MP2351

1.5A, 23V, 1.4MHz Step-Down Converter

The Future of Analog IC Technology™

DESCRIPTION

The MP2351 is a monolithic step down switch mode converter with a built in internal power MOSFET. It achieves 1.5A continuous output current over a wide input supply range with excellent load and line regulation.

Current mode operation provides fast transient response and eases loop stabilization.

Fault condition protection includes cycle-by-cycle current limiting, short circuit frequency foldback and thermal shutdown. In shutdown mode the regulator draws 20µA of supply current.

The MP2351 requires a minimum number of readily available standard external components.

EVALUATION BOARD REFERENCE

Board Number	Dimensions
EV2351DQ-00A	2.3"X x 1.5"Y x 0.5"Z

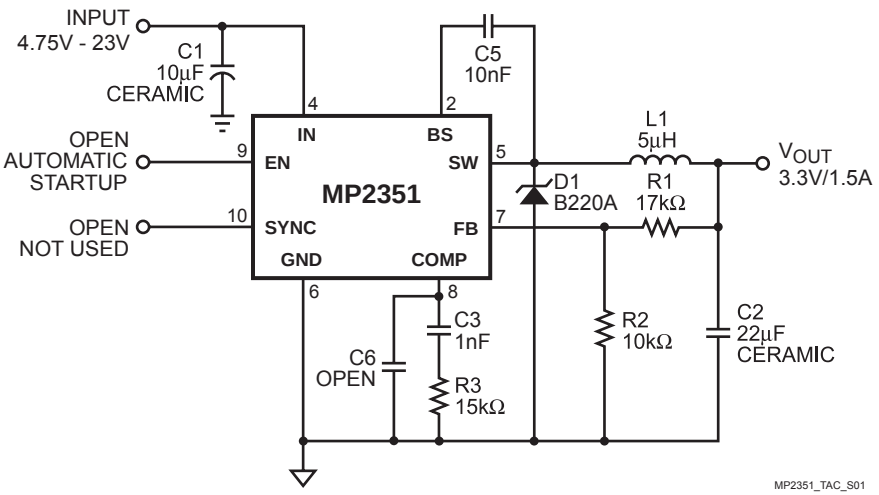
FEATURES

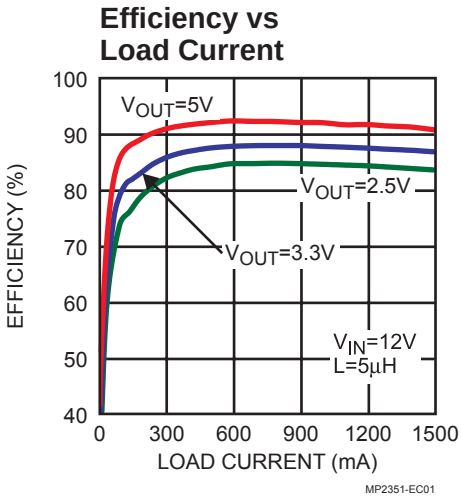
- 1.5A Output Current
- 0.18Ω Internal Power MOSFET Switch
- Stable with Low ESR Output Ceramic Capacitors
- Up to 93% Efficiency
- 20µA Shutdown Mode
- Fixed 1.4MHz Frequency
- Thermal Shutdown
- Cycle-by-Cycle Over Current Protection
- Wide 4.75V to 23V Operating Input Range
- Output Adjustable from 1.23V to 16V
- Programmable Under Voltage Lockout
- Frequency Synchronization Input
- Available in QFN (3mm x 3mm) and tiny 10-Pin MSOP Packages
- **Evaluation Board Available**

APPLICATIONS

- Distributed Power Systems
- Battery Charger
- DSL Modems
- Pre-Regulator for Linear Regulators

