports a wide 3.5V to 36V input voltage (V_{IN}) range. With a small on resistance ($R_{DS(ON)}$), the MPQ5873 provides a highly efficient, compact solution.

The device supports both an internal and configurable, high-accuracy external current limit. This helps clamp the inrush current under short-circuit conditions, which improves overall system reliability. An adjustable start-up slew rate also helps to reduce inrush current during start-up.

The FT/CS pin provides high-accuracy current sensing, which achieves accurate real-time diagnostics without additional calibration. The voltage on the FT/CS pin (V_{CS}) represents 1 / K_{CS} of the load current (I_{LOAD}), where K_{CS} is a constant value across the temperature and supply voltage ranges. The FT/CS pin can report faults by pulling up its voltage.

The MPQ5873 features full diagnostics during both on and off states. By pulling the DIAG_EN pin up or down, off state open-load and short to battery detection can be enabled or disabled, respectively. If off state diagnostics are not required in the system, the function can be disabled to reduce the standby current by connecting the DIAG_EN and GND pins.

The MPQ5873 is available in a QFN-8 (2mmx2.5mm) package. It is available in AEC-Q100 Grade 1 and compliant with AEC-Q100-012 Test Grade A.

FEATURES

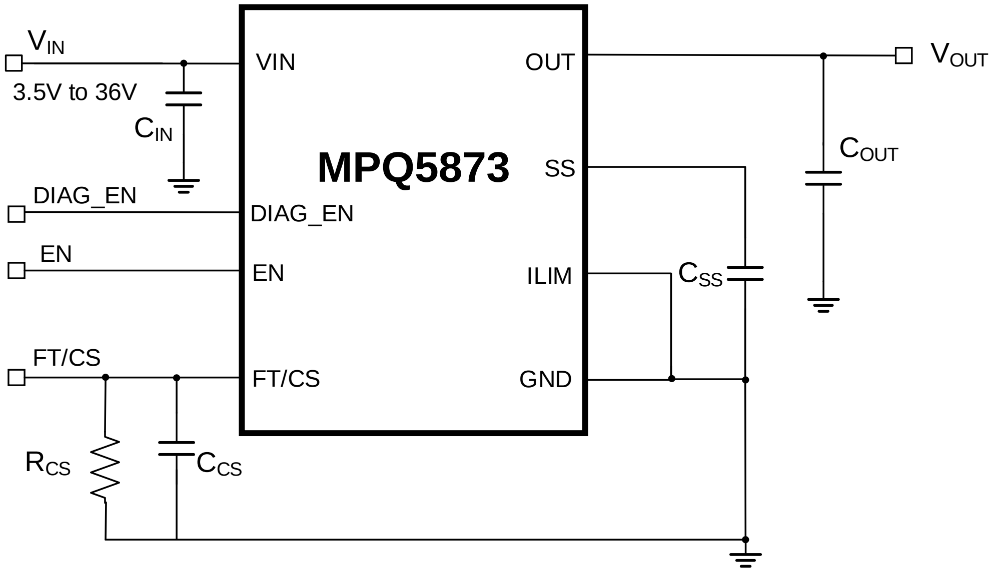
- Built to Handle Tough Automotive Transients and AEC-Q100 Requirement
  - Load Dump Up to 42V
  - Cold Crank Down to 3.5V
  - Available in AEC-Q100 Grade 1
- Cooler Thermals
  - Integrated 60mΩ MOSFET
- Extends Vehicle Battery Life
  - Extremely Low Standby Current: 0.5µA
- Reduces Board Size
  - Available in a QFN-8 (2mmx2.5mm) Package
  - Available in a Wettable Flank Package
- Vast Flexibility
  - Configurable External Current Limit
  - Adjustable Start-Up Slew Rate
  - 3.3V and 5V Logic Compatible
- Full Diagnostics and Robust Protections
  - High-Accuracy Current Sense: ±4% at 1A and ±6% at 300mA
  - On State and Off State Open-Load and Short to Battery Detection
  - Thermal Shutdown
  - Compliant with AEC-Q100-012 Test Grade A
- Functional Safety System Design Capability
  - Documents Available for MPSafe™ QM System Design

MPSafe™ Fusa Compatible

APPLICATIONS

- Smart Switches for Automotive Infotainment Systems
- Power Switches for Advanced Driver-Assistance Systems (ADAS)
- High-Side Power Switches for Sub-Modules
- General Resistive, Inductive, and Capacitive Loads

TYPICAL APPLICATION



ORDERING INFORMATION

Part Number*	Package	Top Marking	MSL Rating
MPQ5873GRPE-AEC1***	QFN-8 (2mmx2.5mm)	*See Below*	1

* For Tape & Reel, add suffix -Z (e.g. MPQ5873GRPE-AEC1-Z).

** Moisture Sensitivity Level Rating

*** Wettable Flank

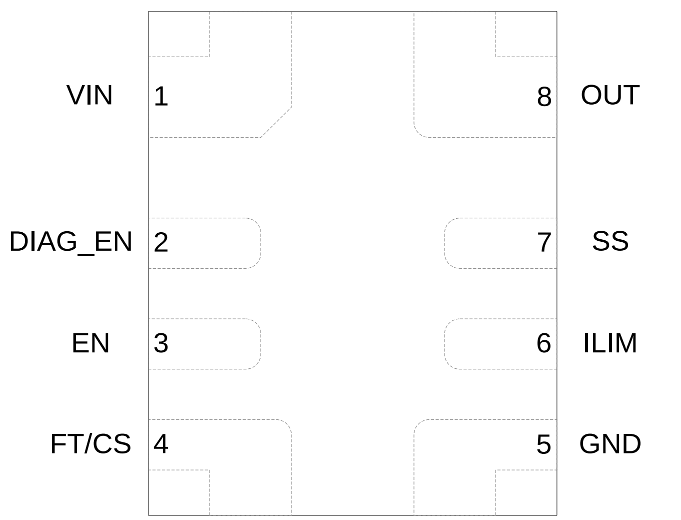
TOP MARKING

MRY
LLL

MR: Product code of MPQ5873GRPE-AEC1
Y: Year code
LLL: Lot number

PACKAGE REFERENCE

TOP VIEW



QFN-8 (2mmx2.5mm)

PIN FUNCTIONS

Pin #	Name	Description
1	VIN	**Input power supply.** The VIN pin is connected to the battery.
2	DIAG_EN	**Enable diagnostics.** Pull the DIAG_EN pin above the specified threshold (1.2V) to enable the diagnostics; pull it below the specified threshold (1V) to disable the diagnostics and reduce the standby current. Connect this pin to GND if not used.
3	EN	**Enable.** Pull the EN pin above the specified threshold (1.2V) to enable the chip. Pull EN below threshold (1V) to shut down the chip.
4	FT/CS	**Fault/Current sense.** A current mirror is used to source 1 / K_{CS} of the load current (I_{LOAD}), which flows to the external resistor (R_{CS}) between FT/CS and GND. The voltage on the FT/CS pin (V_{CS}) reflects I_{LOAD}. FT/CS also reports faults. Place a 470nF capacitor as close to FT/CS as possible. Remove R_{CS} if the current-sense feature is not used.
5	GND	**Device ground.**
6	ILIM	**Configurable current limit.** Connect the ILIM pin to GND via a resistor (R_{CL}) to set the external current limit. See the Operation for details. Connect to GND if the external current limit is not used.
7	SS	**Soft start.** Connect an external capacitor to the SS pin to set the output voltage (V_{OUT}) slew rate during soft start (SS).
8	OUT	**Output to the load**. N-channel MOSFET source.

ABSOLUTE MAXIMUM RATINGS (1)

VIN, OUT ....-0.3 V to +42V
All other pins ....-0.3 V to +6.5V
Junction temperature (T_J) ....150°C
Lead temperature ....260°C
Storage temperature (T_{STG})...... -65°C to +150°C
Continuous power dissipation (2) (7) 4.46W
Inductive load switch-off energy dissipation, single pulse (3) 50mJ

ESD Ratings

Human body model (HBM) ....Class 2 (4)
Charged-device model (CDM) ......Class C2b (5)

Recommended Operating Conditions

Input voltage (V_{IN}) ....5V to 36V
Nominal DC load current (I_{LOAD})............0A to 3A
Operating junction temp (T_J).... -40°C to +150°C

Thermal Resistance	θ_{JA}	θ_{JC}	
QFN-8 (2mmx2.5mm)			
JESD51-7 (6)	67.2	13.6	°C/W
EVQ5873-RP-00A (7)	28		°C/W
		Ψ_{JT}	
JESD51-7 (6)		4.9	°C/W
EVQ5873-RP-00A (7)		4	°C/W

Notes:

1) Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature, T_J (MAX), the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX) - T_A) / θ_{JA}. Exceeding the maximum allowable power dissipation can cause excessive die temperature, and the regulator may go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
3) Test conditions: V_{IN} = 13.5V, L = 10mH, R = 0Ω, T_A = 25°C. Derived from bench characterization. Not tested in production.
4) Per AEC-Q100-002.
5) Per AEC-Q100-011.
6) Obtained based on a JESD51-7, 4-layer PCB. The values given in this table are only valid for comparison with other packages and cannot be used for design purposes. These values were calculated in accordance with JESD51-7, and simulated on a specified JEDEC board. They do not represent the performance obtained in an actual application. The value of θ_{JC} shows the thermal resistance from junction-to-case bottom, and the value of Ψ_{JT} shows the characterization parameter from junction-to-case top.
7) Measured on the MPS MPQ5873 standard EVB, 6.35cmx6.35cm, 2oz copper thickness, 4-layer PCB. The value of Ψ_{JT} shows the characterization parameter from junction-to-case top.

ELECTRICAL CHARACTERISTICS

V_{IN} = 12V, T_J = -40°C to +150°C, typical values are tested at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Operating Voltage						
Recommended input voltage (V_{IN}) range	V_{IN_REC}		5		36	V
Full V_{IN} range	V_{IN_FULL}		3.5		36	V
V_{IN} range for short-circuit protection (SCP)	V_{IN_SCP}				24	V
V_{IN} under-voltage (UV) shutdown threshold	V_{UV_STD}		2.9	3.2	3.5	V
V_{IN} UV shutdown hysteresis	V_{UV_HYS}			0.5		V
Operating Current						
Standby current	I_{STBY}	V_{IN} = 12V, T_J = 25°C, V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V		0.5	1	μA
		V_{IN} = 12V, T_J = -40°C to +125°C (8), V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V			5	μA
		V_{IN} = 12V, T_J = -40°C to +150°C, V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V			8	μA
Standby current with diagnostics enabled	I_{DIAG}	V_{IN} = 12V, V_{EN} = 0V, V_{DIAG_EN} = 5V		0.2	0.5	mA
Quiescent current	I_Q	V_{IN} = 12V, V_{EN} = V_{DIAG_EN} = 5V		0.5	1	mA
Off state leakage current	I_{OFF_LK}	V_{IN} = 12V, V_{EN} = V_{OUT} = 0V, T_J = 25°C		10	100	nA
		V_{IN} = 12V, V_{EN} = V_{OUT} = 0V, T_J = -40°C to +150°C			3	μA
MOSFET Parameters						
On resistance	$R_{DS(ON)}$	V_{IN} ≥ 5V, T_J = 25°C		60	80	mΩ
		V_{IN} ≥ 5V, T_J = -40°C to +150°C			130	mΩ
		V_{IN} = 3.5V, T_J = 25°C		70	100	mΩ
		V_{IN} = 3.5V, T_J = -40°C to +150°C			150	mΩ
Body diode forward voltage	V_F	V_{EN} = 0V, I_{OUT} = -100mA		0.6		V
EN and DIAG_EN						
EN logic high voltage	V_{EN_H}		1	1.2	1.4	V
DIAG_EN logic high voltage	V_{DIAG_H}		1	1.2	1.4	V
EN logic low voltage	V_{EN_L}		0.8	1	1.2	V
DIAG_EN logic low voltage	V_{DIAG_L}		0.8	1	1.2	V
EN voltage hysteresis	V_{EN_HYS}			200		mV
DIAG_EN voltage hysteresis	V_{DIAG_HYS}			200		mV
EN pull-down resistance (8)	R_{EN_PD}			500		kΩ
DIAG_EN pull-down resistance (8)	R_{DIAG_PD}			500		kΩ

ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, T_J = -40°C to +150°C, typical values are tested at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Current Sense (CS)						
CS ratio	K_{CS}			1000		
CS accuracy	dK_{CS}/K_{CS}	I_{OUT} ≥ 1A, within linear range, T_J = 25°C	-4		+4	%
		I_{OUT} ≥ 1A, within linear range, T_J = -40°C to +150°C	-7		+7	%
		I_{OUT} ≥ 0.3A, T_J = 25°C	-6		+6	%
		I_{OUT} ≥ 0.3A, T_J = -40°C to +150°C	-9		+9	%
		I_{OUT} ≥ 30mA	-55		+55	%
Linear FT/CS voltage (V_{CS}) range (9)	V_{CS_LIN}		0		3	V
Output current (I_{OUT}) range for linear V_{CS}	I_{OUT_LIN}	V_{IN} = 12V, $V_{CS} \leq V_{CS\_LIN}$	0		3	A
FT/CS fault voltage	V_{CS_H}		4	4.4	4.8	V
CS fault condition current	I_{CS_H}	V_{CS_H} = 4V, V_{IN} ≥ 5V	7			mA
CS leakage current (DIAG_EN is low)	I_{CS_LK}	V_{EN} = 0V			1	µA
Soft Start (SS)						
Soft-start pull-up current	I_{SS}	Fixed slew rate		10		µA
Current Limit						
Internal current limit	I_{LIM}		4.14	4.6	5	A
Internal current limit threshold	V_{TH_LIM}			0.7		V
Current limit ratio	K_{CL}			1000		
Current limit accuracy	dK_{CL}/K_{CL}	$V_{IN} - V_{OUT}$ < 1V, current limit ≥ 3A	-10		+10	%
Current limit during start-up and short-circuit protection (SCP) (8)	I_{LIM_STA}	$V_{IN} - V_{OUT}$ > 1V	2.5	3.5	5	A
External current limit	I_{EXLIM}	R_{CL} = 233Ω	2.7	3	3.3	A
Current limit deglitch time	$t_{CL,DEG}$	CL lasts for t_{CL_DEG}, device shutdown		100		µs
Fast-off shutdown time (10)	t_{FOFF}	Fast off is triggered, device shutdown in t_{FOFF}		1		µs
Over-current (OC) automatic recovery time	t_{OFF_REC}	OC shutdown; after t_{OFF_REC}, the device turns on automatically		300		ms

ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, T_J = -40°C to +150°C, typical values are tested at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Diagnostics and Protections						
Off-state open-load threshold	V_{OL_OFF}	V_{EN} = 0V, if V_{IN} - V_{OUT} < V_{OL_OFF}, t > t_{OL_OFF}, open load detected	0.75	1.05	1.35	V
Off-state open-load detection deglitch time	t_{OL_OFF}			700		µs
Off-state output sink current with open load	I_{OL_OFF}	V_{EN} = 0V, V_{DIAG_EN} = 5V, I_{OUT} when an open load is detected			-75	µA
Thermal shutdown threshold (8)	T_{SD}			175		°C
Thermal shutdown hysteresis(8)	T_{SD_HYS}			30		°C

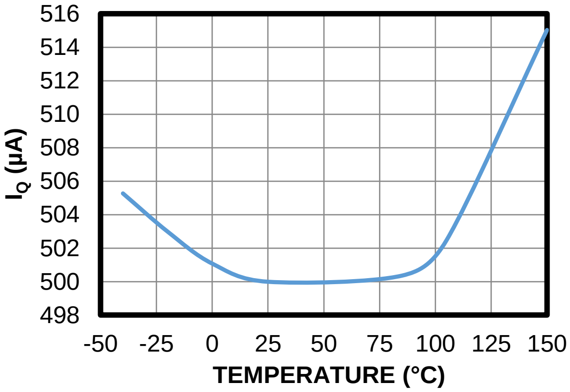
Notes:

8) Guaranteed by design and characterization. Not tested in production.
9) The current accuracy is not guaranteed if V_{CS} exceeds this range.
10) Derived from bench test. Not tested in production.

TYPICAL CHARACTERISTICS

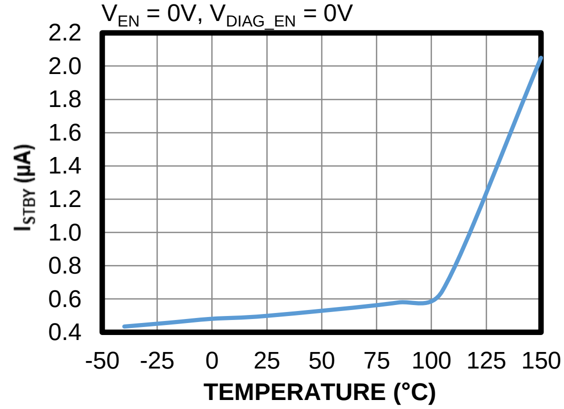
V_{IN} = 12V, unless otherwise noted.

Quiescent Current vs. Temperature



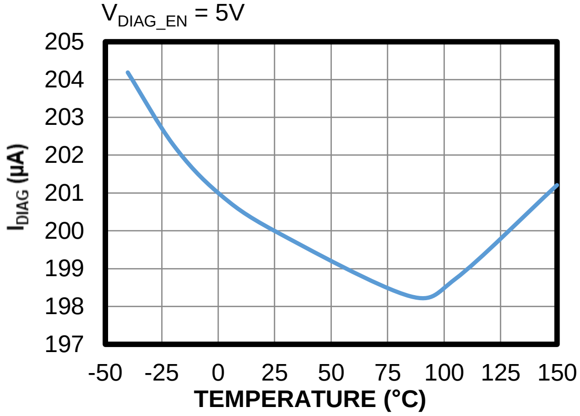
Standby Current vs. Temperature

V_{EN} = 0V, V_{DIAG_EN} = 0V

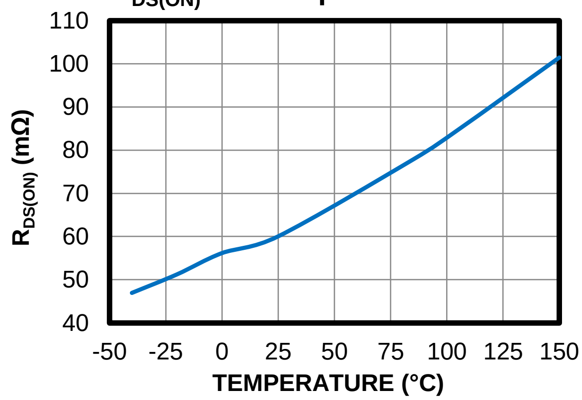


Standby Current vs. Temperature

Diagnostics enabled, V_{EN} = 0V, V_{DIAG_EN} = 5V

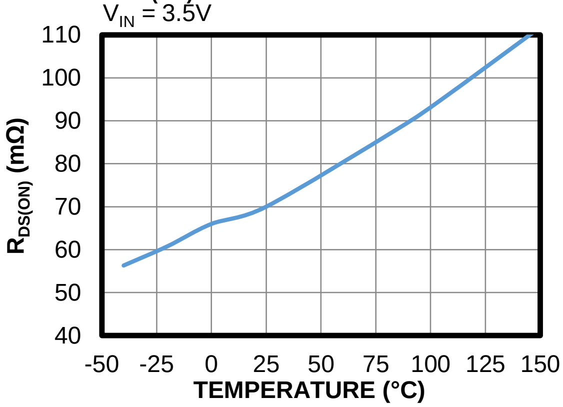


$R_{DS(ON)}$ vs. Temperature

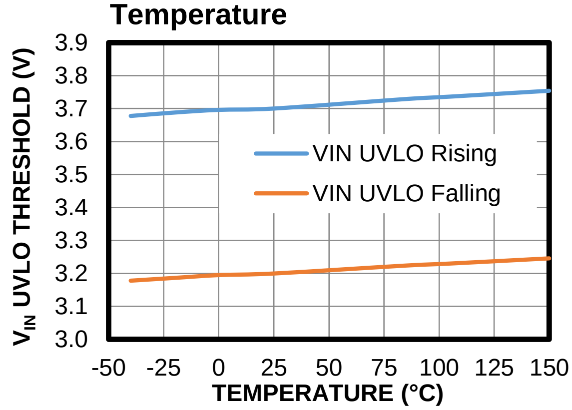


$R_{DS(ON)}$ vs. Temperature

V_{IN} = 3.5V

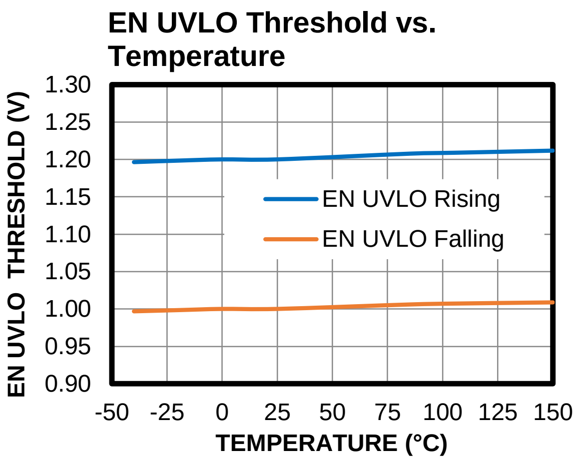


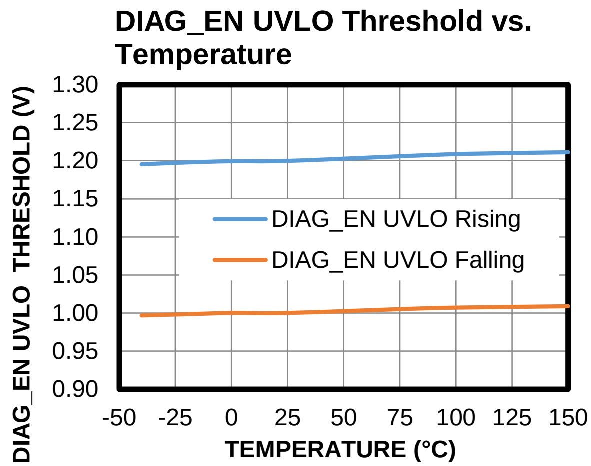
V_{IN} UVLO Threshold vs. Temperature

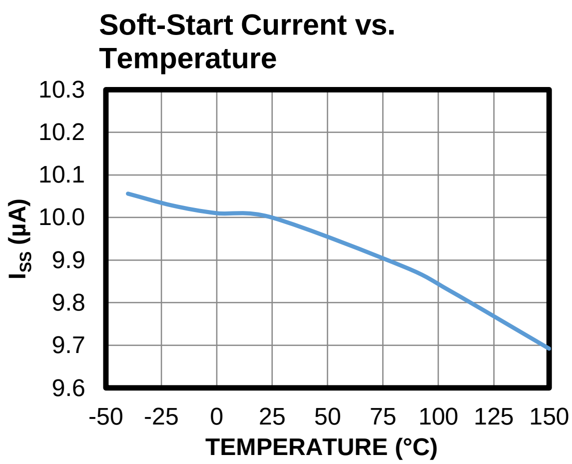


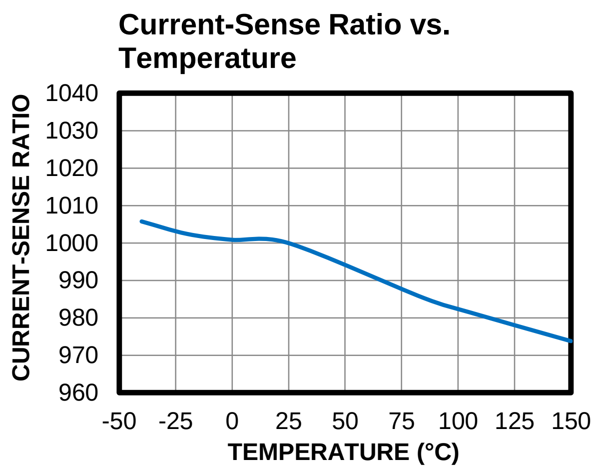
TYPICAL CHARACTERISTICS *(continued)*

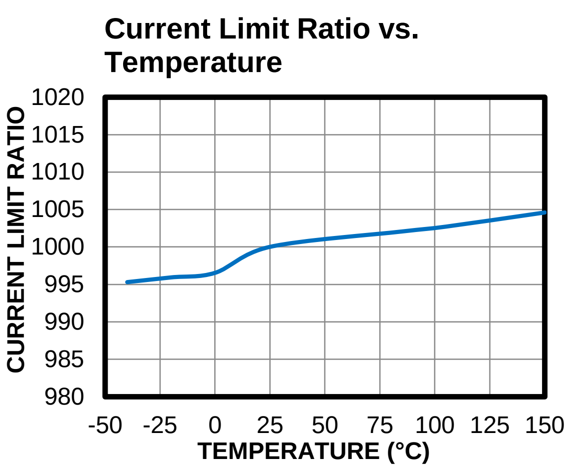
V_{IN} = 12V, unless otherwise noted.

