48V Input, 400 mA Output, 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator

MCP16367/8/9

Description

The MCP16367/8/9 family consists of highly integrated, high-efficiency, fixed-frequency, step-down DC-DC converters available in a compact 8-lead, 3 mm x 3 mm VDFN package supporting input voltages up to 48V. Key integrated features include a high-side switch, fixed-frequency Peak Current Mode Control, Internal Compensation, Power Good indication, Peak Current Limit and Overtemperature Protection. These devices provide all necessary functions for local DC-DC conversion, delivering fast transient response and precise regulation.

High efficiency conversion is achieved by integrating the current-limited, high-speed N-Channel MOSFET and associated drive circuitry. The high switching frequency minimizes the size of the external filtering components, enabling a compact solution.

The MCP16367/8/9 can supply 400 mA of continuous current, with output voltage from 2.0V to 24V. An integrated, high-performance peak current mode control architecture keeps the output voltage tightly regulated, even during input voltage steps and output current transient conditions that are common in power systems.

The MCP16367 is capable of running in PFM/PWM mode. It switches in PFM mode for light load conditions and for large step-down conversion ratios. This results in a higher efficiency over all load ranges.

By comparison, the MCP16368 runs in PWM-only mode and is recommended for applications where the low-frequency component associated with the PFM mode of operation is not desirable.

Besides the two aforementioned options, the MCP16369 is designed for EMI-constrained applications where reduced peak emissions are required. This is achieved by sweeping the switching frequency over a 10% range above the 2.2 MHz nominal value.

Output voltage is set with an external resistor divider. The Power Good output pin transitions from logic-low to logic-high (via an external pull-up resistor) when the output voltage is within 93% of the nominal set point. The EN input is used to turn the device on and off. While off, only a few micro-amps of current are consumed from the input.

The MCP16367/8/9 is offered in a space-saving, 8-lead 3 mm x 3 mm VDFN wettable flanks surface-mount package.

The MCP16367/8/9 also passes automotive AEC-Q100 reliability testing.

Features

- Input Voltage Range: 4.0V (After Start-Up) to 48V
- Adjustable Output Voltage Range: 2.0V to 24V
- Integrated N-Channel Buck Switch: 500 mΩ
- 400 mA Output Current
- 2.2 MHz Fixed Switching Frequency
- Shutdown Current: 3 µA Typical
- Quiescent Current: 18 µA Typical (Not Switching)
- Device Selectable Switching Mode:

- Automatic Pulse Frequency Modulation/Pulse Width Modulation (PFM/PWM) Operation - **MCP16367**
- PWM-only Mode of Operation - **MCP16368**
- PWM-only Mode of Operation with Switching Frequency Dithering for EMI constrained applications - **MCP16369**

- Power Good Output
- Undervoltage Lockout (UVLO)
- Peak Current Mode Control
- Internal Compensation
- Internal Soft-Start
- Internal Bootstrap Diode
- Cycle-By-Cycle Peak Current Limit
- Overtemperature Protection
- Available Package: 8-Lead 3 mm x 3 mm Wettable Flanks VDFN (see Package)
- AEC-Q100 Automotive Qualified, see Product Identification System

Applications

- Automotive DC/DC and 48V Systems
- Microcontroller Bias Supply
- 24V Industrial Input DC-DC Conversion
- Set-Top Boxes, DSL Cable Modems
- Wall Cube Regulation
- SLA Battery-Powered Devices
- AC-DC Digital Control Power Sources
- Power Meters
- Medical and Health Care
- Distributed Power Supplies

1. Typical Application

Figure 1-1. Typical Application Circuits

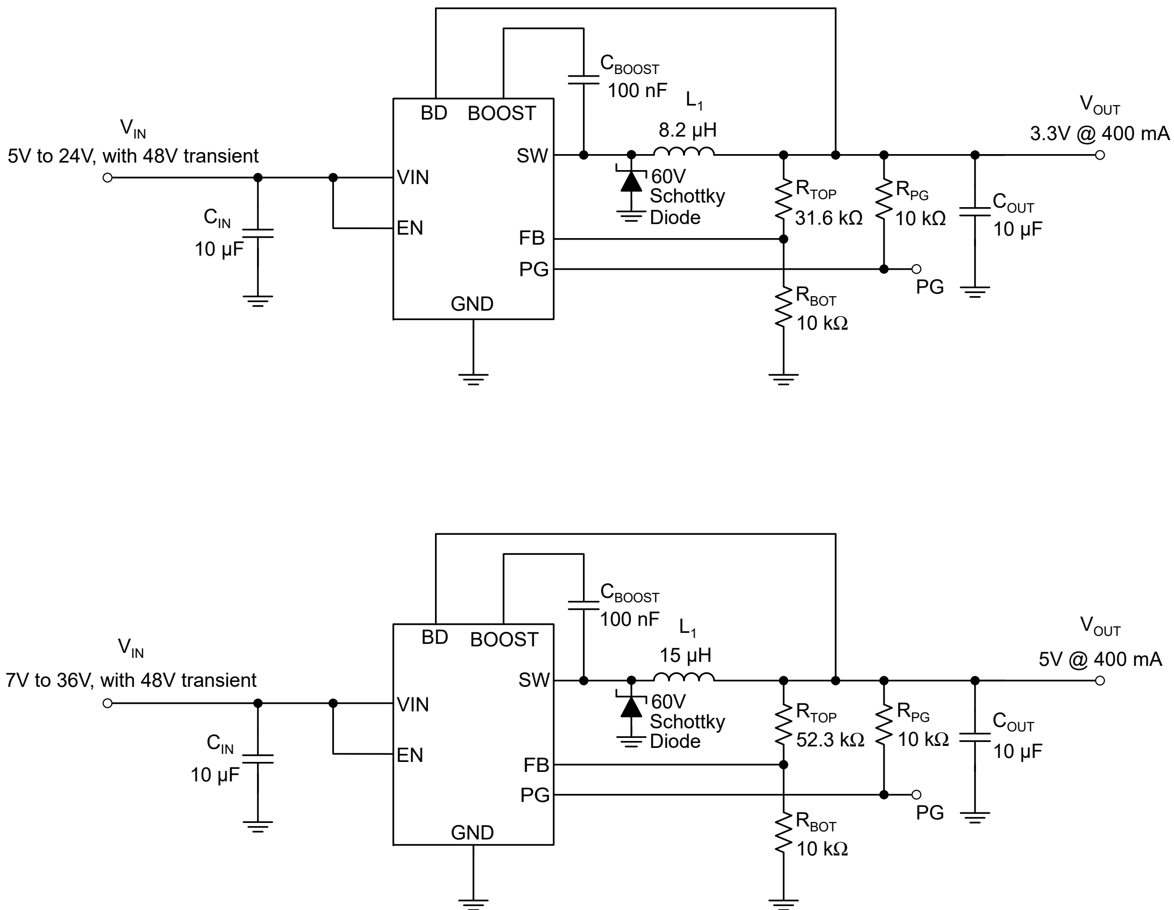
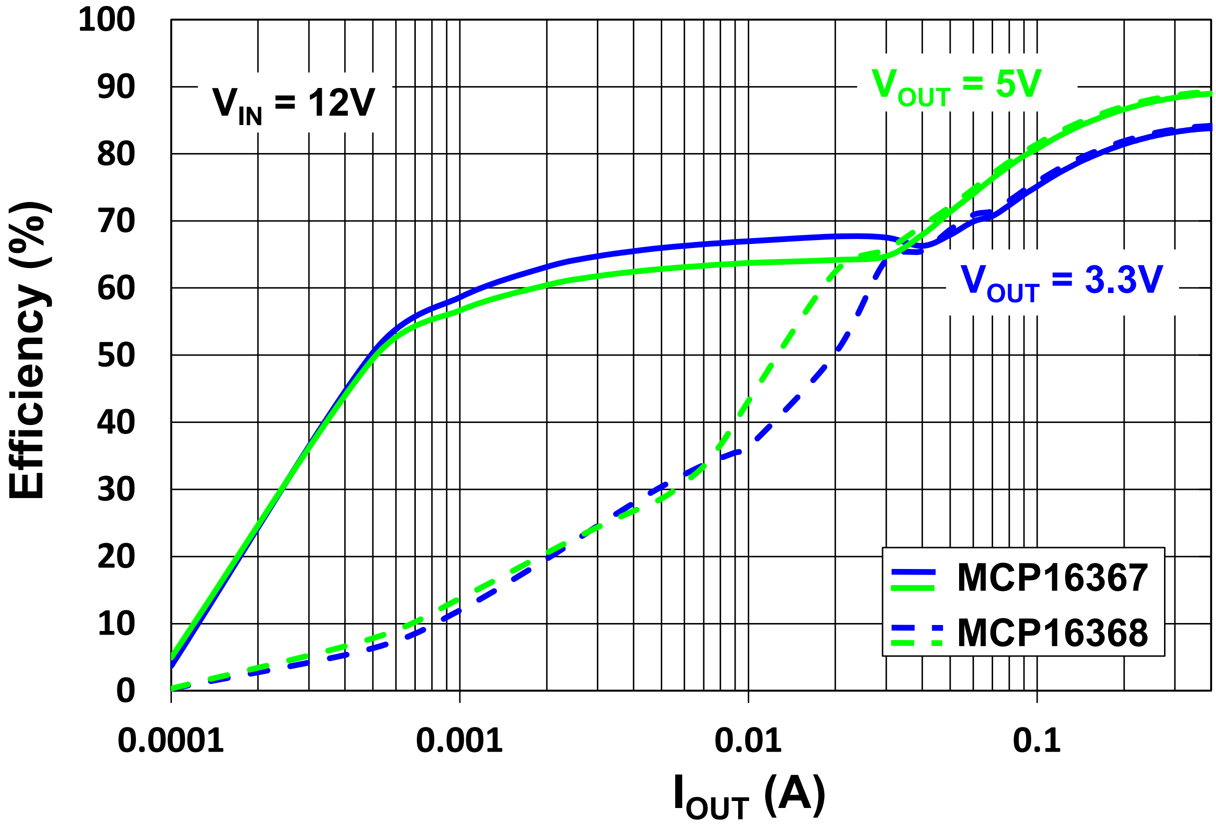


Figure 1-2. Efficiency vs. Output Current



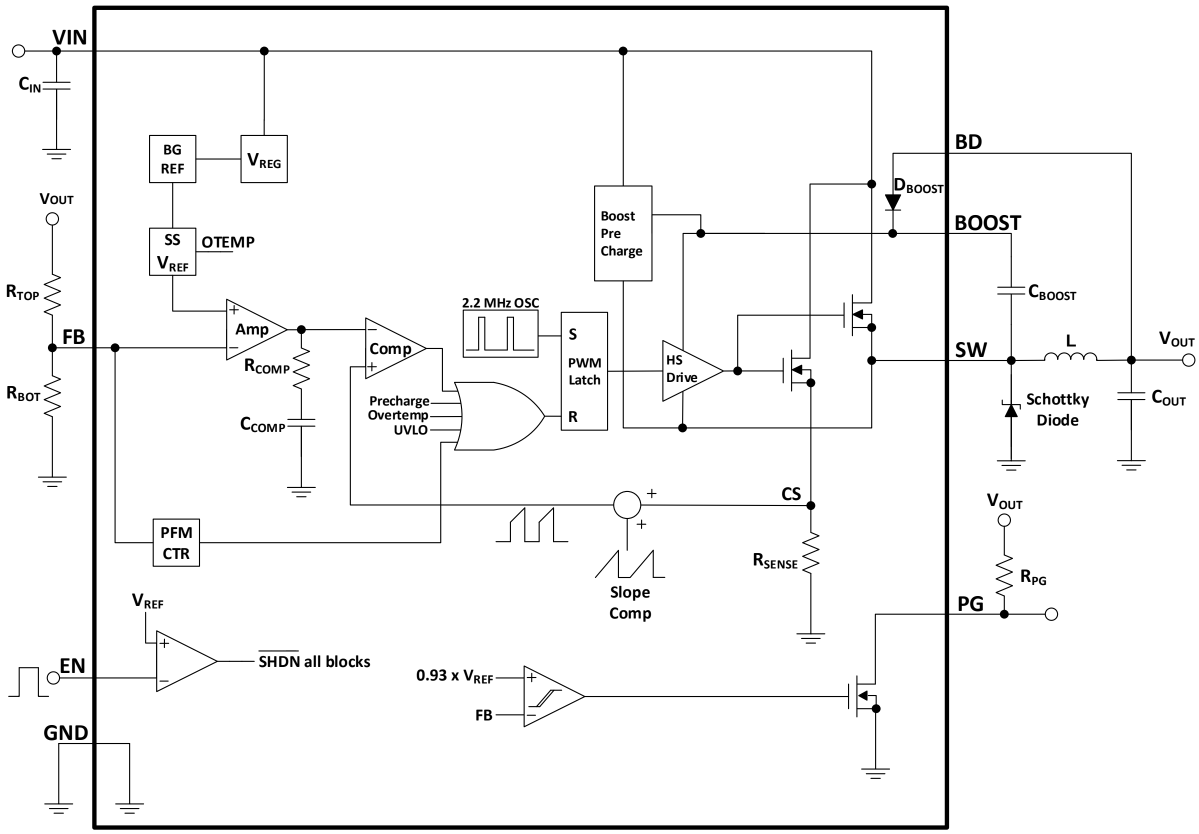
2. Product Family

Table 2-1. Device Options

Part Number	Switching Mode Option	Switching Frequency
MCP16367	PFM/PWM	Fixed 2.2 MHz
MCP16368	PWM Only	Fixed 2.2 MHz
MCP16369	PWM Only	2.2 MHz with +10% Frequency Dithering

