# PWM Step-Down Controller

## ❖ GENERAL DESCRIPTION

The AX3301 integrates Pulse-Width-Modulation (PWM) control circuit into a single chip. These devise include a reference voltage source, oscillation circuit, error amplifier and etc.

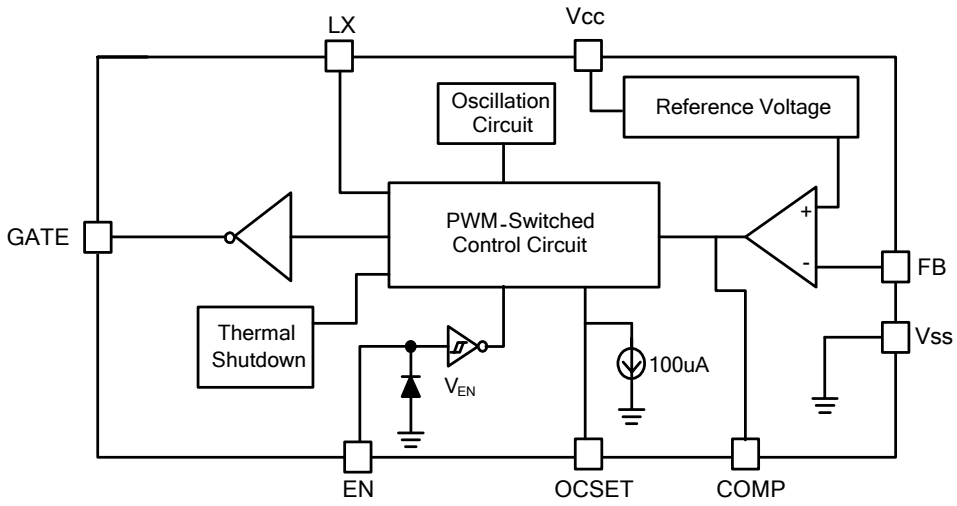
AX3301 provides low-ripple power, high efficiency, and excellent transient characteristics. The PWM control circuit is able to the duty ratio linearly form 0 up to 100%. An enable function, an over current protect function and short circuit protect function are built inside, and when OCP or SCP happens, the operation frequency will be reduced. Also, an external compensation can be system all used MLCC.

With the addition of an external P-channel Power MOS, a coil, capacitors, and a diode connected externally, these components can function as step-down switching regulators. They serve as ideal power supply units for portable devices when coupled with the SOP-8L & MSOP-8L mini-package, providing such outstanding features as low current consumption. Since this converter can accommodate an input voltage up to 24V, it is also suitable for the operation via an AC adapter.

## ❖ FEATURES

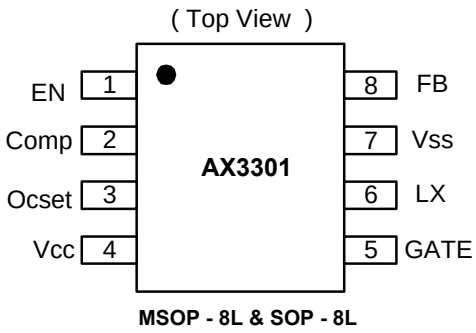
- Input voltage：4V to 24V
- Output voltage：0.8V to Vcc
- Duty ratio：0% to 100% PWM control
- Oscillation frequency：330KHz typ.
- Current Limit (CL), Enable function.
- Thermal Shutdown function.
- Short Circuit Protect (SCP).
- Low ESR output capacitor (Multi-layer chip capacitor (MLCC)) application.
- External SW P-channel MOS.
- MSOP-8L & SOP-8L Pb-Free package.

## ❖ Block Diagram




## ❖ PIN ASSIGNMET

These packages of AX3301 are MSOP-8L & SOP-8L; the pin assignment is given by:




**MSOP - 8L & SOP - 8L**

| Name | Description |
|---|---|
| EN | Shutdown Control Input.<br>H：normal operation(Step-down)<br>L：Shutdown mode |
| Comp | Compensation pin |
| OCSET | Add an external resistor to set max switch output current. |
| $V_{CC}$ | IC power supply pin |
| GATE | Gate drive for external P-channel MOSFET. |
| LX | LX is the current sense input. |
| $V_{SS}$ | GND pin |
| FB | Feedback pin |

## ❖ ORDER/MARKING INFORMATION

| Order Information | Top Marking |
|---|---|
| **AX3301 X X X**<br>Frequency: Blank : 330Khz<br>Package Type: S: SOP-8L, U:MSOP-8L<br>Packing: Blank : Tube, A : Taping | Logo ← AX 3301 → Part number<br>X X X X X → ID code: internal<br>→ WW: 01~52<br>→ Year : 06 = 2006 |