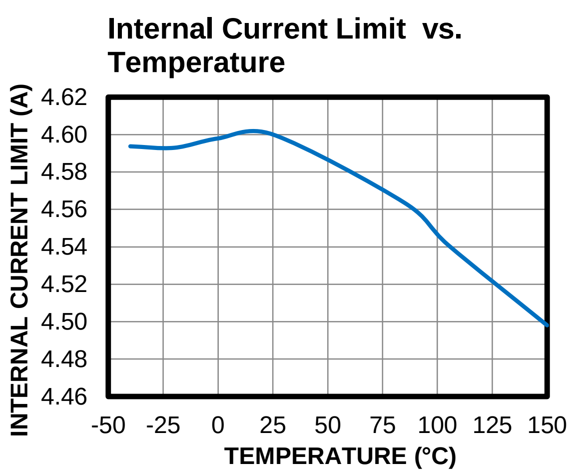






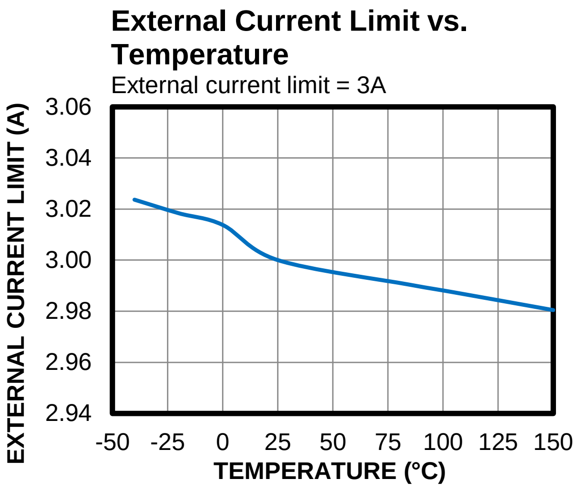


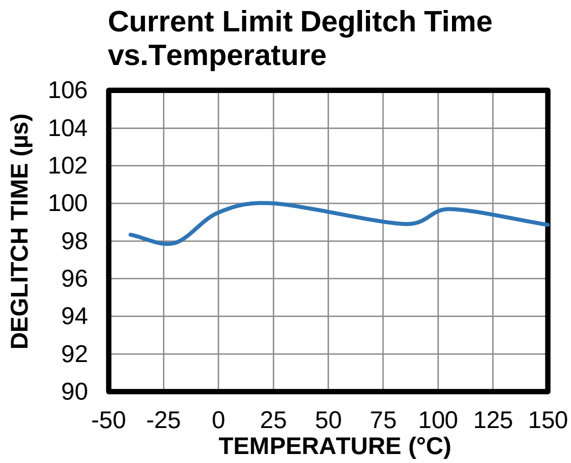




TYPICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, unless otherwise noted.

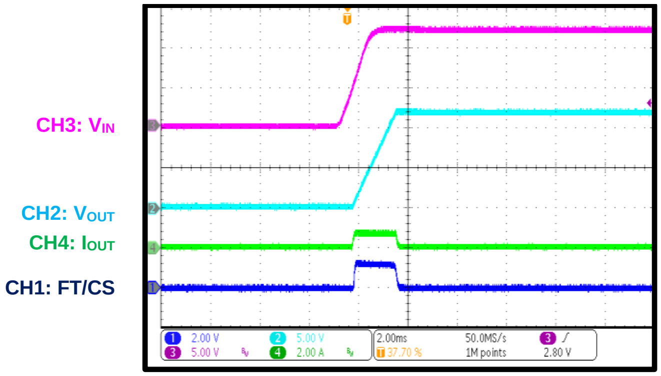




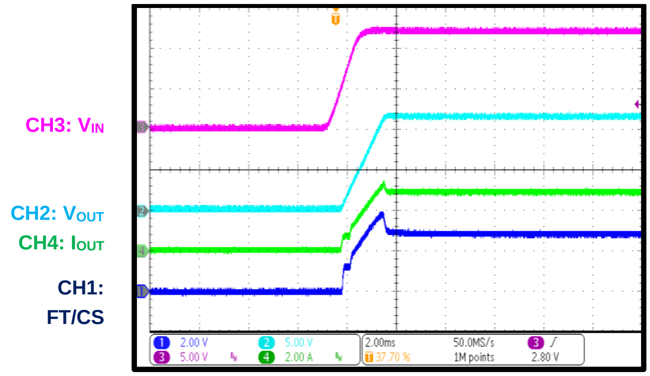
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 100µF, T_A = 25°C, unless otherwise noted.

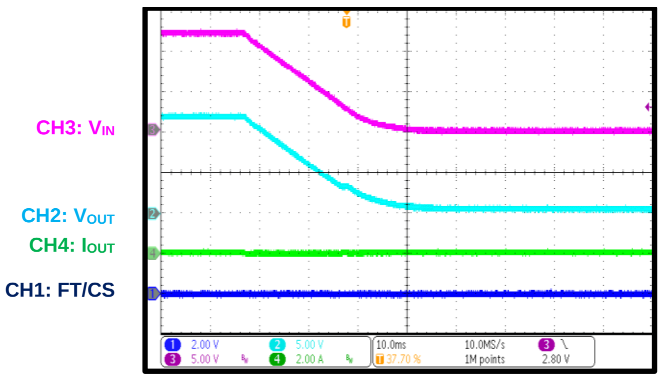
Start-Up through VIN
I_{OUT} = 0A



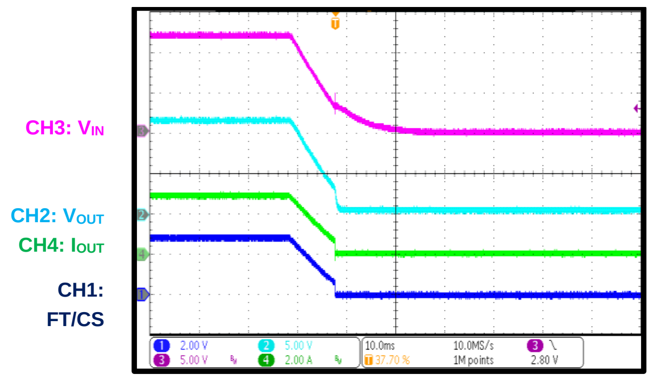
Start-Up through VIN
I_{OUT} = 3A



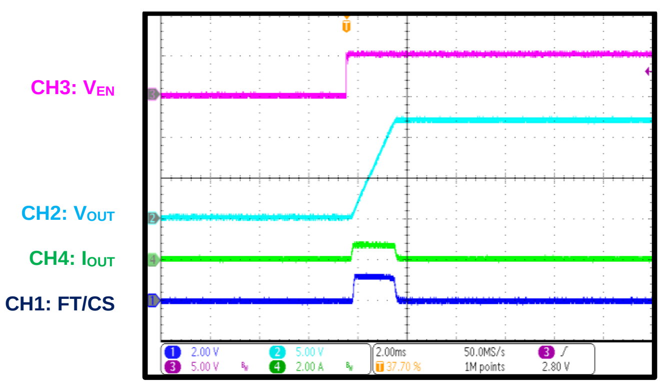
Shutdown through VIN
I_{OUT} = 0A



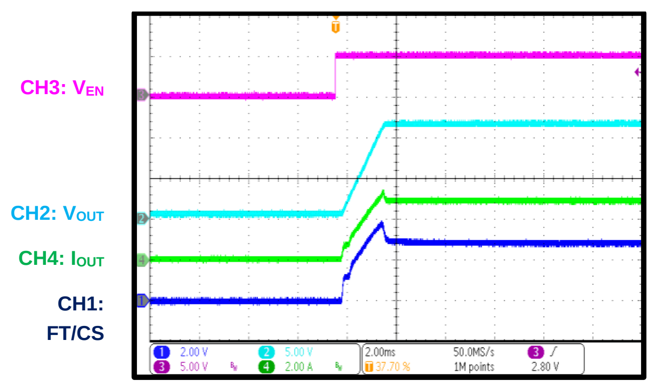
Shutdown through VIN
I_{OUT} = 3A



Start-Up through EN
I_{OUT} = 0A



Start-Up through EN
I_{OUT} = 3A

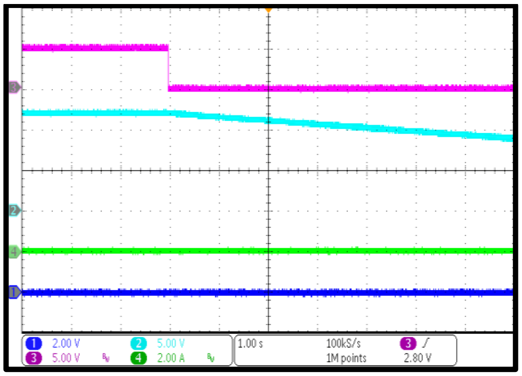


TYPICAL PERFORMANCE CHARACTERISTICS (*continued*)

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 100µF, T_A = 25°C, unless otherwise noted.

