MIC2009/2019

Adjustable Current Limit Power Distribution Switch

General Description

The MIC2009 and MIC2019 are current limiting, high-side power switches, designed for general purpose power distribution and control in PCs, PDAs, printers and other self-powered systems.

The MIC2009 and MIC2019's primary functions are current limiting and power switching. They are thermally protected and will shutdown should their internal temperature reach unsafe levels. This protects both the device and the load under high current or fault conditions.

Features include: fault reporting, with fault blanking to eliminate noise-induced false alarms; output slew rate limiting and under voltage detection. Both devices offer user programmable current limiting thereby providing designers a continuous spectrum of current limits from 200mA to 2 Amps.

The MIC2019 offers a unique new feature: Kickstart™, which allows momentary high current surges to pass unrestricted without sacrificing overall system safety.

The MIC2009 and MIC2019 are excellent choices for USB and IEEE 1394 (FireWire) applications or for any system where current limiting and power control are desired.

The MIC2009 and MIC2019 are offered in space saving 6-pin SOT-23 and 2mm x 2mm MLF packages.

Features

- 70mΩ typical on-resistance
- 2.5V - 5.5V operating range
- User adjustable current limit: 0.2A – 2.0A
- Kickstart™
- Fault status flag
- Fault masking: prevents nuisance alarms on current surges or hot plug events
- Thermal Protection
- Under voltage lock-out
- Built-in slew rate control
- Low quiescent current

Applications

- USB / IEEE 1394 Power Distribution
- Desktop and Laptop PCs
- Set top boxes
- Game consoles
- PDAs
- Printers
- Docking stations
- Chargers

Typical Application

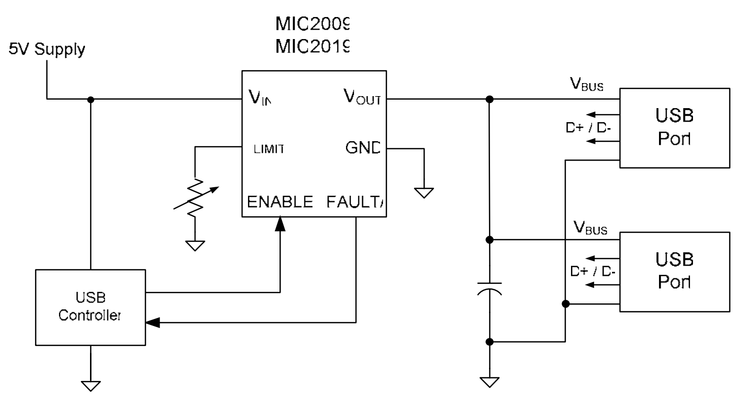


Figure 1. Typical Application Circuit

Kickstart is a trademark of Micrel, Inc
MLF and *Micro*LeadFrame are trademarks of Amkor Technology, Inc.

MIC2000 Family Members

Part Number			Pin Function					
Normal Limiting	Kickstart	I Limit	I Adj.	Enable	C_{SLEW}	FAULT/	DLM*	Load Discharge
2003	2013	Fixed	--	--	--	--	--	--
2004	2014		--	▲	--	--	--	▲
2005	2015		--	▲	▲	▲	--	--
2006	2016		--	▲	▲	--	▲	--
2007	2017	Adj.	▲	▲	▲	--	--	▲
2008	2018		▲	▲	▲	--	--	--
2009	2019		▲	▲	--	▲	--	--

* Dynamic Load Management Adj = Adjustable current limit Fixed = Factory programmed current limit

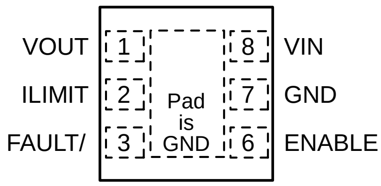
Ordering Information

Part Number	Marking[1]	Current Limit	Kickstart	Pb-Free	Package
MIC2009YM6	FKAA	0.2A – 2.0A	No	Yes	SOT-23-6
MIC2009YML[2]	KAA				2mmX2mm MLF
MIC2019YM6	FSAA		Yes		SOT-23-6
MIC2019YML[2]	SAA				2mm X2 mm MLF

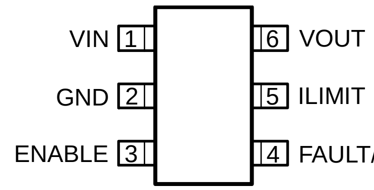
Notes:

1. Under-bar symbol (_) may not be to scale.
2. Consult Factory for availability

Pin Configuration



6-Pin 2mm X 2mm MLF (ML)



SOT 23-6 (M6)

Pin Description

Pin Number SOT-23	Pin Number MLF	Pin Name	Type	Description
1	6	VIN	Input	Supply input. This pin provides power to both the output switch and the MIC2009/2019's internal control circuitry.
2	5	GND	--	Ground.
3	4	ENABLE	Input	Output enable pin. A logic HIGH activates the output switch, applying power to the load attached to V_{OUT}.
4	3	FAULT/	Output	Fault status. A logic LOW on this pin indicates the MIC2009/2019 is in current limiting, or has been shut down by the thermal protection circuit. This is an 'Open Drain' output allowing logical OR'ing of multiple MIC2009/2019s.
5	2	I_{LIMIT}	Input	Sets the current limit threshold via a resistor connected between I_{LIMIT} and GND. I_{LIMIT} = Current Limiting Factor (CLF) / R_{SET}.
6	1	VOUT	Output	Switch output. The load being driven by MIC2009/2019 is connected to this pin.

Absolute Maximum Ratings[1]

All pins .... –0.3 to 6V
Power Dissipation .... Internally Limited
Continuous Output Current 2.25A
Maximum Junction Temperature .... 150°C
Storage Temperature .... –65°C to 150°C

Operating Ratings[2]

Supply Voltage .... 2.5V to 5.5V
Continuous Output Current Range.................... 0 to 2.1A
Ambient Temperature Range ....–40°C to 85°C

Package Thermal Resistance (θ_{JA})
SOT-23-6 .... 230°C/W
MLF 2x2 mm .... 90°C/W
MLF 2x2 mm θ_{JC} [5] .... 45°C/W

Electrical Characteristics

V_{IN} = 5V, $T_{AMBIENT}$ = 25°C unless specified otherwise. **Bold** indicates –40°C to +85°C limits.

