

2 MHz 3A PWM Buck Regulator

Feature

- 2.7 to 5.5V Supply Voltage
- 2 MHz PWM Mode
- Output Current to 3A
- >94% Efficiency
- 100% Maximum Duty Cycle
- Adjustable Output Voltage Option Down to 1V
- Ultra-Fast Transient Response
- Ultra Small External Components
Stable with 1 μ H Inductor and a 4.7 μ F Output Capacitor
- Fully Integrated 3A MOSFET Switch
- Micropower Shutdown
- Thermal Shutdown and Current Limit Protection
- Pb-Free 12-Pin 3 mm x 3 mm x 0.9 mm DFN Package
- -40°C to $+125^{\circ}\text{C}$ Junction Temperature Range

Applications

- 5V or 3.3V Point of Load Conversion
- Telecom/Networking Equipment
- Set Top Boxes
- Storage Equipment
- Video Cards
- DDR Power Supply

General Description

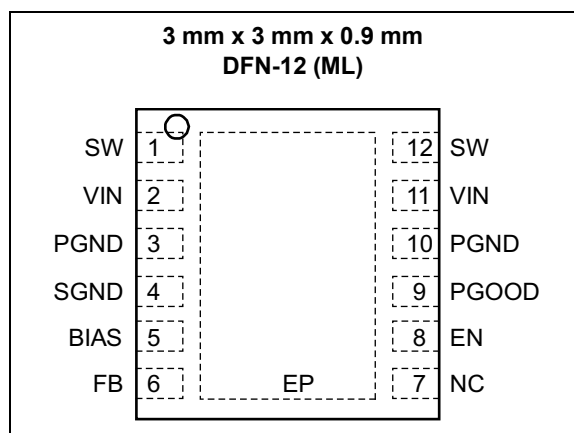
The MIC2207 is a high-efficiency PWM buck (step-down) regulator that provides up to 3A of output current. The MIC2207 operates at 2 MHz and has proprietary internal compensation that allows a closed loop bandwidth of over 200 kHz.

The low on-resistance internal P-channel MOSFET of the MIC2207 allows efficiencies over 94%, reduces external components count and eliminates the need for an expensive current sense resistor.

The MIC2207 operates from 2.7V to 5.5V input and the output can be adjusted down to 1V. The devices can operate with a maximum duty cycle of 100% for use in low-dropout conditions.

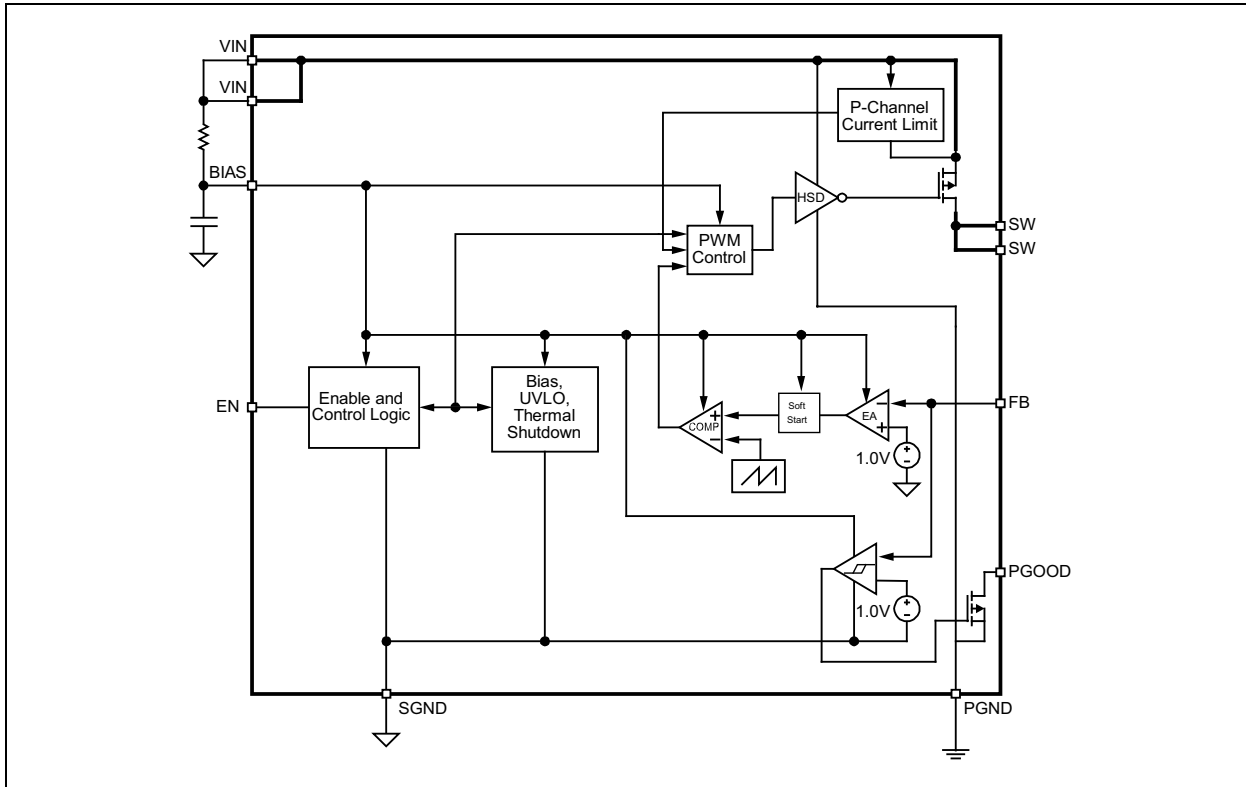
The MIC2207 is available in a 3 mm x 3 mm DFN-12 package with an operating junction temperature range from -40°C to $+125^{\circ}\text{C}$.

Package Type

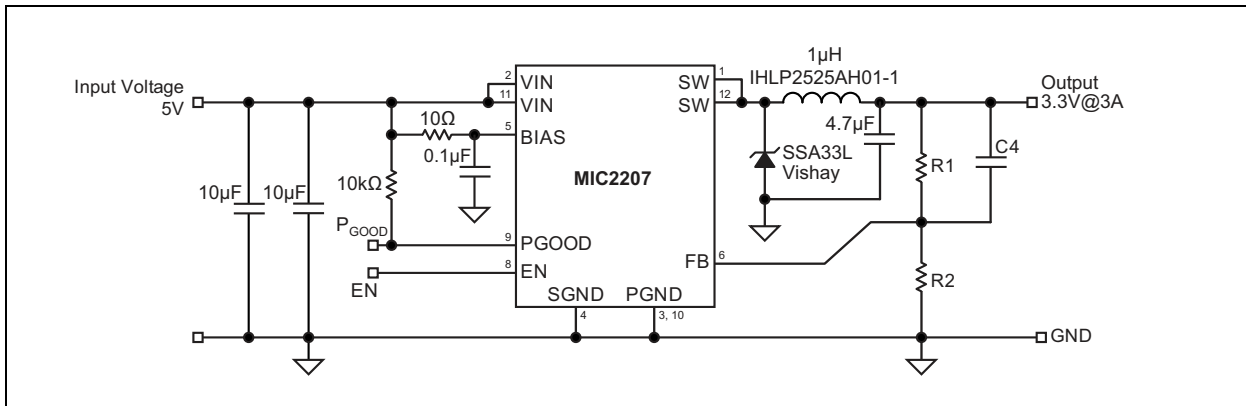


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Functional Block Diagram



Typical Application Circuit



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

Supply Voltage (V_{IN})	+6V
Output Switch Voltage (V_{SW})	+6V
Output Switch Current (I_{SW})	11A
Logic Input Voltage (V_{EN}, V_{LOWQ})	-0.3V to V_{IN}
Storage Temperature (T_S)	-60°C to +150°C
ESD Rating (Note 1)	2 kV

Operating Ratings ‡

Supply Voltage (V_{IN})	+2.7V to +5.5V
Logic Input Voltage (V_{EN})	0V to V_{IN}
Junction Temperature (T_J)	-40°C to +125°C

† **Notice:** Stresses above those listed under “Absolute 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.

‡ **Notice:** The device is not guaranteed to function outside its operating ratings.

Note 1: Devices are ESD sensitive. Handling precautions recommended. Human body model: 1.5 k Ω in series with 100 pF.

ELECTRICAL CHARACTERISTICS (Note 2)

Electrical Characteristics: $V_{IN} = V_{EN} = 3.6V$; $L = 1 \mu H$; $C_{OUT} = 4.7 \mu F$; $T_A = 25^\circ C$, **Bold** values indicate $-40^\circ C \leq T_J \leq +125^\circ C$; unless otherwise noted.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Supply Voltage Range	V_{IN}	2.7	—	5.5	V	—
Undervoltage Lockout Threshold	UVLO	2.45	2.55	2.65	V	Turn-On
UVLO Hysteresis	UVLO_HYS	—	100	—	mV	—
Quiescent Current	I_Q	—	570	900	μA	$V_{FB} = 0.9 * V_{NOM}$ (not switching)
Shutdown Current	I_{SHD}	—	2	10	μA	$V_{EN} = 0V$
[Adjustable] Feedback Voltage	V_{FB}	0.99	1	1.01	V	$\pm 1\% I_{LOAD} = 100 mA$
		0.98	—	1.02		$\pm 2\%$ (overtemperature) $I_{LOAD} = 100 mA$
FB Pin Input Current	—	—	1	—	nA	—
Current Limit in PWM Mode	ILIM	3.5	5	—	A	$V_{FB} = 0.9 * V_{NOM}$
Output Voltage Line Regulation	—	—	0.07	—	%	$V_{OUT} > 2V$; $V_{IN} = V_{OUT} + 500 mV$ to 5.5V; $I_{LOAD} = 100 mA$ $V_{OUT} < 2V$; $V_{IN} = 2.7V$ to 5.5V; $I_{LOAD} = 100 mA$
Output Voltage Load Regulation	—	—	0.2	0.5	%	$20 mA < I_{LOAD} < 3A$
Maximum Duty Cycle	D_{MAX}	100	—	—	%	$V_{FB} \leq 0.4V$
PWM Switch-On Resistance	$R_{DS(ON)}$	—	95	200 300	m Ω	$I_{SW} = 50 mA$ $V_{FB} = 0.7 * V_{FB_NOM}$ (High-Side Switch)
Oscillator Frequency	f_{SW}	1.8	2	2.2	MHz	—
Enable Threshold	V_{EN}	0.5	0.85	1.3	V	—
Enable Hysteresis	V_{EN_HYS}	—	50	—	mV	—
Enable Input Current	—	—	0.1	2	μA	—

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ELECTRICAL CHARACTERISTICS (Note 2)

Electrical Characteristics: $V_{IN} = V_{EN} = 3.6V$; $L = 1 \mu H$; $C_{OUT} = 4.7 \mu F$; $T_A = 25^\circ C$, **Bold** values indicate $-40^\circ C \leq T_J \leq +125^\circ C$; unless otherwise noted.

