MPM3804

0.6A, 5.5V Input Step-Down Module Synchronous Regulator with Integrated Inductor in Ultra-Small 2x2x0.9mm QFN Package

DESCRIPTION

The MPM3804 is a monolithic, step-down, switch-mode converter with built-in, internal power MOSFETs and an inductor. The MPM3804 achieves 0.6A of continuous output current from a 2.3V to 5.5V input voltage range with excellent load and line regulation. The output voltage can be regulated as low as 0.6V. Only input capacitors, output capacitors, and feedback (FB) resistors are required to complete the design.

The constant-on-time (COT) control scheme provides a fast transient response, high light-load efficiency, and easy loop stabilization.

Full protection features include cycle-by-cycle current limiting and thermal shutdown.

The MPM3804 is ideal for a wide range of applications, including high-performance DSPs, wireless power, portable and mobile devices, and other low-power systems.

The MPM3804 requires a minimal number of readily available, standard, external components and is available in an ultra-small QFN-10 (2mmx2mm) package.

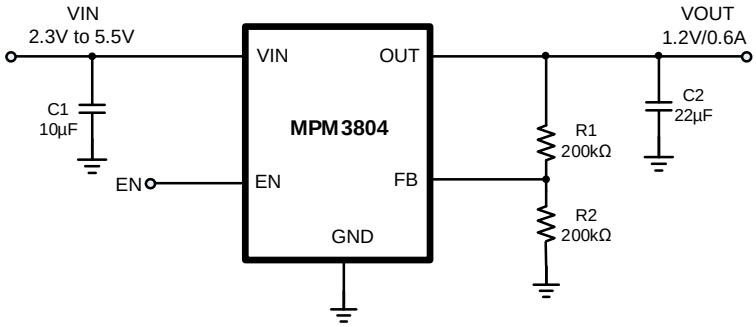
FEATURES

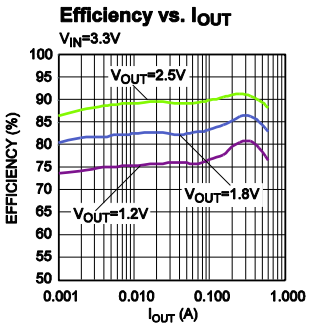
- Up to 91% Peak Efficiency
- Low I_Q: 11µA
- Wide 2.3V to 5.5V Operating Input Range
- Output Voltage as Low as 0.6V
- 100% Duty Cycle in Dropout
- 0.6A Output Current
- 120mΩ and 80mΩ Internal Power MOSFETs
- 2.4MHz Frequency
- EN and Power Good for Power Sequencing
- Cycle-by-Cycle Over-Current Protection (OCP)
- 0.5ms Internal Soft-Start Time
- Output Discharge
- Short-Circuit Protection (SCP) with Hiccup Mode
- Thermal Shutdown
- Stable with Low ESR Output Ceramic Capacitors
- Ultra-Small 2mm x 2mm x 0.9mm QFN-10 Package

APPLICATIONS

- Optical Modules
- Industrial Products
- IOT Devices
- Space Constrained Applications
- Low-Voltage I/O Supplies
- LDO Replacement

TYPICAL APPLICATION





ORDERING INFORMATION

Part Number	Package	Top Marking
MPM3804GG*	QFN-10 (2mmx2mm)	*See Below*
MPM3804GG-12**		
MPM3804GG-15**		
MPM3804GG-18**		
MPM3804GG-25**		
MPM3804GG-33**		

* FOR TAPE & REEL, ADD SUFFIX –Z (E.G. MPM3804GG–Z)
** For fixed output options, please contact the factory (the fixed output versions have not been released yet).

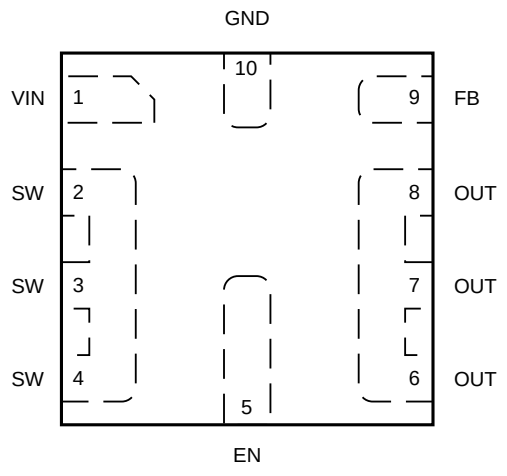
TOP MARKING

$\overline{\text{DLY}}$
LLL

DL: Product code of MPM3804GG
Y: Year code
LLL: Lot number

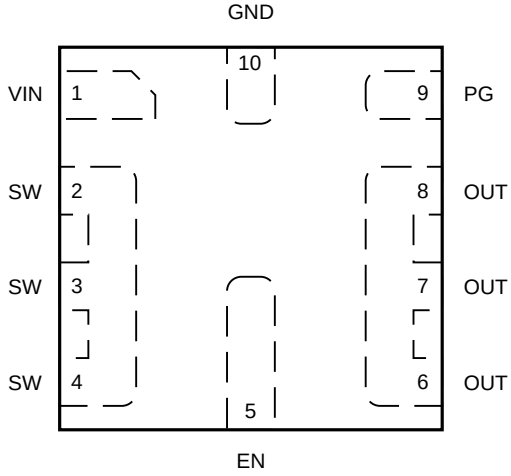
PACKAGE REFERENCE

TOP VIEW



MPM3804GG

TOP VIEW



MPM3804GG-12 MPM3804GG-15 MPM3804GG-18 MPM3804GG-25 MPM3804GG-33

QFN-10 (2mmx2mm)

ABSOLUTE MAXIMUM RATINGS (1)

Supply voltage (VIN) 6V
V_{SW} ..... -0.3V (-5V for <10ns) to 6V (8V for <10ns or 10V for <3ns)
All other pins ..... -0.3V to 6V
Junction temperature ..... 150°C
Lead temperature ..... 260°C
Continuous power dissipation (T_A = +25°C) (2) 1.6W
Storage temperature ..... -65°C to +150°C

Recommended Operating Conditions (3)

Supply voltage (VIN) ..... 2.3V to 5.5V
Operating junction temp. (T_J) ..... -40°C to +125°C

Thermal Resistance (4)

	θ_{JA}	θ_{JC}	
QFN-10 (2mmx2mm)	80	16	°C/W

NOTES:

1) Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature T_J (MAX), the junction-to-ambient thermal resistance θ_{JA}, and the ambient temperature T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX)-T_A)/θ_{JA}. Exceeding the maximum allowable power dissipation produces an excessive die temperature, causing the regulator to go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
3) The device is not guaranteed to function outside of its operating conditions.
4) Measured on JESD51-7, 4-layer PCB.