3. Block Diagram

Figure 3-1. Simplified Block Diagram



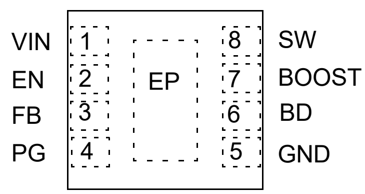
4. Pin Configuration

Table 4-1. Pin Function Table

Pin Number	Symbol	Description
1	VIN	Input supply voltage pin for power and internal biasing.
2	EN	Enable pin. Logic high enables the operation. Do not allow this pin to float.
3	FB	Output voltage feedback pin. Connect FB to an external resistor divider to set the output voltage.
4	PG	Open-drain Power Good output.
5	GND	Signal and Power Ground Reference.
6	BD	Anode of the internal bootstrap diode. Connect to V_{OUT} or to a power source < 5.5V.
7	BOOST	Boost voltage that drives the internal NMOS control switch. Connect a bootstrap capacitor between the BOOST and SW pins.
8	SW	Output switch node. Connects to the inductor, freewheeling diode and the bootstrap capacitor.
9	EP	Exposed Pad. Must be connected to the GND plane to help dissipate power.

4.1. Package

Figure 4-1. Pin Configuration 8-Lead 3 mm x 3 mm VDFN (Top View)



4.2. Pin Description

Power Supply Input Voltage Pin (VIN)

The VIN pin supplies voltage to both the buck converter power stage and the internal circuitry. It is connected to the drain terminal of the internal high-side N-Channel MOSFET. A minimum 10 μF ceramic capacitor must be placed as close as possible between VIN and GND. For optimal performance, a combination of multiple ceramic capacitors of varying sizes is recommended.

Enable Pin (EN)

The EN pin is a logic-level input used to enable or disable the device operation, reducing quiescent current when disabled. To turn off the device, pull the EN pin low. Do not leave this pin floating.

Feedback Voltage Pin (FB)

The FB pin is used to provide output voltage regulation via a resistor divider. When the output is in regulation, the typical feedback voltage (V_{FB}) is 0.800V.

Power Good Output Pin (PG)

The PG pin is the drain connection of an internal N-channel FET. When the output voltage is within 93% of the nominal set point, this pin transitions from logic-low to logic-high (through an external pull-up resistor).

Ground Pin (GND)

The ground or return pin is used for circuit ground connection. To minimize noise, keep the trace lengths from the input capacitor return, output capacitor return, and GND pin as short as possible.

Boost Diode Pin (BD)

The BD pin is the anode of a diode, which is connected to the BOOST pin. It must be connected to a voltage source between 3V and 5.5V. If the output voltage of the converter is set between these values, connecting the BD pin to the output is recommended.

Boost Pin (BOOST)

The BOOST pin supplies voltage to the driver of the high-side N-Channel power MOSFET. Connect a bootstrap capacitor to this pin.

Switch Node Pin (SW)

The SW pin is internally connected to the source of the high-side N-channel MOSFET and externally to the switching node, which includes the inductor, Schottky diode, and bootstrap capacitor. Place these external components as close as possible to the SW pin to minimize the size of the switching node.

Exposed Pad (EP)

The exposed pad is not electrically connected to the GND pin. Connect with thermal vias to the ground plane to ensure adequate heat-sinking.

5. Functional Description

The MCP16367/8/9 is a high input voltage step-down regulator capable of supplying 400 mA to a regulated output voltage ranging from 2.0V to 24V. The device features a precision-trimmed 2.2 MHz internal oscillator that provides a fixed switching frequency. Output voltage regulation is achieved through a Peak Current Mode Control architecture, which adjusts the duty cycle as needed. An internal floating driver controls the high-side integrated N-Channel MOSFET, with power supplied to the driver via an external bootstrap capacitor. This capacitor is typically biased from a fixed voltage between 3.0V and 5.5V, such as the converter's input or output voltage. For applications where the output voltage falls outside this range (e.g., 12V), the bootstrap capacitor can be biased from the output using a simple Zener diode regulator.

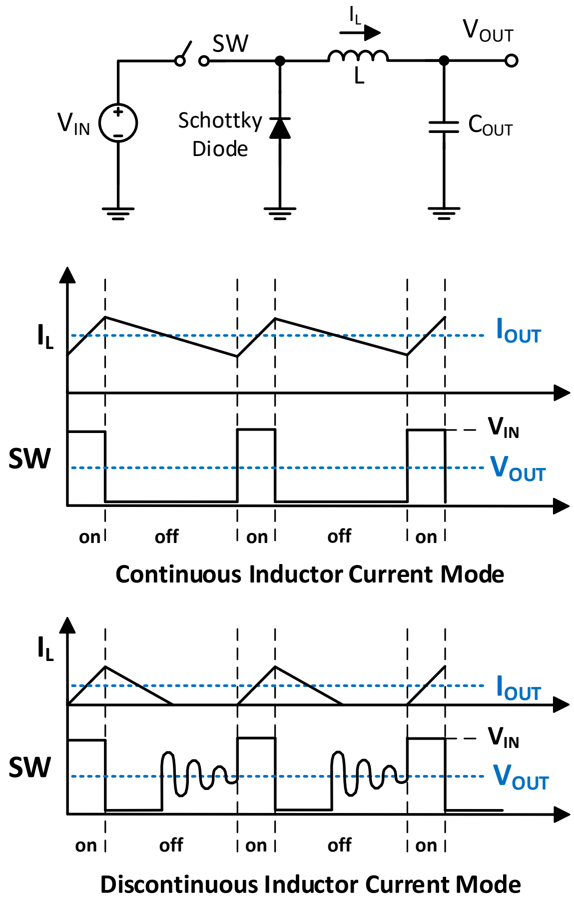
5.1. Theory of Operation

The integrated high-side switch modulates the input voltage using a controlled duty cycle for output voltage regulation. High efficiency is achieved by using a low-resistance switch, a low forward voltage drop diode, a low equivalent series resistance inductor (DCR) and a capacitor (ESR). When the switch is on, a DC voltage is applied to the inductor (V_{IN} – V_{OUT}), resulting in a positive linear ramp of inductor current. When the switch is turned off, the applied inductor voltage is equal to -V_{OUT}, resulting in a negative linear ramp of inductor current (ignoring the forward voltage drop of the Schottky diode).

In steady-state, continuous inductor current operation, the positive inductor current ramp must equal the negative current ramp in magnitude. While operating in steady state, the switch duty cycle must be equal to the relationship of V_{OUT}/V_{IN} for constant output voltage regulation, provided that the inductor current is continuous or never reaches zero. In discontinuous inductor current operation, the steady-state duty cycle is less than V_{OUT}/V_{IN} to maintain voltage regulation. The average of the chopped input voltage, or SW node voltage, is equal to the output voltage, while the average of the inductor current is equal to the output current.

For graphical representations of the switching waveform and inductor current in both continuous and discontinuous inductor current modes, see Figure 5-1.

Figure 5-1. Step-Down Converter



The MCP16367/8/9 features an integrated Peak Current Mode Control architecture, resulting in superior AC regulation while minimizing the number and size of the voltage loop compensation components integrated in the device. Peak Current Mode Control takes a small portion of the inductor current, replicates it and compares this replicated current sense signal with the output voltage of the integrated error amplifier. In practice, the inductor current and the internal switch current are equal during the switch-on time. By adding this peak current sense to the system control, the step-down power train system is reduced from a 2nd order to a 1st order. This reduces the system complexity and increases its dynamic performance.

5.2. Pulse-Width Modulation

For Pulse-Width Modulation (PWM) duty cycles that exceed 50%, the control system can become bimodal, where a wide pulse followed by a short pulse repeats instead of the desired fixed pulse width. To prevent this mode of operation, an internal compensating ramp is added to the current, as shown in Figure 5-1.

The internal oscillator initiates each switching period at a fixed frequency of 2.2 MHz for the MCP16367/8/9. When the integrated switch is turned on, the inductor current ramps up until the sum of the current sense signal and the slope compensation ramp exceeds the output of the integrated error amplifier. The error amplifier output slews up or down to increase or decrease the inductor peak current feeding into the output LC filter. If the regulated output voltage falls below its target, the error amplifier output increases, resulting in a higher inductor current to correct the output voltage. The fixed frequency duty cycle is terminated when the sensed inductor peak current, combined with the internal slope compensation, exceeds the error amplifier output voltage. The PWM latch is set by turning off the internal switch and preventing it from turning on until the beginning of the next cycle. An overtemperture signal or bootstrap capacitor undervoltage can also reset the PWM latch to asynchronously terminate the switching cycle.

5.3. Pulse Frequency Mode of Operation (PFM)

The MCP16367 selects the best operating switching mode (PFM or PWM) for high efficiency across a wide range of load currents. In PFM, the duty cycle is determined by a fixed peak current, which may cause the output voltage to rise slightly above the typical regulation point. When the output voltage increases and the feedback voltage exceeds 810 mV typical, the MCP16367 stops switching and enters Sleep mode. Normal operations resume when the output voltage decreases. By switching to PFM mode at light load currents and leveraging the device's very low quiescent current (I_Q) when not switching, the MCP16367 achieves exceptionally high efficiency at very low loads. During the sleep period between switching bursts, the device draws only 18 µA (typical) from the supply. Since the switching pulse packets occupy a small portion of the total operating cycle, the average current drawn from the power supply remains minimal.

It is important to note that PFM/PWM operation can result in higher output voltage ripple and a variable PFM mode frequency. The threshold for entering PFM mode depends on the input voltage, output voltage, and load conditions.

5.4. Internal Reference Voltage V_{REF}

An integrated, precise 0.8V reference combined with an external resistor divider sets the desired converter output voltage. The resistor divider range can vary without affecting the control system gain. High-value resistors consume less current but are more susceptible to noise.

5.5. Internal Compensation

All necessary control system components for stable operation across the entire device operating range are integrated, including the error amplifier and inductor current slope compensation. The amount of slope compensation is automatically adjusted based on the inductor value and output voltage (see Table 8-1).

5.6. Enable Input

Enable (EN) input is used to enable or disable the device. When disabled, the MCP16367/8/9 device draws minimal current from the input supply. Upon enabling, the internal soft-start function manages the output voltage ramp-up, preventing excessive inrush current and output voltage overshoot. For automatic start-up when input voltage is applied, connect the EN pin directly to the input supply.

5.7. Soft Start

The internal reference voltage rate of rise is controlled during start-up, minimizing the output voltage overshoot and the inrush current. The typical soft-start time is 1200 µs.

5.8. Undervoltage Lockout

The integrated Undervoltage Lockout (UVLO) function prevents the converter from starting until the input voltage is high enough for normal operation. The device typically starts at 4V and operates down to 3.6V. Hysteresis is added to prevent repeated start-up and shutdown cycles due to input voltage fluctuations during start-up.

5.9. Overtemperature Protection

Overtemperature protection safeguards the device by shutting down the converter if the silicon die temperature reaches 155°C. Normal operation automatically resumes once the temperature drops to 125°C.

5.10. High-Side Drive and Bootstrap

The MCP16367 features an integrated high-side N-Channel MOSFET to enable high efficiency step-down power conversion. An N-Channel MOSFET is used for its low resistance and size (instead of a P-Channel MOSFET). The N-Channel MOSFET gate must be driven above its source to fully turn on the transistor. A gate drive voltage above the input supply is necessary to turn on the high-side N-Channel MOSFET. The high-side drive voltage must be between 3.0V and 5.5V.

The N-Channel MOSFET source is connected to the inductor and Schottky diode or switch node. When the switch is off, the inductor current flows through the Schottky diode, providing a path to recharge the bootstrap capacitor from the boost voltage source, which is typically the output voltage for 3.0V to 5.5V output applications.

