MPQ5871

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

DESCRIPTION

The MPQ5871 is designed as a smart high-side power switch for a nominal 1A load. The device supports a wide 3.5V to 36V input voltage (V_{IN}) range. The MPQ5871 provides a highly efficient and compact solution with a small on resistance ($R_{DS(ON)}$).

The device supports both an internal current limit and a configurable, high-accuracy external current limit. These limits clamp the inrush current under short-circuit conditions, which improves 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 diagnostics in real time without additional 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 ranges. The FT/CS pin can report faults by pulling up its voltage.

The MPQ5871 provides full diagnostic capabilities when it is in both on and off states. By pulling the DIAG_EN pin up or down, users can enable or disable off-state open-load or battery short detection. If the system does not require off-state diagnostics, turn off this function and reduce the standby current by connecting the DIAG_EN pin to the GND pin.

The MPQ5871 is available in a QFN-8 (2mmx2.5mm) package, and is available in AEC-Q100 Grade 1 and AEC-Q100-012 Test Grade A.

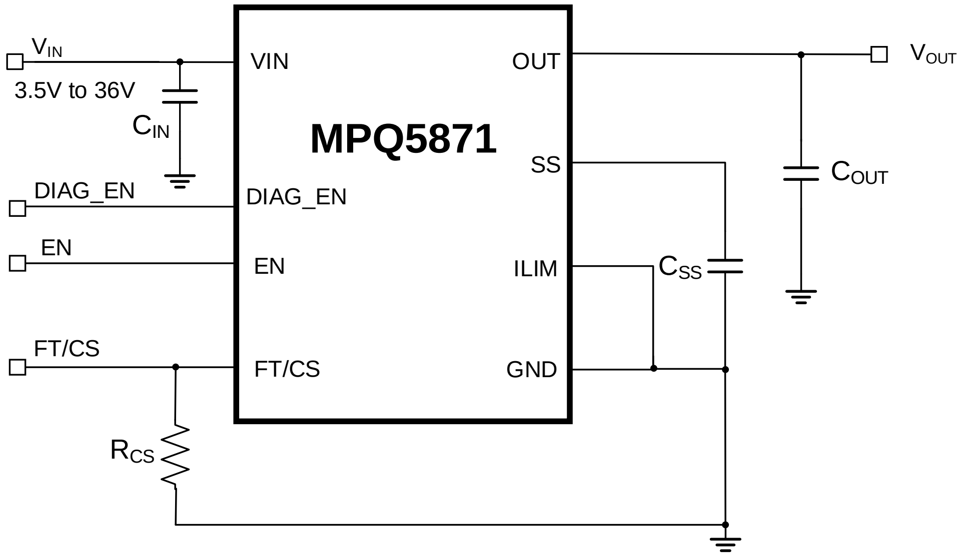
FEATURES

- 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
  - Extremely Low Standby Current: 0.5µA
- Reduces Board Size
  - Available in a QFN-8 (2mmx2.5mm) Package
- Flexibility
  - Configurable External Current Limit
  - Adjustable Start-Up Slew Rate
  - Compatible with 3.3V and 5V Logic
- Full Diagnostics and Protections
  - Supports Functional Safety Application
  - High-Accuracy Current Sense: ±4% at 1A and ±6% at 300mA
  - On-State and Off-State Open-Load And Battery Short Detection
  - Thermal Shutdown
  - Available in a Wettable Flank Package
  - Available in AEC-Q100 Grade 1
  - Available in AEC-Q100-012 Test Grade A

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**
MPQ5871GRPE-AEC1***	QFN-8 (2mmx2.5mm)	*See Below*	1

* For Tape & Reel, add suffix -Z (e.g. MPQ5871GRPE-AEC1-Z).
** Moisture Sensitivity Level Rating
*** Wettable Flank

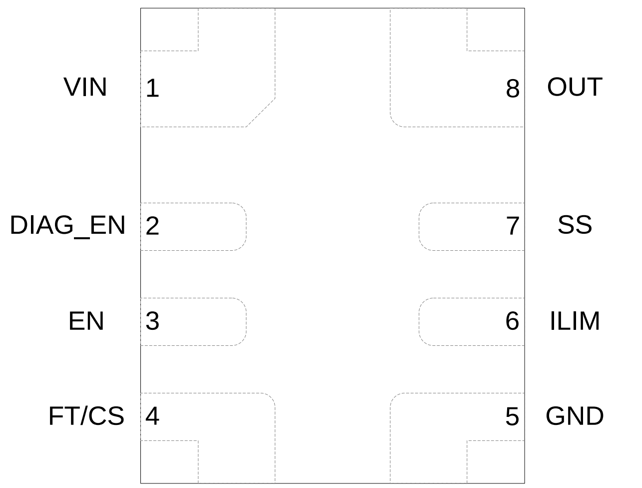
TOP MARKING

NCY
LLL

NC: Product code of MPQ5871GRPE-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 diagnostics. Pull DIAG_EN below the threshold (1V) to disable diagnostics and reduce the standby quiescent current. Connect this pin to GND if it is not used.
3	EN	**Enable.** Pull the EN pin above the specified threshold (1.2V) to enable the chip. Pull EN below the threshold (1V) to shut down the chip.
4	FT/CS	**Fault/current sense.** A current mirror sources 1 / K_{CS} of the load current, which flows to the external resistor (R_{CS}) connected between FT/CS and GND. The voltage on the FT/CS pin (V_{CS}) reflects the load current. This pin also reports faults. Float this pin if the current-sense feature is not used.
5	GND	**Device ground.**
6	ILIM	**Configurable current limit pin.** Connect the ILIM pin to GND via a resistor (R_{CL}) to set the external current limit. See the Internal Current Limit and Configurable, External Current Limit section on page 16 for more details. Connect ILIM 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's slew rate during soft start.
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 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 2b (5)

Recommended Operating Conditions

Supply voltage (V_{IN}) ....5V to 36V
Nominal DC load current.......................0A to 1A
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)
EVQ5871-RP-00A……….28…………..°C/W (7)

Ψ_{JT}

JESD51-7…………………………..4.9…..°C/W (6)
EVQ5871-RP-00A……...…..........4.......°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 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. θ_{JC} shows the thermal resister from junction-to-case bottom, and Ψ_{JT} shows the characterization parameter from junction-to-case top.
7) Measured on MPS's MPQ5871 standard EVB, 6.35cmx6.35cm, 2oz copper thickness, 4-layer PCB, and 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						
Input voltage (V_{IN}) operation	V_{IN_REC}		5		36	V
V_{IN} operation (extended)	V_{IN_FULL}	In the extended range, the channel's R_{ON} exceeds the value that it would be within V_{IN_REC}	3.5		36	V
V_{IN} range for short-circuit protection (SCP)	V_{IN_SCP}				24	V
V_{IN} under-voltage (UV) shutdown	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-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
Enable (EN) and Enable Diagnostics (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	1.0	1.2	V
EN pull-down resistance (8)	R_{EN_PD}			500		kΩ
Logic low voltage for DIAG_EN	V_{DIAG_L}		0.8	1.0	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 Sensing						
Current-sense (CS) ratio	K_{CS}			1000		
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		1	A
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	%
Fault voltage for the 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						
Internal current limit	I_{LIM}	CL short to GND	1.6	2	2.4	A
Internal current limit threshold voltage	V_{TH_LIM}			0.7		V
Current limit ratio	K_{CL}			1000		
External current limit accuracy during normal operation	dK_{CL}/K_{CL}	V_{IN} - V_{OUT} < 1V, Current limit ≥ 0.5A (R_{CL} ≤ 1.4kΩ)	-15		+15	%
		V_{IN} - V_{OUT} < 1V, Current limit ≥ 1A (R_{CL} ≤ 700Ω)	-8		+8	%
Current limit during start-up and short-circuit protection (SCP)	I_{LIM_SAT}	V_{IN} - V_{OUT} > 1V, R_{CL} = 1.4kΩ, T_J = 25°C to 150°C	0.13	0.25	0.57	A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 1.4kΩ, T_J = -40°C to +25°C (10)	0.10			A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 700Ω, T_J = 25°C to 150°C	0.35	0.60	1.08	A
		V_{IN} - V_{OUT} > 1V, R_{CL} = 700Ω, T_J = -40°C to +25°C (10)	0.30			A
		V_{IN} - V_{OUT} > 1V, CL short to GND, T_J = 25°C to 150°C	1.00	1.45	2.40	A
		V_{IN} - V_{OUT} > 1V, CL short to GND, T_J = -40°C to +25°C (10)	0.90			A
Current limit deglitch time	t_{CL_DEG}	Current limit lasts for t_{CL_DEG} (device shutdown)		800		us
Fast turn-off shutdown time (11)	t_{FOFF}	Fast-off triggered, device shuts down in t_{FOFF}		1		µs
Over-current (OC) auto-recovery	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.

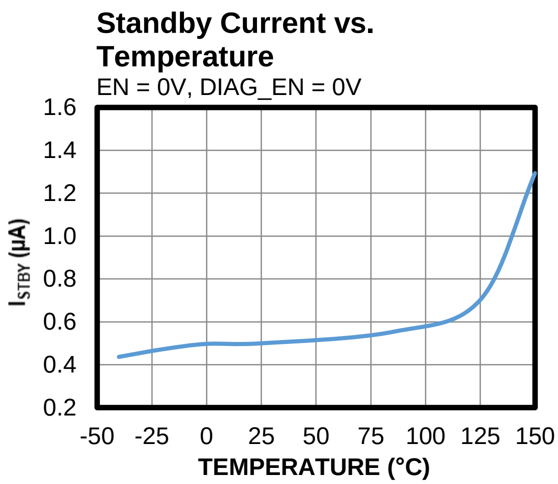
Parameter	Symbol	Condition	Min	Typ	Max	Units
Diagnostics and Protection						
Off-state open-load threshold	V_{OL_OFF}	EN = 0V, if V_{IN} - V_{OUT} < V_{OL_OFF}, t > t_{OL_OFF}, open load detected	0.75	1.05	1.35	V
Off-state open-load detection deglitch time	t_{OL_OFF}			700		μs
Off-state output sink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

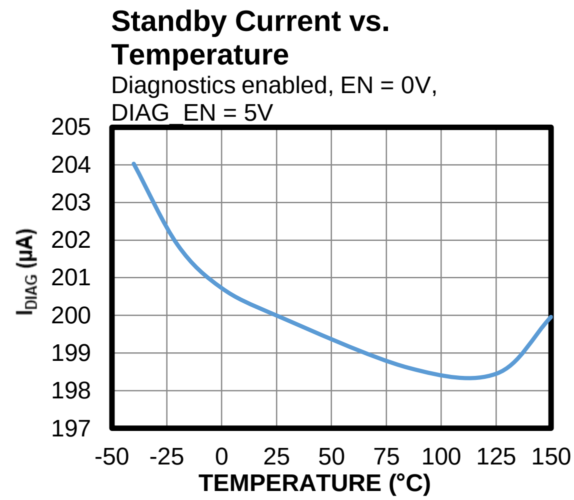
Notes:

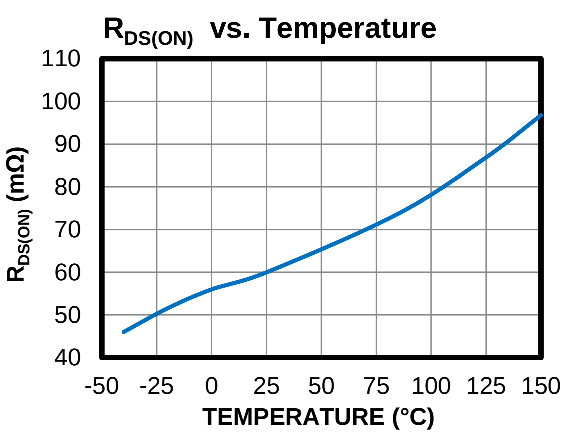
8) Not tested in production. Guaranteed by design and characterization.
9) The current accuracy is not guaranteed if V_{CS} exceeds this range.
10) Minimum value guaranteed by characterization. Not tested in production.
11) Derived from bench characterization. Not tested in production.

