
Chipsmall
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采购部

MCP16331

High-Voltage Input Integrated Switch Step-Down Regulator

Features

- Up to 96% Efficiency
- Input Voltage Range: 4.4V to 50V
- Output Voltage Range: 2.0V to 24V
- 2% Output Voltage Accuracy
- Qualification: AEC-Q100 Rev. G, Grade 1 (-40°C to 125°C)
- Integrated N-Channel Buck Switch: 600 mΩ
- Minimum 500 mA Output Current Over All Input Voltage Ranges (see Figure 2-9 for Maximum Output Current vs. V_{IN})
  - Up to 1.2A output current at 3.3V and 5V V_{OUT}, $V_{IN} > 12V$, SOT-23 package at +25°C ambient temperature
  - Up to 0.8A output current at 12V V_{OUT}, $V_{IN} > 18V$, SOT-23 package at +25°C ambient temperature
- 500 kHz Fixed Frequency
- Adjustable Output Voltage
- Low Device Shutdown Current
- Peak Current Mode Control
- Internal Compensation
- Stable with Ceramic Capacitors
- Internal Soft Start
- Internal Pull-up on EN
- Cycle-by-Cycle Peak Current Limit
- Undervoltage Lockout (UVLO): 4.1V to Start; 3.6V to Stop
- Overtemperature Protection
- Available Package: 6-Lead SOT-23, 8-Lead 2x3 TDFN

Applications

- PIC® MCU/dsPIC® DSC Microcontroller Bias Supply
- 48V, 24V and 12V Industrial Input DC-DC Conversion
- Set-Top Boxes (STB)
- DSL Cable Modems
- Automotive
- AC/DC Adapters
- SLA Battery-Powered Devices
- AC-DC Digital Control Power Source
- Power Meters
- Consumer
- Medical and Health Care
- Distributed Power Supplies

General Description

The MCP16331 is a highly integrated, high-efficiency, fixed frequency, step-down DC-DC converter in a popular 6-pin SOT-23 or 8-pin 2x3 TDFN package that operates from input voltage sources up to 50V. Integrated features include a high-side switch, fixed frequency Peak Current-Mode control, internal compensation, peak current limit and overtemperature protection. Minimal external components are necessary to develop a complete step-down DC-DC converter power supply.

High converter efficiency is achieved by integrating the current-limited, low-resistance, high-speed N-Channel MOSFET and associated drive circuitry. High switching frequency minimizes the size of external filtering components, resulting in a small solution size.

The MCP16331 can supply 500 mA of continuous current while regulating the output voltage from 2.0V to 24V. An integrated, high-performance Peak Current-Mode architecture keeps the output voltage tightly regulated, even during input voltage steps and output current transient conditions that are common in power systems.

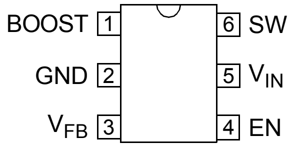
The EN input is used to turn the device on and off. While off, only a few μA of current are consumed from the input for power shedding and load distribution applications. This pin is internally pulled up, so the device will start, even if the EN pin is left floating.

Output voltage is set with an external resistor divider.

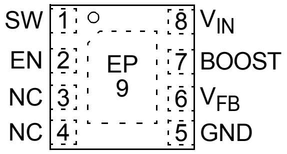
The MCP16331 is offered in a space-saving 6-lead SOT-23 and 8-lead 2x3 TDFN surface mount package.

Package Type

MCP16331
6-Lead SOT-23

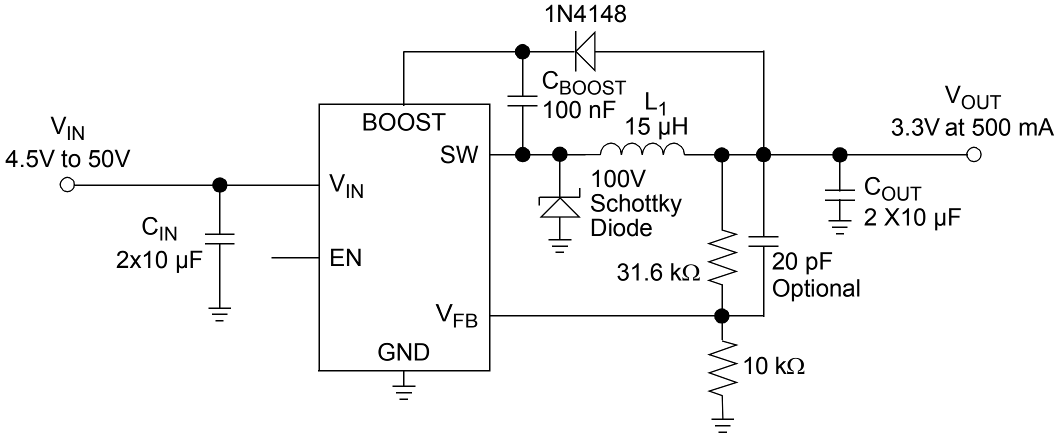


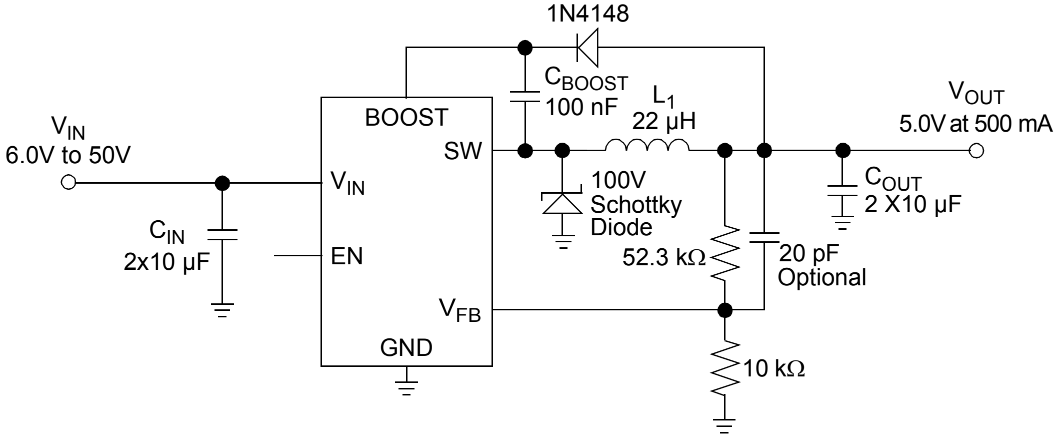
MCP16331
8-Lead 2x3 TDFN*



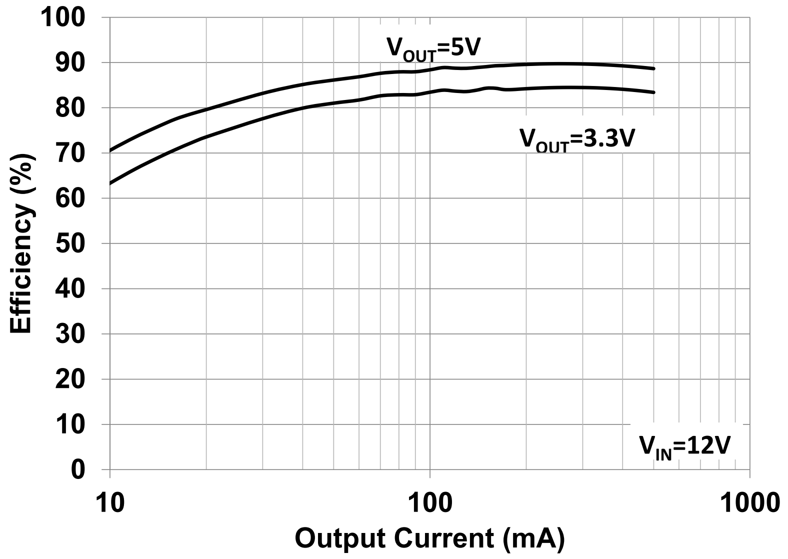
*Includes Exposed Thermal Pad (EP); see Table 3-1.

Typical Applications





Note: EN has an internal pull-up, so the device will start even if the EN pin is left floating.



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings†

V_{IN}, SW	-0.5V to 54V
BOOST – GND	-0.5V to 60V
BOOST – SW Voltage	-0.5V to 6.0V
V_{FB} Voltage	-0.5V to 6.0V
EN Voltage	-0.5V to (V_{IN} + 0.3V)
Output Short-Circuit Current	Continuous
Power Dissipation	Internally Limited
Storage Temperature	-65°C to +150°C
Ambient Temperature with Power Applied	-40°C to +125°C
Operating Junction Temperature	-40°C to +160°C
ESD Protection on All Pins:	
HBM	4 kV
MM	300V

† Notice: 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.

DC CHARACTERISTICS

Electrical Characteristics: Unless otherwise indicated, T_A = +25°C, $V_{IN} = V_{EN}$ = 12V, $V_{BOOST} - V_{SW}$ = 3.3V, V_{OUT} = 3.3V, I_{OUT} = 100 mA, L = 15 µH, $C_{OUT} = C_{IN}$ = 2 x 10 µF X7R Ceramic Capacitors.
Boldface specifications apply over the T_A range of -40°C to +125°C.

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
Input Voltage	V_{IN}	**4.4**	—	**50**	V	**Note 1**
Feedback Voltage	V_{FB}	**0.784**	0.800	**0.816**	V	
Output Voltage Adjust Range	V_{OUT}	**2.0**	—	**24**	V	**Note 1**, **Note 3**
Feedback Voltage Line Regulation	$\lvert(\Delta V_{FB}/V_{FB})/\Delta V_{IN}\rvert$	—	0.002	0.1	%/V	V_{IN} = 5V to 50V
Feedback Voltage Load Regulation	$\lvert\Delta V_{FB}/V_{FB}\rvert$	—	0.13	0.35	%	I_{OUT} = 50 mA to 500 mA
Feedback Input Bias Current	I_{FB}	—	+/- 3	—	nA	
Undervoltage Lockout Start	$UVLO_{STRT}$	—	4.1	**4.4**	V	V_{IN} rising
Undervoltage Lockout Stop	$UVLO_{STOP}$	**3**	3.6	—	V	V_{IN} falling
Undervoltage Lockout Hysteresis	$UVLO_{HYS}$	—	0.5	—	V	
Switching Frequency	f_{SW}	**425**	500	**550**	kHz	
Maximum Duty Cycle	DC_{MAX}	**90**	93	—	%	V_{IN} = 5V; V_{FB} = 0.7V; I_{OUT} = 100 mA
Minimum Duty Cycle	DC_{MIN}	—	1	—	%	**Note 4**
NMOS Switch-On Resistance	$R_{DS(ON)}$	—	0.6	—	Ω	$V_{BOOST} - V_{SW}$ = 5V, **Note 3**
NMOS Switch Current Limit	$I_{N(MAX)}$	—	1.3	—	A	$V_{BOOST} - V_{SW}$ = 5V, **Note 3**
Quiescent Current	I_Q	—	1	**1.7**	mA	V_{IN} = 12V; **Note 2**
Quiescent Current – Shutdown	I_Q	—	6	**10**	µA	V_{OUT} = EN = 0V
Output Current	I_{OUT}	500	—	—	mA	**Note 1**; see Figure 2-9

Note 1: The input voltage should be > output voltage + headroom voltage; higher load currents increase the input voltage necessary for regulation. See characterization graphs for typical input to output operating voltage range.