## ❖ Absolute Maximum Ratings (at Ta=25℃)

| Characteristics | Symbol | Rating | Unit |
|---|---|---|---|
| VCC Pin Voltage | $V_{CC}$ | $V_{SS}$ - 0.3 to $V_{SS}$ + 26 | V |
| Feedback Pin Voltage | $V_{FB}$ | $V_{SS}$ - 0.3 to $V_{CC}$ | V |
| ON/OFF Pin Voltage | $V_{EN}$ | $V_{SS}$ - 0.3 to $V_{CC}$ + 0.3 | V |
| Switch Pin Voltage | $V_{SW}$ | $V_{SS}$ - 0.3 to $V_{CC}$ + 0.3 | V |
| Power Dissipation | PD | Internally limited | mW |
| Storage Temperature Range | $T_{ST}$ | -40 to +150 | ℃ |
| Operating Junction Temperature Range | $T_J$ | -20 to +125 | ℃ |
| Operating Supply Voltage | $V_{OP}$ | +4 to +24 | V |
| Thermal Resistance from Junction to case | $\theta_{JC}$ | SOP8=40, MSOP8=45 | ℃/W |
| Thermal Resistance from Junction to ambient | $\theta_{JA}$ | SOP8=120, MSOP8=200 | ℃/W |

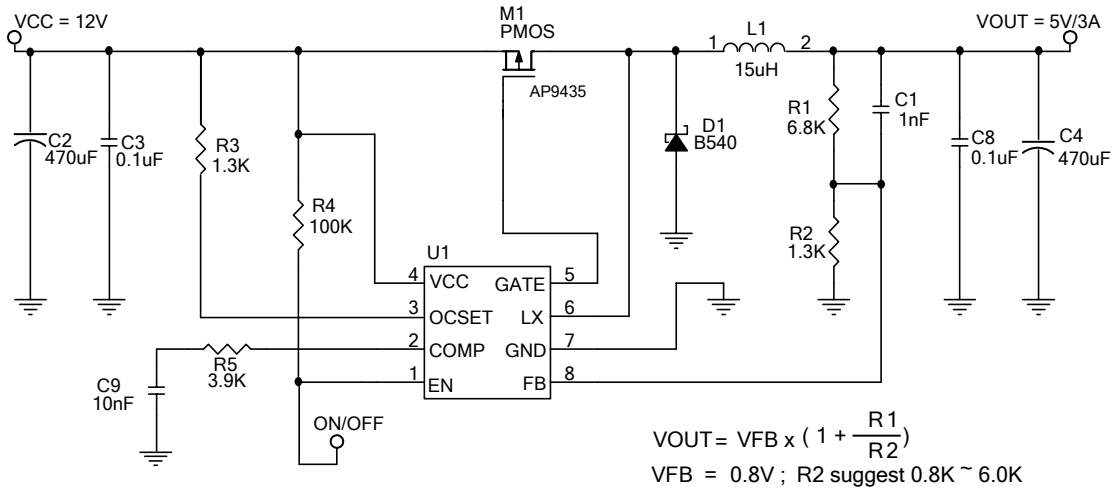
Note : $\theta_{JA}$ is measured with the PCB copper area of approximately 1 $in^2$(Multi-layer).

## ❖ Electrical Characteristics ($V_{CC}$ = 12V, Ta=25°C, unless otherwise specified)

| Characteristics | Symbol | Conditions | | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|---|
| Feedback Voltage | $V_{FB}$ | $I_{OUT}$=0.1A | | 0.784 | 0.800 | 0.816 | V |
| Quiescent Current | $I_{CCQ}$ | $V_{FB}$=1.2V force driver off | | | 3 | 5 | mA |
| Feedback Bias Current | $I_{FB}$ | $I_{OUT}$=0.1A | | - | 0.1 | 0.5 | uA |
| Shutdown Supply Current | $I_{SD}$ | $V_{EN}$ =0V | | - | 2 | 10 | uA |
| OCSET pin bias current | $I_{OCSET}$ | | | 95 | 110 | 125 | uA |
| Line Regulation | $\triangle V_{OUT}/V_{OUT}$ | $V_{CC}$ = 5V~24V, $I_{OUT}$=0.2A | | - | 0.6 | 1.2 | % |
| Load Regulation | $\triangle V_{OUT}/V_{OUT}$ | $I_{OUT}$ = 0.1 to 3A | | - | 0.3 | 0.5 | % |
| Oscillation Frequency | $F_{OSC}$ | SW pin | | 260 | 330 | 400 | KHz |
| EN Pin Logic input threshold voltage | $V_{SH}$ | High (regulator ON) | | 2.0 | - | - | V |
| | $V_{SL}$ | Low (regulator OFF) | | - | - | 0.8 | |
| EN Pin Input Current | $I_{SH}$ | $V_{EN}$=2.5V (ON) | | - | 20 | - | uA |
| | $I_{SL}$ | $V_{EN}$=0.3V (OFF) | | - | -10 | - | uA |
| LX Rise Time | $T_{LXR}$ | $C_{LX}$=1000pF | | | 45 | | nS |
| LX Fall Time | $T_{LXF}$ | $C_{LX}$=1000pF | | | 45 | | |
| Efficiency | EFFI | $V_{OUT}$ = 5V | $I_{OUT}$ = 2A | - | 92 | - | % |
| | | | $I_{OUT}$ = 3A | - | 91 | - | |
| Thermal shutdown Temp | TSD | | | | 125 | | ℃ |