Parameter	Symbol	Min.	Typ.	Max.	Units	Conditions
Power Good Range	—	—	± 7	± 10	%	—
Power Good Resistance	—	—	145	250	Ω	$I_{PGOOD} = 500 \mu A$
Overtemperature Shutdown	T_{SHD}	—	160	—	$^\circ C$	—
Overtemperature Hysteresis	T_{SHD_HYS}	—	20	—	$^\circ C$	—

Note 1: Specification for packaged product only.

- Dropout voltage is defined as the input-to-output differential at which the output voltage drops 2% below its nominal value that is initially measured at a 1V differential. For outputs below 2.7V, the dropout voltage is the input-to-output voltage differential with a minimum input voltage of 2.7V.

TEMPERATURE SPECIFICATIONS (Note 1)

Parameters	Symbol	Min.	Typ.	Max.	Units	Conditions
Temperature Ranges						
Storage Temperature	T_S	-60	—	+150	$^\circ C$	—
Junction Temperature Range	T_J	-40	—	+125	$^\circ C$	—
Package Thermal Resistance						
Thermal Resistance 12-Lead DFN	θ_{JA}	—	60	—	$^\circ C/W$	—

Note 1: The maximum allowable power dissipation is a function of ambient temperature, the maximum allowable junction temperature and the thermal resistance from junction to air (i.e., T_A , T_J , θ_{JA}). Exceeding the maximum allowable power dissipation will cause the device operating junction temperature to exceed the maximum +125 $^\circ C$ rating. Sustained junction temperatures above +125 $^\circ C$ can impact the device reliability.

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.

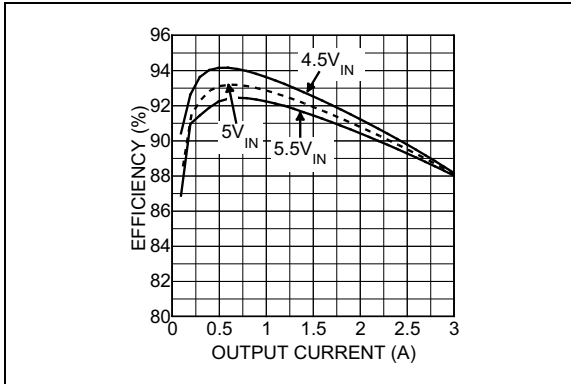


FIGURE 2-1: 3.3 V_{OUT} Efficiency.

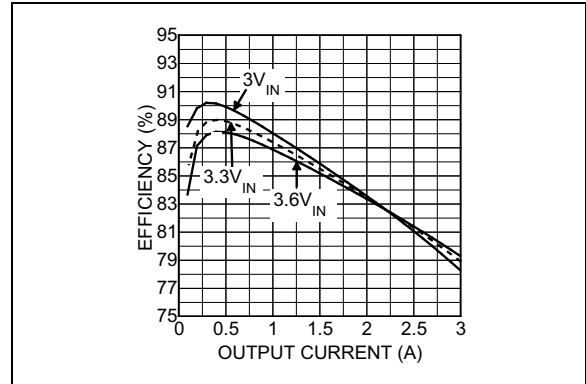


FIGURE 2-4: 1.8 V_{OUT} Efficiency.

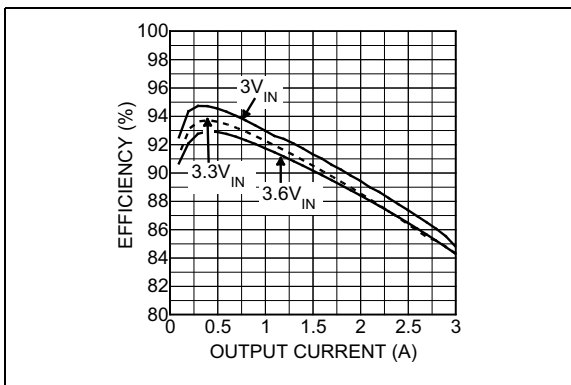


FIGURE 2-2: 2.5 V_{OUT} Efficiency.

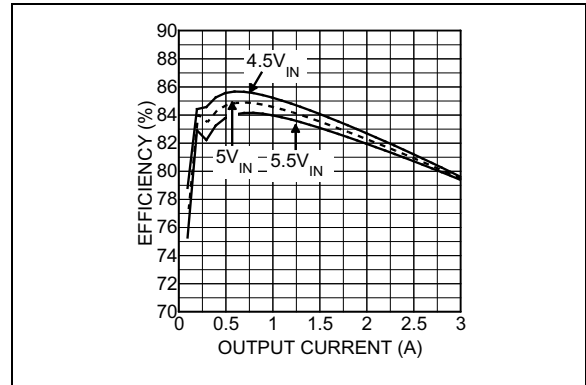


FIGURE 2-5: 1.8 V_{OUT} Efficiency.

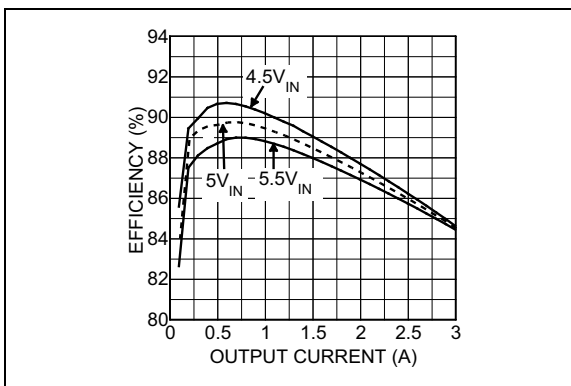


FIGURE 2-3: 2.5 V_{OUT} Efficiency.

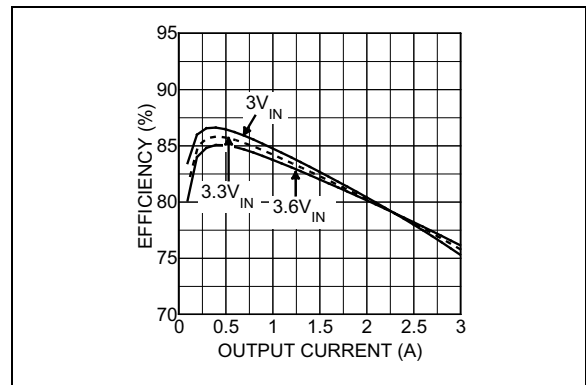


FIGURE 2-6: 1.5 V_{OUT} Efficiency.

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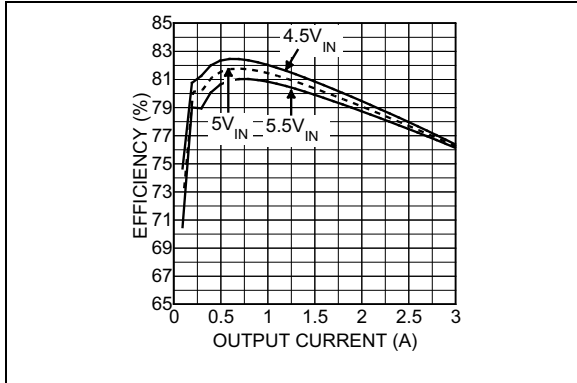


FIGURE 2-7: 1.5 V_{OUT} Efficiency.

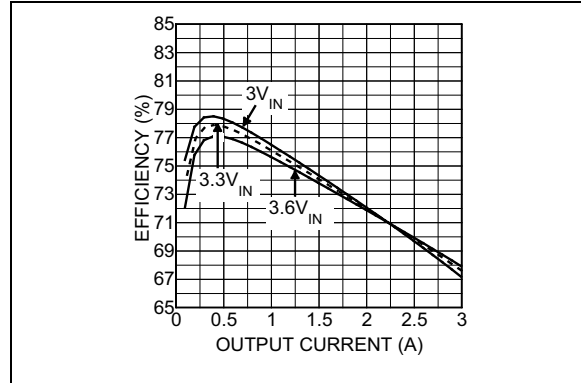


FIGURE 2-10: 1 V_{OUT} Efficiency.

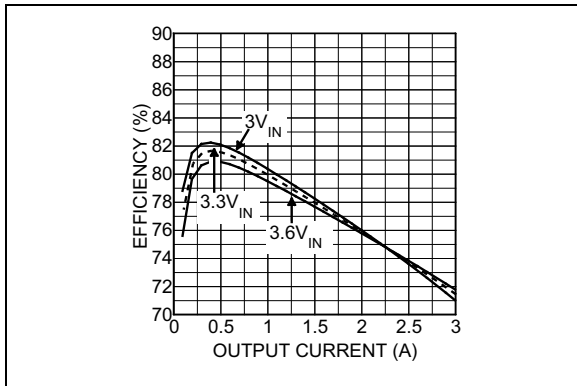


FIGURE 2-8: 1.2 V_{OUT} Efficiency.