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{IN}	Switch Input Voltage		**2.5**		**5.5**	V
I_{IN}	Internal Supply Current	Switch = OFF, ENABLE = 0V		1	**5**	µA
I_{IN}	Internal Supply Current	Switch = ON, I_{OUT} = 0 ENABLE = 1.5V		80	**330**	µA
I_{LEAK}	Output Leakage Current	V_{IN} = 5V, V_{OUT} = 0 V, ENABLE = 0		1.2	**10**	µA
$R_{DS(ON)}$	Power Switch Resistance	V_{IN} = 5V, I_{OUT} = 100 mA		70	100	mΩ
					125	mΩ
CLF	Current Limit: Factor $R_{SET}(\Omega) = \frac{CLF\ (V)}{I_{OUT}\ (A)}$	I_{OUT} = 2.0A, V_{OUT} = 0.8V_{IN}	210	250	286	V
		I_{OUT} = 1.0A, V_{OUT} = 0.8V_{IN}	190	243	293	V
		I_{OUT} = 0.5A, V_{OUT} = 0.8V_{IN}	168	235	298	V
		I_{OUT} = 0.2A, V_{OUT} = 0.8V_{IN}	144	225	299	V
I_{LIMIT_2nd}	Secondary current limit (Kickstart)	MIC2019, V_{IN} = 2.5V	2.2	4	6	A
$UVLO_{THRESHOLD}$	Under Voltage Lock Out threshold	V_{IN} rising	**2.0**	2.25	**2.5**	V
		V_{IN} falling	**1.9**	2.15	**2.4**	V
V_{EN}	ENABLE Input Voltage	V_{IL}(max.)			**0.5**	V
		V_{IH}(min.)	**1.5**			
I_{EN}	ENABLE Input Current	V_{EN} = 0V to 5.0V		1	**5**	µA
V_{FAULT}	Fault status Output Voltage	I_{OL} = 10mA		.25	**0.4**	V
$OT_{THRESHOLD}$	Over-temperature Threshold	T_J increasing		145		°C
		T_J decreasing		135		

AC Characteristics

Symbol	Parameter	Condition	Min	Typ	Max	Units
t_{RISE}	Output turn-ON rise time	R_L = 10Ω, C_{LOAD} = 1µF, V_{OUT} = 10% to 90%	500	1000	1500	µs
t_{D_FAULT}	Delay before asserting FAULT/ or releasing	Time from current limiting to FAULT/ state change. MIC2009	**20**	32	**49**	ms
		Time from Iout continuously exceeding primary current limit condition to FAULT/ state change. MIC2019	**77**	128	**192**	ms
t_{D_LIMIT}	Delay before current limiting	MIC2019	**77**	128	**192**	ms
t_{RESET}	Delay before resetting Kickstart current limit delay, t_{D_LIMIT}	Out of current limit following a current limit event. MIC2019	**77**	128	**192**	ms
t_{ON_DLY}	Output Turn-on Delay	R_L = 43Ω, C_L = 120µF, , V_{EN} = 50% to V_{OUT} = 10%		1000	1500	µs
t_{OFF_DLY}	Output Turn-off Delay	R_L = 43Ω, C_L = 120µF, V_{EN} = 50% to V_{OUT} = 90%			700	µs

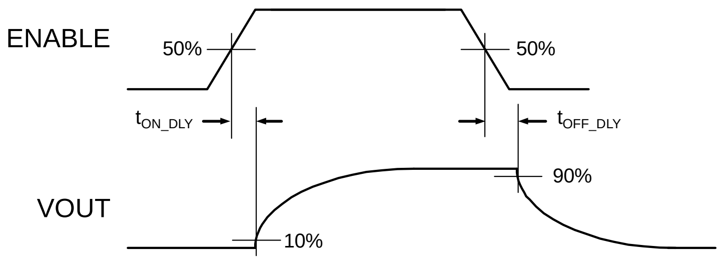
ESD

Symbol	Parameter	Condition	Min	Typ	Max	Units
V_{ESD_HB}	Electrostatic Discharge Voltage: Human Body Model	V_{OUT} and GND	± 4			kV
		All other pins	± 2			kV
V_{ESD_MCHN}	Electrostatic Discharge Voltage; Machine Model	All pins Machine Model	± 200			V

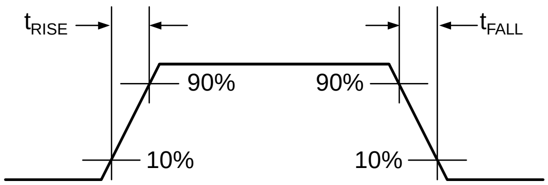
Notes:

1. Exceeding the absolute maximum rating may damage the device.
2. The device is not guaranteed to function outside its operating rating.
3. Devices are ESD sensitive. Handling precautions recommended. Human body model, 1.5k in series with 100pF.
4. Specification for packaged product only.
5. Requires proper thermal mounting to achieve this performance.