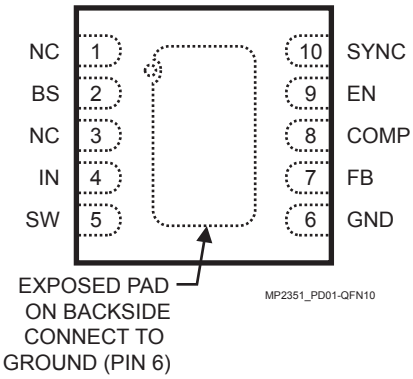
TYPICAL APPLICATION





PACKAGE REFERENCE

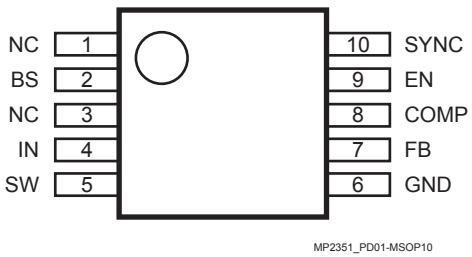
TOP VIEW



Part Number*	Package	Temperature
MP2351DQ	QFN10 (3mm x 3mm)	–40°C to +85°C

* For Tape & Reel, add suffix –Z (eg. MP2351DQ–Z)
For Lead Free, add suffix –LF (eg. MP2351DQ –LF–Z)

TOP VIEW



Part Number*	Package	Temperature
MP2351DK	MSOP10	–40°C to +85°C

* For Tape & Reel, add suffix –Z (eg. MP2351DK–Z)
For Lead Free, add suffix –LF (eg. MP2351DK –LF–Z)

ABSOLUTE MAXIMUM RATINGS (1)

Supply Voltage (V_{IN})..... 25V
Switch Voltage (V_{SW})..... 26V
Bootstrap Voltage (V_{BS}) ..... V_{SW} + 6V
Feedback Voltage (V_{FB}) .....–0.3V to +6V
Enable/UVLO Voltage (V_{EN}).....–0.3V to +6V
Comp Voltage (V_{COMP}) .....–0.3V to +6V
Sync Voltage (V_{SYNC}).....–0.3V to +6V
Junction Temperature.....+150°C
Lead Temperature .....+260°C
Storage Temperature..... –65°C to +150°C

Recommended Operating Conditions (2)

Supply Voltage (V_{IN}) .....4.75V to 23V
Operating Temperature.....–40°C to +85°C

Thermal Resistance (3)

	θ_{JA}	θ_{JC}	
QFN10 (3x3)	50	12	°C/W
MSOP10	150	65	°C/W

Notes:
1) Exceeding these ratings may damage the device.
2) The device is not guaranteed to function outside of its operating conditions.
3) Measured on approximately 1" square of 1 oz copper.

ELECTRICAL CHARACTERISTICS

V_{IN} = 12V, T_A = +25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Feedback Voltage	V_{FB}	4.75V ≤ V_{IN} ≤ 23V	1.195	1.230	1.265	V
Upper Switch-On Resistance	$R_{DS(ON)1}$			0.18		Ω
Lower Switch-On Resistance	$R_{DS(ON)2}$			10		Ω
Upper Switch Leakage		V_{EN} = 0V, V_{SW} = 0V		0	10	μA
Current Limit (4)			2.4	2.8	5.2	A
Current Sense Transconductance Output Current to Comp Pin Voltage	G_{CS}			1.95		A/V
Error Amplifier Voltage Gain	A_{VEA}			400		V/V
Error Amplifier Transconductance	G_{EA}	ΔI_C = ±10 μA	500	770	1100	μA/V
Oscillator Frequency	f_S		1.15	1.40	1.65	MHz
Short Circuit Frequency		V_{FB} = 0V		180		KHz
Sync Frequency		Sync Drive 0V to 2.7V	1.6		2.1	MHz

ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, T_A = +25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Maximum Duty Cycle	D_{MAX}	V_{FB} = 1.0V		70		%
Minimum On Time	$T_{ON (MIN)}$	V_{FB} = 1.5V		70		ns
EN Shutdown Threshold Voltage		I_{CC} > 100µA	0.7	1.0	1.3	V
Enable Pull Up Current		V_{EN} = 0V	1.15	1.50		µA
EN UVLO Threshold Rising		V_{EN} Rising	2.37	2.50	2.62	V
EN UVLO Threshold Hysteresis				210		mV
Supply Current (Shutdown)		$V_{EN} \leq$ 0.4V		20	36	µA
Supply Current (Quiescent)		$V_{EN} \geq$ 3V, V_{FB} = 1.4V		1.1	1.3	mA
Thermal Shutdown				160		°C

Note:

4) Equivalent output current = 1.5A ≥ 50% Duty Cycle
2.0A ≤ 50% Duty Cycle
Assumes ripple current = 30% of load current.
Slope compensation changes current limit above 40% duty cycle.

