

### Description

The AP5101 is a current mode step-down converter with a built-in power MOSFET to enable smallest solution size power conversion.

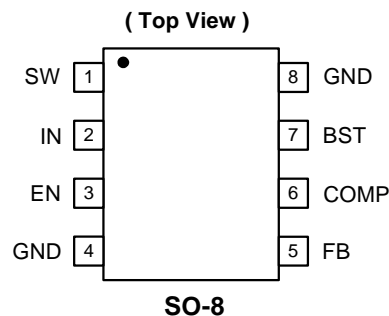
With the low series resistance power switch it enables a constant output current of up to 1.5A over a wide input supply range. The load and line regulation has excellent response time over the operating input voltage and temperature range.

The AP5101 is self protected, through a cycle-by-cycle current limiting algorithm and an on chip thermal protection.

The AP5101 will provide the voltage conversion with a low count of widely available standard external components.

The AP5101 is available in SO-8 package.

### Pin Assignments



### Features

- $V_{IN}$  4.75 to 22V
- 1.5A Peak Output Current
- Stable with Low ESR Ceramic Output Capacitors
- External compensation
- Up to 92% Efficiency
- 0.1 $\mu$ A Shutdown Mode
- Fixed 1.4MHz Frequency
- Thermal Shutdown
- Cycle-by-Cycle Over Current Protection
- Output Adjustable from 0.81V to 15V
- SO-8: Available in "Green" Molding Compound (No Br, Sb)
- Lead Free Finish/ RoHS Compliant (Note 1)

### Applications

- Distributed Power Systems
- Battery Charger
- Pre-Regulator for Linear Regulators
- WLED Driver

Note: 1. EU Directive 2002/95/EC (RoHS). All applicable RoHS exemptions applied. Please visit our website at [http://www.diodes.com/products/lead\\_free.html](http://www.diodes.com/products/lead_free.html).

### Typical Application Circuit

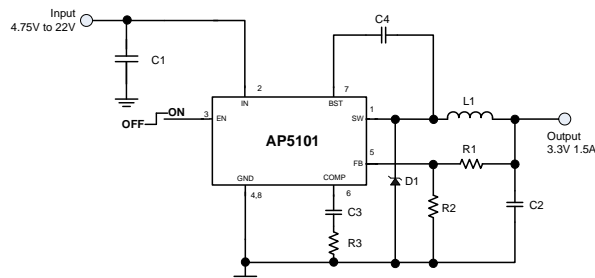
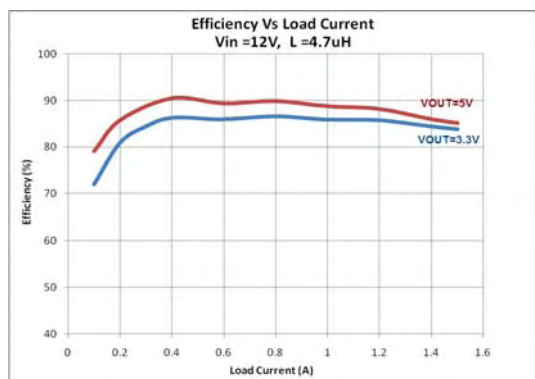
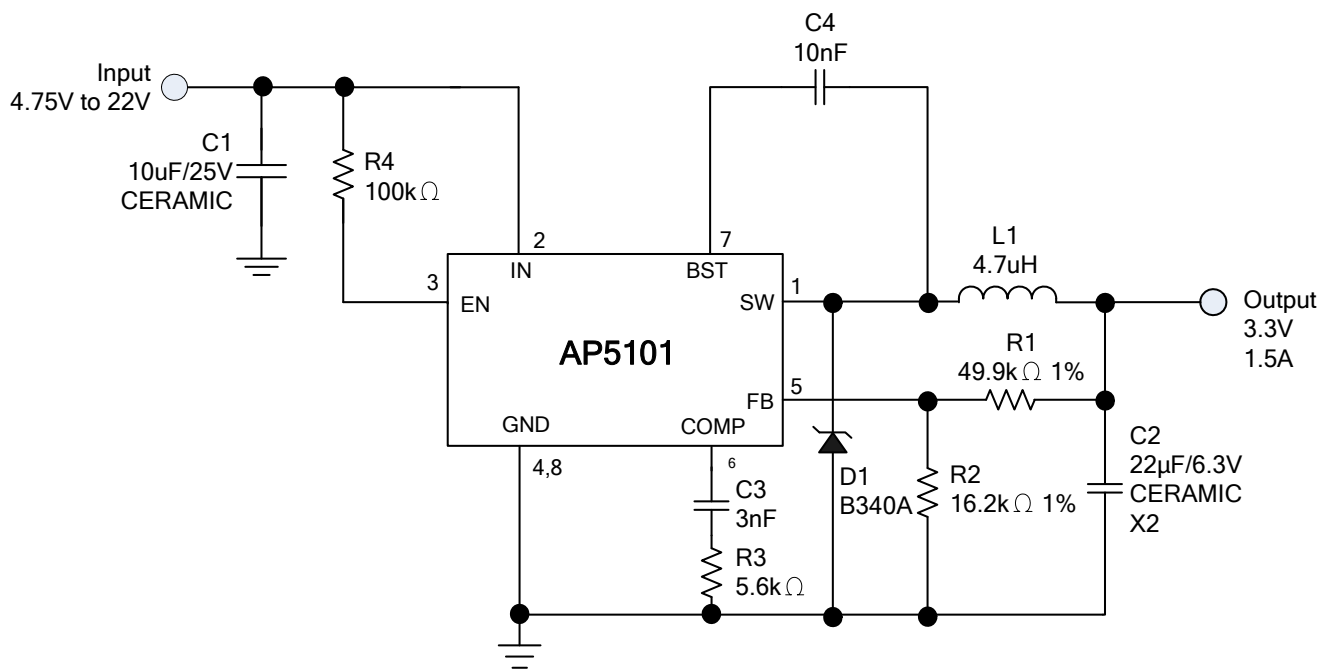


