# DUAL HIGH-EFFICIENCY PWM STEP-DOWN DC-DC CONVERTER

## Description

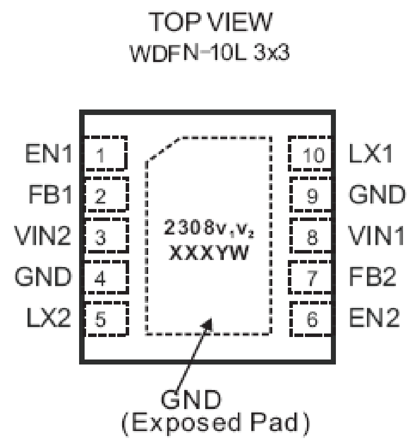
The PAM2308 is a dual step-down current-mode, DC-DC converter. At heavy load, the constant frequency PWM control performs excellent stability and transient response. To ensure the longest battery life in portable applications, the PAM2308 provides a power-saving Pulse- Skipping Modulation (PSM) mode to reduce quiescent current under light load operation.

The PAM2308 supports a range of input voltages from 2.5V to 5.5V, allowing the use of a single Li+/Li-polymer cell, multiple Alkaline/NiMH cell, USB, and other standard power sources. The dual output voltages are available for 3.3V, 2.8V, 2.5V, 1.8V, 1.5V, 1.2V or adjustable. All versions employ internal power switch and synchronous rectifier to minimize external part count and realize high efficiency. During shutdown, the input is disconnected from the output and the shutdown current is less than 0.1μA. Other key features include under-voltage lockout to prevent deep battery discharge.

## Features

- Efficiency up to 96%
- Only 40μA (typ per channel) Quiescent Current
- Output Current: Up to 1A per Channel
- Internal Synchronous Rectifier
- 1.5MHz Switching Frequency
- Soft-Start
- Under-Voltage Lockout
- Short Circuit Protection
- Thermal Shutdown
- Small WDFN3x3-10L Packages
- Pb-Free Package and RoHS Compliant

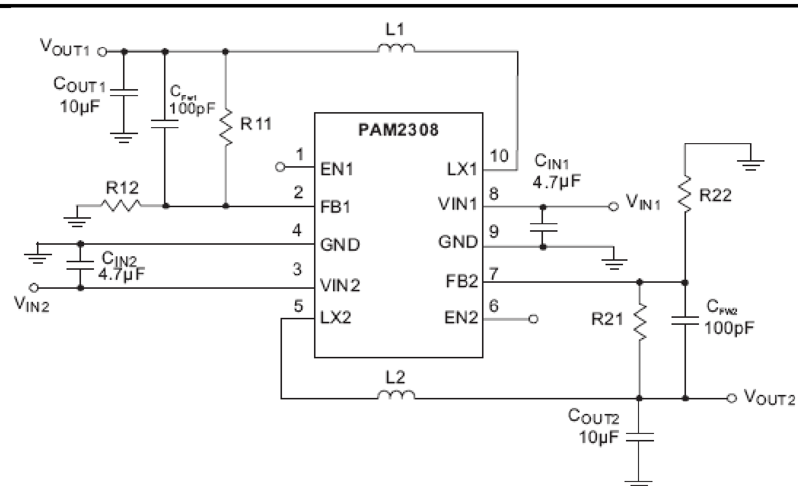
## Pin Assignments




## Applications

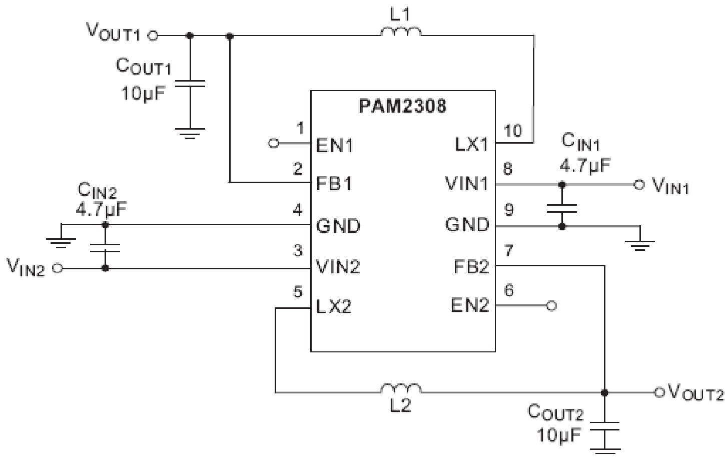
- Cellular Phone
- Portable Electronics
- Personal Information Appliances
- Wireless and DSL Modems
- MP3 Players

## Typical Applications Circuit




$$V_{OUTx} = V_{REF}\left(1 + \frac{Rx1}{Rx2}\right)$$ Figure 1. Adjustable Voltage Regulator