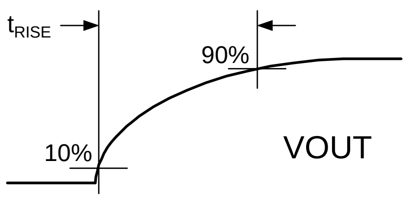
Timing Diagrams



Switching Delay Times



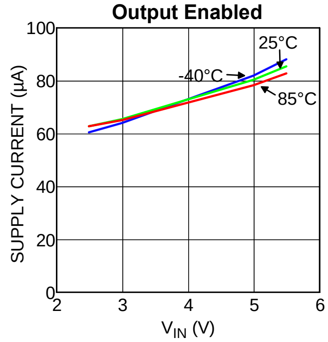
Rise and Fall Times



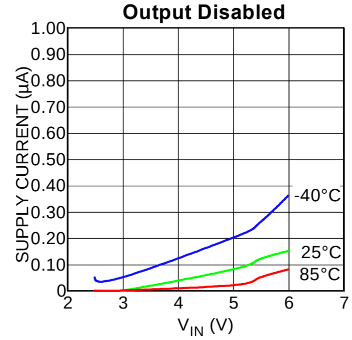
Output Rise Time

Typical Characteristics

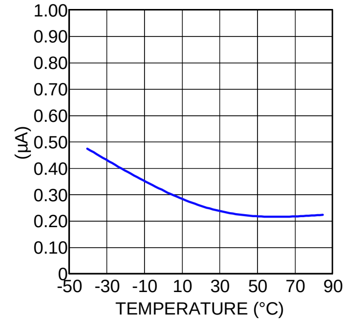
Supply Current Output Enabled



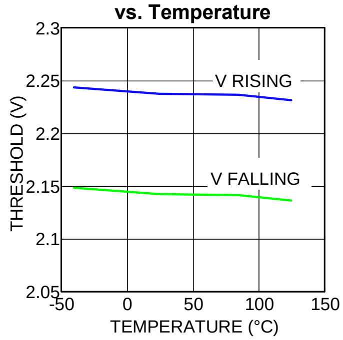
Supply Current Output Disabled



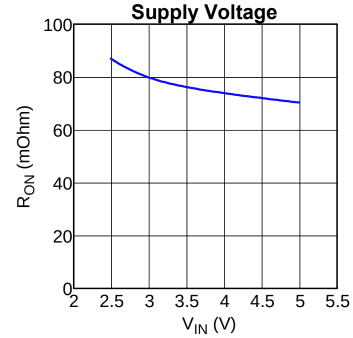
Switch Leakage Current - OFF



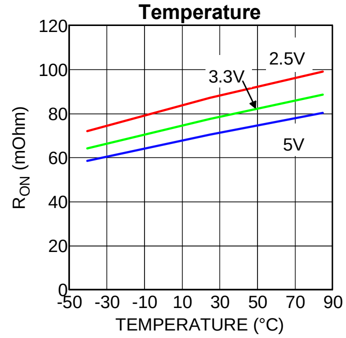
UVLO Threshold vs. Temperature



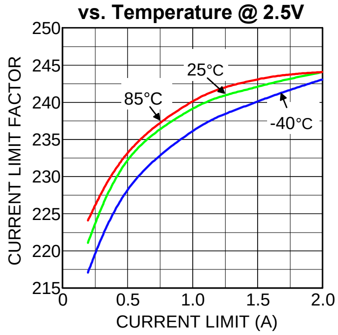
R_{ON} vs. Supply Voltage



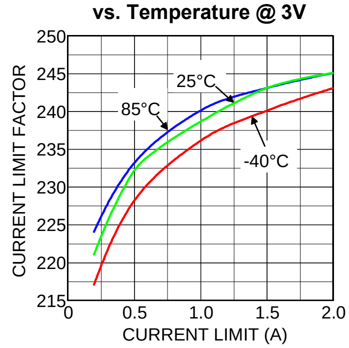
R_{ON} vs. Temperature



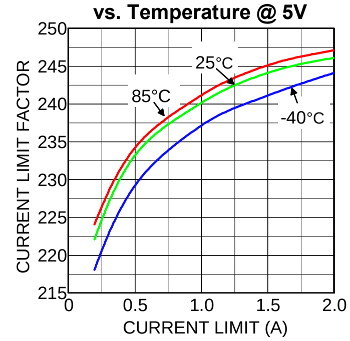
Current Limit Factor vs. Temperature @ 2.5V



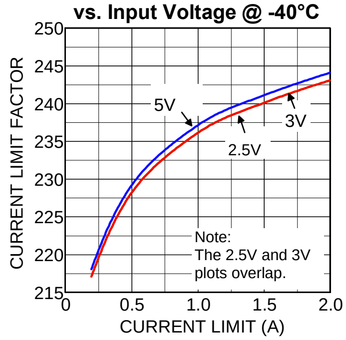
Current Limit Factor vs. Temperature @ 3V



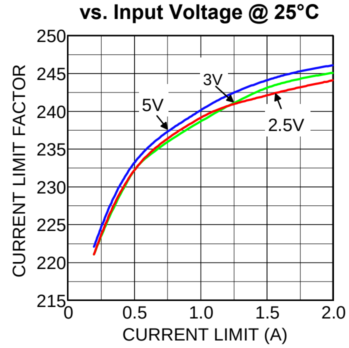
Current Limit Factor vs. Temperature @ 5V



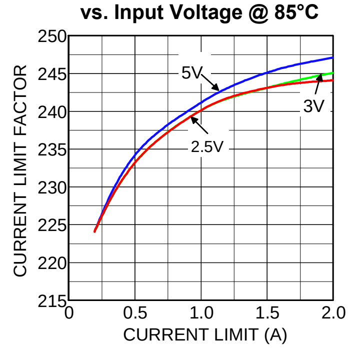
Current Limit Factor vs. Input Voltage @ -40°C