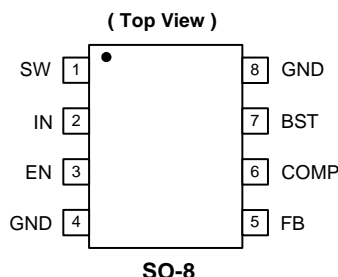
Figure 1 Typical Application Circuit

**Typical Application Circuit (continued)**



**Figure 2. 1.4MHz, 3.3V Output at 1.5A Step-Down Converter**

## Pin Descriptions



Pin Name	Pin Number	Descriptions
SW	1	Switch Output. This is the reference for the floating top gate driver.
IN	2	Supply Voltage. The AP5101 operates from a +4.75V to +22V unregulated input. A decoupling capacitor C1 is required to prevent large voltage spikes from appearing at the input. Place this capacitor near the IC.
EN	3	On/Off Control Input. Do not leave this pin floating. To turn the device ON, pull EN above 1.2V and to turn it off pull below 0.4V. If enable/disable is not used, connect a 100kΩ resistor between EN to V <sub>IN</sub> .
GND	4	Ground. This pin is the voltage reference for the regulated output voltage. For this reason care must be taken in its layout. This node should be placed outside of the D1 to C1 ground path to prevent switching current spikes from inducing voltage noise into the part.
FB	5	Feedback. To set the output voltage, connect this pin to the output resistor divider or directly to V <sub>OUT</sub> . To prevent current limit run away during a current limit condition, the frequency foldback comparator lowers the oscillator frequency when the FB voltage is below 400mV.
COMP	6	Compensation. COMP is used to compensate the regulation control loop. Connect a series RC network from COMP to GND.
BST	7	Bootstrap. To form a boost circuit, a capacitor is connected between SW and BST pins to form a floating supply across the power switch driver. This capacitor is needed to drive the power switch's gate above the supply voltage. Typical values for C <sub>BST</sub> range from 0.1μF to 1μF.
GND	8	Ground. This pin is the voltage reference for the regulated output voltage. All control circuits are referenced to this pin. For this reason care must be taken in its layout.

### Absolute Maximum Ratings (Note 2)

Symbol	Parameter	Rating	Unit
$V_{IN}$	Supply Voltage	26	V
$V_{SW}$	Switch Voltage	$-0.3$ to $V_{IN} + 0.3$	V
$V_{BS}$	Boost Voltage	$V_{SW} + 6$	V
	All Other Pins	$-0.3$ to $+6$	V
$T_{ST}$	Storage Temperature	$-65$ to $+150$	°C
$T_J$	Junction Temperature	$+150$	°C
$T_L$	Lead Temperature	$+260$	°C
<b>ESD Susceptibility</b>			
HBM	Human Body Model	2	kV
MM	Machine Model	200	V

Note: 2. Exceeding these ratings may damage the device.