ELECTRICAL CHARACTERISTICS

V_{IN} = 3.6V, T_J = -40°C to +125°C, typical value is tested at T_J = +25°C. The limit over temperature is guaranteed by characterization, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Feedback voltage	V_{FB}	2.3V ≤ V_{IN} ≤ 5.5V, T_J = 25°C	0.594	0.600	0.606	V
		2.3V ≤ V_{IN} ≤ 5.5V	0.591	0.600	0.609	
Feedback current	I_{FB}	V_{FB} = 0.65V		50	100	nA
P-FET switch on resistance	R_{DSON_P}			120		mΩ
N-FET switch on resistance	R_{DSON_N}			80		mΩ
Dropout resistance	R_{DR}	100% on duty		440		mΩ
Switch leakage		V_{EN} = 0V, V_{IN} = 6V, V_{SW} = 0V, T_J = 25°C		0	1	μA
P-FET peak current limit			1	1.3	1.6	A
N-FET valley current limit				0.4		A
Switching frequency	f_s	V_{OUT} = 1.2V	1920	2400	2910	kHz
		T_J = -40°C to +85°C(6)	1800	2400	3000	kHz
Minimum off time	$T_{MIN-OFF}$			60		ns
Minimum on time(5)	T_{MIN-ON}			60		ns
Soft-start time	T_{SS-ON}			0.5		ms
Under-voltage lockout threshold rising				2	2.25	V
Under-voltage lockout threshold hysteresis				150		mV
EN input logic-low voltage					0.4	V
EN input logic-high voltage			1.2			V
EN input current		V_{EN} = 2V		1.2		μA
		V_{EN} = 0V		0		μA
Supply current (shutdown)		V_{EN} = 0V, T_J = 25°C		0	1	μA
Supply current (quiescent)		V_{EN} = 2V, V_{IN} = 3.6V, 5V, V_{FB} = 0.63V, T_J = 25°C		11	15	μA
Thermal shutdown(6)				160		°C
Thermal hysteresis(6)				30		°C
Output discharge resistor	RDIS	V_{EN} = 0V, V_{OUT} = 1.2V		1		kΩ
Output inductor	L	Test frequency = 1MHz		1		μH
	DCR		0.24	0.32	0.4	Ω

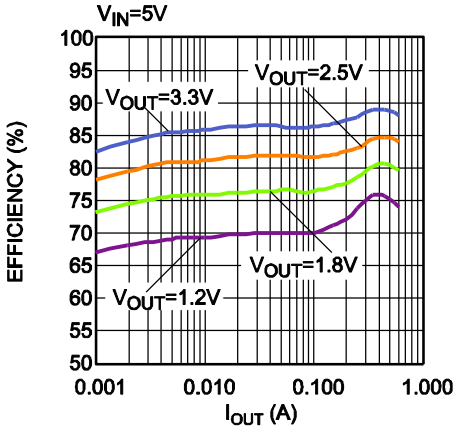
NOTES:

5) Guaranteed by characterization.
6) Guaranteed by design.

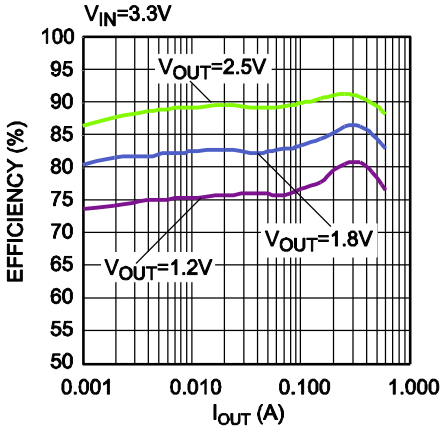
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 5V, V_{OUT} = 1.2V, C_{OUT} = 22µF, T_A = +25°C, unless otherwise noted.

