MPQ5872

42V Load Dump Test, 60mΩ Single-Channel, Smart High-Side Load Switch, AEC-Q100 Qualified

DESCRIPTION

The MPQ5872 is a smart high-side load switch for nominal 2A loads. The device features an input voltage (V_{IN}) as low as 3.5V, and can withstand load dumps up to 42V. With a small on resistance ($R_{DS(ON)}$) in a tiny QFN-8 (2mmx2.5mm) package, MPQ5872 provides a highly efficient, compact solution.

The device supports both an internal and configurable, high-accuracy external current limits. 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 further calibration. The voltage on the FT/CS pin represents 1 / K_{CS} of the load current, where K_{CS} is a constant value across the temperature and supply voltage. In addition, the FT/CS pin can report a fault by pulling up its voltage.

The MPQ5872 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 DIAG_EN to the GND pin.

The MPQ5872 is available in a QFN-8 (2mmx2.5mm) package with wettable flanks, and is available in AEC-Q100 Grade 1 or AEC-Q100-012 Test Grade A.

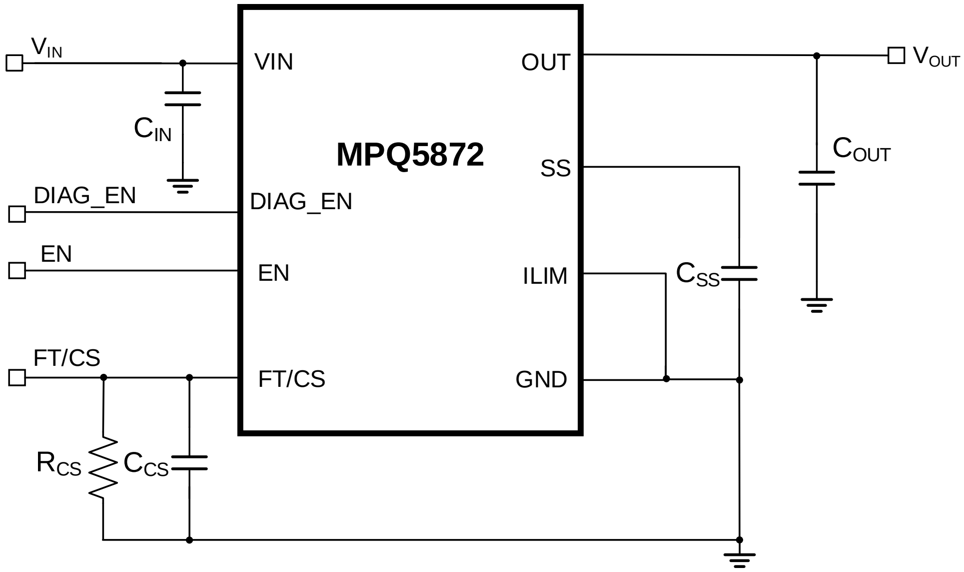
FEATURES

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

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**
MPQ5872GRPE-AEC1***	QFN-8 (2mmx2.5mm)	*See Below*	1

* For Tape & Reel, add suffix -Z (e.g. MPQ5872GRPE-AEC1-Z).

** Moisture Sensitivity Level Rating

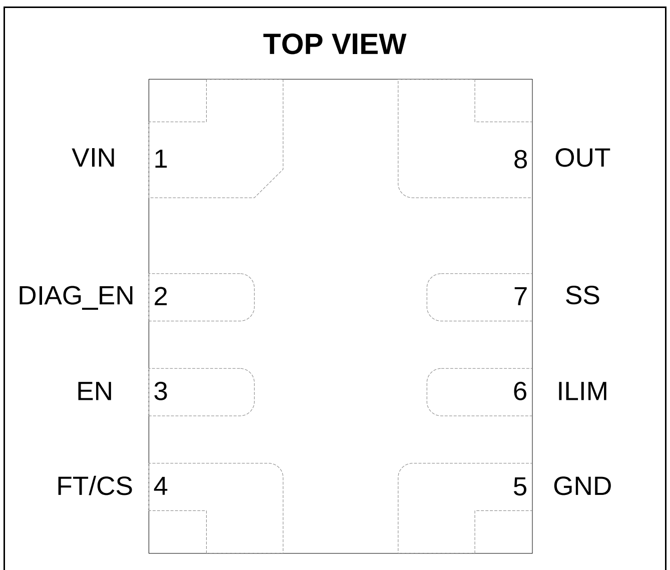
*** Wettable Flank

TOP MARKING

NJY
LLL

NJ: Product code of MPQ5872GRPE-AEC1
Y: Year code
LLL: Lot number

PACKAGE REFERENCE



QFN-8 (2mmx2.5mm)

PIN FUNCTIONS

Pin #	Name	Description
1	VIN	**Input power supply.** Connect this pin to the battery.
2	DIAG_EN	**Enable diagnostics.** Pull this pin above the specified threshold (1.2V) to enable diagnostics. Pull it below the specified threshold (1V) to disable diagnostics and reduce the standby current. Connect this pin to GND if not used.
3	EN	**Enable.** Pull EN above the specified threshold (1.2V) to enable the chip. Pull EN below the specified 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, flowing to the external current-sense resistor (R_{CS}) between FT/CS and GND. The voltage on the FT/CS pin (V_{CS}) reflects the load current. This pin also reports faults. Add a 100nF capacitor as close as possible to the the FT/CS pin. If the current sense feature is not used, remove R_{CS}.
5	GND	**Device ground.**
6	ILIM	**Configurable current limit pin.** Connect this pin to GND via a resistor (R_{CL}) to set the external current limit. See the Operation section on page 17 for more details. If the external current limit its not used, connect this pin directly to GND. Do not float this pin.
7	SS	**Soft start.** An external capacitor connected to this pin sets the output voltage (V_{OUT}) slew rate for the soft start (SS) period.
8	OUT	**Output to the load**. N-channel MOSFET source.

ABSOLUTE MAXIMUM RATINGS (1)

VIN, OUT ....-0.3V to +42V
All other pins ....-0.3V to +6.5V
Junction temperature (T_J) ....150°C
Lead temperature ....260°C
Storage temp .... -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

Continuous supply voltage (V_{IN})..........5V to 28V
Maximum load dump voltage....................... 42V
Nominal DC load current.......................0A to 2A
Operating junction temp (T_J).... -40°C to +150°C

Thermal Resistance	θ_{JA}	θ_{JC}	
QFN-8 (2mmx2.5mm)			
JESD51-7	67.2	13.6	°C/W(6)
EVQ5872-RP-00A	28		°C/W(7)
		Ψ_{JT}	
JESD51-7		4.9	°C/W(6)
EVQ5872-RP-00A		4.0	°C/W(7)

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 resister from junction-to-case bottom, and the value of Ψ_{JT} shows the characterization parameter from junction-to-case top.
7) Measured on an MPS MPQ5872 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 at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Operating Voltage						
Recommended continuous supply voltage	V_{IN_REC}		5		28	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, V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V, T_J = 25°C		0.5	1	µA
		V_{IN} = 12V, V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V, T_J = -40°C to +125°C (8)			5	µA
		V_{IN} = 12V, V_{EN} = V_{DIAG_EN} = V_{CS} = V_{ILIM} = V_{OUT} = 0V, T_J = -40 to +150°C			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 to +150°C			3	µA
MOSFET Parameters						
On-state resistance	$R_{DS(ON)}$	V_{IN} ≥ 5V, T_J = 25°C		60	80	mΩ
		V_{IN} ≥ 5V, T_J = -40 to +150°C			130	mΩ
		V_{IN} = 3.5V, T_J = 25°C		70	100	mΩ
		V_{IN} = 3.5V, T_J = -40 to +150°C			150	mΩ
Body diode forward voltage	V_F	V_{EN} = 0V, I_{OUT} = -100mA		0.6		V
EN and DIAG_EN						
Logic high voltage for EN	V_{EN_H}		1	1.2	1.4	V
Logic high voltage for DIAG_EN	V_{DIAG_H}		1	1.2	1.4	V
Logic low voltage for EN	V_{EN_L}		0.8	1	1.2	V
EN pull-down resistance (8)	R_{EN_PD}			500		kΩ
Logic low voltage for DIAG_EN	V_{DIAG_L}		0.8	1	1.2	V
Hysteresis voltage for EN	V_{EN_HYS}			200		mV
Hysteresis voltage for DIAG_EN	V_{DIAG_HYS}			200		mV
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 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 region, T_J = 25°C	-4		+4	%
		I_{OUT} ≥ 1A, within linear region, 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 V_{CS} range(9)	V_{CS_LIN}		0		3	V
I_{OUT} range for linear V_{CS}	I_{OUT_LIN}	V_{IN} ≥ 5V, V_{CS} ≤ V_{CS_LIN}	0		2	A
Fault voltage for FT/CS pin	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 low)	I_{CS_LK}	EN = 0V			1	µA
Soft Start (SS)						
SS pull-up current	I_{SS}	Fixed slew rate		10		µA
Current Limit (CL)						
Internal CL	I_{LIM}	CL short to GND	2.55	3	3.45	A
CL threshold voltage	V_{TH_LIM}			0.7		V
CL ratio	K_{CL}			1000		
External CL accuracy during normal operation	dK_{CL}/K_{CL}	V_{IN} - V_{OUT} < 1V, CL ≥ 0.5A (R_{CL} ≤ 1.4kΩ)	-15		+15	%
		V_{IN} - V_{OUT} < 1V, CL ≥ 1A (R_{CL} ≤ 700Ω)	-8		+8	%
CL during start-up and SCP (10)	I_{LIM_SAT}	V_{IN} - V_{OUT} > 1V, R_{CL} = 700Ω, T_J = 25°C to 150°C	0.35	0.6	1.08	A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 700Ω, T_J = -40°C to +25°C (10)	0.3			A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 350Ω, T_J = 25°C to 150°C	1.1	1.45	2.16	A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 350Ω, T_J = -40°C to +25°C (10)	1			A
		V_{IN} - V_{OUT} > 1V, CL short to GND (8), T_J = 25°C to 150°C	1.6	2.3	3.45	A
		V_{IN} - V_{OUT} > 1V, CL short to GND (8), T_J = -40°C to +25°C	1.5			A
CL deglitch time	t_{CL_DEG}	CL lasts for t_{CL_DEG}, device shutdown		100		µs
Fast-off shutdown time (11)	t_{FOFF}	Fast off 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 at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Diagnostics and Protection						
Off-state open-load threshold	V_{OL_OFF}	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 (OLD) deglitch time	t_{OL_OFF}			700		µs
Off-state output sink current with open load	I_{OL_OFF}	EN = 0V, DIAG_EN = 5V, I_{OUT} when open load detected			-75	µA
Thermal shutdown threshold (8)	T_{SD}			175		°C
Thermal shutdown hysteresis (8)	T_{SD_RST}			30		°C

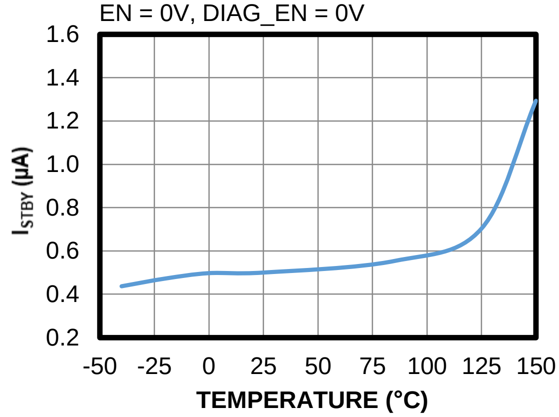
Notes:

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

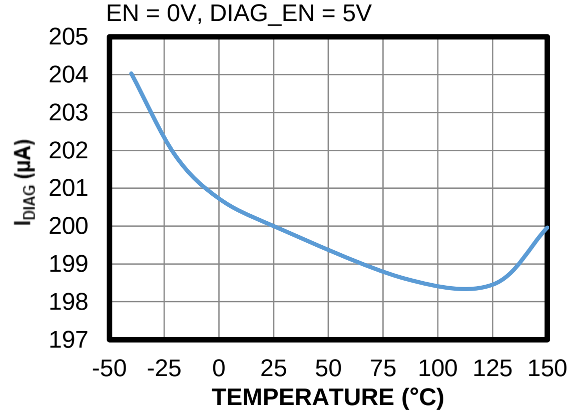
TYPICAL CHARACTERISTICS

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

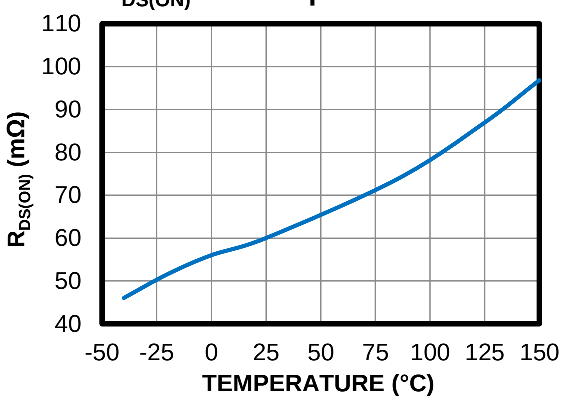
Standby Current vs. Temperature
EN = 0V, DIAG_EN = 0V



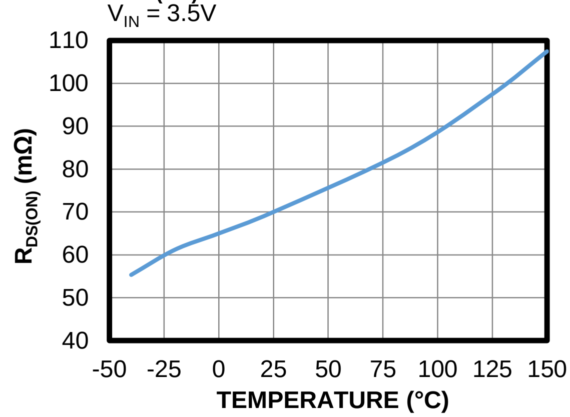
Standby Current vs. Temperature
EN = 0V, DIAG_EN = 5V



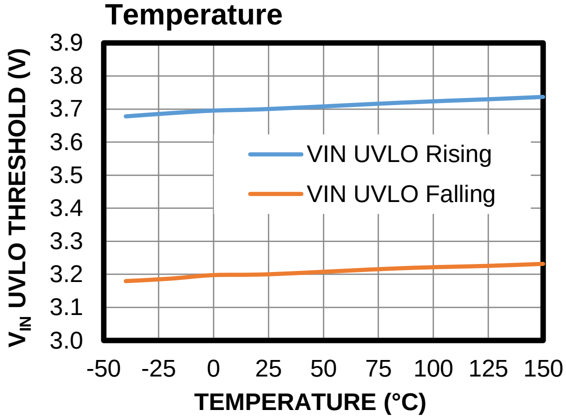
$R_{DS(ON)}$ vs. Temperature



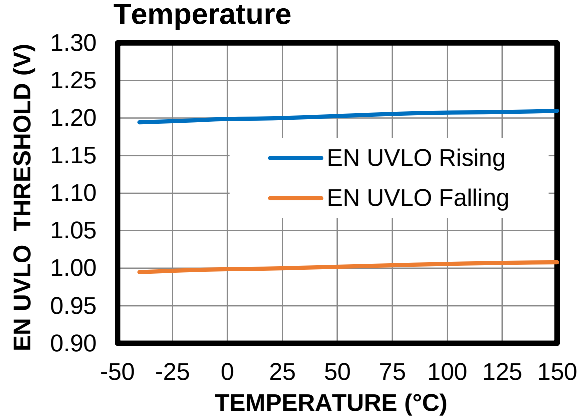
$R_{DS(ON)}$ vs. Temperature
V_{IN} = 3.5V



V_{IN} UVLO Threshold vs. Temperature

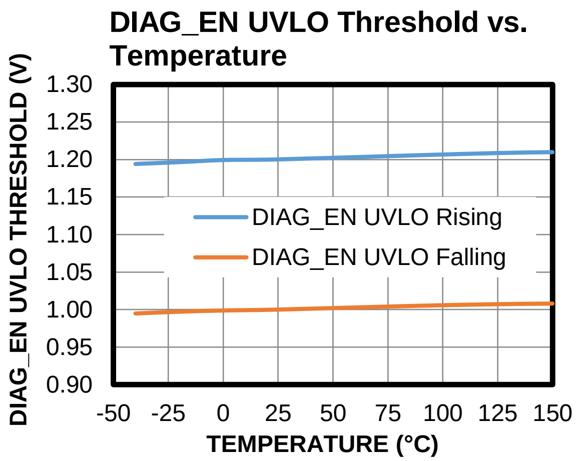


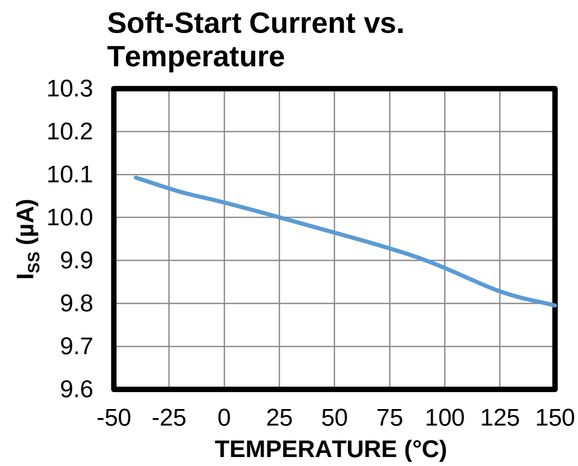
EN UVLO Threshold vs. Temperature

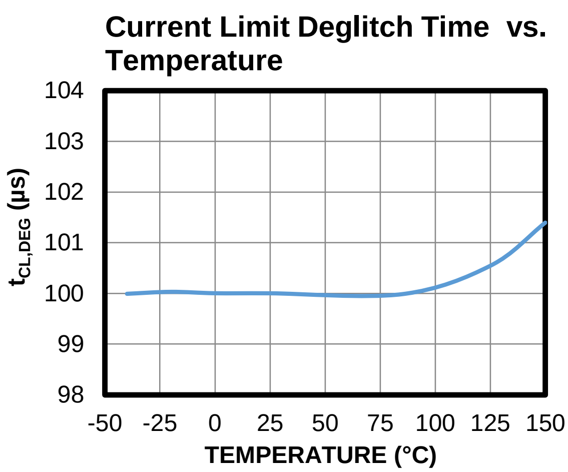


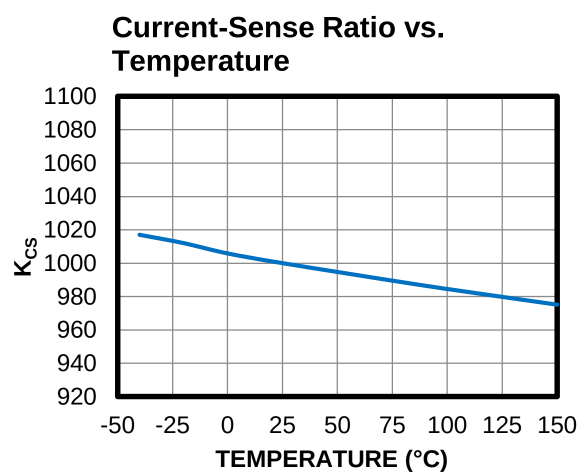
TYPICAL CHARACTERISTICS *(continued)*

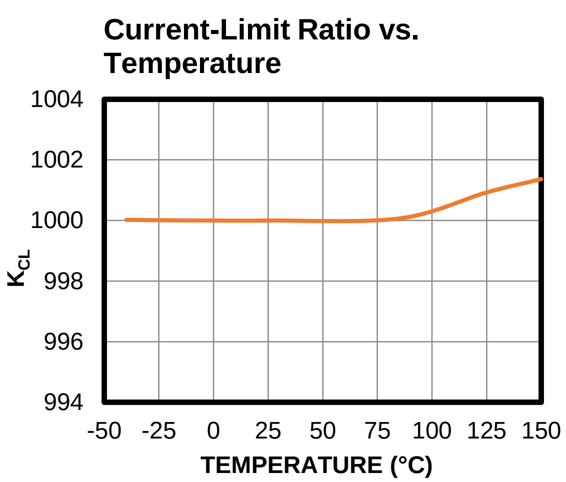
V_{IN} = 12V, unless otherwise noted.

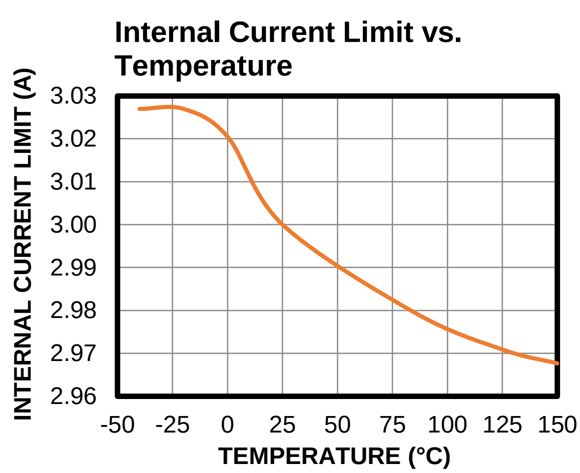










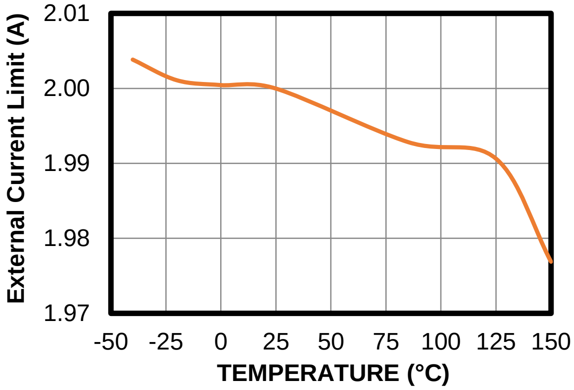


TYPICAL CHARACTERISTICS *(continued)*

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

External Current Limit vs. Temperature

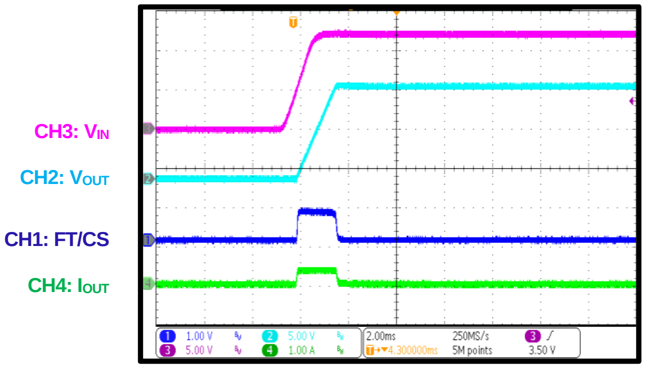
External current limit = 2A



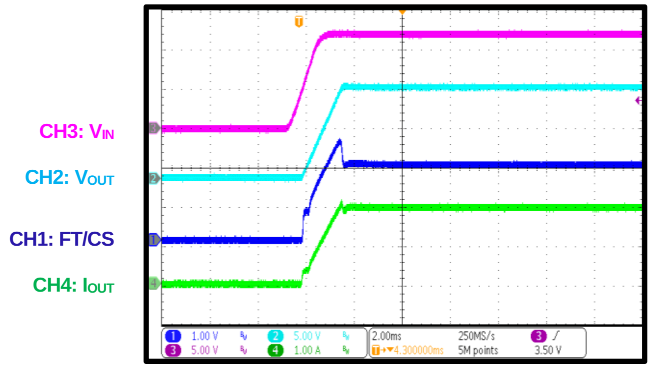
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47µF, T_A = 25°C, unless otherwise noted.