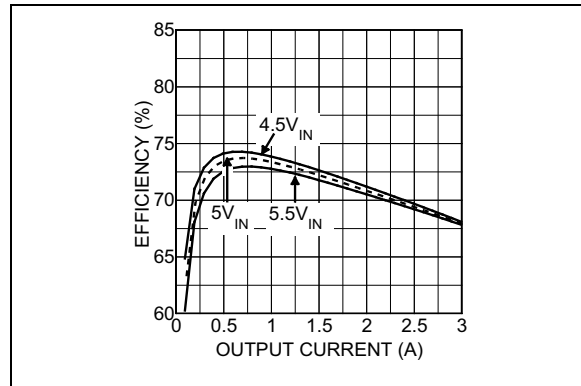


FIGURE 2-11: 1 V_{OUT} Efficiency.

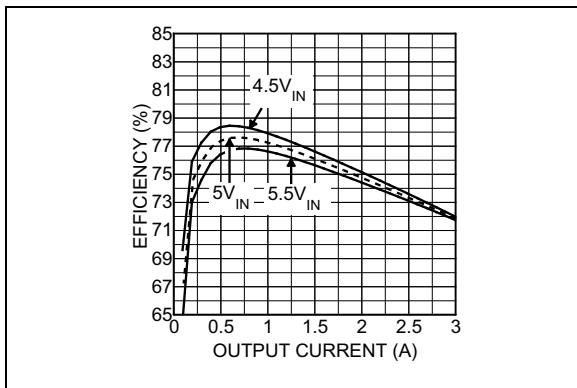


FIGURE 2-9: 1.2 V_{OUT} Efficiency.

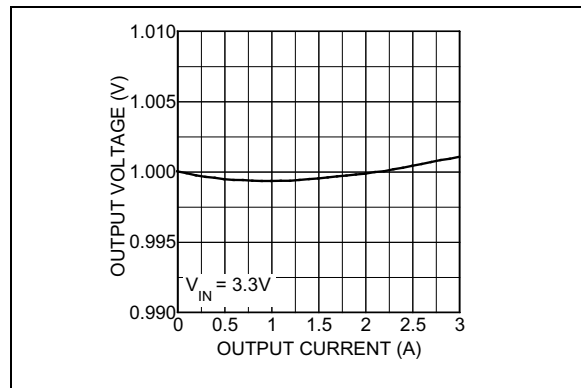


FIGURE 2-12: Load Regulation.

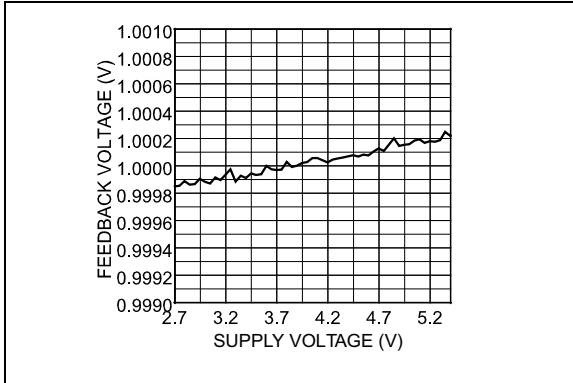


FIGURE 2-13: Line Regulation.

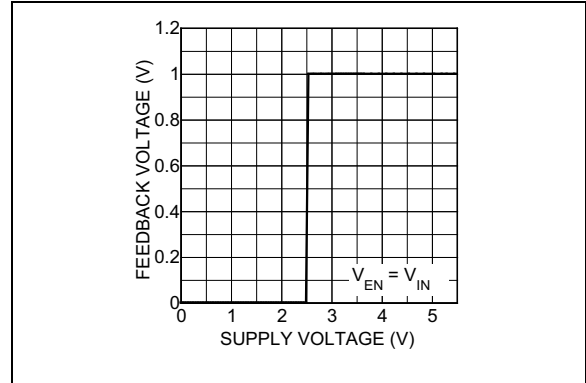


FIGURE 2-16: Feedback Voltage vs. Supply Voltage.

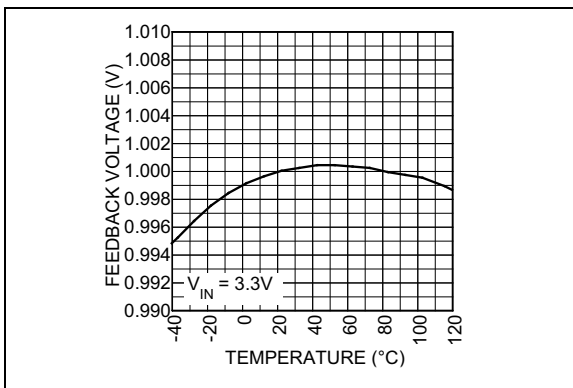


FIGURE 2-14: Feedback Voltage vs. Temperature.

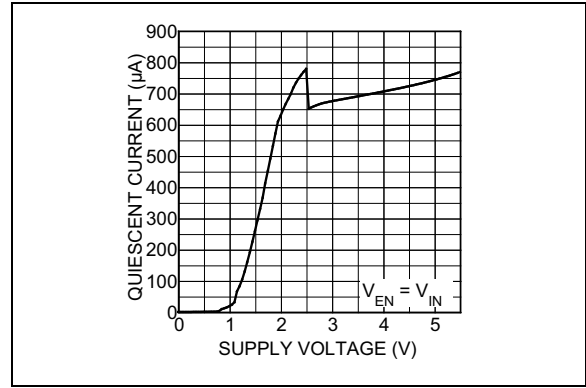


FIGURE 2-17: Quiescent Current vs. Supply Voltage.

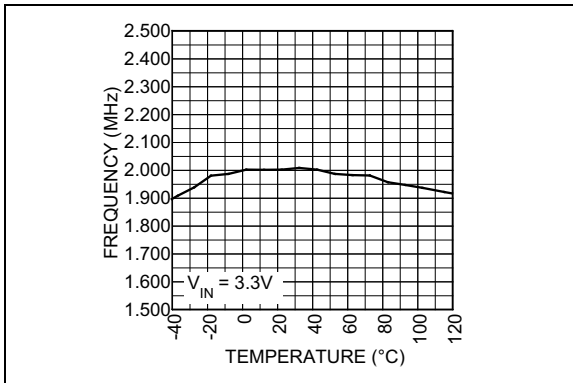


FIGURE 2-15: Frequency vs. Temperature.

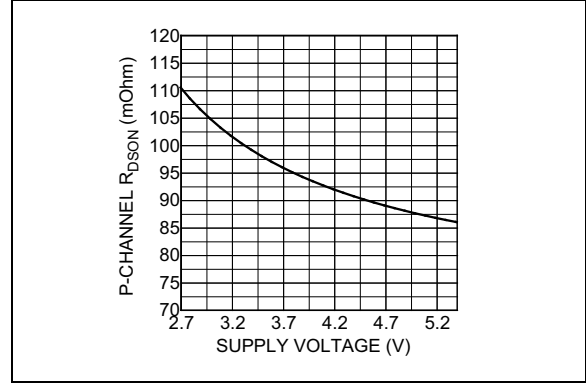


FIGURE 2-18: $R_{DS(ON)}$ vs. Supply Voltage.

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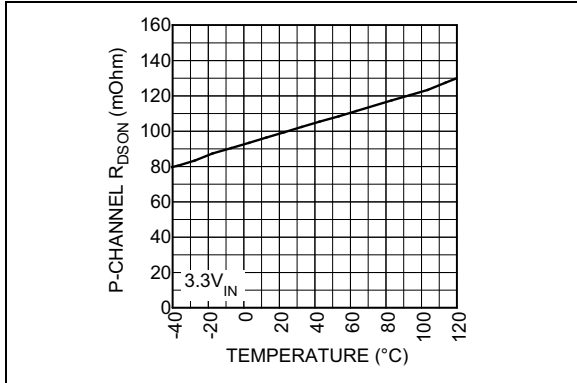


FIGURE 2-19: $R_{DS(ON)}$ vs. Temperature.

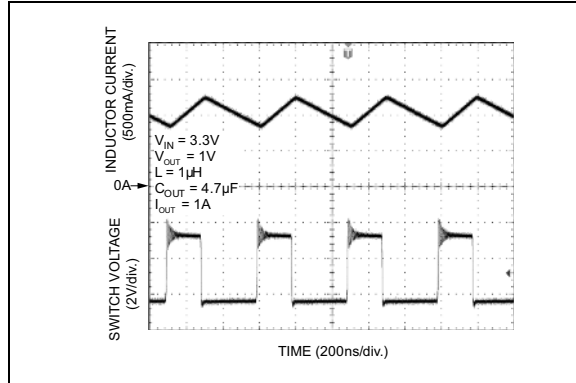


FIGURE 2-22: Continuous Current.

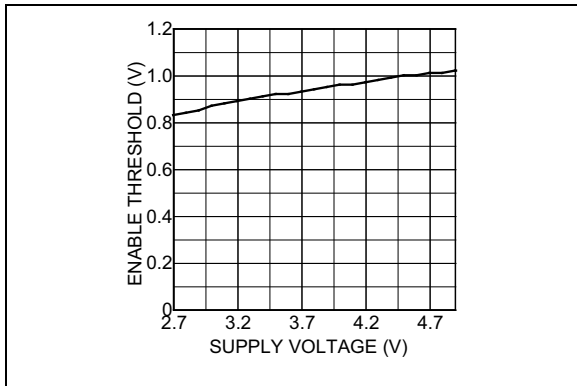


FIGURE 2-20: Enable Threshold vs. Supply Voltage.

