MPQ4409

24V, 900mA, 2.2MHz, High-Efficiency, Synchronous Step-Down Converter, AEC-Q100 Qualified

DESCRIPTION

The MPQ4409 is a high-frequency, synchronous, rectified, step-down switch-mode converter with built-in power MOSFETs. The MPQ4409 offers a very compact solution that achieves 900mA of continuous output current, with excellent load and line regulation across a wide input supply range. The MPQ4409 uses synchronous mode operation for higher efficiency across the output current load range.

Current mode operation provides fast transient response and eases loop stabilization. Full protection features include over-current protection (OCP) and thermal shutdown.

The MPQ4409 requires a minimal number of readily available, standard external components. It is available in a space-saving QFN-13 (2.5mmx3mm) package.

FEATURES

- Wide 4V to 24V Operating Input Range
- 900mA Continuous Load Current
- 90mΩ/50mΩ Low $R_{DS(ON)}$ Internal Power MOSFETs
- High-Efficiency Synchronous Mode Operation
- Default 2.2MHz Switching Frequency
- 450kHz to 2.2MHz Frequency Sync
- Forced Continuous Conduction Mode (CCM)
- Internal Soft Start (SS)
- Power Good (PG) Indicator
- Over-Current Protection (OCP) with Valley-Current Detection and Hiccup Mode
- Thermal Shutdown
- Output Adjustable from 0.807V
- CISPR25 Class 5 Compliant
- Available in a QFN-13 (2.5mmx3mm) Package
- Available in a Wettable Flank Package
- Available in AEC-Q100 Grade 1

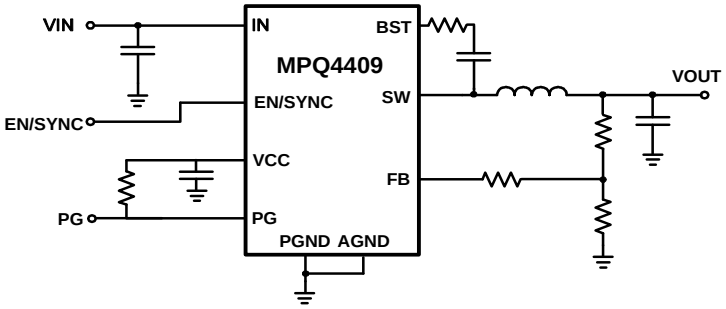
APPLICATIONS

- Automotive Infotainment
- Automotive Clusters
- Automotive Telematics
- Industrial Power Systems

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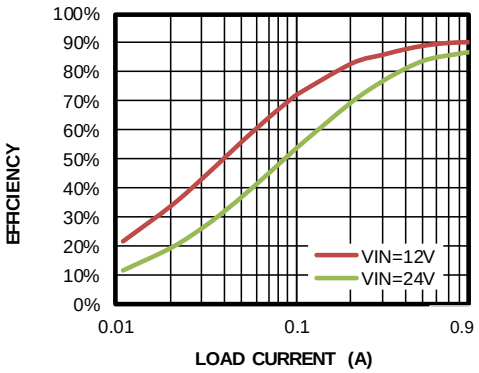
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TYPICAL APPLICATION



Efficiency vs. Load Current

V_{OUT} = 5V, L = 2.2µH



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ORDERING INFORMATION

Part Number*	Package	Top Marking	MSL Rating**
MPQ4409GQBE-AEC1***	QFN-13 (2.5mmx3mm)	*See Below*	1

* For Tape & Reel, add suffix –Z (e.g. MPQ4409GQBE-AEC1–Z).

** Moisture Sensitivity Level Rating.

*** Wettable Flank.

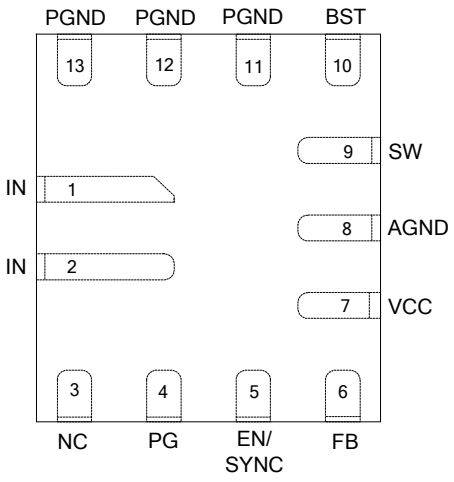
TOP MARKING

BPZ
YWW
LLL

BPZ: Product code of MPQ4409GQBE-AEC1
Y: Year code
WW: Week code
LLL: Lot number

PACKAGE REFERENCE

TOP VIEW



QFN-13 (2.5mmx3mm)

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PIN FUNCTIONS

Pin #	Name	Description
1, 2	IN	**Supply voltage.** IN supplies power for the internal MOSFET and regulator. The MPQ4409 operates from a 4V to 24V input rail. A low-ESR, low-inductance capacitor is required to decouple the input rail. Place the input capacitor very close to IN and connect it with wide PCB traces and multiple vias.
3	NC	**No connection.** Do not connect.
4	PG	**Power good indicator.** The output of PG is an open drain. PG goes high if the output voltage exceeds 88% of the nominal voltage.
5	EN/SYNC	**Enable/synchronize.** Pull EN/SYNC high to enable the MPQ4409. Float EN/SYNC or connect EN/SYNC to ground to disable the MPQ4409. If an external sync clock is applied to EN/SYNC, the internal clock follows the sync frequency.
6	FB	**Feedback.** Connect FB to the tap of an external resistor divider from the output to AGND to set the output voltage. The frequency foldback comparator lowers the oscillator frequency when the FB voltage is below 400mV. This prevents current limit runaway during a short-circuit fault. Place the resistor divider as close to FB as possible. Avoid placing vias on the FB traces.
7	VCC	**Internal bias supply.** Decouple VCC with a 0.1µF to 0.22µF capacitor. The capacitance should be not exceed 0.22µF.
8	AGND	**Analog ground.** AGND is the reference ground of the logic circuit. AGND is internally connected to PGND. Do not add external connections to PGND.
9	SW	**Switch output.** Connect SW using a wide PCB trace.
10	BST	**Bootstrap.** Connect a capacitor between SW and BST to form a floating supply across the high-side switch driver. It is strongly recommended to place a 20Ω resistor between the SW and BST capacitor to reduce SW voltage spikes.
11, 12, 13	PGND	**Power ground.** PGND is the reference ground of the power device, and requires careful consideration when designing the PCB layout. For the best results, connect PGND with copper pours and vias.

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ABSOLUTE MAXIMUM RATINGS (1)

Supply voltage (V_{IN}) .....-0.3V to +28V
Switch voltage (V_{SW}) .....-0.3V to V_{IN} + 0.3V
BST voltage (V_{BST}) ..... V_{SW} + 6V
All other pins ..... -0.3V to +6V (2)
Continuous power dissipation (T_A = 25°C) (3)
QFN-13 (2.5mmx3mm)..... 2.08W
Junction temperature .....150°C
Lead temperature .....260°C
Storage temperature..... -65°C to 150°C

Electrostatic Discharge (ESD) Level

Human body model (HBM) ..... ±2kV
Charged device model (CDM) …….. ±750V

Recommended Operating Conditions

Supply voltage (V_{IN}) .....4V to 24V
Output voltage (V_{OUT})..... 0.807V to V_{IN} x D_{MAX}
Operating junction temp (T_J).... -40°C to +125°C

Thermal Resistance θ_{JA} θ_{JC}

QFN-13 (2.5mmx3mm)		
JESD51-7 (4)	60	13 °C/W
EVQ4409-QB-00A (5)	42	2.5 °C/W

Notes:

1) Absolute maximum ratings are rated under room temperature unless otherwise noted. Exceeding these ratings may damage the device.
2) For details on EN/SYNC's ABS max rating, see the Enable/SYNC section on page 14.
3) 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) = (TJ (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.
4) Measured on JESD51-7, 4-layer PCB.
5) Measure on MPS standard EVB of MPQ4409, 4-layer PCB, 64mmx64mm.