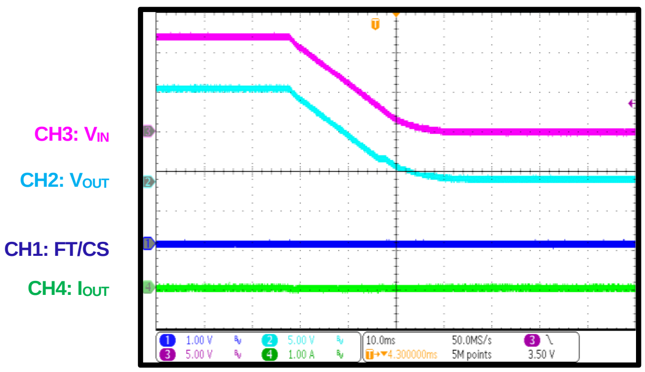
Start-Up through VIN
I_{OUT} = 0A



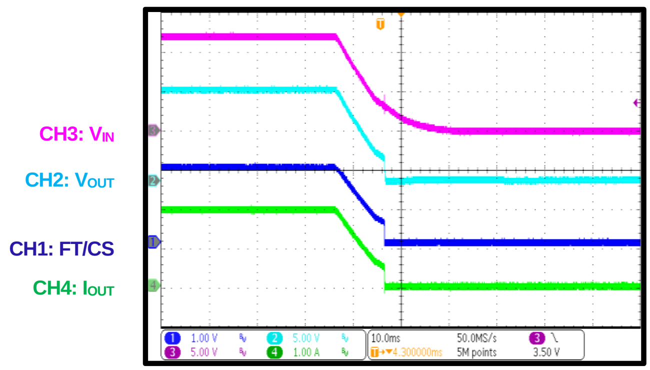
Start-Up through VIN
I_{OUT} = 2A



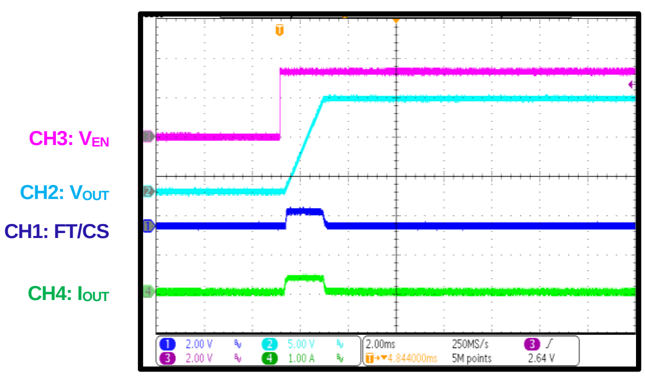
Shutdown through VIN
I_{OUT} = 0A



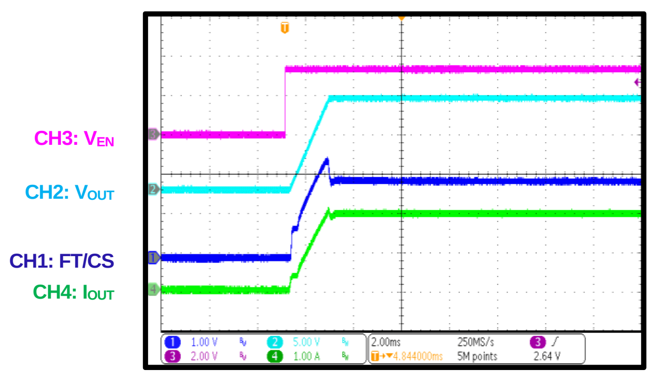
Shutdown through VIN
I_{OUT} = 2A



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



Start-Up through EN
I_{OUT} = 2A

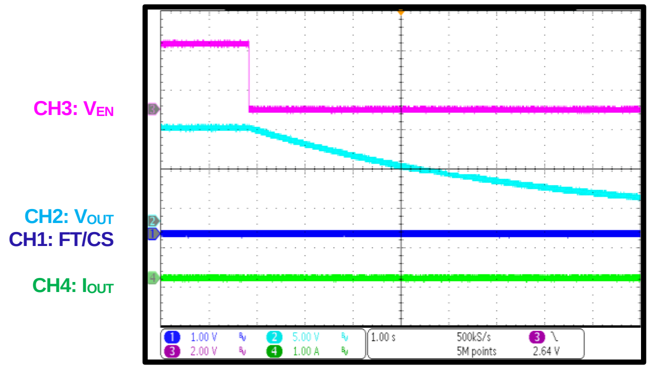


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47µF, T_A = 25°C, unless otherwise noted.

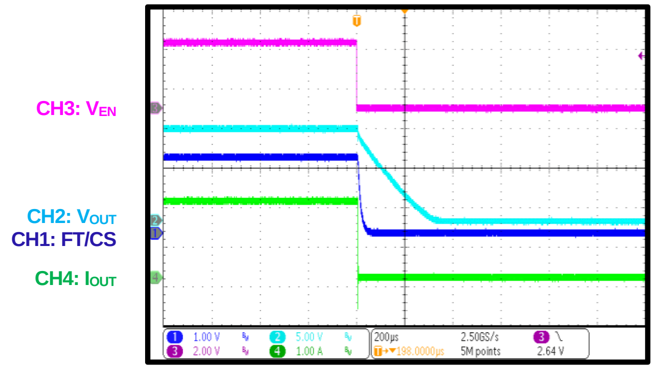
Shutdown through EN

I_{OUT} = 0A



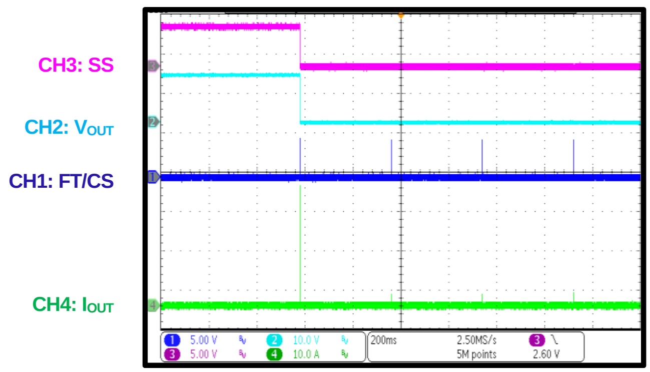
Shutdown through EN

I_{OUT} = 2A



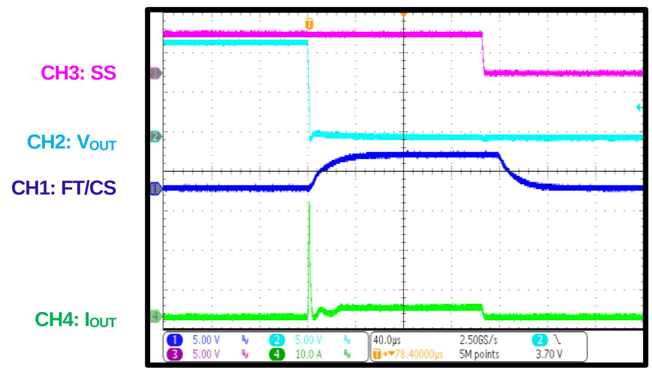
SCP Entry

I_{OUT} = 0A



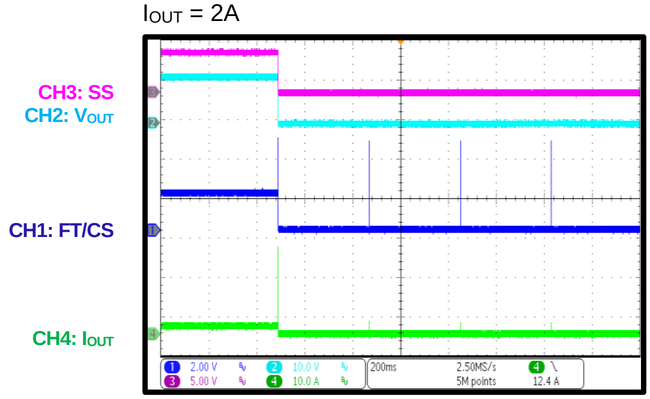
SCP Entry

I_{OUT} = 0A



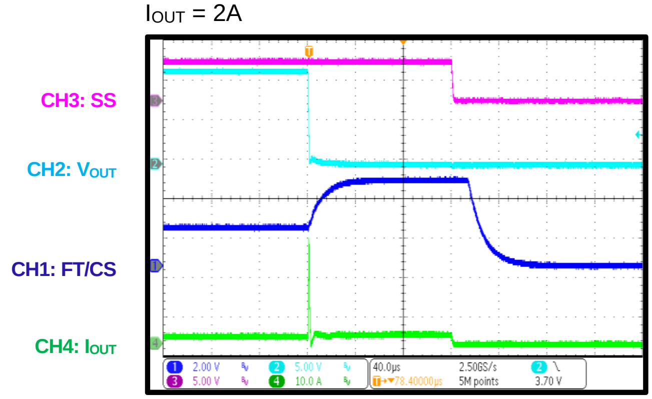
SCP Entry

I_{OUT} = 2A



SCP Entry

I_{OUT} = 2A

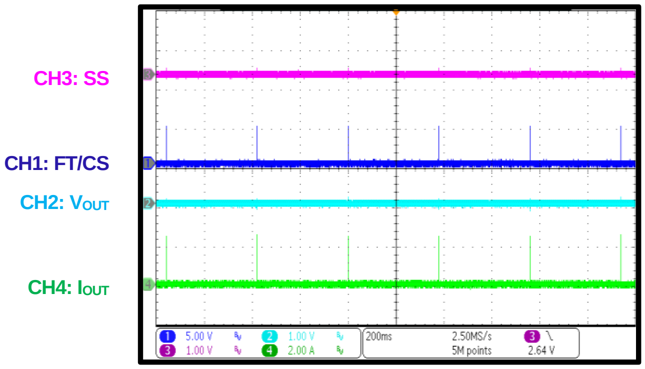


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47µF, T_A = 25°C, unless otherwise noted.