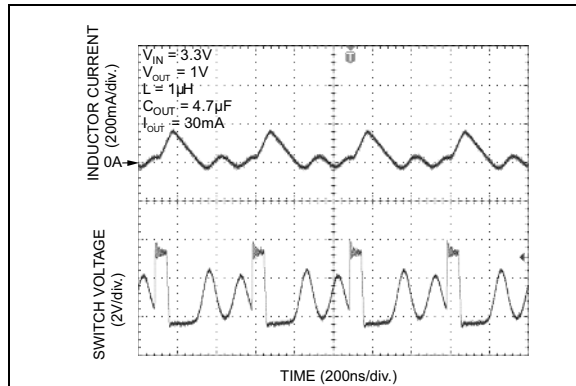


FIGURE 2-23: Discontinuous Current.

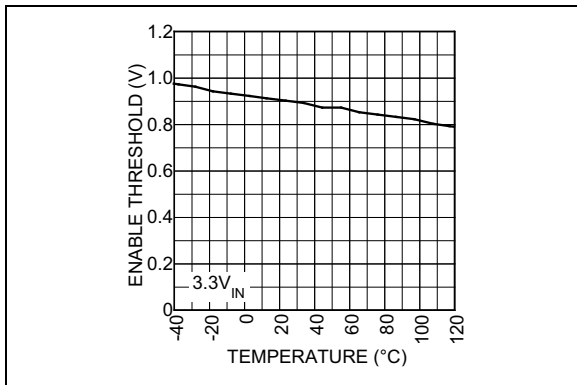


FIGURE 2-21: Enable Threshold vs. Temperature.

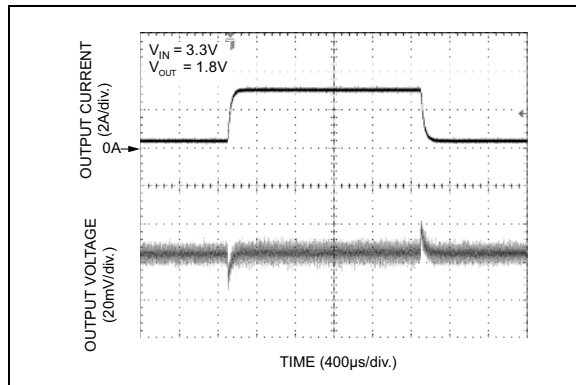


FIGURE 2-24: Load Transient Response.

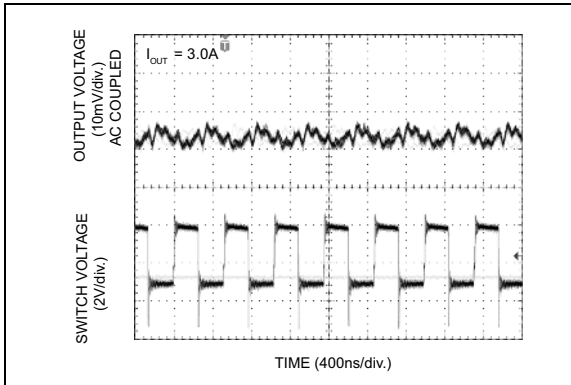


FIGURE 2-25: Output Ripple.

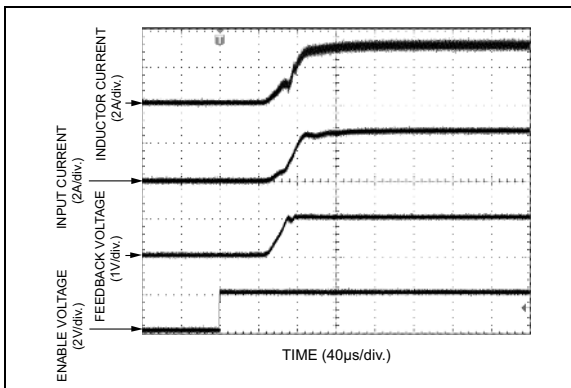


FIGURE 2-26: Start-Up Waveforms.

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3.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in [Table 3-1](#).

TABLE 3-1: PIN FUNCTION TABLE

Pin Number	Pin Name	DescrGNDiption
1, 12	SW	Switch (Output): Internal power P-Channel MOSFET output switch.
2, 11	VIN	Supply Voltage (Input): Supply voltage for the source of the internal P-channel MOSFET and driver. Requires bypass capacitor to GND.
3, 10	PGND	Power Ground. Provides the ground return path for the high-side drive current.
4	SGND	Signal (Analog) Ground. Provides return path for control circuitry and internal reference.
5	BIAS	Internal circuit bias supply. Must be bypassed with a 0.1 μ F ceramic capacitor to SGND.
6	FB	Feedback. Input to the error amplifier, connect to the external resistor divider network to set the output voltage.
7	NC	No Connect. Not internally connected to die. This pin can be tied to any other pin if desired.
8	EN	Enable (Input). Logic level low will shutdown the device, reducing the current draw to less than 5 μ A.
9	PGOOD	Power Good. Open drain output that is pulled to ground when the output voltage is outside 7% of the set regulation voltage.
EP	GND	Connect to ground.

4.0 FUNCTIONAL DESCRIPTION

4.1 VIN

Two pins for VIN provide power to the source of the internal P-channel MOSFET along with the current limiting sensing. The V_{IN} operating voltage range is from 2.7V to 5.5V. Due to the high switching speeds, a 10 μ F capacitor is recommended close to VIN and the power ground (PGND) for each pin for bypassing.

4.2 BIAS

The bias (BIAS) provides power to the internal reference and control sections of the MIC2207. A 10 Ω resistor from VIN to BIAS and a 0.1 μ F from BIAS to SGND is required for clean operation.

4.3 EN

The enable pin provides a logic level control of the output. In the off state, supply current of the device is greatly reduced (typically <1 μ A). Do not drive the enable pin above the supply voltage.

4.4 FB

The feedback pin (FB) provides the control path to control the output. For adjustable versions, a resistor divider connecting the feedback to the output is used to adjust the desired output voltage. The output voltage is calculated as follows:

EQUATION 4-1:

$$V_{OUT} = V_{REF} \times \left(\frac{R1}{R2} + 1 \right)$$

Where:

$$V_{REF} = 1.0V$$

A feed-forward capacitor is recommended for most designs using the adjustable output voltage option. To reduce current draw, a 10K feedback resistor is recommended from the output to the FB pin (R1). Also, a feed-forward capacitor should be connected between the output and feedback (across R1). The large resistor value and the parasitic capacitance of the FB pin can cause a high frequency pole that can reduce the overall system phase margin. By placing a feed-forward capacitor, these effects can be significantly reduced. Feed-forward capacitance (C_{FF}) can be calculated as follows:

EQUATION 4-2:

$$C_{FF} = \frac{1}{2 \times \pi \times R1 \times 200kHz}$$

4.5 SW

The switch (SW) pin connects directly to the inductor and provides the switching current necessary to operate in PWM mode. Due to the high speed switching on this pin, the switch node should be routed away from sensitive nodes. This pin also connects to the cathode of the free-wheeling diode.

4.6 PGOOD

Power good is an open drain pull down that indicates when the output voltage has reached regulation. For a power good low, the output voltage is outside 10% of the set regulation voltage. For output voltages within $\pm 10\%$ of the output voltage, the PGOOD pin is high. This should be connected to the input supply through a pull up resistor. A delay can be added by placing a capacitor from PGOOD to ground.

4.7 PGND

Power ground (PGND) is the ground path for the high current PWM mode. The current loop for the power ground should be as small as possible and separate from the signal ground (SGND) loop.

4.8 SGND

Signal ground (SGND) is the ground path for the biasing and control circuitry. The current loop for the signal ground should be separate from the power ground (PGND) loop.

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5.0 APPLICATIONS INFORMATION

The MIC2207 is a 3A PWM non-synchronous buck regulator. By switching an input voltage supply, and filtering the switched voltage through an inductor and capacitor, a regulated DC voltage is obtained. Figure 5-2 shows a simplified example of a non-synchronous buck converter.

FIGURE 5-1:

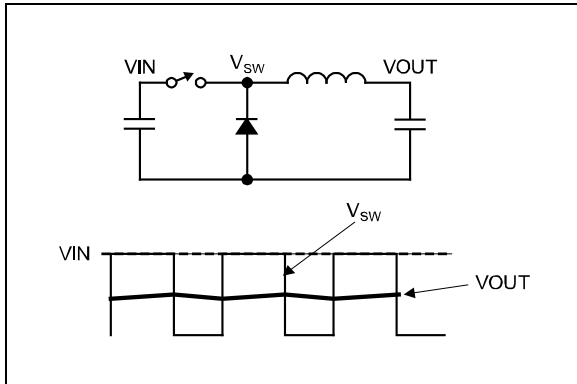


FIGURE 5-2: Non-Synchronous Buck Converter.

For a non-synchronous buck converter, there are two modes of operation; continuous and discontinuous. Continuous or discontinuous refer to the inductor current. If current is continuously flowing through the inductor throughout the switching cycle, it is in continuous operation. If the inductor current drops to zero during the off time, it is in discontinuous operation. Critically continuous is the point where any decrease in output current will cause it to enter discontinuous operation. The critically continuous load current can be calculated as follows:

EQUATION 5-1:

$$I_{OUT} = \frac{V_{OUT} - \frac{V_{OUT}^2}{V_{IN}}}{2MHz \times 2 \times L}$$

Continuous or discontinuous operation determines how to calculate peak inductor current.

5.1 Continuous Operation

Figure 5-3 illustrates the switch voltage and inductor current during continuous operation.