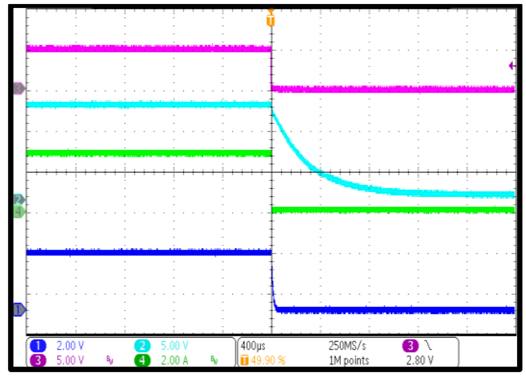
Shutdown through EN

I_{OUT} = 0A



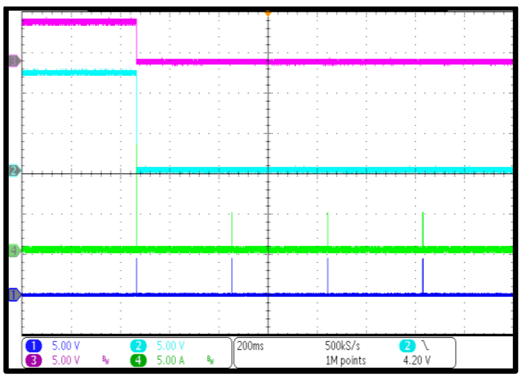
Shutdown through EN

I_{OUT} = 3A



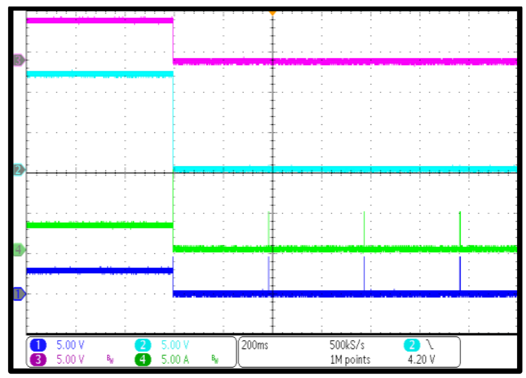
SCP Entry

I_{OUT} = 0A

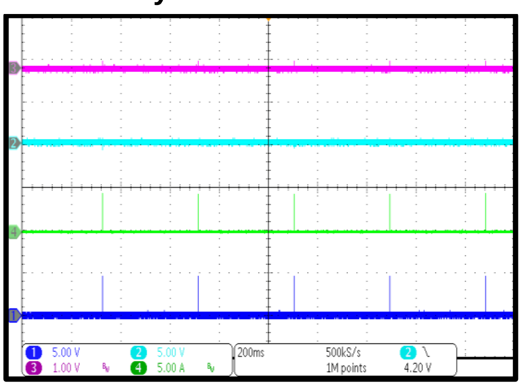


SCP Entry

I_{OUT} = 3A

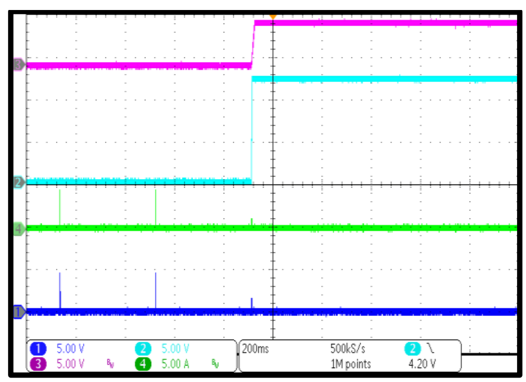


SCP Steady State



SCP Recovery

I_{OUT} = 0A

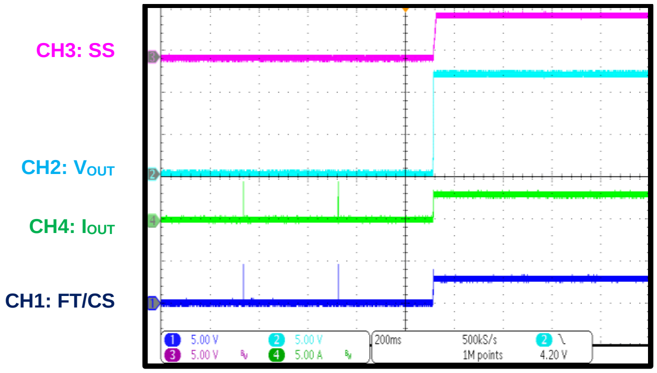


TYPICAL PERFORMANCE CHARACTERISTICS (*continued*)

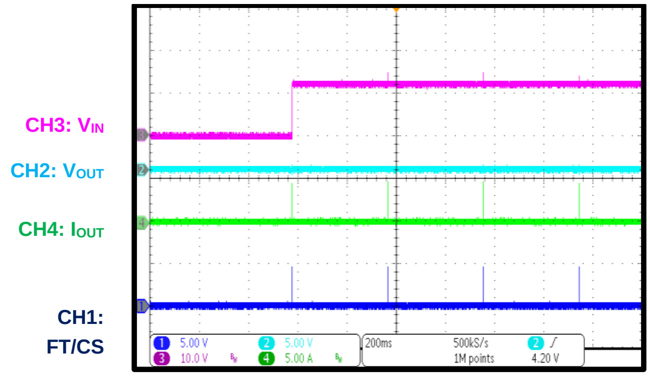
V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 100µF, T_A = 25°C, unless otherwise noted.

SCP Recovery

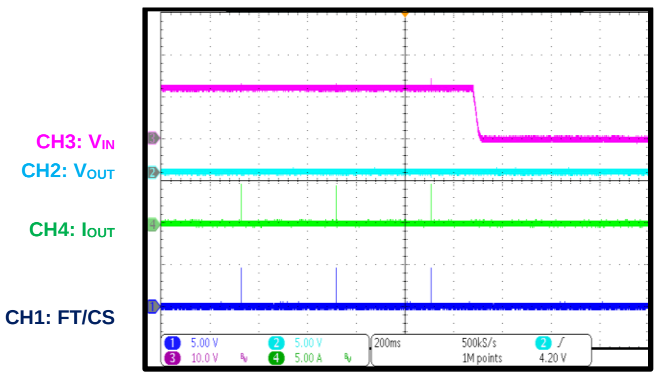
I_{OUT} = 3A



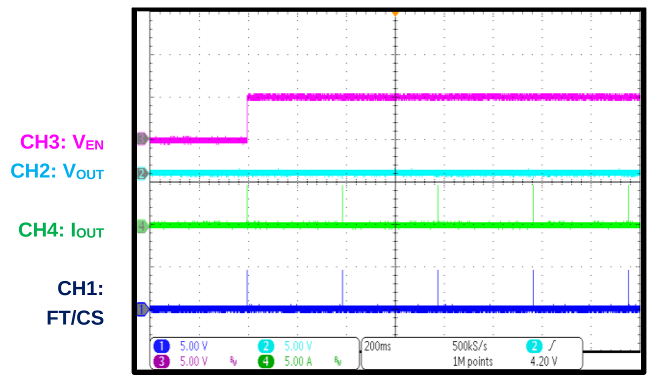
SCP Start-Up



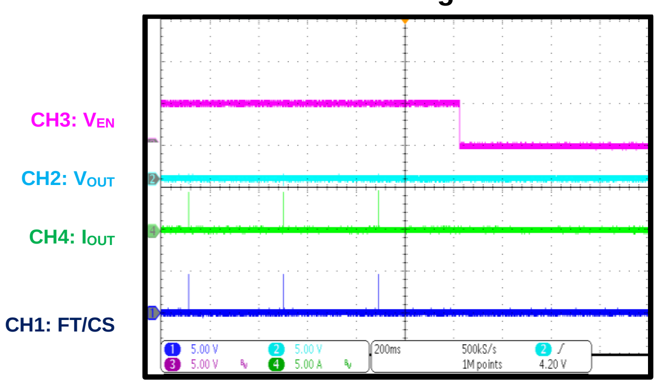
SCP Shutdown



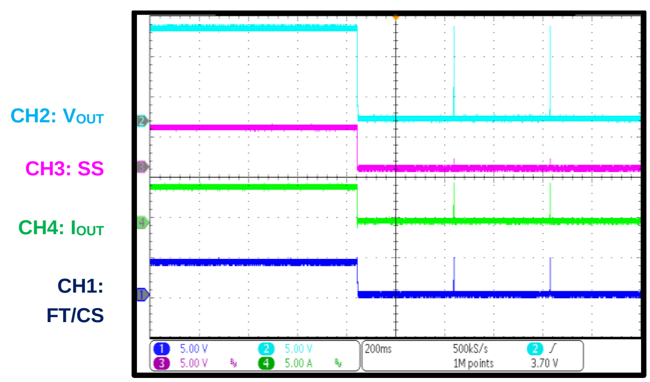
SCP Start-Up through EN



SCP Shutdown through EN



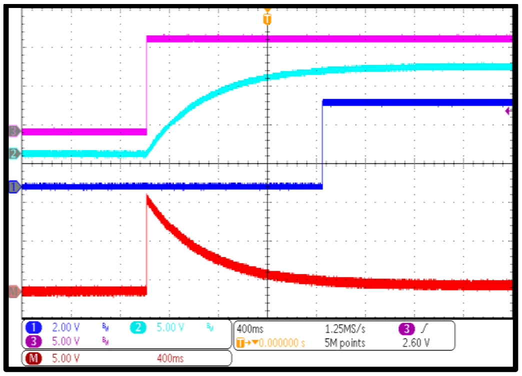
Over-Current Protection



TYPICAL PERFORMANCE CHARACTERISTICS (*continued*)

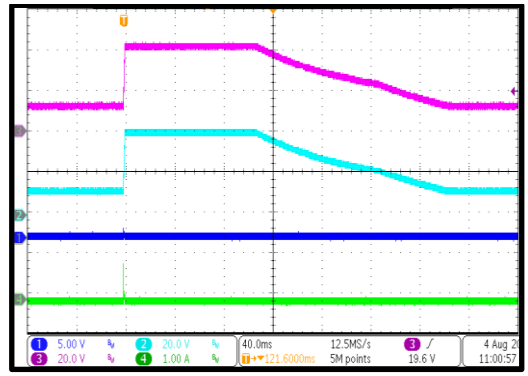
V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} =100µF, T_A = 25°C, unless otherwise noted.