Prior to start-up, the bootstrap capacitor has no stored charge to drive the switch. An internal regulator is used to *precharge* the bootstrap capacitor. Once precharged, the switch is turned on and the inductor current starts to flow. When the switch turns off, the inductor current freewheels through the Schottky diode, providing a path to recharge the bootstrap capacitor. The worst-case conditions for recharge occur when the switch turns off for a very short time at light load, limiting the inductor current ramp. In this case, there is a small amount of time for the bootstrap capacitor to recharge. For high input voltages, there is enough precharge current to replenish the bootstrap capacitor charge. For input voltages above 5.5V typical, the MCP16367/8/9 device will regulate the output voltage with no load. After starting, the MCP16367/8/9 will regulate the output voltage until the input voltage decreases below 4V.

5.11. Integrated Bootstrap Diode

To reduce the number of external components, the bootstrap diode is integrated into the device such that the anode is connected to the BD pin and cathode to the BOOST pin.

The allowable voltage range to be used on this pin is 3V and 5.5V.

5.12. Frequency Dithering

When designing a DC-DC switching power supply, one of the challenges that must be overcome is controlling the electromagnetic interference (EMI) emissions produced during normal operation. EMI is most significant at the fundamental switching frequency of the switch-mode power supply and is reduced for each higher order harmonic. To decrease this peak emission, modulating or dithering the switching frequency is used so that the EMI is spread over a band of frequencies.

In the MCP16369, the switching frequency is varied by +10% above the nominal 2.2 MHz help lower EMI peak levels.

5.13. Power Good

The Power Good (PG) pin is an open-drain output that requires an external pull-up resistor to a voltage not exceeding the input voltage in order to assert a logic-high level.

PG is asserted when the output voltage reaches 93% of its target regulation value. If the output voltage drops below 90% of the target, PG is deasserted after a typical delay of 50 µs, which serves as a deglitch timer to filter out short transients. PG is immediately deasserted if the EN pin falls below the enable threshold, or in the event of an undervoltage or thermal shutdown condition. The pull-up resistor should be selected to limit the PG pin current to less than 5 mA.

5.14. Overcurrent Protection

The MCP16367/8/9 provides instantaneous cycle-by-cycle current limiting by sensing the current through the high-side switch.

Leading edge blanking is implemented on the high-side switch to prevent false triggering of the overcurrent limit.

The device also incorporates frequency fold-back and advanced overcurrent protection features. During prolonged overloads or short-circuit conditions, future switching pulses are inhibited to protect the device and external components. Specifically, if an overcurrent event is detected during a sustained overload at high input voltages, the next three switching pulses are inhibited, allowing the inductor current to decrease to safer levels.

Additionally, if the feedback voltage decreases, the switching frequency will also decrease as low as 200 kHz.

5.15. Overvoltage Protection

The MCP16367/8/9 includes Overvoltage Protection (OVP) to minimize the output voltage overshoot, particularly during recovering from strong unload transients in designs with low output capacitance. In scenarios where the load is suddenly removed, the regulator output can increase faster than the response of the error amplifier, resulting in an output overshoot.

To address this, the OVP circuitry continuously monitors the feedback (FB) voltage and compares it to the OVP threshold, typically set at 860 mV. If the FB voltage exceeds this threshold, the high-side MOSFET is immediately turned off to prevent excessive output voltage.

6. Electrical Characteristics

6.1. Absolute Maximum Ratings

Table 6-1. Absolute Maximum Ratings

Parameters	Minimum	Maximum	Unit
VIN, SW	-0.5	+53	V
BOOST – GND	-0.5	+60	V
BOOST – SW Voltage	-0.5	+5.5	V
FB, BD	-0.5	+5.5	V
PG, EN	-0.5	V_{IN} + 0.3	V
Storage Temperature	-65	+150	°C
Operating Junction Temperature	-40	+125	°C

Table 6-2. ESD Protection on All Pins

Parameters	Minimum	Maximum	Unit
HBM	-2	+2	kV
CDM	-2	+2	kV

Note: Stresses above those listed under “Maximum Ratings” may cause permanent damage to the device. This is a stress rating only, and functional operation of the device at those or any other conditions above those indicated in the operational sections of this specification is not intended. Exposure to maximum rating conditions for extended periods may affect device reliability.

6.2. DC Characteristics

Electrical Characteristics: Unless otherwise indicated, $T_A = T_J$ = +25°C, $V_{IN} = V_{EN}$ = 12V, $V_{BOOST} - V_{SW}$ = 3.3V, V_{OUT} = 3.3V, I_{OUT} = 100 mA, L = 8.2 µH, C_{IN} = 10 µF X7R Ceramic Capacitor, C_{OUT} = 10 µF X7R Ceramic Capacitor. **Boldface** specifications apply over the T_J range of -40°C to 125°C.						
Parameters	**Symbol**	**Min.**	**Typ.**	**Max.**	**Units**	**Conditions**
Input Voltage	V_{IN}	**4.1**	—	**48**	V	**Note 1**
Feedback Voltage	V_{FB}	**0.776**	0.800	**0.824**	V	V_{IN} = 12V, PWM mode, Standard Part
		0.784	0.800	**0.816**	V	V_{IN} = 12V, PWM mode, AEC-Q100 Automotive Qualified
Output Voltage Adjust Range	V_{OUT}	**2**	—	**24**	V	**Note 2**, **Note 4**
Feedback Voltage Line Regulation	$(\Delta V_{FB}/V_{FB})/\Delta V_{IN}$	—	0.01	—	%/V	MCP16368, V_{IN} = 5V to 16V
Feedback Voltage Load Regulation	$(\Delta V_{FB}/V_{FB})$	—	0.3	—	%	MCP16368, I_{OUT} = 10 mA to 400 mA
Feedback Input Bias Current	I_{FB}	—	+/- 10	—	nA	Sink/Source
Undervoltage Lockout Start	$UVLO_{STRT}$	—	4	—	V	V_{IN} Rising
Undervoltage Lockout Stop	$UVLO_{STOP}$	—	3.6	—	V	V_{IN} Falling
Undervoltage Lockout Hysteresis	$UVLO_{HYS}$	—	0.4	—	V	
Switching Frequency	f_{SW}	**1.8**	2.2	**2.6**	MHz	PWM mode

Notes:

1. The input voltage must be > output voltage + headroom voltage; higher load currents increase the input voltage necessary for regulation. See the characterization graphs for typical input to output operating voltage range.
2. For the conditions explained in Input Voltage Limitations.
3. V_{BOOST} supply is derived from V_{OUT}.
4. Determined by characterization; not production tested.

DC Characteristics (continued)

Electrical Characteristics: Unless otherwise indicated, $T_A = T_J = +25°C$, $V_{IN} = V_{EN} = 12V$, $V_{BOOST} - V_{SW} = 3.3V$, $V_{OUT} = 3.3V$, $I_{OUT} = 100$ mA, L = 8.2 µH, C_{IN} = 10 µF X7R Ceramic Capacitor, C_{OUT} = 10 µF X7R Ceramic Capacitor. **Boldface** specifications apply over the T_J range of -40°C to 125°C.						
Parameters	**Symbol**	**Min.**	**Typ.**	**Max.**	**Units**	**Conditions**
Switching Frequency Dithering	$f_{SW,dither}$	—	+10	—	%	MCP16369
Maximum Duty Cycle	DC_{MAX}	—	87	—	%	**Note 4**
Minimum On Time	Ton_{MIN}	—	65	—	ns	**Note 4**
NMOS Switch On Resistance	$R_{DS(ON)}$	—	0.5	—	Ω	$V_{BOOST} - V_{SW} = 3.3V$ (**Note 4**)
NMOS Switch Current Limit	$I_{N(MAX)}$	—	0.75	—	A	$V_{BOOST} - V_{SW} = 3.3V$ (**Note 4**)
Quiescent Current – PWM	$I_{Q,PWM}$	—	1.8	**3.8**	mA	$V_{BOOST} = 3.3V$; MCP16368 Switching
Quiescent Current – PFM	$I_{Q,PFM}$	—	55	**135**	µA	$V_{BOOST} = 3.3V$; MCP16367 Switching
Quiescent Current – PFM – Non-Switching	I_Q	—	18	**24**	µA	$V_{BOOST} = 3.3V$; MCP16367 Non-Switching
Quiescent Current – Shutdown	$I_{Q,SHD}$	—	3	**6**	µA	V_{OUT} = EN = 0V
EN Input Logic High	V_{IH}	**1.8**	—	—	V	
EN Input Logic Low	V_{IL}	—	—	**0.4**	V	
EN Input Leakage Current	I_{ENLK}	—	0.1	**0.15**	µA	$V_{EN} = 12V$
Soft-Start Time	t_{SS}	—	1.2	—	ms	EN Low to High, 90% of V_{OUT} (**Note 4**)
Power Good Threshold	V_{PG}	**89**	93	**97**	%	
Power Good Hysteresis	$V_{PG,hyst}$	—	3	—	%	
Power Good Blanking	$PG_{Blanking}$	—	55	**57**	µs	
Thermal Shutdown Die Temperature	T_{SD}	—	155	—	°C	**Note 4**
Die Temperature Hysteresis	T_{SDHYS}	—	25	—	°C	

Notes:

1. The input voltage must be > output voltage + headroom voltage; higher load currents increase the input voltage necessary for regulation. See the characterization graphs for typical input to output operating voltage range.
2. For the conditions explained in Input Voltage Limitations.
3. V_{BOOST} supply is derived from V_{OUT}.
4. Determined by characterization; not production tested.

6.3. Temperature Specifications

Parameters	Symbol	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Operating Junction Temperature Range	T_J	-40	—	+125	°C	Steady State
Storage Temperature Range	T_A	-65	—	+150	°C	
Maximum Junction Temperature	T_J	—	—	+150	°C	Transient
Package Thermal Resistances						
Thermal Resistance Junction to Ambient (1)	$R_{θJA}$	—	61.1	—	°C/W	
Thermal Resistance Junction to Case (1)	$R_{θJC}$	—	76.4	—	°C/W	
Thermal Resistance Junction to Top of Package (1)	$Ψ_{JT}$	—	2.4	—	°C/W	
Thermal Resistance Junction to Board (1)	$R_{θJB}$	—	21.8	—	°C/W	
Thermal Resistance Junction to Board Characterization Parameter (1)	$Ψ_{JB}$	—	15.8	—	°C/W	

Note:

1. Simulated on the MCP16367/8/9 Evaluation Board EV56E71A, a 50 mm x 50 mm, 1 oz, 2-layer PCB.

7. Typical Performance Curves

Notes:

- The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and, therefore, outside the warranted range.
- Unless otherwise indicated, T_A = +25℃, V_{IN} = V_{EN} = 12V, V_{BOOST} – V_{SW} = 5V, V_{OUT} = 5V, I_{OUT} = 100 mA, L = 15 µH, C_{IN} = 10 µF X7R Ceramic Capacitor, C_{OUT} = 10 µF X7R Ceramic Capacitor.