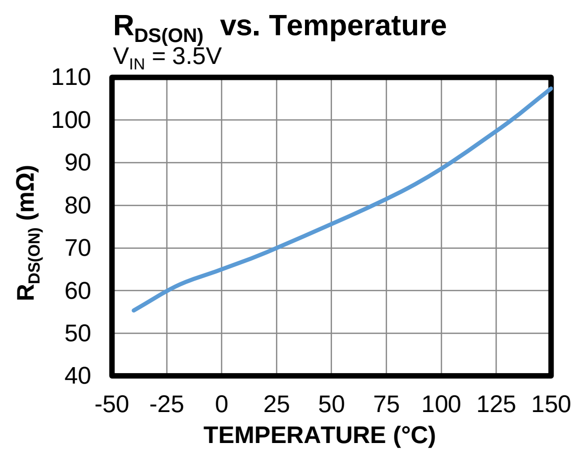
TYPICAL CHARACTERISTICS

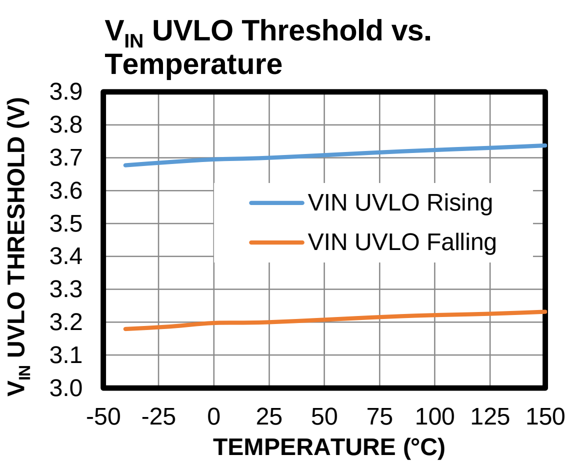
V_{IN} = 12V, unless otherwise noted.

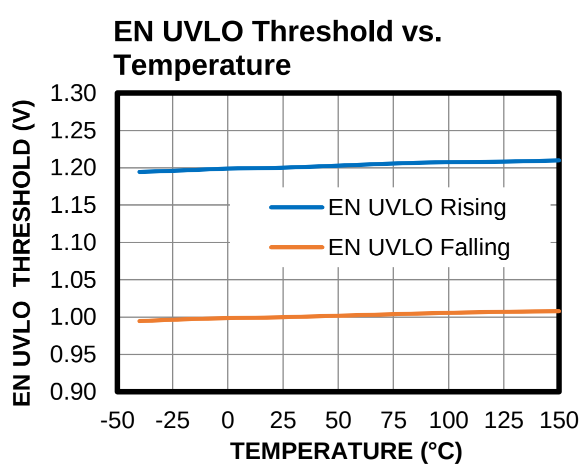






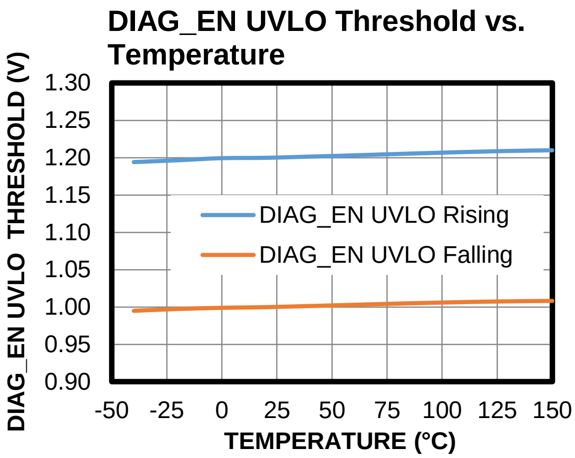


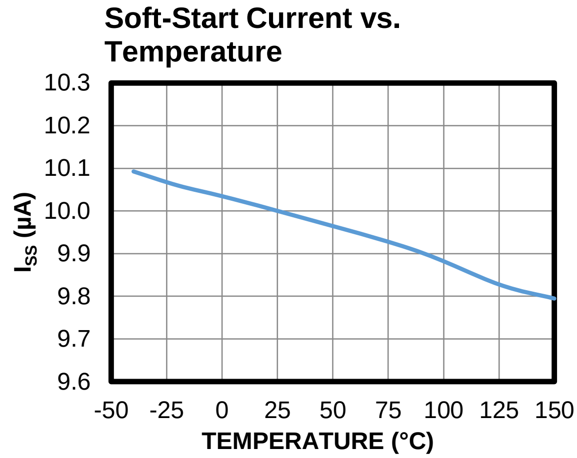


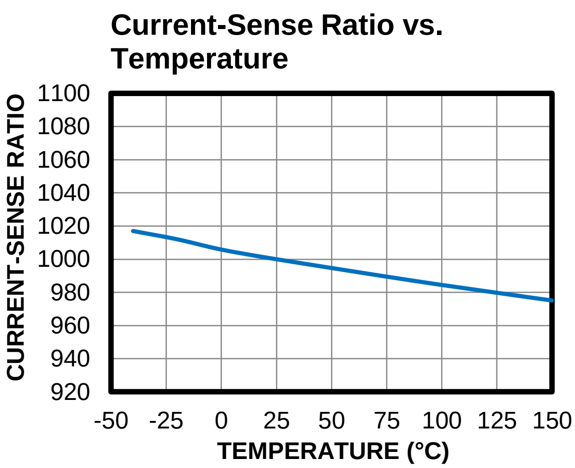


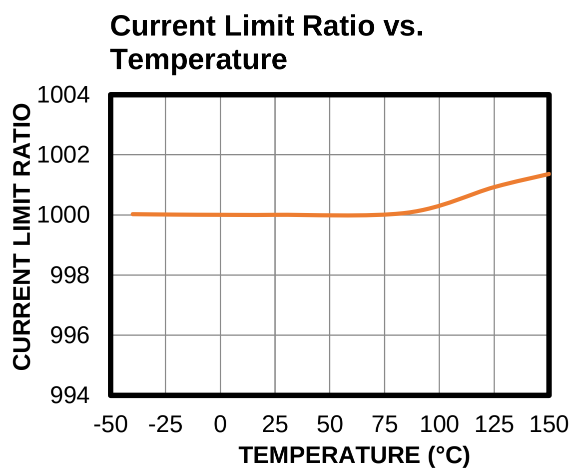
TYPICAL CHARACTERISTICS *(continued)*

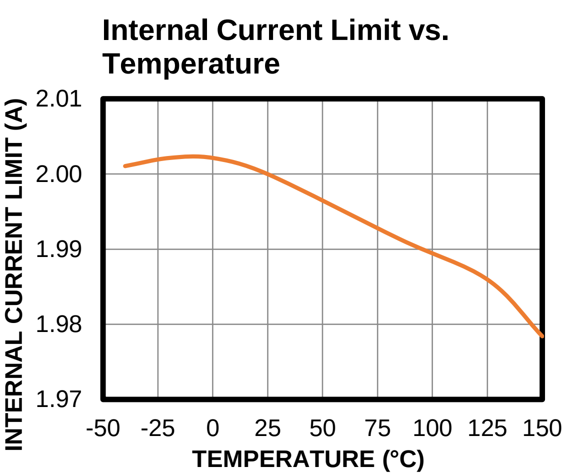
V_{IN} = 12V, unless otherwise noted.