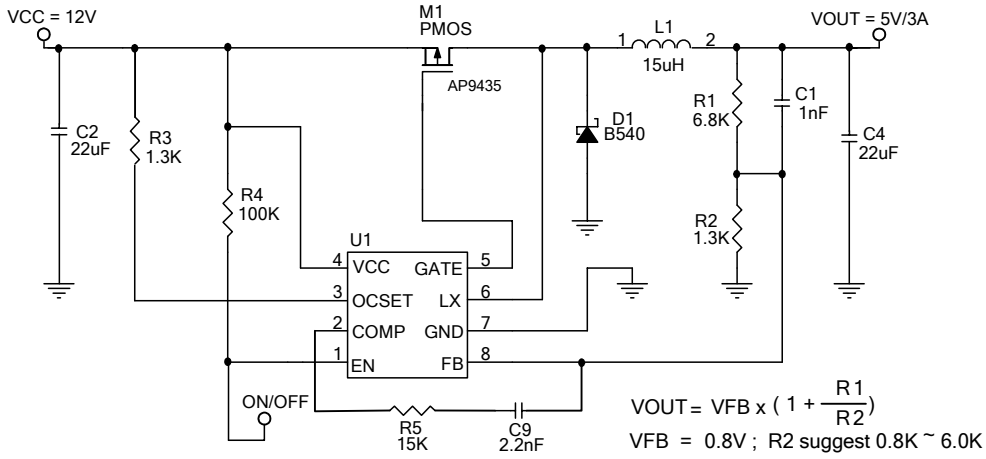
## ❖ Application Circuit

### A. AL CAP




| Compensation Capacitor Selection(AL CAP) | | | | |
|---|---|---|---|---|
| VIN | $V_{OUT}$ | R5 | C9 | C1 |
| 5-16V | 5/3.3/2.5/1.8V | 3.9K | 10nF | 1nF |

### B. MLCC




| Compensation Capacitor Selection(MLCC) | | | | |
|---|---|---|---|---|
| VIN | $V_{OUT}$ | R5 | C9 | C1 |
| 12V | 5.0/ 3.3/2.5V | 15K | 2200pF | 1nF |
| 12V | 1.8V | 10K | 2200pF | 1nF |
| 5V | 3.3/2.5/1.8V | 15K | 2200pF | 1nF |

## ❖ Function Descriptions

### PWM Control

The AX3301 integrates Pulse-Width-Modulation (PWM) control circuit into a single chip. The pulse width varies in a range from 0 to 100%, according to the load current. The ripple voltage produced by the switching can easily be removed through a filter because the switching frequency remains constant. Therefore, these controllers provide a low-ripple power over broad ranges of input voltage and load current.

### RDS(ON) Current Limiting

The current limit threshold is setting by the external resistor (R3) connecting from $V_{CC}$ supply to OCSET pin. The internal 110uA sink current crossing the resistor sets the voltage at pin of OCSET. When the PWM voltage is less than the voltage at OCSET, an over-current condition is triggered. Please refer to the formula for setting the current limit value

$$I_{SW(MAX)} = \frac{I_{OCSET} \times R3 + 0.075}{R_{DS(ON)}}$$

(Normally, The $I_{SW(MAX)}$ setting more than $I_{OUT}$ 0.5~1.0A ).

Example:

$I_{SW}$ = (110uA * 1.3k + 0.075)/ 50mΩ (AP9435GM SPEC) = 4.36A

### Setting the Output Voltage

Application circuit item shows the basic application circuit with AX3301 adjustable output version. The external resistor sets the output voltage according to the following equation:

$$V_{OUT} = 0.8V \times \left(1 + \frac{R1}{R2}\right)$$

Table 1 Resistor select for output voltage setting

| $V_{OUT}$ | R2 | R1 |
|---|---|---|
| 5V | 1.3K | 6.8K |
| | 5.6K | 30K |
| 3.3V | 1.5K | 4.7K |
| | 5.6K | 18K |
| 2.5V | 2.2K | 4.7K |
| | 5.6K | 12K |
| 1.8V | 1.2K | 1.5K |
| 1.5V | 2.2K | 2.0K |

## Inductor Selection

For most designs, Low inductance values are physically smaller but require faster switching, which results in some efficiency loss. The inductor value can be derived from the following equation:

$$L = \frac{V_{OUT} \times (V_{IN} - V_{OUT})}{V_{IN} \times \Delta I_L \times f_{LX}}$$

Where is inductor Ripple Current. Large value inductors lower ripple current and small value inductors result in high ripple currents. Choose inductor ripple current approximately 15% of the maximum input current 3A, $\Delta I_L$=0.45A.