Current Limit Factor vs. Input Voltage @ 25°C

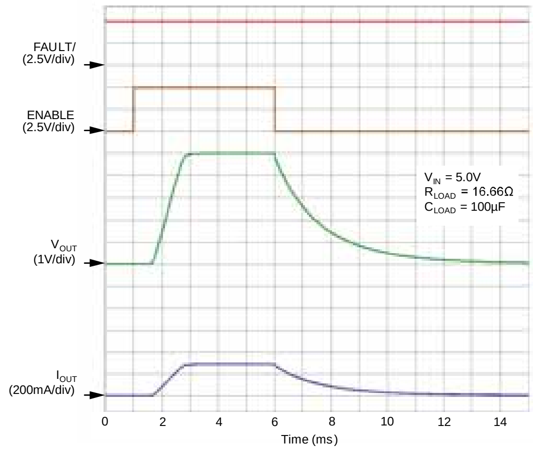


Current Limit Factor vs. Input Voltage @ 85°C

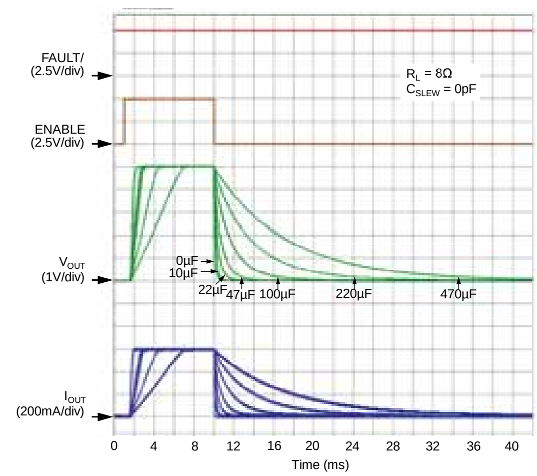


Functional Characteristics

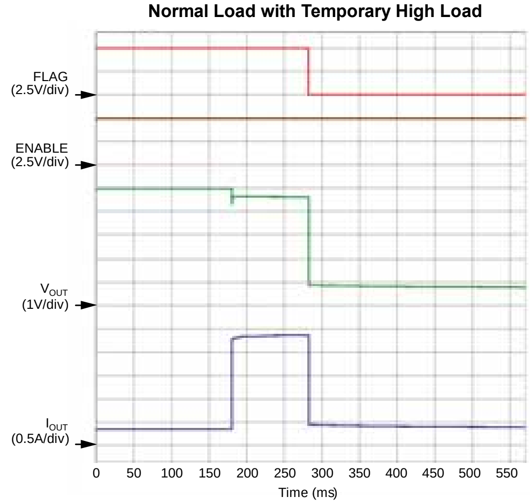
Turn-On/ Turn-Off



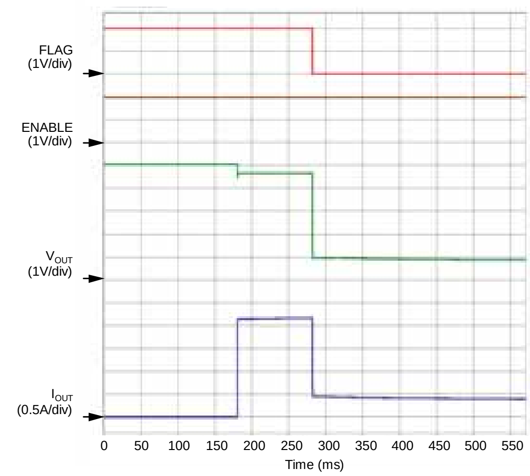
Inrush Current Response



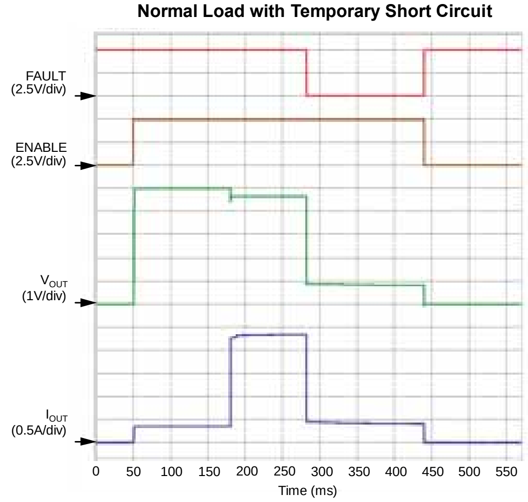
**Kickstart Response
Normal Load with Temporary High Load**



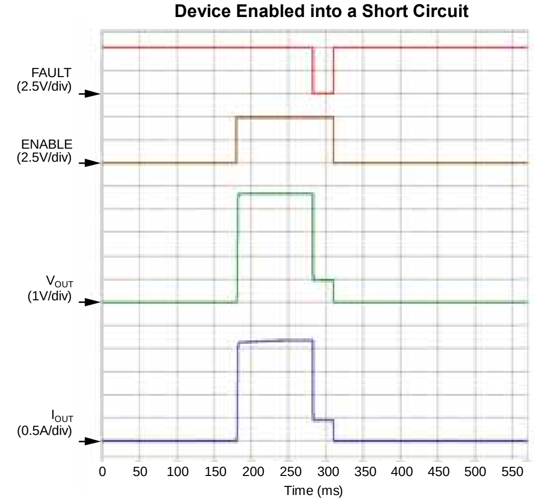
**Kickstart Response
No Load to Short Circuit**



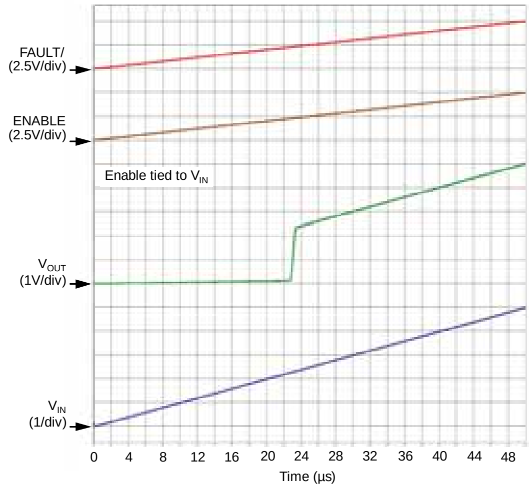
**Kickstart Response
Normal Load with Temporary Short Circuit**



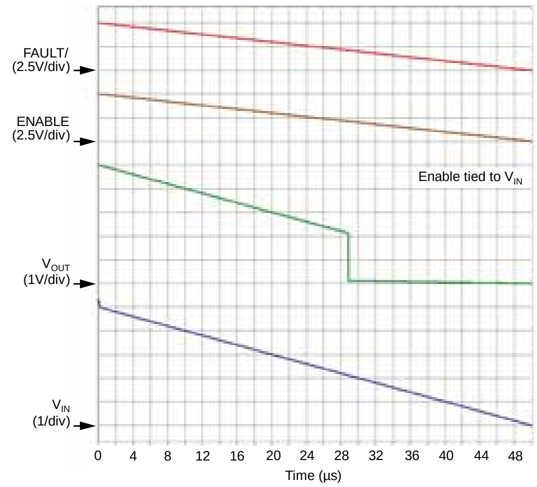
**Kickstart Response
Device Enabled into a Short Circuit**