## Typical Applications Circuit (cont.)



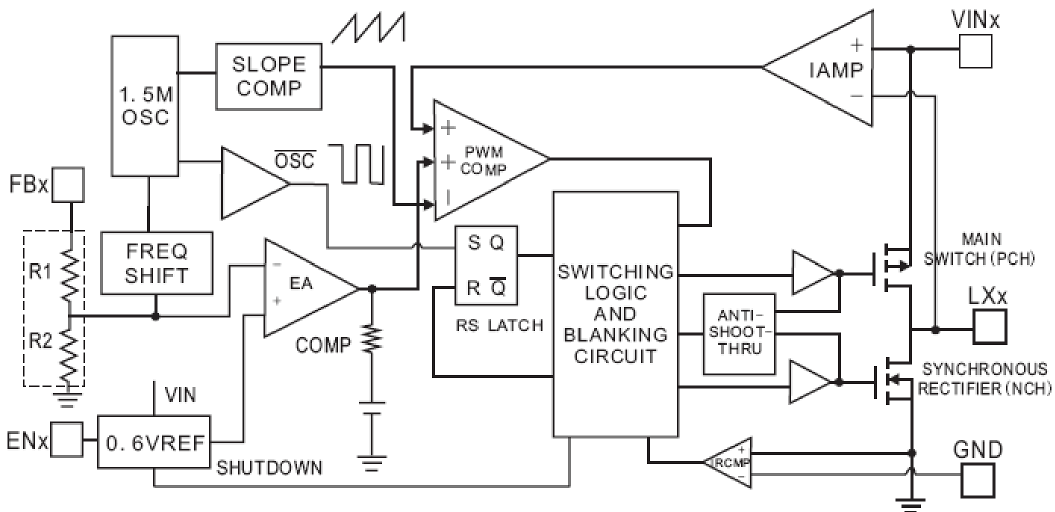

$V_{OUTx}$ = 1.2V, 1.5V, 1.8V, 2.5V, 2.8V or 3.3V

Figure 2. Fixed Voltage Regulator

## Pin Descriptions

| Pin Name | Pin Number | Function |
|---|---|---|
| EN1 | 1 | Chip Enable of Channel 1(Active High). $V_{EN1} \leq V_{IN1}$. |
| FB1 | 2 | Feedback of Channel 1. |
| VIN2 | 3 | Power Input of Channel 2. |
| GND | 4, 9 | Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation. |
| LX2 | 5 | Pin for Switching of Channel 2. |
| EN2 | 6 | Chip Enable of Channel 2 (Active High).$V_{EN2} \leq V_{IN2}$. |
| FB2 | 7 | Feedback of Channel 2. |
| VIN1 | 8 | Power Input of Channel 1. |
| LX1 | 10 | Pin for Switching of Channel 1. |

## Functional Block Diagram




## Absolute Maximum Ratings (@$T_A$ = +25°C, unless otherwise specified.)

These are stress ratings only and functional operation is not implied. Exposure to absolute maximum ratings for prolonged time periods may affect device reliability. All voltages are with respect to ground.

| Parameter | Rating | Unit |
|---|---|---|
| Input Voltage | -0.3 to +6.5 | V |
| EN1, FB1, LX1, EN2, FB2 AND LX2 Pin Voltage | -0.3 to ($V_{IN}$ +0.3) | V |
| Maximum Junction Temperature | 150 | °C |
| Storage Temperature Range | -65 to +150 | °C |
| Soldering Temperature | 260, 10sec | °C |

## Recommended Operating Conditions (@$T_A$ = +25°C, unless otherwise specified.)

| Parameter | Rating | Unit |
|---|---|---|
| Supply Voltage | 2.5 to 5.5 | V |
| Ambient Temperature Range | -40 to +85 | °C |
| Junction Temperature Range | -40 to +125 | |

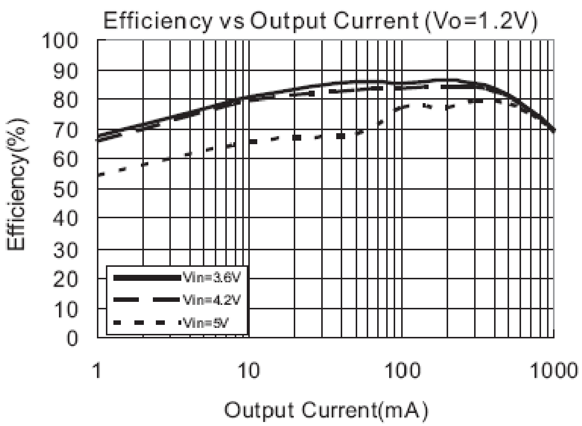
## Thermal Information

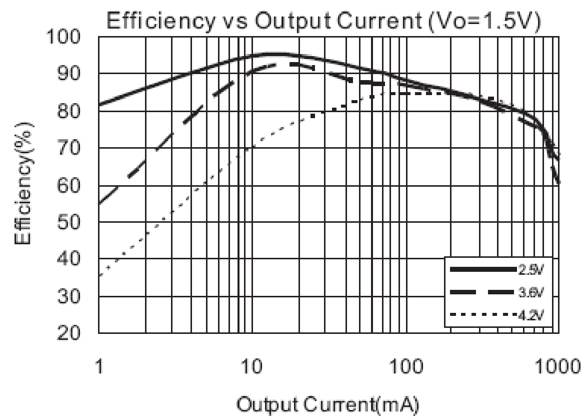
| Parameter | Symbol | Package | Max | Unit |
|---|---|---|---|---|
| Thermal Resistance (Junction to Ambient) | $\theta_{JA}$ | W-DFN3x3-10 | 60 | °C/W |
| Thermal Resistance (Junction to Case) | $\theta_{JC}$ | W-DFN3x3-10 | 8.5 | |
| Thermal Resistance (Junction to Case) | $P_D$ | W-DFN3x3-10 | 1.66 | W |

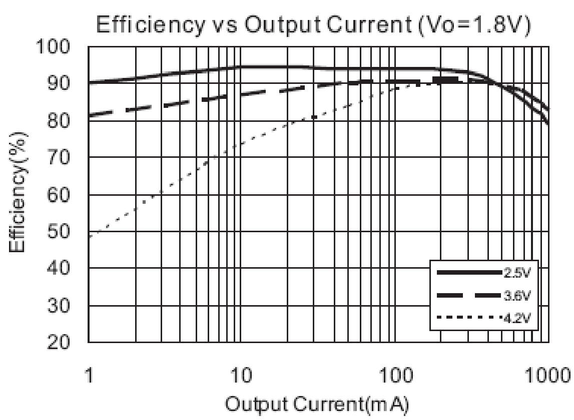
## Electrical Characteristics (@$T_A$ = +25°C, $V_{IN}$ = 3.6V, $V_O$ = 1.8V, $C_{IN}$ = 10μF, $C_O$ = 10μF, L = 2.2μH, unless otherwise specified.)