PIN FUNCTIONS

Pin #	Name	Description
1	NC	No Connect.
2	BS	Bootstrap (C5). This capacitor is needed to drive the power switch's gate above the supply voltage. It is connected between SW and BS pins to form a floating supply across the power switch driver. The voltage across C5 is about 5V and is supplied by the internal +5V supply when the SW pin voltage is low.
3	NC	No Connect.
4	IN	Supply Voltage. The MP2351 operates from a +4.75V to +23V unregulated input. C1 is needed to prevent large voltage spikes from appearing at the input.
5	SW	Switch. This connects the inductor to either IN through M1 or to GND through M2.
6	GND	Ground. This pin is the voltage reference for the regulated output voltage. For this reason care must be taken in its layout. This node should be placed outside of the D1 to C1 ground path to prevent switching current spikes from inducing voltage noise into the part.
7	FB	Feedback. An external resistor divider from the output to GND, tapped to the FB pin sets the output voltage. To prevent current limit run away during a short circuit fault condition the frequency foldback comparator lowers the oscillator frequency when the FB voltage is below 700mV.
8	COMP	Compensation. This node is the output of the transconductance error amplifier and the input to the current comparator. Frequency compensation is done at this node by connecting a series R-C to ground. See the compensation section for exact details.
9	EN	Enable/UVLO. A voltage greater than 2.62V enables operation. Leave EN unconnected for automatic startup. An Under Voltage Lockout (UVLO) function can be implemented by the addition of a resistor divider from V_{IN} to GND. For complete low current shutdown it's the EN pin voltage needs to be less than 700mV.
10	SYNC	Synchronization Input. This pin is used to synchronize the internal oscillator frequency to an external source. There is an internal 11kΩ pull down resistor to GND, therefore leave SYNC unconnected if unused.

OPERATION

The MP2351 is a current mode regulator. That is, the COMP pin voltage is proportional to the peak inductor current. At the beginning of a cycle: the upper transistor M1 is off; the lower transistor M2 is on; the COMP pin voltage is higher than the current sense amplifier output; and the current comparator's output is low. The rising edge of the 1.4MHz CLK signal sets the RS Flip-Flop. Its output turns off M2 and turns on M1 thus connecting the SW pin and inductor to the input supply. The increasing inductor current is sensed and amplified by the Current Sense Amplifier. Ramp compensation is summed to Current Sense Amplifier output and compared to the Error Amplifier output by the Current Comparator. When the Current Sense Amplifier plus Slope Compensation signal exceeds the COMP pin voltage, the RS Flip-Flop is reset and the MP2351 reverts to its initial M1 off, M2 on state. If the Current Sense Amplifier plus Slope Compensation signal does not exceed the COMP voltage, then the falling edge of the CLK resets the Flip-Flop.

The output of the Error Amplifier integrates the voltage difference between the feedback and the 1.230V bandgap reference. The polarity is such that an FB pin voltage lower than 1.230V increases the COMP pin voltage. Since the COMP pin voltage is proportional to the peak inductor current an increase in its voltage increases current delivered to the output. The lower 10Ω switch ensures that the bootstrap capacitor voltage is charged during light load conditions. External Schottky Diode D1 carries the inductor current when M1 is off.