Figure 7-1. 3.3V V_{OUT} Efficiency vs. I_{OUT}

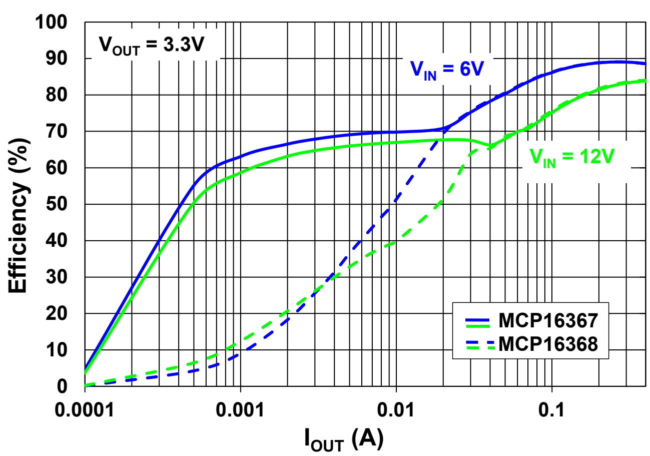


Figure 7-2. 3.3V V_{OUT} vs. I_{OUT}

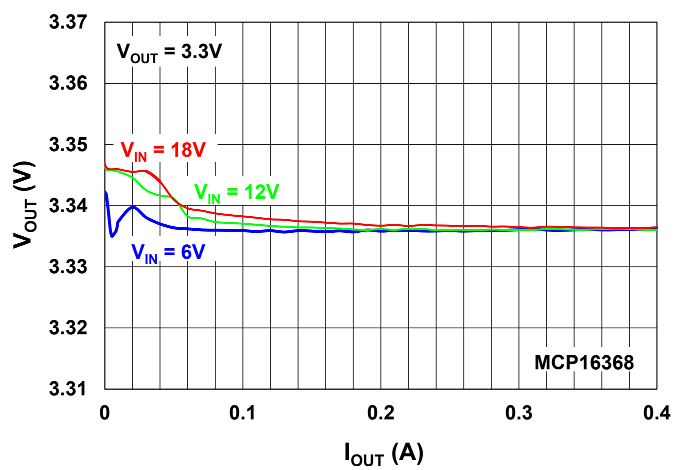


Figure 7-3. 5V V_{OUT} Efficiency vs. I_{OUT}

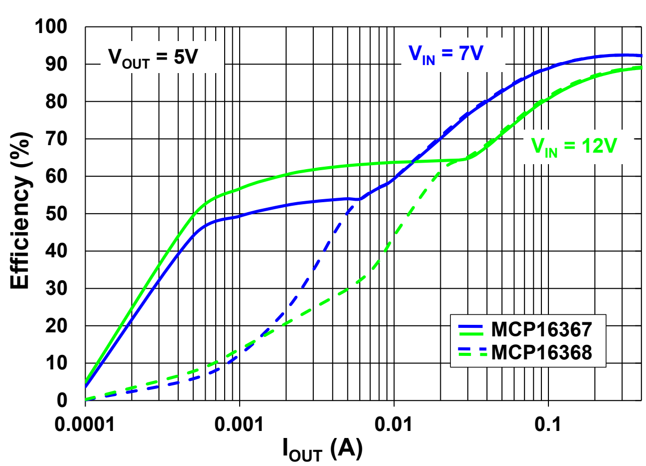


Figure 7-4. 5V V_{OUT} vs. I_{OUT}

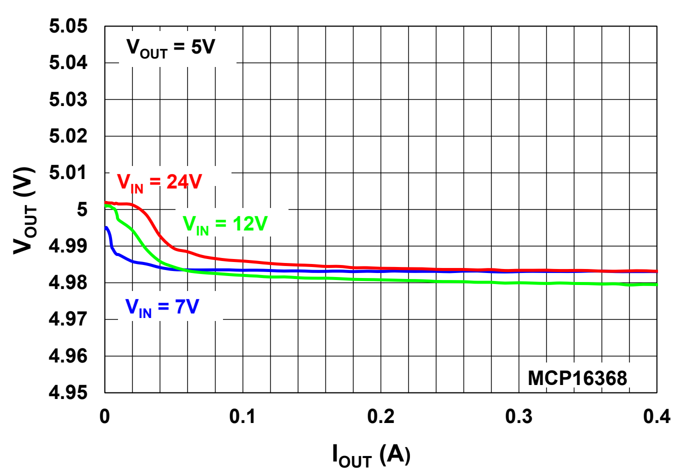


Figure 7-5. 12V V_{OUT} Efficiency vs. I_{OUT}

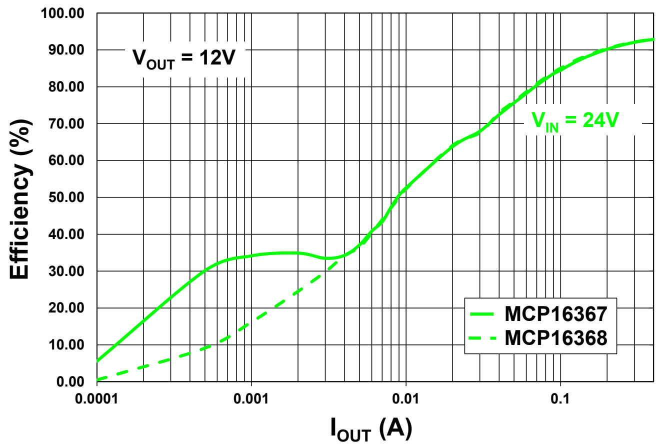


Figure 7-6. 12V V_{OUT} vs. I_{OUT}

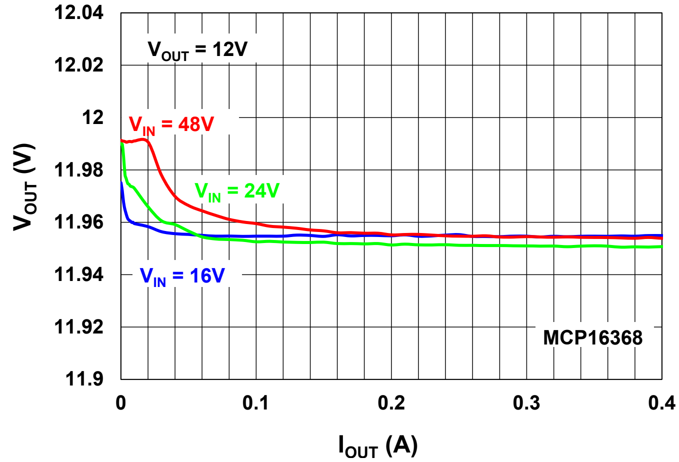


Figure 7-7. V_{OUT} vs. V_{IN}

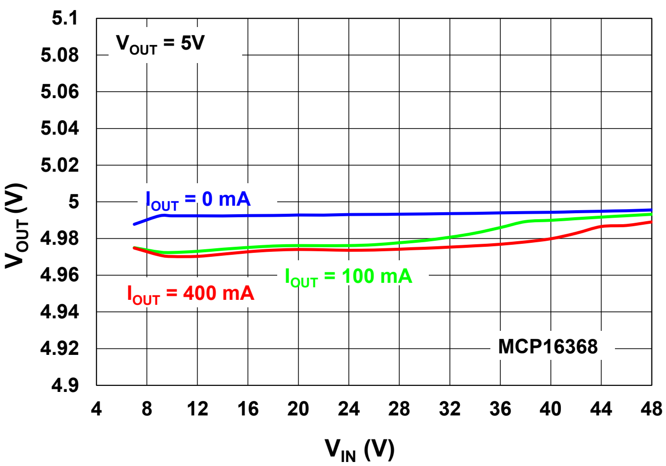


Figure 7-8. Switch R_{DSON} vs. Temperature

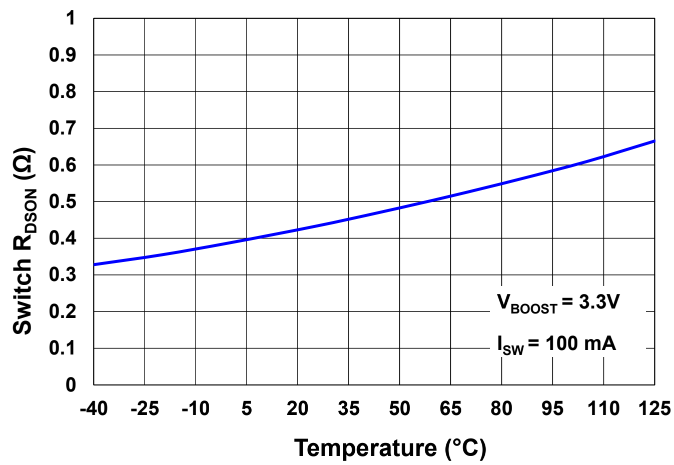


Figure 7-9. V_{FB} vs. Temperature

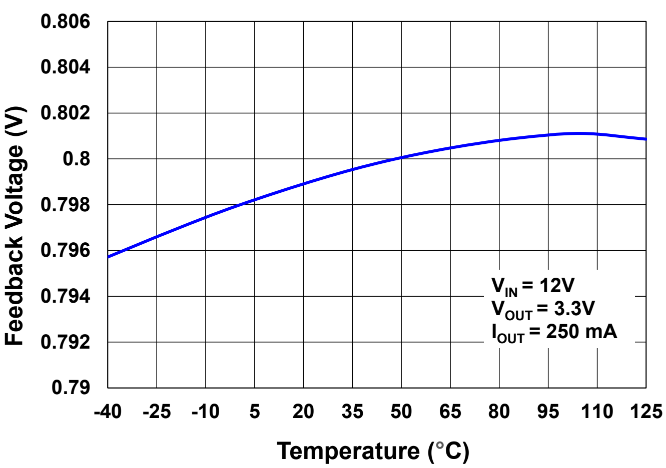


Figure 7-10. Switch R_{DSON} vs. V_{BOOST}

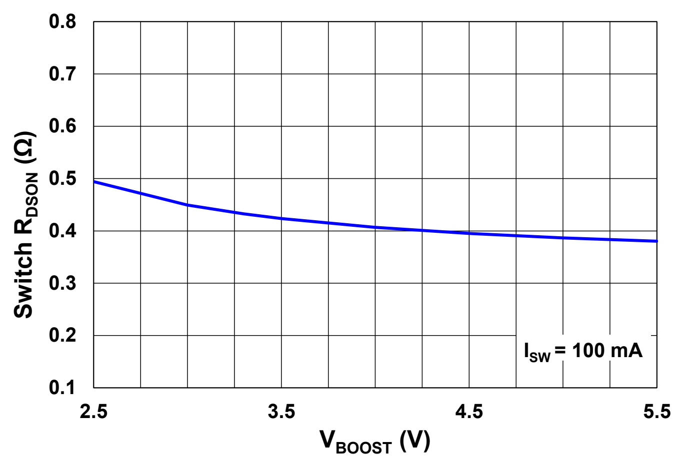


Figure 7-11. Peak Current Limit vs. Temperature

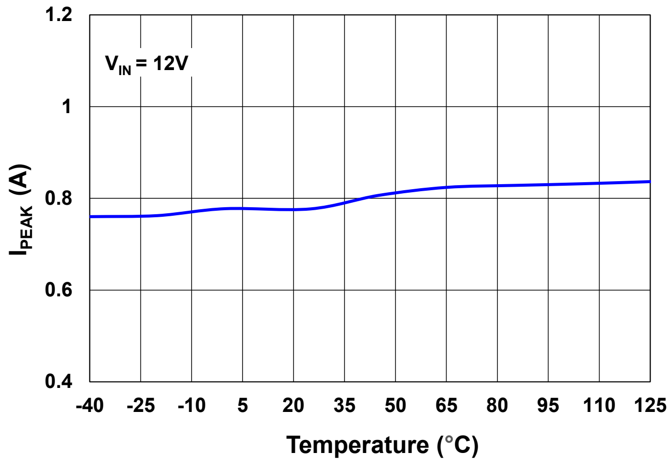


Figure 7-12. Undervoltage Lockout vs. Temperature

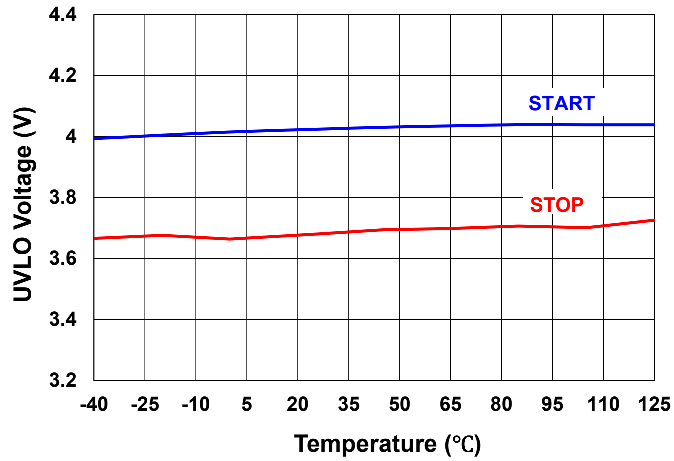


Figure 7-13. EN Threshold Voltage vs. Temperature

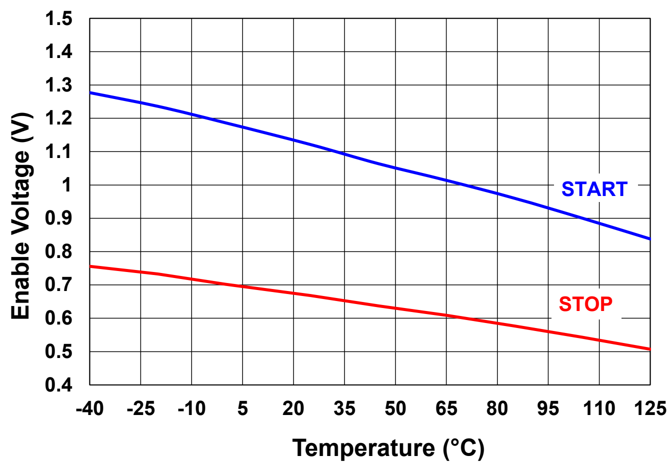


Figure 7-14. No Load Input Current vs. V_{IN}, MCP16367

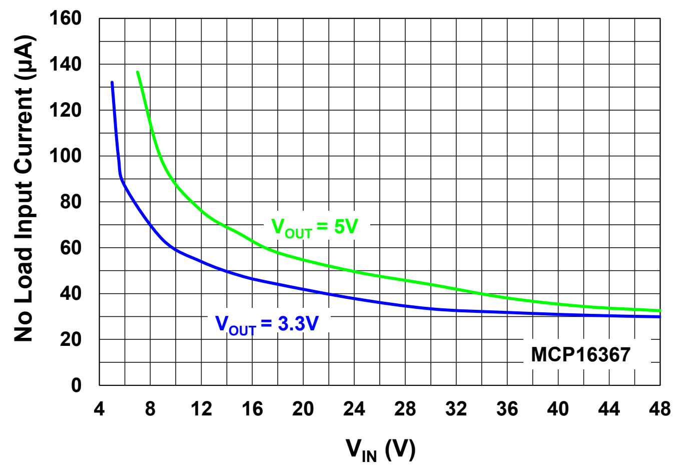


Figure 7-15. Input Quiescent Current vs. V_{IN}

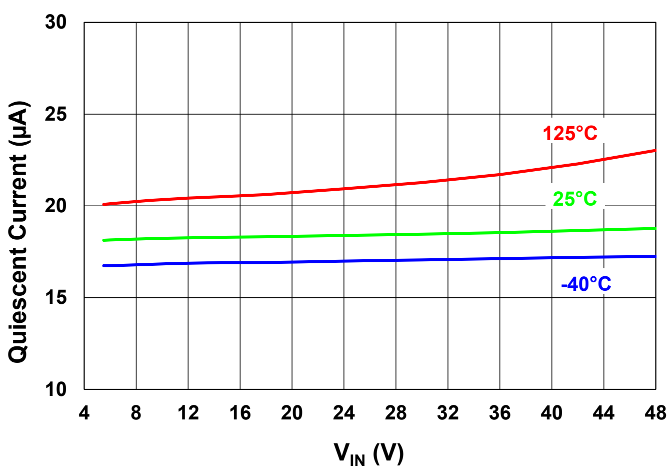


Figure 7-16. No Load Input Current vs. V_{IN}, MCP16368

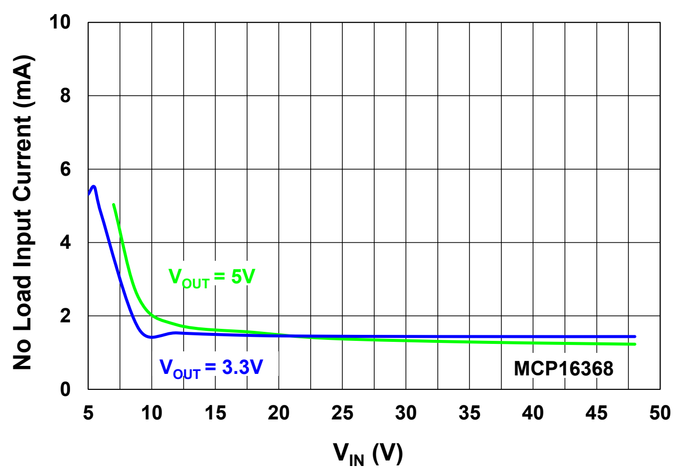


Figure 7-17. Shutdown Current vs. V_{IN}

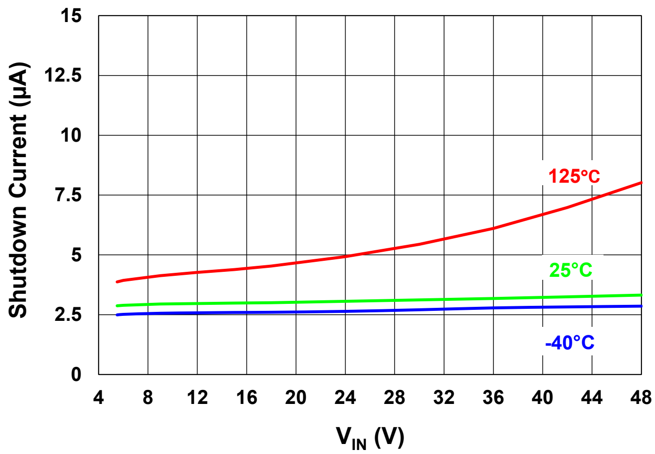


Figure 7-18. PFM/PWM Threshold

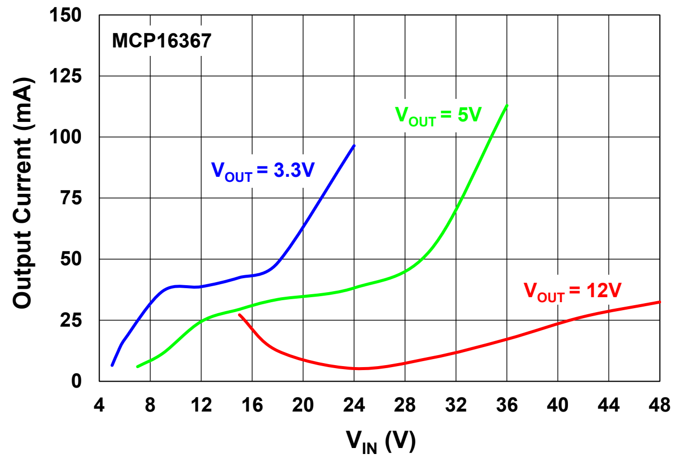


Figure 7-19. PWM/Skipping Threshold

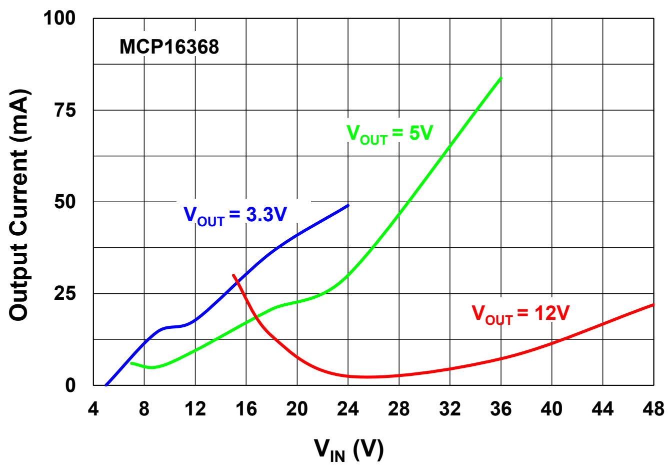


Figure 7-20. Switching Frequency vs. Feedback Voltage

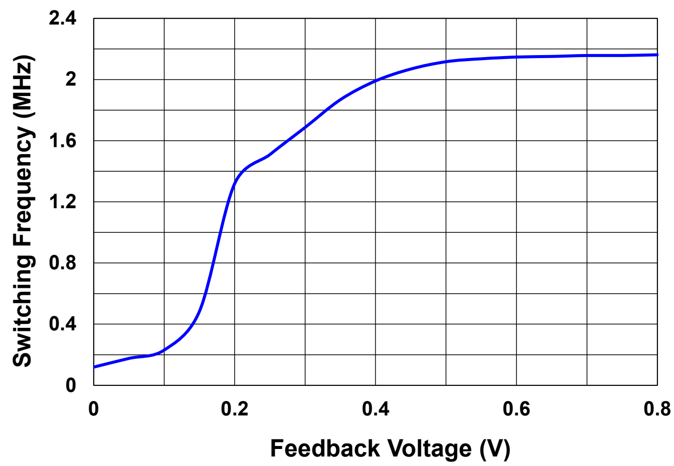


Figure 7-21. Minimum Input Voltage vs. Output Current

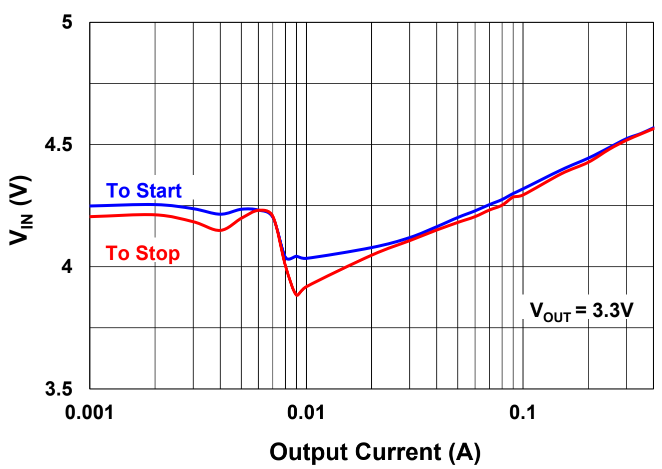


Figure 7-22. Switching Frequency vs. Temperature

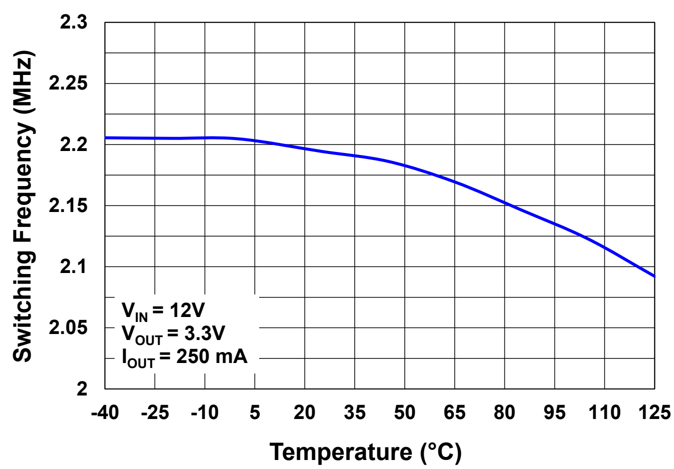


Figure 7-23. Heavy Load Switching Waveforms

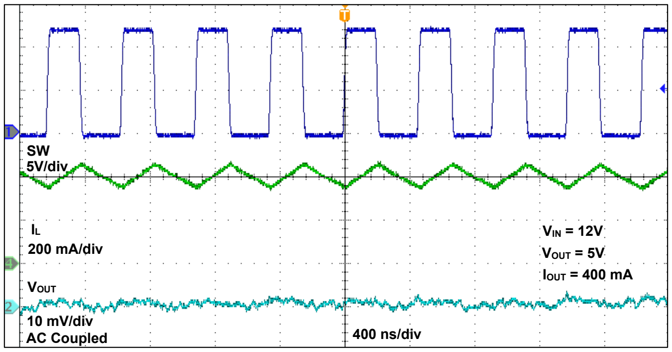


Figure 7-24. PFM to PWM Transition

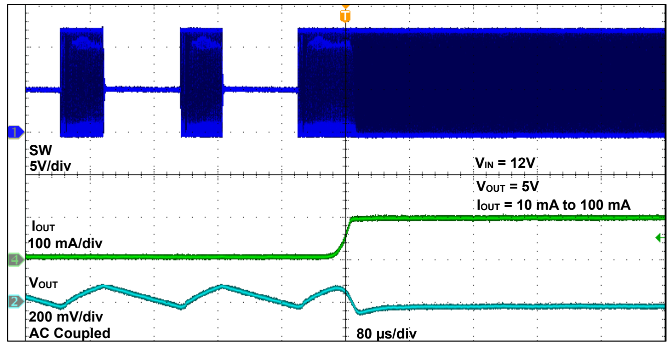


Figure 7-25. Light Load Switching Waveforms – MCP16367

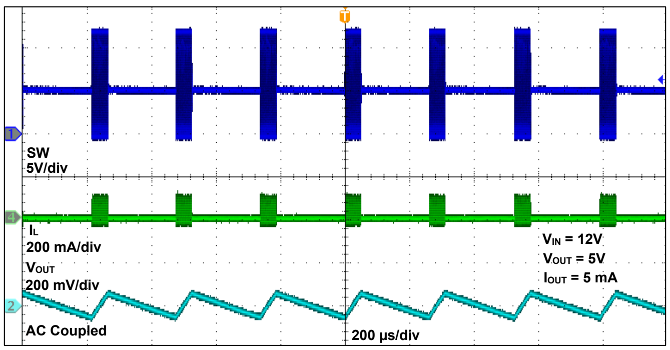


Figure 7-26. Start-Up from V_{IN}

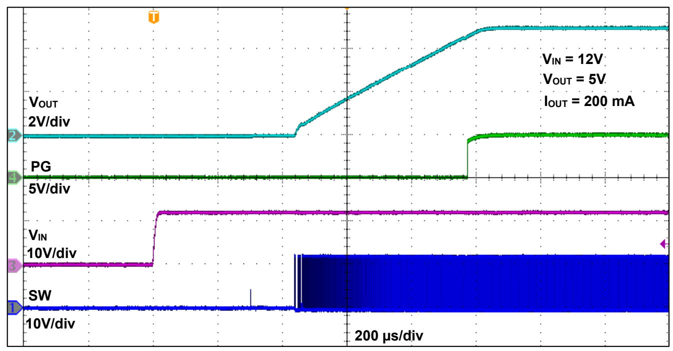


Figure 7-27. Light Load Switching Waveforms – MCP16368

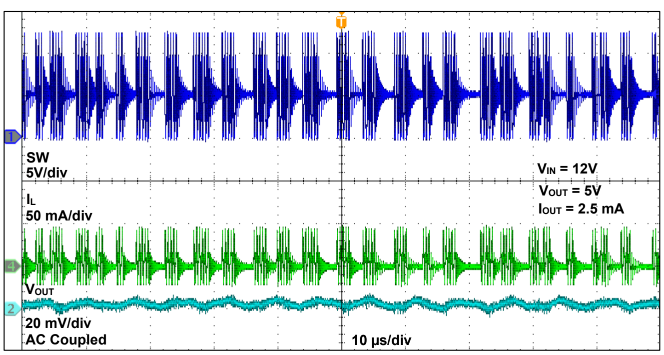


Figure 7-28. Start-Up from EN

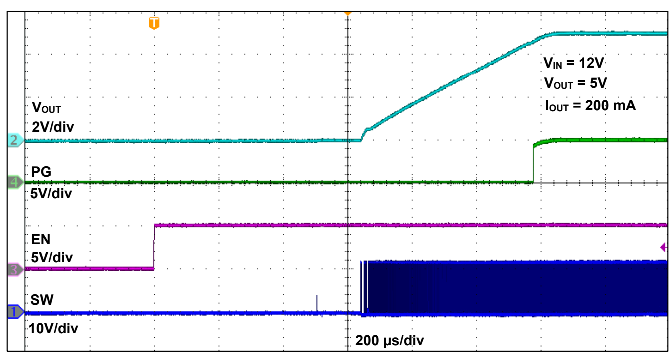


Figure 7-29. MCP16368 Load Transient Response (1 mA to 200 mA)

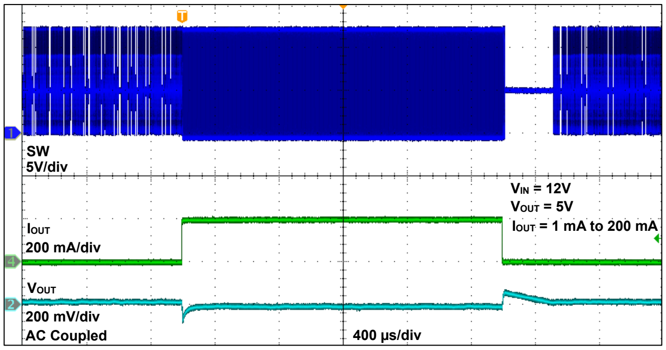


Figure 7-30. MCP16368 Load Transient Response (100 mA to 400 mA)

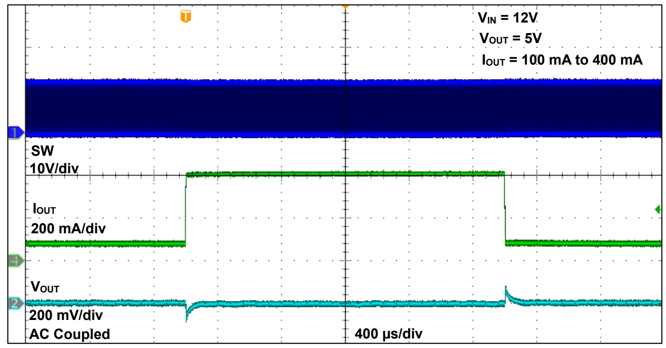
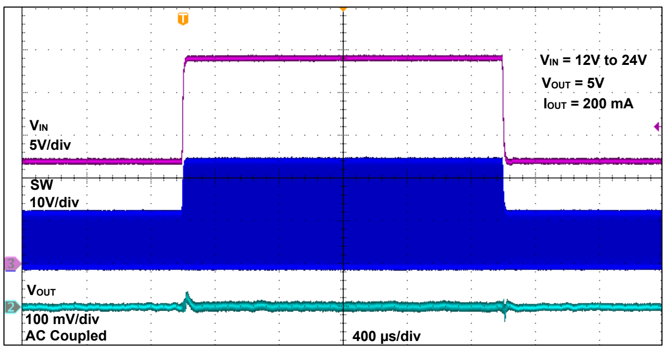


Figure 7-31. Line Transient Response



8. Application Information

8.1. Adjustable Output Voltage Calculations

To calculate the resistor divider values for the MCP16367/8/9, Equation 8-1 can be used. R_{TOP} is connected to V_{OUT}, R_{BOT} is connected to GND, and both are connected to the FB input pin.

Equation 8-1. Resistor Divider Values

$$R_{TOP} = R_{BOT} \times \left(\frac{V_{OUT}}{V_{FB}} - 1\right)$$

3.3V Output Example

V_{OUT_target}	=	3.3V
V_{FB}	=	0.8V
R_{BOT}	=	10 kΩ
R_{TOP}	=	31.25 kΩ (Standard Value = 31.6 kΩ)

The gain of the transconductance error amplifier is determined by its internal impedance, and the external resistor divider does not affect the system gain. Therefore, a wide range of resistor values can be used for the feedback network. It is recommended to use feedback resistors with 1% tolerance or better for improved accuracy. To enhance efficiency at light loads, larger resistor values are preferred; however, excessively high values may increase susceptibility to noise.

8.2. Inductor Selection and Slope Compensation