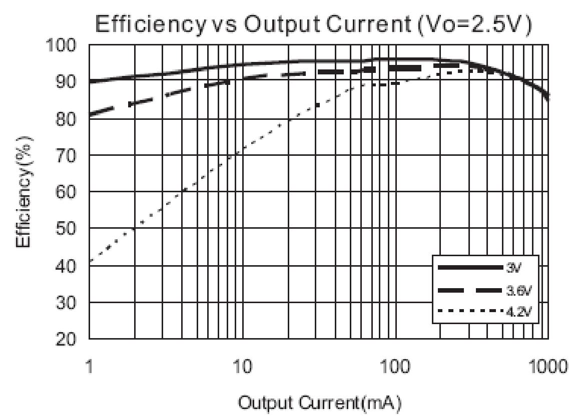
| Parameter | Symbol | Test Conditions | | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|---|
| Input Voltage Range | $V_{IN}$ | | | 2.5 | | 5.5 | V |
| Regulated Feedback Voltage | $V_{FB}$ | | | 0.588 | 0.6 | 0.612 | V |
| Reference Voltage Line Regulation | $\Delta V_{FB}$ | | | | 0.3 | | %/V |
| Regulated Output Voltage Accuracy | $V_O$ | $I_O$ = 100mA | | -3 | | +3 | % |
| Peak Inductor Current | $I_{PK}$ | $V_{IN}$ = 3V, $V_{FB}$ = 0.5V or $V_O$ = 90% | | | 1.5 | | A |
| Output Voltage Line Regulation | LNR | $V_{IN}$ = 2.5V TO 5V, $I_O$ = 10mA | | | 0.2 | 0.5 | %/V |
| Output Voltage Load Regulation | LDR | $I_O$ = 1mA to 1A | | | 0.5 | 1.5 | % |
| Quiescent Current (per channel) | $I_Q$ | No load | | | 40 | 70 | μA |
| Shutdown Current (per channel) | $I_{SD}$ | $V_{EN}$ = 0V | | | 0.1 | 1 | μA |
| Oscillator Frequency | fosc | $V_O$ = 100% | | 1.2 | 1.5 | 1.8 | MHz |
| | | $V_{FB}$ = 0V or $V_O$ = 0V | | | 500 | | kHz |
| Drain-Source On-State Resisitance | $R_{DS(ON)}$ | $I_{DS}$ = 100mA | P MOSFET | | 0.3 | 0.45 | Ω |
| | | | N MOSFET | | 0.35 | 0.5 | Ω |
| SW Leakage Current | $I_{LSW}$ | | | | ±0.01 | 1 | μA |
| High Efficiency | η | | | | 96 | | % |
| EN Threshold High | $V_{EH}$ | | | 1.5 | | | V |
| EN Threshold Low | $V_{EL}$ | | | | | 0.3 | V |
| EN Leakage Current | $I_{EN}$ | | | | ±0.01 | | μA |
| Over Temperature Protection | OTP | | | | 150 | | °C |
| OTP Hysteresis | OTH | | | | 30 | | °C |

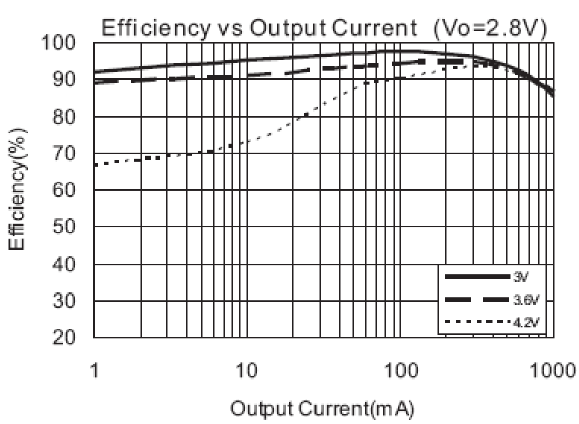
## Typical Performance Characteristics (@$T_A$ = +25°C, $C_{IN}$ = 10µF, $C_O$ = 10µF, L = 4.7µH, unless otherwise specified.)