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ELECTRICAL CHARACTERISTICS

V_{IN} = 12V, V_{EN} = 2V, T_J = -40°C to +125°C, typical values are at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Shutdown supply current	I_{SHDN}	V_{EN} = 0V			8	μA
Quiescent supply current	I_Q	V_{EN} = 2V, V_{FB} = 1V, no switching		0.6	0.8	mA
HS switch on resistance	R_{ON_HS}	V_{BST-SW} = 5V		90	155	mΩ
LS switch on resistance	R_{ON_LS}	V_{CC} = 5V		50	105	mΩ
Switch leakage	I_{SW_LKG}	V_{EN} = 0V, V_{SW} = 12V			1	μA
Current limit (6)	I_{LIMIT}	20% duty cycle	2.2	3.8	6.0	A
Low-side valley current limit			1.5	2.3	3.5	A
Reverse current limit				1.2		A
Oscillator frequency	f_{SW}	V_{FB} = 700mV	1800	2200	2600	kHz
Foldback frequency during soft start (6)	f_{FB}	V_{FB} = 200mV		440		kHz
Maximum duty cycle	D_{MAX}	V_{FB} = 700mV		85		%
Minimum on time (6)	t_{ON_MIN}			46		ns
Synchronous frequency range	f_{SYNC}		450		2200	kHz
Feedback voltage	V_{FB}	T_J = 25°C	795	807	819	mV
		T_J = -40°C to +125°C	790	807	824	mV
Feedback current	I_{FB}	V_{FB} = 820mV		10	50	nA
EN/SYNC rising threshold	V_{EN_RISING}		1.1	1.45	1.8	V
EN/SYNC falling threshold	$V_{EN_FALLING}$		0.7	1	1.3	V
EN/SYNC threshold hysteresis	V_{EN_HYS}			450		mV
EN/SYNC input current	I_{EN}	V_{EN} = 2V		5	10	μA
		V_{EN} = 0V		0	0.2	μA
EN turn off delay				3		μs
V_{IN} under-voltage lockout rising threshold	$INUV_{RISING}$		3	3.5	3.8	V
V_{IN} under-voltage lockout threshold hysteresis	$INUV_{HYS}$			330		mV

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ELECTRICAL CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{EN} = 2V, T_J = -40°C to +125°C, typical values are at T_J = 25°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
PG rising threshold	PG_{VTH_RISING}	As a percentage of V_{FB}	83	88	93	%
PG falling threshold	$PG_{VTH_FALLING}$	As a percentage of V_{FB}	78	83	88	%
PG threshold hysteresis	PG_{VTH_HYS}	As a percentage of V_{FB}		5		%
PG rising delay	PG_{TD_RISING}		30	90	160	µs
PG falling delay	$PG_{TD_FALLING}$		30	55	95	µs
PG sink current capability	V_{PG}	Sink 4mA			0.4	V
PG leakage current	I_{PG_LKG}			10	100	nA
VCC regulator	V_{CC}	I_{CC} = 0mA	4.6	4.9	5.2	V
VCC load regulation		I_{CC} = 5mA		1.5	4	%
Soft-start time	t_{SS}	V_{OUT} from 10% to 90%	0.45	1.5	3	ms
Thermal shutdown (6)				170		°C
Thermal hysteresis (6)				30		°C

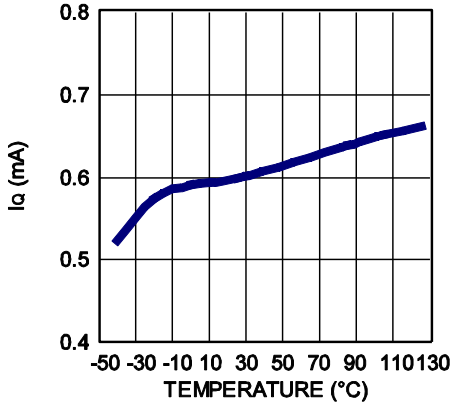
Note:

6) Not tested in production. Guaranteed by design and characterization.

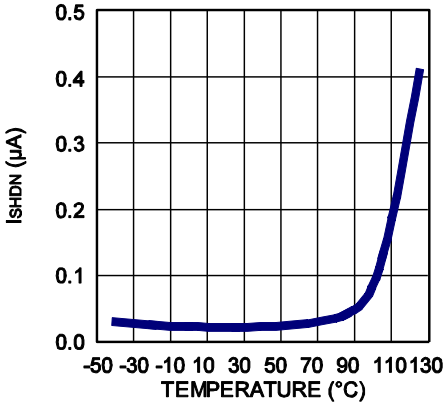
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TYPICAL CHARACTERISTICS

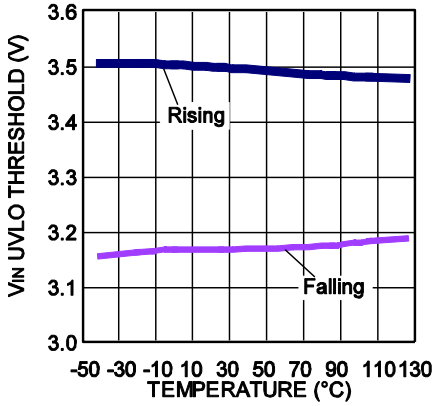
Quiescent Current vs. Temperature



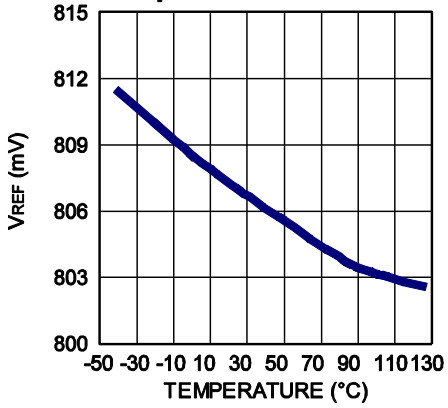
Shutdown Current vs. Temperature



VIN UVLO Threshold vs. Temperature



Feedback Reference vs. Temperature



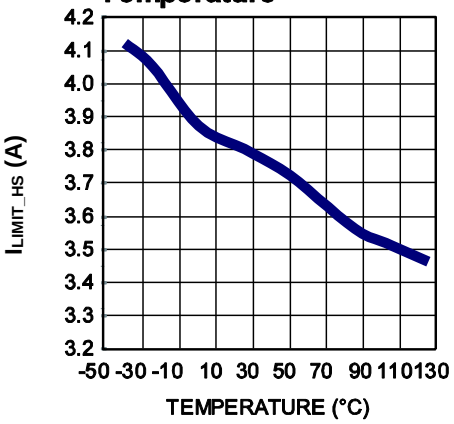
Switching Frequency vs. Temperature



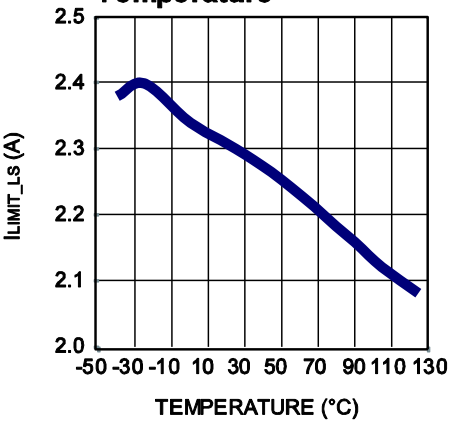
Max Duty Cycle vs. Temperature



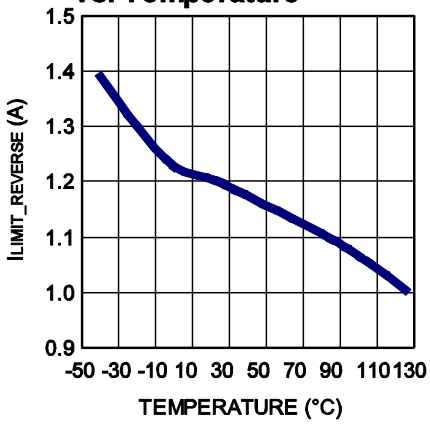
Current Limit vs. Temperature



Valley Current Limit vs. Temperature



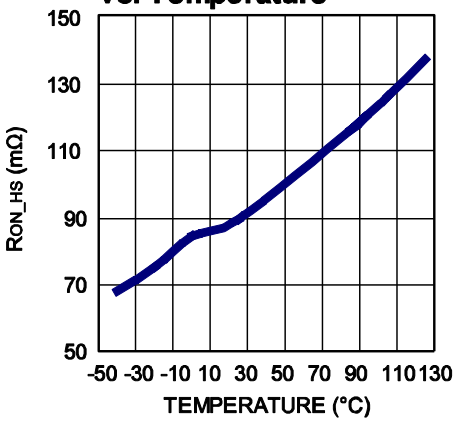
Reverse Current Limit vs. Temperature



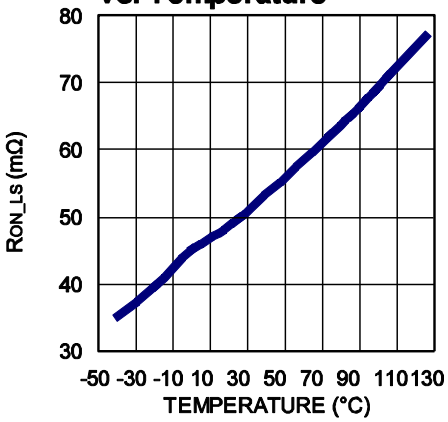
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TYPICAL CHARACTERISTICS *(continued)*