### Thermal Resistance (Note 3)

Symbol	Parameter	Rating	Unit
$\theta_{JA}$	Junction to Ambient	120	°C/W
$\theta_{JC}$	Junction to Case	15	°C/W

Note: 3. Test condition for SO-8: Measured on approximately 1" square of 1 oz copper.

### Recommended Operating Conditions (Note 4)

Symbol	Parameter	Min	Max	Unit
$V_{IN}$	Supply Voltage	4.75	22	V
$T_A$	Operating Ambient Temperature Range	-40	+85	°C
$V_{OUT}$	Output Voltage	0.81	15	V

Note: 4. The device function is not guaranteed outside of the recommended operating conditions.

### Electrical Characteristics ( $V_{IN} = 12V$ , $T_A = +25^\circ C$ , unless otherwise noted)

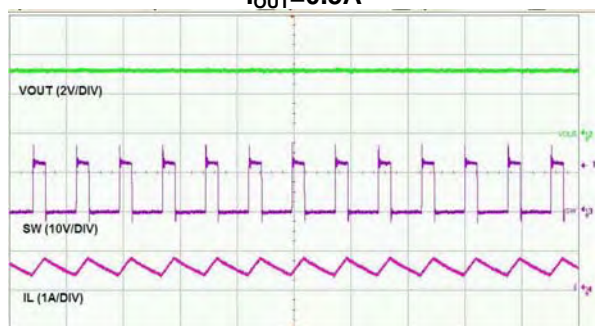
Symbol	Parameter	Test Conditions	Min	Typ.	Max	Unit
$V_{FB}$	Feedback Voltage	$4.75V \leq V_{IN} \leq 22V$	0.790	0.810	0.830	V
$I_{FB}$	Feedback Current	$V_{FB} = 0.8V$		0.1		$\mu A$
$R_{DS(ON)}$	Switch-On Resistance (Note 5)			0.35		$\Omega$
	Switch Leakage	$V_{EN} = 0V$ , $V_{SW} = 0V$			10	$\mu A$
	Current Limit (Note 5)			2.5		A
$G_{CS}$	Current Sense Transconductance Output Current to Comp Pin Voltage			1.3		A/V
$A_{VEA}$	Error Amplifier Voltage Gain (Note 5)			400		V/V
$G_{EA}$	Error Amplifier Transconductance	$\Delta IC = \pm 10\mu A$		850		$\mu A/V$
$f_{SW}$	Oscillator Frequency	$V_{FB} = 0.6V$	1.1	1.4	1.7	MHz
	Fold-back Frequency	$V_{FB} = 0V$		500		kHz
	Maximum Duty Cycle	$V_{FB} = 0.6V$		65		%
$t_{ON}$	Minimum On-Time (Note 5)			100		ns
	Under Voltage Lockout Threshold Rising		3.8	4.0	4.2	V
	Under Voltage Lockout Threshold Hysteresis			100		mV
	EN Input Low Voltage				0.4	V
	EN Input High Voltage		1.2			V
	EN Input Current	$V_{EN} = 2V$		2.1		$\mu A$
		$V_{EN} = 0V$		0.1		$\mu A$
$I_S$	Supply Current (Shutdown)	$V_{EN} = 0V$		0.1	1.0	$\mu A$
$I_Q$	Supply Current (Quiescent)	$V_{EN} = 2V$ , $V_{FB} = 1V$		0.5	0.7	mA
	Thermal Shutdown (Note 5)			150		$^\circ C$

Note: 5. Guaranteed by design

**Typical Performance Characteristics**

$V_{IN}=12V$ ,  $V_{OUT}=3.3V$ ,  $L=4.7\mu H$ ,  $C1=10\mu F$ ,  $C2=22\mu F$ ,  $T_a=+25^{\circ}C$ , unless otherwise noted.