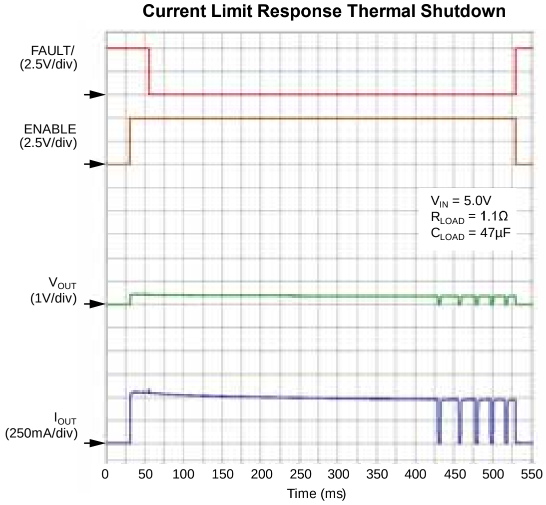
UVLO Increasing



UVLO Decreasing



Current Limit Response Thermal Shutdown



Functional Diagram

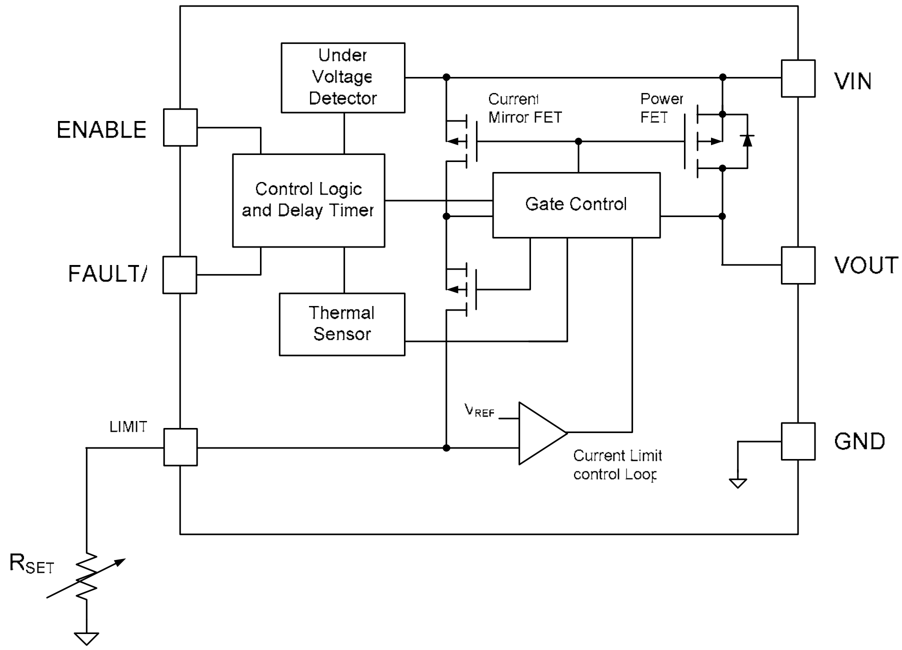


Figure 2. MIC2009/2019 Block Diagram

Functional Description

Input and Output

V_{IN} is both the power supply connection for the internal circuitry driving the switch and the input (Source connection) of the power MOSFET switch. V_{OUT} is the Drain connection of the power MOSFET and supplies power to the load. In a typical circuit, current flows from V_{IN} to V_{OUT} toward the load. Since the switch is bi-directional when enabled, if V_{OUT} is greater than V_{IN}, current will flow from V_{OUT} to V_{IN}.

When the switch is disabled, current will not flow to the load, except for a small unavoidable leakage current of a few microamps. However, should V_{OUT} exceed V_{IN} by more than a diode drop (~0.6V), while the switch is disabled, current will flow from output to input via the power MOSFET's body diode. This effect can be used to advantage when large bypass capacitors are placed on MIC2009/2019's's output. When power to the switch is removed, the output capacitor will be automatically discharged.

If discharging C_{LOAD} is required by your application, consider using MIC2004/2014 or MIC2007/2017 in place of MIC2009/2019. These MIC2000 family members are equipped with a discharge FET to insure complete discharge of C_{LOAD}.

Current Sensing and Limiting

The MIC2009/2019 protects the system power supply and load from damage by continuously monitoring current through the on-chip power MOSFET. Load current is monitored, by means of a current mirror, in parallel with the power MOSFET switch. Current limiting is invoked when the load exceeds an externally set over-current threshold. When current limiting is activated the output current is constrained to the limit value, and remains at this level until either the load/fault is removed, the load's current requirement drops below the limiting value, or the MIC2009/2019 goes into thermal shutdown.

Kickstart (MIC2019 only)

The MIC2019 is designed to allow momentary current surges (Kickstart) before the onset of current limiting, which permits dynamic loads, such as small disk drives or portable printers to draw the energy needed to overcome inertial loads without sacrificing system safety. In this respect, the MIC2019 differs markedly from MIC2009 and its peers, which immediately limit load current, potentially starving the motor and causing the appliance to stall or stutter.

During this delay period, typically 128 ms, a secondary current limit is in effect. If the load demands a current in excess of the secondary limit, the MIC2019 acts immediately to restrict output current to the secondary limit for the duration of the Kickstart period. After this time, the MIC2019 reverts to its normal current limit. An example of Kickstart operation is shown below.

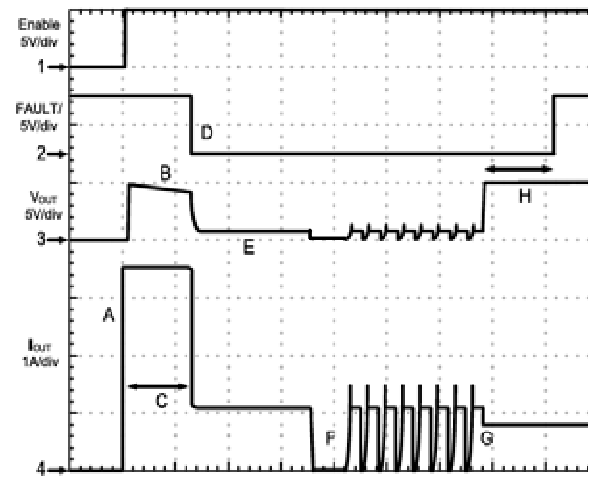


Figure 3. Kickstart Operation

Picture Key:

A) MIC2019 is enabled into an excessive load (slew rate limiting not visible at this time scale) The initial current surge is limited by either the overall circuit resistance and power supply compliance, or the secondary current limit, whichever is less.

B) R_{ON} of the power FET increases due to internal heating (effect exaggerated for emphasis).

C) Kickstart period.

D) Current limiting initiated. FAULT/ goes LOW.

E) V_{OUT} is non-zero (load is heavy, but not a dead short where V_{OUT} = 0. Limiting response will be the same for dead shorts).

F) Thermal shutdown followed by thermal cycling.

G) Excessive load released, normal load remains. MIC2019 drops out of current limiting.

H) FAULT/ delay period followed by FAULT/ going HIGH.

Under Voltage Lock Out

Under voltage lock-out insures no anomalous operation occurs before the device's minimum input voltage of 2.5V had been achieved. Prior to reaching this voltage, the output switch (power MOSFET) is OFF and no circuit functions, such as FAULT/ or ENABLE, are considered to be valid or operative.

Enable

ENABLE is a HIGH true control signal, which activates the main MOSFET switch. ENABLE will operate with logic running from supply voltages as low as 1.8V. ENABLE can be wire-OR'd with other MIC2009/2019s or similar devices without damage to the device.

ENABLE may be driven higher than V_{IN}, but no higher than 5.5V.

FAULT/

FAULT/ is an N-channel 'open drain' output, which is asserted (LOW true) when MIC2009/2019's either begins current limiting or enters thermal shutdown.

In MIC2009, FAULT/ asserts after a brief delay period, usually 32 ms. This delay ensures that FAULT/ is asserted only upon valid, enduring, over-current conditions and that transitory event error reports are filtered out.

MIC2019's FAULT/ asserts at the end of the Kickstart period. This masks initial current surges, such as would be seen by a motor load starting up. If the load current remains above the current limit threshold, after the Kickstart has timed out, then FAULT/ will be asserted.

After a fault clears, FAULT/ remains asserted for the delay period; 32ms for the MIC2009 or 128 ms for the MIC2019.