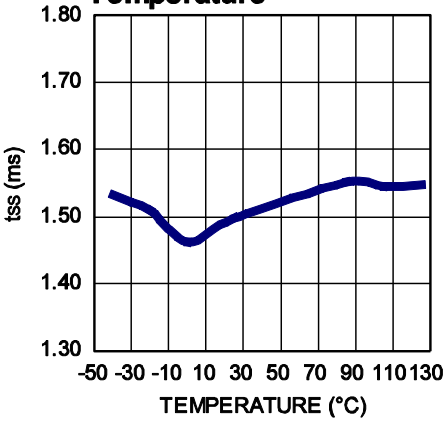
HS-FET On Resistance vs. Temperature



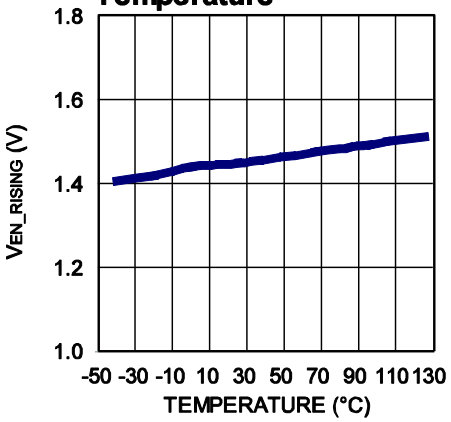
LS-FET On Resistance vs. Temperature



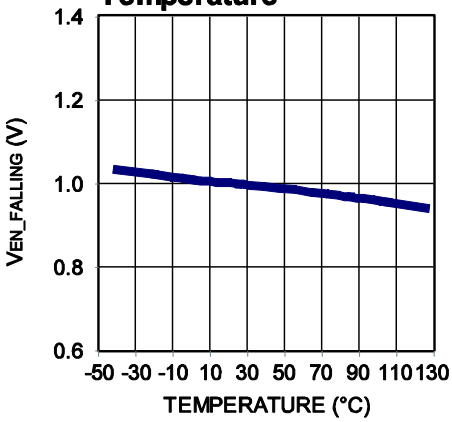
Soft-Start Time vs. Temperature



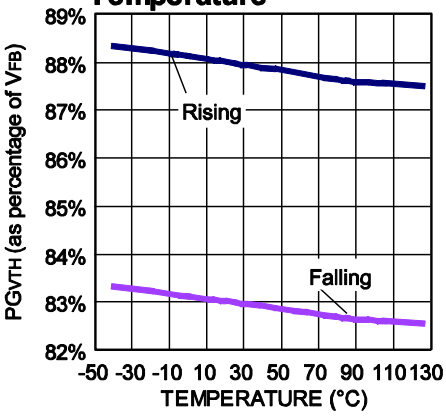
EN Rising Threshold vs. Temperature



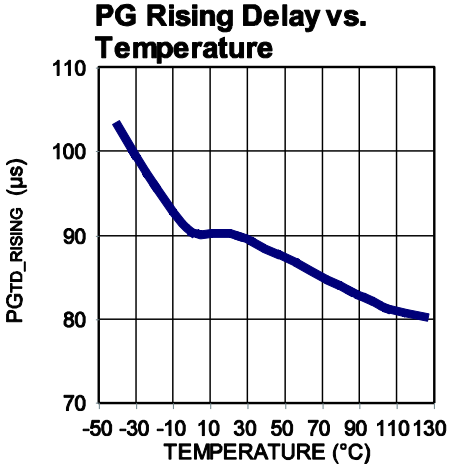
EN Falling Threshold vs. Temperature



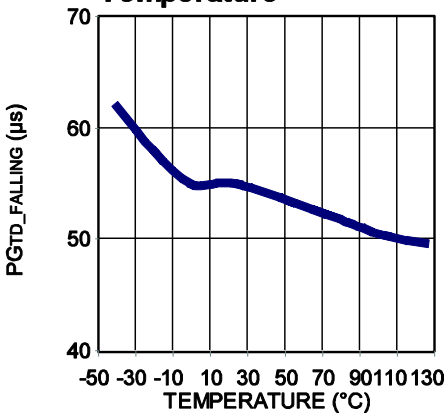
PG Threshold vs. Temperature



PG Rising Delay vs. Temperature



PG Falling Delay vs. Temperature

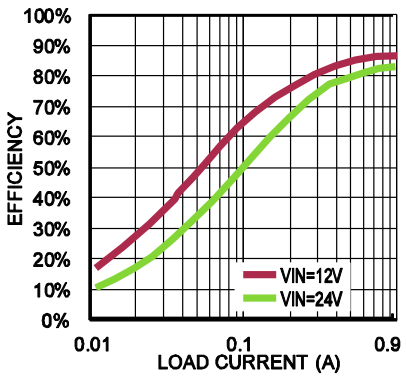


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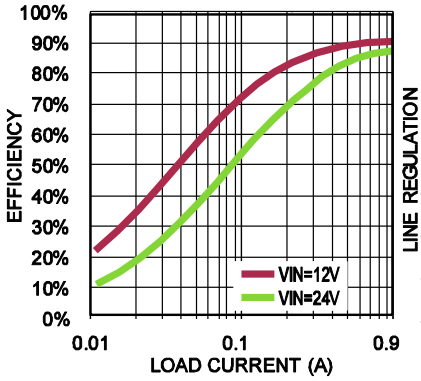
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 3.3V, L = 2.2µH, f_{SW} = 2.2MHz, T_A = 25°C, unless otherwise noted.

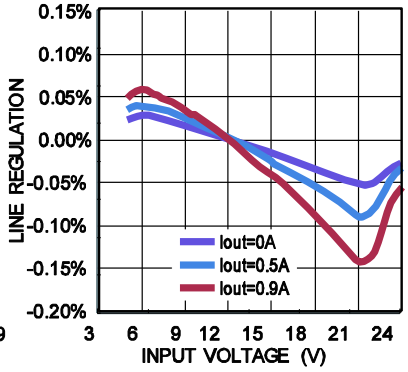
Efficiency vs. Load Current
V_{OUT} = 3.3V



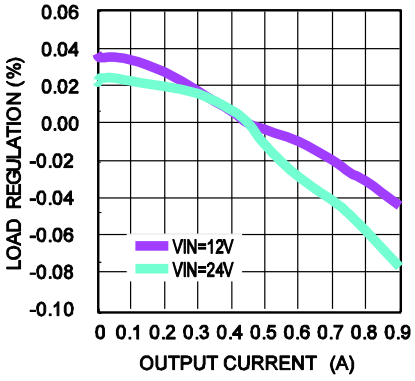
Efficiency vs. Load Current
V_{OUT} = 5V



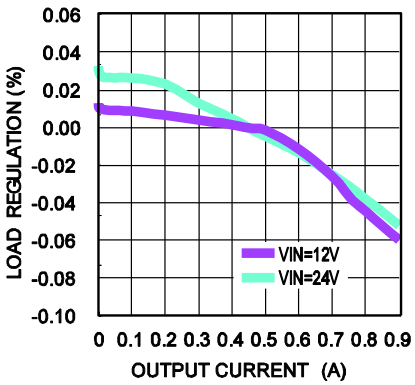
Line Regulation
I_{OUT} = 3.3V



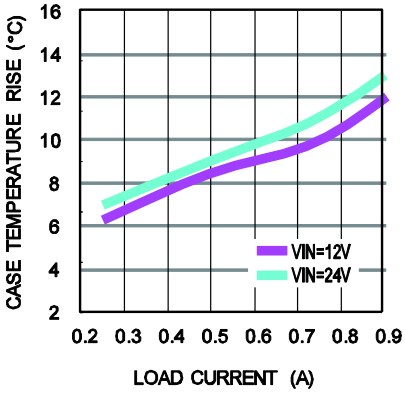
Load Regulation
V_{OUT} = 3.3V



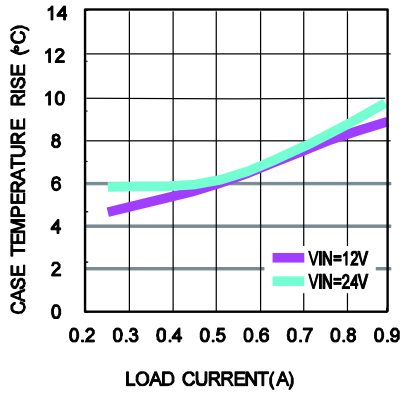
Load Regulation
V_{OUT} = 5V



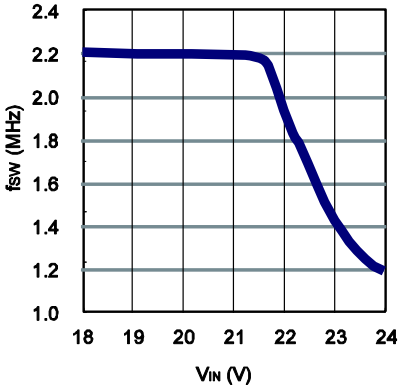
Case Temperature Rise vs. Load Current
V_{OUT} = 3.3V