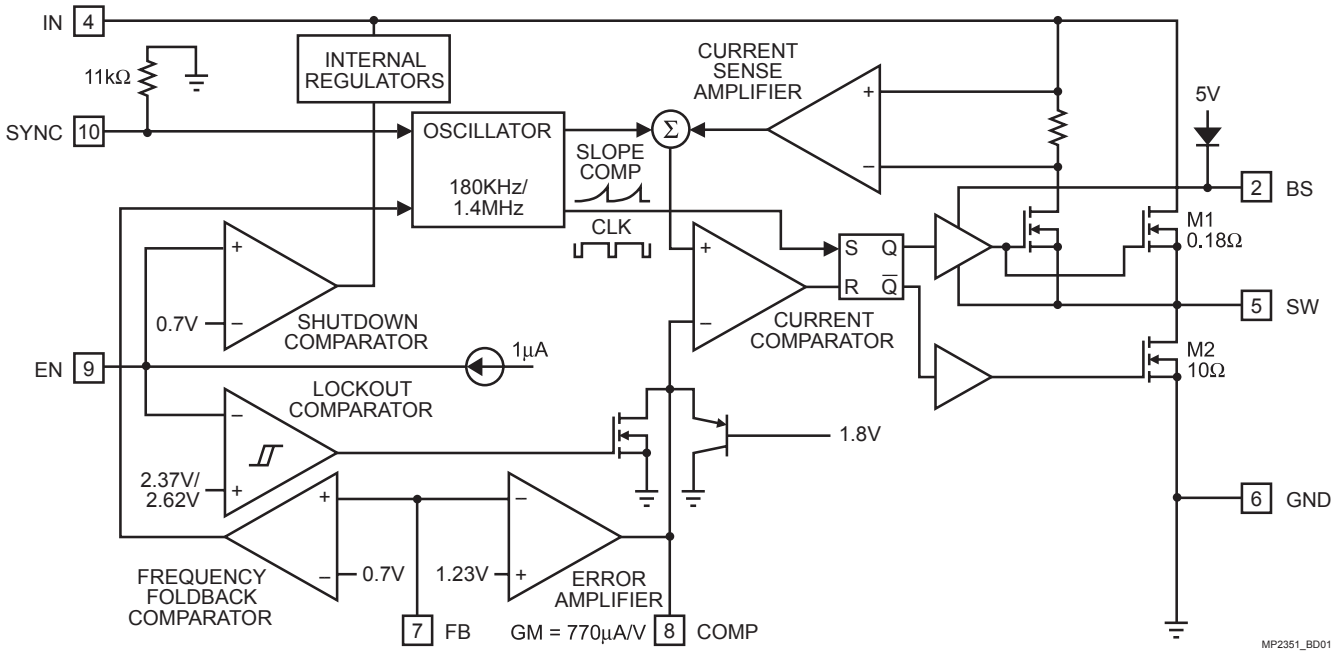


Figure 1—Functional Block Diagram

APPLICATION INFORMATION

COMPONENT SELECTION

Setting the Output Voltage

The output voltage is set using a resistive voltage divider from the output voltage to FB pin. The voltage divider divides the output voltage down to the feedback voltage by the ratio:

$$V_{FB} = V_{OUT} \frac{R2}{R1+R2}$$

Where V_{FB} is the feedback voltage and V_{OUT} is the output voltage.

Thus the output voltage is:

$$V_{OUT} = 1.23 \times \frac{R1+R2}{R2}$$

R2 can be as high as 100kΩ, but a typical value is 10kΩ. Using that value, R1 is determined by:

$$R1 = 8.18 \times (V_{OUT} - 1.23)$$

For example, for a 3.3V output voltage, R2 is 10kΩ, and R1 is 17kΩ.

Inductor

The inductor is required to supply constant current to the output load while being driven by the switched input voltage. A larger value inductor will result in less ripple current that will result in lower output ripple voltage. However, the larger value inductor will have a larger physical size, higher series resistance, and/or lower saturation current. A good rule for determining the inductance to use is to allow the peak-to-peak ripple current in the inductor to be approximately 30% of the maximum switch current limit. Also, make sure that the peak inductor current is below the maximum switch current limit. The inductance value can be calculated by:

$$L = \frac{V_{OUT}}{f_S \times \Delta I_L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Where V_{IN} is the input voltage, f_S is the switching frequency and ΔI_L is the peak-to-peak inductor ripple current.

Choose an inductor that will not saturate under the maximum inductor peak current. The peak inductor current can be calculated by:

$$I_{LP} = I_{LOAD} + \frac{V_{OUT}}{2 \times f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Where, I_{LOAD} is the load current.

Output Rectifier Diode

The output rectifier diode supplies the current to the inductor when the high-side switch is off. To reduce losses due to the diode forward voltage and recovery times, use a Schottky diode.

Choose a diode whose maximum reverse voltage rating is greater than the maximum input voltage, and whose current rating is greater than the maximum load current.

Input Capacitor

The input current to the step-down converter is discontinuous, therefore a capacitor is required to supply the AC current to the step-down converter while maintaining the DC input voltage. Use low ESR capacitors for the best performance. Ceramic capacitors are preferred, but tantalum or low-ESR electrolytic capacitors may also suffice.