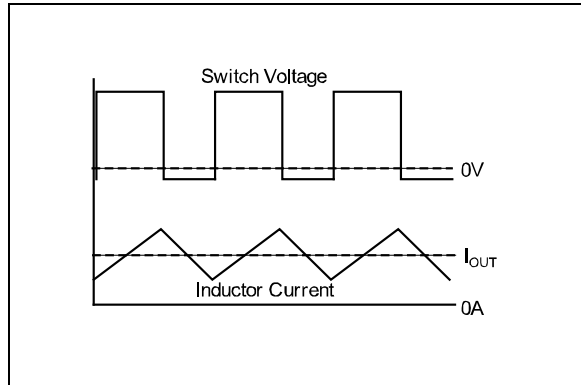


FIGURE 5-3: Continuous Operation.

The output voltage is regulated by pulse width modulating (PWM) the switch voltage to the average required output voltage. The switching can be broken up into two cycles; On and Off.

During the on-time, the high side switch is turned on, current flows from the input supply through the inductor and to the output.

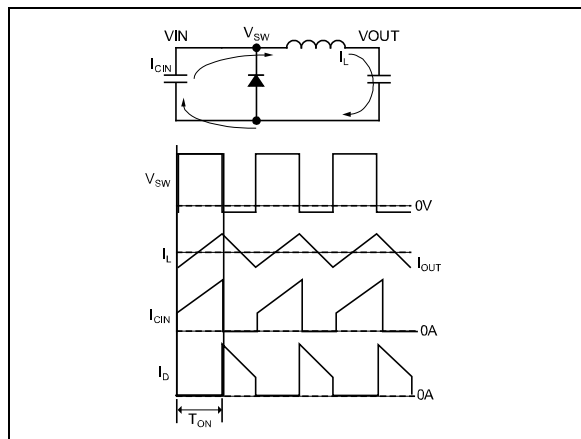


FIGURE 5-4: On-Time.

The inductor current is charged at the rate:

EQUATION 5-2:

$$\frac{V_{IN} - V_{OUT}}{L}$$

To determine the total on-time, or time at which the inductor charges, the duty cycle needs to be calculated. The duty cycle can be calculated as:

EQUATION 5-3:

$$D = \frac{V_{OUT}}{V_{IN}}$$

and the On time is:

EQUATION 5-4:

$$T_{ON} = \frac{D}{2MHz}$$

Therefore, peak to peak ripple current is:

EQUATION 5-5:

$$I_{PK-PK} = \frac{(V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}}}{2MHz \times L}$$

Since the average peak to peak current is equal to the load current. The actual peak (or highest current the inductor will see in a steady state condition) is equal to the output current plus ½ the peak to peak current.

EQUATION 5-6:

$$I_{PK} = I_{OUT} + \frac{(V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}}}{2 \times 2MHz \times L}$$

Figure 5-5 demonstrates the off-time. During the off-time, the high-side internal P-Channel MOSFET turns off. Since the current in the inductor has to discharge, the current flows through the free-wheeling Schottky diode to the output. In this case, the inductor discharge rate is (where V_D is the diode forward voltage):

EQUATION 5-7:

$$\frac{-V_{OUT} + V_D}{L}$$

The total off time can be calculated as:

EQUATION 5-8:

$$T_{OFF} = \frac{1 - D}{2MHz}$$

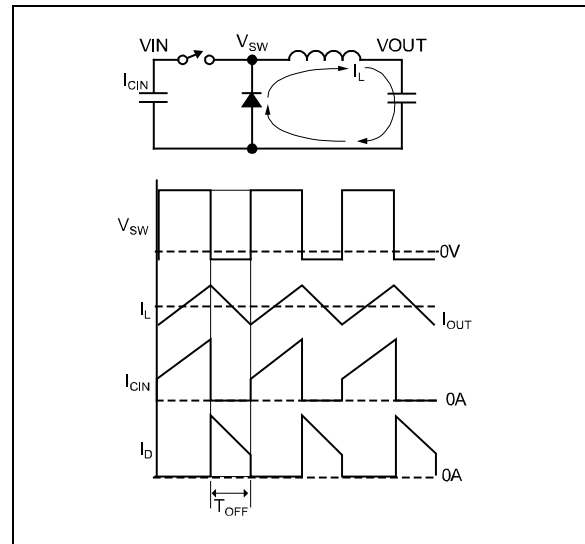


FIGURE 5-5: Off-Time.

5.2 Discontinuous Operation

Discontinuous operation is when the inductor current discharges to zero during the off cycle. Figure 5-6 demonstrates the switch voltage and inductor currents during discontinuous operation.

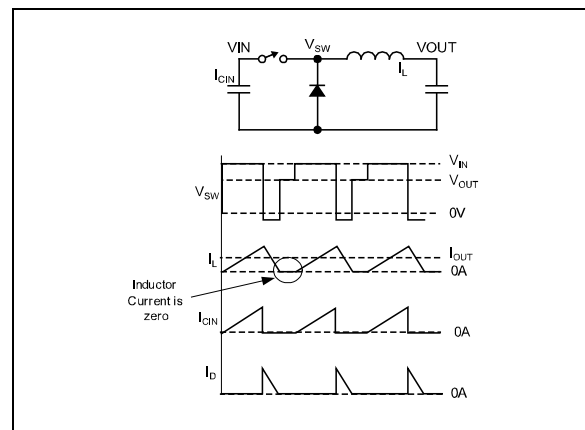


FIGURE 5-6: Discontinuous Operation.

When the inductor current (I_L) has completely discharged, the voltage on the switch node rings at the frequency determined by the parasitic capacitance and

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the inductor value. In [Figure 5-6](#), it is drawn as a DC voltage, but to see actual operation (with ringing) refer to [Figure 2-22](#) to [Figure 2-26](#).

Discontinuous mode of operation has the advantage over full PWM in that at light loads, the MIC2207 will skip pulses as necessary, reducing gate drive losses, drastically improving light load efficiency.

5.3 Efficiency Considerations

Calculating the efficiency is as simple as measuring power out and dividing it by the power in:

EQUATION 5-9:

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100$$

Where input power P_{IN} is:

EQUATION 5-10:

$$P_{IN} = V_{IN} \times I_{IN}$$

and output power (P_{OUT}) is calculated as:

EQUATION 5-11:

$$P_{OUT} = V_{OUT} \times I_{OUT}$$

The Efficiency of the MIC2207 is determined by several factors.

- $R_{DS(ON)}$ (Internal P-channel Resistance)
- Diode conduction losses
- Inductor Conduction losses
- Switching losses

$R_{DS(ON)}$ losses are caused by the current flowing through the high side P-channel MOSFET. The amount of power loss can be approximated by:

EQUATION 5-12:

$$P_{SW} = R_{DS(ON)} \times I_{OUT}^2 \times D$$

Where:

D = Duty cycle

Since the MIC2207 uses an internal P-channel MOSFET, $R_{DS(ON)}$ losses are inversely proportional to supply voltage. Higher supply voltage yields a higher gate to source voltage, reducing the $R_{DS(ON)}$, reducing the MOSFET conduction losses. Please refer to [Figure 2-18](#).

Diode conduction losses occur due to the forward voltage drop (V_F) and the output current. Diode power losses can be approximated as in [Equation 5-13](#):

EQUATION 5-13:

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

For this reason, the Schottky diode is the rectifier of choice. Using the lowest forward voltage drop will help reduce diode conduction losses, and improve efficiency.

Duty cycle, or the ratio of output voltage to input voltage, determines whether the dominant factor in conduction losses will be the internal MOSFET or the Schottky diode. Higher duty cycles place the power losses on the high side switch, and lower duty cycles place the power losses on the Schottky diode.

Inductor conduction losses (P_L) can be calculated by multiplying the DC resistance (DCR) times the square of the output current:

EQUATION 5-14:

$$P_L = DCR \times I_{OUT}^2$$

Also, be aware that there are additional core losses associated with switching current in an inductor. Since most inductor manufacturers do not give data on the type of material used, approximating core losses becomes very difficult, so verify inductor temperature rise.

Switching losses occur twice each cycle, when the switch turns on and when the switch turns off. This is caused by a non-ideal world where switching transitions are not instantaneous, and neither are currents. Figure 5-7 demonstrates how switching losses due to the transitions dissipate power in the switch.

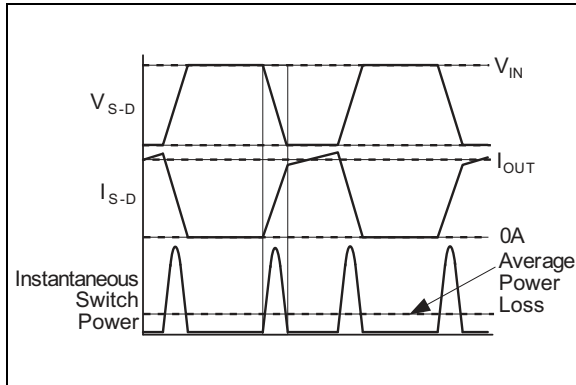


FIGURE 5-7: Switching Transition Losses.

Normally, when the switch is on, the voltage across the switch is low (virtually zero) and the current through the switch is high. This equates to low power dissipation. When the switch is off, voltage across the switch is high and the current is zero, again with power dissipation being low. During the transitions, the voltage across the switch (V_{S-D}) and the current through the switch (I_{S-D}) are at midpoint of their excursions and cause the transition to be the highest instantaneous power point. During continuous mode, these losses are the highest. Also, with higher load currents, these losses are higher. For discontinuous operation, the transition losses only occur during the off transition since the on transitions there is no current flow through the inductor.