2: V_{BOOST} supply is derived from V_{OUT}.

3: Determined by characterization, not production tested.

4: This is ensured by design.

DC CHARACTERISTICS (CONTINUED)

Electrical Characteristics: Unless otherwise indicated, T_A = +25°C, V_{IN} = V_{EN} = 12V, $V_{BOOST} - V_{SW}$ = 3.3V, V_{OUT} = 3.3V, I_{OUT} = 100 mA, L = 15 µH, C_{OUT} = C_{IN} = 2 x 10 µF X7R Ceramic Capacitors.
Boldface specifications apply over the T_A range of -40°C to +125°C.

Parameters	Sym.	Min.	Typ.	Max.	Units	Conditions
EN Input Logic High	V_{IH}	**1.9**	—	—	V	
EN Input Logic Low	V_{IL}	—	—	**0.4**	V	
EN Input Leakage Current	I_{ENLK}	—	0.007	0.5	µA	V_{IN} = EN = 5V
Soft Start Time	t_{SS}	—	600	—	µs	EN Low-to-high, 90% of V_{OUT}
Thermal Shutdown Die Temperature	T_{SD}	—	160	—	°C	**Note 3**
Die Temperature Hysteresis	T_{SDHYS}	—	30	—	°C	**Note 3**

Note 1: The input voltage should be > output voltage + headroom voltage; higher load currents increase the input voltage necessary for regulation. See characterization graphs for typical input to output operating voltage range.
2: V_{BOOST} supply is derived from V_{OUT}.
3: Determined by characterization, not production tested.
4: This is ensured by design.

TEMPERATURE SPECIFICATIONS

Electrical Specifications

Parameters	Sym.	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	—	—	+160	°C	Transient
Package Thermal Resistances						
Thermal Resistance, 6L-SOT-23	θ_{JA}	—	190.5	—	°C/W	EIA/JESD51-3 Standard
Thermal Resistance, 8L-2x3 TDFN	θ_{JA}	—	52.5	—	°C/W	EIA/JESD51-3 Standard

2.0 TYPICAL PERFORMANCE CURVES

Note: 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.

Note: Unless otherwise indicated, V_{IN} = EN = 12V, C_{OUT} = C_{IN} = 2 x10 µF, L = 15 µH, V_{OUT} = 3.3V, I_{LOAD} = 100 mA, T_A = +25°C, 6-Lead SOT-23 package.

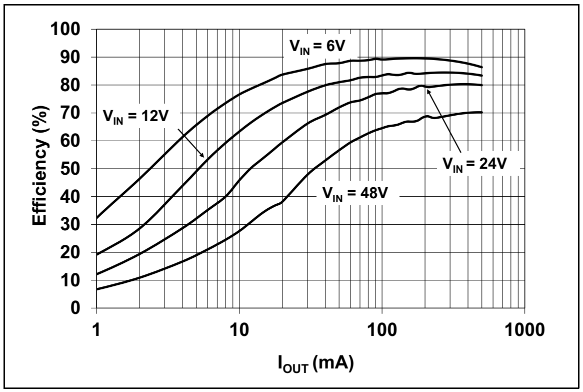


FIGURE 2-1: 3.3V V_{OUT} Efficiency vs. I_{OUT}.

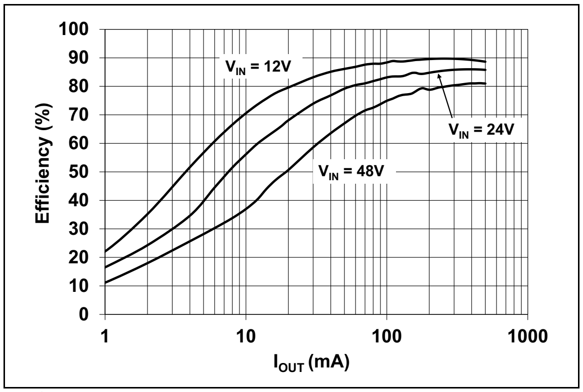


FIGURE 2-2: 5V V_{OUT} Efficiency vs. I_{OUT}.

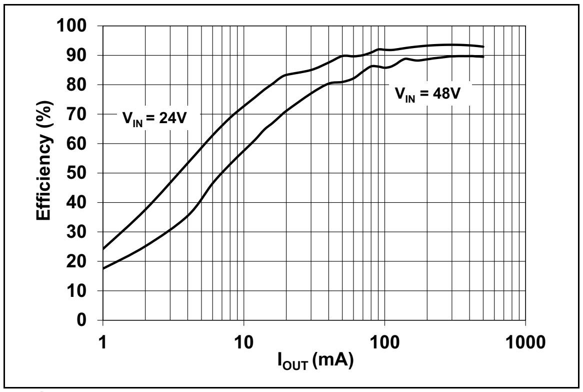


FIGURE 2-3: 12V V_{OUT} Efficiency vs. I_{OUT}.

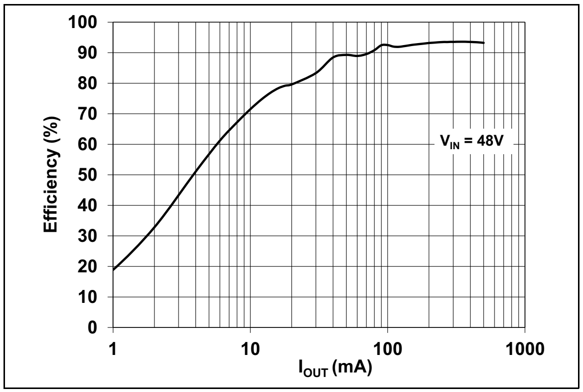


FIGURE 2-4: 24V V_{OUT} Efficiency vs. I_{OUT}.

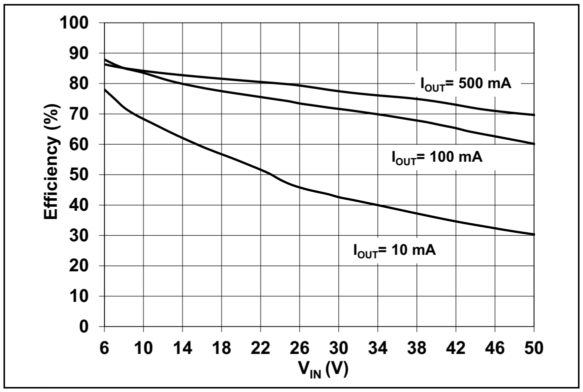


FIGURE 2-5: 3.3V V_{OUT} Efficiency vs. V_{IN}.

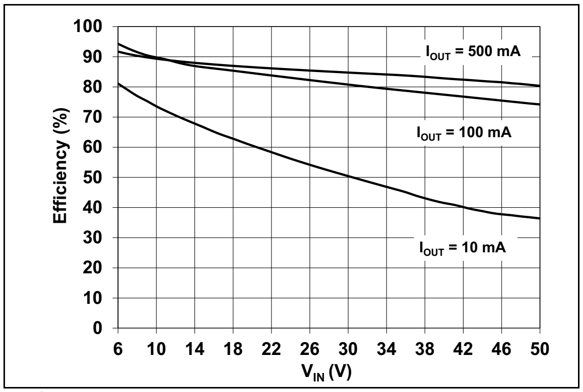


FIGURE 2-6: 5V V_{OUT} Efficiency vs. V_{IN}.

Note: Unless otherwise indicated, V_{IN} = EN = 12V, C_{OUT} = C_{IN} = 2 x10 µF, L = 15 µH, V_{OUT} = 3.3V, I_{LOAD} = 100 mA, T_A = +25°C, 6-Lead SOT-23 package.