Open Load Detection



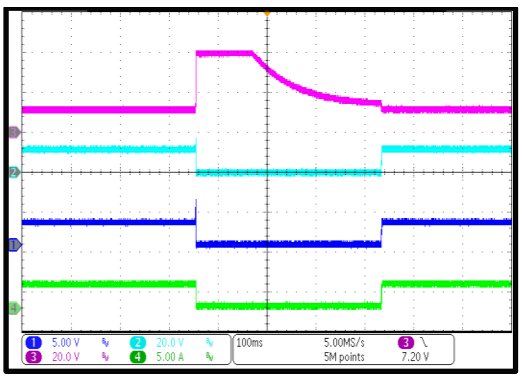
Load Dump

I_{OUT} = 0A



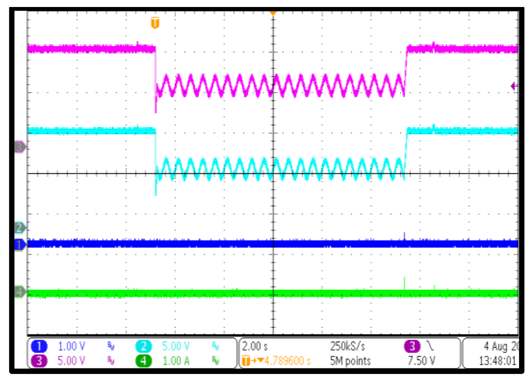
Load Dump

I_{OUT} = 3A



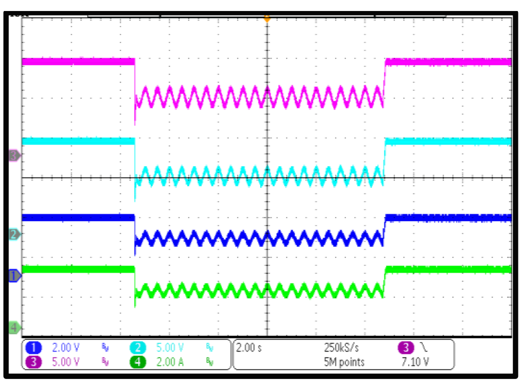
Cold Crank

I_{OUT} = 0A



Cold Crank

I_{OUT} = 3A



FUNCTIONAL BLOCK DIAGRAM

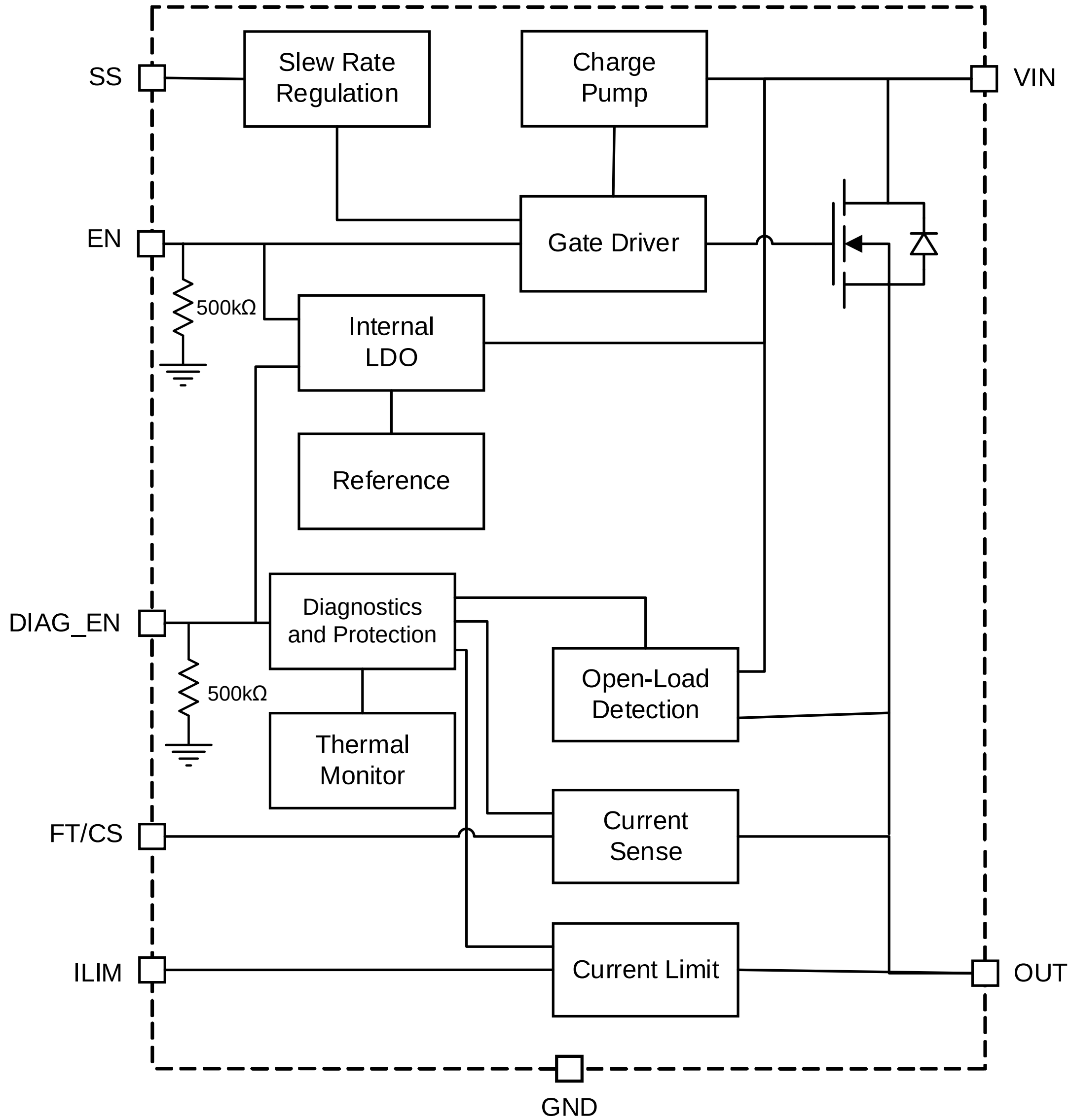


Figure 1: Functional Block Diagram

OPERATION

Operation Modes

The MPQ5873 has three operation modes: normal mode, standby mode, and diagnostic mode. If a low standby current is required during the off state, the part can be set to standby mode by pulling the DIAG_EN pin down, where the standby current is about 0.5µA. If off state diagnostics are required, the typical standby current is about 0.2mA when DIAG_EN is high. Figure 2 shows the operation mode state machine.

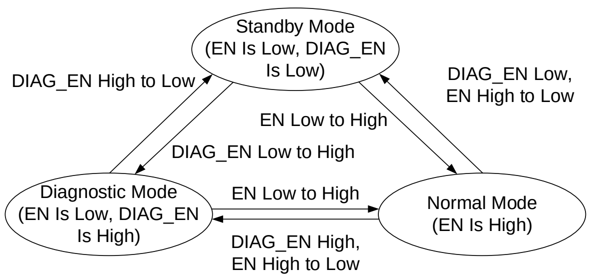


Figure 2: Operation Mode State Machine

High-Accuracy Current Sensing

The MPQ5873 integrates a high-accuracy current-sense block to realize the real-time current monitoring and diagnostics. A current mirror sources 1 / K_{CS} of the load current (I_{LOAD}), flowing to the external resistor (R_{CS}) between FT/CS and GND. The voltage on the FT/CS pin (V_{CS}) reflects I_{LOAD} .

K_{CS} represents the ratio between the output current (I_{OUT}) and the sensed current. K_{CS} is a constant value across the temperature and the supply voltage ranges, and it is internally calibrated. Users do not need to calibrate K_{CS}.

Figure 3 shows the current-sense accuracy. When I_{LOAD} exceeds 1A, the accuracy is ±4%. For load currents above 300mA, the accuracy can reach ±6%.

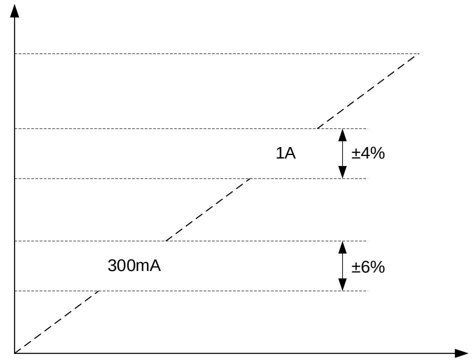


Figure 3: Current Sensing Accuracy

During normal operation, V_{CS} should be designed in the linear region. R_{CS} can be calculated with Equation (1).

$$R_{CS} = \frac{V_{CS}}{I_{CS}} = \frac{K_{CS}V_{CS}}{I_{OUT}} \quad (1)$$

To improve V_{CS} signal stability and eliminate transferred noise to the microcontroller (MCU), place a 470nF capacitor close to the FT/CS pin.

Fault Report Function

The FT/CS pin reports if a fault condition occurs. If an open load or battery short occurs when the device is on, V_{CS} is below the open-load threshold. If a current-limit condition, thermal shutdown, or open load/battery short is detected in the off state, V_{CS} is pulled up to V_{CS_H}. Figure 4 shows the MPQ5873's conditions and its corresponding V_{CS} range.

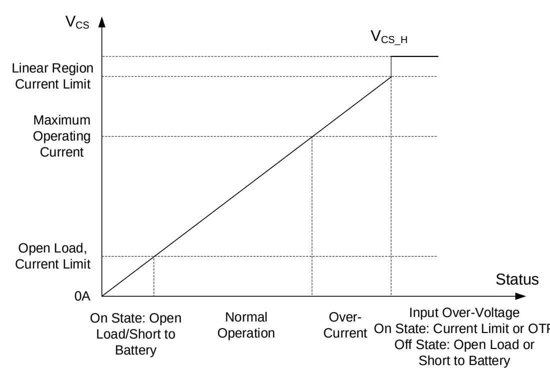


Figure 4: V_{CS} Range and the MPQ5873's Status

Internal Current Limit and Configurable External Current Limit

The MPQ5873 has an internal current limit and a configurable external current limit to improve the device's reliability and provide protection in a short circuit or start-up.

When I_{LOAD} reaches the internal or the external current limit, I_{OUT} is regulated to its limited value, and the FT/CS pin is pulled up to V_{CS_H}. The device shuts down if the regulation period lasts for longer than 100µs. In addition to the current limit, an open-loop, fast-response behavior is set to turn off the channel immediately (<1µs) if the channel's current dramatically increases, and before the current-limit closed-loop is set up. That is to protect the device when the output load is short to GND. The device will auto recover after 300ms.

The internal current limit is fixed to 4.6A. To use the internal current limit, ILIM can be directly connected to GND pin.

The external configurable current can set the current limit value. The external current cannot be set below 3A. By connecting a resistor (R_{CL}) between the ILIM and GND pins, a proportional I_{LOAD} is converted into a voltage (V_{CL}), which is compared with an internal reference voltage (V_{TH_LIM}). If V_{CL} exceeds V_{TH_LIM}, a closed-loop is set to regulate the gate-to-source voltage (V_{GS}). As a result, the drain-to-source voltage (V_{DS}) and I_{LOAD} are clamped at the set value. To increase the sensing accuracy, R_{CL} should be connected to the MPQ5873's GND pin. R_{CL} can be calculated with Equation (2):

$$R_{CL} = \frac{K_{CL} \times V_{TH\_LIM}}{I_{CL}} \qquad (2)$$

Where I_{CL} is the set external current.

Figure 5 shows the current sensing and current limit functional diagram. Whichever value is lower between the internal current limit and configurable external current limit values is applied as the actual value.

Note that the external current limit is masked during a short circuit or start-up (when V_{IN} - V_{OUT} > 1V), and it is typically 3.5A during normal operation.

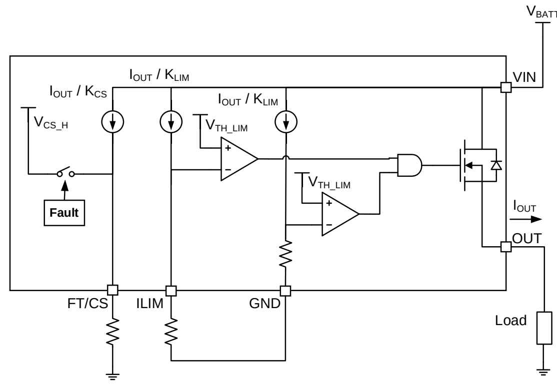


Figure 5: Current Sensing and Current Limit Functional Diagram

Adjustable Start-Up Slew Rate

A capacitor connected to the SS pin (C_{SS}) determines the soft-start time. An internal 10µA constant-current source C_{SS} and ramps up the voltage on the SS pin (V_{SS}). The output voltage rises at (K_{SS} x slew rate) to V_{SS}. K_{SS} is typically 16.7.

The V_{OUT} rising time (t_{VOUT_RISING}) can be calculated with Equation (3):

$$t_{VOUT\_RISING}(ms) = \frac{1}{K_{SS}} \times \frac{V_{OUT}(V) \times C_{SS}(nF)}{I_{SS}(\mu A)} \qquad (3)$$

Where I_{SS} is the internal constant current, and C_{SS} is the external SS capacitor.

If the SS pin is floating or C_{SS} is too small, the V_{OUT} slew rate is limited by the current limit. If C_{SS} is too large, the device has to dissipate a large energy during start-up, and the thermals may be suboptimal.

If the output capacitance is too high, the start-up current may reach the current limit during start-up, and the MPQ5873 shuts down. C_{SS} and the output capacitance should be selected to avoid thermal shutdown and over-current protection (OCP) during start-up. See the Component Selection section on page 22 for more details.

Inductive Load Switching-Off Clamp

When an inductive load switches off, V_{OUT} pulls down to a negative value due to the inductance characteristics. The energy in the inductor dissipates on the MPQ5873 without the external protection circuit. For inductive loads below 2mH, if the maximum switch-off current is below 5A, then the MPQ5873 can be used for demagnetization energy dissipation. If not, then external freewheeling circuitry is required to protect the devices. Figure 10 on page 20 shows the freewheeling circuit.

Full Protection and Diagnostics

The MPQ5873 provides flexible protections and diagnostic functions. When the DIAG_EN pin is high, all diagnostics are enabled, and faults can be distinguished. Table 1 shows the fault statuses and related trigger conditions. When DIAG_EN is low, the open-load/short to battery diagnostic during the off state is disabled.

These protections are described in greater detail in the following sections.

Input Under Voltage Lockout (UVLO)

The device monitors the input voltage (V_{IN}) to protect the device when V_{IN} is too low. When V_{IN} falls to the V_{IN} under-voltage (UV) shutdown threshold (V_{UV_STD}) during the on state, the switch turns off immediately. When V_{IN} rises to the UV rising threshold (V_{UV_RST}), the device turns on.

Load Current Monitoring

If I_{OUT} exceeds the nominal current, but is below the current limit, the device continues to operate. In this scenario, the user can monitor I_{LOAD} by sensing V_{CS}. The maximum V_{CS} during normal operation (V_{OC}) can be defined by the user to determine whether I_{LOAD} is within its normal range.

Table 1: Fault Table

IC Status	Fault Condition	EN	DIAG_EN	OUT	CS/FT	Recover
Normal	-	Low	-	Low	0	-
		High	-	High	$V_{OC} > V_{CS} > V_{UC}$	
V_{IN} UVLO	$V_{IN} < V_{US\_STD}$	High	-	Low	0	$V_{IN} > V_{UV\_RST}$
On state over-current (OC) or output to GND short	Current limit is triggered	High	-	Low	V_{CS_H} during current limit deglitch; 0 after device shutdown	Automatic
Off state: output to GND short	-	Low	-	Low	0	-
I_{LOAD} exceeds nominal current	$V_{CS} > V_{OC}$ (V_{OC}: max V_{CS} during normal operation, defined by the user)	High	-	High	$V_{CS\_H} > V_{CS} > V_{OC}$ (assume current limit is not triggered)	Automatic
On state short to battery or open load	$V_{CS} < V_{UC}$ (V_{UC}: min V_{CS} during normal operation, defined by the user)	High	-	High	Close to 0	Automatic
Off state short to battery or open load (11)	$V_{IN} - V_{OUT} < V_{OL\_OFF}$	Low	High	High	V_{CS_H} after deglitch	$V_{IN} - V_{OUT} > V_{OL\_OFF}$
		Low	Low	High	0	-
Thermal shutdown	$T > T_{SD}$	High	-	Low	V_{CS_H}	$T < T_{SD\_RST}$

Note:

11) For off state open-load detection, an external pull-up resistor is required.