Since the input capacitor (C1) absorbs the input switching current it requires an adequate ripple current rating. The RMS current in the input capacitor can be estimated by:

$$I_{C1} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)}$$

The worst-case condition occurs at $V_{IN} = 2V_{OUT}$, where:

$$I_{C1} = \frac{I_{LOAD}}{2}$$

For simplification, choose the input capacitor whose RMS current rating greater than half of the maximum load current.

The input capacitor can be electrolytic, tantalum or ceramic. When using electrolytic or tantalum capacitors, a small, high quality ceramic capacitor, i.e. 0.1μF, should be placed as close to the IC as possible. When using ceramic capacitors, make sure that they have enough capacitance to provide sufficient charge to prevent excessive voltage ripple at input. The input voltage ripple caused by capacitance can be estimated by:

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_S \times C1} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

Output Capacitor

The output capacitor is required to maintain the DC output voltage. Ceramic, tantalum, or low ESR electrolytic capacitors are recommended. Low ESR capacitors are preferred to keep the output voltage ripple low. The output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_S \times C2}\right)$$

Where R_{ESR} is the equivalent series resistance (ESR) value of the output capacitor and C2 is the output capacitance value.

In the case of ceramic capacitors, the impedance at the switching frequency is dominated by the capacitance. The output voltage ripple is mainly caused by the capacitance. For simplification, the output voltage ripple can be estimated by:

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_S^2 \times L \times C2} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)$$

In the case of tantalum or electrolytic capacitors, the ESR dominates the impedance at the switching frequency. For simplification, the output ripple can be approximated to:

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times R_{ESR}$$

The characteristics of the output capacitor also affect the stability of the regulation system. The MP2351 can be optimized for a wide range of capacitance and ESR values.

Compensation Components

The MP2351 employs current mode control for easy compensation and fast transient response. The system stability and transient response are controlled through the COMP pin. COMP pin is the output of the internal transconductance error amplifier. A series capacitor-resistor combination sets a pole-zero combination to control the characteristics of the control system.

The DC gain of the voltage feedback loop is:

$$A_{VDC} = R_{LOAD} \times G_{CS} \times A_{VEA} \times \frac{V_{FB}}{V_{OUT}}$$

Where A_{VEA} is the error amplifier voltage gain, G_{CS} is the current sense transconductance and R_{LOAD} is the load resistor value.

The system has two poles of importance. One is due to the compensation capacitor (C3) and the output resistor of error amplifier, and the other is due to the output capacitor and the load resistor. These poles are located at:

$$f_{P1} = \frac{G_{EA}}{2\pi \times C3 \times A_{VEA}}$$

$$f_{P2} = \frac{1}{2\pi \times C2 \times R_{LOAD}}$$

Where G_{EA} is the error amplifier transconductance.

The system has one zero of importance, due to the compensation capacitor (C3) and the compensation resistor (R3). This zero is located at:

$$f_{Z1} = \frac{1}{2\pi \times C3 \times R3}$$

The system may have another zero of importance, if the output capacitor has a large capacitance and/or a high ESR value. The zero, due to the ESR and capacitance of the output capacitor, is located at:

$$f_{ESR} = \frac{1}{2\pi \times C2 \times R_{ESR}}$$

In this case, a third pole set by the compensation capacitor (C6) and the compensation resistor (R3) is used to compensate the effect of the ESR zero on the loop gain. This pole is located at:

$$f_{P3} = \frac{1}{2\pi \times C6 \times R3}$$

The goal of compensation design is to shape the converter transfer function to get a desired loop gain. The system crossover frequency where the feedback loop has the unity gain is important.

Lower crossover frequencies result in slower line and load transient responses, while higher crossover frequencies could cause system unstable. A good rule of thumb is to set the crossover frequency to below one-tenth of the switching frequency.

To optimize the compensation components, the following procedure can be used:

1. Choose the compensation resistor (R3) to set the desired crossover frequency. Determine the R3 value by the following equation:

$$R3 = \frac{2\pi \times C2 \times f_C}{G_{EA} \times G_{CS}} \times \frac{V_{OUT}}{V_{FB}}$$

Where f_C is the desired crossover frequency, which is typically less than one tenth of the switching frequency.

2. Choose the compensation capacitor (C3) to achieve the desired phase margin. For applications with typical inductor values, setting the compensation zero, f_{Z1}, to below one forth of the crossover frequency provides sufficient phase margin. Determine the C3 value by the following equation:

$$C3 > \frac{4}{2\pi \times R3 \times f_C}$$

Where R3 is the compensation resistor.