Table 2 Inductor select for output voltage setting (AX3301 at $V_{CC}$=12V)

| $V_{OUT}$ | 2.5V | 3.3V | 5V | 3.3V(5A) | 5V(5A) |
|---|---|---|---|---|---|
| L1 Value | 15uH | 18uH | 22uH | 12uH | 15uH |

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 (3A+0.3A).

## Input Capacitor Selection

(EL CAP)

This capacitor should be located close to the IC using short leads and the voltage rating should be approximately 1.5 times the maximum input voltage. The RMS current rating requirement for the input capacitor of a buck regulator is approximately 1⁄2 the DC load current. A low ESR input capacitor sized for maximum RMS current must be used. A 220µF low ESR capacitor for most applications is sufficient.

(MLCC CAP)

A 22µF MLCC capacitor for most applications is sufficient.

## Output Capacitor Selection

(EL CAP)

The output capacitor is required to filter the output and provide regulator loop stability. The important capacitor parameters are; the 100KHz Equivalent Series Resistance (ESR), the RMS ripples current rating, voltage rating, and capacitance value. For the output capacitor, the ESR value is the most important parameter. The ESR can be calculated from the following formula.

$$V_{RIPPLE} = \Delta I_L \times ESR$$ **= 0.4A x 110mΩ= 44mV**

An aluminum electrolytic capacitor's ESR value is related to the capacitance and its voltage rating. In most case, higher voltage electrolytic capacitors have lower ESR values. Most of the time, capacitors with much higher voltage ratings may be needed to provide the low ESR values required for low output ripple voltage. It is recommended to replace this low ESR capacitor by using a 330µF low ESR values < 110mΩ.

(MLCC CAP)
A 22µF MLCC capacitor for most applications is sufficient.

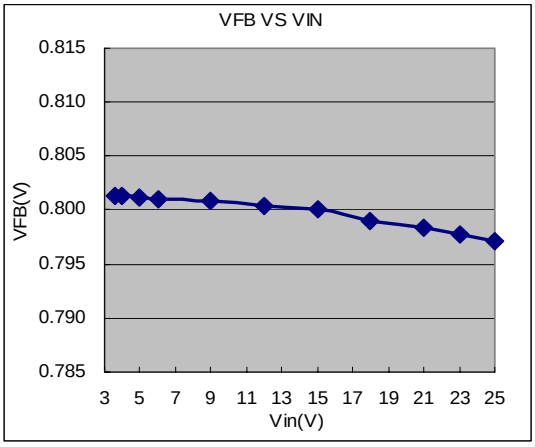
## Layout Guidance

When laying out the PC board, the following suggestions should be taken to ensure proper operation of the AX3301. These items are also illustrated graphically in below.

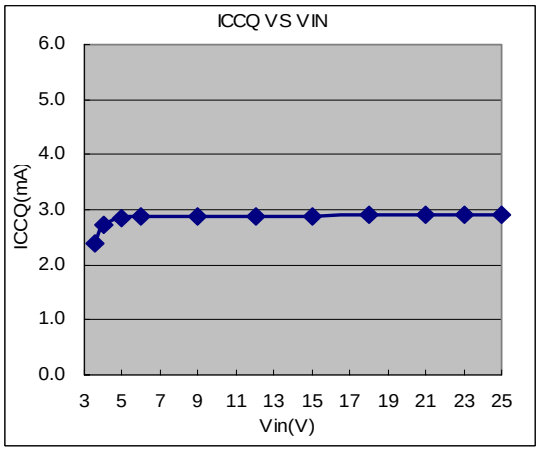
1. The power traces, including the PMOS Drain & Source trace, the Schottky and the C2 trace should be kept short, direct and wide to allow large current flow.
2. Keep the switching node, away from the sensitive FB node.
3. Connect ground side of the C2 & D1 as closely as possible.
4. Connect PMOS Source and R3 as closely as possible.
5. Do not trace signal line under inductor.