Because FAULT/ is an 'open drain' it must be pulled HIGH with an external resistor output and it may be wire-OR'd with other similar outputs, sharing a single pull-up resistor. FAULT/ may be tied to a pull-up voltage source which is higher than V_{IN}, but no greater than 5.5V.

Slew Rate Control

Large capacitive loads can create significant current surges when charged through a high-side switch such as the MIC2009/2019. For this reason, MIC2009/2019 provides built-in slew rate control to limit the initial inrush currents upon enabling the power MOSFET switch.

Slew rate control is active upon powering up, and upon re-enabling the load. At shutdown, the discharge slew rate is controlled by the external load and output capacitor.

Thermal Shutdown

Thermal shutdown is employed to protect the MIC2009/2019 from damage should the die temperature exceed safe operating levels. Thermal shutdown shuts off the output MOSFET and asserts the FAULT/ output if the die temperature reaches 145°C.

The MIC2009/2019 will automatically resume operation when the die temperature cools down to 135°C. If resumed operation results in reheating of the die, then another shutdown cycle will occur and the MIC2009/2019 will continue cycling between ON and OFF states until the offending load has been removed.

Depending upon PCB layout, package type, ambient temperature, etc., hundreds of milliseconds may elapse from the incidence of a fault to the output MOSFET being shut off. This delay is due to thermal time constants within the system itself. In no event will the device be damaged due to thermal overload because die temperature is monitored continuously by on-chip circuitry.

Application Information

Setting I_{LIMIT}

The MIC2009/2019's current limit is user programmable and controlled by a resistor connected between the I_{LIMIT} pin and Ground. The value of this resistor is determined by the following equation:

$$I_{LIMIT} = \frac{\text{Current Limit Factor (CLF)}}{R_{SET}}$$

or

$$R_{SET}\ (\Omega) = \frac{\text{Current Limit Factor (V)}}{I_{LIMIT}\ (A)}$$

Example: Set I_{LIMIT} = 1.25A

Looking in the Electrical specifications we will find CLF at I_{LIMIT} = 1A. For the sake of this example, we will say the typical value of CLF at an I_{OUT} of 1A is 235V. Applying the equation above:

$$R_{SET}\ (\Omega) = \frac{235\ V}{1.25\ A}$$

$$R_{SET} = 188\ \Omega$$

Designers should be aware that variations in the measured I_{LIMIT} for a given R_{SET} resistor, will occur because of small differences between individual ICs (inherent in silicon processing) resulting in a spread of I_{LIMIT} values. In the example above we used the typical value of CLF to calculate R_{SET}. We can determine I_{LIMIT}'s spread by using the minimum and maximum values of CLF and the calculated value of R_{SET}.

$$R_{SET} = 187\ \Omega$$

(the closest standard 1% value)

$$I_{LIMIT\_MIN} = \frac{210V}{187\Omega} = 1.12A$$

$$I_{LIMIT\_MIN} = \frac{260V}{187\Omega} = 1.39A$$

Giving us a maximum I_{LIMIT} variation over temperature of:

I_{LIMIT_MIN}	I_{LIMIT_TYP}	I_{LIMIT_MAX}
1.12A	1.25A	1.39A

or 1.25A ±11%

I_{LIMIT} vs. I_{OUT} measured

The MIC2009/2019's's current limiting circuitry is designed to act as a constant current source to the load. As the load tries to pull more than the allotted current, V_{OUT} drops and the input to output voltage differential increases. When V_{IN} -V_{OUT} exceeds 1V, I_{OUT} drops below I_{LIMIT} to reduce the drain of fault current on the system's power supply and to limit internal heating of the MIC2009/2019.

When measuring I_{OUT} it is important to bear this voltage dependence in mind. Otherwise, the measurement data may appear to indicate a problem when none really exists. This voltage dependence is illustrated in Figures 4 and 5.

In Figure 4, output current is measured as V_{OUT} is pulled below V_{IN}, with the test terminating when V_{OUT} is 1V below V_{IN}. Observe that once I_{LIMIT} is reached I_{OUT} remains constant throughout the remainder of the test. In Figure 5, this test is repeated but with V_{IN} - V_{OUT} exceeding 1V.

When V_{IN} - V_{OUT} > 1V, the MIC2009/2019's current limiting circuitry responds by decreasing I_{OUT}, as can be seen in Figure 5. In this demonstration, V_{OUT} is being controlled and I_{OUT} is the measured quantity. In real life applications, V_{OUT} is determined in accordance with Ohm's law by the load and the limiting current.

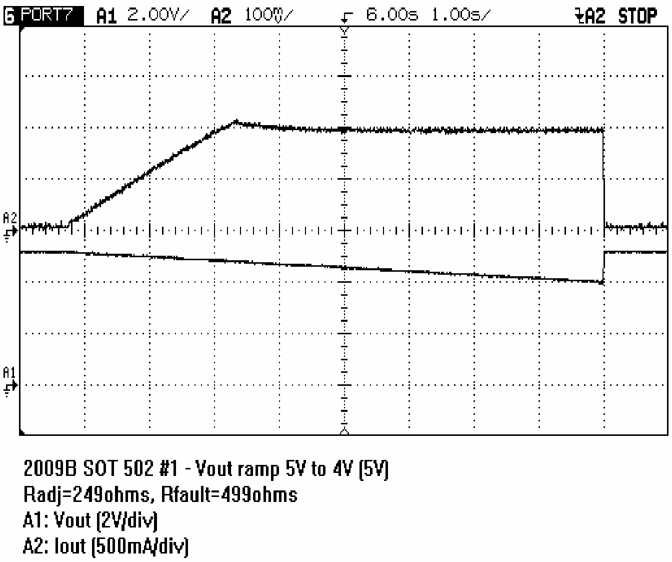


Figure 4. I_{OUT} in Current Limiting for V_{IN} - V_{OUT} ≤1V

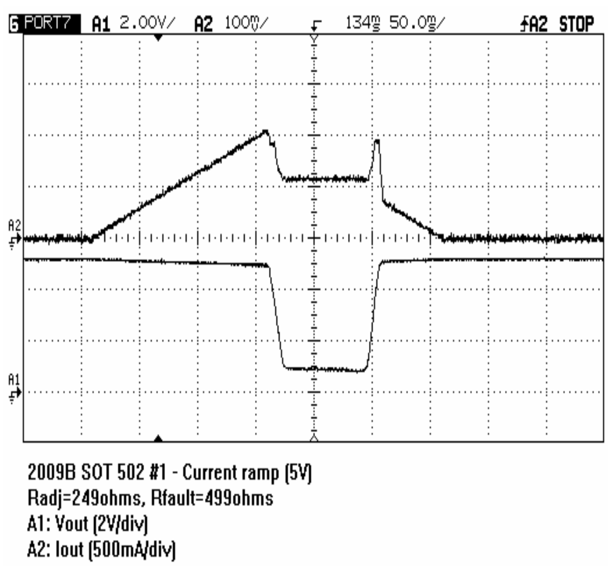


Figure 5. I_{OUT} in Current Limiting for V_{IN} - V_{OUT} >1V

This folding back of I_{LIMIT} can be generalized by plotting I_{LIMIT} as a function of V_{OUT}, as shown below. The slope of V_{OUT} between I_{OUT} = 0 and I_{OUT} = I_{LIMIT} (where I_{LIMIT} = 1) is determined by R_{ON} of MIC2009/2019 and I_{LIMIT}.

