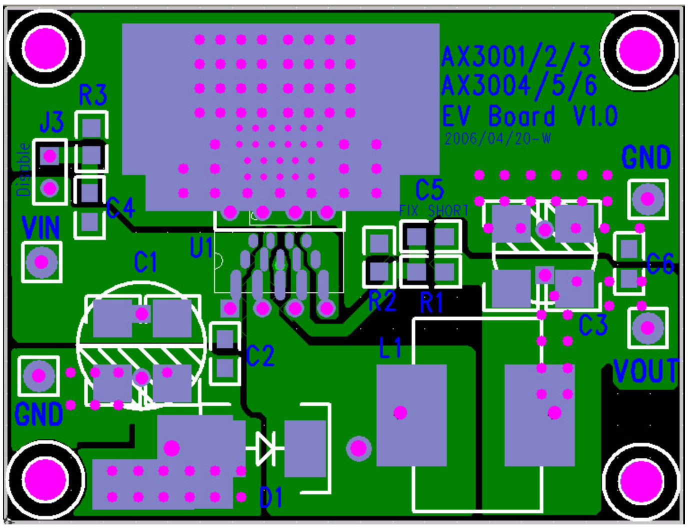
150KHz, 2A PWM Buck DC/DC Converter



1. AX3001 Specification

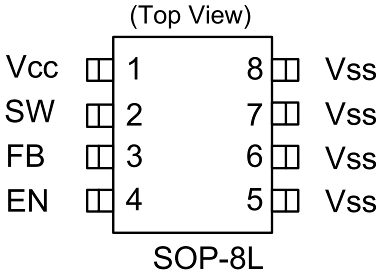
1.1 Features

- Output voltage: 3.3V, 5V, 12V and adjustable output version.
- Adjustable version output voltage range, 1.23V to 18V+4%.
- 150KHz +15% fixed switching frequency.
- Thermal-shutdown and current-limit protection.
- ON/OFF shutdown control input.
- Operating voltage can be up to 22V.
- Output load current: 2A.
- Short Circuit Protect (SCP).
- SOP-8L Pb-Free packages.
- Low power standby mode.
- Built-in switching transistor on chip.

1.2 General Descriptions

The AX3001 series are monolithic IC designed for a step-down DC/DC converter, and own the ability of driving a 2A load without additional transistor. It saves board space. The external shutdown function can be controlled by logic level and then come into standby mode. The internal compensation makes feedback control having good line and load regulation without external design. Regarding protected function, thermal shutdown is to prevent over temperature operating from damage, and current limit is against over current operating of the output switch. If current limit function occurs and V_{FB} is down below 0.5V, the switching frequency will be reduced. The AX3001 series operates at a switching frequency of 150KHz thus allow smaller sized filter components than what would be needed with lower frequency switching regulators. Other features include a guaranteed +4% tolerance on output voltage under specified input voltage and output load conditions, and +15% on the oscillator frequency. The output version included fixed 3.3V, 5V, 12V, and an adjustable type. The chips are available in a standard 8-lead SOP package.

1.3 Pin Assignment



1.4 Pin Descriptions

Name	Description
Vcc	Operating voltage input
SW	Switching output
FB	Output voltage feedback control
EN	ON/OFF Shutdown
Vss	GND pin

1.5 Absolute Maximum Ratings

Characteristics	Symbol	Rating	Unit
Maximum Supply Voltage	V_{CC}	+24	V
ON/OFF Pin Input Voltage	V_{EN}	-0.3 to +18	V
Feedback Pin Voltage	V_{FB}	-0.3 to +18	V
Output Voltage to Ground	V_{OUT}	-1	V
Power Dissipation Internally limited	PD	-	W
Storage Temperature Range	T_{ST}	-65 to +150	℃
Operating Temperature Range	T_{OP}	-40 to +125	℃
Operating Supply Voltage	V_{OP}	+4.5 to +22	V
Thermal Resistance from Junction to case	θ_{JC}	20	℃/W
Thermal Resistance from Junction to ambient	θ_{JA}	60	℃/W

Note : θ_{JA} is measured with the PCB copper area(need connect to V_{SS} pins) of approximately 1.5 in^2 (Multi-layer).