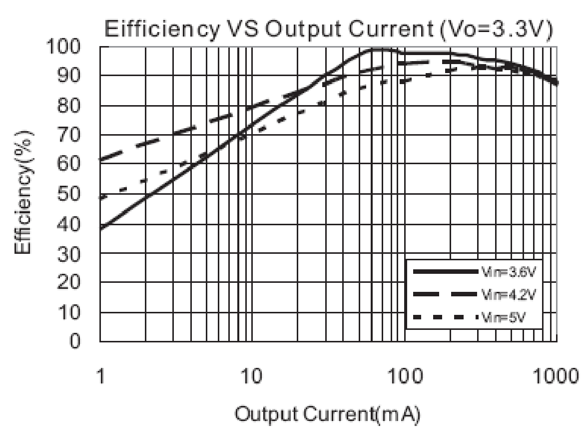


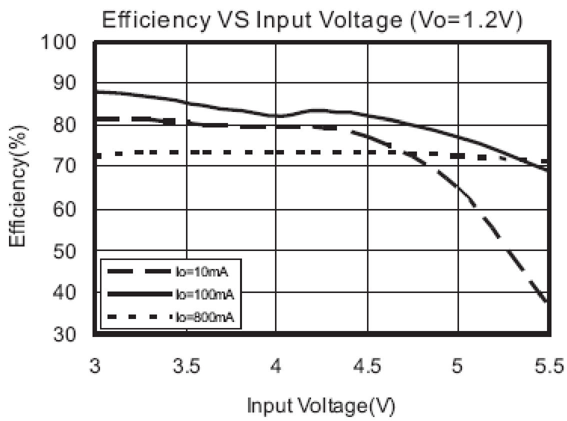



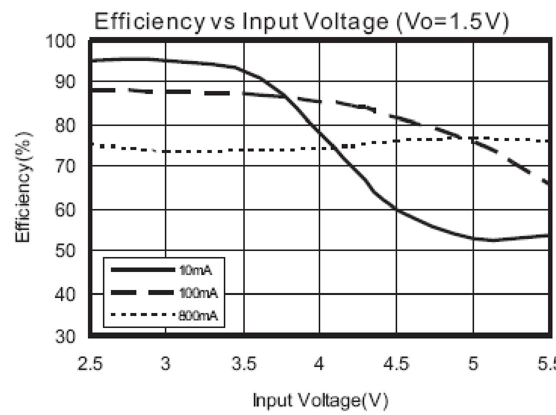



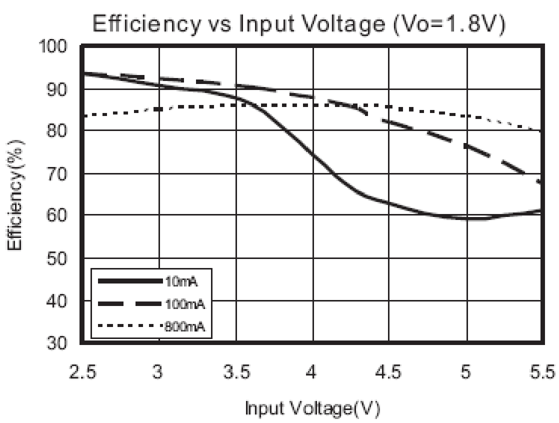



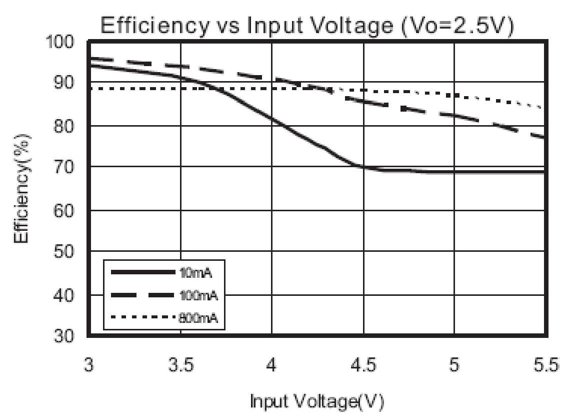
## Typical Performance Characteristics (cont.)

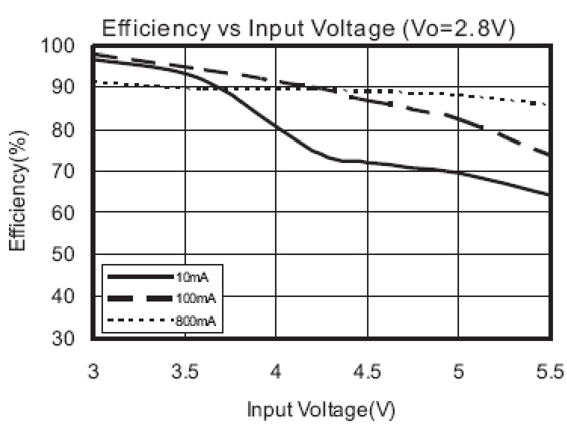
(@$T_A$ = +25°C, $C_{IN}$ = 10µF, $C_O$ = 10µF, L = 4.7µH, unless otherwise specified.)

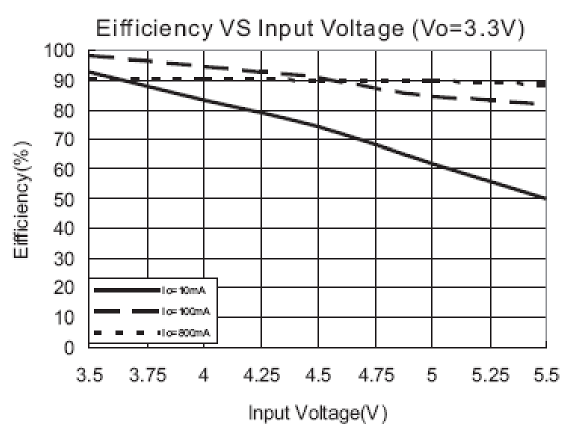


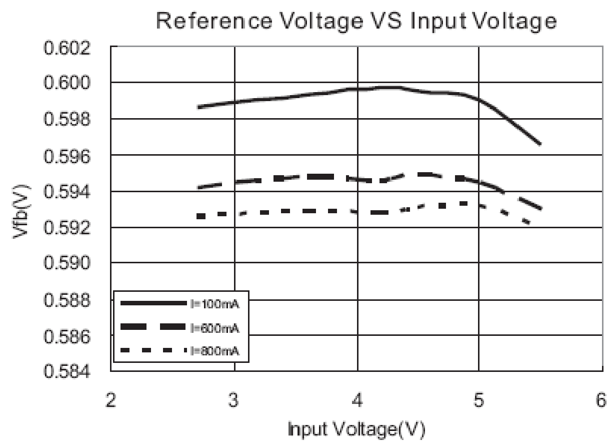



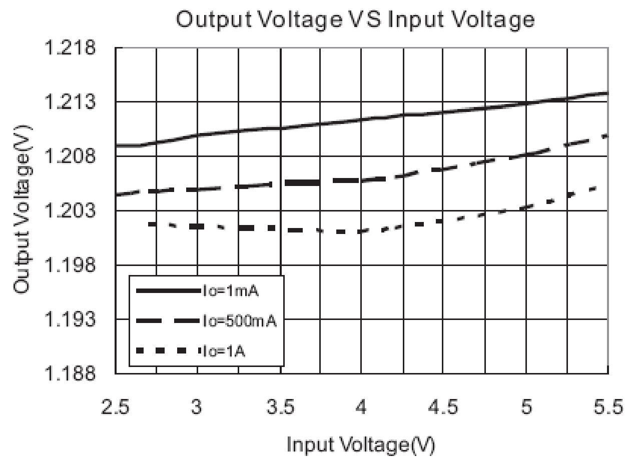



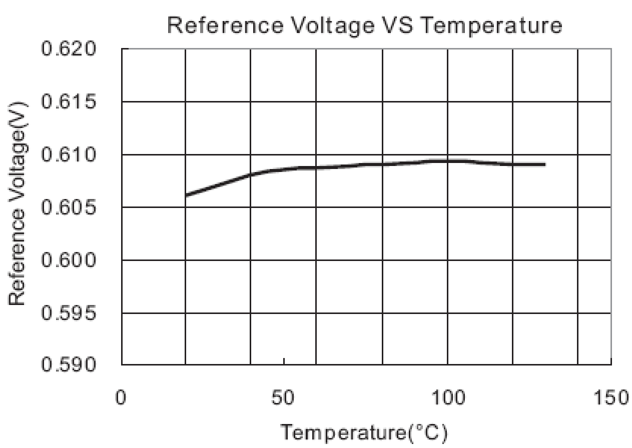



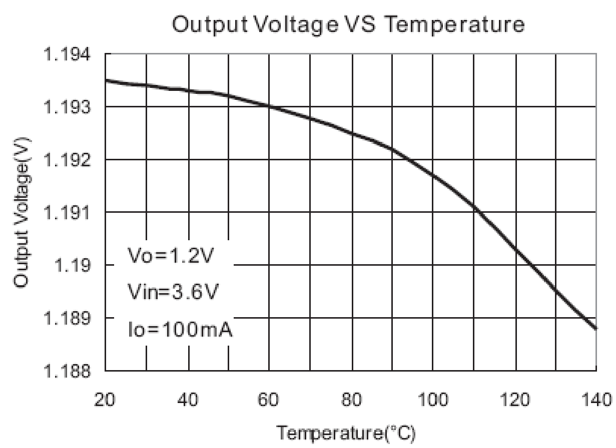
## Typical Performance Characteristics (cont.)