**Steady State Test**  
 $I_{OUT}=0.5A$



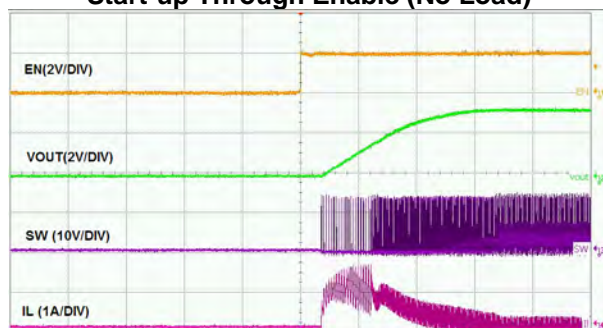
Time- 1us/div

**Load Transient Test**  
 $I_{OUT}=0.2A$  to  $0.8A$ . Step at  $0.8A/\mu s$



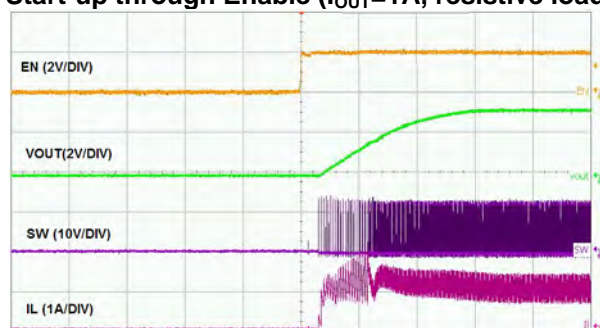
Time- 100us/div

**Start-up Through Enable (No Load)**



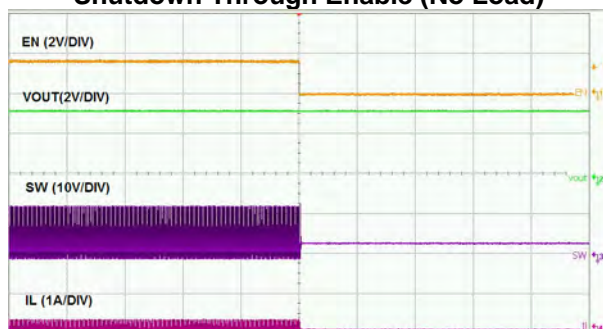
Time- 50us/div

**Start-up through Enable ( $I_{OUT}=1A$ , resistive load)**



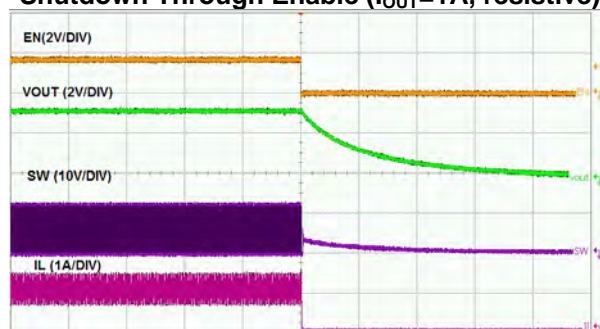
Time- 50us/div

**Shutdown Through Enable (No Load)**



Time- 50us/div

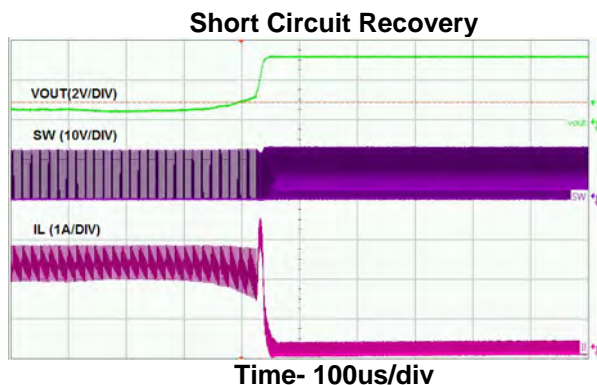
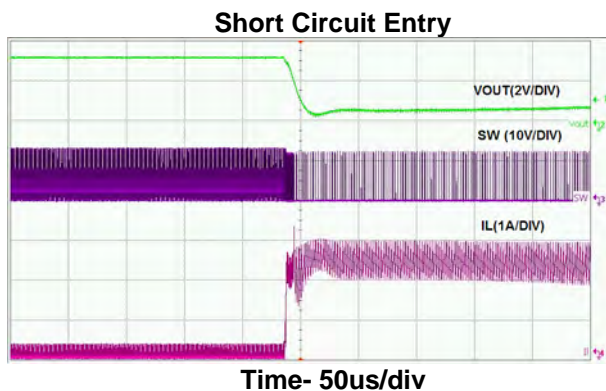
**Shutdown Through Enable ( $I_{OUT}=1A$ , resistive)**