Over-Current Protection (OCP) and Output to GND Short

If a current limit is triggered during the on state, a fault is reported by pulling V_{CS} up to V_{CS_H}, and I_{OUT} is regulated to the set current limit value. If the condition lasts for 100µs, the device shuts down.

The part tries to automatically recover after 300ms. If I_{OUT} falls below the current limit threshold before 100µs, the MPQ5873 resumes normal operation.

If I_{LOAD} increases rapidly due to a short circuit, the current may significantly exceed the current limit threshold before the control loop can respond. In this scenario, an open-loop, fast-response behavior is set to turn off the channel immediately (<1µs). This protects the device when the output load is shorted to GND.

Open-Load Detection

In the on state, an open load is diagnosed by reading the voltage on the FT/CS pin. V_{CS} is below the minimum V_{CS} during normal operation (V_{UC}), which is defined by the user. Note that when setting V_{UC}, the current-source accuracy should be considered. High-accuracy current sensing helps achieve a very low open-load detection threshold, which allows for wide normal operating range.

Figure 6 shows the recommended normal operating range and open-load detection threshold. A ±50% tolerance is considered at a 30mA output current to avoid malfunctions.

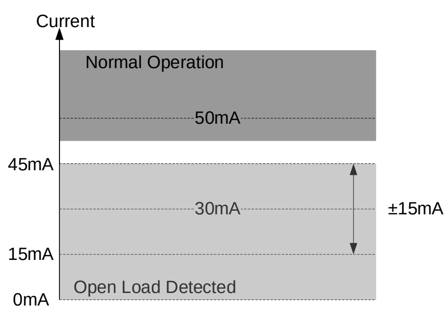


Figure 6: Recommended Normal Operating Range and On State Open-Load Thresholds

If the load is disconnected in the off state, V_{OUT} is almost equal to V_{IN}. This means that an open load can be detected as V_{IN} - V_{OUT} < V_{OL_OFF}. In this case, V_{CS} pulls up to V_{CS_H}. Figure 7 shows off state open-load detection.

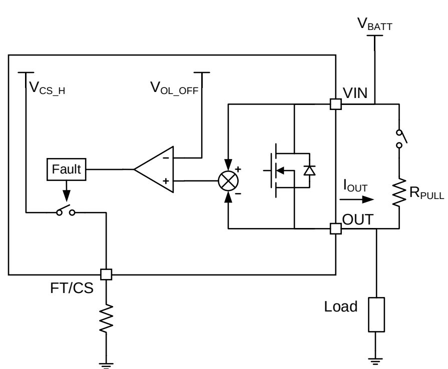


Figure 7: Off State Open-Load Detection Functional Diagram

Due to the internal logic control path or external humidity, there is a leakage current present on the output. In Figure 7, a pull-up resistor (R_{PULL}) is applied to offset the leakage current. To avoid false detection, the pull-up current should be below the operating current. It is recommended that R_{PULL} be 10kΩ.

Output to Battery Short Detection

Output to battery short detection has the same detection mechanism and behavior as open-load detection, both in the on state and off state.

If V_{IN} is connected to the battery when an output to battery short occurs, there is no reverse current flowing through the device. If V_{IN} is powered by a supply with a lower voltage, a reverse protection diode is recommended to protect the device and the supply for if an output to battery short occurs (see Figure 8).

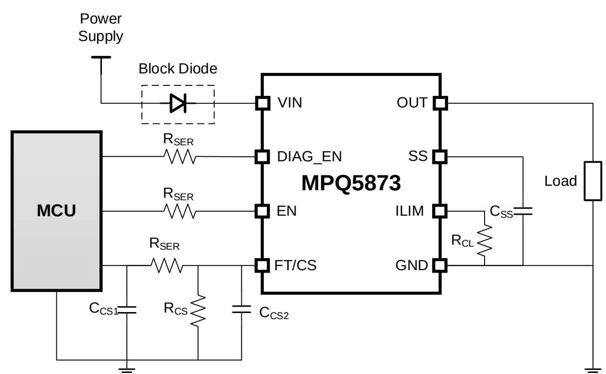


Figure 8: Protection Circuit with Block Diode

Thermal Protection

When the junction temperature (T_J) rises to the thermal shutdown threshold (T_{SD}), the part shuts down and V_{CS} is pulled up to V_{CS_H} to report the fault. As T_J falls to the thermal shutdown recovery threshold (T_{SD_RST}), the device turns on and the fault is cleared. When the exceeds T_{SD_RST}, the part does not restart.

Loss of Power Supply Protection

If there is a loss of the power supply, the MPQ5873 shuts down, regardless of EN (see Figure 9 on page 20).

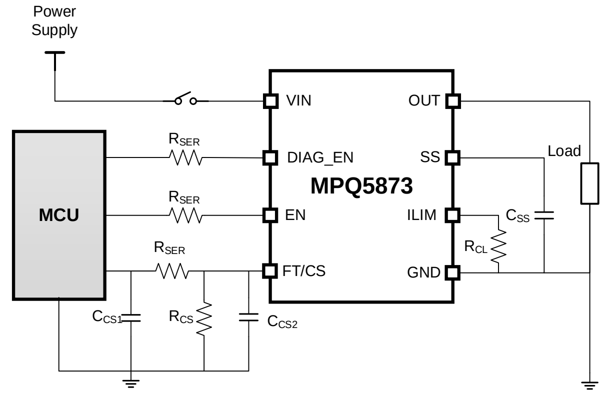


Figure 9: Loss of Power Supply

For resistive or capacitive loads, the device can easily handle a loss of the power supply. However, for an inductive load, a current from the MCU's general-purpose input/outputs (GPIOs) is absorbed, which may damage the device and the MCU. In this case, MCU series resistors, a ground network, or an external freewheeling circuit is required. Figure 10 shows the protection circuit.

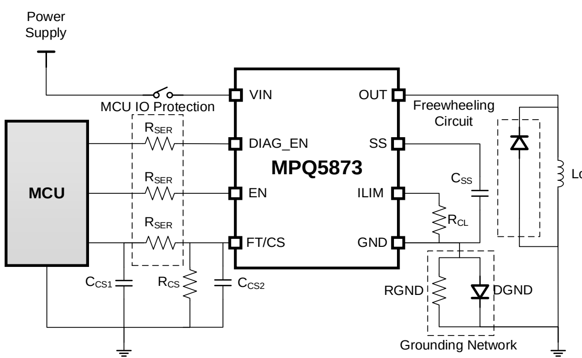


Figure 10: Loss of Power Supply Protection

Reverse Polarity Protection

A diode between the device's GND and the module ground is required to block the reverse voltage, which also creates a ground shift (about 600mV). If a GND voltage shift occurs, ensure that R_{CL} and C_{SS} are connected to the device's GND during normal operation.

For an inductive load, a negative spike can occur when the device is switched off, which may damage the diode. It is strongly recommended to add a 1kΩ resistor in parallel to the diode when driving an inductive load (see Figure 11). The diode's continuous forward current (I_F) should exceed 100mA.

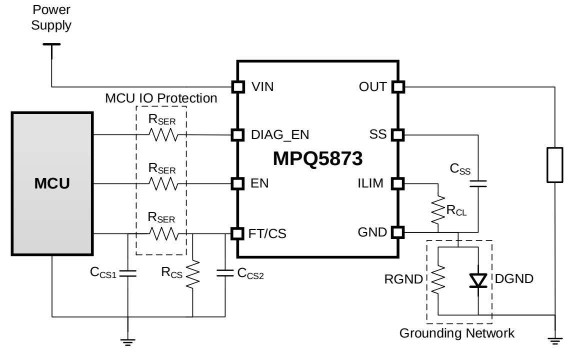


Figure 11: Reverse Polarity Battery Protection

AEC Q100-012 Test Grade A Certification

Short circuit reliability is critical for smart high-side power switch devices. The AEC-Q100-012 standard is used to determine the reliability of a device when operating in a continuous short-circuit. Different grade levels are specified according to the pass cycles. The MPQ5873 is qualified with the highest level (Grade A), 1 million times short to GND certification.

The applicable test modes are listed below:

- Cold, repetitive short-circuit test (long pulse)
- Cold, repetitive short-circuit test (short pulse)
- Hot, repetitive short-circuit test (continuous)

Transient Disturbances Tests

The MPQ5873 meets the requirements specified in ISO 7637-2 and ISO 16750-2 standards with a proper external circuit (see Figure 12).

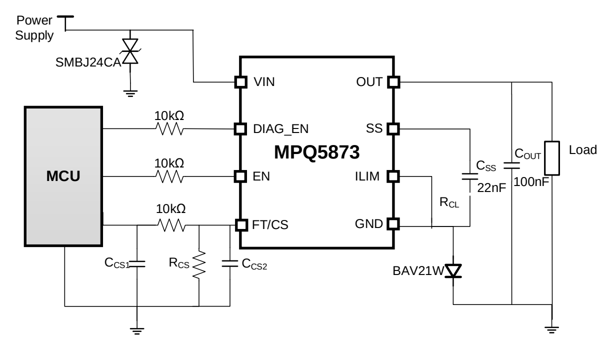


Figure 12: Circuit for Pulse Tests

Table 2 on page 21 shows the transient disturbance test details. R_{IN} is the power source's internal resistance, U_{S^*} is the maximum V_{IN} set-up value, U_S is the V_{IN}, t_R is the US rising time, and *t* is the US duration time.

Table 2: Tests in ISO7637-2 and ISO16750-2

Standard	Test Item	Level	Description
7637-2	1	III	-112V, 2ms
	2a	III	55V, 50µs
	2b	IV	10V, R_{IN} (0Ω)
	3a	IV	-220V, 0.1µs
	3b	IV	150V, 0.1µs
16750-2	Load Dump Test B		U_{S*} = 42V, $t_R \leqslant$ 5ms
	Reverse Polarity Voltage		U_S = - 30V, *t* < 60s

During the load dump transient, it is not recommended to trigger the current limit, as the device may shut down. The load capacitor (C_{LOAD}) must be selected carefully.

C_{LOAD} can be estimated with Equation (4):

$$C_{LOAD} \le \frac{I_{LIMIT} - I_{LOAD}}{SR} \quad (4)$$

Where I_{LIMIT} is the lower value between the internal and external current limit, I_{LOAD} is the load current, and SR is the source voltage's slew rate.

Based on the definition of the load dump pulse, SR should not exceed 20V/ms. For an application with a 4.6A current limit and 3A of continuous current, it is recommended to that C_{LOAD} is below 100µF.

APPLICATION INFORMATION

Component Selection

Figure 13 shows the MPQ5873's application circuit.

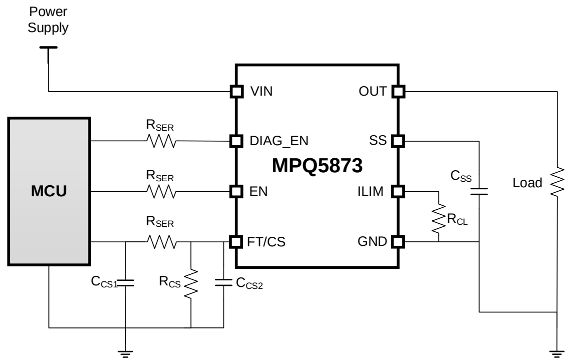


Figure 13: MPQ5873 Application Circuit

For the design example in Figure 13, follow the specifications below:

- Connect V_{IN} to a 12V battery.
- Set the nominal current at 3A.
- Implement current sensing for applications where $I_{OUT} \leq 3A$ and the normal V_{CS} for a 3A load = 3V.
- Set the external current limit at 4A. Skip this step if the external current limit is not used.
- Set the start-up time to about 1.5ms.
- Use full diagnostics with the 5V MCU.
- A grounding network required for protection.
- A 470nF capacitor (C_{CS2}) required for signal stability.