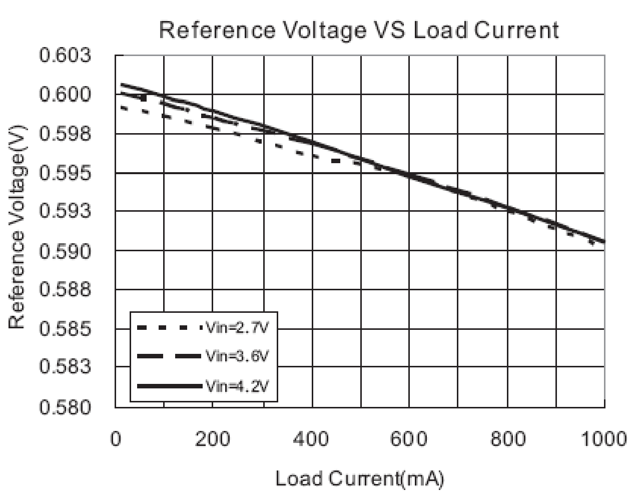
(@$T_A$ = +25°C, $C_{IN}$ = 10µF, $C_O$ = 10µF, L = 4.7µH, unless otherwise specified.)

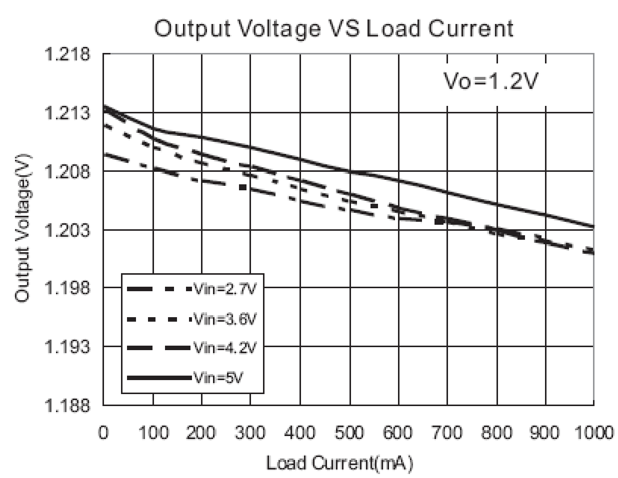


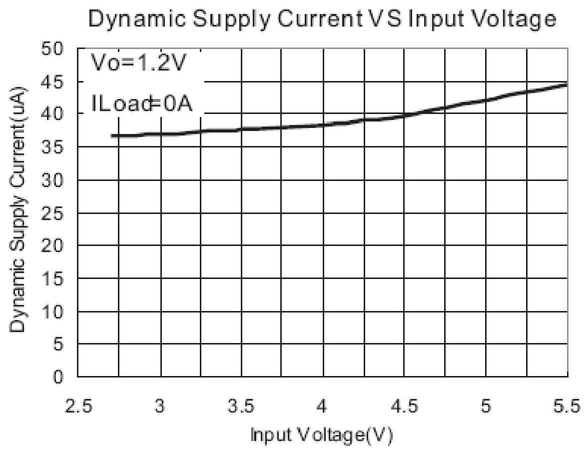



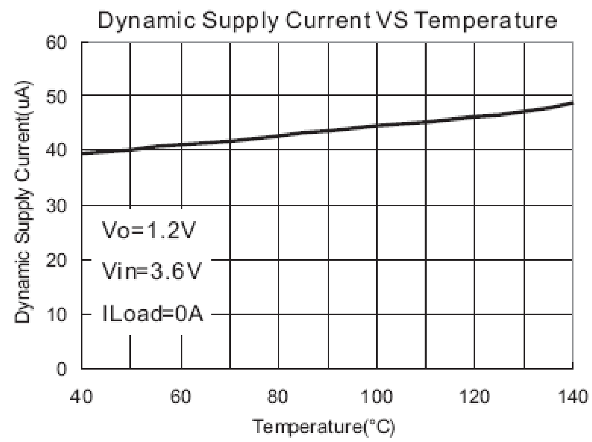



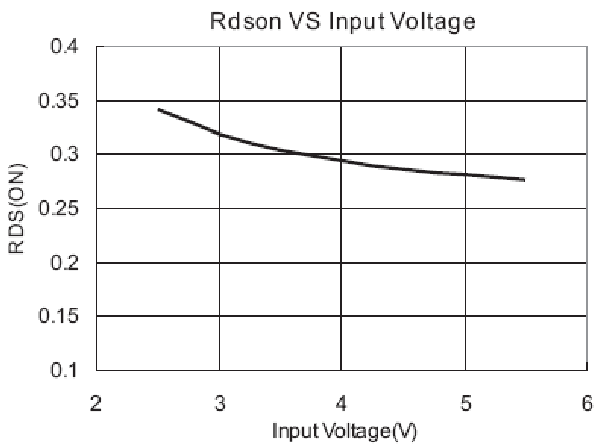



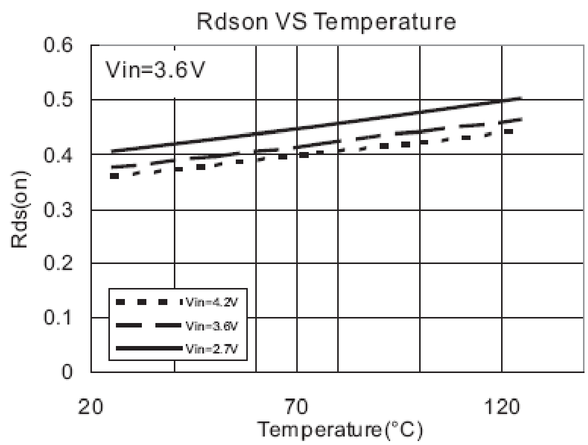
## Typical Performance Characteristics (cont.)