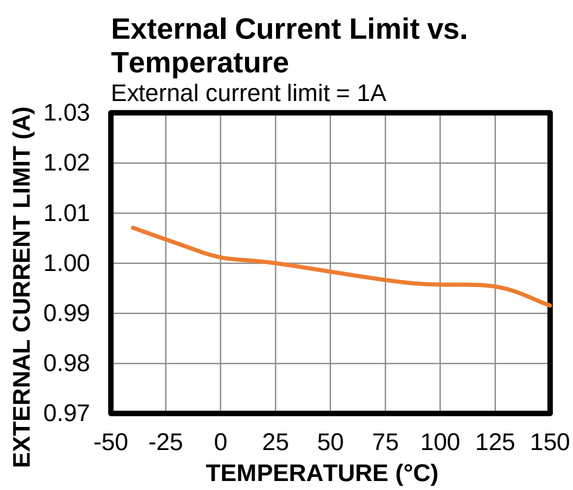






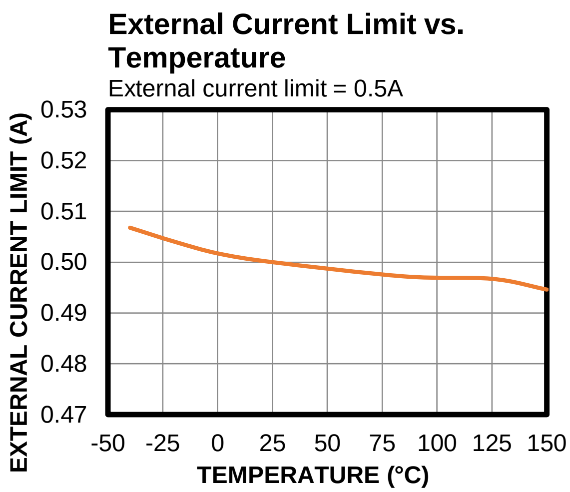






TYPICAL CHARACTERISTICS *(continued)*

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

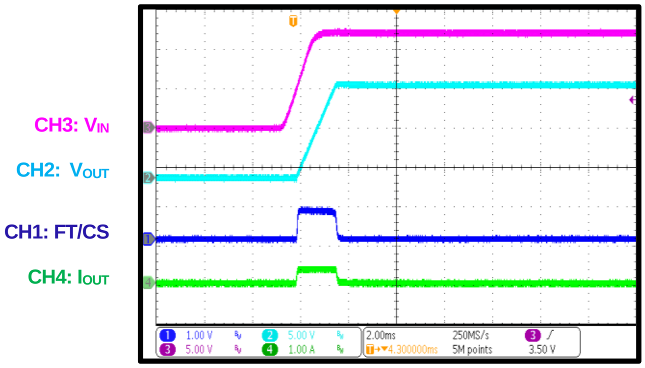


TYPICAL PERFORMANCE CHARACTERISTICS

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

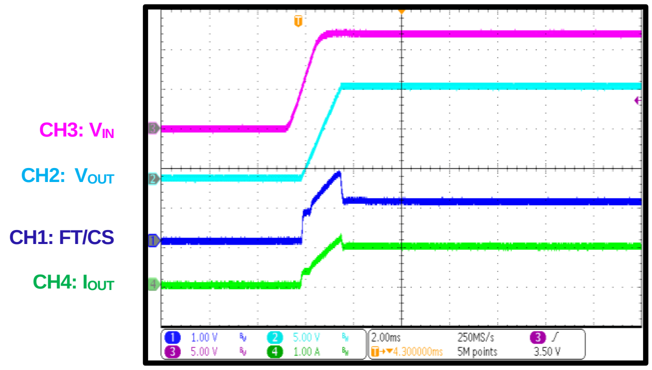
Start-Up through VIN

I_{OUT} = 0A



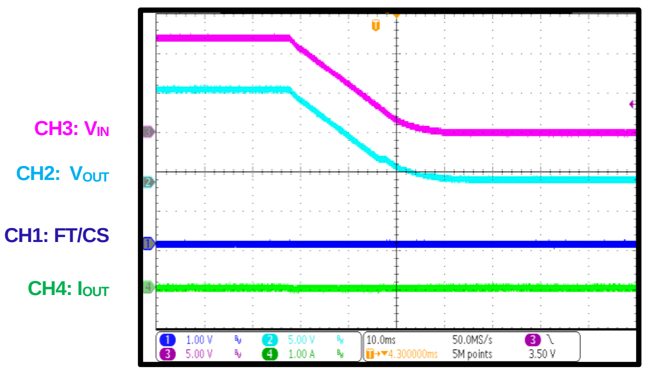
Start-Up through VIN

I_{OUT} = 1A



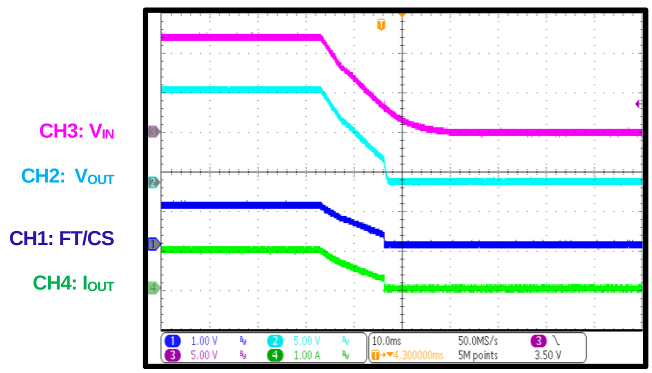
Shutdown through VIN

I_{OUT} = 0A



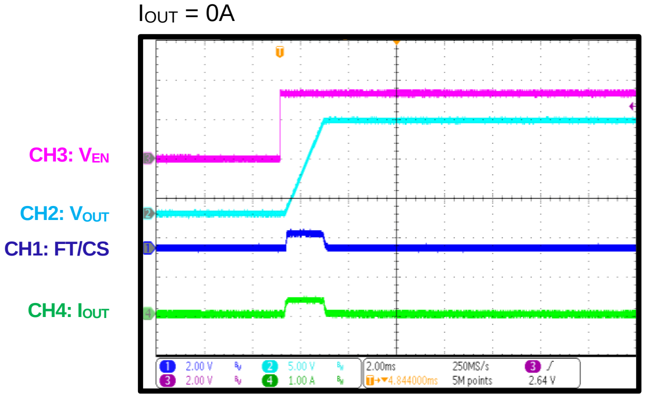
Shutdown through VIN

I_{OUT} = 1A



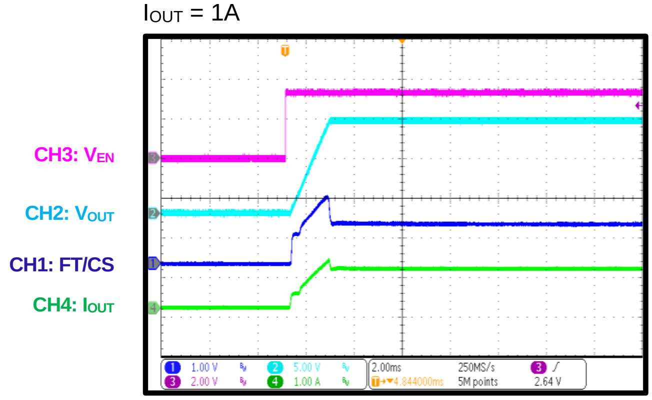
Start-Up through EN

I_{OUT} = 0A



Start-Up through EN

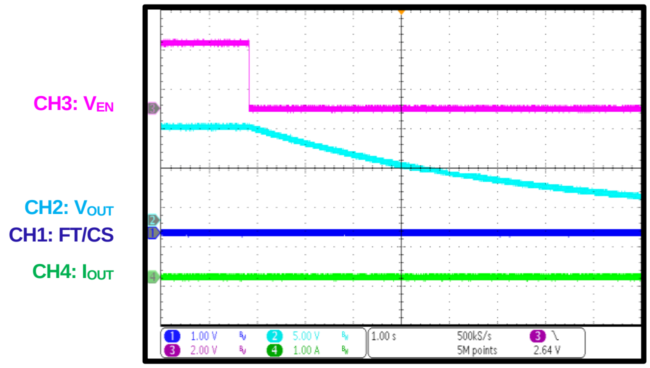
I_{OUT} = 1A



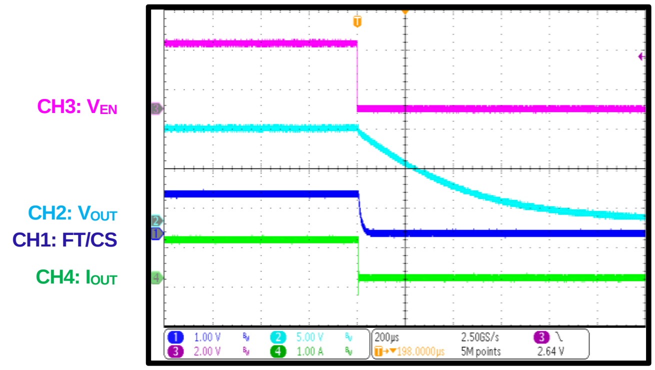
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