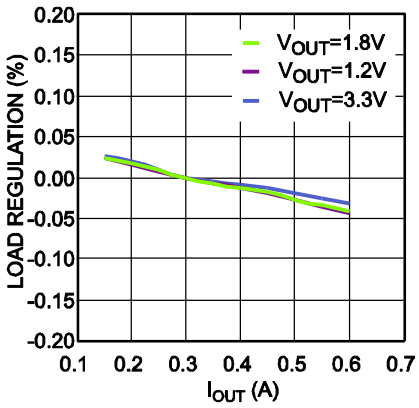
Efficiency vs. I_{OUT}



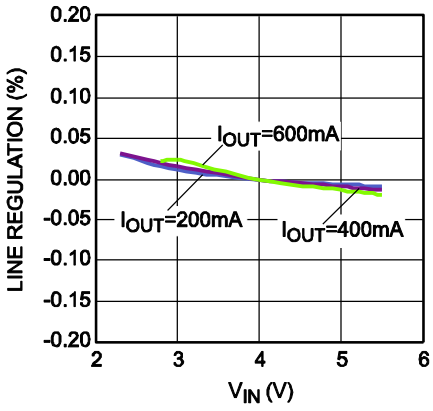
Efficiency vs. I_{OUT}



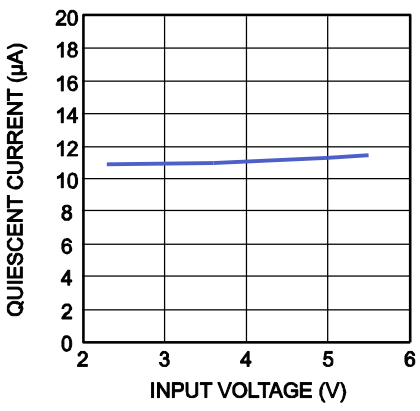
Load Regulation vs. I_{OUT}



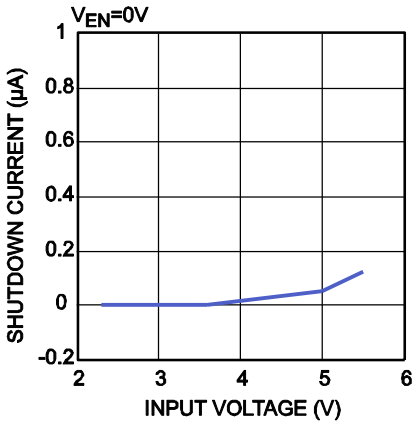
Line Regulation vs. V_{IN}



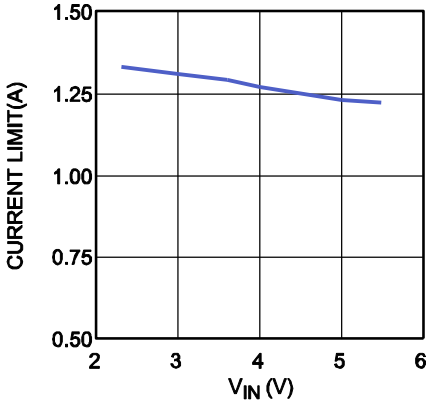
Quiescent Current vs. Input Voltage



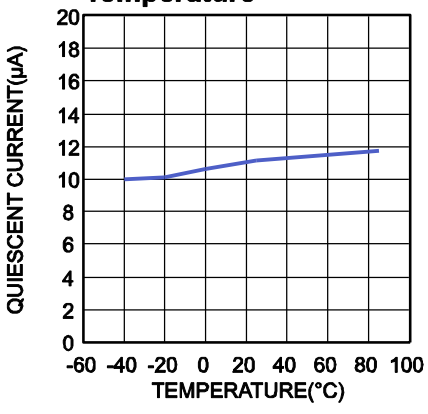
Shutdown Current vs. Input Voltage



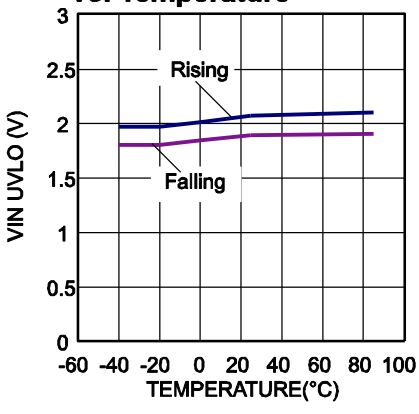
Current Limit vs. V_{IN}



Quiescent Current vs. Temperature



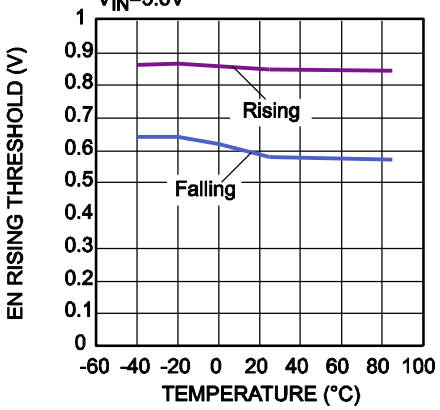
VIN UVLO Rising Threshold vs. Temperature



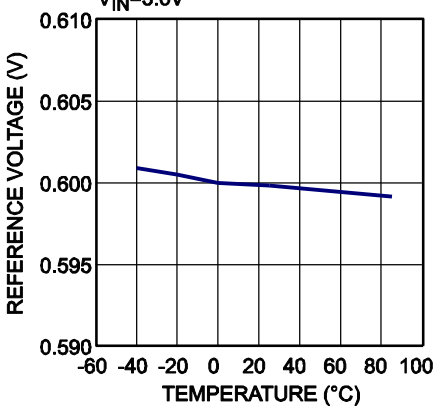
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 5V, V_{OUT} = 1.2V, C_{OUT} = 22µF, T_A = +25°C, unless otherwise noted.

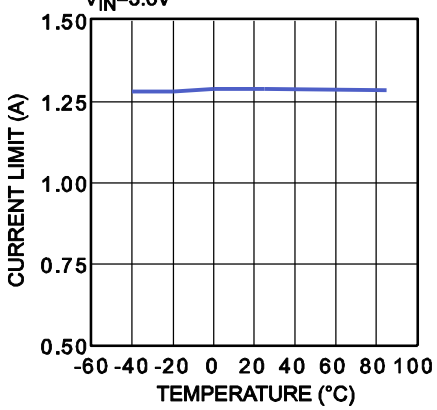
EN Rising Voltage vs. Temperature



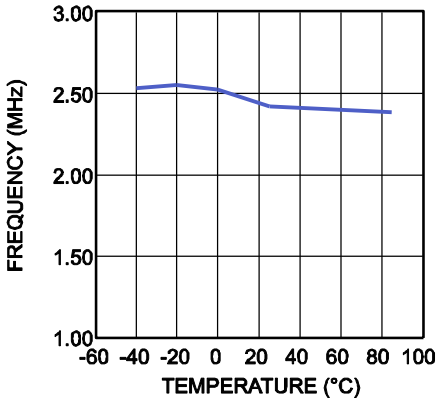
Reference Voltage vs. Temperature



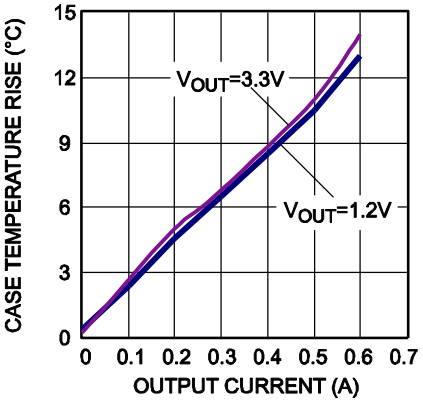
Current Limit vs. Temperature



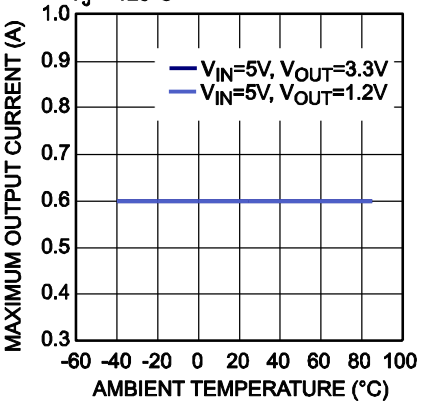
Frequency vs. Temperature



Case Temperature Rise



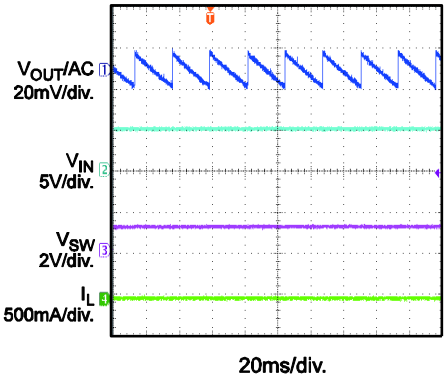
Output Current Derating vs. Ambient Temperature