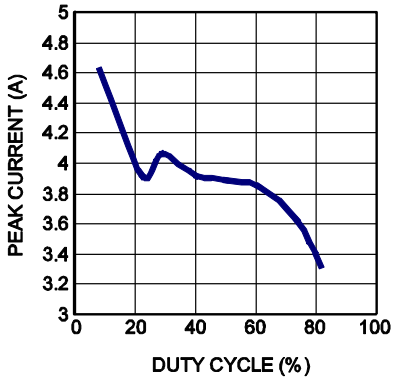
Case Temperature Rise vs. Load Current
V_{OUT} = 5V



FREQUENCY VS. V_{IN}



Peak Current vs. Duty Cycle



Note:

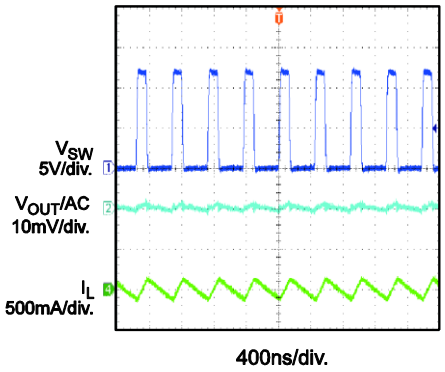
7) The load/line regulation diagrams do not take the feedback voltage accuracy into account.

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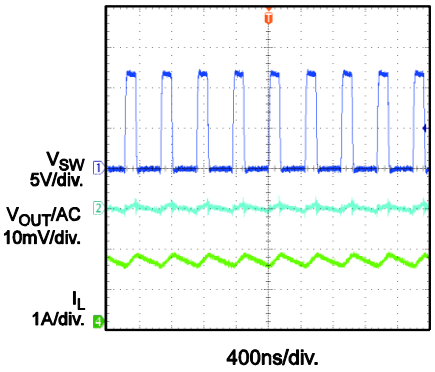
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 3.3V, L = 2.2µH, f_{SW} = 2.2MHz, T_A = 25°C, unless otherwise noted.

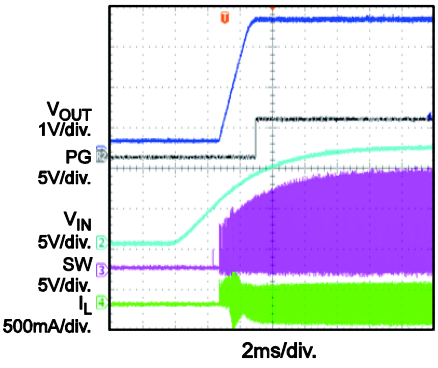
Steady State
I_{OUT} = 0A



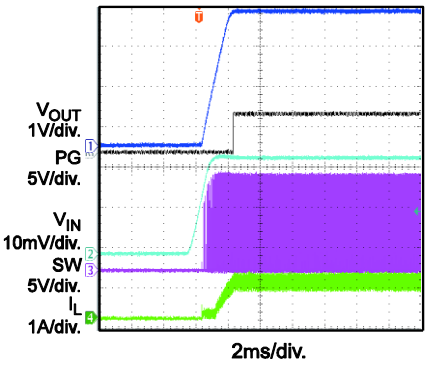
Steady State
I_{OUT} = 0.9A



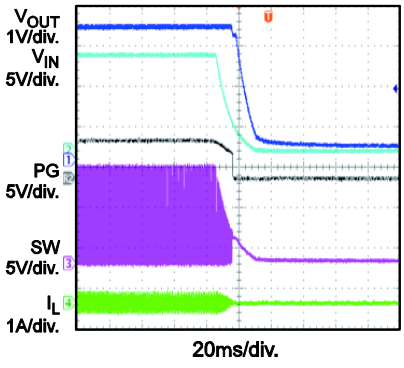
Start-Up through Input Voltage
I_{OUT} = 0A



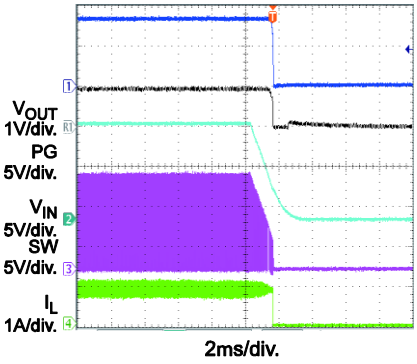
Start-Up through Input Voltage
I_{OUT} = 0.9A



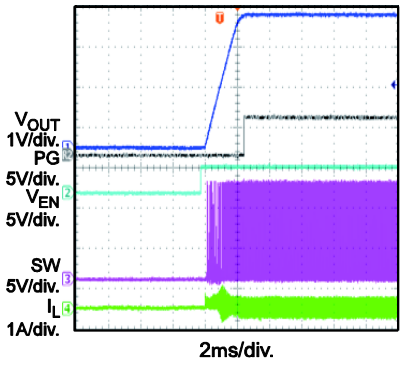
Shutdown through Input Voltage
I_{OUT} = 0A



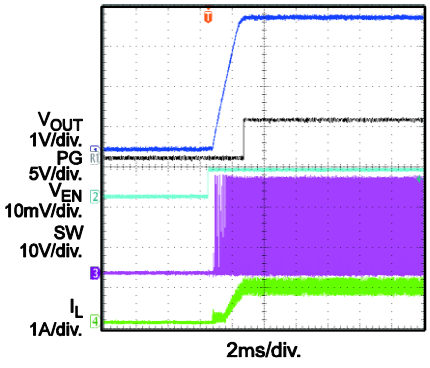
Start-Up through Input Voltage
I_{OUT} = 0.9A



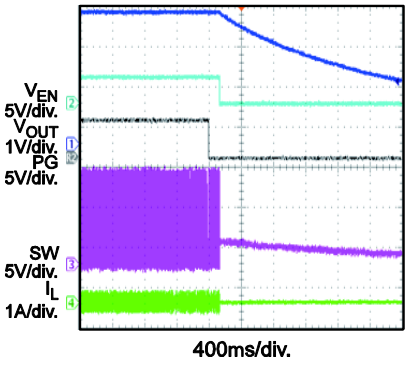
Start-Up through Enable
I_{OUT} = 0A



Start-Up through Enable
I_{OUT} = 0.9A



Shutdown through Enable
I_{OUT} = 0A

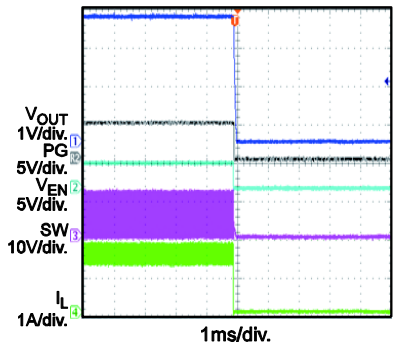


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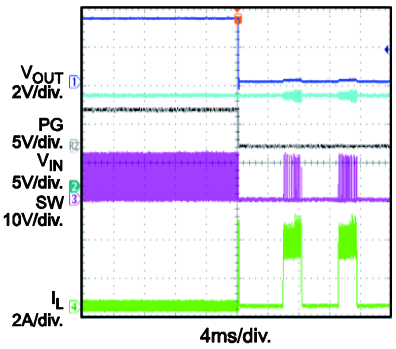
TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

V_{IN} = 12V, V_{OUT} = 3.3V, L = 2.2µH, f_{SW} = 2.2MHz, T_A = 25°C, unless otherwise noted.