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

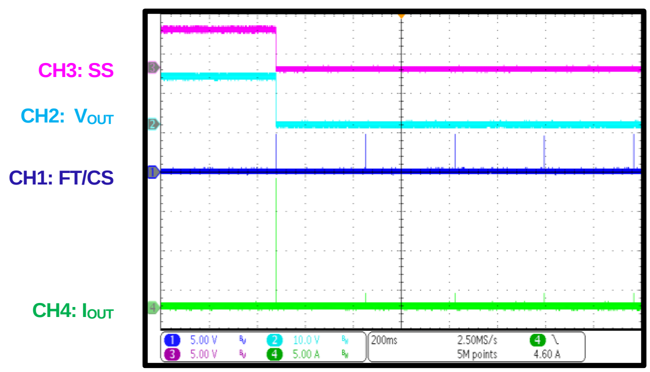
Shutdown through EN
I_{OUT} = 0A



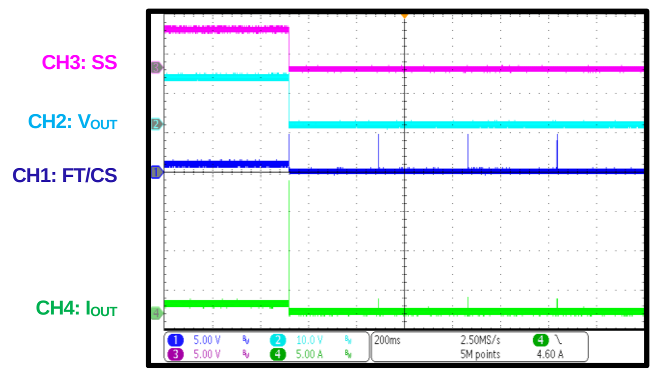
Shutdown through EN
I_{OUT} = 1A



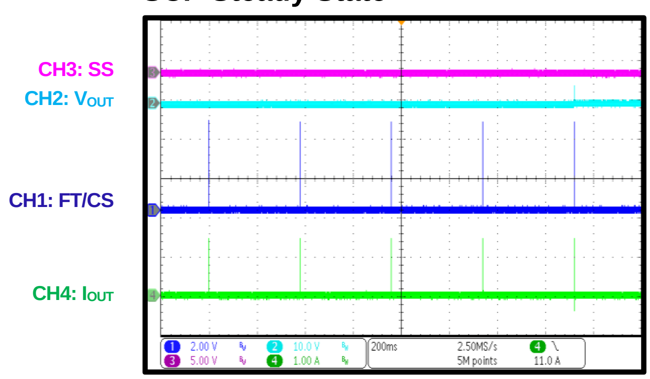
SCP Entry
I_{OUT} = 0A



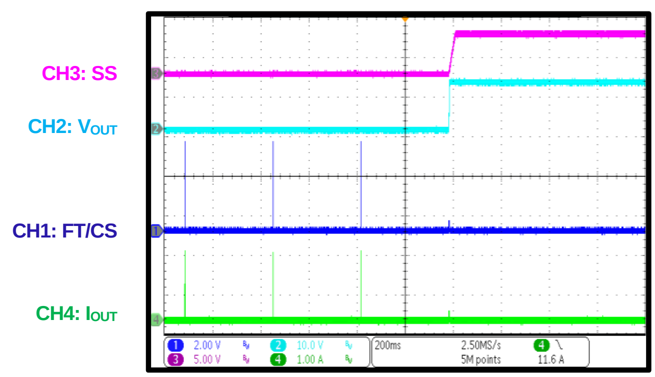
SCP Entry
I_{OUT} = 1A



SCP Steady State



SCP Recovery
I_{OUT} = 0A

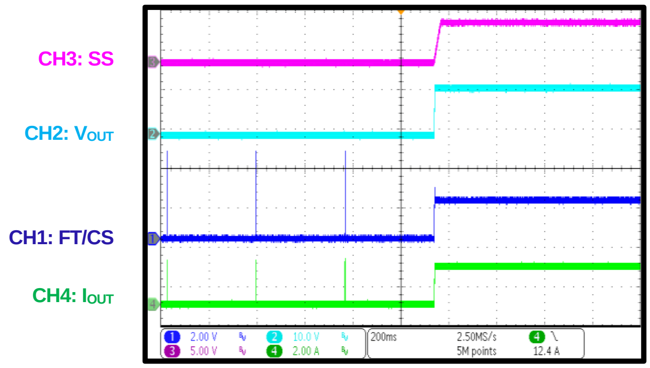


TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

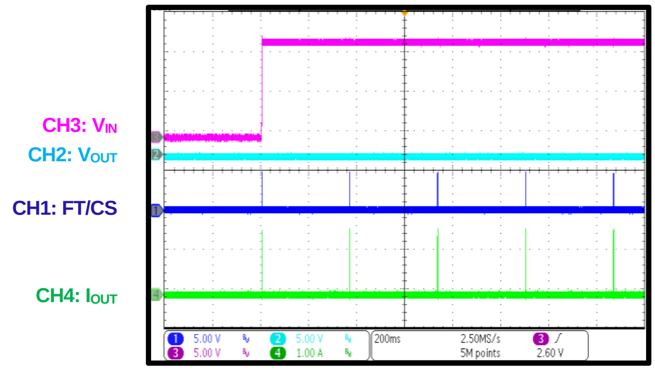
V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47μF, T_A = 25°C, unless otherwise noted.

SCP Recovery

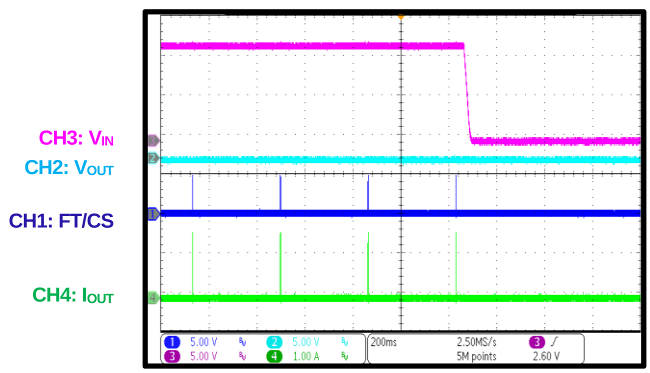
I_{OUT} = 1A



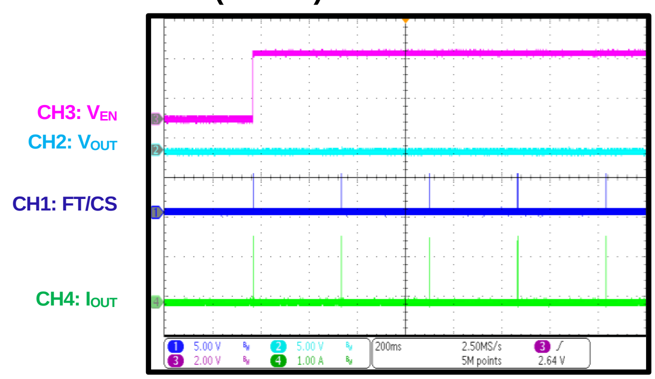
SCP Start-Up



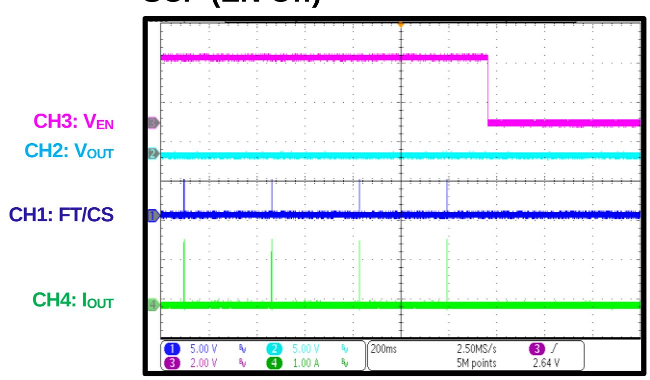
SCP Shutdown



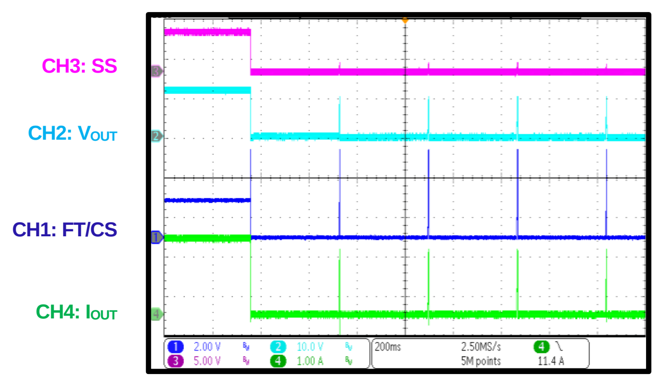
SCP (EN On)



SCP (EN Off)



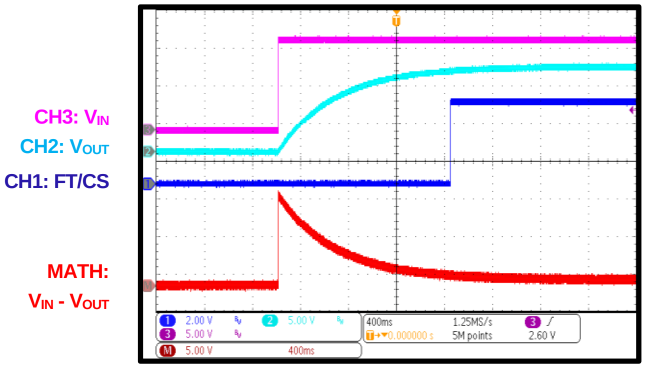
OCP



TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

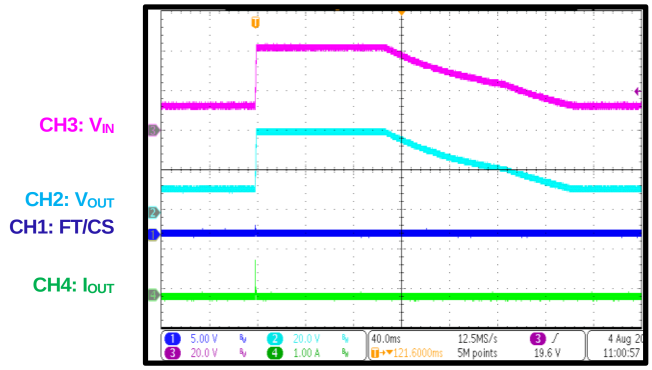
V_{IN} = 12V, V_{OUT} = 12V, C_{LOAD} = 47µF, T_A = 25°C, unless otherwise noted.