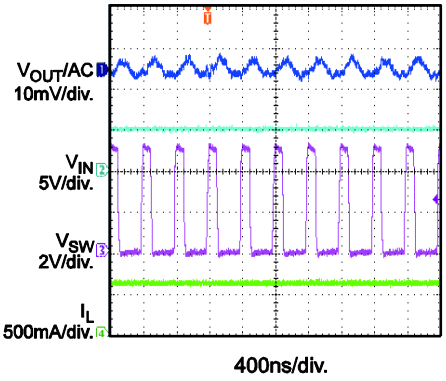
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 5V, V_{OUT} = 1.2V, C_{OUT} = 22µF, T_A = +25°C, unless otherwise noted.

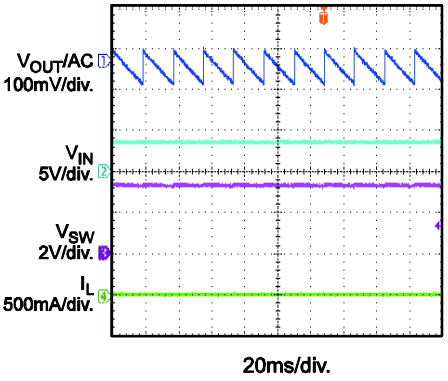
Steady State
I_{OUT}=0A



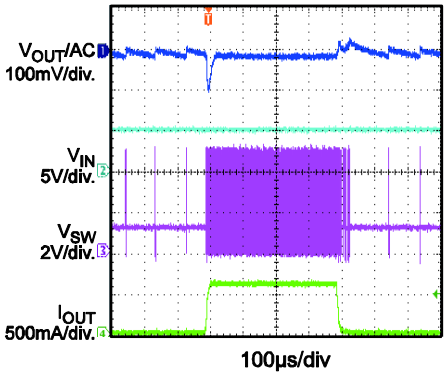
Steady State
I_{OUT}=0.6A



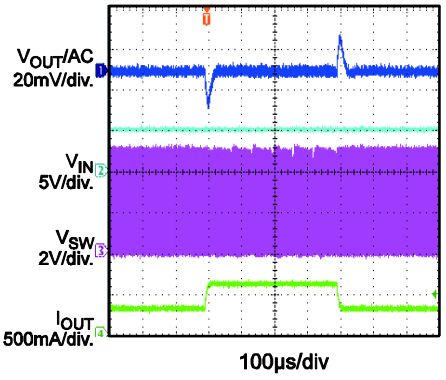
Steady State
V_{IN}=3.6V, V_{OUT}=3.3V, I_{OUT}=0A



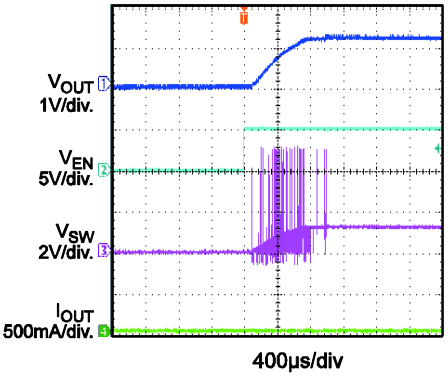
Load Transient Response
I_{OUT}=0A-0.6A



Load Transient Response
I_{OUT}=0.3A-0.6A



EN On
I_{OUT}=0A



EN On
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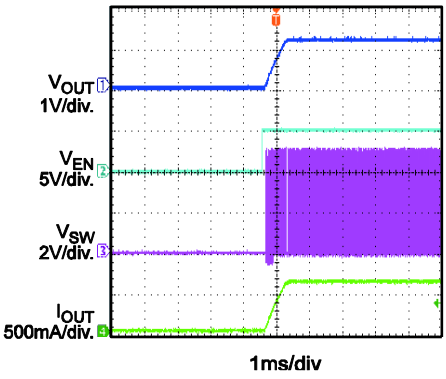
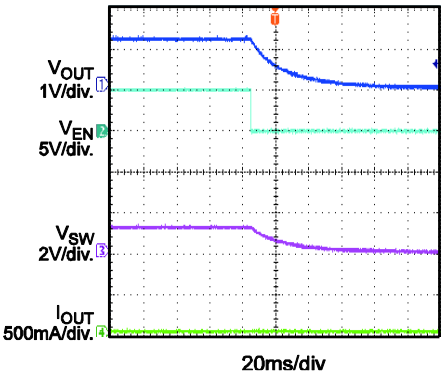
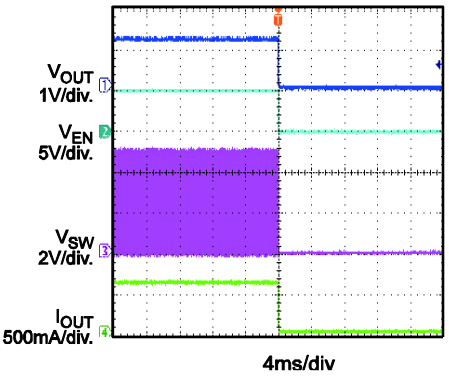


EN Off
I_{OUT}=0A



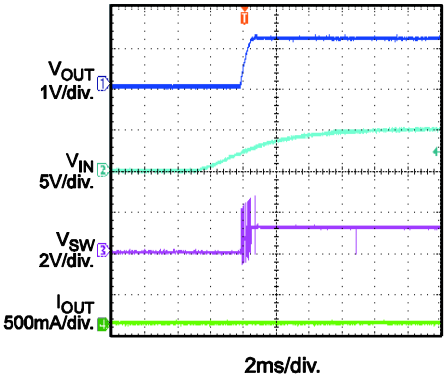
EN Off
I_{OUT}=0.6A



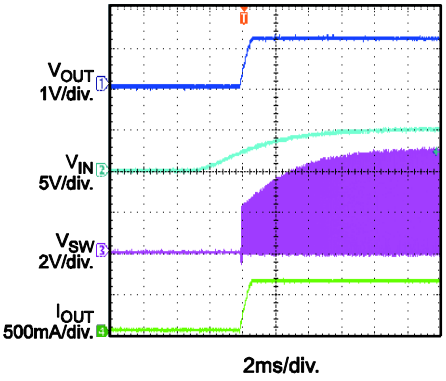
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 5V, V_{OUT} = 1.2V, C_{OUT} = 22µF, T_A = +25°C, unless otherwise noted.