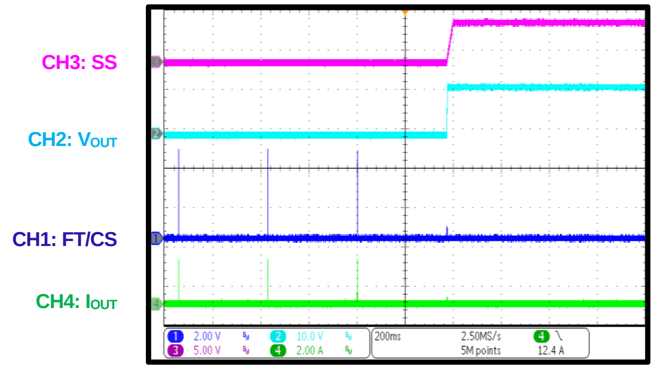
SCP Steady State

I_{OUT} = 0A



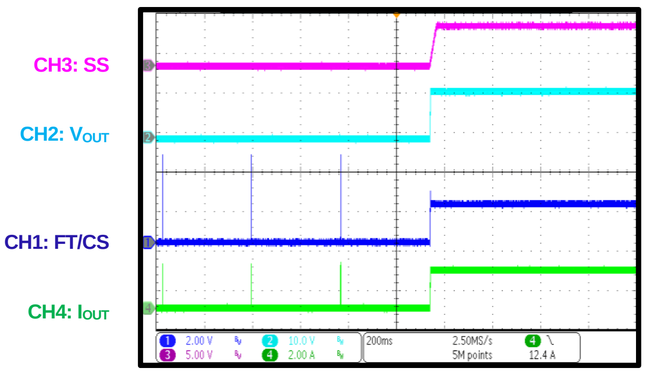
SCP Recovery

I_{OUT} = 0A

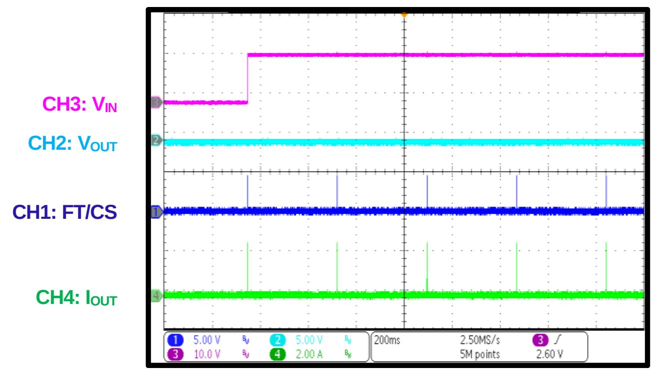


SCP Recovery

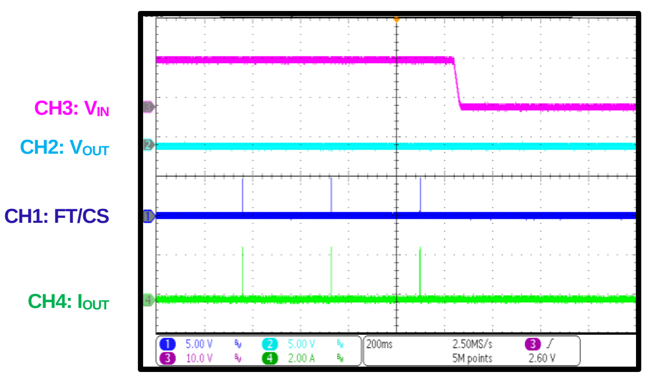
I_{OUT} = 2A



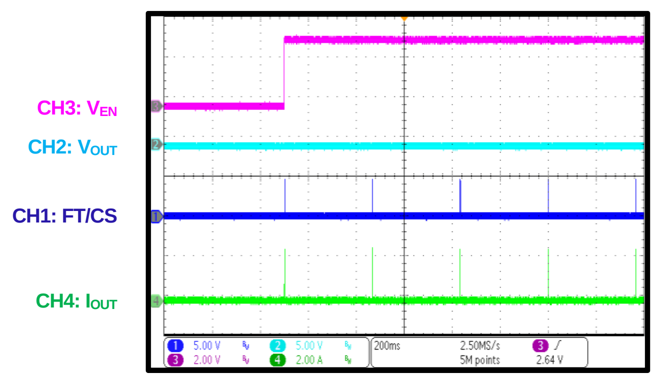
SCP Power On



SCP Power Off



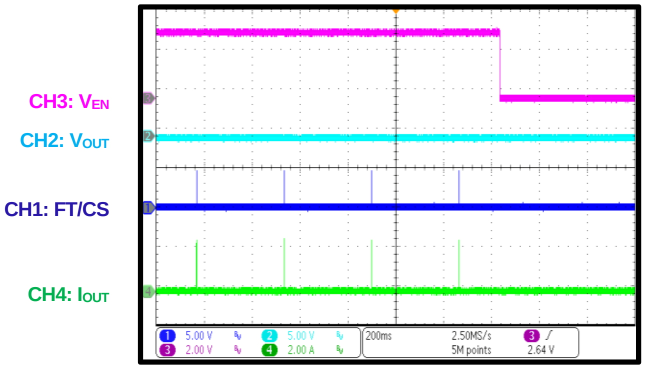
SCP EN On



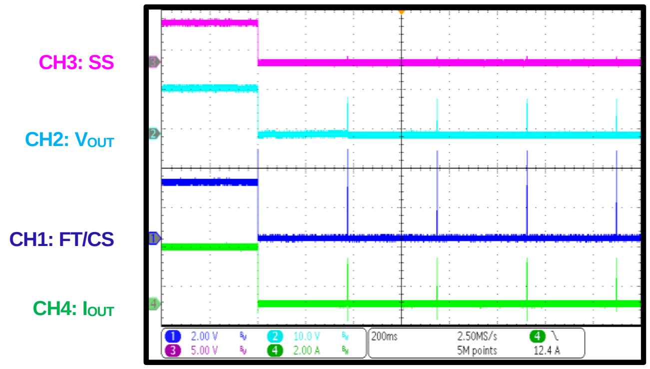
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47μF, T_A = 25°C, unless otherwise noted.

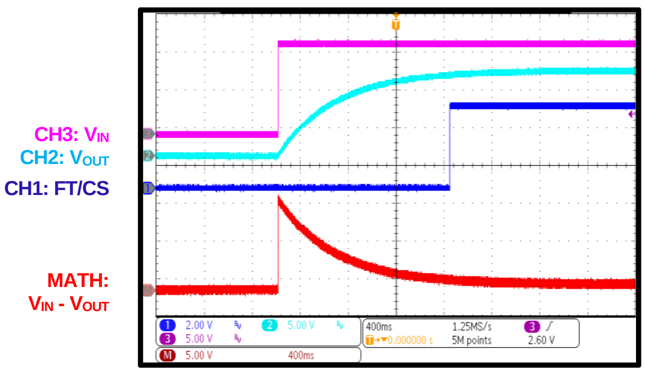
SCP EN Off



OCP

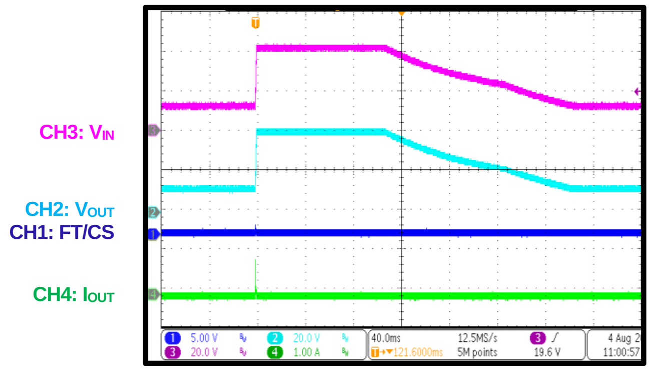


Open-Load Detection



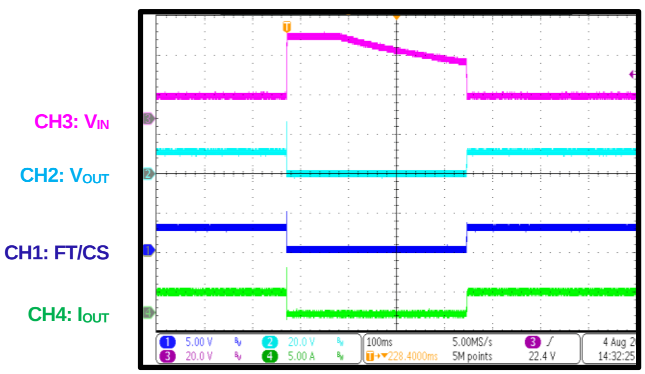
Load Dump

I_{OUT} = 0A



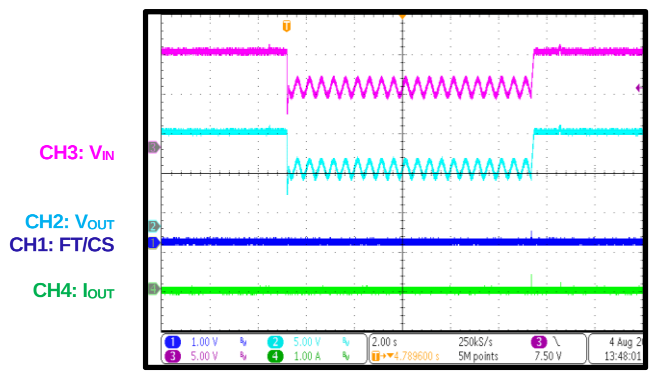
Load Dump

I_{OUT} = 2A



Cold Crank

I_{OUT} = 0A

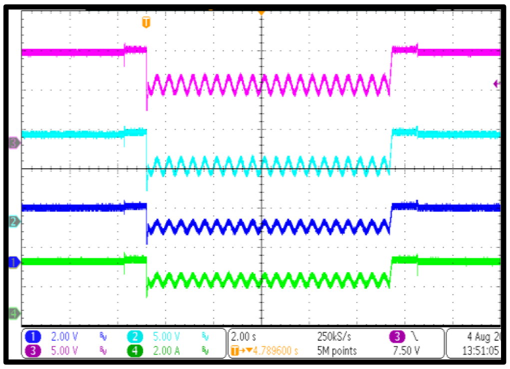


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47µF, T_A = 25°C, unless otherwise noted.