When selecting an inductor for the MCP16367/8/9, key parameters to consider include inductance value, RMS current rating, saturation current, and DC resistance (DCR).

The inductance value is especially important for ensuring stable operation. For duty cycles above 50%, internal slope compensation is applied based on the output voltage and the input-to-output voltage ratio to maintain current loop stability.

To achieve the appropriate amount of slope compensation, it is recommended to keep the inductor down-slope current constant by adjusting the inductance value in relation to V_{OUT}.

Table 8-1. Recommended Inductor Values

V_{OUT}	$L_{STANDARD}$
2.0V	5.6 µH
3.3V	8.2 µH
5.0V	15 µH
12V	33 µH
15V	33 µH

The inductor RMS current rating indicates the current level at which the inductor’s temperature increases by +20°C to +40°C, depending on the manufacturer’s specifications. The saturation current is defined as the peak current at which the inductor’s inductance decreases by 10% to 30%, also depending on the manufacturer. For reliable operation, ensure that both the nominal and peak currents in your application remain well within the inductor’s specified RMS and saturation current ratings

The peak inductor current can be calculated with Equation 8-2.

Equation 8-2. Peak Inductor Current

$$I_{LPEAK} = \left(I_{OUT} + V_{OUT} \times \frac{1 - V_{OUT}/V_{IN}}{2 \times f_{sw} \times L}\right)$$

Where:

I_{OUT}	=	Nominal output current
V_{OUT}	=	Output voltage
V_{IN}	=	Input voltage
f_{sw}	=	Switching frequency
L	=	Inductance value

When choosing the inductor, sufficient design margin must be taken into account to prevent the inductor from entering deep saturation. Overcurrent conditions must also be taken into account, especially at high input voltages where inductor current rise rapidly

8.3. Freewheeling Diode

The MCP16367/8/9 requires a freewheeling diode to create a path for the inductor current flow when the internal switch is turned off. The diode must have a reverse voltage rating greater than the maximum input voltage expected in the application. Additionally, its peak current rating must be higher than the maximum inductor current. A diode with a lower forward voltage drop increases the efficiency of the regulator, which is why Schottky diodes are typically recommended for this application.

It is also important to ensure that the diode has an adequate power rating. During the off-time of the internal power switch, the diode conducts the output current. In applications with a high V_{IN} to V_{OUT} ratio, diode conduction losses can become significant. These losses can be estimated using Equation 8-3.

Equation 8-3. Diode Conduction Losses

$$P_D = \frac{(V_{IN} - V_{OUT}) \times I_{OUT} \times V_{FW}}{V_{IN}}$$

Where:

I_{OUT}	=	Nominal output current
V_{OUT}	=	Output voltage
V_{IN}	=	Input voltage
V_{FW}	=	Forward voltage drop of the diode

Because of the high switching frequency, the AC losses of the diode must also be taken into account. These losses are caused by the charging and discharging of the junction capacitance and the reverse recovery charge.

8.4. Input Capacitor Selection

The step-down converter input capacitor must filter the high input current ripple generated by the pulsing of the input voltage. The MCP16367/8/9 input voltage pin is used to supply power to both the power train and the internal bias circuitry. A low equivalent series resistance (ESR), preferably a ceramic capacitor of at least 10 µF capacitance, is recommended. Depending on the loading profile and conditions, the application will benefit from additional bulk capacitance.

The minimum capacitance for a given input peak-to-peak voltage ripple can be calculated using Equation 8-4.

Equation 8-4. Input Capacitor Ripple

$$C_{IN(MIN)} = \frac{I_{OUT} \times D \times (1 - D)}{\Delta V_{ripple,in} \times f_{SW}}$$

Where:

I_{OUT}	=	Nominal output current
D	=	Duty-cycle