3. Determine if the second compensation capacitor (C6) is required. It is required if the ESR zero of the output capacitor is located at less than half of the switching frequency, or the following relationship is valid:

$$\frac{1}{2\pi \times C2 \times R_{ESR}} < \frac{f_S}{2}$$

If this is the case, then add the second compensation capacitor (C6) to set the pole f_{P3} at the location of the ESR zero. Determine the C6 value by the equation:

$$C6 = \frac{C2 \times R_{ESR}}{R3}$$

External Bootstrap Diode

It is recommended that an external bootstrap diode be added when the system has a 5V fixed input or the power supply generates a 5V output. This helps improve the efficiency of the regulator. The bootstrap diode can be a low cost one such as IN4148 or BAT54.

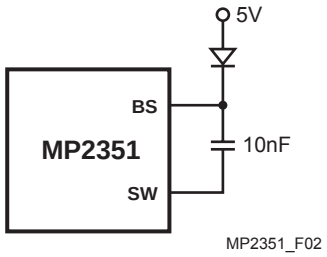
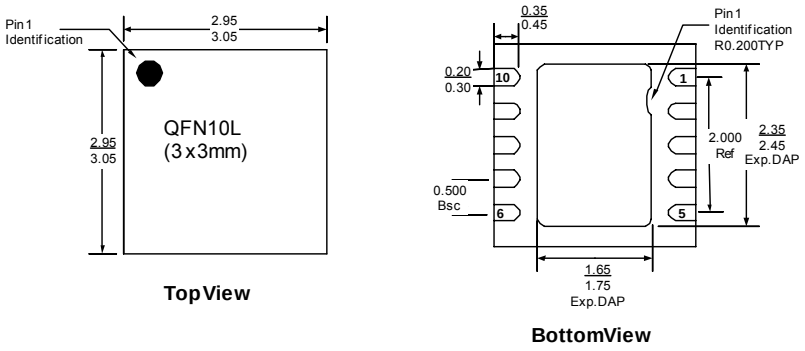


Figure 2—External Bootstrap Diode

This diode is also recommended for high duty cycle operation (when $\frac{V_{OUT}}{V_{IN}}$>65%) and high output voltage (V_{OUT}>12V) applications.

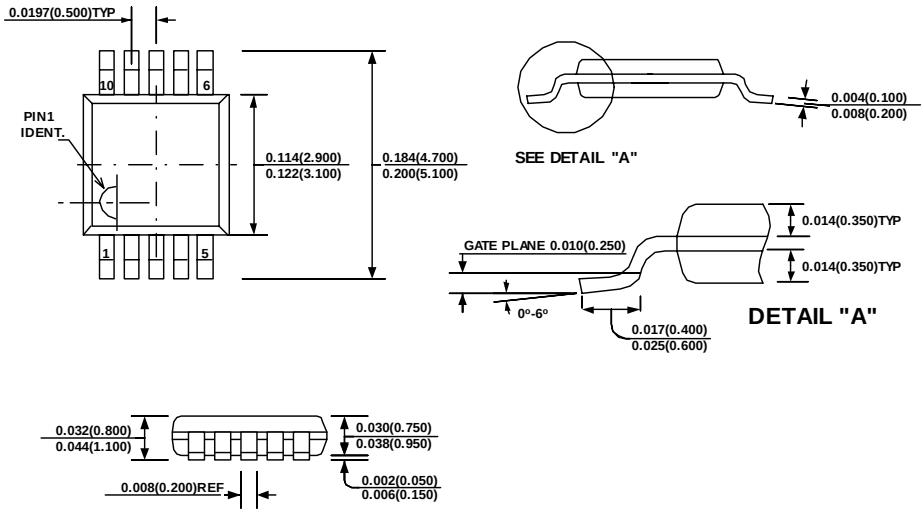
PACKAGE INFORMATION

QFN10 (3mm x 3mm)



Note:
1) Dimensions are in millimeters.

MSOP10



NOTE:
1) Control dimension is in inches. Dimension in bracket is millimeters.
2) Package length does not include mold flash, protrusions or gate burr.
3) Package width does not include interlead flash or protrusions.