Cold Crank

I_{OUT} = 2A



FUNCTIONAL BLOCK DIAGRAM

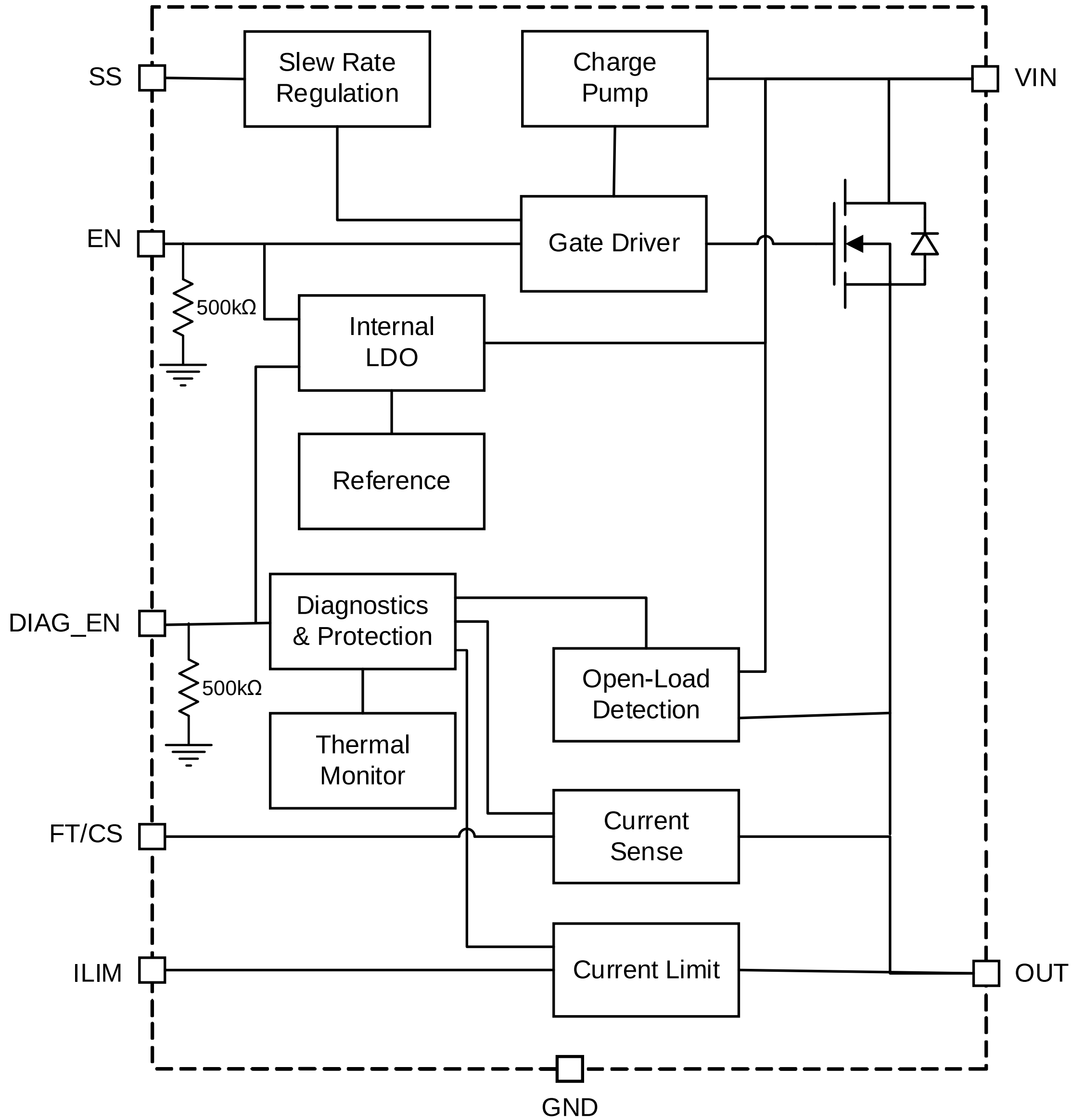


Figure 1: Functional Block Diagram

OPERATION

Operation Modes

The MPQ5872 has three operation modes: normal mode, standby mode, and diagnostic mode. If low standby current is required during the off state, the part can be set to standby mode by pulling down DIAG_EN, whereby the standby current is about 0.5µA. If off-state diagnostics are required, pull DIAG_EN high, whereby the typical standby current is about 0.2mA. Figure 2 shows the operation mode state machine diagram.

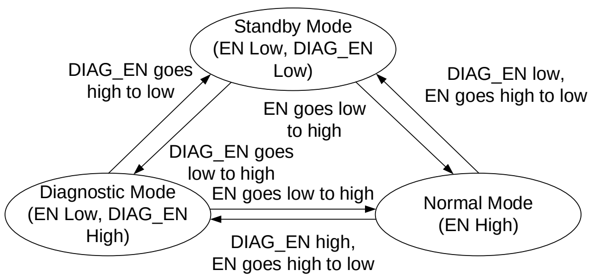


Figure 2: Operation Mode State Machine Diagram

High-Accuracy Current Sensing

The MPQ5872 integrates a high-accuracy current-sense (CS) block to achieve real-time current monitoring and diagnostics. A current mirror is used to source 1 / K_{CS} of the load current, flowing to the external resistor (R_{CS}) between the FT/CS and GND pins. The voltage on the FT/CS pin (V_{CS}) reflects the load current.

K_{CS} represents the ratio of the output current (I_{OUT}) and the sensed current. It is a constant value across the temperature and the supply voltage ranges, and is internally calibrated. There is no need for the user to do calibration.

Figure 3 shows the CS accuracy. When the load current (I_{LOAD}) exceeds 1A, the accuracy is ±4%; for the load current larger than 300mA, the accuracy reaches ±6%.

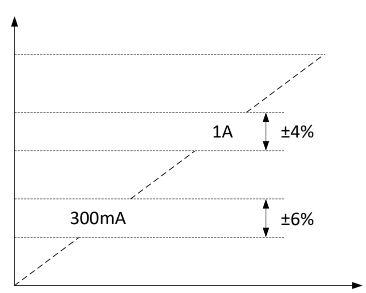


Figure 3: Current-Sense Accuracy

During normal operation, V_{CS} must 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 100nF capacitor close to FT/CS pin.

Fault Reporting Function

The FT/CS pin also reports when a fault condition occurs. If an open load or short-to-battery condition occurs while the device is on, V_{CS} is below the open-load current limit. However, if a current limit event, over-temperature protection (OTP), off state open-load condition or short-to-battery condition is detected, V_{CS} is pulled up to V_{CS_H}. Figure 4 shows the corresponding V_{CS} range for various conditions.

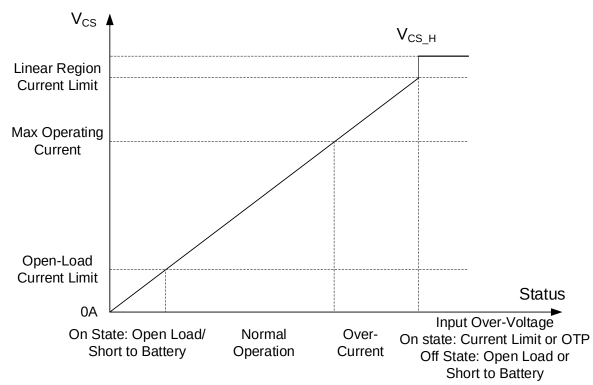


Figure 4: V_{CS} Range and IC Status

Internal Current Limit and Configurable External Current Limit

The MPQ5872 has an internal current limit (CL) and a configurable external CL to improve the reliability and to provide protection during short-circuit conditions and start-up. This function allows the part to be used in low-current applications.

When I_{LOAD} reaches the internal or the external CL, I_{OUT} is regulated to the limit value and the FT/CS pin is pulled up to V_{CS_H}. If the regulation lasts for more than 100µs, the part shuts down. In addition to the CL, an open-loop fast-response function immediately turns off the channel (<1µs) if the channel current dramatically increases before the CL closed loop is set up. This protects the device when the output load is shorted to GND. The device auto-recovers after 300ms.

The internal CL is fixed to 3A. To use the internal CL, connect the ILIM pin directly to the GND pin.

The external configurable CL allows the user to set the CL value. By connecting a resistor (R_{CL}) between the ILIM and GND pins, a proportional load current is converted into a voltage (V_{CL}), which is compared to an internal reference voltage (V_{TH_LIM}). When V_{CL} exceeds V_{TH_LIM}, a closed loop is set up to regulate the internal MOSFET's gate-to-source voltage (V_{GS}). As a result, the MOSFET's drain-to-source voltage (V_{DS}) and I_{LOAD} are clamped at their set values. To increase the sensing accuracy, connect the resistor to the GND pin. R_{CL} can be calculated with Equation (2):

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

Where I_{CL} is the set external CL.

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

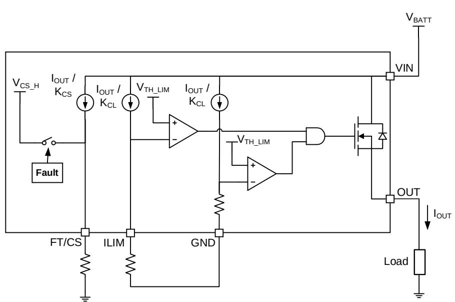


Figure 5: Current Sensing and CL Functional Diagram

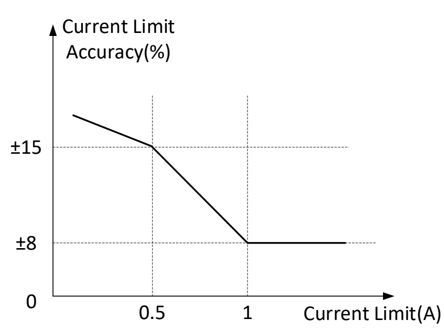


Figure 6: CL Accuracy

It is recommended to set the external CL above 500mA. Figure 6 shows the guaranteed CL accuracy during normal operation (V_{IN} - V_{OUT} < 1V) when the external CL is above 500mA.

During short-circuit conditions or start-up (when V_{IN} - V_{OUT} > 1V), the CL is smaller than during normal operation. The smaller the external CL is, the worse the accuracy becomes. When the external CL is set to 1A, the CL during short-circuit conditions or start-up ranges from 30% to 100% of the typical CL during normal operation. Take the derating into consideration when designing to ensure the part can start up normally.

Adjustable Start-Up Slew Rate

A capacitor connected to the SS pin determines the soft-start (SS) time (t_{SS}). An internal, 10μA constant current source charges the SS capacitor (C_{SS}) and ramps up the voltage on the SS pin (V_{SS}). V_{OUT} follows (V_{SS} x K_{SS}) during t_{SS}. Typically, K_{SS} is about 16.7.

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

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

Where t_{VOUT_RISING} is the V_{OUT} rising time, I_{SS} is the internal SS 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 CL. If C_{SS} is too large, the device must dissipate a large amount of energy during start-up, and the thermal levels become a concern. If the output capacitor (C_{OUT}) is too large, I_{LOAD} during start-up may reach the CL during start-up, and the part may shut down. Therefore, C_{SS} and C_{OUT} should be selected to avoid over-temperature (OT) and over-current (OC) conditions during start-up. See the Application Information section on page 22 for more details.

Inductive Load Switch-Off Clamp

When an inductive load is switching off, V_{OUT} is pulled down to a negative value due to the inductance characteristics. The energy in the inductor dissipates on the MPQ5872 if an external protection circuit is not used. For inductive loads below 5mH, if the maximum switch-off current is below 3A, the MPQ5872 can be used for demagnetization energy dissipation.

If not, external freewheeling circuitry is necessary for device protection. For inductive loads above 5mH, freewheeling circuitry is required. Figure 11 on page 21 shows the freewheeling circuit.

Full Protection and Diagnostic Features

The MPQ5872 provides comprehensive, flexible protection and diagnostic functions. When DIAG_EN is high, all diagnostics are enabled, and the faults can be identified. Table 1 shows the IC status under various fault conditions. Based on the IC status, the type of fault can be determined. When DIAG_EN is low, the open-load and short-to-battery diagnostics are disabled when the device is in the off state. Additional protection and diagnostic information is described below.

V_{IN} Under-Voltage Lockout (UVLO)

The MPQ5872 monitors the input voltage (V_{IN}) to protect the device if the voltage goes too low. If V_{IN} falls to the V_{IN} UVLO threshold (V_{UV_STD}) during the on state, the MOSFET turns off immediately. Once V_{IN} rises back to the UVLO recovery voltage (V_{UV_RST}), the device turns on again and resumes normal operation.

Load Current Monitoring

When I_{OUT} exceeds the nominal current (but is below the CL), the device still operates. In this scenario, the user can monitor I_{LOAD} by sensing V_{CS}. The max V_{CS} during normal operation (V_{OC}) can be defined by the user to determine whether I_{LOAD} is within the normal range.

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

During the on state, if the CL is reached, a fault is reported by pulling up V_{CS} to V_{CS_H}, and I_{OUT} is regulated to the set CL. If the condition lasts for 100µs, the device shuts down. The part tries to auto-recover after 300ms. If I_{OUT} falls below the CL threshold before 100µs has passed, then the MPQ5872 resumes normal operation.

If the load current increases rapidly due to a short circuit, the current may significantly exceed the CL threshold before the control loop can respond. Integrated open-loop fast-response behavior turns off the channel immediately (<1µs) to protect the device when the output load is shorted to GND.

Open-Load Detection

During the on state, an open load is diagnosed by reading the voltage on the FT/CS pin. If V_{CS} is below V_{UC} (the minimum V_{CS} in normal operation, which can be defined by the user). Consider the CS accuracy when setting the V_{UC}. High-accuracy CS helps achieve a very low open load detection threshold and a wide normal operation range.