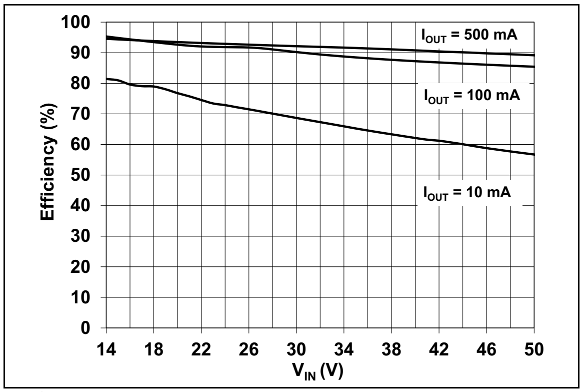


FIGURE 2-7: *12V V_{OUT} Efficiency vs. V_{IN}.*

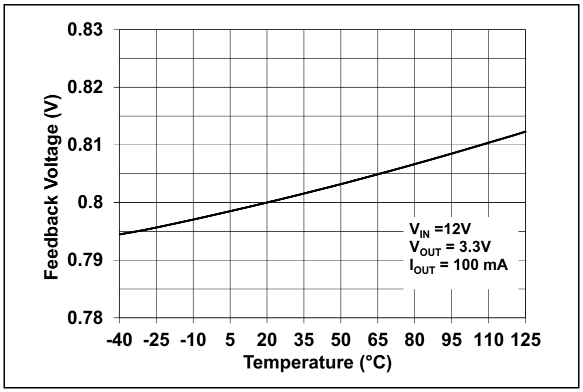


FIGURE 2-10: *V_{FB} vs. Temperature.*

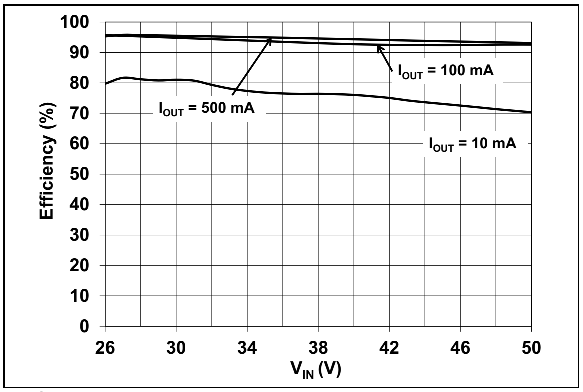


FIGURE 2-8: *24V V_{OUT} Efficiency vs. V_{IN}.*

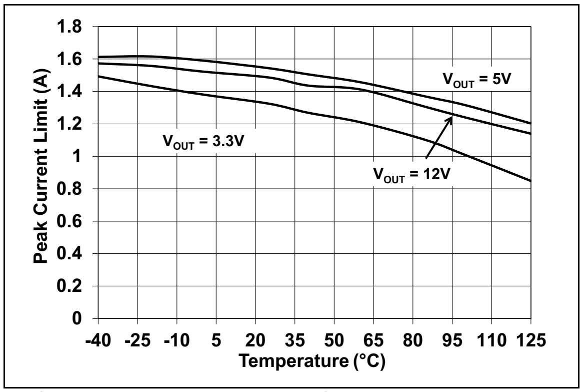


FIGURE 2-11: *Peak Current Limit vs. Temperature.*

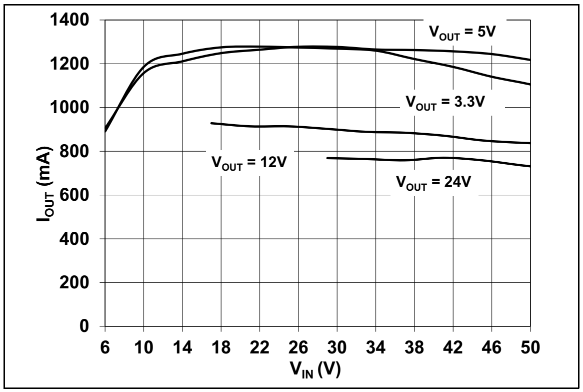


FIGURE 2-9: *Max I_{OUT} vs. V_{IN}.*

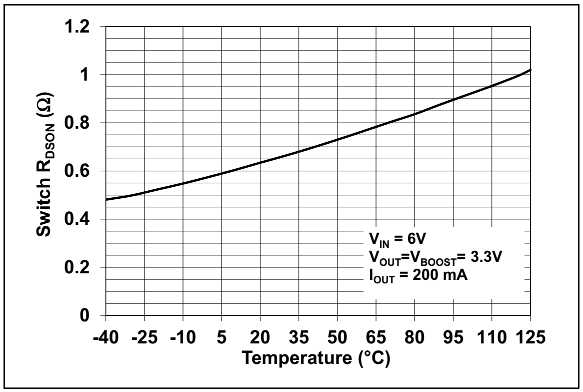


FIGURE 2-12: *Switch R_{DSON} vs. Temperature.*

Note: Unless otherwise indicated, V_{IN} = EN = 12V, C_{OUT} = C_{IN} = 2 x10 µF, L = 15 µH, V_{OUT} = 3.3V, I_{LOAD} = 100 mA, T_A = +25°C, 6-Lead SOT-23 package.

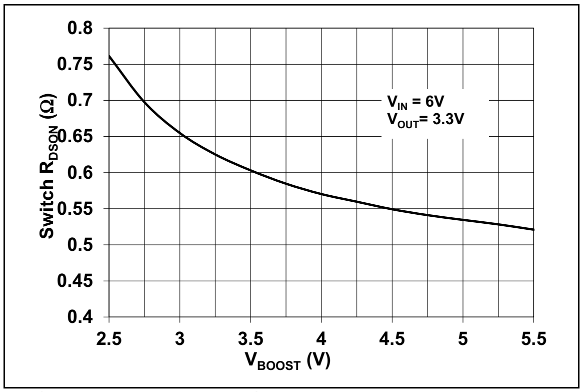


FIGURE 2-13: *Switch R_{DSON} vs. V_{BOOST}.*

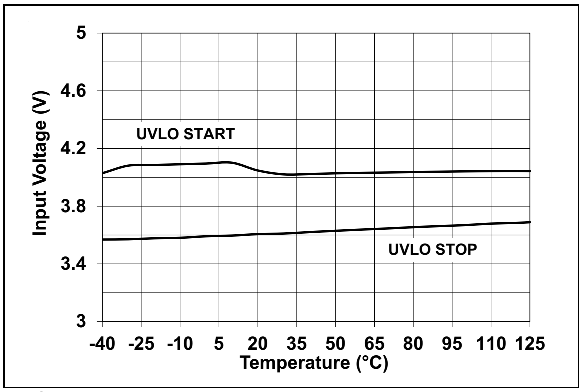


FIGURE 2-14: *Undervoltage Lockout vs. Temperature.*

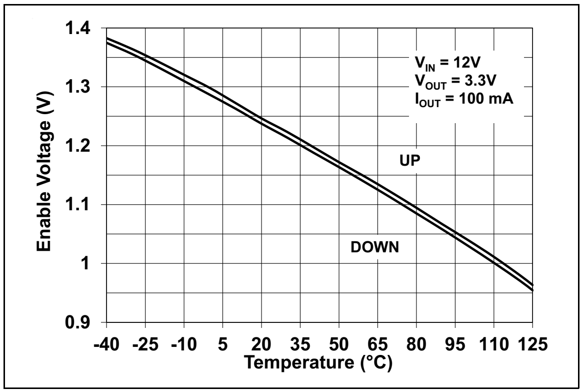


FIGURE 2-15: *EN Threshold Voltage vs. Temperature.*

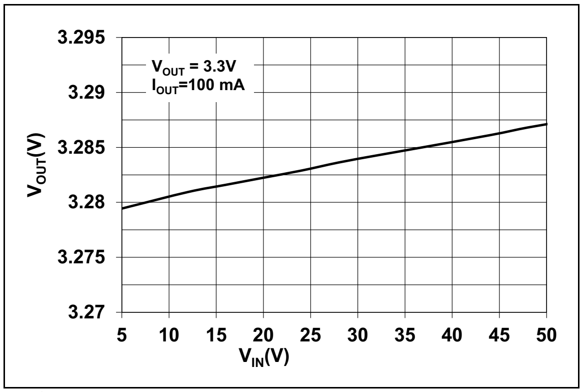


FIGURE 2-16: *V_{OUT} vs. V_{IN}.*

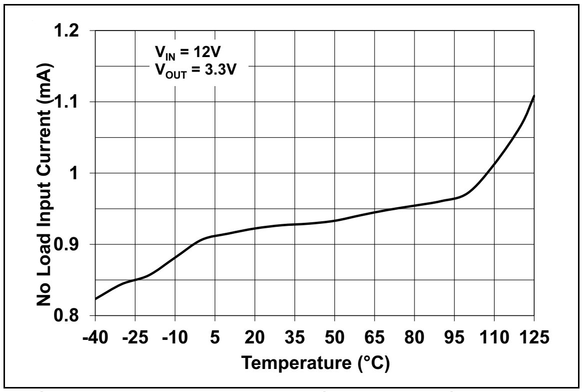


FIGURE 2-17: *Input Quiescent Current vs. Temperature.*

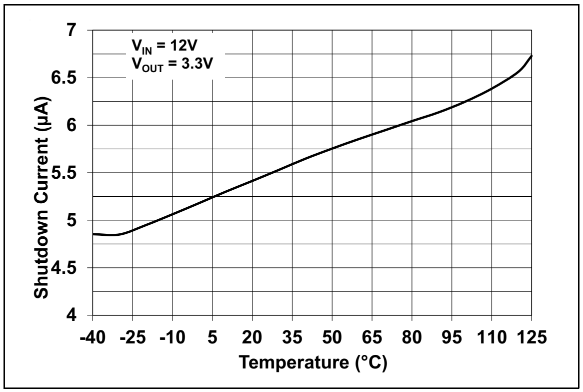


FIGURE 2-18: *Shutdown Current vs. Temperature.*

Note: Unless otherwise indicated, V_{IN} = EN = 12V, C_{OUT} = C_{IN} = 2 x10 µF, L = 15 µH, V_{OUT} = 3.3V, I_{LOAD} = 100 mA, T_A = +25°C, 6-Lead SOT-23 package.

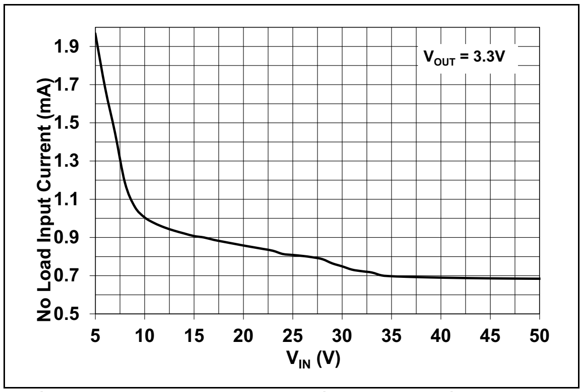


FIGURE 2-19: *Input Quiescent Current vs. V_{IN}.*

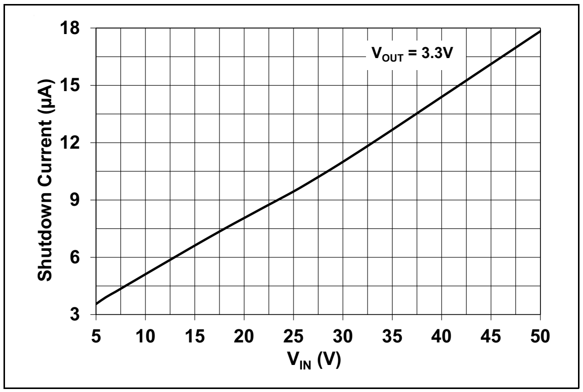


FIGURE 2-20: *Shutdown Current vs. V_{IN}.*

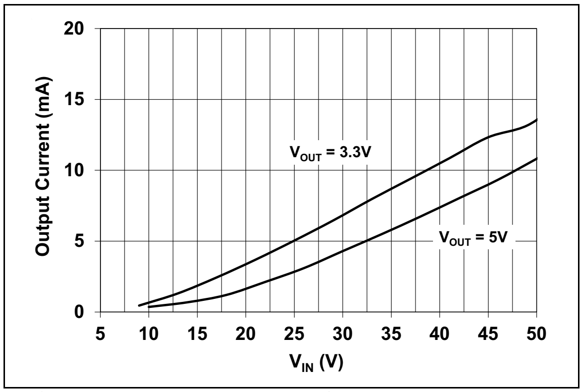


FIGURE 2-21: *PWM/Skipping I_{OUT} Threshold vs. V_{IN}.*

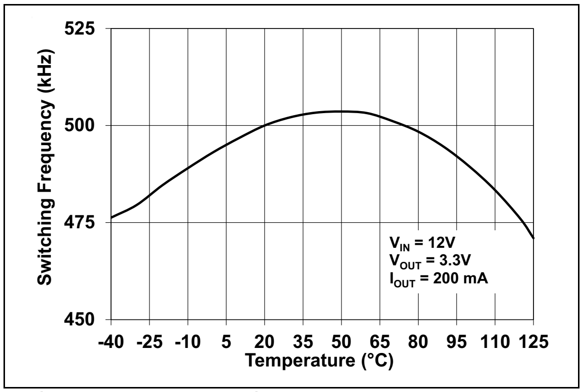


FIGURE 2-22: *Switching Frequency vs. Temperature.*

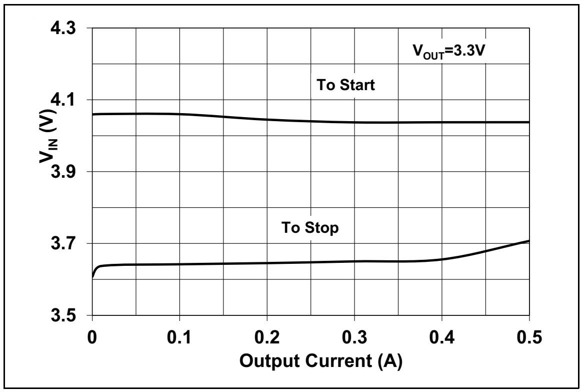


FIGURE 2-23: *Minimum Input Voltage vs. Output Current.*

Note: Unless otherwise indicated, V_{IN} = EN = 12V, C_{OUT} = C_{IN} = 2 x10 µF, L = 15 µH, V_{OUT} = 3.3V, I_{LOAD} = 100 mA, T_A = +25°C, 6-Lead SOT-23 package.