$\Delta V_{ripple,in}$	=	Required input voltage ripple
f_{SW}	=	Switching frequency

The value of ceramic capacitors varies significantly with temperature and DC bias; therefore, design margins must be taken into account to ensure sufficient capacitance at the input of the regulator. To mitigate temperature variations, X5R and X7R capacitors are recommended. Additionally, the reduction in capacitance due to DC bias should be taken into account during the design process.

8.5. Output Capacitor Selection

The output capacitor helps in providing a stable output voltage during sudden load transients and reduces the output voltage ripple. As with the input capacitor, X5R and X7R ceramic capacitors are well suited for this application.

The output capacitor voltage rating must be a minimum of V_{OUT} plus margin.

When calcluating the steady-state voltage ripple, both the ESR component and the capacitive ripple must be considered, as shown in Equation 8-5.

Equation 8-5. Output Capacitor Ripple

$$\Delta V_{ripple,out} = ESR \times \Delta I_L + \frac{\Delta I_L}{8 \times f_{SW} \times C_{OUT}}$$

Where:

ESR	=	Output capacitor series resistance
f_{SW}	=	Switching frequency
C_{OUT}	=	Output capacitance
ΔI_L	=	Inductor current ripple

The worst-case load transient for output capacitor calculations is an instantaneous load release from full load to no load. In this situation, the energy stored in the inductor, which is at its peak value, must be absorbed by the output capacitor.

The resulting output voltage overshoot can be calculated using Equation 8-6.

Equation 8-6. Output Voltage Overshoot

$$\Delta V_{OUT} = \sqrt{{V_{OUT}}^2 + \frac{L}{C_{OUT}} \times {I_{LPEAK}}^2} - V_{OUT}$$

Where:

V_{OUT}	=	Output voltage
L	=	Inductance value
I_{LPEAK}	=	Inductor peak current
C_{OUT}	=	Output capacitance

As with input capacitors, it is important to include sufficient design margin for output capacitors to account for variations due to temperature and DC bias.

8.6. Bootstrap Charging and Maximum Duty Cycle Limitations

The bootstrap capacitor supplies current to the internal high-side drive circuitry that is above the input voltage of the converter. It must store enough energy to completely drive the high-side switch on and off. A 0.1 µF X5R or X7R capacitor is recommended for all applications. The bootstrap capacitor maximum voltage is 5.5V; therefore, a capacitor with a voltage rating of 6.3V or 10V is recommended.

The bootstrap capacitor is charged during the off-time of the switching cycle, when the SW node is pulled to GND through the BD pin. When operating at a low voltage difference between input and output, the duty cycle can reach its limit of approximately 87%. Combined with the high switching frequency of 2.2 MHz, this results in a charging window of only 50 ns for the bootstrap capacitor.

In most cases, this 50 ns interval is sufficient to replenish the energy lost during each switching cycle. However, when the voltage applied on the BD pin is below 3V and the maximum duty cycle is reached, the voltage on the bootstrap capacitor can decrease, reaching 2V and forcing an internal charge of the bootstrap capacitor and, therefore, a stop in switching activity.

To enhance performance at low input voltages, where the boost charge time reaches 50 ns, the MCP16367/8/9 further limits the maximum duty cycle to 75% typical when the input voltage is below 5.1V. This adjustment allows the device to continue switching and operating correctly, albeit with a greater margin between V_{IN} and V_{OUT}. When V_{IN} exceeds 6V, the maximum duty cycle returns to 87% for normal operation.

When the maximum duty cycle operation is expected to improve the operation at low V_{IN}, an ultra-fast external bootstrap diode can be connected to the boost pin to improve the charging of the bootstrap capacitor.