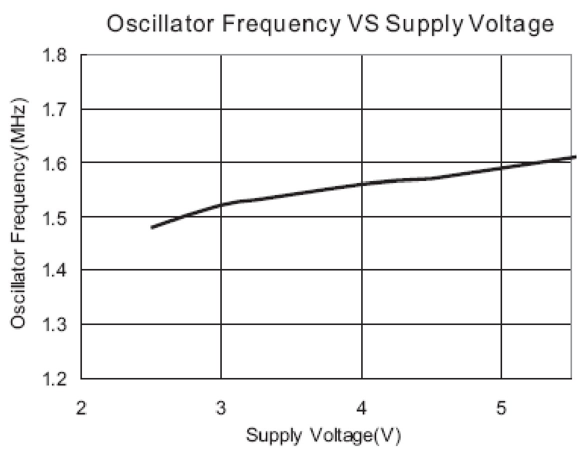
(@$T_A$ = +25°C, $C_{IN}$ = 10μF, $C_O$ = 10μF, L = 4.7μH, unless otherwise specified.)

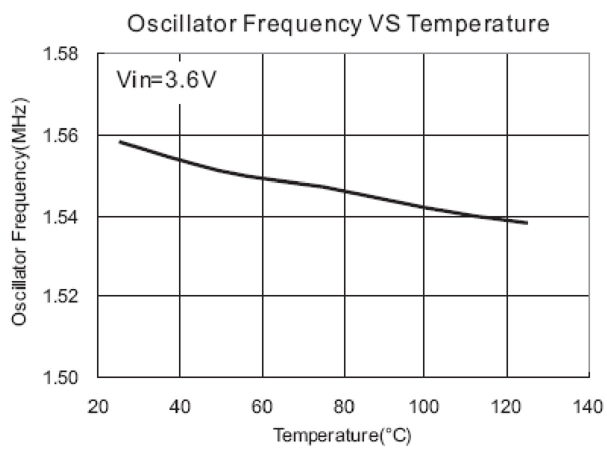


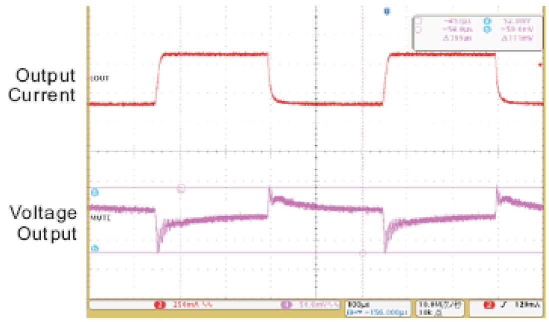



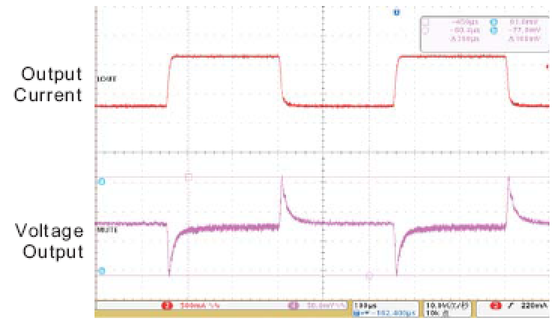
## Typical Performance Characteristics (cont.)

(@$T_A$ = +25°C, $C_{IN}$ = 10µF, $C_O$ = 10µF, L = 4.7µH, unless otherwise specified.)

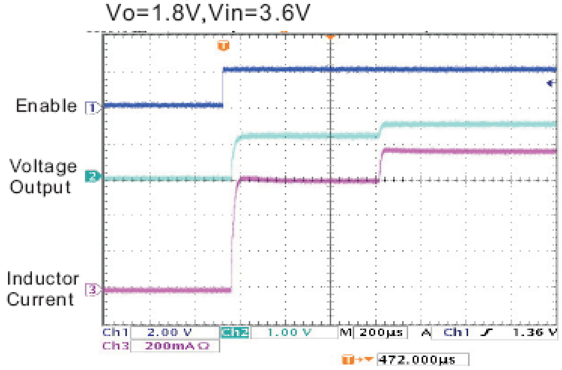
Load Transient
Io=0-500mA Vo=3.3V Vin=5V




Load Transient
Io=0-1A Vo=1.2V Vin=3.6V




Start-up from Shutdown
Vo=1.8V,Vin=3.6V



## Application Information

The basic PAM2308 application circuit is shown on Page 1 and 2. External component selection is determined by the load requirement, selecting L first and then $C_{IN}$ and $C_{OUT}$.

### Inductor Selection

For most applications, the value of the inductor will fall in the range of 1μH to 4.7μH. Its value is chosen based on the desired ripple current. Large value inductors lower ripple current and small value inductors result in higher ripple currents. Higher $V_{IN}$ or $V_{OUT}$ also increases the ripple current as shown in Equation 1. A reasonable starting point for setting ripple current is $\Delta I_L$ = 400mA (40% of 1A).

$$\Delta I_L = \frac{1}{(f)(L)} V_{OUT}\left(1 - \frac{V_{OUT}}{V_{IN}}\right) \qquad \text{Equation} \quad (1)$$

The DC current rating of the inductor should be at least equal to the maximum load current plus half the ripple current to prevent core saturation. Thus, a 1.4A rated inductor should be enough for most applications (1A + 400mA). For better efficiency, choose a low DC-resistance inductor.

| $V_O$ | 1.2V | 1.5V | 1.8V | 2.5V | 3.3V |
|---|---|---|---|---|---|
| L | 2.2μH | 2.2μH | 2.2μH | 4.7μH | 4.7μH |

### $C_{IN}$ and $C_{OUT}$ Selection

In continuous mode, the source current of the top MOSFET is a square wave of duty cycle $V_{OUT}/V_{IN}$. To prevent large voltage transients, a low ESR input capacitor sized for the maximum RMS current must be used. The maximum RMS capacitor current is given by:

$$C_{IN} \text{ required } I_{RMS} \cong I_{OMAX} \frac{\left[V_{OUT}\left(V_{IN} - V_{OUT}\right)\right]^{1/2}}{V_{IN}}$$

This formula has a maximum at $V_{IN} = 2V_{OUT}$, where $I_{RMS} = I_{OUT}/2$. This simple worst-case condition is commonly used for design because even significant deviations do not offer much relief. Note that the capacitor manufacturer's ripple current ratings are often based on 2000 hours of life. This makes it advisable to further derate the capacitor, or choose a capacitor rated at a higher temperature than required. Consult the manufacturer if there is any question.