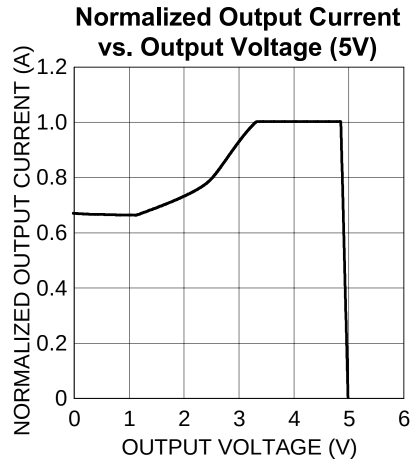


Figure 6.

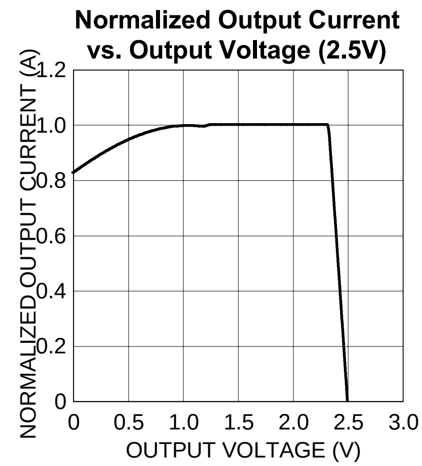


Figure 7.

Kickstart (MIC2019)

Kickstart allows brief current surges to pass to the load before the onset of normal current limiting. This, in turn, permits dynamic loads to draw bursts of energy without sacrificing system safety.

Functionally, Kickstart is a forced override of the normal current limiting function provided by the MIC2019. The Kickstart period is governed by an internal timer which allows current to pass unimpeded to the load for 128ms and then normal (primary) current limiting goes into action.

During Kickstart a secondary current limiting circuit is monitoring output current to prevent damage to the MIC2019. This is because a hard short, combined with a robust power supply, can result in currents of many tens of amperes. This secondary current limit is nominally set at 4 Amps and reacts immediately and independently of the Kickstart period. Once the Kickstart timer has finished its count, the primary current limiting circuit takes over and holds I_{OUT} to its programmed limit for as long as the excessive load persists.

Once the MIC2019 drops out of current limiting the Kickstart timer initiates a lock-out period of 128ms such that no further bursts of current above the primary current limit, will be allowed until the lock-out period has expired.

Kickstart may be over-ridden by the thermal protection circuit and if sufficient internal heating occurs, Kickstart will be terminated and $I_{OUT} \rightarrow 0$. Upon cooling, if the load is still present $I_{OUT} \rightarrow I_{LIMIT}$, not $I_{KICKSTART}$.

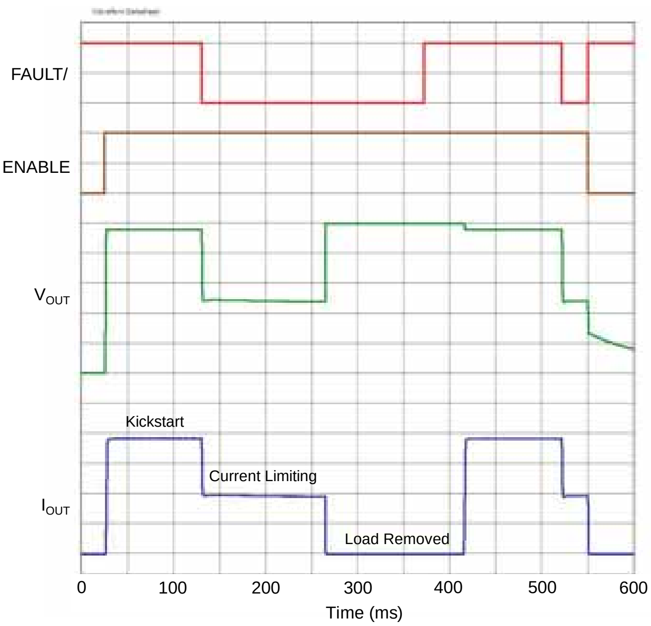


Figure 9. Kickstart operation with varying load

Supply Filtering

A 0.1µF to 1µF bypass capacitor positioned close to the V_{IN} and GND pins of MIC2009/2019 is both good design practice and required for proper operation of the MIC2009/2019. This will control supply transients and ringing. Without a bypass capacitor, large current surges or an output short may cause sufficient ringing on V_{IN} (from supply lead inductance) to cause erratic operation of the MIC2009/2019's control circuitry. Good quality, low ESR capacitors, such as Panasonic's TE or ECJ series, are suggested.

When bypassing with capacitors of 10µF and up, it is good practice to place a smaller value capacitor in parallel with the larger to handle the high frequency components of any line transients. Values in the range of 0.01µF to 0.1µF are recommended. Again, good quality, low ESR capacitors should be chosen.

Power Dissipation

Power dissipation depends on several factors such as the load, PCB layout, ambient temperature, and supply voltage. Calculation of power dissipation can be accomplished by the following equation:

$$P_D = R_{DS(ON)} \times (I_{OUT})^2$$

To relate this to junction temperature, the following equation can be used:

$$T_J = P_D \times R_{\theta(J\text{-}A)} + T_A$$

Where: T_J = junction temperature,

T_A = ambient temperature

$R_{\theta(J\text{-}A)}$ is the thermal resistance of the package

In normal operation, the MIC2009/2019's Ron is low enough that no significant I^2R heating occurs. Device heating is most often caused by a short circuit — or very heavy load — when a significant portion of the input supply voltage appears across the MIC2009/2019's power MOSFET. Under these conditions, the heat generated will exceed the package and PCB's ability to cool the device and thermal limiting will be invoked.