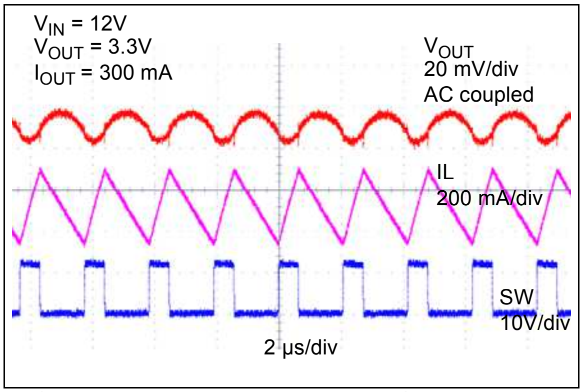


FIGURE 2-24: *Heavy Load Switching Waveforms.*

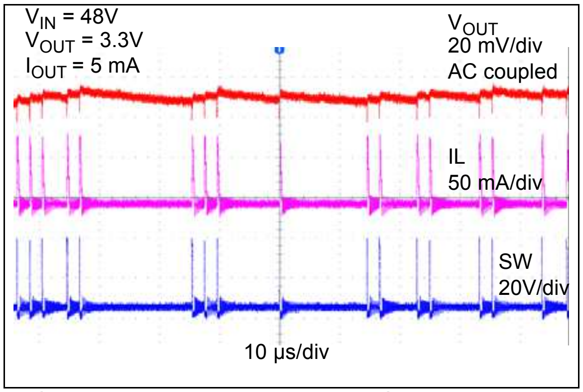


FIGURE 2-25: *Light Load Switching Waveforms.*

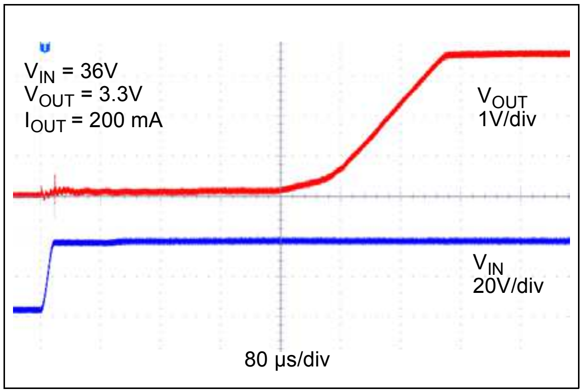


FIGURE 2-26: *Start-up from V_{IN}.*

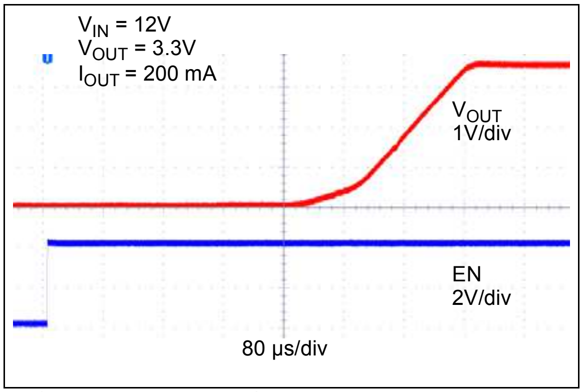


FIGURE 2-27: *Start-up from EN.*

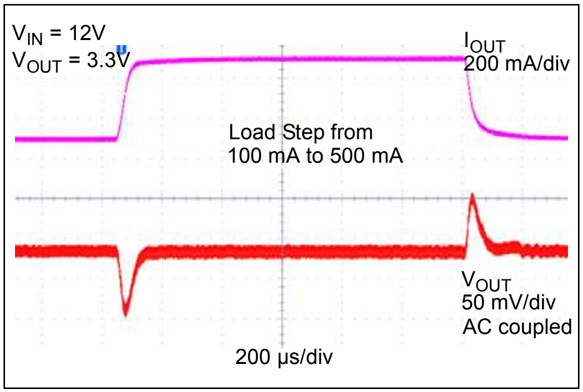


FIGURE 2-28: *Load Transient Response.*

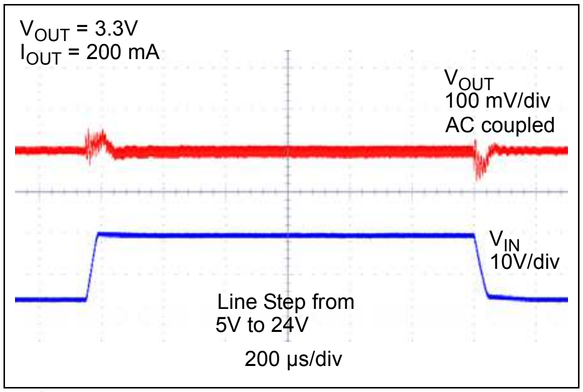


FIGURE 2-29: *Line Transient Response.*

3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 3-1.

TABLE 3-1: PIN FUNCTION TABLE

MCP16331		Symbol	Description
TDFN	SOT-23		
1	6	SW	Output switch node. Connects to the inductor, freewheeling diode and the bootstrap capacitor.
2	4	EN	Enable pin. There is an internal pull-up on the V_{IN}. To turn the device off, connect EN to GND.
3	—	NC	Not connected.
4	—	NC	Not connected.
5	2	GND	Ground pin.
6	3	V_{FB}	Output voltage feedback pin. Connect V_{FB} to an external resistor divider to set the output voltage.
7	1	BOOST	Boost voltage that drives the internal NMOS control switch. A bootstrap capacitor is connected between the BOOST and SW pins.
8	5	V_{IN}	Input supply voltage pin for power and internal biasing.
9	—	EP	Exposed Thermal Pad

3.1 Switch Node (SW)

The switch node pin is connected internally to the NMOS switch, and externally to the SW node consisting of the inductor and Schottky diode. The external Schottky diode should be connected close to the SW node and GND.

3.2 Enable Pin (EN)

The EN pin is a logic-level input used to enable or disable the device switching and lower the quiescent current while disabled. By default the MCP16331 is enabled through an internal pull-up. To turn off the device, the EN pin must be pulled low.

3.3 Ground Pin (GND)

The ground or return pin is used for circuit ground connection. The length of the trace from the input cap return, output cap return and GND pin should be made as short as possible to minimize the noise on the GND pin.

3.4 Feedback Voltage Pin (V_{FB})

The V_{FB} pin is used to provide output voltage regulation by using a resistor divider. The V_{FB} voltage will be 0.8V typical with the output voltage in regulation.

3.5 Boost Pin (BOOST)

The supply for the floating high-side driver, used to turn the integrated N-Channel MOSFET on and off, is connected to the BOOST pin.

3.6 Power Supply Input Voltage Pin (V_{IN})

Connect the input voltage source to V_{IN}. The input source should be decoupled to GND with a 4.7 µF-20 µF capacitor, depending on the impedance of the source and output current. The input capacitor provides current for the switch node and a stable voltage source for the internal device power. This capacitor should be connected as close as possible to the V_{IN} and GND pins.

3.7 Exposed Thermal Pad Pin (EP)

There is an internal electrical connection between the EP and GND pin for the TDFN package.

NOTES:

4.0 DETAILED DESCRIPTION

4.1 Device Overview

The MCP16331 is a high input voltage step-down regulator, capable of supplying 500 mA to a regulated output voltage, from 2.0V to 24V. Internally, the trimmed 500 kHz oscillator provides a fixed frequency, while the Peak Current-Mode control architecture varies the duty cycle for output voltage regulation. An internal floating driver is used to turn the high-side, integrated N-Channel MOSFET on and off. The power for this driver is derived from an external boost capacitor (C_{BOOST}) whose energy is supplied from a fixed voltage, ranging between 3.0V and 5.5V, typically the input or output voltage of the converter. For applications with an output voltage outside of this range, 12V for example, the boost capacitor bias can be derived from the output using a simple Zener diode regulator.

4.1.1 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.

4.1.2 INTERNAL COMPENSATION

All control system components necessary for stable operation over the entire device operating range are integrated, including the error amplifier and inductor current slope compensation. To add the proper amount of slope compensation, the inductor value changes along with the output voltage (see Table 5-1).

4.1.3 EXTERNAL COMPONENTS

External components consist of:

- Input capacitor
- Output filter (inductor and capacitor)
- Freewheeling diode
- Boost capacitor
- Boost blocking diode
- Resistor divider

The selection of the external inductor, output capacitor, input capacitor and freewheeling diode is dependent upon the output voltage, input voltage, and the maximum output current.

4.1.4 ENABLE INPUT

The enable input is used to disable the device while connected to GND. If disabled, the MCP16331 device consumes a minimal current from the input.

4.1.5 SOFT START

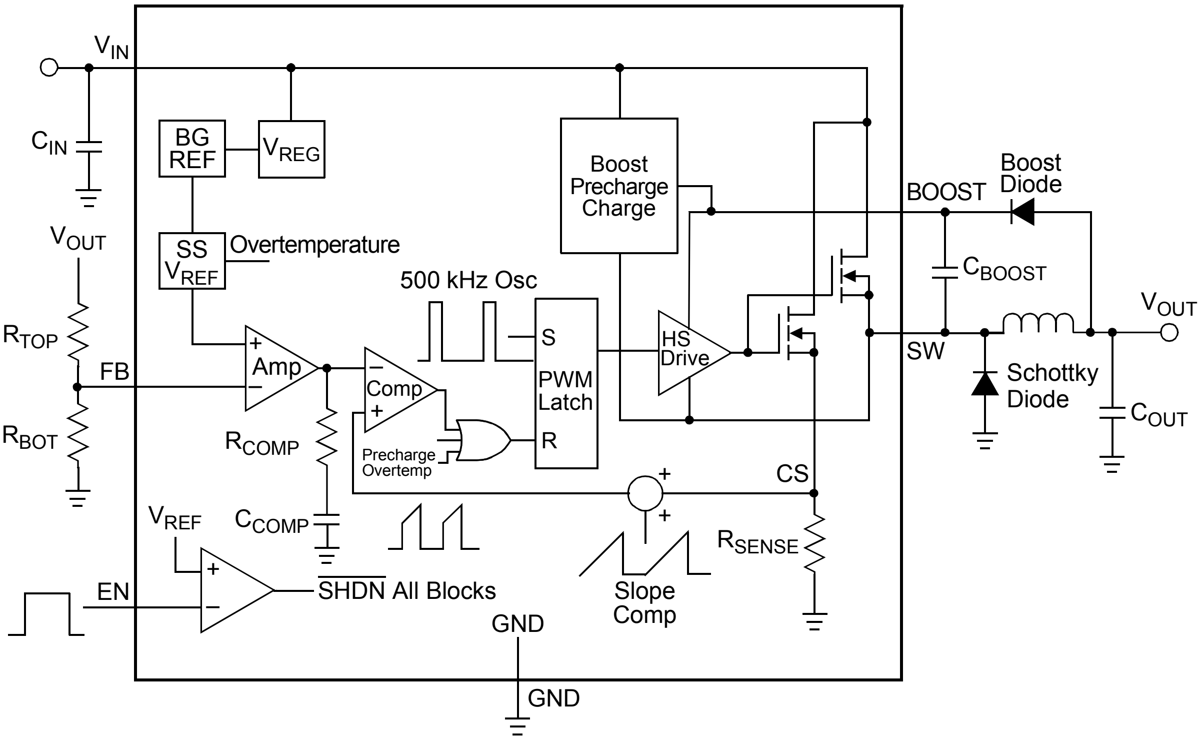
The internal reference voltage rate of rise is controlled during start-up, minimizing the output voltage overshoot and the inrush current.