Table 1: Fault Table

IC Status	Fault Condition	EN	DIAG_EN	OUT	CS/FT	Recovery
Normal	N/A	L	N/A	L	= 0	N/A
		H	N/A	H	$V_{OC} > V_{CS} > V_{UC}$	
V_{IN} UVLO	$V_{IN} < V_{US\_STD}$	H	N/A	L	= 0	$V_{IN} > V_{UV\_RST}$
On-state OC or OUT short to GND	CL reached	H	N/A	L	= V_{CS_H} during current limit deglitch; = 0 after device shutdown	Auto
Off-state OUT short to GND	N/A	L	N/A	L	= 0	N/A
Load current above nominal current	$V_{CS} > V_{OC}$ (where V_{OC} is the max V_{CS} during normal operation, defined by the user)	H	N/A	H	$V_{CS\_H} > V_{CS} > V_{OC}$ (assume CL not reached)	Auto
On-state short to battery or open load	$V_{CS} < V_{UC}$ (where V_{UC} is the min V_{CS} during normal operation, defined by the user)	H	N/A	H	Close to Zero	Auto
Off-state short to battery or open load (12)	$V_{IN} - V_{OUT} < V_{OL\_OFF}$	L	H	H	= V_{CS_H} after deglitch	$V_{IN} - V_{OUT} > V_{OL\_OFF}$
		L	L	H	= 0	N/A
Thermal shutdown	$T > T_{SD}$	H	N/A	L	V_{CS_H}	$T < T_{SD\_RST}$

Note:

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

Figure 7 shows the recommended normal operation range and open-load detection threshold. A ±55% tolerance is considered at a 30mA I_{OUT} to avoid malfunctions.

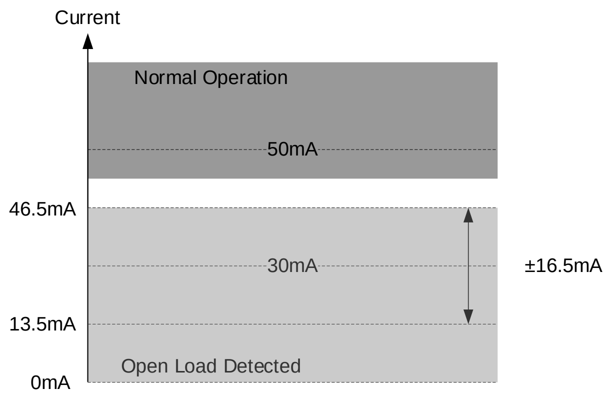


Figure 7: Recommended Normal Operation and On-State Open-Load Threshold

If the load is disconnected in the off state, V_{OUT} is close to V_{IN}. Therefore, an open load can be detected as V_{IN} - V_{OUT} < $V_{OL,OFF}$ (1.05V). In this scenario, V_{CS} is pulled up to V_{CS_H}. Figure 8 shows the off-state open-load detection diagram.

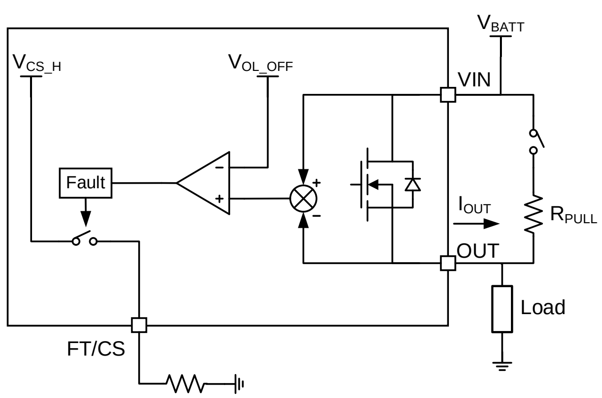


Figure 8: Off-State Open-Load Detection Functional Diagram

Due to the internal logic control path, external humidity, or other factor, there may be a leakage current present on the output. Apply a pull-up resistor (R_{PULL}) to offset the leakage current (see Figure 8). To avoid false detection, the pull-up current should be below the operation current. R_{PULL} is recommended to be 10kΩ.

OUT Short to Battery Detection

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

If VIN is connected to the battery and the output is shorted to the battery, there is no reverse current flowing through the device. If VIN is powered by a supply with lower voltage, it is recommended to use a reverse protection diode to protect the device and power supply when the output is shorted to the battery (see Figure 9).

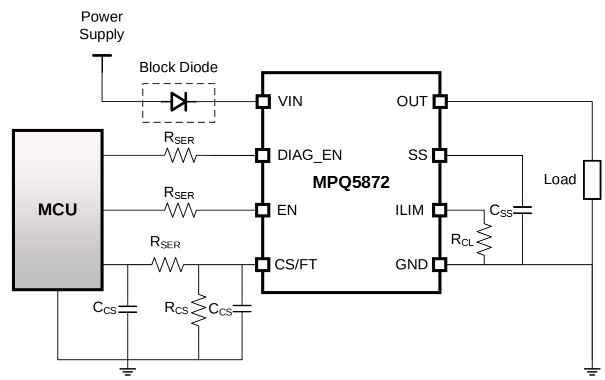


Figure 9: Protection Circuit with Block Diode

Thermal Protection

When the temperature rises up 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. Once the temperature falls to the thermal shutdown hysteresis (T_{SD_RST}), the fault is cleared and the device restarts and resumes normal operation. As long as the temperature remains above T_{SD_RST}, the part will not restart.

Loss of Power Supply Protection

If loss of power supply occurs, the device shuts down regardless of the EN state (see Figure 10).

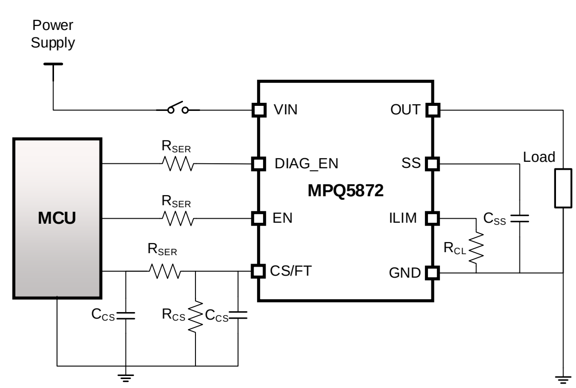


Figure 10: Loss of Power Supply

The device can easily handle resistive or capacitive loads. However, for inductive loads, a current is absorbed from the MCU's general-purpose input/outputs (GPIOs), which may damage the device and the MCU. In this scenario, MCU series resistors, ground network or an external freewheeling circuit is required (see Figure 11).

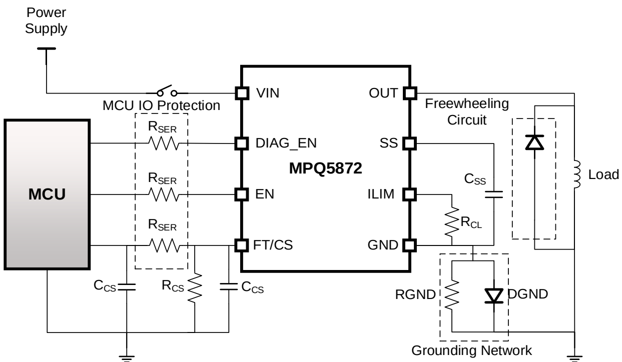


Figure 11: Loss of Power Supply Protection

Reverse Polarity Protection

A diode between the device GND and module ground is required to block possible reverse voltage, which also causes a ground shift (about 600mV). Ensure that R_{CL} and C_{SS} are properly connected to the device GND in the event that a GND voltage shift occurs. For inductive loads, a negative spike may occur during the off state, which may damage the diode. Therefore, it is strongly recommended to add a 1kΩ resistor in parallel with the diode when driving an inductive load to help protect the diode in parallel. The diode's I_F should be greater than 100mA.

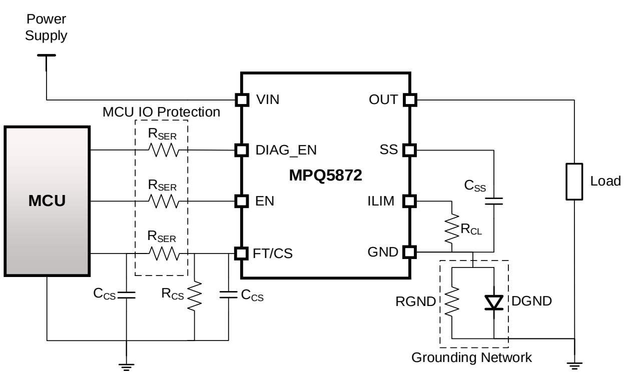


Figure 12: Reverse Polarity Battery Protection

AEC Q100-012 Test Grade A Certification

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

Applicable Test Modes

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

Transient Disturbances Tests

The MPQ5872 meets requirements specified in ISO 7637-2 and ISO 16750-2 standards with proper external circuitry (see Figure 13). Table 2 shows additional details.

Table 2: Tests in ISO 7637-2 and ISO 16750-2

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* = 40V t_R ≤ 5ms
	Reverse polarity voltage		U_S = -30V t < 60s

If the CL is reached during a load dump transient, the device shutdown. Therefore, the load capacitor (C_{LOAD}) should be selected based on Equation (4):

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

where I_{LIMIT} is the lower one of the internal and external current limit, I_{LOAD} is the load current, and SR is the slew rate of the source voltage.

Based on the load dump pulse definition, SR must be no greater than 20V/ms. Therefore, for an application with 3A current limit and 2A continuous current, it is recommended C_{LOAD} to be no more than 47µF.

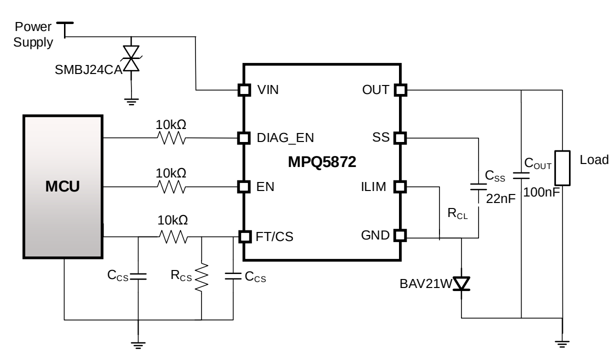


Figure 13: Pulse Test Circuit

APPLICATION INFORMATION

Component Selection

Figure 14 shows the MPQ5872's application circuit.

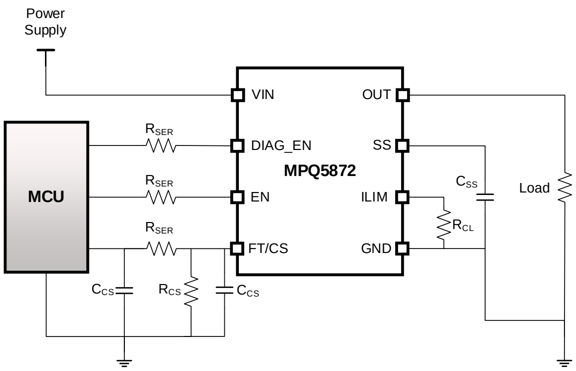


Figure 14: MPQ5872 Application Circuit

In this section, the following example is given as a guideline for component selection:

- VIN is connected to a 12V battery
- 2A nominal current.
- Current sensing required for $I_{OUT} \leq 2A$
- The normal V_{CS} for a 2A load is 2V
- 2.5A external current limit required
- Start-up time is about 1.5ms
- Full diagnostics required with 5V MCU
- Grounding network required for protection
- 100nF C_{CS} required for signal stability

Design Procedure

Select R_{CS} using Equation (5):

$$R_{CS}=\frac{K_{CS} \times V_{CS}}{I_{OUT}}=1000\times\frac{2}{2}=1k\Omega \qquad (5)$$

Select R_{CL} using Equation (6):

$$R_{CL}=\frac{K_{CL} \times V_{TH\_LIM}}{I_{CL}}=1000\times\frac{0.7}{2.5}=280\Omega \qquad (6)$$

Select C_{SS} using Equation (7):

$$C_{SS}=K_{SS}\frac{T_{VO\_R} \times I_{SS}}{V_{OUT}}=16.7\times\frac{1.5\times10}{12}=22nF \qquad (7)$$

It is recommended for R_{SER} = 10kΩ.