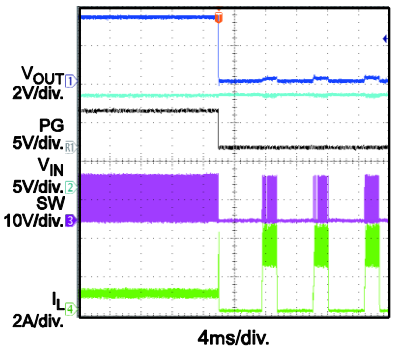
Shutdown through Enable
I_{OUT} = 1.5A



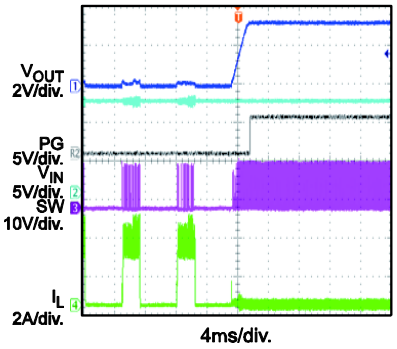
SCP Entry
I_{OUT} = 0A



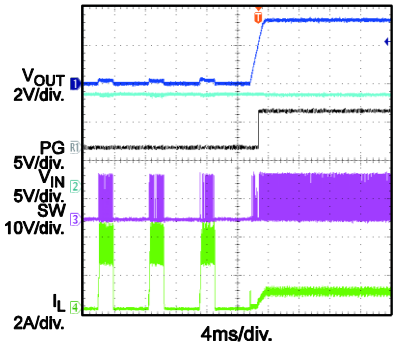
SCP Entry
I_{OUT} = 0.9A



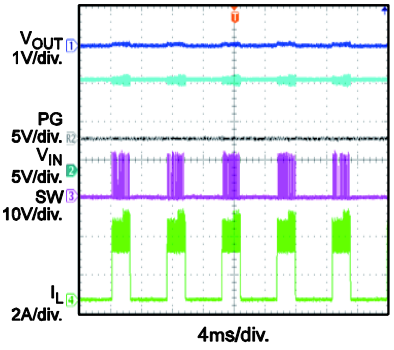
SCP Recovery
I_{OUT} = 0A



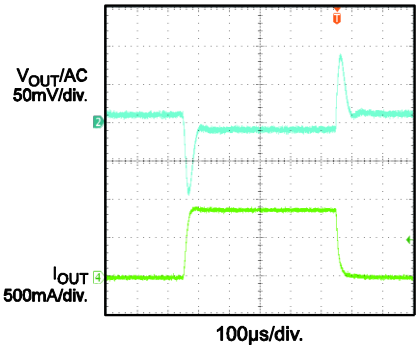
SCP Recovery
I_{OUT} = 0.9A



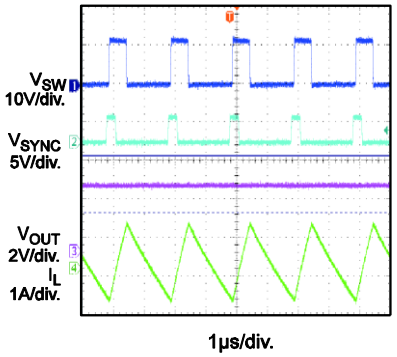
SCP Steady State



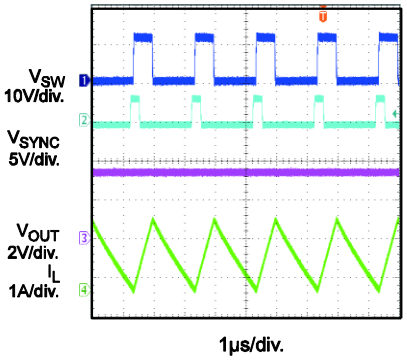
Load Transient
I_{OUT} = 0A to 0.9A



SYNC Operation
f_{SYNC} = 500kHz, D = 15%, I_{OUT} = 0A



SYNC Operation
f_{SYNC} = 500kHz, D = 15%, I_{OUT} = 0.9A



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FUNCTIONAL BLOCK DIAGRAM

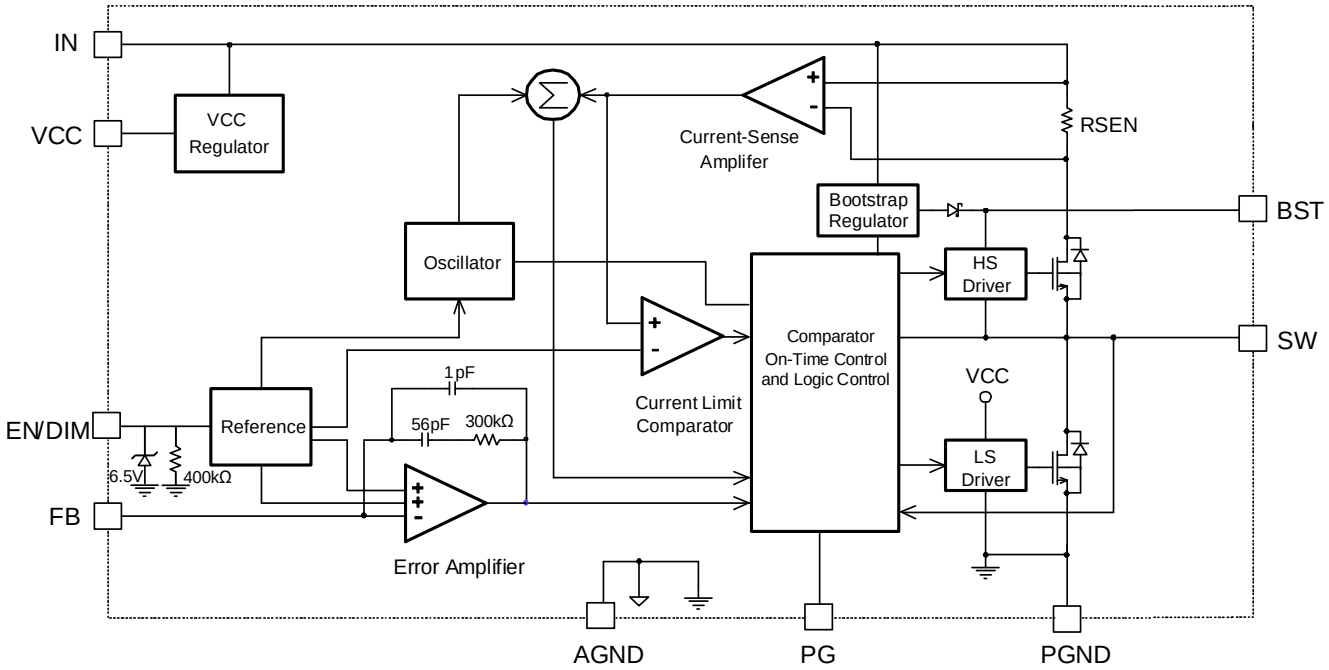


Figure 1: Functional Block Diagram

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OPERATION

The MPQ4409 is a high-frequency, synchronous, rectified, step-down switch-mode converter with built-in power MOSFETs. The MPQ4409 offers a very compact solution and achieves 900mA of continuous output current, with excellent load and line regulation across a 4V to 24V input supply range.

The MPQ4409 operates in a fixed-frequency, peak current control mode to regulate the output voltage. An internal clock initiates a pulse-width modulation (PWM) cycle. The integrated high-side power MOSFET (HS-FET) turns on and remains on until the current reaches the value set by the COMP voltage (V_{COMP}). When the power switch is off, it remains off until the next clock cycle begins. If the current in the power MOSFET does not reach the value set by V_{COMP} within 85% of one PWM period, the power MOSFET is forced off.

Internal Regulator

A 4.9V internal regulator powers most of the internal circuitries. This regulator uses V_{IN} as the input and operates in the full V_{IN} range. When V_{IN} exceeds 4.9V, the output of the regulator is in full regulation. When V_{IN} falls below 4.9V, the output decreases following V_{IN}. A 0.1µF decoupling ceramic capacitor is required at VCC.

Forced Continuous Conduction Mode (FCCM) Operation

The MPQ4409 uses forced continuous conduction mode (FCCM) to ensure that the part works with a fixed frequency from a no load to a full load range. The advantages of FCCM are its controllable frequency and lower output ripple under light-load conditions.

Frequency Foldback

The MPQ4409 enters frequency foldback when the input voltage exceeds 21V. The frequency decreases to half the nominal value and changes to 1.1MHz.

Frequency foldback also occurs during soft start and short-circuit protection.

Error Amplifier (EA)

The error amplifier (EA) compares the FB voltage (V_{FB}) to the internal 0.807V reference (V_{REF}) and outputs a current proportional to the difference between the two values. This output current then charges or discharges the internal compensation network to form V_{COMP}, which controls the power MOSFET current. The optimized internal compensation network minimizes the external component count and simplifies control loop design.

Under-Voltage Lockout (UVLO)

Under-voltage lockout (UVLO) protects the chip from operating at an insufficient supply voltage. The UVLO comparator monitors the output voltage of the internal regulator (VCC). The UVLO rising threshold is about 3.5V, with a 330mV hysteresis.

Enable/SYNC

EN/SYNC is a control pin that turns the regulator on and off. Drive EN/SYNC high to turn the regulator on; drive EN/SYNC low to turn it off. An internal 400kΩ resistor from EN/SYNC to GND allows EN/SYNC to be floated to shut down the chip.

EN/SYNC is clamped internally using a 6.5V series Zener diode (see Figure 2). Connecting the EN/SYNC input through a pull-up resistor to the voltage on VIN limits the EN input current below 100µA. For example, with 12V connected to V_{IN}, $R_{PULLUP} \geq (12V - 6.5V) / 100\mu A = 55k\Omega$.