4.1.6 UNDERVOLTAGE LOCKOUT

An integrated Undervoltage Lockout (UVLO) prevents the converter from starting until the input voltage is high enough for normal operation. The converter will typically start at 4.1V and operate down to 3.6V. Hysteresis is added to prevent starting and stopping, during start-up, as a result of loading the input voltage source.

4.1.7 OVERTEMPERATURE PROTECTION

Overtemperature protection limits the silicon die temperature to +160°C by turning the converter off. The normal switching resumes at +130°C.



Note: EN has an internal pull-up, so the device will start even if the EN pin is left floating.

FIGURE 4-1: *MCP16331 Block Diagram.*

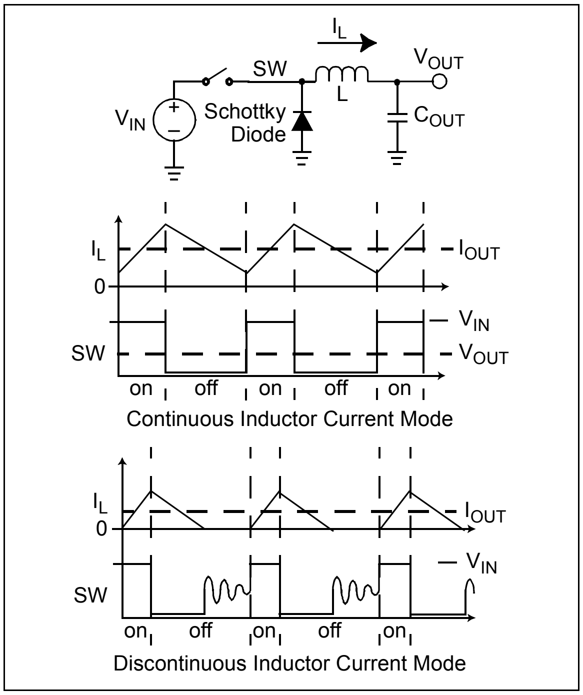
4.2 Functional Description

4.2.1 STEP-DOWN OR BUCK CONVERTER

The MCP16331 is a non-synchronous, step-down or buck converter capable of stepping input voltages, ranging from 4.4V to 50V, down to 2.0V to 24V for $V_{IN} > V_{OUT}$.

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

For 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, under the condition that the inductor current is continuous or never reaches zero. For discontinuous inductor current operation, the steady-state duty cycle will be 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.



Continuous Inductor Current Mode

Discontinuous Inductor Current Mode

FIGURE 4-2: *Step-Down Converter.*

4.2.2 PEAK CURRENT MODE CONTROL

The MCP16331 integrates a Peak Current-Mode control architecture, resulting in superior AC regulation while minimizing the number of voltage loop compensation components and their size for integration. Peak Current-Mode control takes a small portion of the inductor current, replicates it and compares this replicated current sense signal with the output of the integrated error voltage. 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.

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 summed into the current shown in Figure 4-2.

4.2.3 PULSE-WIDTH MODULATION (PWM)

The internal oscillator periodically starts the switching period, which in the MCP16331 device's case, occurs every 2 µs or 500 kHz. With the integrated switch turned on, the inductor current ramps up until the sum of the current sense and slope compensation ramp exceeds the integrated error amplifier output. 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 is lower than its target, the error amplifier output rises. This results in an increase in the inductor current to correct for error in the output voltage. The fixed frequency duty cycle is terminated when the sensed inductor peak current, summed with the internal slope compensation, exceeds the output voltage of the error amplifier. 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 overtemperature signal or boost cap undervoltage can also reset the PWM latch to terminate the cycle.

When working close to the boundary conduction threshold, a jitter on the SW node may occur, reflecting in the output voltage. Although the low-frequency output component is very small, it may be desirable to completely eliminate this component. To achieve this, different methods can be applied to reduce or completely eliminate this component. In addition to a very good layout, a capacitor in parallel with the top feedback resistor, or an RC snubber between the SW node and GND, can be added.

Typical values for the snubber are 680 pF and 430Ω, while the capacitor in parallel with the top feedback resistor can use values from 10 pF to 47 pF. Using such a snubber eliminates the ringing on the SW node, but decreases the overall efficiency of the converter.

4.2.4 HIGH-SIDE DRIVE

The MCP16331 features an integrated high-side N-Channel MOSFET for high-efficiency step-down power conversion. An N-Channel MOSFET is used for its low resistance and size (instead of a P-Channel MOSFET). A gate drive voltage above the input is necessary to turn on the high-side N-Channel. The high-side drive voltage should be between 3.0V and 5.5V. The N-Channel source is connected to the inductor and Schottky diode or switch node. When the switch is off, the boost cap voltage is replenished, typically from the output voltage for 3V to 5V output applications. A boost blocking diode is used to prevent current flow from the boost cap back into the output during the internal switch-on time.

Prior to start-up, the boost cap has no stored charge to drive the switch. An internal regulator is used to "precharge" the boost cap. Once precharged, the switch is turned on and the inductor current flows. When the switch turns off, the inductor current freewheels through the Schottky diode, providing a path to recharge the boost cap. Worst-case conditions for recharge occur when the switch turns on for a very short duty cycle at light load, limiting the inductor current ramp. In this case, there is a small amount of time for the boost capacitor to recharge. For high input voltages there is enough precharge current to replace the boost cap charge. For input voltages above 5.5V typical, the MCP16331 device will regulate the output voltage with no load. After starting, the MCP16331 will regulate the output voltage until the input voltage decreases below 4V. See Figure 2-23 for device range of operation over input voltage, output voltage and load.

4.2.5 ALTERNATIVE BOOST BIAS

For 3.0V to 5.0V output voltage applications, the boost supply is typically the output voltage. For applications with V_{OUT} < 3.0V or V_{OUT} > 5.0V, an alternative boost supply can be used.

Alternative boost supplies can be from the input, input derived, output derived or an auxiliary system voltage.

For low-voltage output applications with unregulated input voltage, a shunt regulator derived from the input can be used to derive the boost supply. For applications with high output voltage or regulated high input voltage, a series regulator can be used to derive the boost supply. In case the boost is biased from an external source while in shutdown, the device will draw slightly higher current.

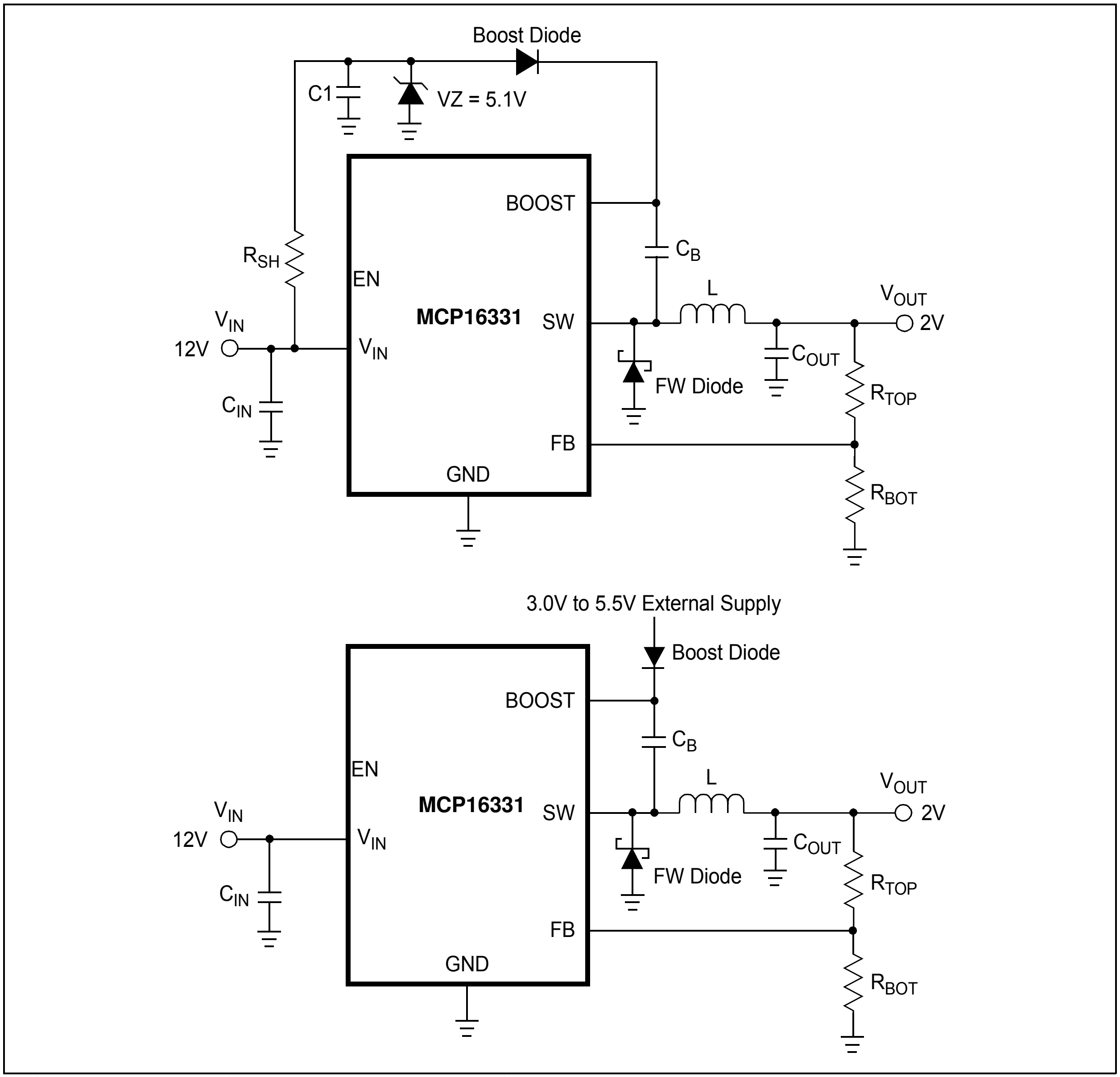


FIGURE 4-3: *Shunt and External Boost Supply.*

Shunt boost supply regulation is used for low output voltage converters operating from a wide ranging input source. A regulated 3.0V to 5.5V supply is needed to provide high-side drive bias. The shunt uses a Zener diode to clamp the voltage within the 3.0V to 5.5V range using the resistance shown in Figure 4-3.

To calculate the shunt resistance, the boost drive current can be estimated using Equation 4-1.

I_{BOOST_TYP} for 3.3V Boost Supply = 0.6 mA

I_{BOOST_TYP} for 5.0V Boost Supply = 0.8 mA.