5.4 Component Selection

5.4.1 INPUT CAPACITOR

A 10 μF ceramic is recommended on each VIN pin for bypassing. X5R or X7R dielectrics are recommended for the input capacitor. Y5V dielectrics lose most of their capacitance over temperature and are therefore not recommended. Also, tantalum and electrolytic capacitors alone are not recommended because of their reduced RMS current handling, reliability, and ESR increases.

An additional 0.1 μF is recommended close to the VIN and PGND pins for high frequency filtering. Smaller case size capacitors are recommended due to their lower ESR and ESL.

5.4.2 OUTPUT CAPACITOR

The MIC2207 is designed for a 4.7 μF output capacitor. X5R or X7R dielectrics are recommended for the output capacitor. Y5V dielectrics lose most of their capacitance over temperature and are therefore not recommended.

In addition to a 4.7 μF , a small 0.1 μF is recommended close to the load for high frequency filtering. Smaller case size capacitors are recommended due to their lower equivalent series ESR and ESL.

The MIC2207 utilizes type III voltage mode internal compensation and utilizes an internal zero to compensate for the double pole roll off of the LC filter. For this reason, larger output capacitors can create instabilities. In cases where a 4.7 μF output capacitor is not sufficient, the MIC2208 offers the ability to externally control the compensation, allowing for a wide range of output capacitor types and values.

5.4.3 INDUCTOR SELECTION

The MIC2207 is designed for use with a 1 μH inductor. Proper selection should ensure the inductor can handle the maximum average and peak currents required by the load. Maximum current ratings of the inductor are generally given in two methods; permissible DC current and saturation current. Permissible DC current can be rated either for a 40°C temperature rise or a 10% to 20% loss in inductance. Ensure the inductor selected can handle the maximum operating current. When saturation current is specified, make sure that there is enough margin that the peak current will not saturate the inductor.

5.4.4 DIODE SELECTION

Since the MIC2207 is non-synchronous, a free wheeling diode is required for proper operation. A Schottky diode is recommended due to the low forward voltage drop and their fast reverse recovery time. The diode should be rated to be able to handle the average output current. Also, the reverse voltage rating of the diode should exceed the maximum input voltage. The lower the forward voltage drop of the diode the better the efficiency.

5.4.5 FEEDBACK RESISTORS

The feedback resistor set the output voltage by dividing down the output and sending it to the feedback pin. The feedback voltage is 1.0V. To calculate the set output voltage refer to Equation 5-15:

EQUATION 5-15:

$$V_{OUT} = V_{FB} \left(\frac{R1}{R2} + 1 \right)$$

MIC2207

Where R1 is the resistor from V_{OUT} to FB and R2 is the resistor from FB to GND. Although the range of resistance for the FB resistors is very wide, R1 is recommended to be 10 kΩ. This minimizes the effect the parasitic capacitance of the FB node.

5.4.6 FEED-FORWARD CAPACITOR (C_{FF})

A capacitor across the resistor from the output to the feedback pin (R1) is recommended for most designs. This capacitor can give a boost to phase margin and increase the bandwidth for transient response. Also, large values of feed-forward capacitance can slow down the turn-on characteristics, reducing inrush current. For maximum phase boost, C_{FF} can be calculated as shown in Equation 5-16:

EQUATION 5-16:

$$C_{FF} = \frac{1}{2\pi \times 200k\text{Hz} \times R1}$$

5.4.7 BIAS FILTER

A small 10Ω resistor is recommended from the input supply to the bias pin along with a small 0.1 μF ceramic capacitor from bias to ground. This will bypass the high frequency noise generated by the violent switching of high currents from reaching the internal reference and control circuitry. Tantalum and electrolytic capacitors are not recommended for the bias, these types of capacitors lose their ability to filter at high frequencies.

5.5 Loop Stability and Bode Analysis

Bode analysis is an excellent way to measure small signal stability and loop response in power supply designs. Bode analysis monitors gain and phase of a control loop. This is done by breaking the feedback loop and injecting a signal into the feedback node and comparing the injected signal to the output signal of the control loop. This will require a network analyzer to sweep the frequency and compare the injected signal to the output signal. The most common method of injection is the use of a transformer. Figure 5-8 demonstrates how a transformer is used to inject a signal into the feedback network.

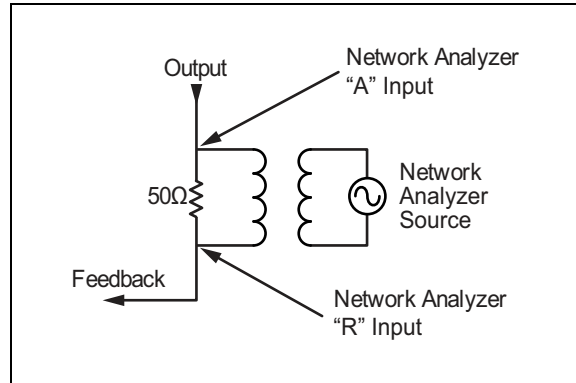


FIGURE 5-8: Transformer Rejection.

A 50Ω resistor allows impedance matching from the network analyzer source. This method allows the DC loop to maintain regulation and allow the network analyzer to insert an AC signal on top of the DC voltage. The network analyzer will then sweep the source while monitoring A and R for an A/R measurement. While this is the most common method for measuring the gain and phase of a power supply, it does have significant limitations. First, to measure low frequency gain and phase, the transformer needs to be high in inductance. This makes frequencies <100 Hz require an extremely large and expensive transformer. Conversely, it must be able to inject high frequencies. Transformers with these wide frequency ranges generally need to be custom made and are extremely expensive (usually to the tune of several hundred dollars!). By using an op-amp, cost and frequency limitations caused by an injection transformer are completely eliminated. Figure 5-9 demonstrates using an op-amp in a summing amplifier configuration for signal injection.

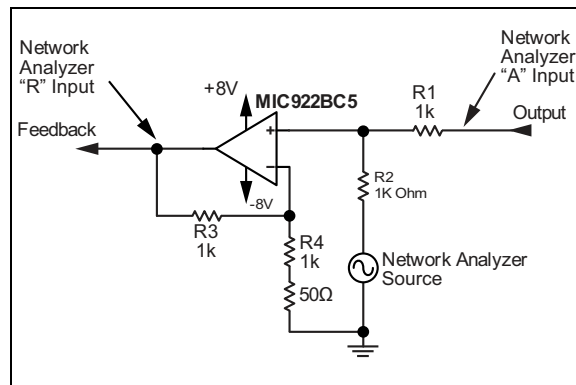


FIGURE 5-9: Op Amp Rejection.

R1 and R2 reduce the DC voltage from the output to the non-inverting input by half. The network analyzer is generally a 50Ω source. R1 and R2 also divide the AC signal sourced by the network analyzer by half. These two signals are summed together at half of their original input. The output is then amplified by 2 by R3 and R4 (the 50Ω is to balance the network analyzer's source

impedance) and sent to the feedback signal. This essentially breaks the loop and injects the AC signal on top of the DC output voltage and sends it to the feedback. By monitoring the feedback “R” and output “A”, gain and phase are measured. This method has no minimum frequency. Ensure that the bandwidth of the op-amp being used is much greater than the expected bandwidth of the power supply’s control loop. An op-amp with >100 MHz bandwidth is more than sufficient for most power supplies (which includes both linear and switching) and are more common and significantly cheaper than the injection transformers previously mentioned. The one disadvantage to using the op-amp injection method, is the supply voltages need to be below the maximum operating voltage of the op-amp. Also, the maximum output voltage for driving 50Ω inputs using the MIC922 is 3V. For measuring higher output voltages, a 1 MΩ input impedance is required for the A and R channels. Remember to always measure the output voltage with an oscilloscope to ensure the measurement is working properly. There should be a single sweeping sinusoidal waveform without distortion on the output. If there is distortion of the sinusoid, reduce the amplitude of the source signal. It could be overdriving the feedback that causes a large signal response.

The following Bode analysis show the small signal loop stability of the MIC2207. The MIC2207 utilizes a type III compensation. This is a dominant low frequency pole, followed by 2 zero’s and finally the double pole of the inductor capacitor filter, creating a final 20dB/decade roll off. Bode analysis gives us a few important data points; speed of response (Gain Bandwidth or GBW) and loop stability. Loop speed or GBW determines the response time to a load transient. Faster response times yield smaller voltage deviations to load steps.

Instability in a control loop occurs when there is gain and positive feedback. Phase margin is the measure of how stable the given system is. It is measured by determining how far the phase is from crossing zero when the gain is equal to 1 (0dB).

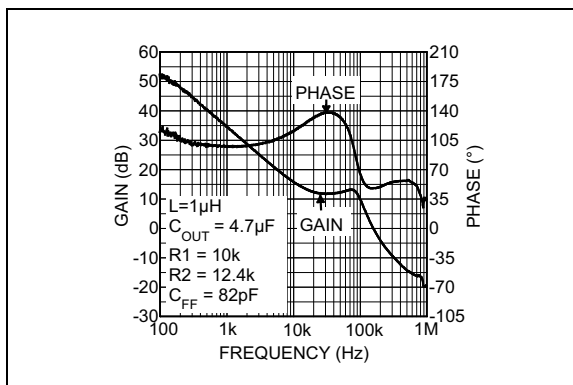


FIGURE 5-10: Bode Plot
($V_{IN} = 3.3V$, $V_{OUT} = 1.8V$, $I_{OUT} = 3A$).

Typically for 3.3 V_{IN} and 1.8 V_{OUT} at 3A load:

- Phase Margin = 47°
- GBW = 156 kHz

Gain will also increase with input voltage. [Figure 5-11](#) shows the increase in GBW for an increase in supply voltage.