In Figure 10, die temperature is plotted against I_{OUT} assuming a constant case temperature of 85°C. The plots also assume a worst case R_{ON} of 140 mΩ at a die temperature of 135°C. Under these conditions, it is clear that an SOT-23 packaged device will be on the verge of thermal shutdown (typically 145°C die temperature) when operating at a load current of 1.25A. For this reason, it is recommend that MLF package be used for any MIC2009/2019 designs intending to supply continuous currents of 1A or more.

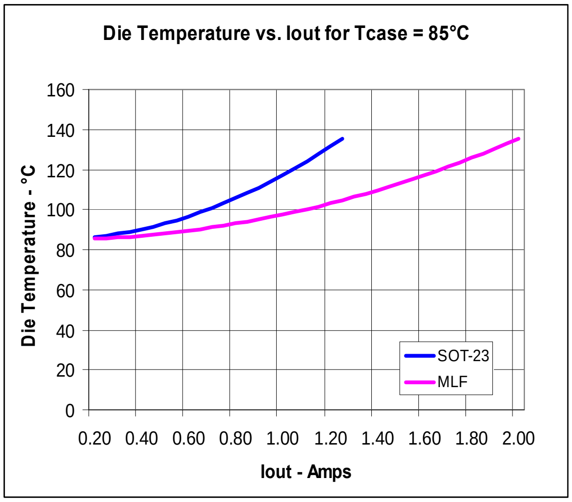


Figure 10. Die temperature vs. Package

Figure 10 assumes no backside contact is made to the thermal pad provided on the MLF package. For optimal performance at higher current levels, or in higher temperature environments, thermal contact with the PCB and the exposed power paddle on the back side of the MLF package should be made. This significantly reduces the package's thermal resistance thereby extending the MIC2009/2019's operating range. It should be noted that this backside paddle is electrically active and is connected to the MIC2009/2019's GND pin.

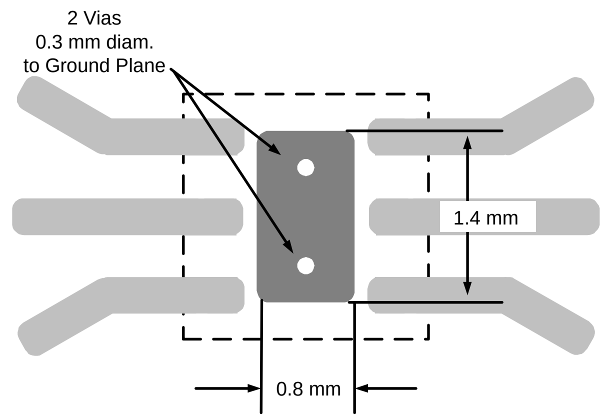
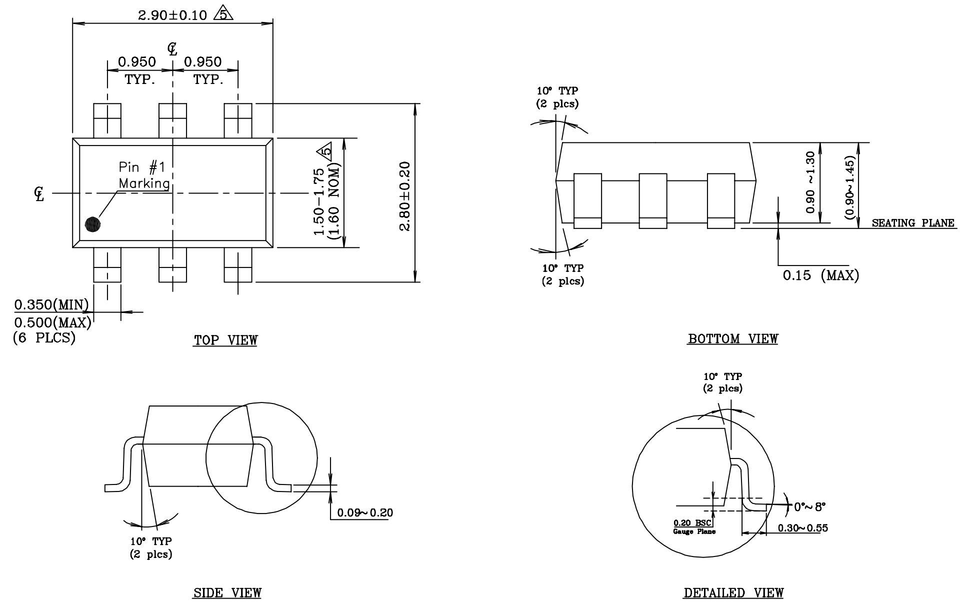
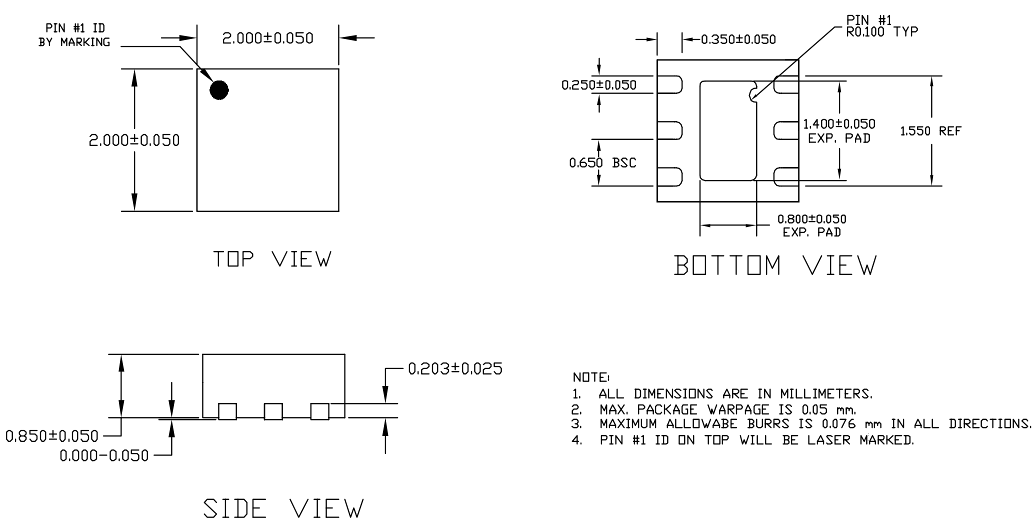


Figure 11. Pad for thermal mounting to PCB

Package Information



6-Pin SOT-23 (M6)



6 Pin 2mm X 2mm MLF (ML)

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