Connecting EN/SYNC to a voltage source directly without a pull-up resistor requires limiting the amplitude of the voltage source to below 6V to prevent damage to the Zener diode.

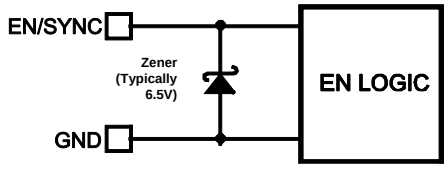


Figure 2: 6.5V Zener Diode Connection

Use an external clock with a range between 450kHz and 2.2MHz to synchronize the internal clock rising edge to the external clock rising edge. The pulse width of the external clock signal should be less than 350ns. The off time of the external clock signal should be less than 1.9µs.

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Internal Soft Start (SS)

Soft start (SS) prevents the converter output voltage from overshooting during start-up. When the chip starts up, the internal circuitry generates a soft-start voltage (V_{SS}). When V_{SS} is below the internal reference (V_{REF}), V_{SS} overrides V_{REF}, so the error amplifier uses V_{SS} as the reference. When V_{SS} exceeds V_{REF}, the error amplifier uses V_{REF} as the reference. The SS time is set to 1.5ms internally.

Power Good (PG)

The MPQ4409 has a power good (PG) indicator. PG is the open drain of a MOSFET, and should be connected to VCC or another voltage source through a resistor (e.g. 100kΩ). In the presence of an input voltage, the MOSFET turns on, and PG is pulled low before SS is ready. After V_{FB} reaches 88% of V_{REF}, PG is pulled high after a delay (typically 90μs). When V_{FB} drops to 83% of V_{REF}, PG is pulled low. PG is also pulled low if thermal shutdown occurs or EN/SYNC is pulled low.

Over-Current Protection (OCP) and Hiccup

The MPQ4409 has cycle-by-cycle peak current limit protection and valley current detection protection. The inductor current is monitored while the HS-FET is on. If the inductor current exceeds the current-limit value set by the COMP high-clamp voltage, the HS-FET turns off immediately. Then the low-side MOSFET (LS-FET) turns on to discharge the energy, and the inductor current decreases.

The HS-FET remains off until the inductor valley current drops below a certain current threshold (the valley current limit), even if the internal clock pulses high. If the inductor current does not drop below the valley current limit when the internal clock pulses high, the HS-FET misses the clock and the switching frequency decreases to half the nominal value. Both the peak and valley current limits prevent the inductor current from running away during an overload or short-circuit condition.

If the output voltage drops below the under-voltage (UV) threshold (typically 50% below V_{REF}), the peak current limit is triggered simultaneously, and the MPQ4409 enters hiccup mode to periodically restart the part.

This protection mode is useful when the output is dead-shorted to ground. It also reduces the average short-circuit current to alleviate thermal issues and protect the regulator. The MPQ4409 exits hiccup mode once the over-current condition is removed.

Thermal Shutdown

Thermal shutdown prevents the chip from operating at exceedingly high temperatures. When the die temperature exceeds 170°C, the entire chip shuts down. When the temperature drops below its lower threshold (typically 140°C), the chip is enabled again.

Floating Driver and Bootstrap Charging

An external bootstrap capacitor powers the floating power MOSFET driver. The floating driver has its own under-voltage lockout (UVLO) protection, with a rising threshold of 2.2V and a hysteresis of 150mV. A dedicated internal regulator charges and regulates the bootstrap capacitor voltage to about 5V (see Figure 3).

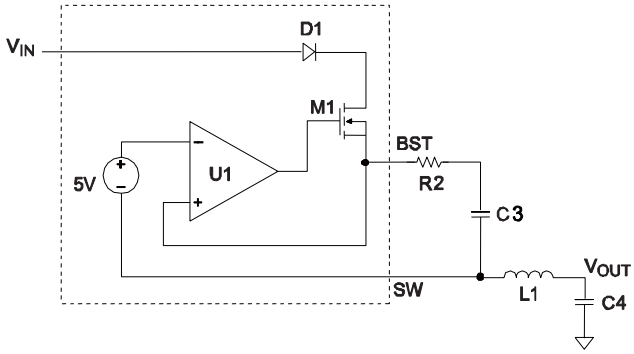


Figure 3: Internal Bootstrap Charging Circuit

When the voltage between the BST and SW nodes drops below regulation, a PMOS pass transistor connected from VIN to BST turns on. Then charging current path goes from VIN to BST to SW. The external circuit should provide enough voltage headroom to facilitate charging.

If V_{IN} stays above SW, the bootstrap capacitor remains charged. If the HS-FET is on, and V_{IN} is about equal to V_{SW}, the bootstrap capacitor cannot be charged. When the LS-FET is on, V_{IN} - V_{SW} reaches its maximum for fast charging.

If there is no inductor current, V_{SW} equals V_{OUT}, and the difference between V_{IN} and V_{OUT} can charge the bootstrap capacitor. To reduce SW

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voltage spikes, place a 20Ω resistor between the SW and BST capacitor.

Start-Up and Shutdown

If both V_{IN} and EN/SYNC exceed their thresholds, the chip starts up. The reference block starts first, generating a stable reference voltage and current, and then the internal regulator is enabled. The regulator provides a stable supply for the remaining circuitries.

Three events can shut down the chip: V_{IN} going low, EN/SYNC going low, and thermal shutdown. During the shutdown procedure, the signaling path is blocked first to avoid unintentional fault triggers. V_{COMP} and the internal supply rail are then pulled down. The floating driver is not subject to this shutdown command.

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APPLICATION INFORMATION

Setting the Output Voltage

The output voltage is set by the external resistor divider connected to FB (see Figure 4). The feedback resistor (R1) sets the feedback loop bandwidth with the internal compensation capacitor. Choose R_{FB1} to be about 40kΩ when V_{OUT} is at least 1V. R_{FB2} can then be calculated with Equation (1):

$$R_{FB2} = \frac{R_{FB1}}{\frac{V_{OUT}}{0.807V} - 1} \quad (1)$$

Use of a T-type network is highly recommended when V_{OUT} is low (see Figure 4).

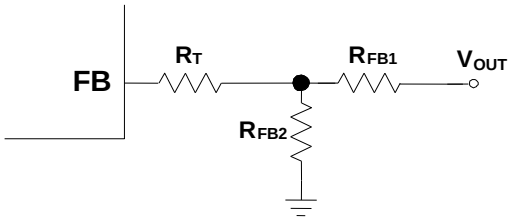


Figure 4: T-Type Feedback Network

R_T and R_{FB1} are used to set the loop bandwidth. The lower $R_T + R_{FB1}$ is, the higher the bandwidth. However, a high bandwidth may cause an insufficient phase margin, resulting in loop instability. Therefore, a proper R_T value is required to make a tradeoff between the bandwidth and phase margin. Table 1 lists the recommended feedback resistor and R_T values for common output voltages.

Table 1: Resistor Selection for Common Output

V_{OUT} (V)	R_{FB1} (kΩ)	R_{FB2} (kΩ)	R_T (kΩ)
3.3	41.2 (1%)	13 (1%)	51 (1%)
5	41.2 (1%)	7.68 (1%)	51 (1%)

Selecting the Input Capacitor

The step-down converter has a discontinuous input current, and requires a capacitor to supply AC current to the converter while maintaining the DC input voltage. For the best performance, use low-ESR capacitors. Ceramic capacitors with X5R or X7R dielectrics are highly recommended because of their low ESR and small temperature coefficients.

For most applications, use a 4.4µF to 10µF capacitor. It is strongly recommended to use another, lower-value capacitor (e.g. 0.1µF) with a small package size (0603) to absorb high-frequency switching noise. Place the smaller capacitor as close to IN and GND as possible.

Since C_{IN} absorbs the input switching current, it requires an adequate ripple current rating. The RMS current in the input capacitor can be estimated with Equation (2):

$$I_{CIN} = I_{LOAD} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \times (1 - \frac{V_{OUT}}{V_{IN}})} \quad (2)$$

The worst-case condition occurs at $V_{IN} = 2V_{OUT}$, calculated with Equation (3):

$$I_{CIN} = \frac{I_{LOAD}}{2} \quad (3)$$

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 ceramic capacitor (e.g. 0.1µF) 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 input. The input voltage ripple caused by the capacitance can be estimated with Equation (4):

$$\Delta V_{IN} = \frac{I_{LOAD}}{f_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \times (1 - \frac{V_{OUT}}{V_{IN}}) \quad (4)$$

Selecting the Output Capacitor

The output capacitor maintains the DC output voltage. Use ceramic, tantalum, or low-ESR electrolytic capacitors. For the best results, use low-ESR capacitors to keep the output voltage ripple low. The output voltage ripple can be estimated with Equation (5):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} \times L} \times (1 - \frac{V_{OUT}}{V_{IN}}) \times (R_{ESR} + \frac{1}{8 f_{SW} \times C_{OUT}}) \quad (5)$$

Where L is the inductor value, and R_{ESR} is the equivalent series resistance (ESR) value of the output capacitor.