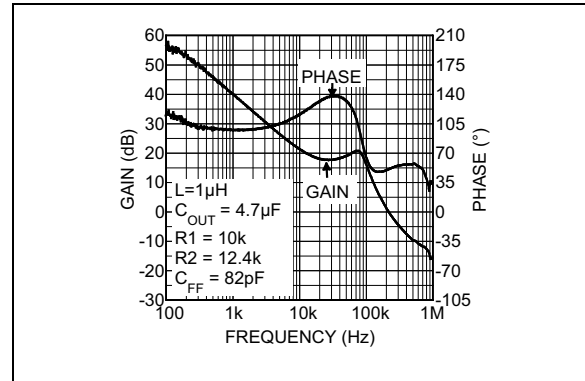


FIGURE 5-11: Bode Plot
($V_{IN} = 5V$, $V_{OUT} = 1.8V$, $I_{OUT} = 3A$).

Typically for 5 V_{IN} and 1.8 V_{OUT} at 3A load:

- Phase Margin = 43.1°
- GBW = 218 kHz

Being that the MIC2207 is non-synchronous; the regulator only has the ability to source current. This means that the regulator has to rely on the load to be able to sink current. This causes a non-linear response at light loads. [Figure 5-12](#) shows the effects of the pole created by the nonlinearity of the output drive during light load (discontinuous) conditions.

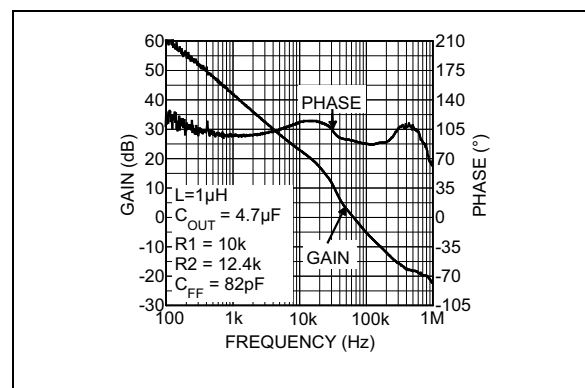


FIGURE 5-12: Bode Plot
($V_{IN} = 3.3V$, $V_{OUT} = 1.8V$, $I_{OUT} = 50 mA$).

Typically for 3.3 V_{IN} and 1.8 V_{OUT} at 50 mA load:

- Phase Margin = 90.5°
- GBW = 64.4 kHz

5.6 Feed-Forward Capacitor

The feedback resistors are a gain reduction block in the overall system response of the regulator. By placing a capacitor from the output to the feedback pin, high frequency signal can bypass the resistor divider, causing a gain increase up to unity gain.

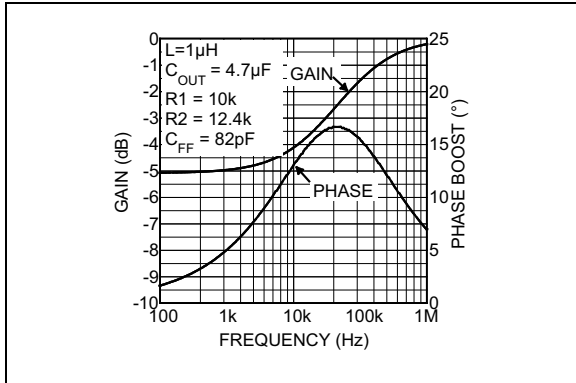


FIGURE 5-13: Gain and Phase vs. Frequency.

Figure 5-13 shows the effects on the gain and phase of the system caused by feedback resistors and a feed-forward capacitor. The maximum amount of phase boost achievable with a feed-forward capacitor is shown in Figure 5-14.

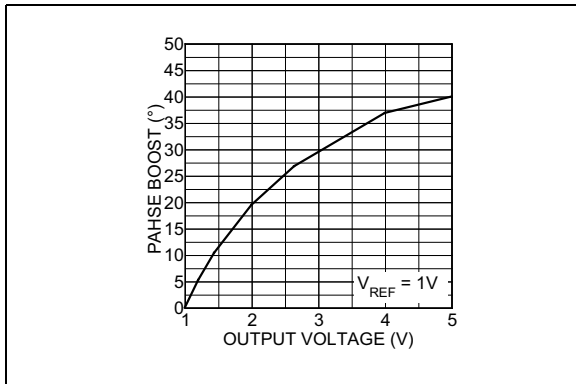


FIGURE 5-14: Maximum Amount of Phase Boost Obtainable using C_{FF} vs. Output Voltage.

By looking at the graph, phase margin can be affected to a greater degree with higher output voltages.

Figure 5-15 shows the phase margin of a 1.8V output at 3A without a feed-forward capacitor.

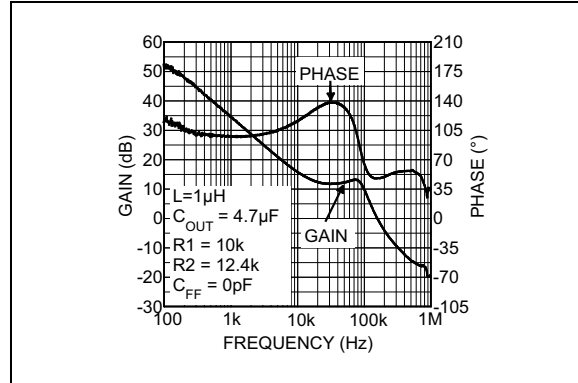


FIGURE 5-15: Bode Plot ($V_{IN} = 3.3V$, $V_{OUT} = 1.8V$, $I_{OUT} = 3A$)

As you can see the typical phase margin, using the same resistor values as before without a feed-forward capacitor results in 33.6° of phase margin. Our prior measurement with a feed-forward capacitor yielded a phase margin of 47°. The feed-forward capacitor has given us a phase boost of 13.4° (47° - 33.6° = 13.4°).

5.7 Output Impedance and Transient Response

Output impedance, simply stated, is the amount of output voltage deviation vs. the load current deviation. The lower the output impedance, the better.

EQUATION 5-17:

$$Z_{OUT} = \frac{\Delta V_{OUT}}{\Delta I_{OUT}}$$

Output impedance for a buck regulator is the parallel impedance of the output capacitor and the MOSFET and inductor divided by the gain:

EQUATION 5-18:

$$Z_{TOTAL} = \frac{R_{DS(ON)} + DCR + X_L}{GAIN} \parallel X_{OUT}$$

To measure output impedance vs. frequency, the load current must be swept across the frequencies measured, while the output voltage is monitored. Figure 5-16 shows a test set-up to measure output impedance from 10 Hz to 1 MHz using the MIC5190 high speed controller.

By setting up a network analyzer to sweep the feedback current, while monitoring the output of the voltage regulator and the voltage across the load resistance, output impedance is easily obtainable. To keep the current from being too high, a DC offset needs to be applied to the network analyzer's source signal. This can be done with an external supply and 50Ω resistor. Make sure that the currents are verified with an oscilloscope first, to ensure the integrity of the signal measurement. It is always a good idea to monitor the A and R measurements with a scope while you are sweeping it. To convert the network analyzer data from dBm to something more useful (such as peak to peak voltage and current in our case):

EQUATION 5-19:

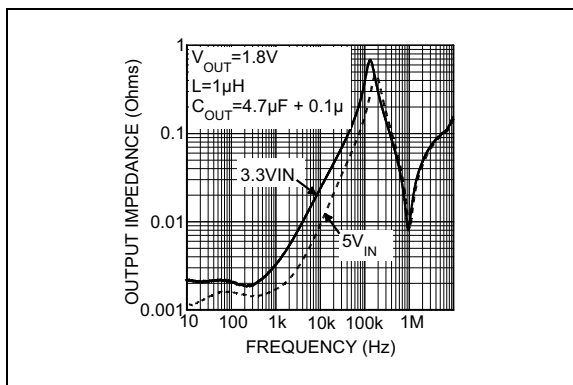
$$\Delta V = \frac{\sqrt{10^{(dBm) \div 10} \times 1mW \times 50\Omega \times 2}}{0.707}$$

and peak to peak current:

EQUATION 5-20:

$$\Delta V = \frac{\sqrt{10^{(dBm) \div 10} \times 1mW \times 50\Omega \times 2}}{0.707 \times R_{LOAD}}$$

The following graph shows output impedance vs frequency at 2A load current sweeping the AC current from 10 Hz to 10 MHz, at 1A peak to peak amplitude.



From this graph, you can see the effects of bandwidth and output capacitance. For frequencies <200 kHz, the output impedance is dominated by the gain and inductance. For frequencies >200 kHz, the output impedance is dominated by the capacitance. A good approximation for transient response can be calculated from determining the frequency of the load step in amps per second:

EQUATION 5-21:

$$f = \frac{A/sec}{2\pi}$$

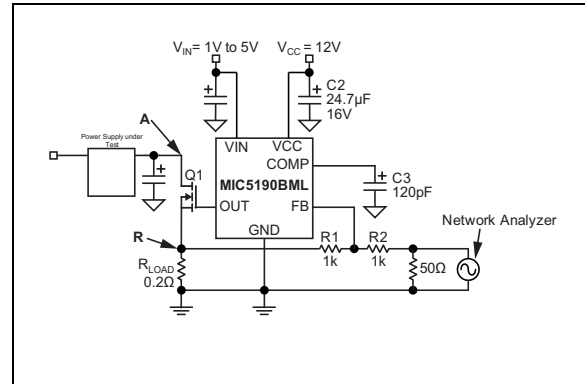


FIGURE 5-16: Output Impedance Measurement.

Then, determine the output impedance by looking at the output impedance vs frequency graph. Next, calculate the voltage deviation times the load step:

EQUATION 5-22:

$$\Delta V_{OUT} = \Delta I_{OUT} \times Z_{OUT}$$

The output impedance graph shows the relationship between supply voltage and output impedance. This is caused by the lower $R_{DS(ON)}$ of the high side MOSFET and the increase in gain with increased supply voltages. This explains why higher supply voltages have better transient response.