C_{SS} Design Procedure

1. Confirm the t_{SS} request and select the C_{SS} value.
2. Calculate the start-up current and select a suitable R_{CL}. If R_{CL} is not suitable, repeat step 1.
3. Evaluate thermal performance based on the Recommended Maximum Junction Temperature (T_J) section on page 23. If T_J is not above 150°C, the design is good. If not, return to step 1.

Determining the Fault Status

The MPQ5872's fault status can be easily determined if V_{IN} and V_{OUT} can be monitored. Figure 15 illustrates this process.

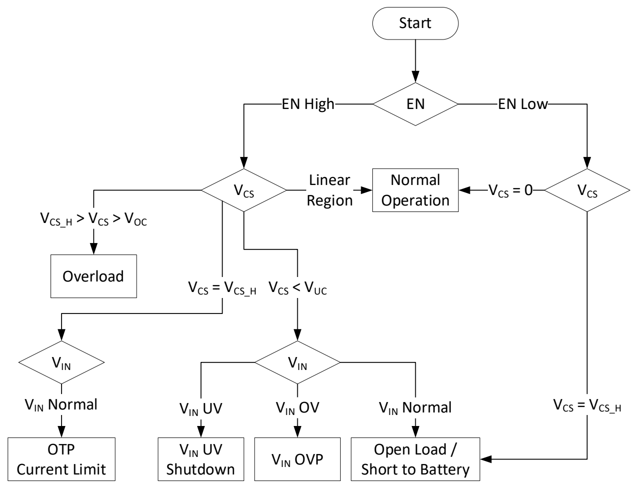


Figure 15: Fault Determination Flowchart 1

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 16).

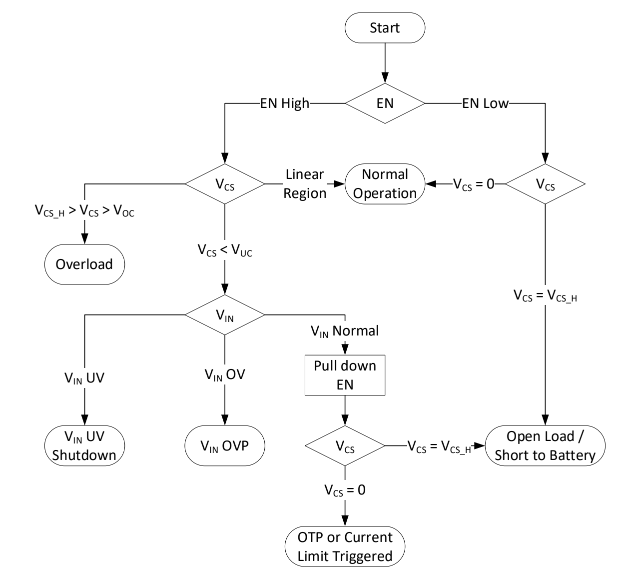


Figure 16: Fault Determination Flowchart 2

If the MCU's ADC observes $V_{CS} < V_{UC}$ during the on state, there are two possible fault conditions:

1. The CL is triggered, and the device is off for 300ms before it tries to restart
2. The load is an open circuit, and the MCU pulls down EN to detect if there is an open load. If V_{CS} is high, the fault is an open load. Otherwise, the fault is an over-current or short circuit condition.

Recommended Maximum Junction Temperature (T_J)

The MPQ5872'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 is related to the MOSFET's power dissipation (Q), which can be calculated with Equation (8):

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

Where Q is the MOSFET's total power dissipation during soft start (SS), $U_{(t)}$ is the voltage drop on the MOSFET, $I_{(t)}$ is the current flowing through the MOSFET, and t_{SS} is the SS time.

t_{SS} is equal to t_{VO_RISING} in Equation (3) on page 18 if C_{SS} is applied and the CL is not reached during start-up.

If the MOSFET current is constant during start-up, then Equation (8) can be simplified to Equation (9):

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

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

Figure 17 shows the T_J rise with difference power dissipation levels and t_{SS} values. The figure can be used to determine whether the value of C_{SS} is reasonable.

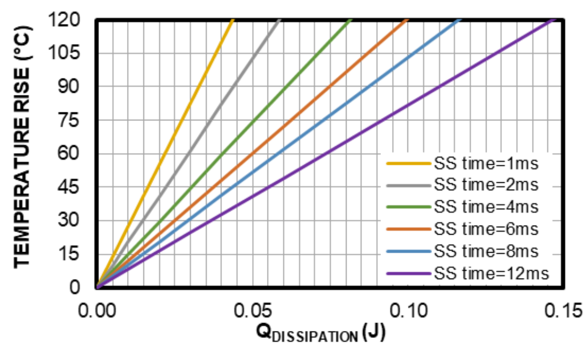


Figure 17: T_J Rise with Different Power Dissipation and SS Times

As an example, assuming V_{IN} = 10V, I_{OUT} = 0.5A, and C_{SS} = 100nF, t_{SS} is calculated as 6ms, and Q is calculated as 0.015J. Based on Figure 17, the T_J rise during start-up is 20°C. Therefore, this design is reasonable.

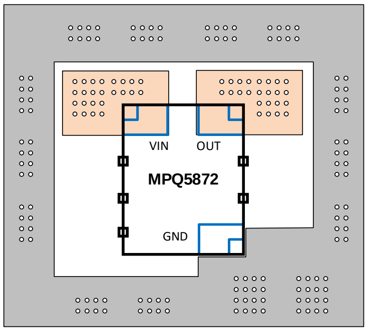
Functional Safety Application Support

Related functional safety documentation, such as Failure in Time (FIT) number and Process Failure Modes and Effects Analysis (PFMEA), is available for the MPQ5872 to aid functional safety design.

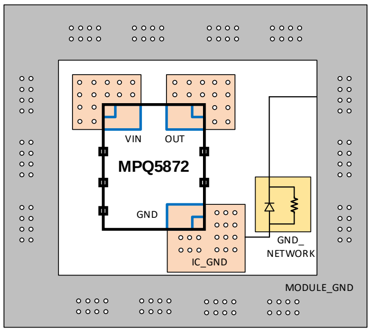
PCB Layout Guidelines

For optimal thermal performance and reliability, refer to Figure 18 follow the guidelines below when designing the PCB layout:

1. Increase the copper area on the PCB (especially for VIN, OUT, and GND) to increase the thermal conductivity of the board.
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 needed, use a single copper layer for the IC's GND plane. Then connect the IC's and module's GND pins via protective components.



(a) Without GND Network



(b) With GND Network

Figure 18: Recommended PCB Layout

TYPICAL APPLICATION CIRCUITS

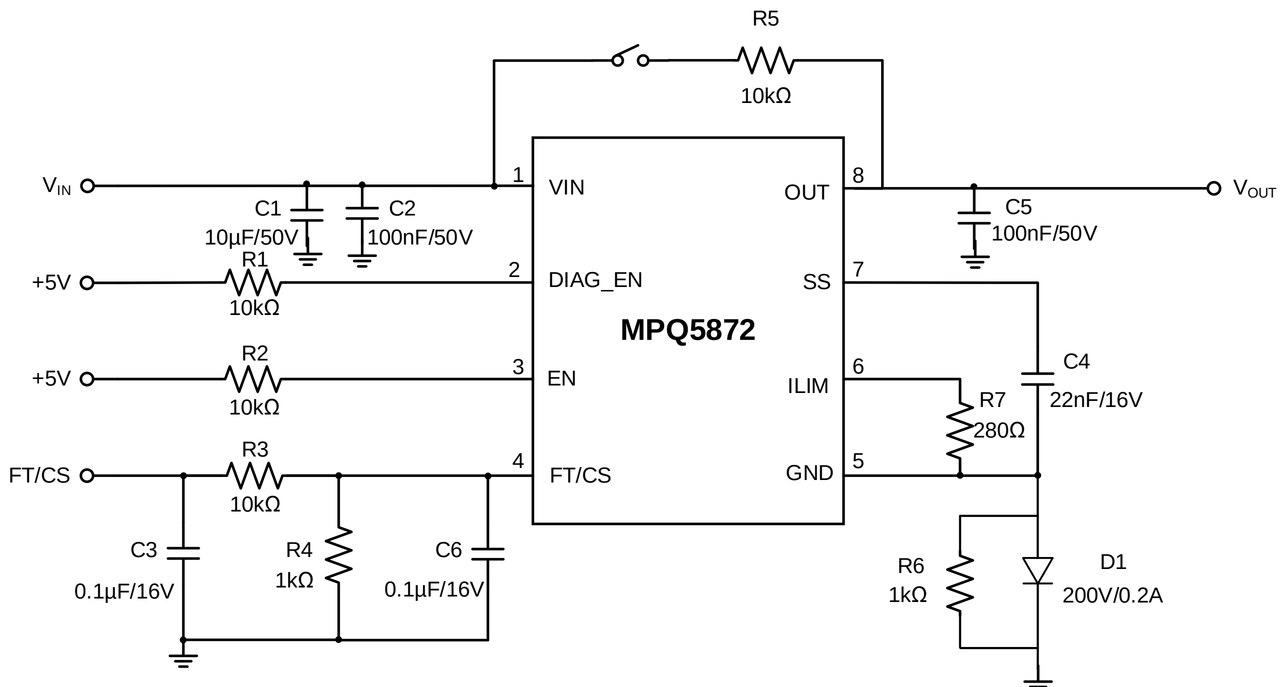


Figure 19: Typical Application Circuit for 2A Output (2.5A External Current Limit) with Ground Network