## ❖ Typical Characteristics

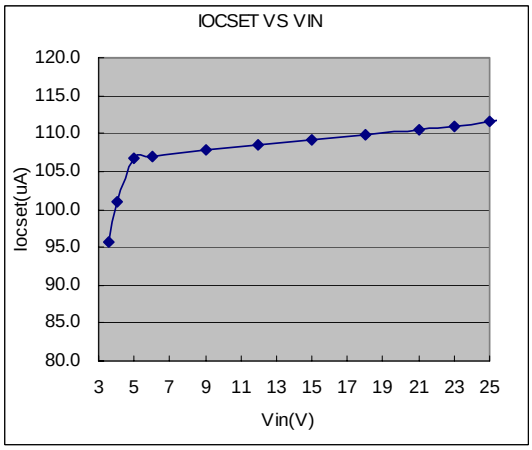
### VFB VS VIN



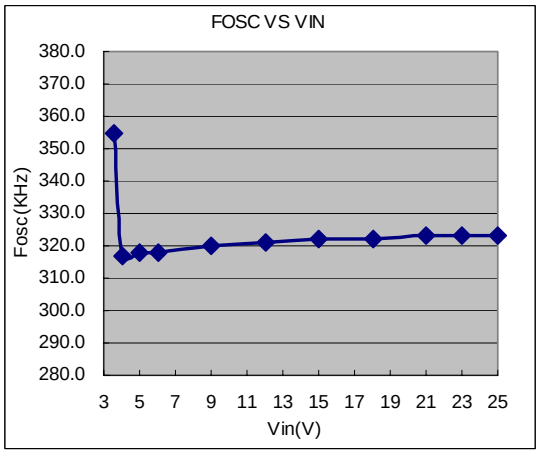

### ICCQ VS VIN



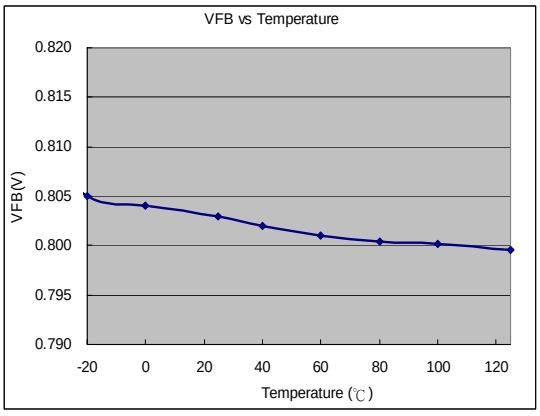

### IOCSET VS VIN



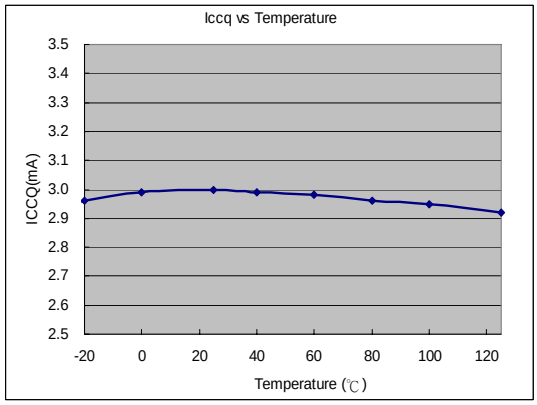

### FOSC VS VIN




### VFB VS TEMPERATURE

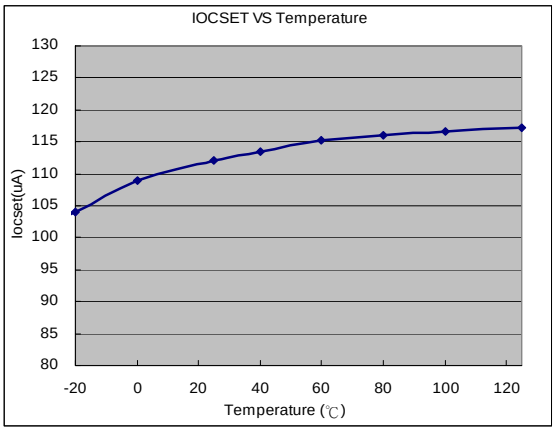



### ICCQ VS TEMPERATURE

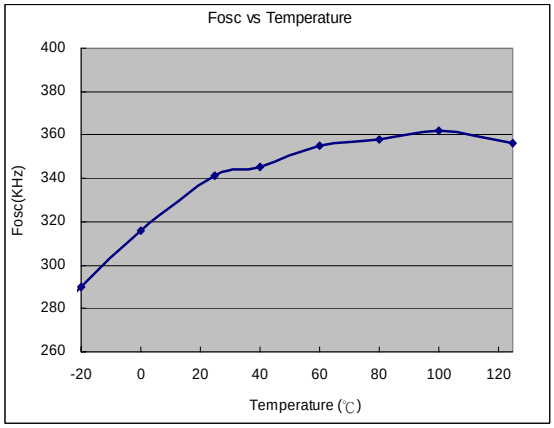


## ❖ Typical Characteristics

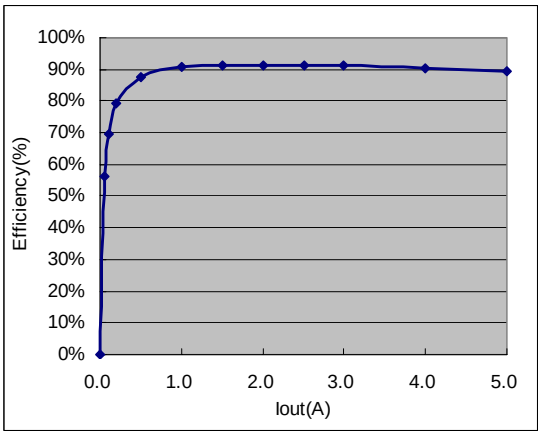
### IOCSET VS TEMPERATURE



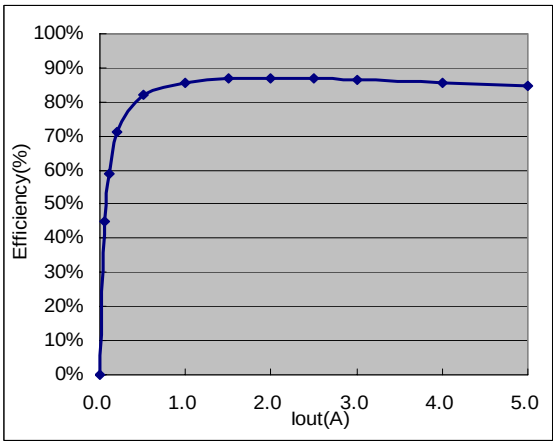

### FOSC VS TEMPERATURE




### Efficiency ($V_{IN}$=12V, $V_{OUT}$=5V)



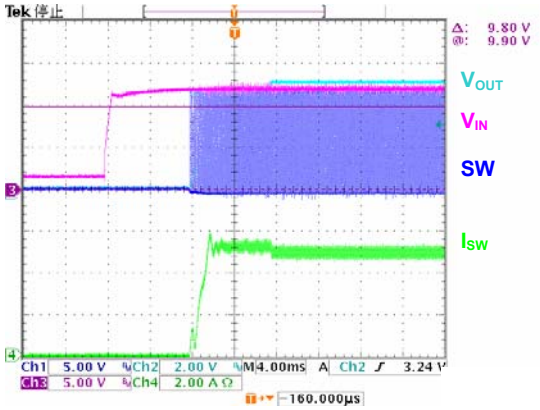

### Efficiency ($V_{IN}$=12V, $V_{OUT}$=3.3V)



## ❖ Typical Characteristics (Typical circuit )

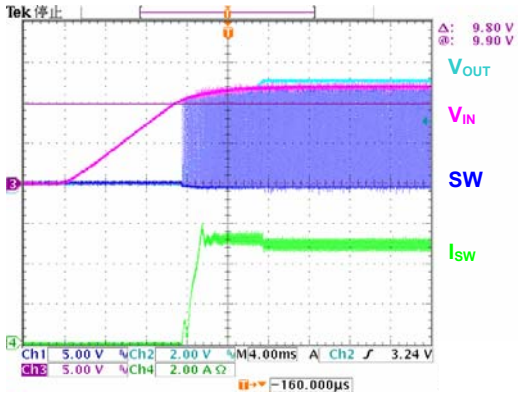