EQUATION 5-23:

$$Falling Z_{TOTAL} = \frac{Falling R_{DS(ON)} + DCR + X_L}{Rising GAIN} \parallel X_{COUT}$$

5.8 Ripple Measurements

To properly measure ripple on either input or output of a switching regulator, a proper ring in tip measurement is required. Standard oscilloscope probes come with a grounding clip, or a long wire with an alligator clip. Unfortunately, for high frequency measurements, this ground clip can pick up high frequency noise and erroneously inject it into the measured output ripple.

The standard evaluation board accommodates a home made version by providing probe points for both the input and output supplies and their respective grounds. This requires the removing of the oscilloscope probe sheath and ground clip from a standard oscilloscope probe and wrapping a non shielded bus wire around the oscilloscope probe. If there does not happen to be any non shielded bus wire immediately available, the leads from axial resistors will work. By maintaining the shortest possible ground lengths on the oscilloscope probe, true ripple measurements can be obtained.

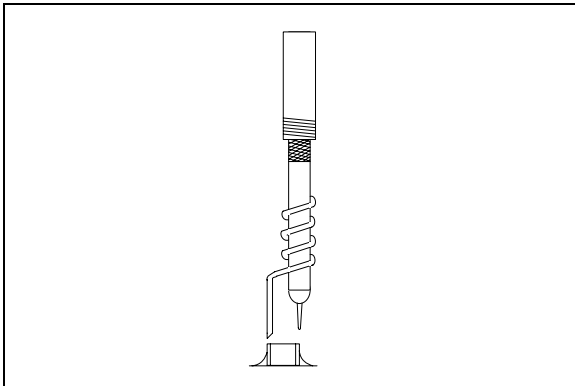
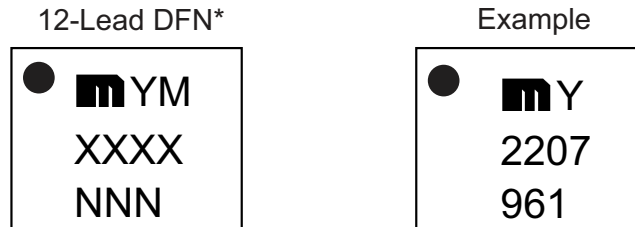


FIGURE 5-17:

6.0 PACKAGING INFORMATION

6.1 Package Marking Information



<p>Legend:</p> <p>XX...X Product code or customer-specific information</p> <p>Y Year code (last digit of calendar year)</p> <p>YY Year code (last 2 digits of calendar year)</p> <p>WW Week code (week of January 1 is week '01')</p> <p>NNN Alphanumeric traceability code</p> <p>(e3) Pb-free JEDEC® designator for Matte Tin (Sn)</p> <p>* This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package.</p> <p>●, ▲, ▼ Pin one index is identified by a dot, delta up, or delta down (triangle mark).</p>
<p>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. Package may or may not include the corporate logo.</p> <p>Underbar (_) and/or Overbar (¯) symbol may not be to scale.</p>

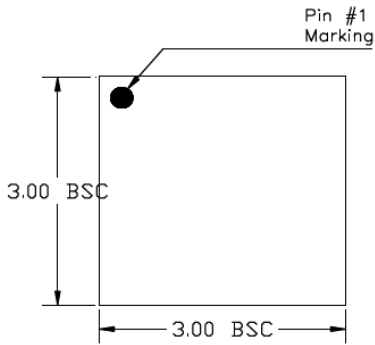
MIC2207

12-Lead DFN (ML) Package Outline and Recommended Land Pattern

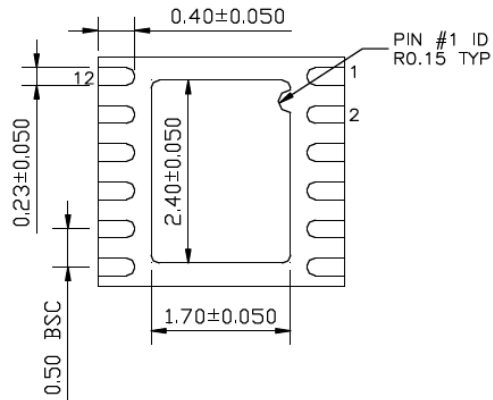
TITLE

12 LEAD DFN 3x3mm PACKAGE OUTLINE & RECOMMENDED LAND PATTERN

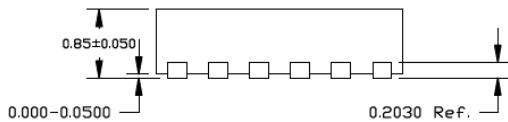
DRAWING #	DFN33-12LD-PL-1	UNIT	MM
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TOP VIEW
NOTE: 1, 2, 3



BOTTOM VIEW
NOTE: 1, 2, 3



SIDE VIEW
NOTE: 1, 2, 3

NOTE:

1. MAX PACKAGE WARPAGE IS 0.05 MM
2. MAX ALLOWABLE BURR IS 0.076 MM IN ALL DIRECTIONS
3. PIN #1 IS ON TOP WILL BE LASER MARKED
4. RED CIRCLE IN LAND PATTERN INDICATE THERMAL VIA. SIZE SHOULD BE 0.30-0.35 MM IN DIAMETER AND SHOULD BE CONNECTED TO GND FOR MAX THERMAL PERFORMANCE
5. GREEN RECTANGLES (SHADED AREA) INDICATE SOLDER STENCIL OPENING ON EXPOSED PAD AREA. SIZE SHOULD BE 0.50x0.95 MM IN SIZE, 0.20 MM SPACING.

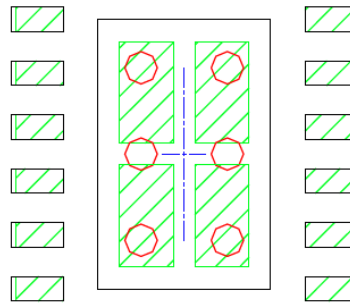
Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>.

12-Lead DFN (ML) Recommended Land Pattern

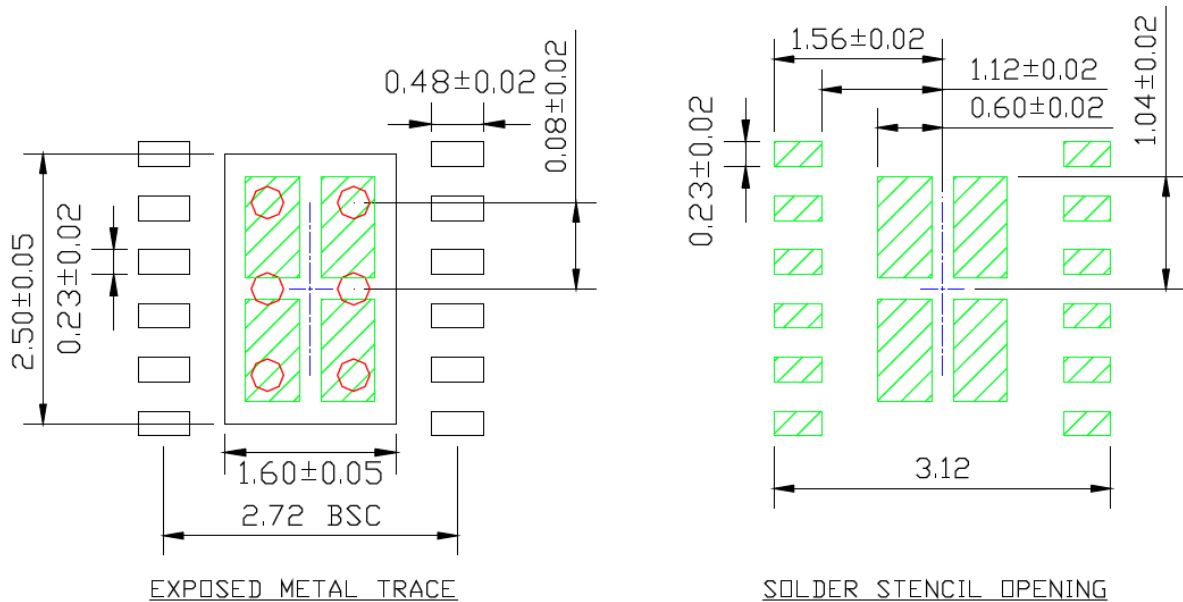
POD-Land Pattern drawing # DFN33-12LD-PL-1

RECOMMENDED LAND PATTERN

NOTE: 4, 5



STACKED-UP



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MIC2207

NOTES:

APPENDIX A: REVISION HISTORY

Revision A (December 2020)

- Converted Micrel document MIC2207 to Microchip data sheet DS20006470A.
- Minor text changes throughout.

MIC2207

NOTES:

PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, contact your local Microchip representative or sales office.

<u>PART NO.</u>	<u>X</u>	<u>XX</u>	<u>-XX</u>
Device	Junction Temperature Range	Package	Media Type
Device:	MIC2207: 2 MHz 3A PWM Buck Regulator		
Feature:	Adjustable Output Voltage		
Junction Temperature Range:	Y =	-40°C to +125°C, RoHS Compliant	
Package:	ML =	12-Lead 3 mm x 3 mm x 0.9 mm DFN	
Media Type:	TR =	5,000/Reel	

Examples:

a) MIC2207YML-TR: 2 MHz 3A PWM Buck Regulator, Adjustable Output Voltage, -40°C to +125°C Junction Temperature Range, RoHS Compliant, 12-Lead 3 mm x 3 mm x 0.9 mm DFN Package, 5000/Reel

Note 1: 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.

MIC2207

NOTES:

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