2. Design Procedure

2.1 Parameter statement

$V_{IN(\max)}$ = Maximum input Voltage

$V_{IN(\min)}$ = Minimum input Voltage

V_{OUT} = Regulated Output Voltage

V_{RIPPLE} = Ripple Voltage (peak to peak), typical value is 1% of the output voltage

$I_{LOAD(\max)}$ = Maximum Load Current

$I_{LOAD(\min)}$ = Minimum Load Current before the circuit becomes discontinuous, typical value is 10% of the maximum load current

F = Switching Frequency (Fixed at a nominal 150KHz)

2.2 Programming Output Voltage (Refer to Demo Board Schematic)

The output voltage is programmed by selection of the divider R1 and R2. Designer should use resistors R1 and R2 with ±1% tolerance in order to obtain best accuracy of output voltage. The output voltage can be calculated from the following formula.

Vout = 1.23 x (1 + R1 / R2)

Select a value for R2 between 470Ω and 2.6KΩ. The lower resistor values minimize noise pickup and high leakage current in the sensitive feedback pin. The Higher resistor values minimize leakage current pickup in the feedback pin.

If designer selects fixed output version of the AX3001, the feedback pin shall be short to the output voltage.

2.3 Compensation Capacitor Selection

The compensation capacitors for increasing phase margin provide additional stability. It is required if the duty less than 15%, Refer to Demo Board Schematic, The optimum values for C5 is 10nF.

2.4 Inductor Selection

A. The minimum inductor $L_{(\min)}$ can be calculated from the following design formula table.

Symbol	Calculation Formula
$D_{ON(\max)}$ (duty on)	$\frac{(V_{OUT}+V_F)}{V_{IN(\min)}-V_{SAT}+V_F}$
$\frac{T_{ON}}{T_{OFF}}$	$\frac{(V_{OUT}+V_F)}{V_{IN(\min)}-V_{SAT}-V_{OUT}}$
$L_{(\min)}$	$\frac{(V_{IN}-V_{OUT})\times V_{OUT}}{2\times F\times I_{LOAD(\min)}\times V_{IN}}$

V_{SAT} = Internal switch saturation voltage of the AX3001 = 1.25V

V_F = Forward voltage drop of output rectifier D1 = 0.5V

B. The inductor must be designed so that it does not saturate or significantly saturate at DC current bias of the I_{PK}. ($I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$ = Peak switch current of Inductor)

2.5 Output Capacitor Selection

A. The output capacitor is required to filter the output and provide regulator loop stability. When selecting an output capacitor, 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.

$$ESR = \left(\frac{V_{RIPPLE}}{2\times I_{LOAD(\min)}}\right) \quad \text{------------------------- (3)}$$

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. If the selected capacitor's ESR is extremely low, resulting in an oscillation at the output. It is recommended to replace this low ESR capacitor by using two general standard capacitors in parallel.

B. The capacitor voltage rating should be at least 1.5 times greater than the output voltage, and often much higher voltage ratings are needed to satisfy the low ESR requirements needed for low output ripple voltage.

2.6 Output Rectifier Selection

A. The output rectifier D1 current rating must be at least greater than the peak switch current IPK. The reverse voltage rating of the output rectifier D1 should be at least 1.25 times the maximum input voltage.

B. The output rectifier D1 must be fast (short reverse recovery time) and must be located close to the AX3001 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best performance and efficiency, and should be the first choice, especially in low output voltage applications.

2.7 Input Capacitor Selection

A. The RMS current rating of the input capacitor can be calculated from the following formula table. The capacitor manufacturer's data sheet must be checked to assure that this current rating is not exceeded.

Symbol	Calculation Formula
δ	*Ton/(Ton+Toff)*
I_{PK}	$I_{LOAD(\max)} + I_{LOAD(\min)}$
I_m	$I_{LOAD(\max)} - I_{LOAD(\min)}$
ΔI_L	$2 \times I_{LOAD(\min)}$
$I_{IN(rms)}$	$\cong \frac{1}{2} \times I_{LOAD(rms)}$

B. 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. In this example, with a 2A load, a capacitor with a RMS current rating of at least 1A is needed.