The general design process is described below:

1. Select R_{CS}, which can be calculated with Equation (5):

$$R_{CS} = \frac{K_{CS} \times V_{CS}}{I_{OUT}} = \frac{1000 \times 3}{3} = 1k\Omega \quad (5)$$

2. Select R_{CL}, which can be calculated with Equation (6):

$$R_{CL} = \frac{K_{CL} \times V_{TH\_LIM}}{I_{CL}} = \frac{1000 \times 0.7}{4} = 175\Omega \quad (6)$$

3. Select C_{SS}, which can be calculated with Equation (7):

$$C_{SS} = K_{SS}\frac{T_{VO\_R} \times I_{SS}}{V_{OUT}} = 16.7 \times \frac{1.5 \times 10}{12} = 22nF \quad (7)$$

4. Select R_{SER}. It is recommended that R_{SER} = 10kΩ.

C_{SS} Design Procedure

Follow the steps below to select C_{SS}:

1. Confirm the start-up time request, and select the value for C_{SS}.
2. Calculate the start-up current, and select an appropriate R_{CL}. If R_{CL} is suitable, move to step 3. If R_{CL} is not suitable, return to step 1.
3. Evaluate the thermal performance based on the Recommended Maximum Junction Temperature (T_J) section on page 23. If T_J does not exceed 150°C, the design is appropriate. Otherwise, return to step 1.

Distinguishing the Fault Status

The fault status can be easily determined if V_{IN} and V_{OUT} can be monitored. Figure 14 shows the fault diagnostics flowchart.

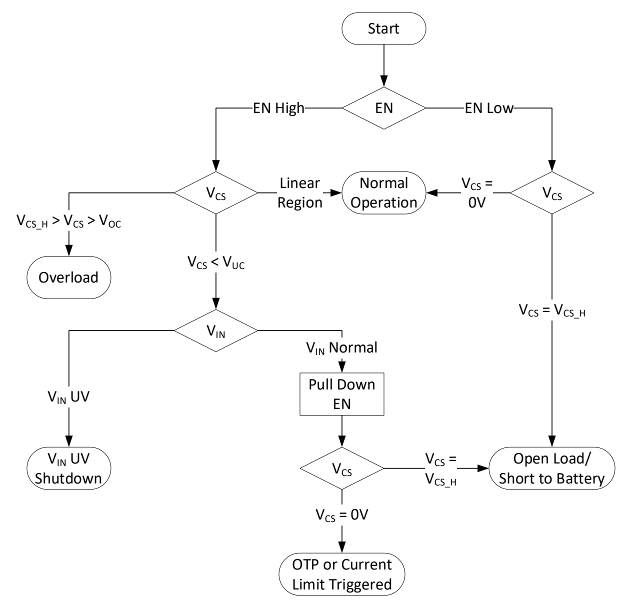


Figure 14: Fault Diagnostics Flowchart

Because the OC deglitch time is short, if an OC condition occurs during the on state, the analog-to-digital converter (ADC) may miss an interval when V_{CS} is high. In this scenario, there is another process to determine the fault condition (see Figure 15 on page 23).

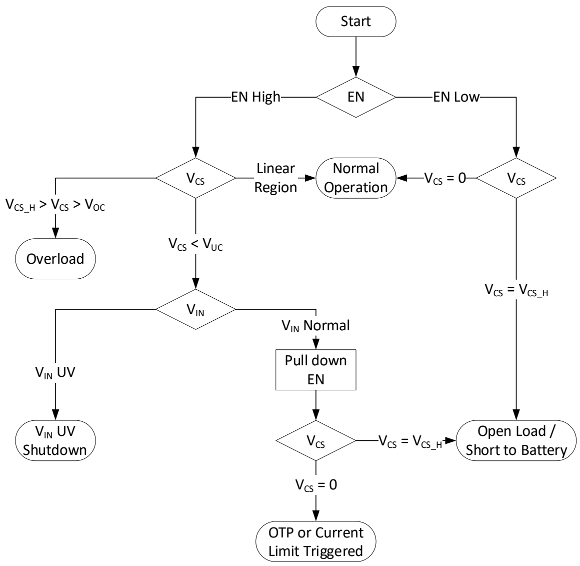


Figure 15: Fault Diagnostics Flowchart 2

Recommended Maximum Junction Temperature (T_J)

The MPQ5873's maximum continuous operating junction temperature (T_J) is 150°C. Considering the start-up and SCP condition, it is recommended to evaluate the application's transient thermal performance. Generally, the temperature rise during start-up or SCP are related to the MOSFET's power dissipation. The MOSFET's total power dissipation during soft start (Q) can be estimated with Equation (8):

$$Q = \int_0^{t_{SS}} U_{(t)} \times I_{(t)} dt \quad (8)$$

Where $U_{(t)}$ is the voltage drop on the MOSFET, $I_{(t)}$ is the current flowing through the MOSFET, and t_{SS} is the soft-start time.

If C_{SS} is applied and the current limit is not triggered during start-up, then t_{SS} is equal to t_{VOUT_RISING}, which can be calculated with Equation (3) on page 17.

If the MOSFET's current is constant during start-up, then Equation (8) can be simplified, and Q can be calculated with Equation (9):

$$Q = \frac{V_{IN} \times I_{OUT\_ST} \times t_{SS}}{2} \quad (9)$$

Where V_{IN} is the input voltage, and I_{OUT_ST} is the MOSFET channel's current during start-up.

Figure 16 shows the relationship between the temperature rise and power dissipation depending on t_{SS}, where $Q_{DISSIPATION}$ is *Q* from Equation (8) and Equation (9).

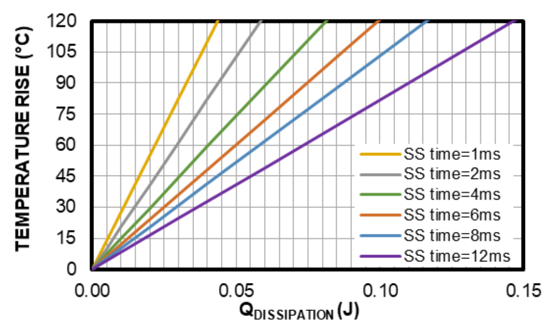


Figure 16: Temperature Rise vs. $Q_{DISSIPATION}$ with Different Soft-Start Times

Figure 16 shows how to determine whether an appropriate C_{SS} is selected. For example, assume V_{IN} = 10V, I_{OUT} = 0.5A, and C_{SS} = 100nF. The soft-start time is calculated as 6ms, and *Q* is calculated as 0.015J. Based on Figure 16, the temperature rise during start-up is 20°C. Therefore, this design is reasonable.

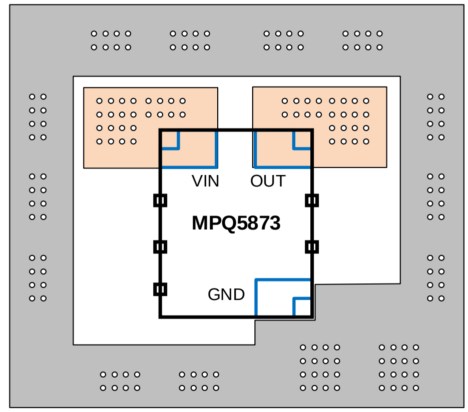
Functional Safety Application Support

Related functional safety documentation, such as the Failure in Time (FIT) number and the Process Failure Modes and Effects Analysis (PFMEA), is available for the MPQ5873 to aid in functional safety design.

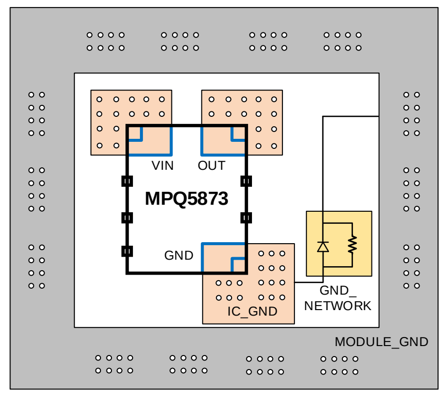
PCB Layout Guidelines

Efficient PCB layout is critical for stable operation, as well as optimal thermal performance and reliability. For the best results, refer to Figure 17 and follow the guidelines below:

1. Increase the copper area on the PCB (especially for VIN, OUT, and GND) to increase the board's the thermal conductivity.
2. Connect the GND pin to the GND planes beneath the IC using as many vias as possible to further improve heat dissipation.
3. If a GND network is required, use a single copper layer for the IC's GND plane. Then connect the IC's and module's GND pins via protective components.



Without GND Network



With GND Network

Figure 17: Recommended PCB Layout

TYPICAL APPLICATION CIRCUITS

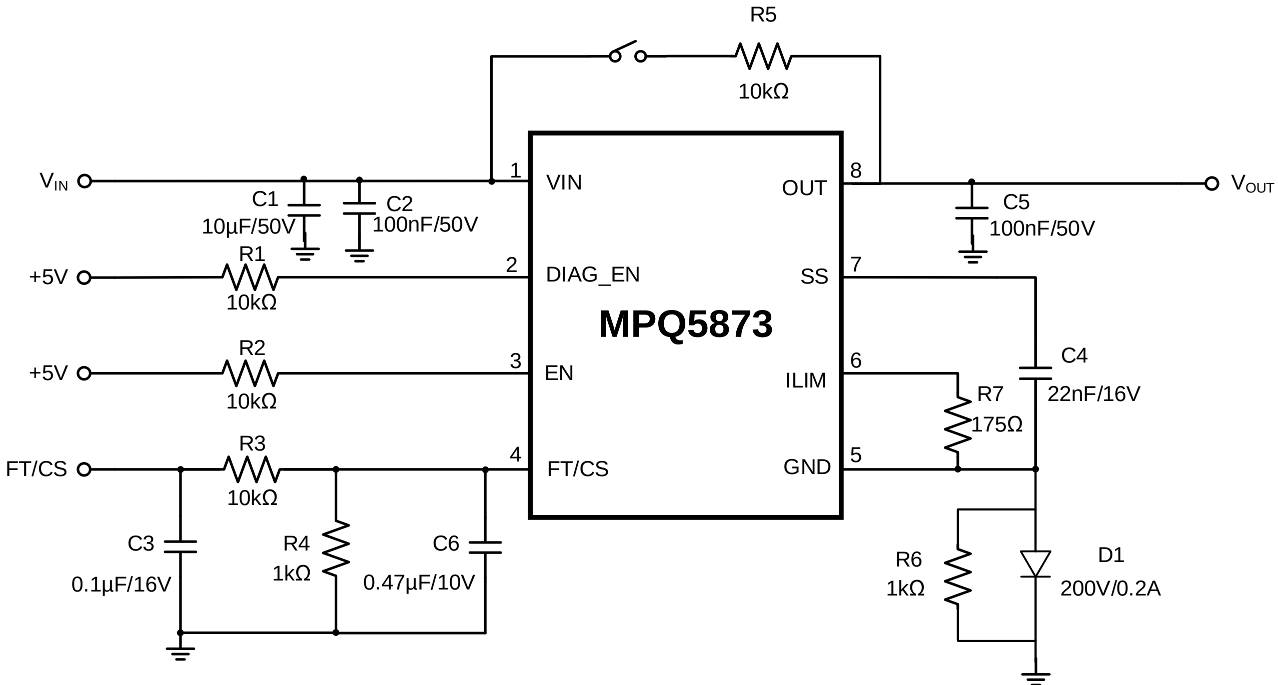


Figure 18: Typical Application Circuit for 3A Output (4A External Current Limit)