Time- 50us/div

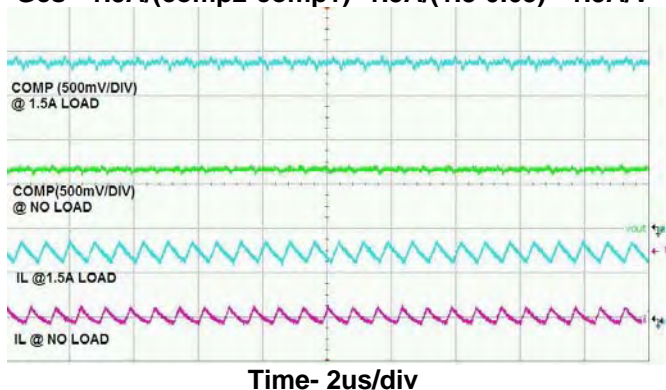
**Typical Performance Characteristics (continued)**

$V_{IN} = 12V$ ,  $V_{OUT} = 3.3V$ ,  $L = 4.7\mu H$ ,  $C1 = 10\mu F$ ,  $C2 = 22\mu F$ ,  $T_a = +25^\circ C$ , unless otherwise noted.



**Current Sense Transconductance (Gcs)**

$$G_{cs} = 1.5A / (comp2 - comp1) = 1.5A / (1.8 - 0.65) = 1.3A/V$$





## Applications Information

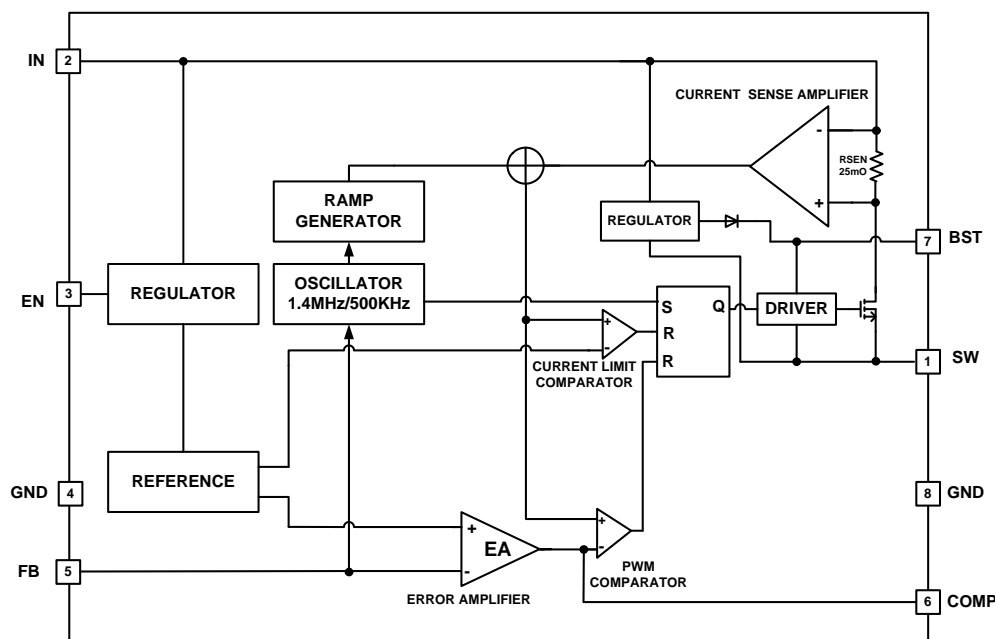
### Operation

The AP5101 is a current mode control, asynchronous buck regulator. Current mode control assures excellent line and load regulation and a wide loop bandwidth for fast response to load transients. Figure 3 depicts the functional block diagram of AP5101.

The operation of one switching can be explained as follows. At the beginning of each cycle, HS (high-side) MOSFET is off. The EA output voltage is higher than the current sense amplifier output, and the current comparator's output is low. The rising edge of the 1.4MHz oscillator clock signal sets the RS Flip-Flop. Its output turns on HS MOSFET.