The selection of $C_{OUT}$ is driven by the required effective series resistance (ESR).

Typically, once the ESR requirement for Cout has been met, the RMS current rating generally far exceeds the $I_{RIPPLE}$ (P-P) requirement. The output ripple $\Delta V_{OUT}$ is determined by:

$$\Delta V_{OUT} \approx \Delta I_L \left(ESR + \frac{1}{8fC_{OUT}}\right)$$

Where f = operating frequency, $C_{OUT}$ =output capacitance and $\Delta I_L$ = ripple current in the inductor. For a fixed output voltage, the output ripple is highest at maximum input voltage since $\Delta I_L$ increases with input voltage.

### Using Ceramic Input and Output Capacitors

Higher values, lower cost ceramic capacitors are now becoming available in smaller case sizes. Their high ripple current, high voltage rating and low ESR make them ideal for switching regulator applications. Using ceramic capacitors can achieve very low output ripple and small circuit size.

When choosing the input and output ceramic capacitors, choose the X5R or X7R dielectric formulations. These dielectrics have the best temperature and voltage characteristics of all the ceramics for a given value and size.

### Thermal Consideration

Thermal protection limits power dissipation in the PAM2308. When the junction temperature exceeds +150°C, the OTP (Over Temperature Protection) starts the thermal shutdown and turns the pass transistor off. The pass transistor resumes operation after the junction temperature drops below +120°C.

For continuous operation, the junction temperature should be maintained below 125°C. The power dissipation is defined as:

$$P_D = I_O^2 \frac{V_O R_{DS(ON)H} + \left(V_{IN} - V_O\right) R_{DS(ON)L}}{V_{IN}} + \left(t_{SW} F_S I_O + I_Q\right) V_{IN}$$

$I_Q$ is the step-down converter quiescent current. The term tsw is used to estimate the full load step-down converter switching losses.

## Application Information (cont.)

For the condition where the step-down converter is in dropout at 100% duty cycle, the total device dissipation reduces to:

$$P_D = I_O^2 R_{DS(ON)H} + I_Q V_{IN}$$

Since $R_{DS(ON)}$, quiescent current, and switching losses all vary with input voltage, the total losses should be investigated over the complete input voltage range. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surrounding airflow and temperature difference between junction and ambient. The maximum power dissipation can be calculated by the following formula:

$$P_D = \frac{T_{J(MAX)} - T_A}{\theta_{JA}}$$

Where $T_{J(MAX)}$ is the maximum allowable junction temperature +125°C. $T_A$ is the ambient temperature and $\theta_{JA}$ is the thermal resistance from the junction to the ambient. Based on the standard JEDEC for a two layers thermal test board, the thermal resistance $\theta_{JA}$ of W-DFN3X3 is 60°C/W. The maximum power dissipation at $T_A$ = +25°C can be calculated by following formula:

P = (125°C - 25°C) /60°C/W = 1.66W

### Setting the Output Voltage

The internal reference is 0.6V (Typical). The output voltage is calculated as below:

$$V_O = 0.6x\left(1 + \frac{R1}{R2}\right)$$

The output voltage is given by Table 1.
**Table 1:** Resistor selection for output voltage setting.

| $V_O$ | R1 | R2 |
|---|---|---|
| 1.2V | 100k | 100k |
| 1.5V | 150k | 100k |
| 1.8V | 200k | 100k |
| 2.5V | 380k | 120k |
| 3.3V | 540k | 120k |

### 100% Duty Cycle Operation

As the input voltage approaches the output voltage, the converter turns the P-Channel transistor continuously on. In this mode the output voltage is equal to the input voltage minus the voltage drop across the P-Channel transistor:

$$V_{OUT} = V_{IN} - I_{LOAD}(R_{DSON} + R_L)$$

where $R_{DS(ON)}$ = P-Channel switch ON resistance, $I_{LOAD}$ = Output Current, $R_L$ = Inductor DC Resistance

### UVLO and Soft-Start

The reference and the circuit remain reset until the $V_{IN}$ crosses its UVLO threshold.

The PAM2308 has an internal soft-start circuit that limits the in-rush current during start-up. This prevents possible voltage drops of the input voltage and eliminates the output voltage overshoot. The soft-start acts as a digital circuit to increase the switch current in several steps to the P-Channel current limit (1500mA).

### Short Circuit Protection

The switch peak current is limited cycle-by-cycle to a typical value of 1500mA. In the event of an output voltage short circuit, the device operates with a frequency of 400kHz and minimum duty cycle, therefore the average input current is typically 200mA.

### Thermal Shutdown

When the die temperature exceeds +150°C, a reset occurs and the reset remains until the temperature decrease to +120°C, at which time the circuit can be restarted.

## Application Information (cont.)

### PCB Layout Check List

When laying out the printed circuit board, the following checklist should be used to ensure proper operation of the PAM2308. These items are also illustrated graphically in Figure 1. Check the following in your layout:

1. The power traces, consisting of the GND trace, the SW trace and the $V_{IN}$ trace should be kept short, direct and wide.
2. Does the FB pin connect directly to the feedback resistors? The resistive divider R1/R2 must be connected between the (+) plate of $C_{OUT}$ and ground.
3. Does the (+) plate of $C_{IN}$ connect to $V_{IN}$ as closely as possible? This capacitor provides the AC current to the internal power MOSFETs.
4. Keep the switching node, SW, away from the sensitive FB node.
5. Keep the (–) plates of $C_{IN}$ and $C_{OUT}$ as close as possible.