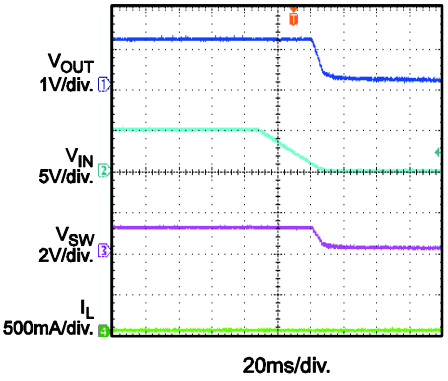
Power On
I_{OUT}=0A



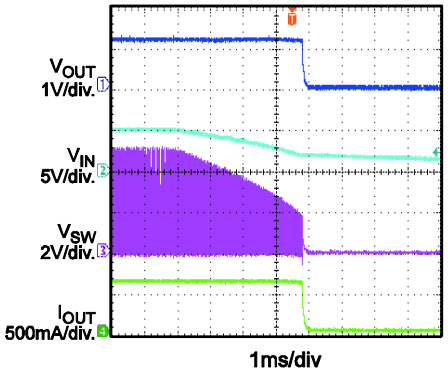
Power On
I_{OUT}=0.6A



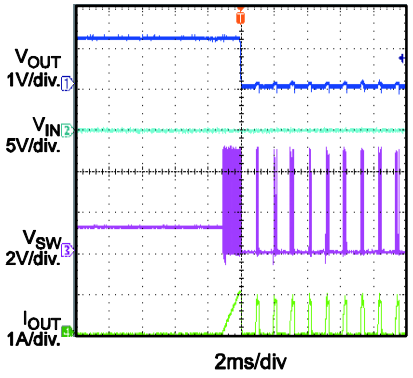
Power Off
I_{OUT}=0A



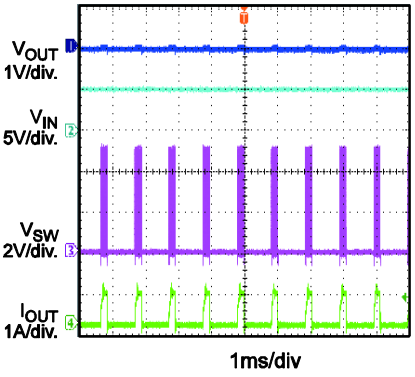
Power Off
I_{OUT}=0.6A



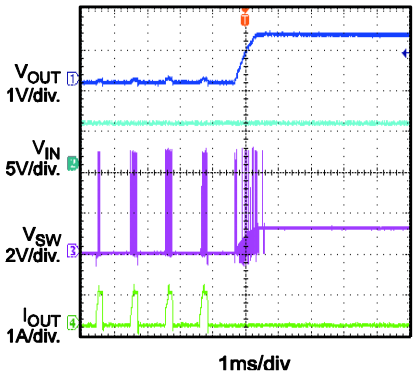
Short-Circuit Entry



Short-Circuit Steady



Short-Circuit Recovery



PIN FUNCTIONS

Pin #	Name	Description
1	VIN	**Supply voltage.** The MPM3804 operates from a +2.3V to +5.5V unregulated input. A decoupling capacitor is needed to prevent large voltage spikes from appearing at the input.
2, 3, 4	SW	**Output switching node.** SW is the drain of the internal, high-side, P-channel MOSFET. SW is not for testing and is for internal use only.
5	EN	**On/off control.**
6, 7, 8	OUT	**Output voltage power rail and output voltage input sense.** Connect the load to OUT. An output capacitor is needed to decrease the output voltage ripple.
9	FB/PG	**MPM3804GG: Feedback.** An external resistor divider from the output to GND tapped to FB sets the output voltage. **MPM3804GG-XX: Power good indicator.** The output of PG is an open-drain output.
10	GND	**Power ground.**