**EN PIN on test wave**

**($V_{IN}$=12V, $V_{OUT}$=5V, $I_{OUT}$=5A)**



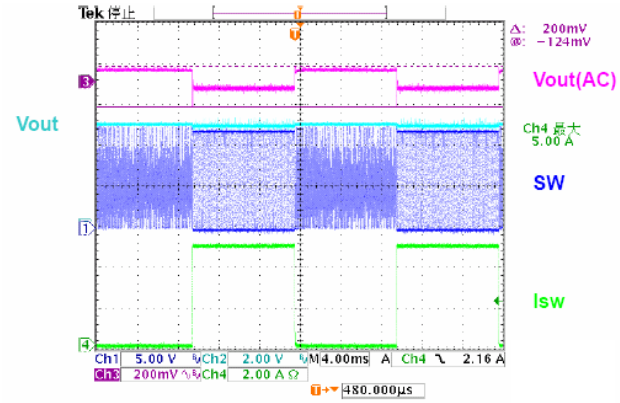

**Power on test wave**

**($V_{IN}$=12V, $V_{OUT}$=5V, $I_{OUT}$=5A)**



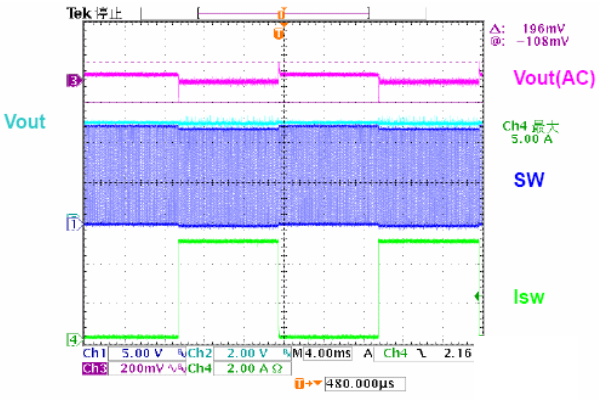

**Load transient Response 0A to 5A**

**($V_{IN}$=12V, $V_{OUT}$=5V)**



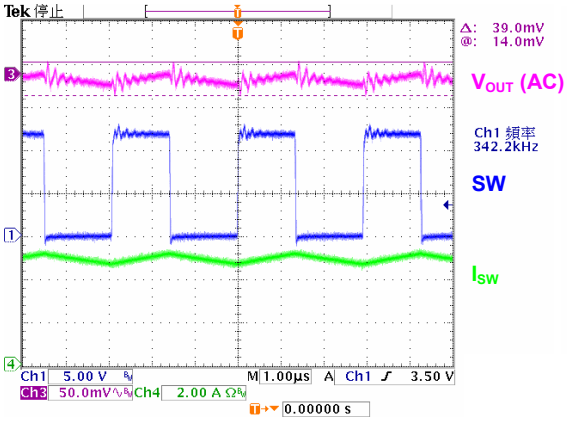

**Load transient Response 0.2A to 5A**

**($V_{IN}$=12V, $V_{OUT}$=5V)**



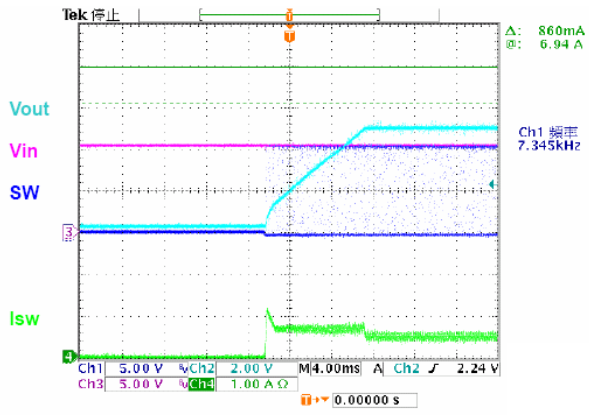

**Output Ripple**

**($V_{IN}$=12V, $V_{OUT}$=5V, $I_{OUT}$=5A)**

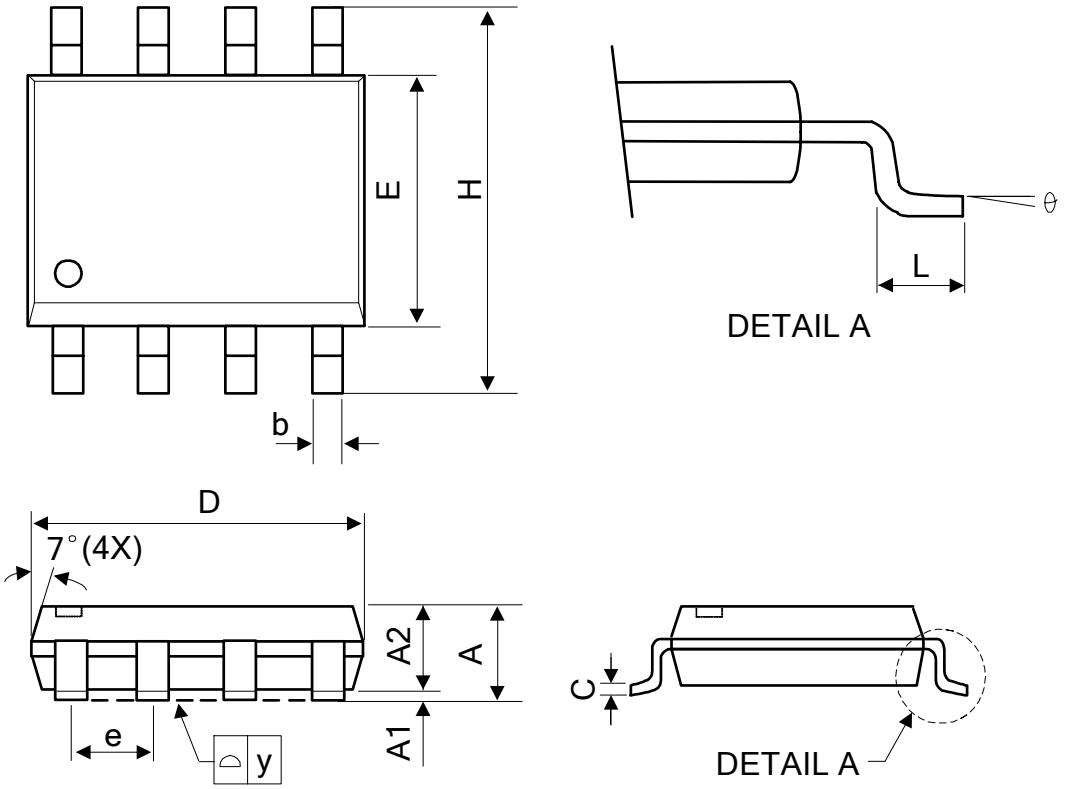



**Start-Up from Thermal Shutdown**

**($V_{IN}$=12V, $V_{OUT}$=5V, $I_{OUT}$=1A )**

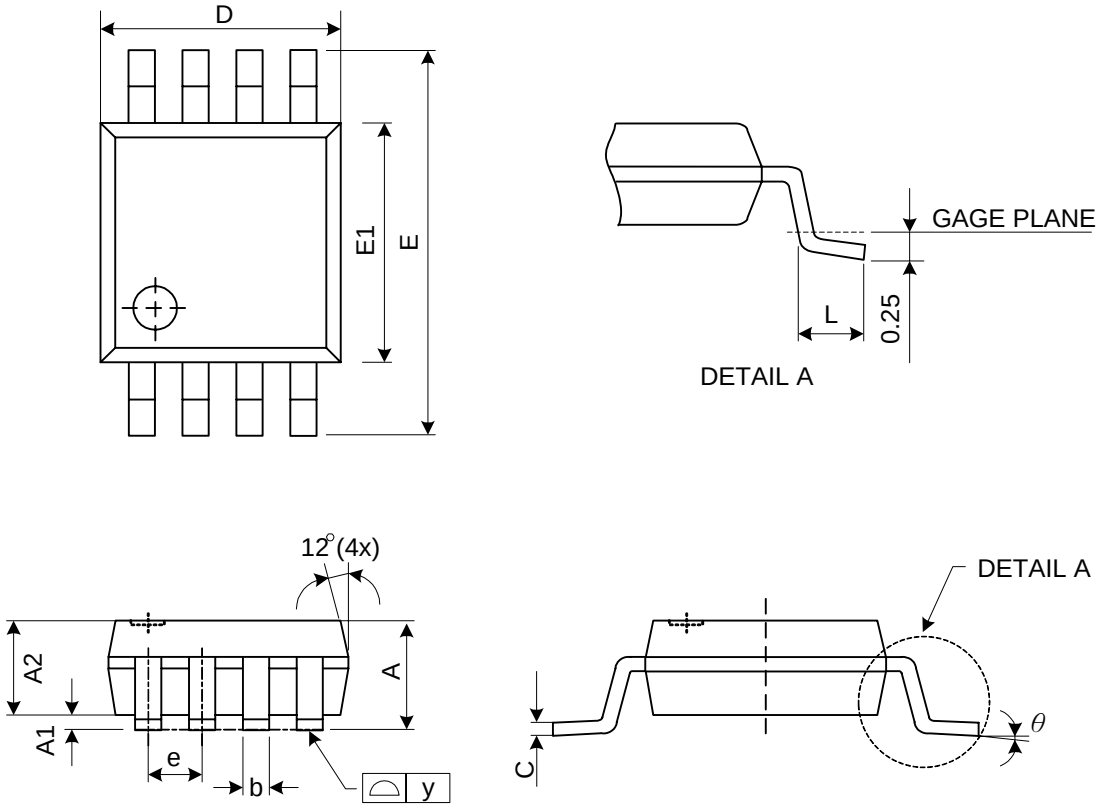