Open-Load Detection



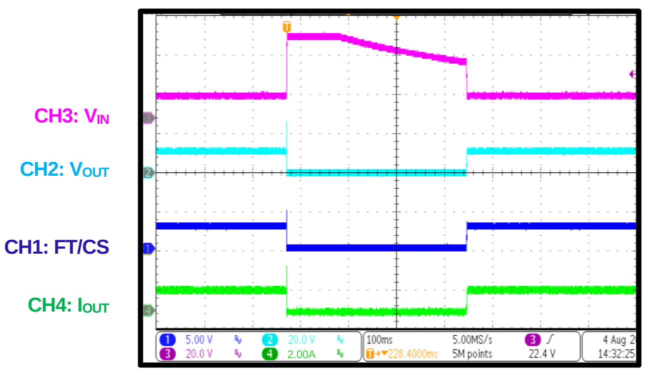
Load Dump

I_{OUT} = 0A



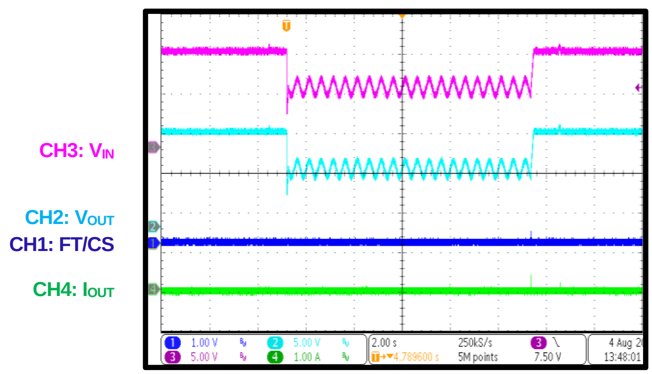
Load Dump

I_{OUT} = 1A



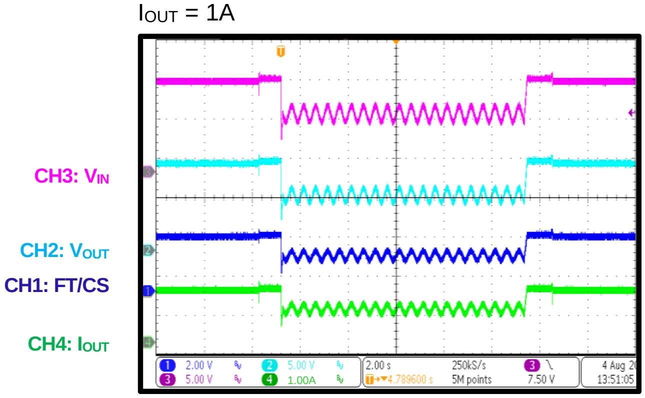
Cold-Crank Conditions

I_{OUT} = 0A



Cold-Crank Conditions

I_{OUT} = 1A



FUNCTIONAL BLOCK DIAGRAM

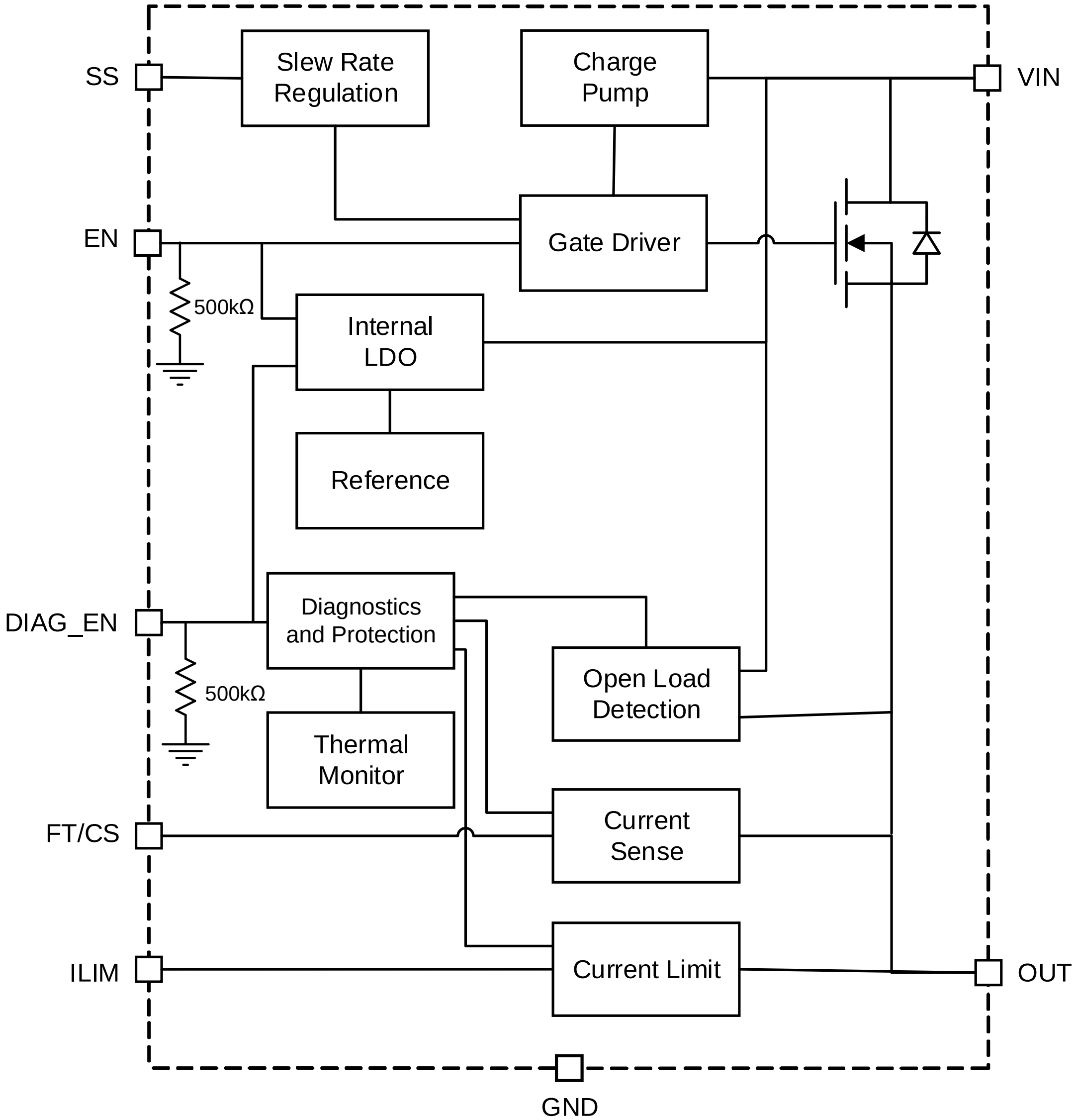


Figure 1: Functional Block Diagram

OPERATION

Operation Modes

The MPQ5871 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 down the DIAG_EN pin, 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.

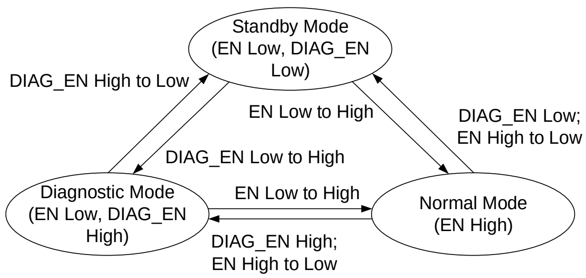


Figure 2: Operation Mode State Machine

High-Accuracy Current Sensing

The MPQ5871 integrates a high-accuracy current-sense block to achieve real-time current monitoring and diagnostics. A current mirror is used to source 1 / K_{CS} of the load current, which flows to the external resistor (R_{CS}) between the FT/CS pin and GND. The voltage on the FT/CS pin (V_{CS}) reflects the load current.

K_{CS} represents the ratio between the output current (I_{OUT}) and the sensed current. It 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 the load current is equal to 1A, the accuracy is ±4%; if the load current is between 300mA and 1A, the accuracy reaches ±6%.

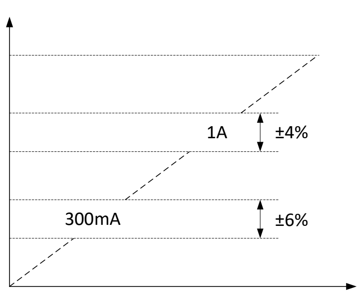


Figure 3: Current-Sense Accuracy

During normal operation, V_{CS} must be designed to be linear. R_{CS} can be calculated with Equation (1):

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

Fault Report Function

The FT/CS pin reports if a fault condition occurs. If an open load or battery short condition 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} pulls up to V_{CS_H}. Figure 4 shows the MPQ5871's conditions and its corresponding V_{CS} range.

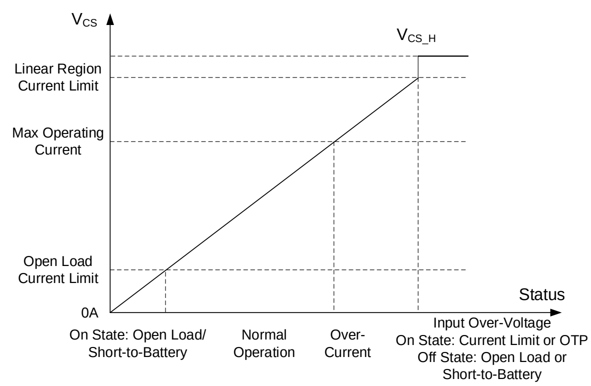


Figure 4: V_{CS} and the MPQ5871's Status

Internal Current Limit and Configurable External Current Limit

The MPQ5871 has an internal current limit and a configurable external current limit to improve the device's reliability and provide protection in the event of a short circuit or start-up. In addition, this function allows the MPQ5871 to be used in low-current applications.

When the load current reaches the internal or the external current limit, I_{OUT} is regulated to its limited value, and the FT/CS pin pulls up to V_{CS_H}. The device shuts down if the regulation period lasts for longer than 800µs. 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. This protects the MPQ5871 when the output load is shorted to

GND. The device automatically recovers after 300ms.

The internal current limit is fixed to 2A. To use the internal current limit, connect the ILIM pin directly to the GND pin.

The external, configurable current limit can set the current limit. 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}). If V_{CL} exceeds V_{TH_LIM}, a closed-loop is set up to regulate the gate-to-source voltage (V_{GS}). As a result, the drain-to-source voltage (V_{DS}) and the load current are clamped at the set value. To increase the sensing accuracy, R_{CL} must be connected to the MPQ5871's GND pin. R_{CL} can be estimated with Equation (2):

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

Where I_{CL} is the set external current. Figure 5 shows the current-sense and current limit functional diagram. The lower value between the internal current limit and configurable, external current limit is used as the actual value.

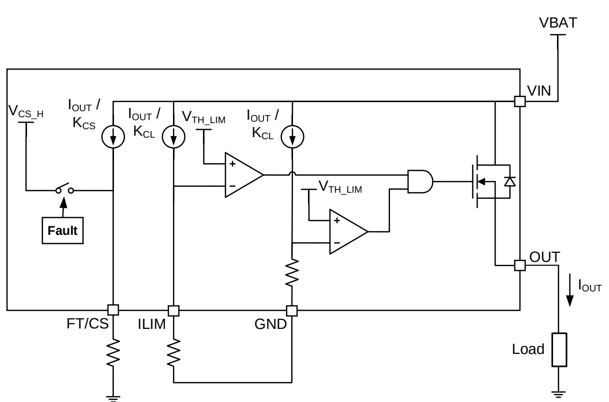


Figure 5: Functional Diagram of Current Sensing and Current Limit

It is recommended to set the external current limit to exceed 500mA. When the external current limit exceeds 500mA, the guaranteed accuracy for the current limit is within normal operation (V_{IN} - V_{OUT} < 1V) (see Figure 6).

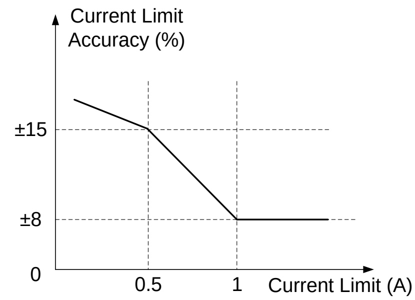


Figure 6: Current Limit Accuracy

Under short-circuit or start-up conditions (when V_{IN} - V_{OUT} > 1V), the current limit is smaller than it would be during normal operation (when V_{IN} - V_{OUT} < 1V). A lower external current limit corresponds with reduced current limit accuracy. When the external current limit is set between 500mA and 1A, the current limit under short-circuit or start-up conditions will fold back. Consider de-rating in the design to ensure that the MPQ5871 can start up normally.

Adjustable Start-Up Slew Rate

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

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

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

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

If the SS pin is floating or the SS capacitance is too small, the V_{OUT} slew rate is limited by the current limit. If the SS capacitance is too high, the device must dissipate a large amount of 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, then the MPQ5871 shuts down. The SS capacitance and 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 Switch-Off Clamp

When an inductive load is switching off, V_{OUT} pulls down to a negative value due to the inductance characteristics. The energy in the inductor dissipates on the MPQ5871 without the external protection circuit. For inductive loads below 5mH, if the maximum switch-off current is below 2A, the MPQ5871 can be used for the demagnetization energy dissipation. If not, external free-wheeling circuitry is required to protect the devices. Figure 11 on page 20 shows the freewheeling circuit.

Full Protection and Diagnostics

The MPQ5871 provides flexible protection and diagnostic functions. When the DIAG_EN pin is high, all the diagnostics are enabled, and the faults can be distinguished. Table 1 shows the MPQ5871's status under various fault conditions. Based on the device's status, the fault can be distinguished. See the Distinguishing the Fault Status section on page 22 for more details. When DIAG_EN is low, the open load/battery short diagnostics during the off state is disabled.