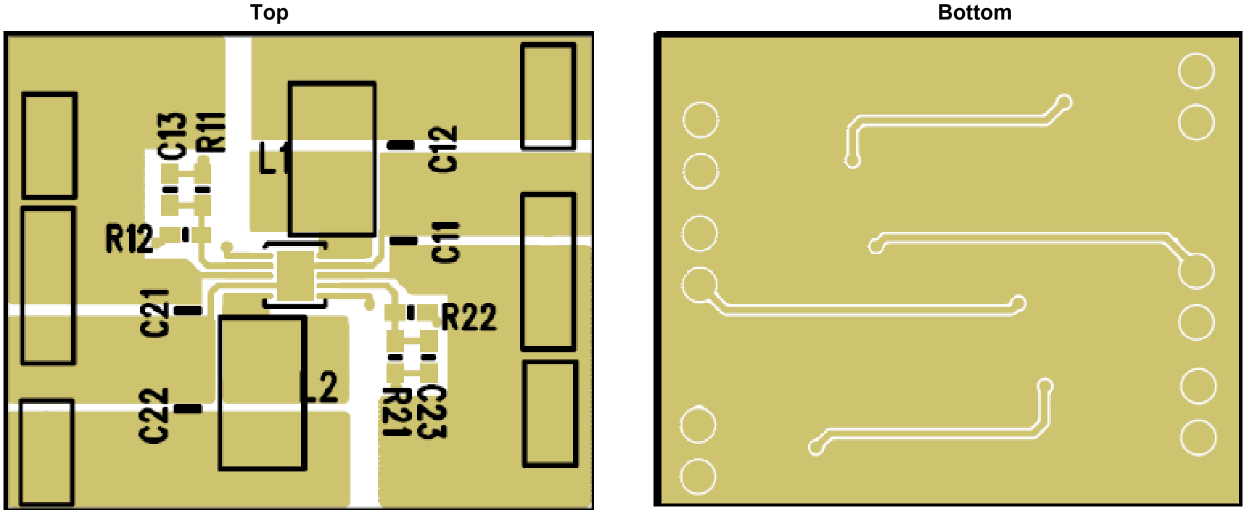



**Figure 1. PAM2308 Suggested Layout**

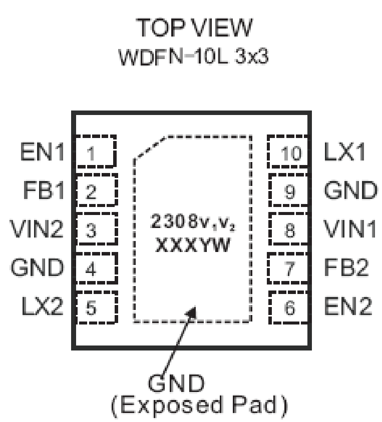
## Ordering Information

**PAM2308 X X X v1 v2**

| Pin Configuration | Package Type | Number of Pins | Output Voltage $V_1$ | Output Voltage $V_2$ |
|---|---|---|---|---|
| B Type: 10 Pins | Y: W-DFN3x3 | M: 10 | K: 3.3V<br>H: 2.8V<br>G: 2.5V<br>E: 1.8V<br>C: 1.5V<br>B: 1.2V<br>A: ADJ | K: 3.3V<br>H: 2.8V<br>G: 2.5V<br>E: 1.8V<br>C: 1.5V<br>B: 1.2V<br>A: ADJ |

| Part Number | Part Marking | Package Type | Standard Package |
|---|---|---|---|
| PAM2308BYM$v_1v_2$ | 2308$v_1v_2$<br>XXXYW | W-DFN3x3-10 | 3000 Units/Tape & Reel |

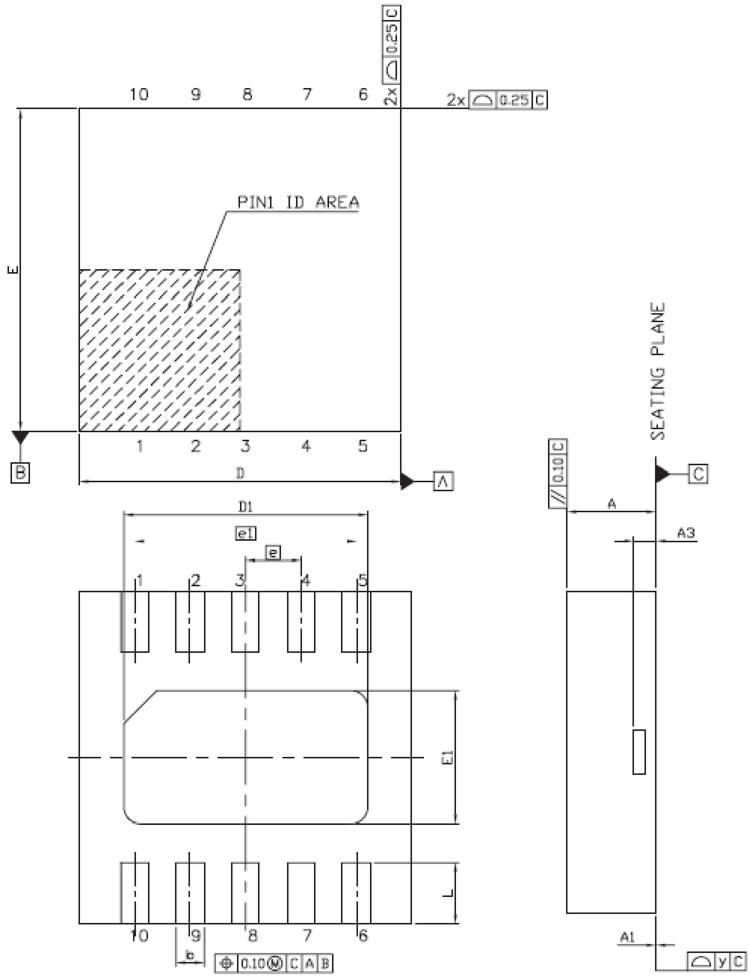
## Marking Information




$v_1$: Output Voltage 1
$v_2$: Output Voltage 2
(refer to "Ordering Information")
X: Internal Code
Y: Year
W: Week

## Package Outline Dimensions (All dimensions in mm.)

**W-DFN3x3-10**




| SYMBOL | DIMENSION (MM) | | |
|---|---|---|---|
| | MIN | NOM. | MAX. |
| A | 0.70 | 0.75 | 0.80 |
| A1 | 0.00 | 0.02 | 0.05 |
| A3 | 0.203 REF | | |
| b | 0.18 | 0.25 | 0.30 |
| D | 2.90 | 3.00 | 3.10 |
| D1 | 2.10 | 2.20 | 2.30 |
| E | 2.90 | 3.00 | 3.10 |
| E1 | 1.10 | 1.20 | 1.30 |
| L | 0.45 | 0.55 | 0.65 |
| e | 0.50 BASIC | | |
| e1 | 2.00 BASIC | | |
| y | 0 | | 0.08 |

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