## ❖ Package Outlines (SOP-8L)




| Symbol | Dimensions In Millimeters | | | Dimensions In Inches | | |
|---|---|---|---|---|---|---|
| | Min. | Nom. | Max. | Min. | Nom. | Max. |
| A | 1.40 | 1.60 | 1.75 | 0.055 | 0.063 | 0.069 |
| A1 | 0.10 | - | 0.25 | 0.040 | - | 0.100 |
| A2 | 1.30 | 1.45 | 1.50 | 0.051 | 0.057 | 0.059 |
| C | 0.19 | 0.20 | 0.25 | 0.0075 | 0.008 | 0.010 |
| D | 4.80 | 4.90 | 5.00 | 0.189 | 0.193 | 0.197 |
| E | 3.80 | 3.90 | 4.00 | 0.150 | 0.154 | 0.157 |
| H | 5.79 | 5.99 | 6.20 | 0.228 | 0.236 | 0.244 |
| L | 0.38 | 0.71 | 1.27 | 0.015 | 0.028 | 0.050 |
| b | 0.33 | 0.41 | 0.51 | 0.013 | 0.016 | 0.020 |
| e | 1.27 TYP | | | 0.050 TYP | | |
| y | - | - | 0.10 | - | - | 0.004 |
| θ | 0° | - | 8° | 0° | - | 8° |