8.7. Input Voltage Limitations

While a high switching frequency offers benefits such as reduced size of external passive components and improved transient response, it also introduces certain design limitations that must be considered, including:

- Dropout operation
- Minimum on-time

To determine the boundaries of the operating range, Equation 8-7 can be used.

Equation 8-7. Input Voltage Range

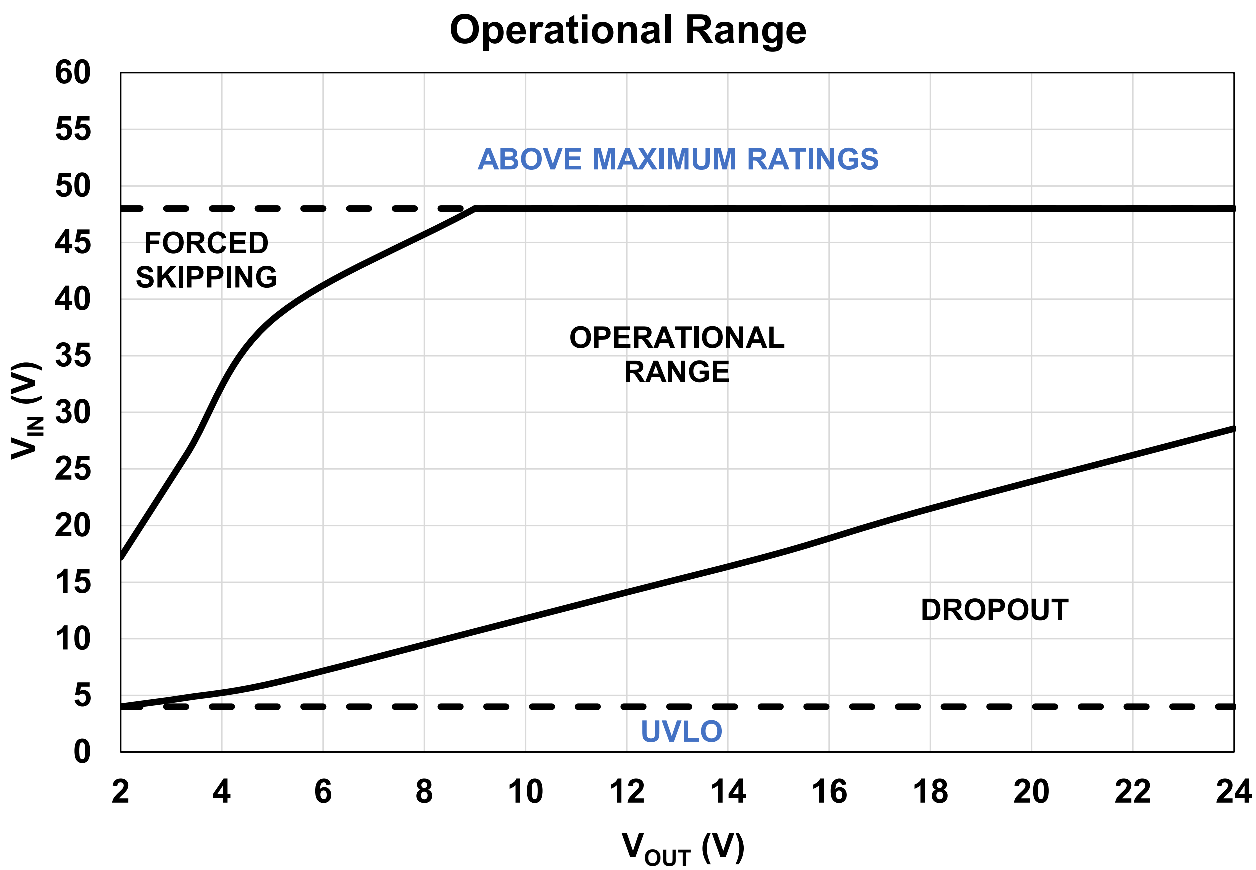
$$V_{IN} = \frac{V_{OUT} + I_{OUT} \times (R_{DCR} + R_{DSON} \times D) + V_{\mathrm{FW}} \times (1 - D)}{D}$$

Where:

V_{OUT}	=	Output voltage
I_{OUT}	=	Output current
L	=	Inductance value
R_{DCR}	=	DCR of the selected inductor
R_{DSON}	=	On-resistance of the internal high-side switch
D	=	Duty cycle
V_{FW}	=	Forward voltage drop of the diode

To determine the minimum input voltage required for proper regulation, use the maximum duty cycle in your calculations. Conversely, to determine the maximum input voltage, calculate the duty cycle to ensure it does not fall below the minimum on-time.

Figure 8-1. Input Voltage Range vs. Output Voltage



8.8. Light Load Efficiency Guidelines

To increase efficiency at light load conditions, the MCP16367 operates in PFM to keep the output voltage regulated while minimizing the input current consumption. In this mode, the MCP16367 delivers a packet of current pulses, followed by sleep periods where the output is maintained by the output capacitor. When in Sleep mode, the MCP16367 consumes around 18 µA from the input. As the output load decreases,both the frequency and duration of the current pulse packets are reduced, resulting in longer sleep periods. By maximizing the sleep time, the converter's no-load input current approaches the 18 µA value. To further optimize the performance at light loads, the current flowing through the feedback resistors and the reverse current through the freewheeling diode must be minimized, as they are seen as load currents. It is recommended that the feedback resistors be in the order of tens of kΩ in range and that the freewheeling diode reverse current be less than 1 µA at room temperature.

8.9. PCB Layout Information

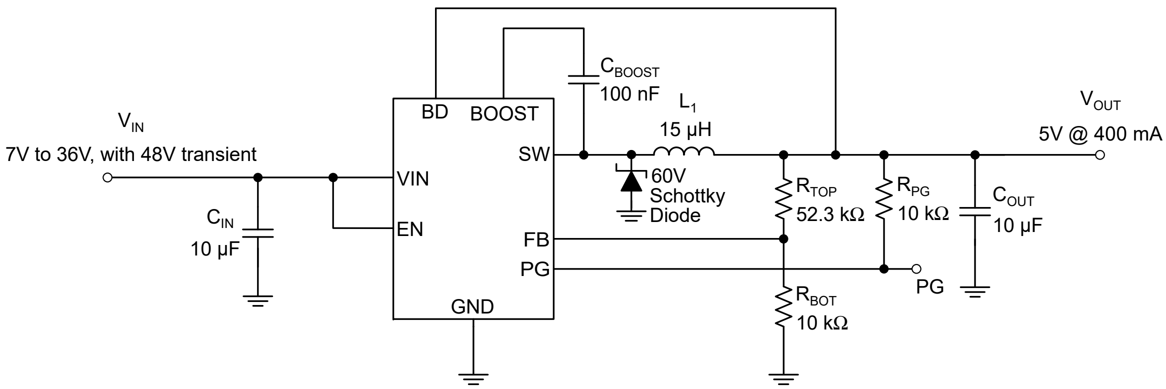
Good printed circuit board layout techniques are important to any switching circuitry, and switch mode power supplies are no different. When wiring the switching high-current paths, short and wide traces must be used. Therefore, it is important that the input and output capacitors be placed as close as possible to the MCP16367/8/9 to minimize the loop area.

The feedback resistors and feedback signal must be routed away from the switching node and the switching current loop. When possible, use ground planes and traces to shield the feedback signal and minimize noise and magnetic interference.

A robust MCP16367/8/9 layout begins with the placement of the input capacitor C_{IN}, which supplies current to the circuit input when the switch is on. In addition to providing high-frequency current, C_{IN} ensures a stable voltage source for the internal circuitry of the MCP16367/8/9. Excessive transients or ringing on the VIN pin can lead to unstable PWM operation, so minimizing these effects is important. Incorporating a ground plane on the bottom of the board ensures a low-resistance, low-inductance path for return current. The next priority is the placement of the freewheeling current loop, formed by the Schottky Diode, C_{OUT} and L. It is advisable to place the C_{OUT} return close to the C_{IN} return. The bootstrap capacitor must be placed between the boost pin and the switch node pin (SW). Additionally, R_{TOP} and R_{BOT} should be routed away from the switch node to prevent noise from coupling into the high-impedance FB input.

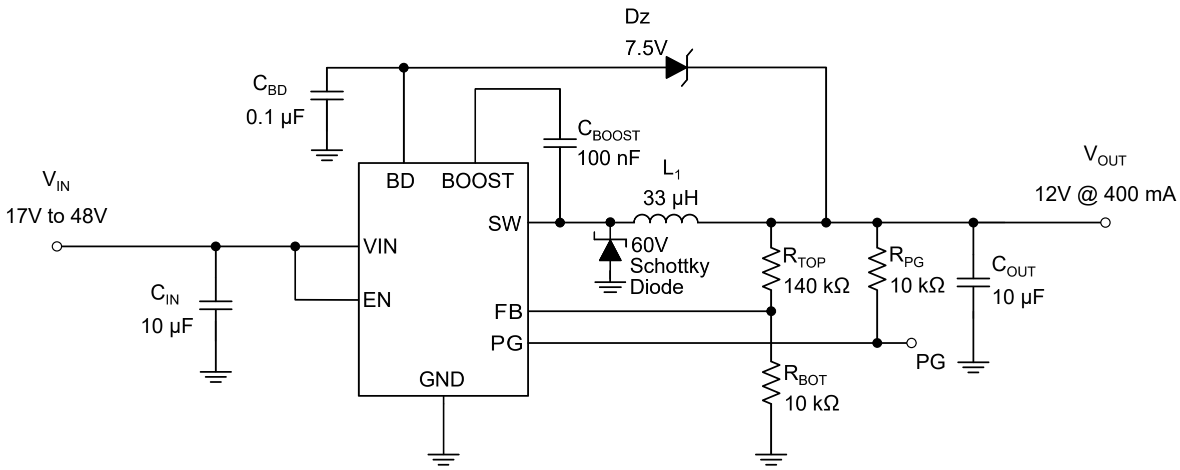
9. Typical Application Circuits

Figure 9-1. Typical Application 7V - 36V V_{IN} (Transient up to 48V) to 5V V_{OUT}



Component	Value	Manufacturer	Part Number	Comment
C_{IN}	10 µF	TDK Corporation	C5750X7S2A106M	Ceramic Capacitor, 10 µF, 100V, X7S, 2220
C_{OUT}	10 µF	TDK Corporation	C3216X7R1C106M160AC	Ceramic Capacitor, 10 µF, X7R, 16V, 1206
L_1	15 µH	Würth Elektronik	7440700150	15 µH, 1.65A, 117 mΩ, Shielded Tiny Power Inductor
FW Diode	PMEG6010ER	NXP Semiconductors	PMEG6010ER	Schottky Diode, 60V, 1A, SOD-323
C_{BOOST}	100 nF	KEMET	C0603X104K4RACTU	Ceramic Capacitor, 0.1 µF, 16V, 10%, X7R, SMD, 0603

Figure 9-2. Typical Application 17V - 48V V_{IN} to 12V V_{OUT} with Boost Drive Derived from Output

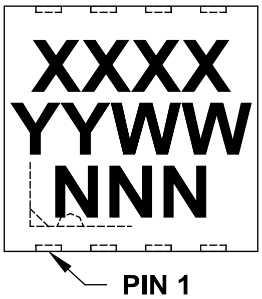


Component	Value	Manufacturer	Part Number	Comment
C_{IN}	10 µF	TDK Corporation	C5750X7S2A106M	Ceramic Capacitor, 10 µF, 100V, X7S, 2220
C_{OUT}	10 µF	TDK Corporation	C3216X7R1E106M160AB	Ceramic Capacitor, 10 µF, 25V, X7R, 1206
L_1	33 µH	Würth Elektronik	744071330	33 µH, 1.9A, 120 mΩ, Shielded Tiny Power Inductor
FW Diode	PMEG6010ER	NXP Semiconductors	PMEG6010ER	Schottky Diode, 60V, 1A, SOD-323
C_{BOOST}	100 nF	KEMET	C0603X104K4RACTU	Ceramic Capacitor, 0.1 µF, 16V, 10%, X7R, SMD, 0603
D_Z	7.5V Zener	Diodes Incorporated®	MMSZ5236BS-7-F	Zener Diode, 7.5V, 200 mW, SOD-323
C_{BD}	0.1 µF	TDK Corporation	C1608X7R1H104K080AA	Ceramic Capacitor, 0.1 µF, 50V, X7R, 0603

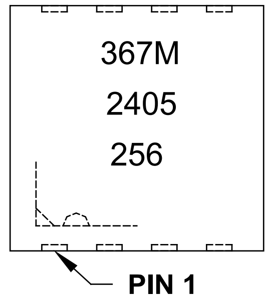
10. Packaging Information

Package Marking Information

8-Lead VDFN (3x3x1 mm)