EQUATION 4-1: BOOST CURRENT

$$I_{BOOST} = I_{BOOST\_TYP} \times 1.5mA$$

To calculate the shunt resistance, the maximum I_{BOOST} and I_Z current are used at the minimum input voltage (Equation 4-2).

EQUATION 4-2: SHUNT RESISTANCE

$$R_{SH} = \frac{V_{INMIN} - V_Z}{I_{Boost} + I_Z}$$

V_Z and I_Z can be found on the Zener diode manufacturer's data sheet. Typically, I_Z = 1 mA.

Series regulator applications use a Zener diode to drop the excess voltage. The series regulator bias source can be input or output voltage derived, as shown in Figure 4-4. The boost supply must remain between 3.0V and 5.5V at all times for proper circuit operation.

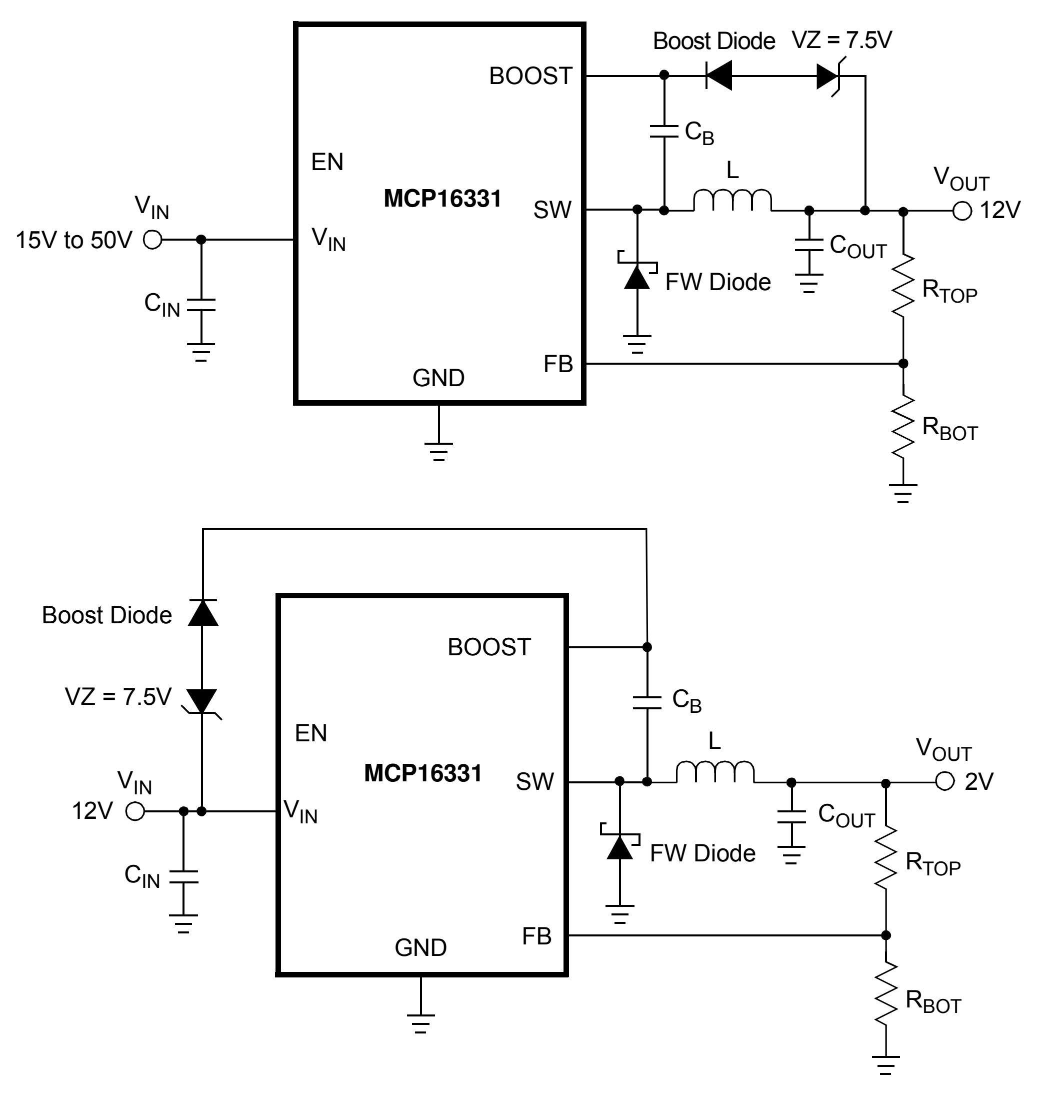


FIGURE 4-4: *Series Regulator Boost Supply.*

5.0 APPLICATION INFORMATION

5.1 Typical Applications

The MCP16331 step-down converter operates over a wide input voltage range, up to 50V maximum. Typical applications include generating a bias or V_{DD} voltage for the PIC® microcontroller product line, digital control system bias supply for AC-DC converters, 24V industrial input and similar applications.

5.2 Adjustable Output Voltage Calculations

To calculate the resistor divider values for the MCP16331, Equation 5-1 can be used. R_{TOP} is connected to V_{OUT}, R_{BOT} is connected to GND and both are connected to the V_{FB} input pin.

EQUATION 5-1:

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

EXAMPLE 5-1:

V_{OUT} = 3.3V
V_{FB} = 0.8V
R_{BOT} = 10 kΩ
R_{TOP} = 31.25 kΩ (standard value = 31.6 kΩ)
V_{OUT} = 3.328V (using standard value)

EXAMPLE 5-2:

V_{OUT} = 5.0V
V_{FB} = 0.8V
R_{BOT} = 10 kΩ
R_{TOP} = 52.5 kΩ (standard value = 52.3 kΩ)
V_{OUT} = 4.98V (using standard value)

The transconductance error amplifier gain is controlled by its internal impedance. The external divider resistors have no effect on system gain so a wide range of values can be used. A 10 kΩ resistor is recommended as a good trade-off for quiescent current and noise immunity.

5.3 General Design Equations

The step-down converter duty cycle can be estimated using Equation 5-2 while operating in Continuous Inductor Current-Mode. This equation also counts the forward drop of the freewheeling diode and internal N-Channel MOSFET switch voltage drop. As the load current increases, the switch voltage drop and diode voltage drop increase, requiring a larger PWM duty cycle to maintain the output voltage regulation. Switch voltage drop is estimated by multiplying the switch current times the switch resistance or R_{DSON}.

EQUATION 5-2: CONTINUOUS INDUCTOR CURRENT DUTY CYCLE

$$D = \frac{(V_{OUT} + V_{Diode})}{(V_{IN} - (I_{SW} \times R_{DSON}))}$$

The MCP16331 device features an integrated slope compensation to prevent the bimodal operation of the PWM duty cycle. Internally, half of the inductor current downslope is summed with the internal current sense signal. For the proper amount of slope compensation, it is recommended to keep the inductor downslope current constant by varying the inductance with V_{OUT}, where K = 0.22V/µH.

EQUATION 5-3:

$$K = V_{OUT} / L$$

TABLE 5-1: RECOMMENDED INDUCTOR VALUES

V_{OUT}	K	$L_{STANDARD}$
2.0V	0.20	10 µH
3.3V	0.22	15 µH
5.0V	0.23	22 µH
12V	0.21	56 µH
15V	0.22	68 µH
24V	0.24	100 µH

5.4 Input Capacitor Selection

The step-down converter input capacitor must filter the high input ripple current as a result of pulsing or chopping the input voltage. The MCP16331 input voltage pin is used to supply voltage for the power train and as a source for internal bias. A low Equivalent Series Resistance (ESR), preferably a ceramic capacitor, is recommended. The necessary capacitance is dependent upon the maximum load current and source impedance. Three capacitor parameters to keep in mind are the voltage rating, Equivalent Series Resistance and the temperature rating. For wide temperature range applications, a multilayer X7R dielectric is mandatory, while for applications with limited temperature range, a multilayer X5R dielectric is acceptable. Typically, input capacitance between 4.7 µF and 20 µF is sufficient for most applications.

The input capacitor voltage rating should be a minimum of V_{IN} plus margin. Table 5-2 contains the recommended range for the input capacitor value.

5.5 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 amount and type of output capacitance, and Equivalent Series Resistance will have a significant effect on the output ripple voltage and system stability. The range of the output capacitance is limited due to the integrated compensation of the MCP16331.

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

Table 5-2 contains the recommended range for the input and output capacitor value:

TABLE 5-2: CAPACITOR VALUE RANGE

Parameter	Min.	Max.
C_{IN}	4.7 µF	None
C_{OUT}	20 µF	—

5.6 Inductor Selection

The MCP16331 is designed to be used with small surface mount inductors. Several specifications should be considered prior to selecting an inductor. To optimize system performance, the inductance value is determined by the output voltage (Table 5-1), so the inductor ripple current is somewhat constant over the output voltage range.

EQUATION 5-4: INDUCTOR RIPPLE CURRENT

$$\Delta_{I_L} = \frac{V_{IN} - V_{OUT}}{L} \times t_{ON}$$

EXAMPLE 5-3:

V_{IN} = 12V
V_{OUT} = 3.3V
I_{OUT} = 500 mA

EQUATION 5-5: INDUCTOR PEAK CURRENT

$$I_{LPK} = \frac{\Delta I_L}{2} + I_{OUT}$$

Inductor Ripple Current = 319 mA

Inductor Peak Current = 660 mA

For the example above, an inductor saturation rating of a minimum 660 mA is recommended. Low DCR inductors result in higher system efficiency. A trade-off between size, cost and efficiency is made to achieve the desired results.

TABLE 5-3: MCP16331 RECOMMENDED 3.3V INDUCTORS

Part Number	Value (µH)	DCR (Ω)	I_{SAT} (A)	Size WxLxH (mm)
Coilcraft®				
ME3220-153	15	0.52	0.90	3.2x2.5x2.0
LPS4414-153	15	0.440	0.92	4.4x4.4x1.4
LPS6235-153	15	0.125	2.00	6.2x6.2x3.5
MSS6132-153	15	0.106	1.56	6.1x6.1x3.2
MSS7341-153	15	0.055	1.78	6.6x6.6x4.1
LPS3015-153	15	0.700	0.62	3.0x3.0x1.5
Wurth Elektronik®				
744025150	15	0.400	0.900	2.8x2.8x2.8
744042150	15	0.22	0.75	4.8x4.8x1.8
7447779115	15	0.081	2.2	7.3x7.3x4.5
Coiltronics®				
SD12-150R	15	0.408	0.692	5.2x5.2x1.2
SD3118-150-R	15	0.44	0.75	3.2x3.2x1.8
SD52-150-R	15	0.161	0.88	5.2x5.5.2.0
Sumida®				
CDPH4D19FNP -150MC	15	0.075	0.66	5.2x5.2x2.0
CDRH3D16/ HPNP-150MC	15	0.410	0.65	4.0x4.0x1.8
TDK - EPCOS®				
B82462G4153M	15	0.097	1.05	6.3x6.3x3

TABLE 5-4: MCP16331 RECOMMENDED 5V INDUCTORS

Part Number	Value (µH)	DCR (Ω)	I_{SAT} (A)	Size WxLxH (mm)
Coilcraft®				
ME3220-223	22	0.787	0.71	3.2x2.5x2.0
LPS4414-223	22	0.59	0.74	4.4x4.4x1.4
LPS6235-223	22	0.145	1.7	6.2x6.2x3.5
MSS6132-223	22	0.158	1.22	6.1x6.1x3.2
MSS7341-223	22	0.082	1.42	6.6x6.6x4.1
LPS3015-223	22	0.825	0.5	3.0x3.0x1.5
Wurth Elektronik®				
744025220	22	0.575	0.75	2.8x2.8x2.8
744042220	22	0.3	0.6	4.8x4.8x1.8
7447779122	22	0.11	1.7	7.3x7.3x4.5
Cooper Bussman®				
SD12-220-R	22	0.633	0.574	5.2x5.2x1.2
SD3118-220-R	22	0.676	0.61	3.2x3.2x1.8
SD52-220-R	22	0.204	0.73	5.2x5.2x2
Sumida®				
CDPH4D19FNP -220MC	22	0.135	0.54	5.2x5.2x2
CDRH3D16/ HPNP-220MC	22	0.61	0.55	4.0x4.0x1.8
TDK - EPCOS®				
82462G4223M	22	0.15	0.85	6.3x6.3x3

5.7 Freewheeling Diode

The freewheeling diode creates a path for inductor current flow after the internal switch is turned off. The average diode current is dependent upon the output load current at duty cycle (D). The efficiency of the converter is a function of the forward drop and speed of the freewheeling diode. A low forward drop Schottky diode is recommended. The current rating and voltage rating of the diode is application-dependent. The diode voltage rating should be a minimum of V_{IN} plus margin. The average diode current can be calculated using Equation 5-6.