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For 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 (6):

$$\Delta V_{OUT} = \frac{V_{OUT}}{8 \times f_{SW}^2 \times L \times C_{OUT}} \times (1 - \frac{V_{OUT}}{V_{IN}}) \quad (6)$$

For tantalum or electrolytic capacitors, the ESR dominates the impedance at the switching frequency. For simplification, the output ripple can be estimated with Equation (7):

$$\Delta V_{OUT} = \frac{V_{OUT}}{f_{SW} \times L} \times (1 - \frac{V_{OUT}}{V_{IN}}) \times R_{ESR} \quad (7)$$

The characteristics of the output capacitor also affect the stability of the regulation system. The MPQ4409 can be optimized for a wide range of capacitance and ESR values.

Selecting the Inductor

A 1µH to 10µH inductor with a DC current rating at least 25% greater than the maximum load current is recommended for most applications. For higher efficiency, choose an inductor with a lower DC resistance. A larger-value inductor results in less ripple current and a lower output ripple voltage, but also has a larger physical size, higher series resistance, and lower saturation current. A good rule to determine the inductor value is to allow the inductor ripple current to be approximately 30% of the maximum load current. The inductance value can then be calculated with Equation (8):

$$L = \frac{V_{OUT}}{f_{SW} \times \Delta I_L} \times (1 - \frac{V_{OUT}}{V_{IN}}) \quad (8)$$

Where ΔI_L is the peak-to-peak inductor ripple current.

Choose the inductor ripple current to be approximately 30% of the maximum load current. The maximum inductor peak current can be calculated with Equation (9):

$$I_{LP} = I_{LOAD} + \frac{V_{OUT}}{2 f_{SW} \times L} \times (1 - \frac{V_{OUT}}{V_{IN}}) \quad (9)$$

V_{IN} UVLO Setting

The MPQ4409 has an internal, fixed under-voltage lockout (UVLO) threshold. The rising threshold is 3.5V, while the falling threshold is about 3.17V. For applications that require a higher UVLO point, add an external resistor divider between IN and EN/SYNC to achieve a higher equivalent UVLO threshold (see Figure 5).

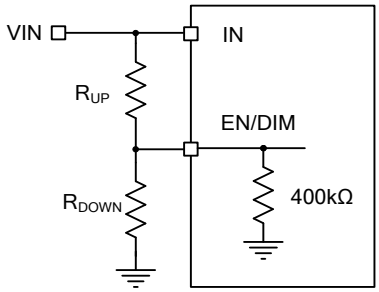


Figure 5: Adjustable UVLO using EN Divider

The UVLO rising threshold and falling threshold can be calculated with Equation (10) and Equation (11), respectively:

$$INUV_{RISING} = (1 + \frac{R_{UP}}{\frac{400k \times R_{DOWN}}{400k + R_{DOWN}}}) \times V_{EN_RISING} \quad (10)$$

$$INUV_{FALLING} = (1 + \frac{R_{UP}}{\frac{400k \times R_{DOWN}}{400k + R_{DOWN}}}) \times V_{EN_FALLING} \quad (11)$$

Where V_{EN_RISING} = 1.45V, and $V_{EN_FALLING}$ = 1V.

When choosing R_{UP}, ensure that it can sufficiently limit the current flowing into EN/SYNC below 100µA.

BST Resistor and External BST Diode

Place a 20Ω resistor in series with the BST capacitor to reduce SW voltage spikes. A higher resistance is better for SW spike reduction, but also compromises efficiency.

An external BST diode can enhance the efficiency of the regulator when the duty cycle is high (>65%). A power supply between 2.5V and 5V can be used to power the external bootstrap diode. VCC or VOUT is recommended for this power supply in the circuit (see Figure 6).

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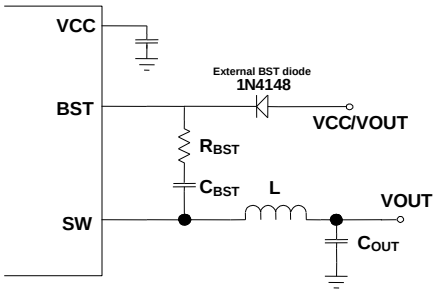


Figure 6: Optional External Bootstrap Diode to Enhance Efficiency

The recommended external BST diode is IN4148, and the recommended BST capacitor value is 0.1µF to 1µF.

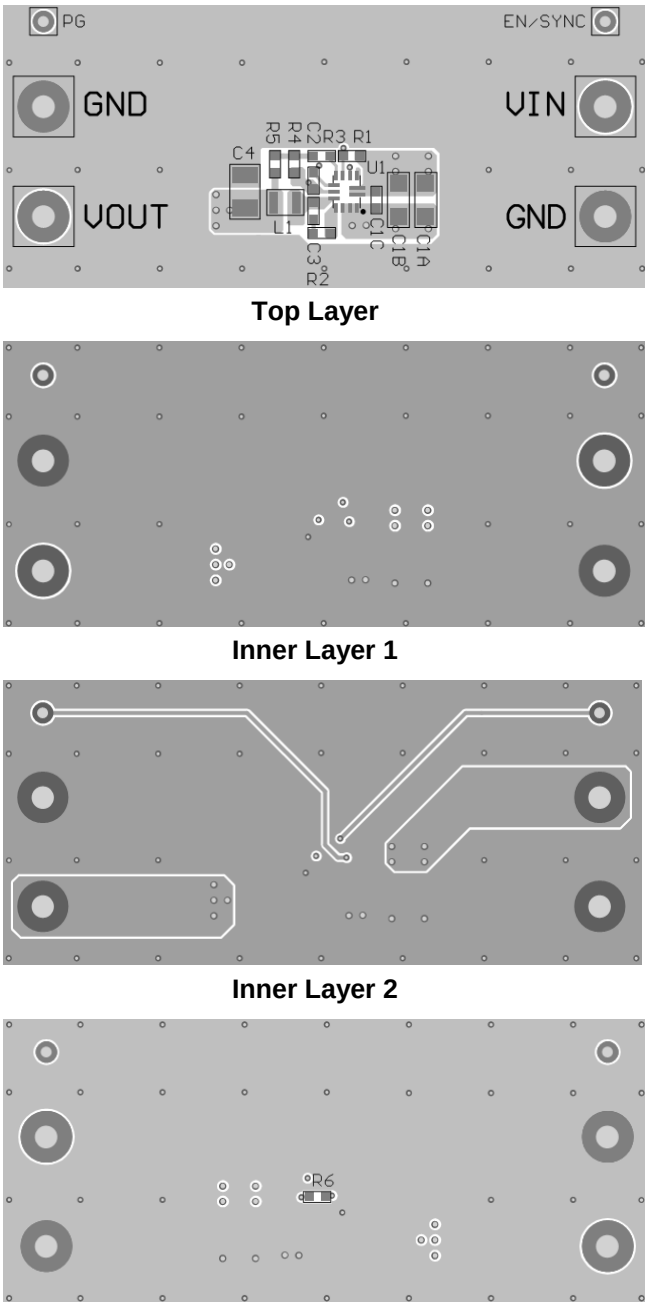
PCB Layout Guidelines (8)

Efficient PCB layout, especially regarding input capacitor placement, is critical for stable operation. A 4-layer layout is strongly recommended to achieve better thermal performance. For the best results, refer to Figure 7 and follow the guidelines below:

1. Use a large ground plane to connect directly to PGND. If the bottom layer is a ground plane, add vias near PGND.
2. Ensure that the high-current paths at GND and IN have short, direct, and wide traces.
3. Place the ceramic input capacitor, especially the small-sized input bypass capacitor (0603), as close to IN and PGND as possible to minimize high-frequency noise.
4. Keep the connection of the input capacitor and IN as short and wide as possible.
5. Place the VCC capacitor to VCC and AGND as close as possible.
6. Route SW and BST away from sensitive analog areas, such as FB.
7. Place the feedback resistors close to the chip to ensure that the trace connecting to FB is as short as possible.
8. Use multiple vias to connect the power planes to internal layers.

Note:

8) The recommended layout is based on Figure 8.