BLOCK DIAGRAM

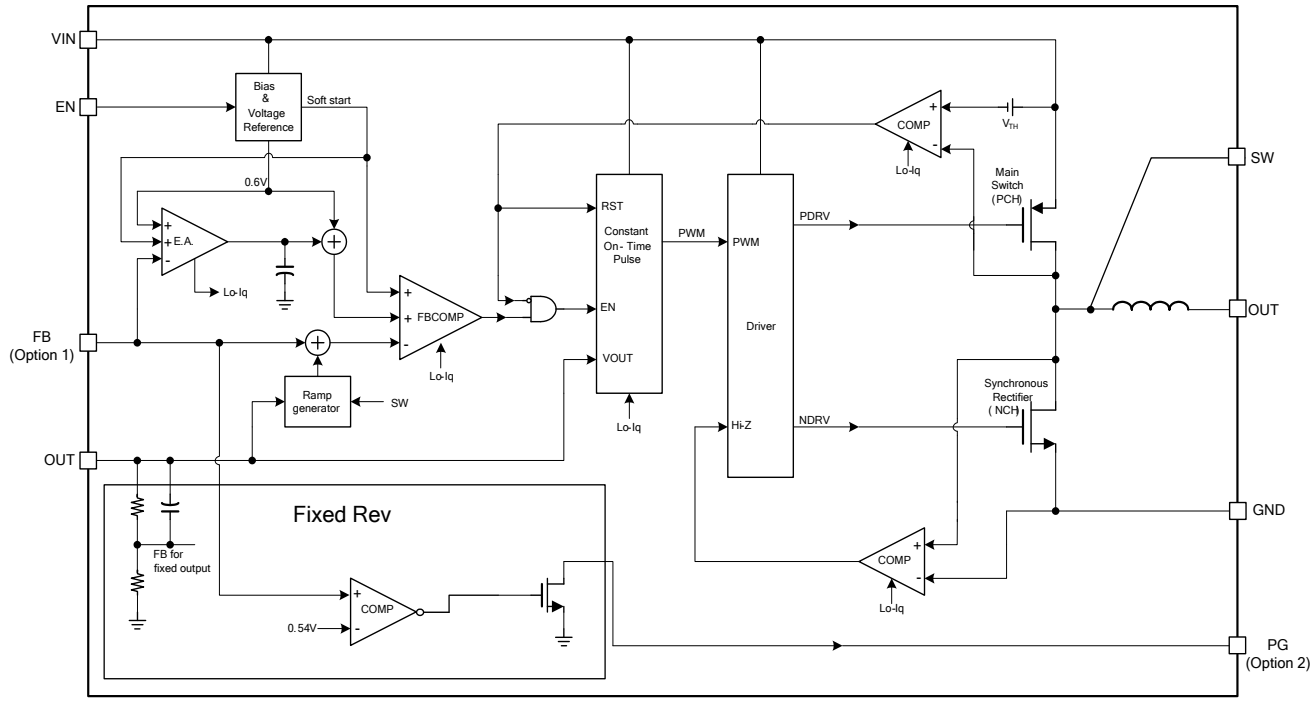


Figure 1: Functional Block Diagram

NOTE: FB is only for the MPM3804GG (option 1); PG is only for the MPM3804GG-XX (option 2).

OPERATION

The MPM3804 uses a constant-on-time (COT) control with input voltage feed-forward to stabilize the switching frequency over the full input range. The MPM3804 achieves 0.6A of continuous output current from a 2.3V to 5.5V input voltage range with excellent load and line regulation. The output voltage can be regulated as low as 0.6V.

Constant-On-Time (COT) Control

Compared to fixed-frequency PWM control, constant-on-time (COT) control offers a simpler control loop and faster transient response. By using an input voltage feed-forward, the MPM3804 maintains a nearly constant switching frequency across the input and output voltage ranges. The switching pulse on time can be estimated with Equation (1):

$$T_{ON} = \frac{V_{OUT}}{V_{IN}} .0.417\mu s \quad (1)$$

To prevent inductor current runaway during the load transient, the MPM3804 has a fixed minimum off time of 60ns. This minimum off time limit will not affect operation in steady state in any way.

Sleep-Mode Operation

The MPM3804 uses sleep mode to achieve high efficiency at extremely light loads. In sleep mode, most of the circuit blocks are turned off except for the error amplifier and PWM comparator. Therefore, the operation current is reduced to a minimal value (see Figure 2).

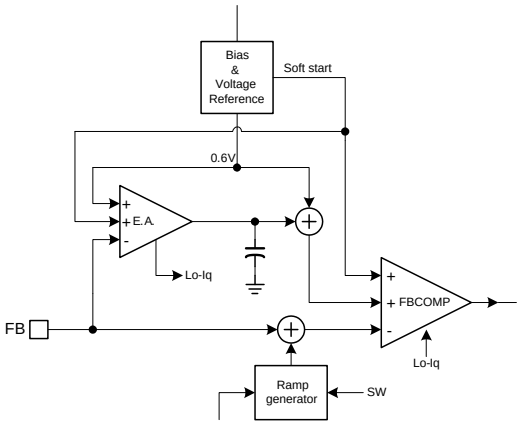


Figure 2: Operation Blocks at Sleep Mode

When the loading becomes lighter, the ripple of the output voltage is bigger and drives the error amplifier output (EAO) lower. When the EAO reaches the internal low threshold, it is clamped at that level, and the MPM3804 enters sleep mode. During sleep mode, the valley of the FB voltage is regulated to the internal reference voltage, and the average output voltage is slightly higher than the output voltage in discontinuous conduction mode (DCM) or continuous conduction mode (CCM). The on-time pulse in sleep mode is around 40% larger than that in DCM or CCM. Figure 3 shows the average FB voltage relationship with the internal reference in sleep mode.

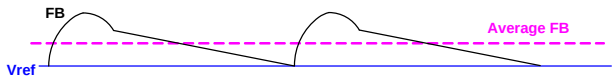


Figure 3: FB Average Voltage in Sleep Mode

When the MPM3804 is in sleep mode, the average output voltage is higher than the internal reference voltage. The EAO is kept low and clamped in sleep mode. When the load increases, the PWM switching period decreases to keep the output voltage regulated, and the output voltage ripple decreases relatively. Once the EAO is higher than the internal low threshold, the MPM3804 exits sleep mode and enters DCM or CCM depending on the load. In DCM or CCM, the error amplifier regulates the average output voltage to the internal reference (see Figure 4).

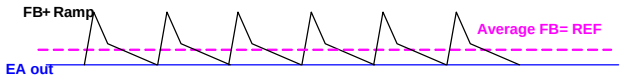


Figure 4: DCM Control

There is always a loading hysteresis when entering and exiting sleep mode due to the error amplifier clamping response time.

AAM Operation at Light-Load Operation

The MPM3804 uses advanced asynchronous modulation (AAM) power-save mode together with a zero-current cross detection (ZCD) circuit for light load.

The MPM3804 has AAM power-save mode for light load. Figure 5 shows the simplified AAM control theory. The AAM current (I_{AAM}) is set

internally. In light-load condition, the SW on pulse time is determined by the on-time generator and AAM comparator.

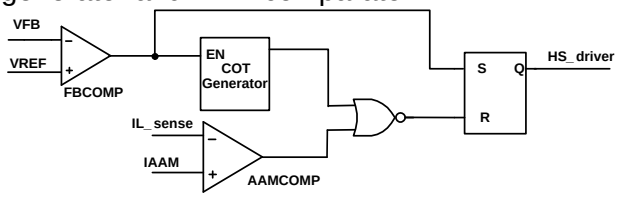


Figure 5: Simplified AAM Control Logic

The MPM3804 uses a ZCD to determine when the inductor current starts to reverse. When the inductor current reaches the ZCD threshold, the low-side switch is turned off.

AAM mode together with the ZCD circuit makes the MPM3804 work in DCM at light load continuously, even if V_{OUT} is close to VIN.

Enable (EN)

When the input voltage is greater than the under-voltage lockout (UVLO) threshold (typically 2V), the MPM3804 can be enabled by pulling EN higher than 1.2V. Leave EN floating or pull EN down to ground to disable the MPM3804. There is an internal 1MΩ resistor from EN to ground.

When the device is disabled, the part goes into output discharge mode automatically. The internal discharge MOSFET provides a resistive discharge path for the output capacitor.