EQUATION 5-6: DIODE AVERAGE CURRENT

$$I_{DAVG} = (1 - D) \times I_{OUT}$$

EXAMPLE 5-4:

I_{OUT} = 0.5A
V_{IN} = 15V
V_{OUT} = 5V
D = 5/15
I_{DAVG} = 333 mA

A 0.5A to 1A diode is recommended.

TABLE 5-5: FREEWHEELING DIODES

App	Mfr.	Part Number	Rating
12 V_{IN}, 500 mA	Diodes Inc.	DFLS120L-7	20V, 1A
24 V_{IN}, 100 mA	Diodes Inc.	B0540Ws-7	40V, 0.5A
18 V_{IN}, 500 mA	Diodes Inc.	B130L-13-F	30V, 1A
48 V_{IN}, 500 mA	Diodes Inc.	B1100	100V, 1A

5.8 Boost Diode

The boost diode is used to provide a charging path from the low-voltage gate drive source while the switch node is low. The boost diode blocks the high voltage of the switch node from feeding back into the output voltage when the switch is turned on, forcing the switch node high.

A standard 1N4148 ultra-fast diode is recommended for its recovery speed, high voltage blocking capability, availability and cost. The voltage rating required for the boost diode is V_{IN}.

For low boost voltage applications, a small Schottky diode with the appropriately rated voltage can be used to lower the forward drop, increasing the boost supply for the gate drive.

5.9 Boost Capacitor

The boost capacitor is used to supply current for the internal high-side drive circuitry that is above the input voltage. The boost capacitor 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 boost capacitor maximum voltage is 5.5V, so a 6.3V or 10V rated capacitor is recommended.

5.10 Thermal Calculations

The MCP16331 is available in the 6-lead SOT-23 and 8-lead TDFN packages. By calculating the power dissipation and applying the package thermal resistance (θ_{JA}), the junction temperature is estimated.

To quickly estimate the internal power dissipation for the switching step-down regulator, an empirical calculation using measured efficiency can be used. Given the measured efficiency, the internal power dissipation is estimated by Equation 5-7. This power dissipation includes all internal and external component losses. For a quick internal estimate, subtract the estimated Schottky diode loss and inductor DCR loss from the P_{DIS} calculation in Equation 5-7.

EQUATION 5-7: TOTAL POWER DISSIPATION ESTIMATE

$$\left(\frac{V_{OUT} \times I_{OUT}}{Efficiency}\right) - (V_{OUT} \times I_{OUT}) = P_{Dis}$$

The difference between the first term, input power and the second term, power delivered, is the total system power dissipation. The freewheeling Schottky diode losses are determined by calculating the average diode current and multiplying by the diode forward drop. The inductor losses are estimated by $P_L = I_{OUT}^2 \times L_{DCR}$.

EQUATION 5-8: DIODE POWER DISSIPATION ESTIMATE

$$P_{Diode} = V_F \times ((1 - D) \times I_{OUT})$$

EXAMPLE 5-5:

V_{IN} = 10V
V_{OUT} = 5.0V
I_{OUT} = 0.4A
Efficiency = 90%
Total System Dissipation = 222 mW
L_{DCR} = 0.15Ω
P_L = 24 mW
Diode V_F = 0.50
D = 50%
P_{Diode} = 125 mW

MCP16331 internal power dissipation estimate:
$P_{DIS} - P_L - P_{DIODE} = 73$ mW

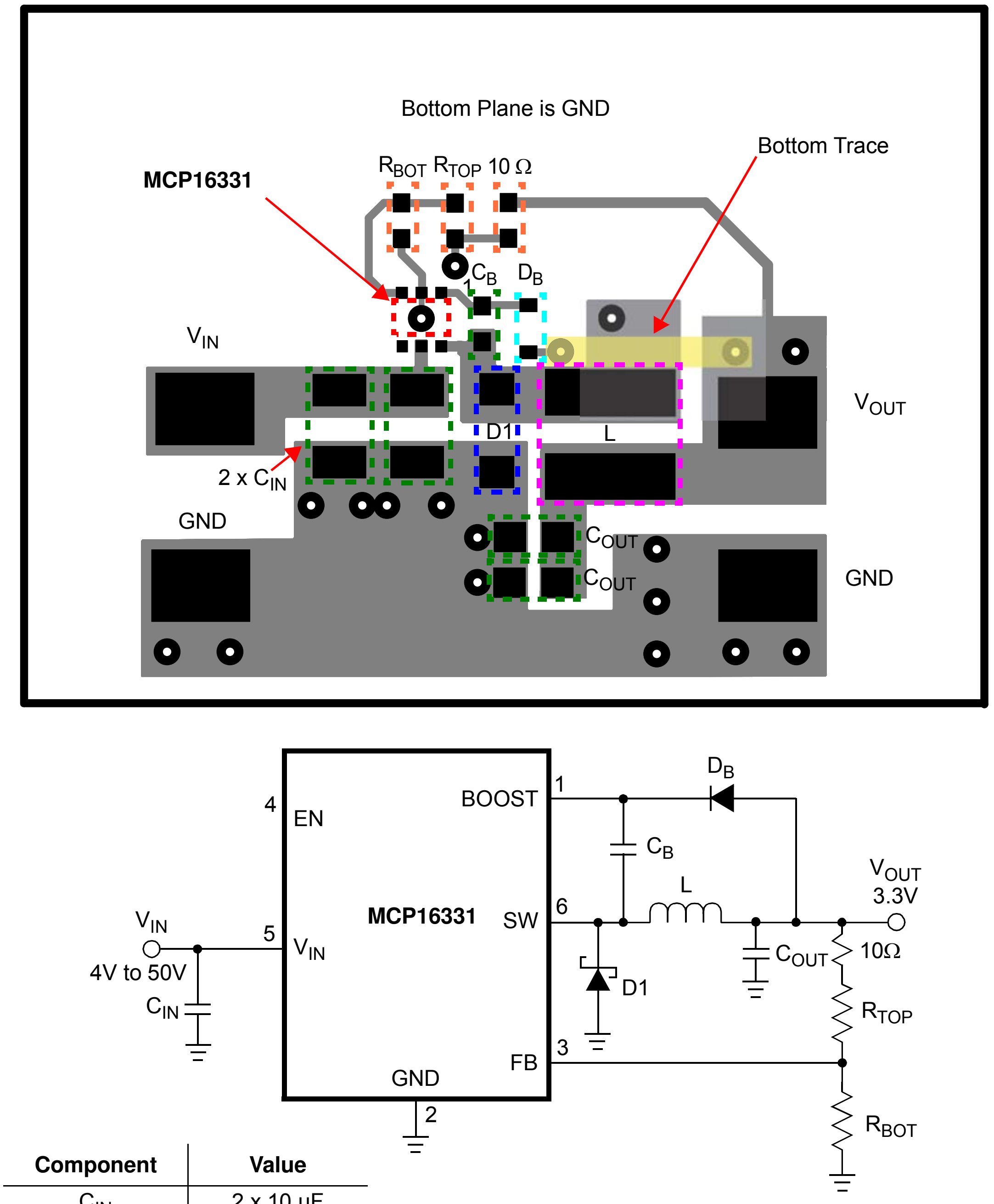
θ_{JA} = 198°C/W
Estimated Junction Temperature Rise = +14.5°C

5.11 PCB Layout Information

Good printed circuit board layout techniques are important to any switching circuitry and switching power supplies are no different. When wiring the switching high-current paths, short and wide traces should be used. Therefore, it is important that the input and output capacitors be placed as close as possible to the MCP16331 to minimize the loop area.