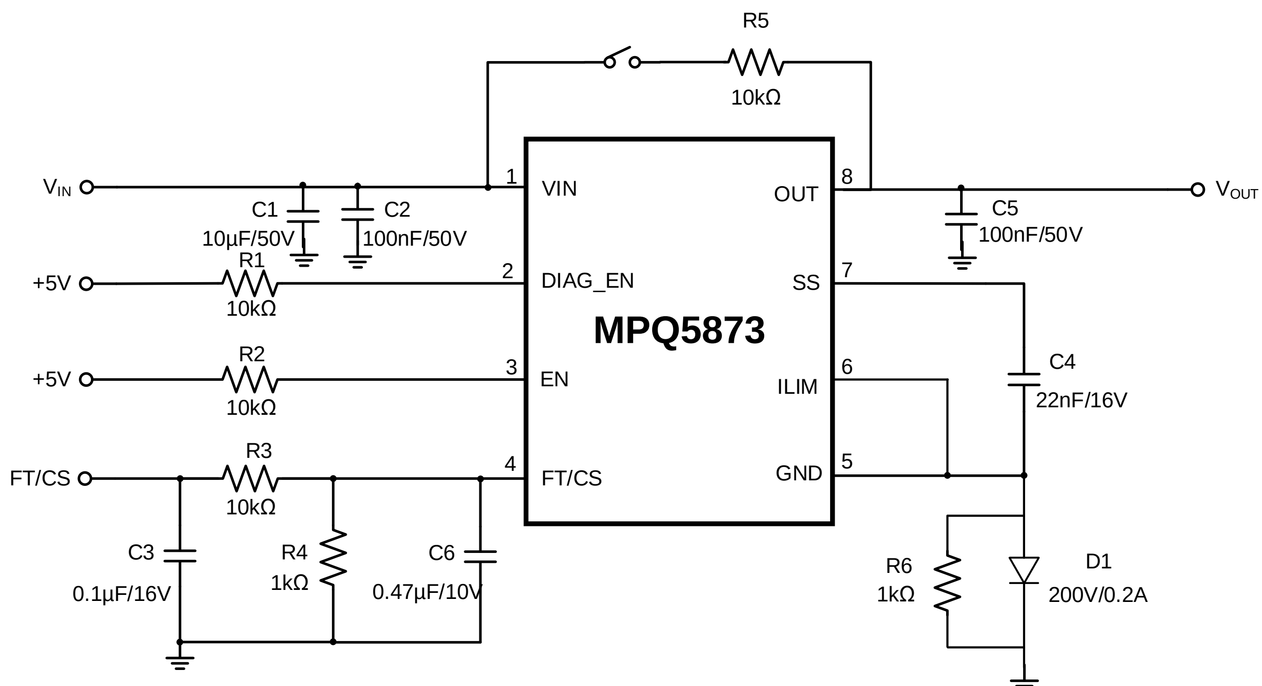


Figure 19: Typical Application Circuit for 3A Output (Internal Current Limit)

TYPICAL APPLICATION CIRCUITS *(continued)*

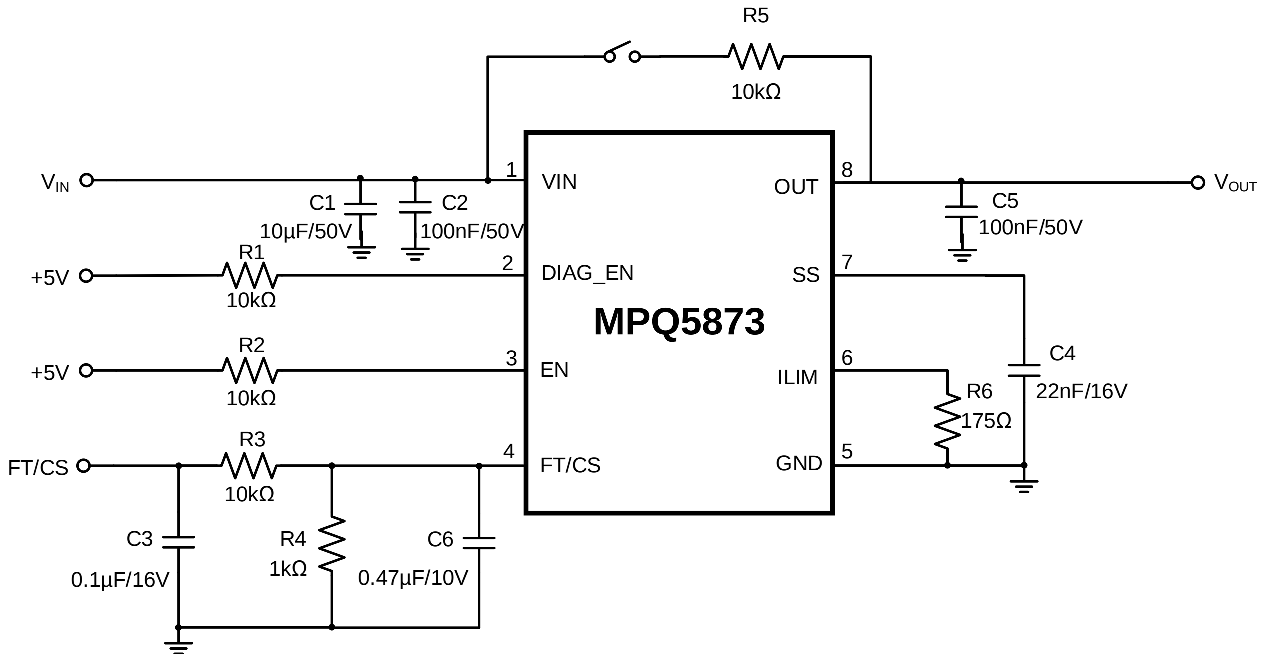


Figure 20: Typical Application Circuit for 3A Output without Ground Network (4A External Current Limit)

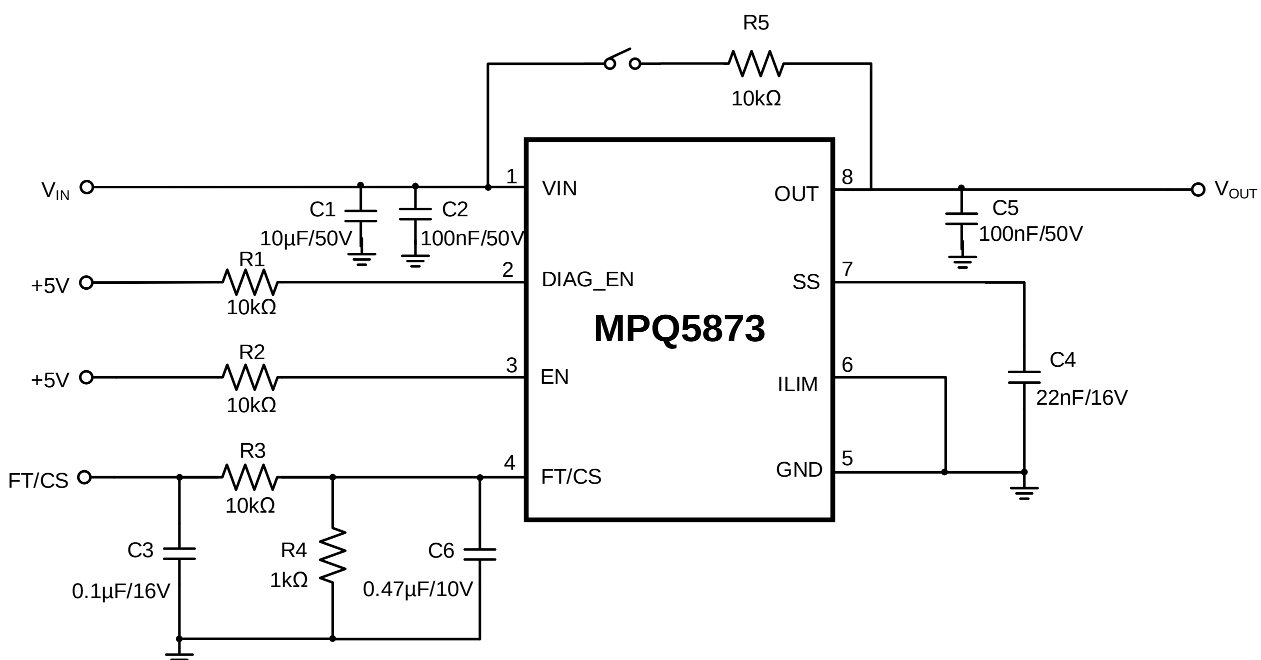
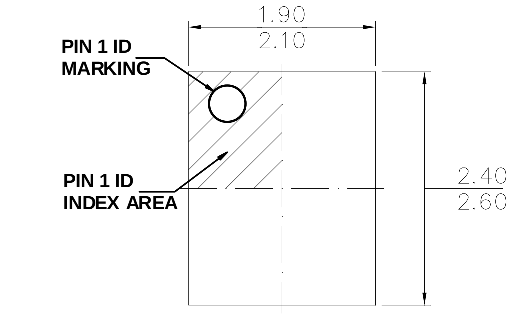


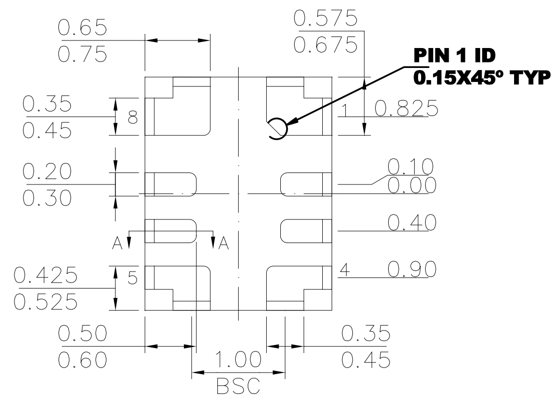
Figure 21: Typical Application Circuit for 3A Output without Ground Network (Internal Current Limit)

PACKAGE INFORMATION

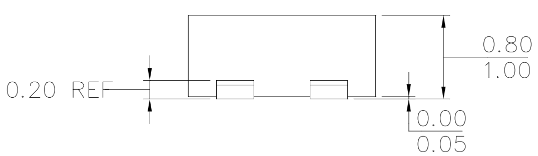
QFN-8 (2mmx2.5mm)
Wettable Flank



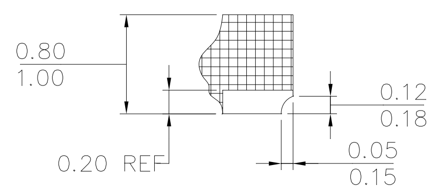
TOP VIEW



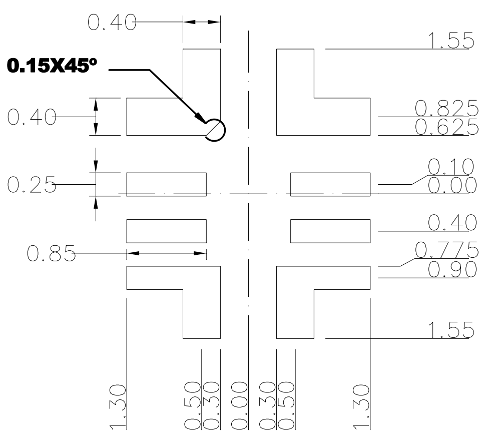
BOTTOM VIEW



SIDE VIEW



SECTION A-A

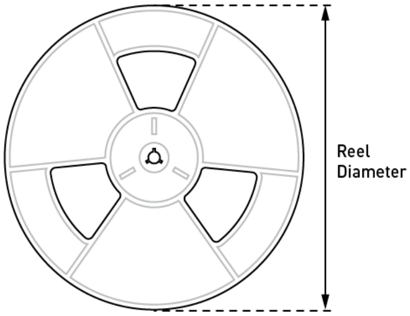


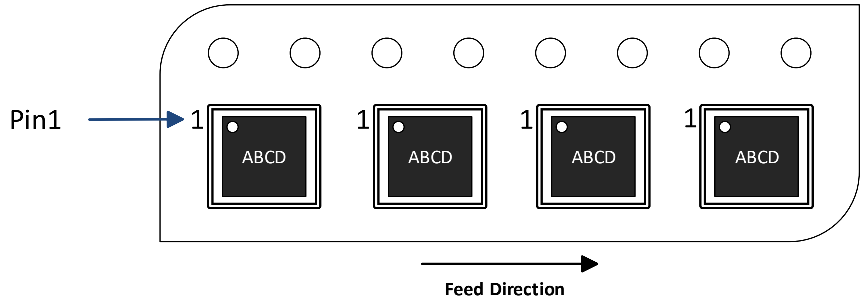
RECOMMENDED LAND PATTERN

NOTE:

1) THE LEAD SIDE IS WETTABLE.
2) ALL DIMENSIONS ARE IN MILLIMETERS.
3) LEAD COPLANARITY SHALL BE 0.08 MILLIMETERS MAX.
4) JEDEC REFERENCE IS MO-220.
5) DRAWING IS NOT TO SCALE.

CARRIER INFORMATION





Part Number	Package Description	Quantity/ Reel	Quantity/ Tube	Quantity/ Tray	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MPQ5873GRPE-AEC1-Z	QFN-8 (2mmx2.5mm)	5000	N/A	N/A	13in	12mm	8mm

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	4/17/2024	Initial Release	-