Table 1: Fault Table

IC Status	Fault Condition	EN	DIAG_EN	OUT	CS/FT	Recovery
Normal	N/A	Low	N/A	Low	0	N/A
		High	N/A	High	$V_{OC} > V_{CS} > V_{UC}$	
V_{IN} UVLO	$V_{IN} < V_{US\_STD}$	High	N/A	Low	0	$V_{IN} > V_{UV\_RST}$
On-state: over-current (OC) or OUT-to-GND short	Current limit triggered	High	N/A	Low	V_{CS_H} during current limit deglitch, or 0 after device shutdown	Automatic
Off-state: OUT-to-GND short	N/A	Low	N/A	Low	0	N/A
Load current exceeds nominal current	$V_{CS} > V_{OC}$ (V_{OC} = max V_{CS} in normal operation, defined by the user)	High	N/A	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} in normal operation, defined by the user)	High	N/A	High	Close to zero	Automatic
Off-state short-to-battery or open load (12)	$V_{IN} - V_{OUT} < V_{OL\_OFF}$	Low	High	High	V_{CS_H} after deglitch	$V_{IN} - V_{OUT} > V_{OL\_OFF}$
		Low	Low	High	0	N/A
Thermal shutdown	$T > T_{SD}$	High	N/A	Low	V_{CS_H}	$T < T_{SD\_RST}$

Note:

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

The protections are described in greater detail below.

V_{IN} 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 down to V_{UV_STD} during the on state, the switch turns off immediately. When V_{IN} rises up to 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 still operates. In this scenario, the user can monitor the load current by sensing V_{CS}. A threshold (V_{OC}, the maximum V_{CS} during normal operation) can be defined by the user to determine whether the load current is within its normal range.

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

If a current limit is triggered during the on state, a fault is reported by pulling up V_{CS} to V_{CS_H}, and I_{OUT} is regulated to the set current limit value. If the condition lasts for 800µs, the device shuts down.

The part tries to automatically recover after 300ms. If I_{OUT} falls below the current-limit threshold before 800µs, the MPQ5871 resumes normal operation.

If the load current 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. An open load occurs if V_{CS} falls below the minimum V_{CS} in normal operation (V_{UC}), which can be defined by the user. When setting V_{UC}, consider the current-sense accuracy. A high-accuracy current sense achieves a very low open-load detection threshold, and allows the MPQ5871 to achieve a wide normal operation region.

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

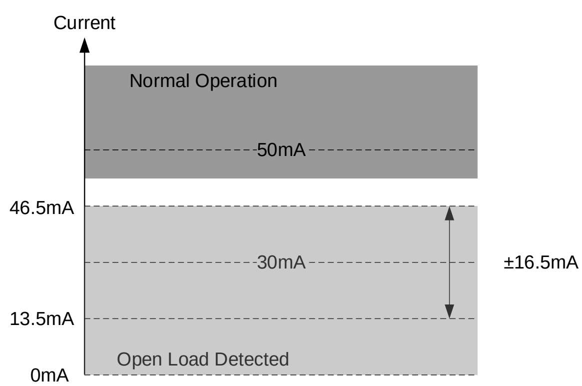


Figure 7: Recommended Normal Operation and On State Open Load Thresholds

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 $V_{IN} - V_{OUT} < V_{OL\_OFF}$ (1.05V). In this scenario, V_{CS} pulls up to V_{CS_H}. Figure 8 shows the diagram for off-state open-load detection.

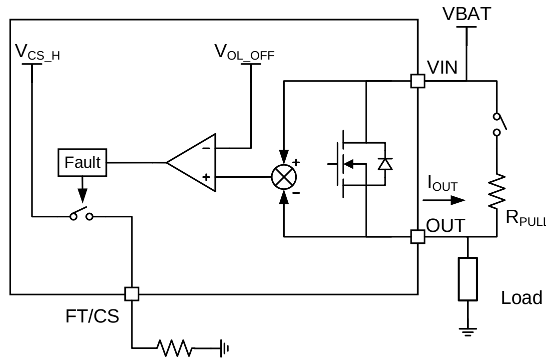


Figure 8: Functional Diagram for Off-State Open-Load Detection

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

OUT-to-Battery Short Detection

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

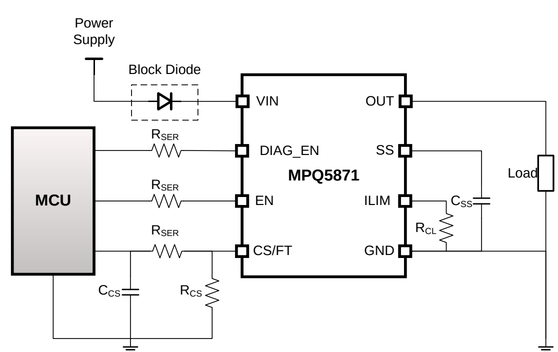


Figure 9: Protection Circuit with Block Diode

Thermal Protection

When the junction temperature (T_J) rises up to T_{SD}, the MPQ5871 shuts down and V_{CS} pulls up to V_{CS_H} to report this fault. As T_J falls to T_{SD_RST}, the MPQ5871 turns on and the fault is cleared.

When T_J exceeds T_{SD_RST}, the MPQ5871 does not restart.

Loss of Power Supply Protection

If there is a loss of the power supply, the MPQ5871 shuts down, regardless of EN (see Figure 10).

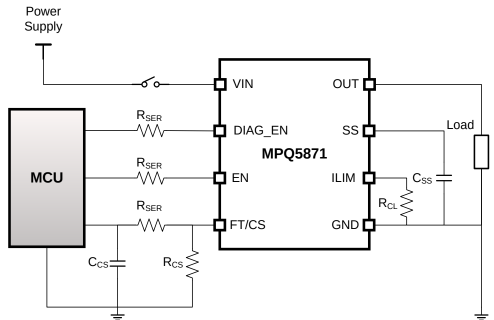


Figure 10: Loss of Power Supply

For resistive or capacitive loads, the device can handle this scenario easily. However, for the inductive load, a current is absorbed from the microcontroller's (MCU) general-purpose input/outputs (GPIOs), which might damage the device and the MCU. In this scenario, the MCU needs a series of resistors, ground network, or external free-wheeling circuit. Figure 11 shows the protection circuits.

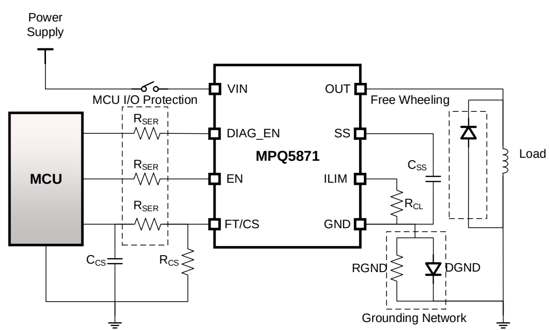


Figure 11: Protection for Loss of Power Supply

Reverse Polarity Protection

A diode between the device's GND and the module ground is required to block the reverse voltage, which also brings 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 for normal operation.

However, for inductive loads, a negative spike may occur when it is switched off, which may damage the diode. Therefore, it is strongly recommended to add a 1kΩ resistor in parallel to the diode when driving an inductive load (se Figure 12). The diode's i_F should exceed 100mA.

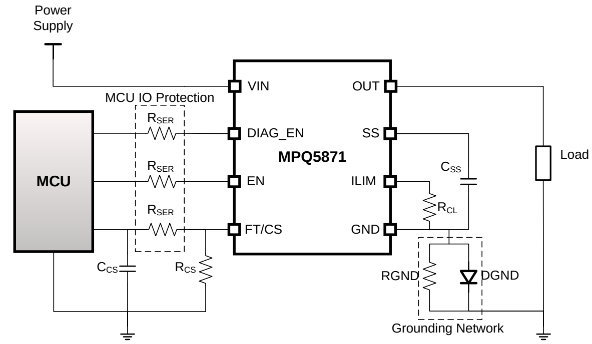


Figure 12: Protection for Reverse Polarity Battery

AEC Q100-012 Test Grade A Certification

Short-circuit reliability is critical for smart, high-side power switch devices. The AEC-Q100-012 standard determines the device's 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 is 1 million times short-to-GND certification.

Applicable Test Modes

1. Cold repetitive short-circuit test (long pulse)
2. Cold repetitive short-circuit test (short pulse)
3. Hot repetitive short-circuit test (continuous)

Transient Disturbances Tests

The MPQ5871 meets the requirements specified in ISO 7637-2 and ISO 16750-2 standards with a proper external circuit (see Figure 13).

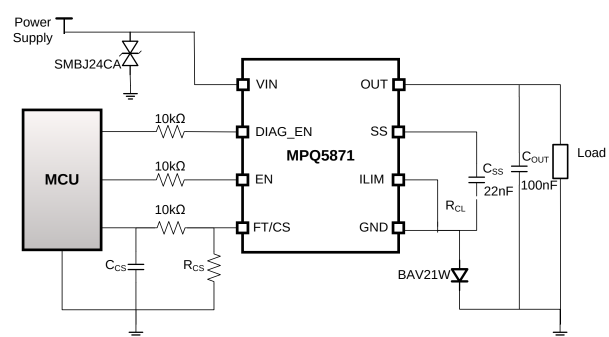


Figure 13: Circuit for Pulse Tests

Table 2 shows the transient disturbance test details, where R_{IN} is the internal resistance of the power source, U_{S*} is the maximum input voltage set-up value, U_S is the input voltage, 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*} = 40V $t_R \le$ 5ms
	Reverse Polarity Voltage		U_S = -30V *t* < 60s

During the load dump transient, it is not recommended to trigger the current limit, otherwise the device may shut down. The capacitor at the load (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. Therefore, for an application with a 2A current limit and 1A of continuous current, it is recommended to use a load capacitor that is below 47µF.

APPLICATION INFORMATION

Component Selection

Figure 14 shows the MPQ5871's application circuit.

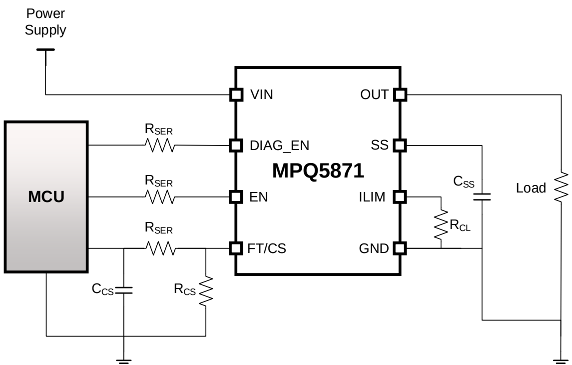


Figure 14: Application Circuit of MPQ5871

For this design example, follow the specifications below:

- Connect VIN to a 12V battery.
- Set a 1A nominal current.
- Implement current-sensing for applications where $I_{OUT} \le 1A$ and the normal V_{CS} for a 1A load is equal to 1V.
- Use an external 1.5A current limit.
- Set the start-up time to about 1.5ms.
- Use full diagnostics with the 5V MCU.
- Use a grounding network for protection.

The general design process is described below. Start by selecting R_{CS}, calculated with Equation (5):

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

Select R_{CL} next, which can be estimated with Equation (6):

$$R_{CL} = \frac{K_{CL} \times V_{TH\_LIM}}{I_{CL}} = 1000 \times \frac{0.7}{1.5} = 467\Omega \quad (6)$$

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

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

It is recommended to select R_{SER} such that it is 10kΩ.