When the HS MOSFET is on, inductor current starts to increase. The Current Sense Amplifier senses and amplifies the inductor current. Since the current mode control is subject to sub-harmonic oscillations that peak at half the switching frequency, Ramp slope compensation is utilized. This will help to stabilize the power supply. This Ramp compensation is summed to the Current Sense Amplifier output and compared to the Error Amplifier output by the PWM Comparator. When the sum of the Current Sense Amplifier output and the Slope Compensation signal exceeds the EA output voltage, the RS Flip-Flop is reset and HS MOSFET is turned off. The external Schottky rectifier diode (D1) conducts the inductor current.

For one whole switching cycle, if the sum of the Current Sense Amplifier output and the Slope Compensation signal does not exceed the EA output, then the falling edge of the oscillator clock resets the Flip-Flop. The output of the Error Amplifier increases when feedback voltage ( $V_{FB}$ ) is lower than the reference voltage of 0.81V. This also increases the inductor current as it is proportional to the EA voltage.



**Figure 3. Functional Block Diagram**



## Applications Information (Continued)

### Component Selection

The output voltage can be adjusted from 0.81V to 15V using an external resistor divider. Table 1 shows a list of resistor selection for common output voltages. Resistor R1 is selected based on a design tradeoff between efficiency and output voltage accuracy. For high values of R1 there is less current consumption in the feedback network. However the trade off is output voltage accuracy due to the bias current in the error amplifier. R2 can be determined by the following equation:

$$R_1 = R_2 \times \left( \frac{V_{OUT}}{0.81} - 1 \right)$$

V <sub>OUT</sub> (V)	R <sub>1</sub> (kΩ)	R <sub>2</sub> (kΩ)
1.8	80.6 (1%)	64.9 (1%)
2.5	49.9 (1%)	23.7 (1%)
3.3	49.9 (1%)	16.2 (1%)
5.0	49.9 (1%)	9.53 (1%)

Table 1. Resistor Selection for Common Output Voltage

### Compensation Components

The AP5101 has an external COMP pin through which system stability and transient response can be controlled. COMP pin is the output of the internal trans-conductance error amplifier. A series capacitor-resistor combination sets a pole-zero combination to control the characteristics of the control system. The DC gain of the voltage feedback loop is given by:

$$A_{VDC} = R_{LOAD} \times G_{CS} \times A_{VEA} \times \frac{V_{FB}}{V_{OUT}}$$

Where V<sub>FB</sub> is the feedback voltage (0.810V), R<sub>LOAD</sub> is the load resistor value, G<sub>CS</sub> is the current sense trans-conductance and A<sub>VEA</sub> is the error amplifier voltage gain.

The control loop transfer function incorporates two poles. One is due to the compensation capacitor (C3) and the output resistor of error amplifier, and the other is due to the output capacitor and the load resistor. These poles are located at:

$$f_{P1} = \frac{G_{EA}}{2\pi \times C3 \times A_{VEA}}$$

$$f_{P2} = \frac{1}{2\pi \times C2 \times R_{LOAD}}$$

Where G<sub>EA</sub> is the error amplifier trans-conductance.

One zero is present due to the compensation capacitor (C3) and the compensation resistor (R3). This zero is located at:

$$f_{Z1} = \frac{1}{2\pi \times C3 \times R3}$$

### Applications Information (Continued)

The goal of compensation design is to shape the converter transfer function to get a desired loop gain. The system crossover frequency where the feedback loop has the unity gain is crucial.

A rule of thumb is to set the crossover frequency to below one-tenth of the switching frequency. Use the following procedure to optimize the compensation components:

1. Choose the compensation resistor (R3) to set the desired crossover frequency. Determine the R3 value by the following equation:

$$R3 = \frac{2\pi \times C2 \times fc}{G_{EA} \times G_{CS}} \times \frac{V_{OUT}}{V_{FB}} < \frac{2\pi \times C2 \times 0.1 \times fs}{G_{EA} \times G_{CS}} \times \frac{V_{OUT}}{V_{FB}}$$

Where  $f_c$  is the crossover frequency, which is typically less than one-tenth of the switching frequency.

2. Choose the compensation capacitor (C3) to achieve the desired phase margin. Set the compensation zero,  $f_{z1}$ , to below one-fourth of the crossover frequency to provide sufficient phase margin. Determine the C3 value by the following equation:

$$C3 > \frac{2}{\pi \times R3 \times fc}$$

Where R3 is the compensation resistor value.