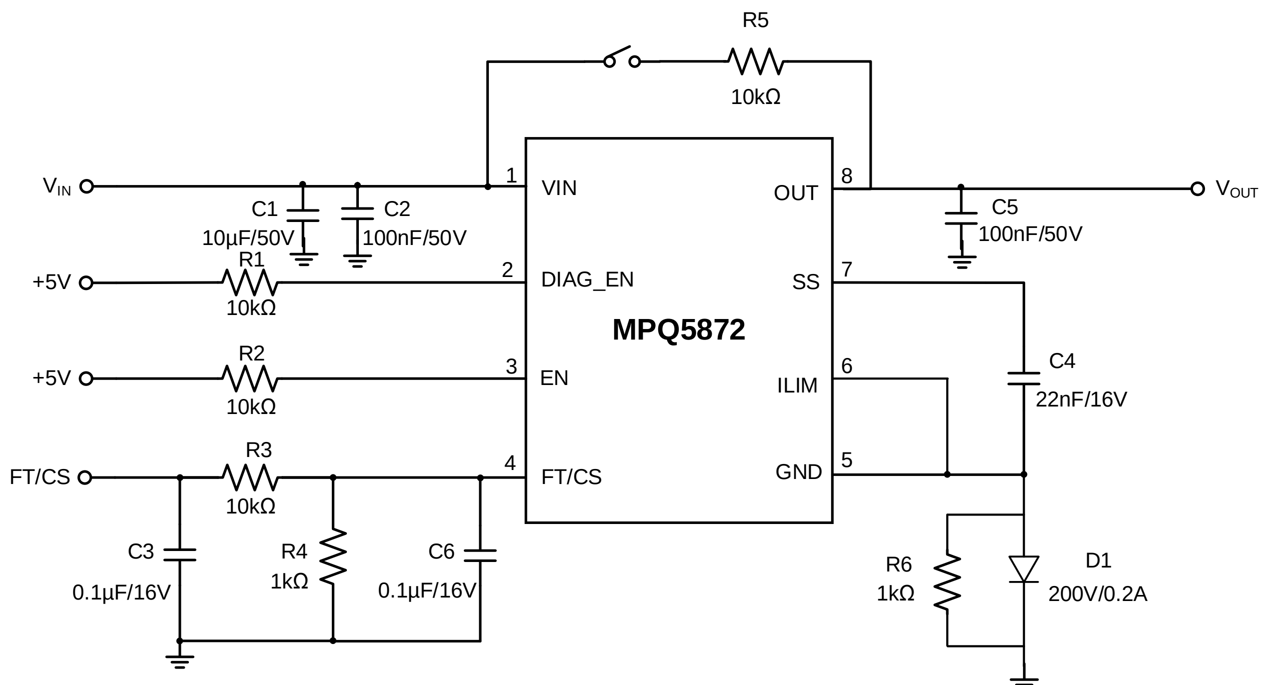


Figure 20: Typical Application Circuit for 2A Output (3A Internal Current Limit) with Ground Network

TYPICAL APPLICATION CIRCUITS *(continued)*

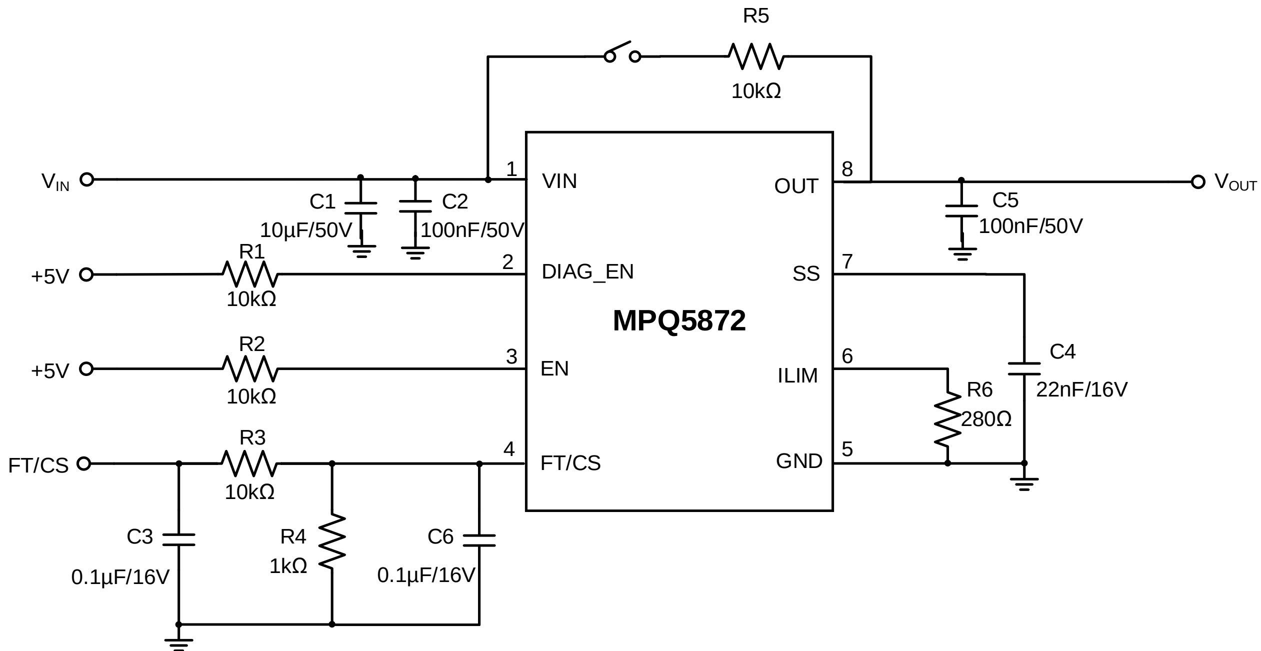


Figure 21: Typical Application Circuit for 2A Output (2.5A External Current Limit) without Ground Network

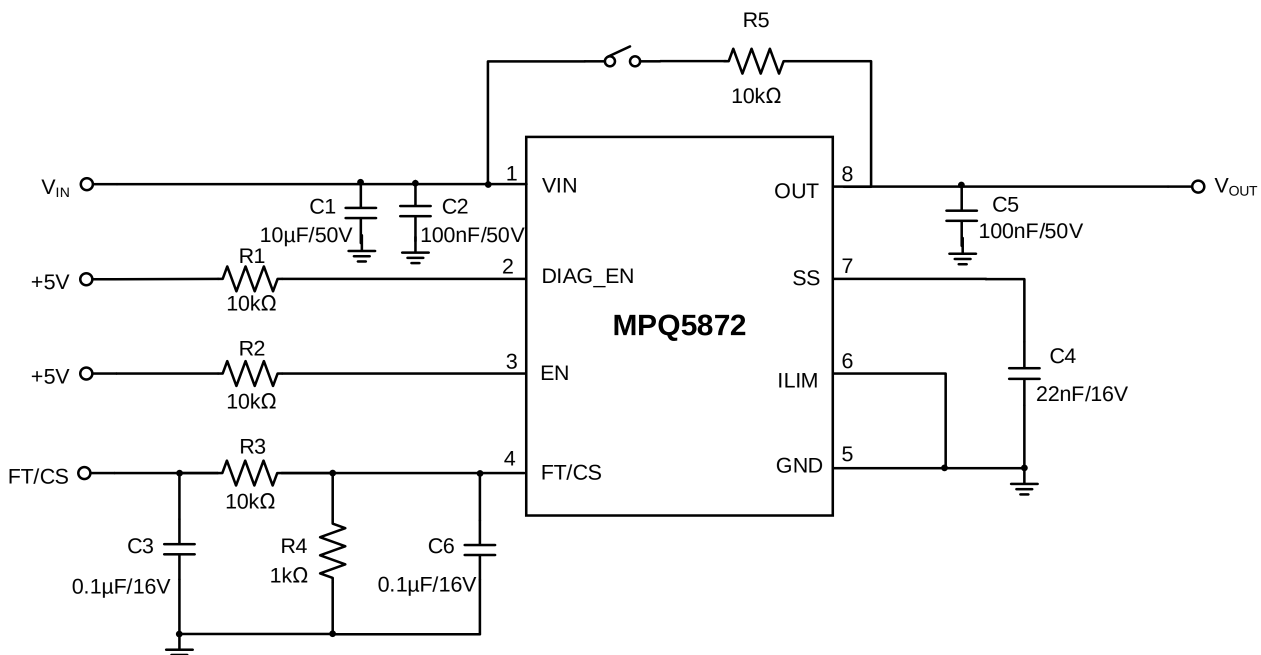
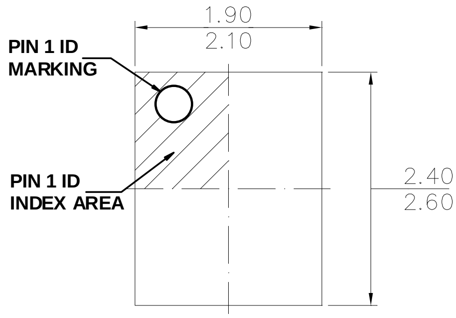


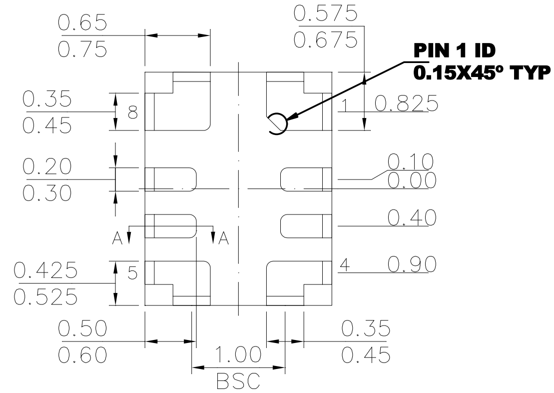
Figure 22: Typical Application Circuit for 2A Output (3A Internal Current Limit) without Ground Network

PACKAGE INFORMATION

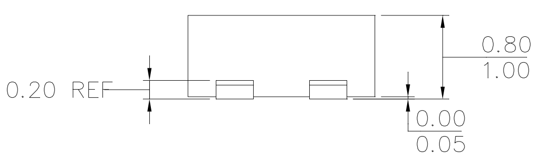
QFN-8 (2mmx2.5mm)
Wettable Flank



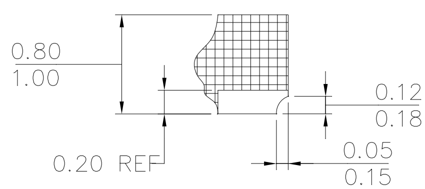
TOP VIEW



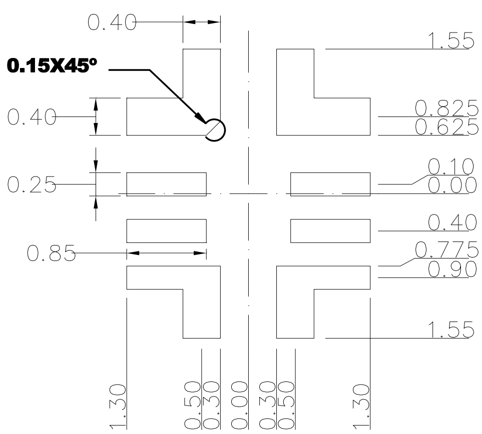
BOTTOM VIEW



SIDE VIEW



SECTION A-A

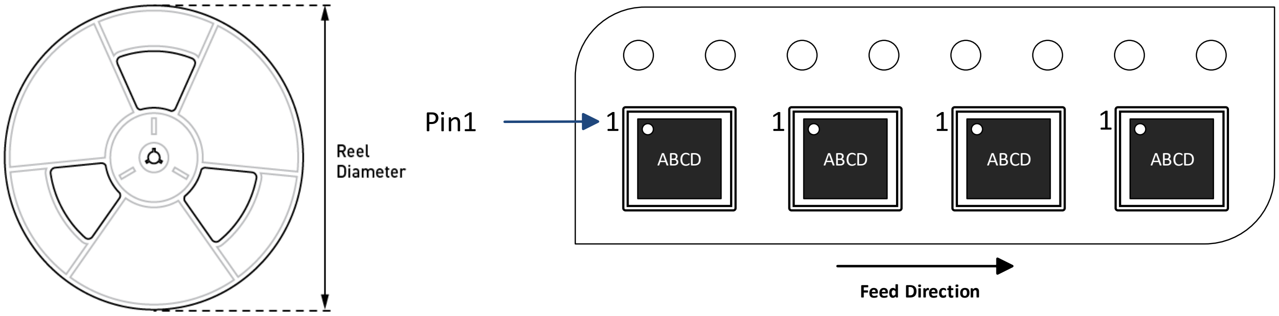


RECOMMENDED LAND PATTERN

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
MPQ5872GRPE-AEC1-Z	QFN-8 (2mmx2.5mm)	5000	N/A	N/A	13in	12mm	8mm

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	10/25/2023	Initial Release	-