## ❖ Package Outlines (MSOP-8L)




| Symbol | Dimensions In Millimeters | | | Dimensions In Inches | | |
|---|---|---|---|---|---|---|
| | Min. | Nom. | Max. | Min. | Nom. | Max. |
| A | 0.81 | 0.96 | 1.12 | 0.032 | 0.038 | 0.044 |
| A1 | 0.05 | - | 0.15 | 0.002 | - | 0.006 |
| A2 | 0.76 | 0.86 | 0.97 | 0.030 | 0.034 | 0.038 |
| b | 0.28 | 0.30 | 0.38 | 0.011 | 0.012 | 0.015 |
| C | 0.13 | 0.15 | 0.23 | 0.005 | 0.006 | 0.009 |
| D | 2.90 | 3.00 | 3.10 | 0.114 | 0.118 | 0.122 |
| E | 4.80 | 4.90 | 5.00 | 0.189 | 0.193 | 0.197 |
| E1 | 2.90 | 3.00 | 3.10 | 0.114 | 0.118 | 0.122 |
| e | - | 0.65 | - | - | 0.0256 | - |
| L | 0.40 | 0.6 | 0.8 | 0.016 | 0.023 | 0.032 |
| y | - | - | 0.076 | - | - | 0.003 |
| θ | 0° | 3° | 6° | 0° | 3° | 6° |