Soft Start (SS)

The MPM3804 has a built-in soft start (SS) that ramps up the output voltage at a controlled slew rate to avoid overshooting at start-up. The soft-start time is about 0.5ms, typically.

Power Good Indicator (only for MPM3804GG-XX)

The MPM3804 has an open drain and requires an external pull-up resistor (100kΩ~500kΩ) for the power good (PG) indicator. When V_{FB} is within -10% of regulation voltage, V_{PG} is pulled up to VIN by the external resistor. If V_{FB} exceeds the -10% window, the internal MOSFET pulls PG to ground. The MOSFET has a maximum $R_{DS(ON)}$ of less than 100Ω.

Current Limit

The MPM3804 has a 1.3A, high-side, switch-current limit, typically. When the high-side switch reaches its current limit, the MPM3804 remains in hiccup mode until the current drops. This prevents the inductor current from continuing to rise and damaging components.

Short Circuit and Recovery

The MPM3804 enters short-circuit protection (SCP) mode when it reaches the current limit and attempts to recover with hiccup mode. The MPM3804 disables the output power stage, discharges the soft-start capacitor, and attempts to soft start automatically. If the short-circuit condition remains after the soft start ends, the MPM3804 repeats this cycle until the short circuit is removed and the output rises back to regulation levels.

APPLICATION INFORMATION

Setting the Output Voltage (only for MPM3804GG)

The external resistor divider sets the output voltage (see the Typical Application Circuits on page 15). Select the feedback resistor (R1) to reduce the V_{OUT} leakage current, typically between 40kΩ to 200kΩ. There is no strict requirement on the feedback resistor. R1 > 10kΩ is reasonable for most applications. R2 can be calculated with Equation (2):

$$R2 = \frac{R1}{\frac{V_{out}}{0.6} - 1} \quad (2)$$

Figure 6 shows the feedback circuit.

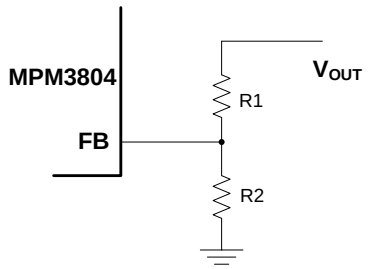


Figure 6: Feedback Network

Table 1 lists the recommended resistor values for common output voltages.

Table 1: Resistor Values for Common Output Voltages

V_{OUT} (V)	R1 (kΩ)	R2 (kΩ)
1.0	200 (1%)	300 (1%)
1.2	200 (1%)	200 (1%)
1.8	200 (1%)	100 (1%)
2.5	200 (1%)	63.2 (1%)
3.3	200 (1%)	44.2 (1%)

Selecting the Input Capacitor

The input current to the step-down converter is discontinuous and therefore requires a capacitor to supply AC current to the step-down converter while maintaining the DC input voltage. Use low ESR capacitors for the best performance. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients. Typically, a 10µF input capacitor is sufficient for most applications.

The input capacitor requires an adequate ripple current rating since it absorbs the input switching current. Estimate the RMS current in the input capacitor with Equation (3):

$$I_{C1} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right)} \quad (3)$$

The worst-case scenario occurs at $V_{IN} = 2V_{OUT}$, shown in Equation (4):

$$I_{C1} = \frac{I_{LOAD}}{2} \quad (4)$$

For simplification, choose an input capacitor with an 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, add a small, high-quality, 0.1µF, ceramic capacitor as close to the IC as possible. When using ceramic capacitors, ensure that they have enough capacitance to provide a sufficient charge to prevent excessive voltage ripple at the input. The input voltage ripple caused by the capacitance can be estimated with Equation (5):

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_S \times C1} \times \frac{V_{OUT}}{V_{IN}} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (5)$$

Selecting the Output Capacitor

The output capacitor (C2) stabilizes the DC output voltage. Low ESR ceramic capacitors are recommended to limit the output voltage ripple. Estimate the output voltage ripple with Equation (6):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L_1} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \left(R_{ESR} + \frac{1}{8 \times f_S \times C2}\right) \quad (6)$$

Where L_1 is the inductor value, and R_{ESR} is the equivalent series resistance (ESR) value of the output capacitor. The MPM3804 has an internal, co-packaged, 1µH power inductor.

When using ceramic capacitors, the capacitance dominates the impedance at the switching frequency and causes most of the output voltage ripple. For simplification, the

output voltage ripple can be estimated with Equation (7):

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_S^2 \times L_1 \times C2} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \quad (7)$$

For tantalum or electrolytic capacitors, the ESR dominates the impedance at the switching frequency. For simplification, the output ripple can be approximated with Equation (8):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_S \times L_1} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times R_{ESR} \quad (8)$$

The characteristics of the output capacitor also affect the stability of the regulation system. Typically, a 10µF output capacitor is sufficient to meet most applications. Add a 22µF output capacitor to achieve a low output voltage ripple.

PCB Layout Guidelines

Efficient PCB layout of the switching power supplies is critical for stable operation. For the high-frequency switching converter, a poor layout design can result in poor line or load regulation and stability issues. For best results, refer to Figure 7 and Figure 8 and follow the guidelines below.

1. Place the high-current paths (GND and IN) very close to the device with short, direct, and wide traces.
2. Place the input capacitor as close to IN and GND as possible.
3. Place the external feedback resistors next to FB (only for the MPM3804GG).

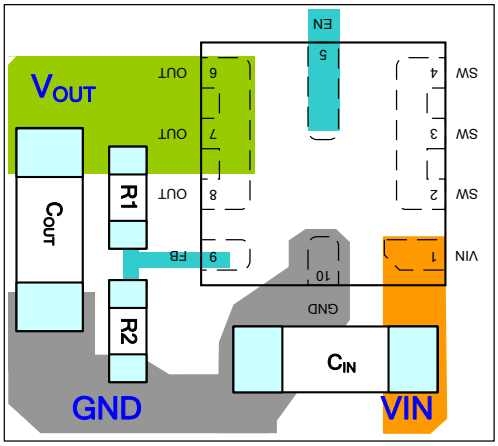
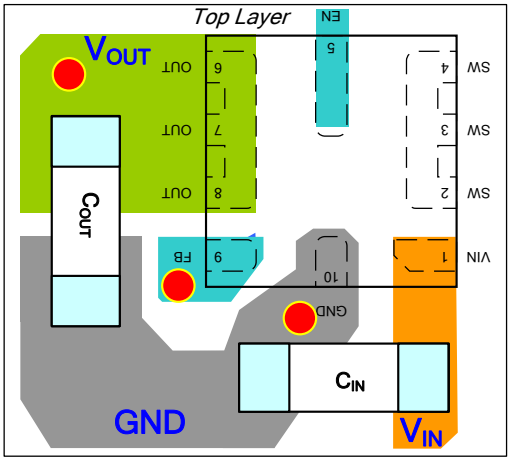