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

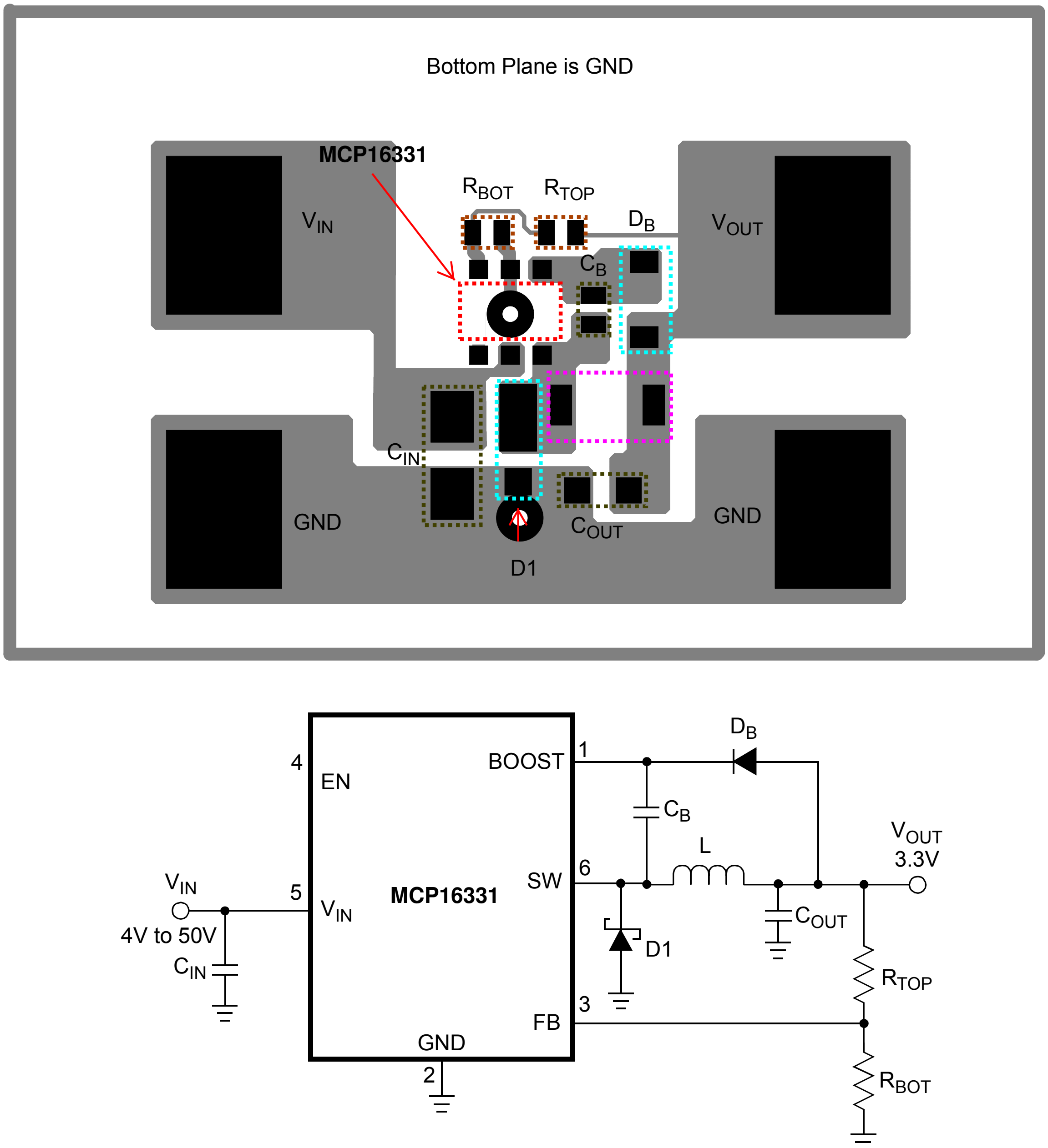
A good MCP16331 layout starts with C_{IN} placement. C_{IN} supplies current to the input of the circuit when the switch is turned on. In addition to supplying high-frequency switch current, C_{IN} also provides a stable voltage source for the internal MCP16331 circuitry. Unstable PWM operation can result if there are excessive transients or ringing on the V_{IN} pin of the MCP16331 device. In Figure 5-1, C_{IN} is placed close to pin 5. A ground plane on the bottom of the board provides a low resistive and inductive path for the return current. The next priority in placement is the freewheeling current loop formed by D1, C_{OUT} and L, while strategically placing the C_{OUT} return close to the C_{IN} return. Next, the boost capacitor should be placed between the boost pin and the switch node pin, SW. This leaves space close to the MCP16331 V_{FB} pin to place R_{TOP} and R_{BOT}. R_{TOP} and R_{BOT} are routed away from the switch node so noise is not coupled into the high-impedance V_{FB} input.



Component	Value
C_{IN}	2 x 10 µF
C_{OUT}	2 x 10 µF
L	15 µH
R_{TOP}	31.2 kΩ
R_{BOT}	10 kΩ
D1	B1100
D_B	1N4148
C_B	100 nF

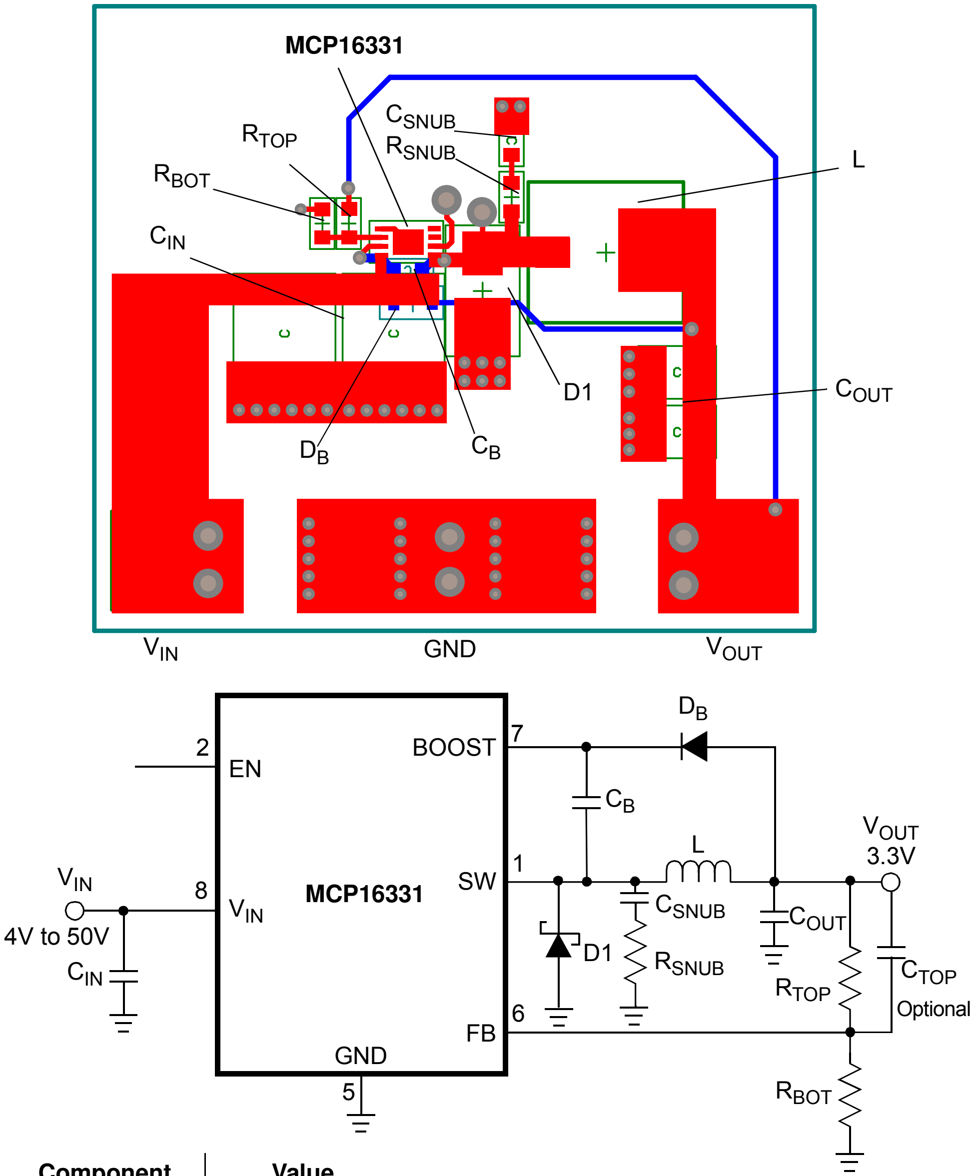
Note: A 10Ω resistor is used with a network analyzer to measure system gain and phase.

FIGURE 5-1: *MCP16331 SOT-23-6 Recommended Layout, 500 mA Design.*



Component	Value
C_{IN}	1 µF
C_{OUT}	10 µF
L	15 µH
R_{TOP}	31.2 kΩ
R_{BOT}	10 kΩ
D1	STPS0560Z
D_B	1N4148
C_B	100 nF

FIGURE 5-2: *Compact MCP16331 SOT-23-6 D^2 Recommended Layout, Low-Current Design.*

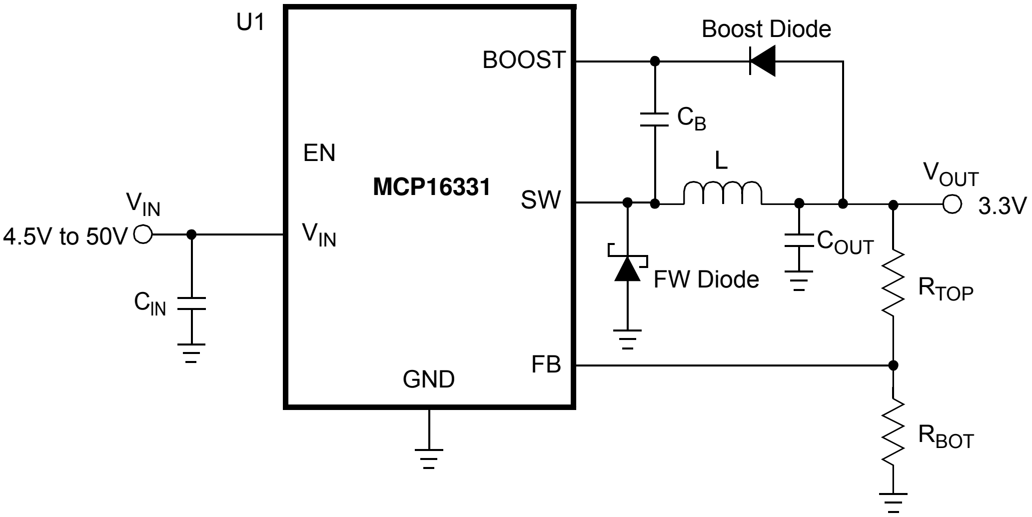


Component	**Value**
C_{IN}	2x10 µF
C_{OUT}	2x10 µF
L	22 µH
R_{TOP}	31.2 kΩ
R_{BOT}	10 kΩ
D1	MBRS1100
D_B	1N4148WS
C_B	100 nF
C_{TOP}	20 pF
C_{SNUB}	430 pF
R_{SNUB}	680Ω

Note: Red represents top layer pads, and traces and blue represent bottom layer pads and traces. On the bottom layer, a GND plane should be placed, which is not represented in the example above for visibility reasons.

FIGURE 5-3: *MCP16331 TDFN-8 Recommended Layout Design.*

6.0 TYPICAL APPLICATION CIRCUITS



Component	Value	Manufacturer	Part Number	Comment
C_{IN}	2 x 10 µF	TDK Corporation	C5750X7S2A106M230KB	Capacitor, 10 µF, 100V, X7S, 2220
C_{OUT}	2 x 10 µF	Taiyo Yuden Co., Ltd.	JMK212B7106KG-T	Capacitor, 10 µF, 6.3V, Ceramic, X7R, 0805, 10%
L	15 µH	Coilcraft®	MSS6132-153ML	MSS6132, 15 µH, Shielded Power Inductor
R_{TOP}	31.6 kΩ	Panasonic®- ECG	ERJ-3EKF3162V	Resistor, 31.6 KΩ, 1/10W, 1%, 0603, SMD
R_{BOT}	10 kΩ	Panasonic - ECG	ERJ-3EKF1002V	Resistor, 10.0 KΩ, 1/10W, 1%, 0603, SMD
FW Diode	B1100	Diodes Incorporated®	B1100-13-F	Schottky, 100V, 1A, SMA
Boost Diode	1N4148	Diodes Incorporated	1N4148WS-7-F	Diode Switch, 75V, 200 mW, SOD-323
C_B	100 nF	AVX Corporation	0603YC104KAT2A	Capacitor, 0.1 µF, 16V Ceramic, X7R, 0603, 10%
U1	MCP16331	Microchip Technology Inc.	MCP16331-E/CH MCP16331-E/MNY	MCP16331, 500 kHz Buck Switcher, 50V, 500 mA

FIGURE 6-1: *Typical Application, 50V V_{IN} to 3.3V V_{OUT}.*