C_{SS} Design Procedure

Follow the steps below for C_{SS} selection:

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} are monitored. Figure 15 shows the flowchart to determine faults.

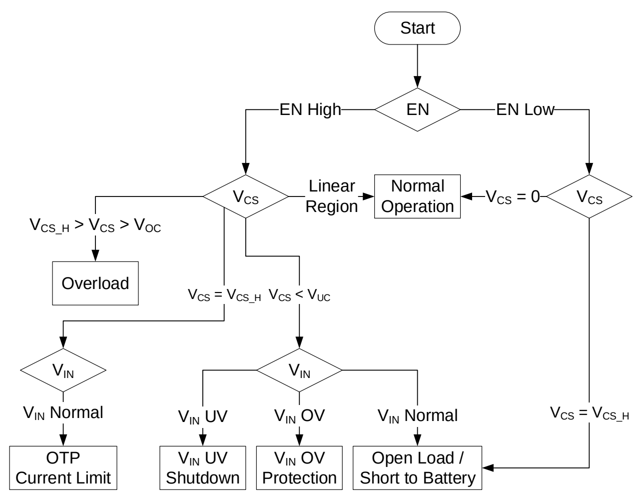


Figure 15: Fault Diagnostics Flowchart

If there is an over-current (OC) condition during the on state, the analog-to-digital converter (ADC) might miss the interval when V_{CS} is high because the OC deglitch time is so short. In this scenario, there is another progress to detect the fault condition (see Figure 16 on page 23).

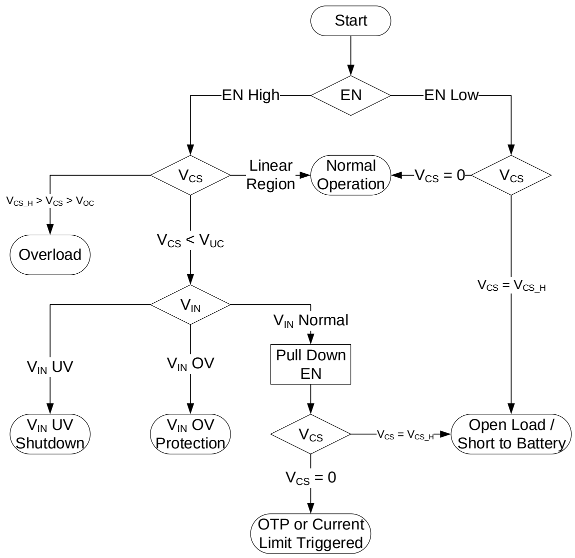


Figure 16: Fault Diagnostics Flowchart (OC Condition)

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

- The current limit is triggered, and the device turns off for 300ms before it tries to restart.
- The load is an open circuit.

The MCU can pull down EN and detect if there is an open load. If V_{CS} is high, the fault condition is an open load. Otherwise, it is an over-current or short-circuit fault.

Recommended Maximum Junction Temperature (T_J)

The MPQ5871'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. Estimate the MOSFET's total power dissipation during soft start (Q) with Equation (8):

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

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 the soft-start capacitor is applied and the current limit is not triggered during start-up, then t_{SS} is equal to t_{VO_RISING}, which is 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):

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

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

Figure 17 shows the relationship between the temperature rise and power dissipation depending on t_{SS}, where $Q_{DISSIPATION}$ is *Q*.

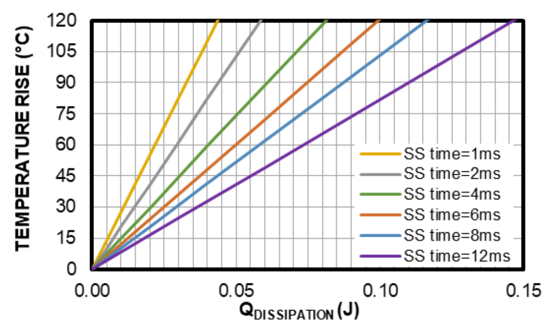


Figure 17: T_J Rise with Different Power Dissipation and SS Time

Figure 17 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 SS time is calculated as 6ms, and *Q* is calculated as 0.015J. Based on Figure. 17, the temperature rise during start-up is 20°C. Therefore, this design is reasonable.

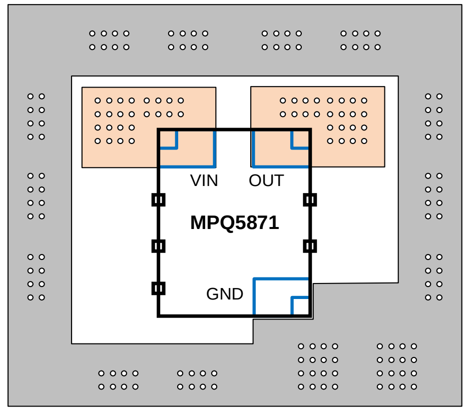
Functional Safety Application Support

The MPQ5871 provides related safety documentation, such as the failure in time (FIT) number and process failure modes and effects analysis (PFMEA), to aid function safety design.

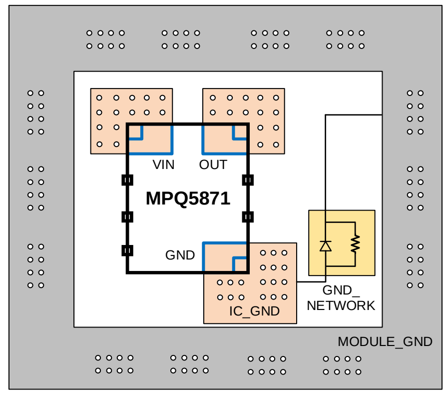
PCB Layout Guidelines

To improve the device's reliability and thermal performance, refer to Figure 18 and follow the guidelines below:

1. Increase the copper area on the PCB to increase the board's thermal conductivity (especially for VIN, OUT, and GND).
2. Connect the GND pin to the GND planes with large copper and as many vias as possible to further improve heat dissipation.
3. Add a solitary copper for the IC's GND if a GND network is required.
4. Connect the IC's GND and the module's GND through the protective components.



Without GND Network



With GND Network

Figure 18: Recommended PCB Layout

TYPICAL APPLICATION CIRCUITS

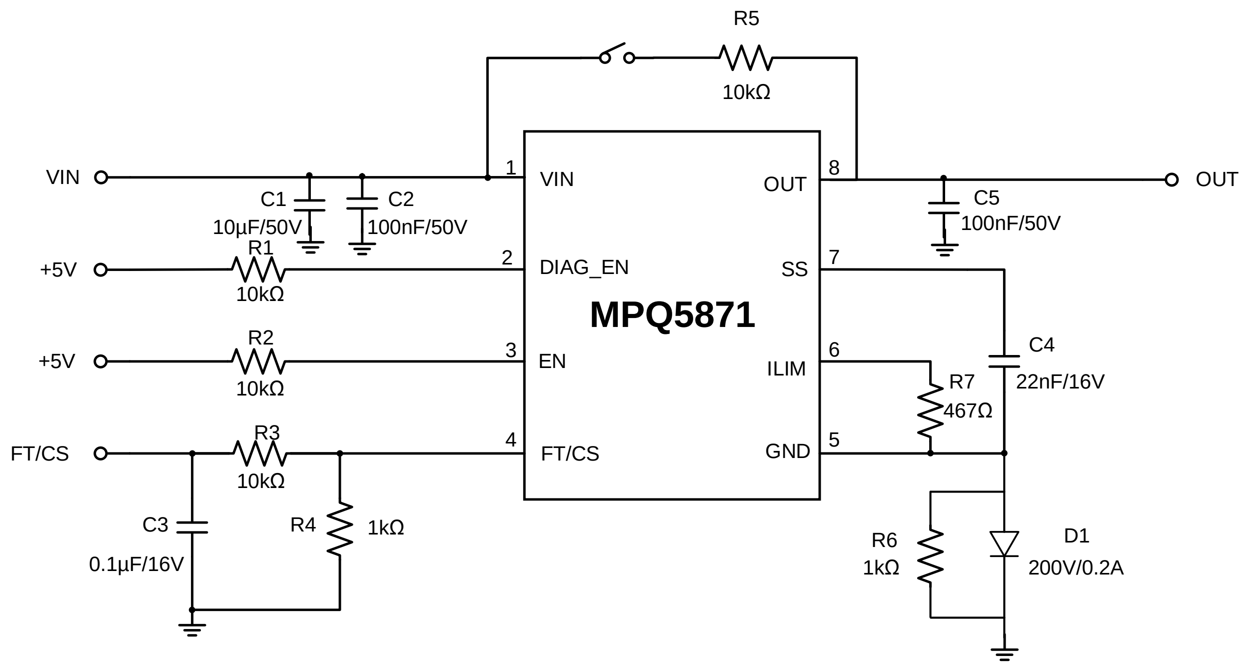


Figure 19: Typical Application Circuit for 1A Output with Ground Network (1.5A External Current Limit)

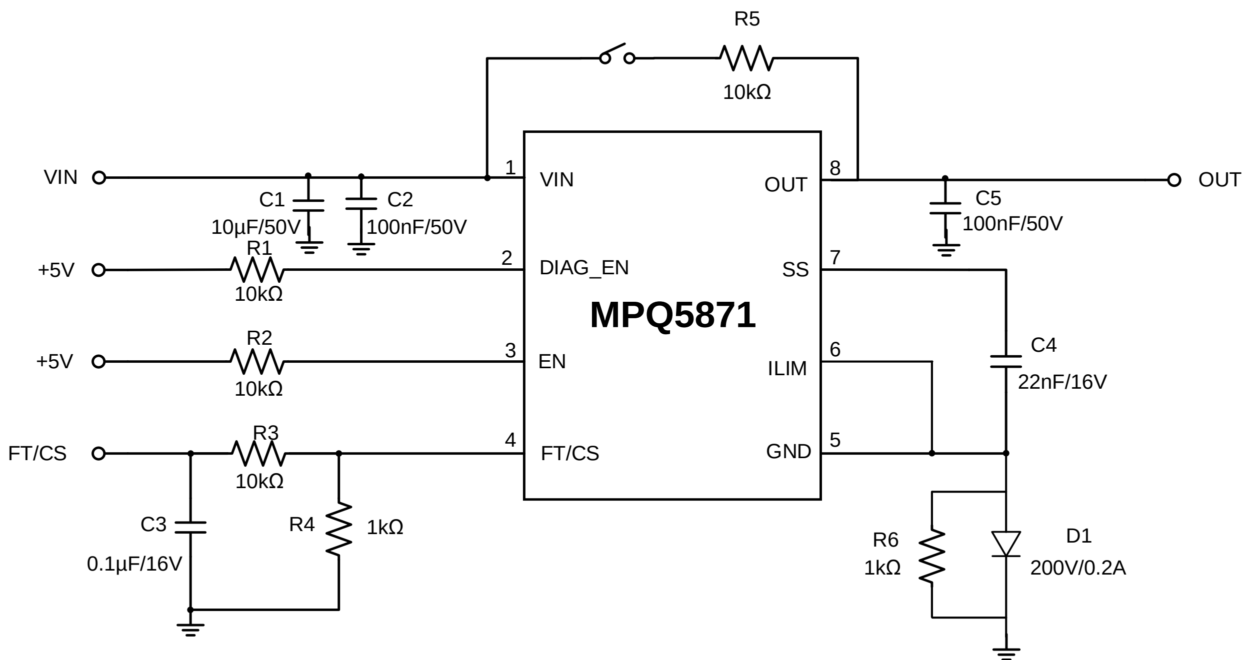


Figure 20: Typical Application Circuit for 1A Output with Ground Network (2A Internal Current Limit)