#### Inductor

Calculating the inductor value is a critical factor in designing a buck converter. For most designs, the following equation can be used to calculate the inductor value;

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

Where  $\Delta I_L$  is the inductor ripple current.

And  $f_{SW}$  is the buck converter switching frequency.

Choose the inductor ripple current to be 30% of the maximum load current. The maximum inductor peak current is calculated from:

$$I_L(MAX) = I_{LOAD} + \frac{\Delta I_L}{2}$$

Peak current determines the required saturation current rating, which influences the size of the inductor. Saturating the inductor decreases the converter efficiency while increasing the temperatures of the inductor, the MOSFET and the diode. Hence choosing an inductor with appropriate saturation current rating is important.

A 1μH to 10μH inductor with a DC current rating of at least 25% percent higher than the maximum load current is recommended for most applications.

For highest efficiency, the inductor's DC resistance should be less than 200mΩ. Use a larger inductance for improved efficiency under light load conditions.

### Applications Information (Continued)

#### Input Capacitor

The input capacitor reduces the surge current drawn from the input supply and the switching noise from the device. The input capacitor has to sustain the ripple current produced during the on time on the upper MOSFET. It must hence have a low ESR to minimize the losses.

Due to large  $di/dt$  through the input capacitors, electrolytic or ceramics should be used. If a tantalum must be used, it must be surge protected. Otherwise, capacitor failure could occur. For most applications, a 4.7 $\mu$ F ceramic capacitor is sufficient.

#### Output Capacitor

The output capacitor keeps the output voltage ripple small, ensures feedback loop stability and reduces the overshoot of the output voltage. The output capacitor is a basic component for the fast response of the power supply. In fact, during load transient, for the first few microseconds it supplies the current to the load.

The converter recognizes the load transient and sets the duty cycle to maximum, but the current slope is limited by the inductor value.

Maximum capacitance required can be calculated from the following equation:

$$C_o = \frac{L(I_{out} + \frac{\Delta I_{inductor}}{2})^2}{(\Delta V + V_{out})^2 - V_{out}^2}$$

Where  $\Delta V$  is the maximum output voltage overshoot.

ESR of the output capacitor dominates the output voltage ripple. The amount of ripple can be calculated from the equation below:

$$V_{out\text{capacitor}} = \Delta I_{inductor} \times ESR$$

An output capacitor with ample capacitance and low ESR is the best option. For most applications, a 22 $\mu$ F ceramic capacitor will be sufficient.

#### External Diode

The external diode's forward current must not exceed the maximum output current. Since power dissipation is a critical factor when choosing a diode, it can be calculated from the equation below:

$$P_{diode} = (1 - \frac{V_{OUT}}{V_{IN}}) \times I_{OUT} \times 0.3V$$

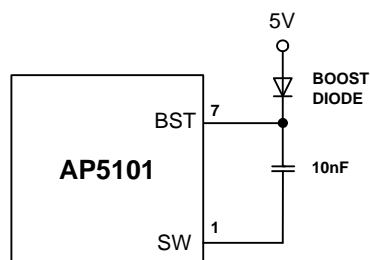
Note: 0.3V is the voltage drop across the Schottky diode. A diode that can withstand this power dissipation must be chosen.

#### PC Board Layout

This is a high switching frequency converter. Hence attention must be paid to the switching currents interference in the layout. Switching current from one power device to another can generate voltage transients across the impedances of the interconnecting bond wires and circuit traces. These interconnecting impedances should be minimized by using wide, short printed circuit traces. The input capacitor needs to be as close as possible to the IN and GND pins. The external feedback resistors should be placed next to the FB pin.

**Applications Information (Continued)**
**External Bootstrap Diode**

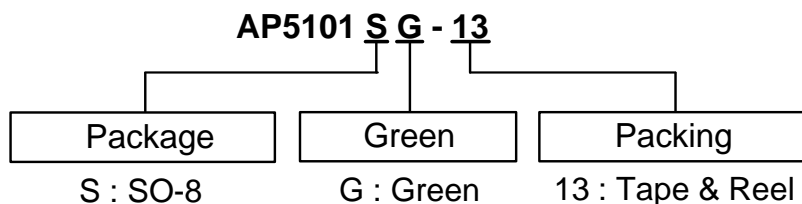
It is recommended that an external bootstrap diode be added when the input voltage is no greater than 5V or the 5V rail is available in the system. This helps improve the efficiency of the regulator. The bootstrap diode can be a low cost one such as IN4148 or BAT54.