Figure 7: Single-Layer PCB Layout



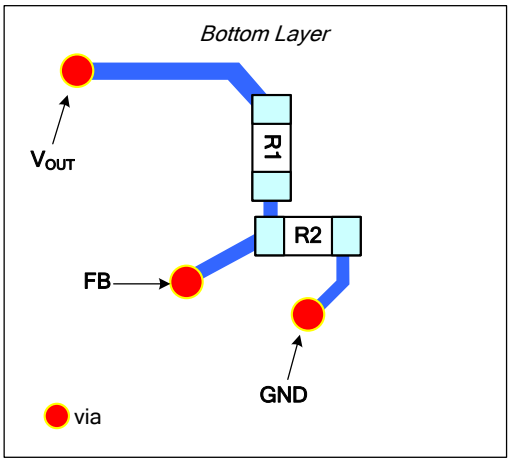


Figure 8: Double-Layer PCB Layout

TYPICAL APPLICATION CIRCUITS

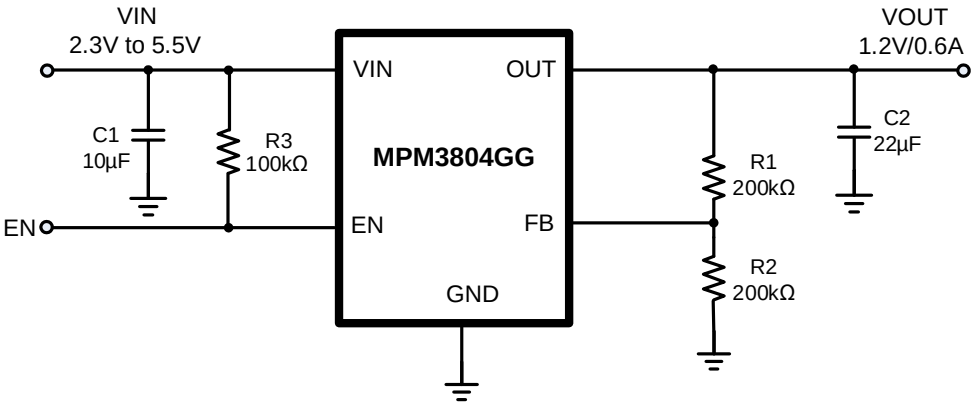


Figure 9: Typical Application Circuit for MPM3804GG

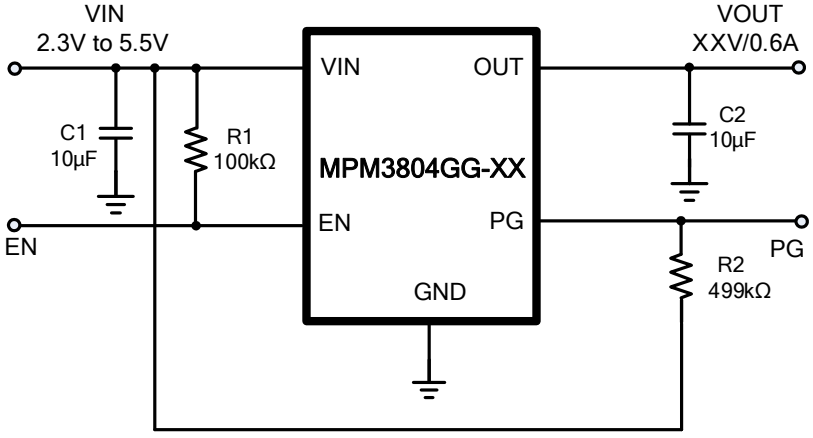
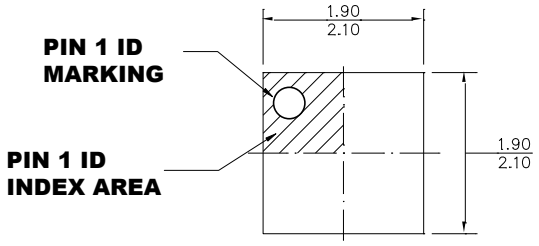


Figure 10: Typical Application Circuit for MPM3804GG-XX

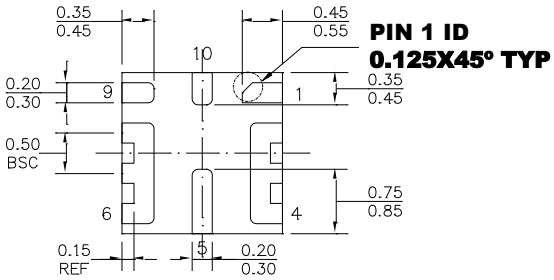
NOTE: VIN > V_{OUT} for application.

PACKAGE INFORMATION

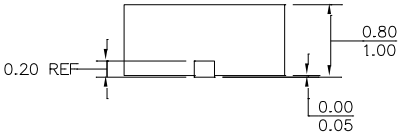
QFN-10 (2mmx2mm)



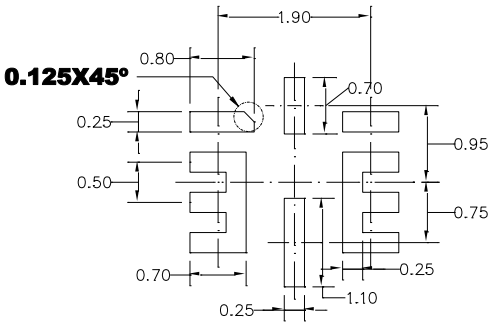
TOP VIEW



BOTTOM VIEW



SIDE VIEW



RECOMMENDED LAND PATTERN

NOTE:

1) ALL DIMENSIONS ARE IN MILLIMETERS.
2) EXPOSED PADDLE SIZE DOES NOT INCLUDE MOLD FLASH.
3) LEAD COPLANARITY SHALL BE 0.10 MILLIMETERS MAX.
4) JEDEC REFERENCE IS MO-220.
5) DRAWING IS NOT TO SCALE.