Top Layer

Inner Layer 1

Inner Layer 2

Bottom Layer

Figure 7: Recommended PCB Layout

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TYPICAL APPLICATION CIRCUITS

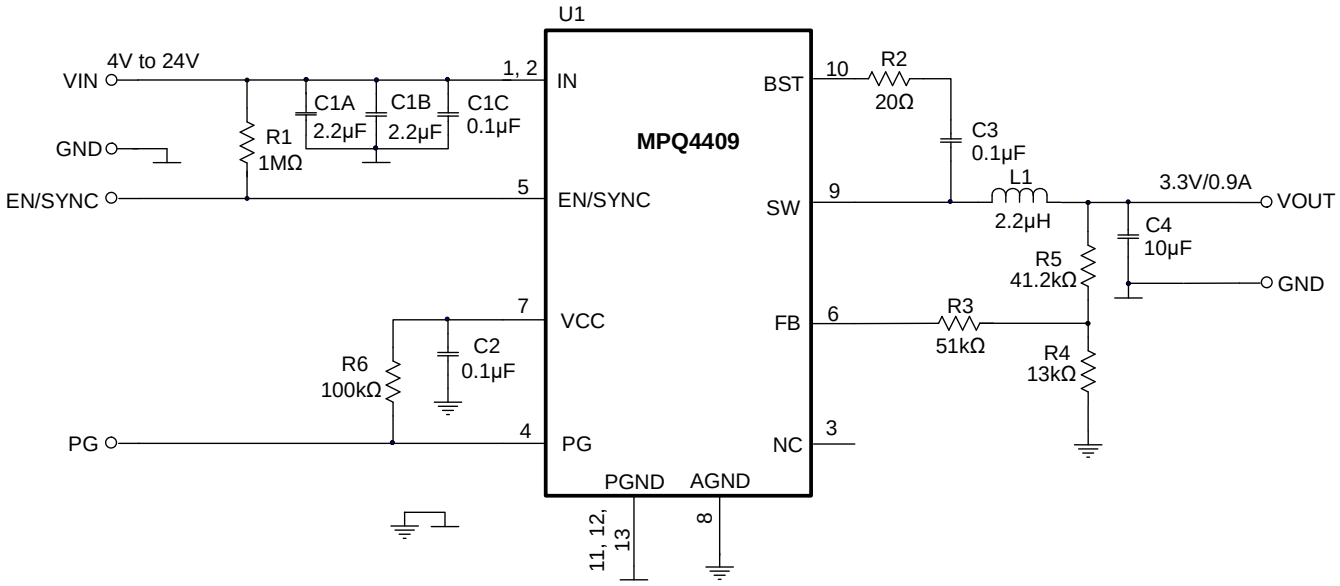


Figure 8: Typical Application Circuit, V_{OUT} = 3.3V, I_{OUT} = 900mA

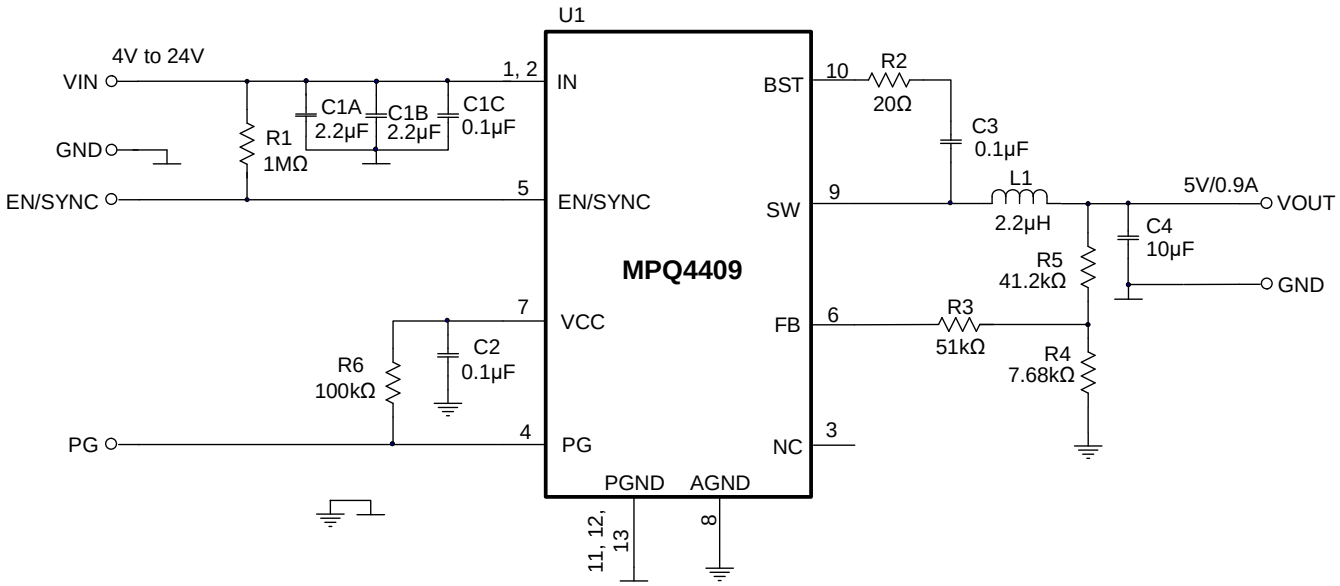


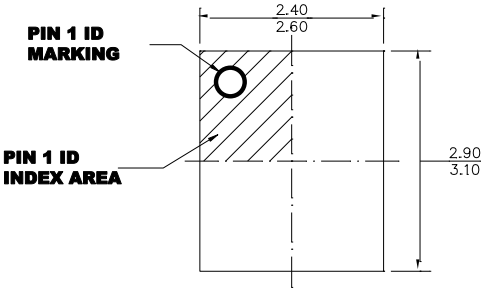
Figure 9: Typical Application Circuit, V_{OUT} = 5V, I_{OUT} = 900mA

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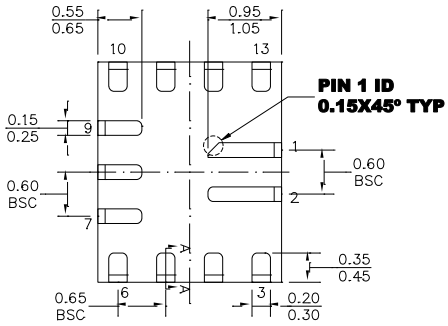
PACKAGE INFORMATION

QFN-13 (2.5mmx3mm)

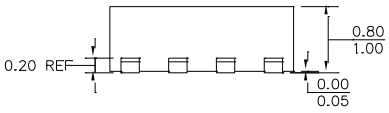
Wettable Flank



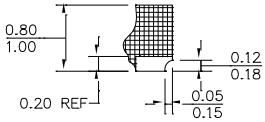
TOP VIEW



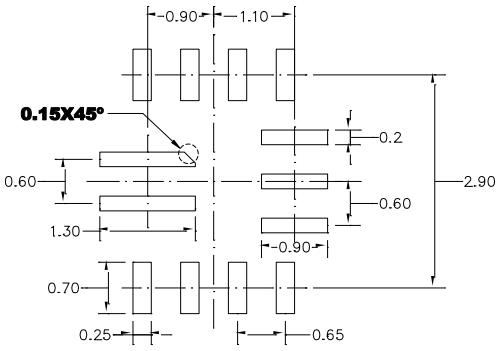
BOTTOM VIEW



SIDE VIEW



SECTION A-A



RECOMMENDED LAND PATTERN

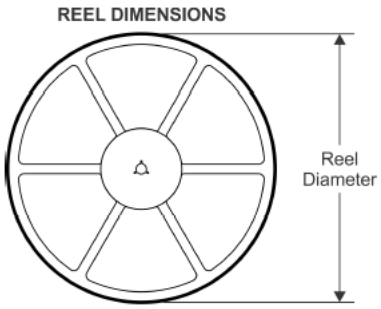
NOTE:

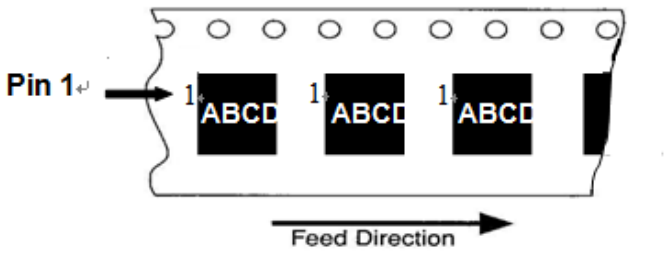
1) THE LEAD SIDE IS WETTABLE.
2) ALL DIMENSIONS ARE IN MILLIMETERS.
3) LEAD COPLANARITY SHALL BE 0.08 MILLIMETERS MAX.
4) JEDEC REFERENCE IS MO-220.
5) DRAWING IS NOT TO SCALE.

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CARRIER INFORMATION





Part Number	Package Description	Quantity/ Reel	Quantity/ Tube	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MPQ4409GQBE-AEC1–Z	QFN-13 (2.5mmx3mm)	5000	N/A	13in	12mm	8mm

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Revision History

Revision #	Revision Date	Description	Pages Updated
1.0	4/30/2020	Initial Release	-

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