**Figure 4. External Bootstrap Diode**

Manufacturer	Part Number	Inductance( $\mu$ H)	Max DCR ( $\Omega$ )	Current Rating (A)	Dimensions L x W x H (mm3)
Toko	A921CY-4R7M	4.7	0.027	1.66	6.0 x 6.3 x 3.0
Sumida	CDRH4D28C/LD	4.7	0.036	1.50	5.1 x 5.1 x 3.0
Würth Electronics	7440530047	4.7	0.038	2.00	5.8 x 5.8 x 2.8

**Table 2. Suggested Surface Mount Inductors**

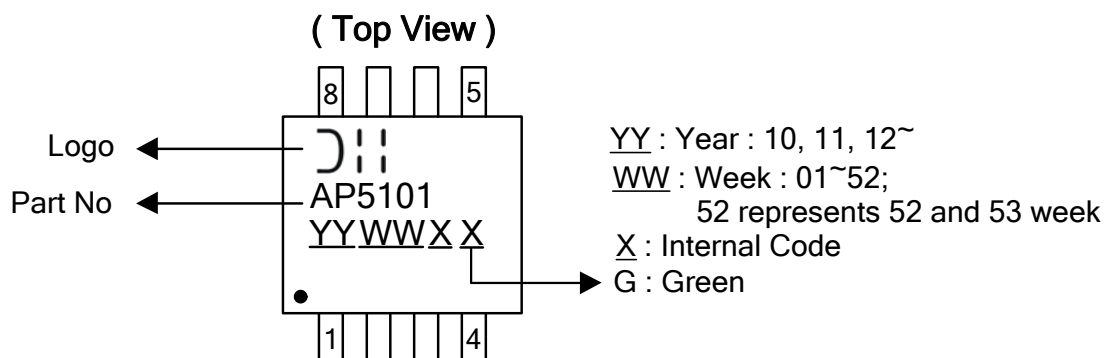
## Ordering Information



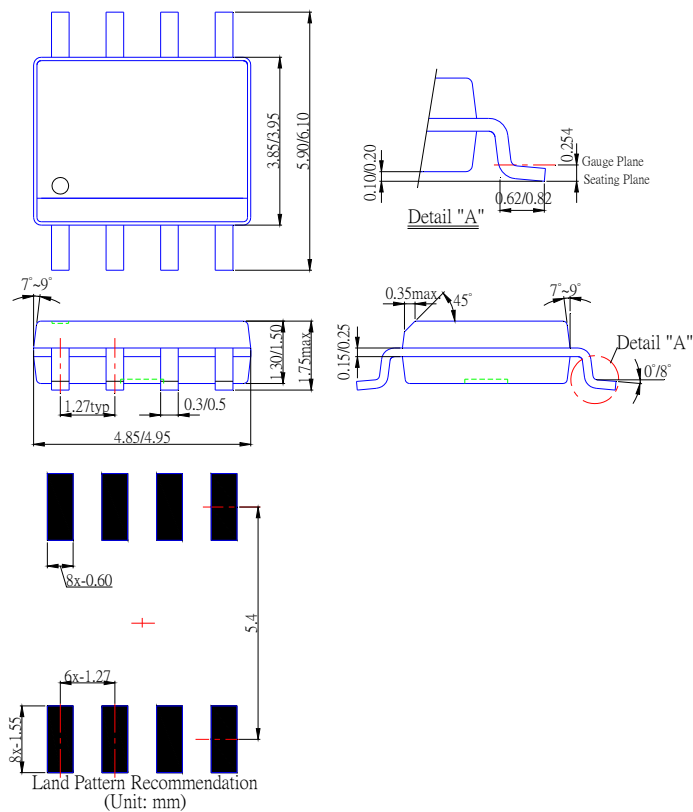
Device	Package Code	Packaging (Note 6)	13" Tape and Reel	
			Quantity	Part Number Suffix
AP5101SG-13	S	SO-8	2500/Tape & Reel	-13

Note: 6. Pad layout as shown on Diodes Inc. suggested pad layout document AP02001, which can be found on our website at <http://www.diodes.com/datasheets/ap02001.pdf>.

## Marking Information



**Package Outline Dimensions (All Dimensions in mm)**



## 1.5A Step-Down Converter with 1.4MHz Switching Frequency

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