Example

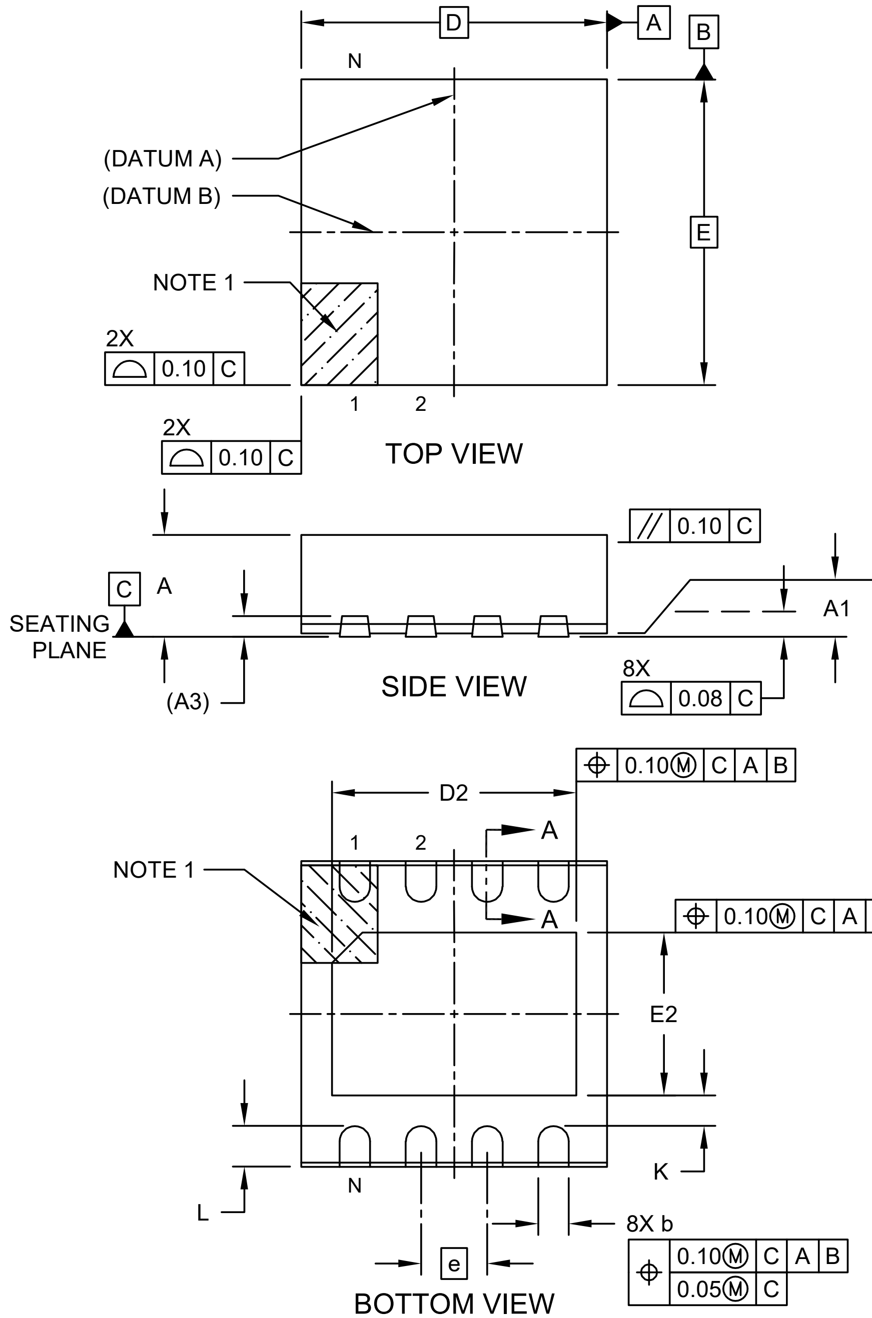


Legend:	XX...X	Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package.

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

8-Lead Very Thin Plastic Dual Flat, No Lead Package (Q8B) - 3x3x1 mm Body [VDFN] With 2.40x1.60 mm Exposed Pad and Stepped Wettable Flanks; Atmel Legacy YCL

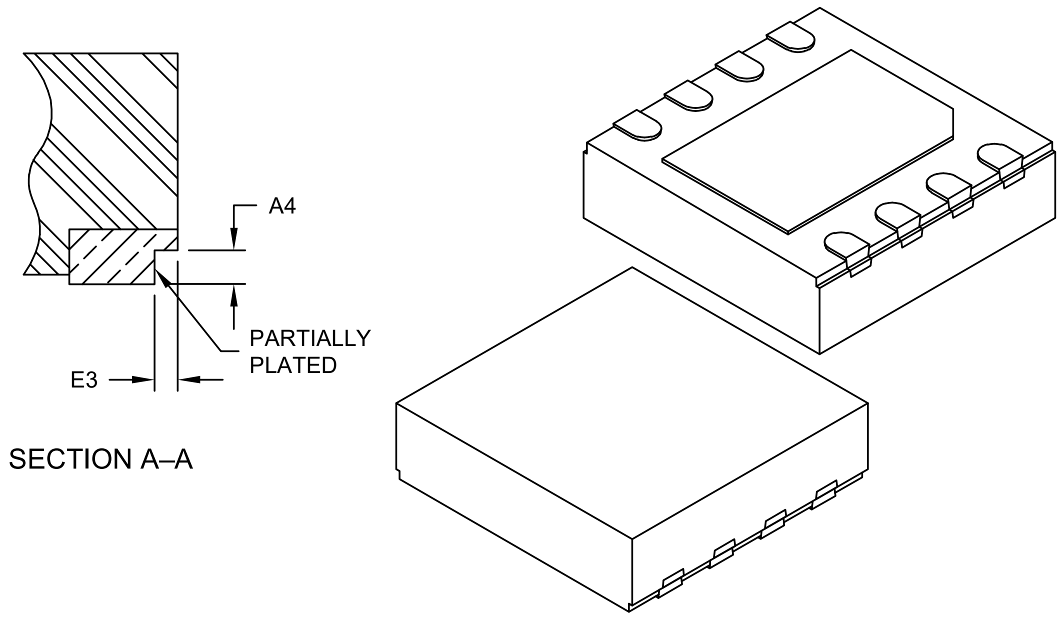
Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Microchip Technology Drawing C04-21358 Rev D Sheet 1 of 2

8-Lead Very Thin Plastic Dual Flat, No Lead Package (Q8B) - 3x3x1 mm Body [VDFN] With 2.40x1.60 mm Exposed Pad and Stepped Wettable Flanks; Atmel Legacy YCL

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Number of Terminals	N	8		
Pitch	e	0.65 BSC		
Overall Height	A	0.80	0.90	1.00
Standoff	A1	0.00	0.035	0.05
Terminal Thickness	A3	0.203 REF		
Overall Length	D	3.00 BSC		
Exposed Pad Length	D2	2.30	2.40	2.50
Overall Width	E	3.00 BSC		
Exposed Pad Width	E2	1.50	1.60	1.70
Terminal Width	b	0.25	0.30	0.35
Terminal Length	L	0.35	0.40	0.45
Terminal-to-Exposed-Pad	K	0.20	-	-
Wettable Flank Step Cut Depth	A4	0.10	-	0.19
Wettable Flank Step Cut Width	E3	-	-	0.085

Notes:

1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. Package is saw singulated
3. Dimensioning and tolerancing per ASME Y14.5M

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

   REF: Reference Dimension, usually without tolerance, for information purposes only.

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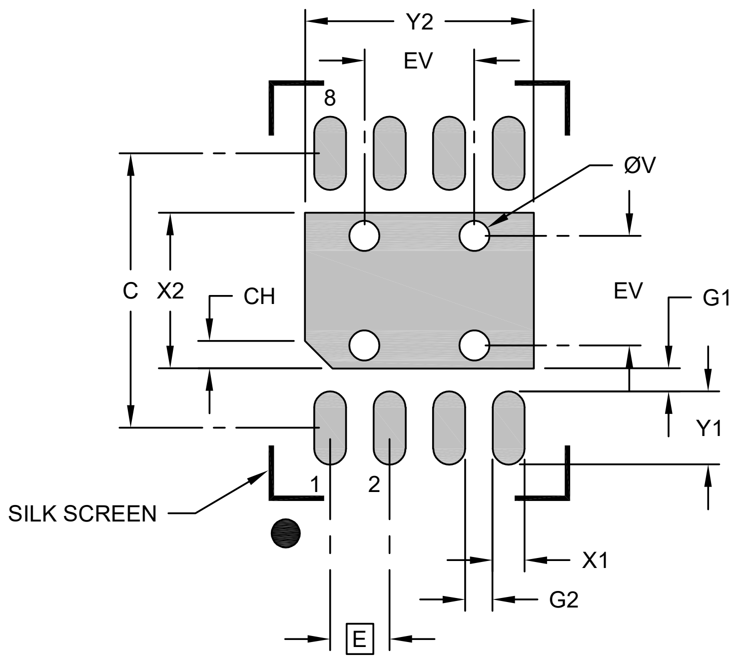
8-Lead Very Thin Plastic Dual Flat, No Lead Package (Q8B) - 3x3x1 mm Body [VDFN] With 2.40x1.60 mm Exposed Pad and Stepped Wettable Flanks

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



RECOMMENDED LAND PATTERN

	Units	MILLIMETERS		
	Dimension Limits	MIN	NOM	MAX
Contact Pitch	E		0.65 BSC	
Optional Center Pad Width	X2			1.70
Optional Center Pad Length	Y2			2.50
Contact Pad Spacing	C		3.00	
Contact Pad Width (X8)	X1			0.35
Contact Pad Length (X8)	Y1			0.80
Contact Pad to Center Pad (X8)	G1	0.20		
Contact Pad to Contact Pad (X6)	G2	0.20		
Pin 1 Index Chamfer	CH	0.20		
Thermal Via Diameter	V		0.33	
Thermal Via Pitch	EV		1.20	

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M
   BSC: Basic Dimension. Theoretically exact value shown without tolerances.
2. For best soldering results, thermal vias, if used, should be filled or tented to avoid solder loss during reflow process

Microchip Technology Drawing C04-23358 Rev D

11. Revision History

Revision B (July 2025)

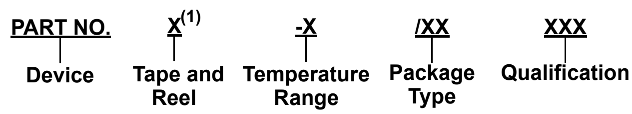
- Updated figure 7-24
- Updated Equation 8-7
- Updated the Product Identification System section.

Revision A (February 2025)

Initial release of this document

12. Product Identification System

To order or obtain information, for example, on pricing or delivery, contact Microchip: https://www.microchip.com/en-us/about/contact-us.



Device*:	MCP16367/8/9	48V Input, 400 mA Output, 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator
Tape and Reel Option[1]:	(Blank)	= Standard Packaging (Tube) – 120/Tube
	T	= Tape and Reel – 3300/Reel
Temperature:	E	= -40°C to +125°C (Extended)
Package Type:	Q8B	= 8-Lead 3 mm x 3 mm x 1 mm VDFN
Qualification:	(Blank)	= Standard Part
	VAO	= AEC-Q100 Automotive Qualified
	VXX	= AEC-Q100 Automotive Qualified, custom device, additional terms or conditions may apply
*Device Options:	MCP16367	= PFM/PWM, Fixed 2.2 MHz Switching Frequency
	MCP16368	= PWM Only, Fixed 2.2 MHz Switching Frequency
	MCP16369	= PWM Only, 2.2 MHz +10% Frequency Dithering

- MCP16367-E/Q8B: 48V Input, 400 mA Output, PFM/PWM, Fixed 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tube
- MCP16368-E/Q8B: 48V Input, 400 mA Output, PWM Only, Fixed 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tube
- MCP16369T-E/Q8B: 48V Input, 400 mA Output, PWM Only, 2.2 MHz +10% Frequency Dithering, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tape and Reel
- MCP16367-E/Q8BVAO: 48V Input, 400 mA Output, PFM/PWM, Fixed 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tube, AEC-Q100 Automotive Qualified
- MCP16368-E/Q8BVAO: 48V Input, 400 mA Output, PWM Only, Fixed 2.2 MHz Switching Frequency, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tube, AEC-Q100 Automotive Qualified
- MCP16369T-E/Q8BVAO: 48V Input, 400 mA Output, PWM Only, 2.2 MHz +10% Frequency Dithering, Integrated Switch Step-Down Regulator, -40°C to +125°C Temperature Range, 8-Lead VDFN Package, Tape and Reel, AEC-Q100 Automotive Qualified

Note: Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option.

13. Product Change Notification Service

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