TYPICAL APPLICATION CIRCUITS *(continued)*

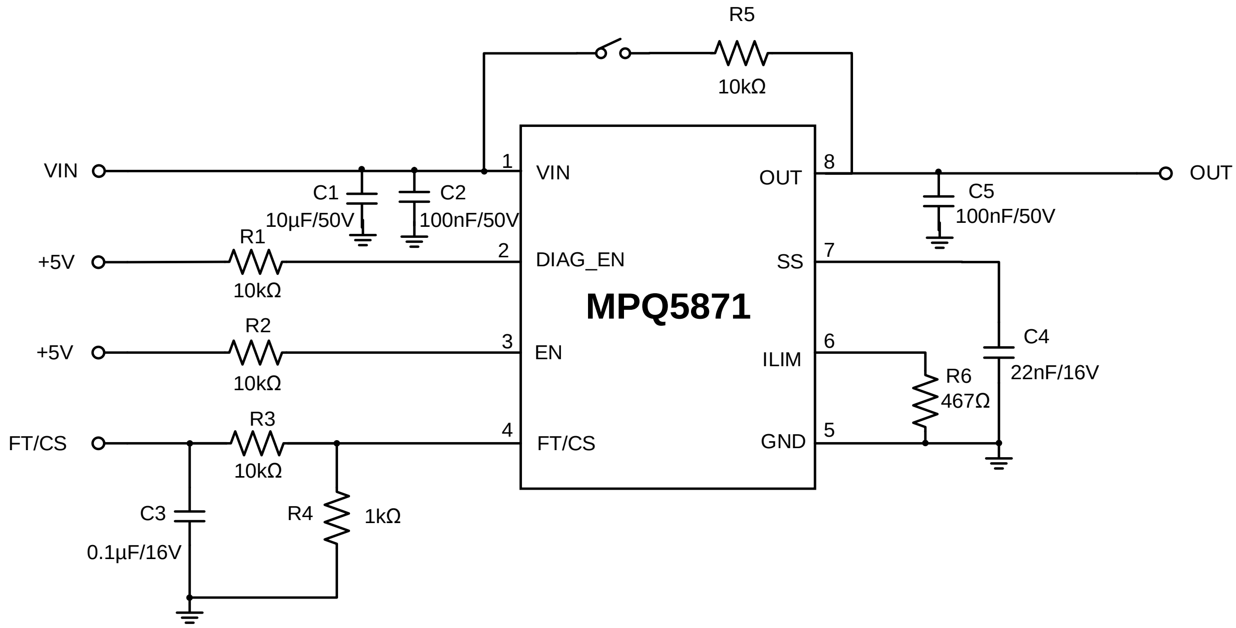


Figure 21: Typical Application Circuit for 1A Output without Ground Network (1.5A External Current Limit)

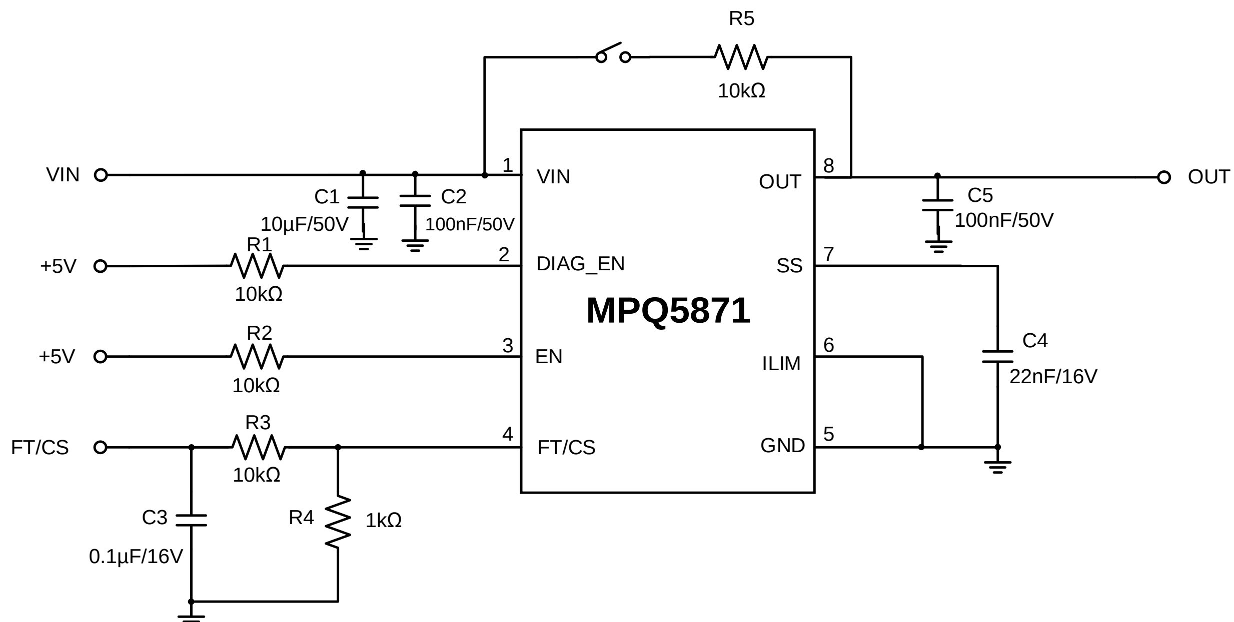
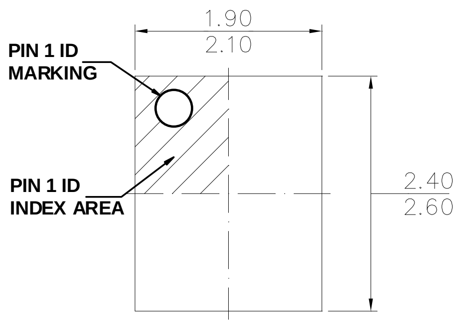


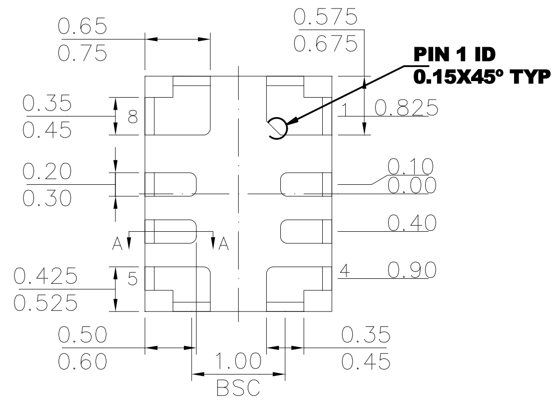
Figure 22: Typical Application Circuit for 1A Output without Ground Network (2A Internal Current Limit)

PACKAGE INFORMATION

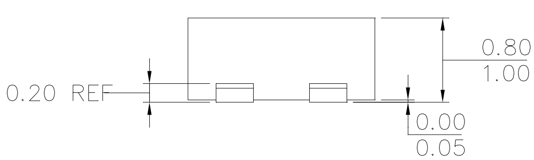
QFN-8 (2mmx2.5mm)



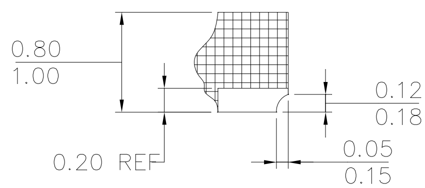
TOP VIEW



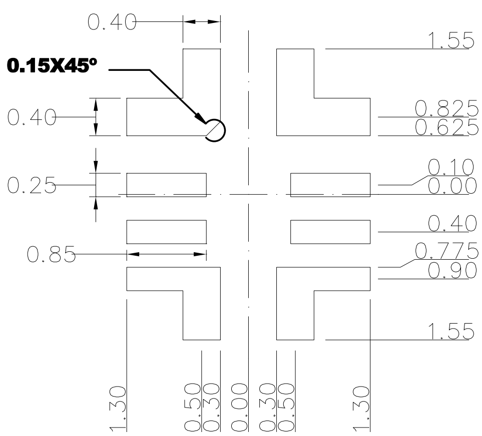
BOTTOM VIEW



SIDE VIEW



SECTION A-A

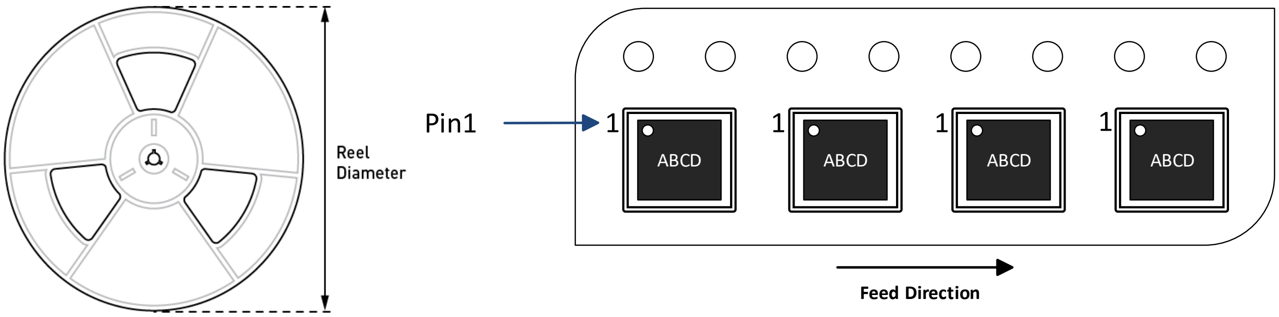


RECOMMENDED LAND PATTERN

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	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MPQ5871GRPE-AEC1-Z	QFN-8 (2mmx2.5mm)	5000	N/A	13in	12mm	8mm

REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	9/7/2023	Initial Release	-

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