3. Design Example(Refer to Demo Board Schematic)

3.1 Summary of Target Specifications

Input Power	$V_{IN(\max)}$ = +12V; $V_{IN(\min)}$ = +12V
Regulated Output Power	V_{OUT} = + 5.0V; $I_{LOAD(\max)}$ = 2A; $I_{LOAD(\min)}$ = 0.2A
Output Ripple Voltage	$V_{RIPPLE} \leq$ 50 mV peak-to-peak
Output Voltage Load Regulation	1.5% (1/2 full load to full load)
Efficiency	80% minimum at full load.
Switching Frequency	F = 150KHz ± 15 %

3.2 Calculating and Components Selection

Calculation Formula	Select Condition	Component spec.
$V_{OUT}=V_{FB} \times ((R1/R2)+1)$ $V_{FB}=1.23V$	470Ω≤R2≤2.6KΩ	R1=4.7kΩ; R2=1.5kΩ
$L_{(\min)} \geq \frac{(V_{IN}-V_{OUT})\times V_{OUT}}{2\times F\times I_{LOAD(\min)}\times V_{IN}}$ $I_{PK}=I_{LOAD(\max)}+I_{LOAD(\min)}$	$L_{(\min)} \geq 48uH$ $I_{rms} \leq I_{PK} = 2.2A$	Select L1=47uH/2.5A
$ESR=\left(\frac{V_{RIPPLE}}{2\times I_{LOAD(\min)}}\right)$ $V_{WVDC} \geq 1.5\times V_{OUT}$	ESR≤125mΩ $V_{WVDC} \geq 7.5V$	Select C_{OUT}(C3) 220~680uF/10V*1pcs
$V_{SBD(MIN)} \geq 1.25\times V_{IN(\max)}$	$V_{SBD(MIN)} \geq 15V$ $I_{PK}=2.2A$	Select SBD(D1): 20V/2A or 20V/3A
$I_{IN(rms)} \cong \frac{1}{2}\times I_{LOAD(rms)}$ $V_{WVDC} \geq 1.5\times V_{IN(\max)}$	$I_{Ripple} \geq I_{IN(rms)}$ =1A $V_{WVDC} \geq 18V$	Select C_{IN}(C1)≥ 330uF/25V*1pcs

Note: The I_{Ripple} is the RMS current rating requirement for the input capacitor.

3.3 Demo Board Efficiency Calculation

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	Efficiency	F_{OSC} (KHz)	V_{FB} (V)	IC's Temp (℃)
12.08	0.005	5.073	0.000	-	-	1.270	33.0
12.07	0.054	5.004	0.100	76.76%	150	1.251	36.0
12.07	0.102	4.973	0.200	80.81%	150	1.243	40.0
12.06	0.244	4.925	0.500	83.72%	151	1.231	45.0
12.03	0.481	4.911	1.000	84.84%	152	1.227	55.0
12.01	0.723	4.899	1.500	84.61%	153	1.224	70.0
12.07	0.965	4.878	2.000	83.73%	153	1.218	88.0

V_{IN} (V)	I_{IN} (A)	V_{OUT} (V)	I_{OUT} (A)	Efficiency	F_{OSC} (KHz)	V_{FB} (V)	IC's Temp (℃)
12.04	0.005	3.410	0.000	0.000		1.268	12.04
12.04	0.039	3.372	0.100	71.81%	147	1.255	12.04
12.04	0.073	3.356	0.200	76.39%	147	1.250	12.04
12.03	0.173	3.335	0.500	80.14%	150	1.242	12.03
12.01	0.342	3.327	1.000	80.98%	150	1.239	12.01
12.00	0.515	3.319	1.500	80.58%	151	1.233	12.00
12.00	0.693	3.309	2.000	79.61%	152	1.229	12.00

4. Hardware Design

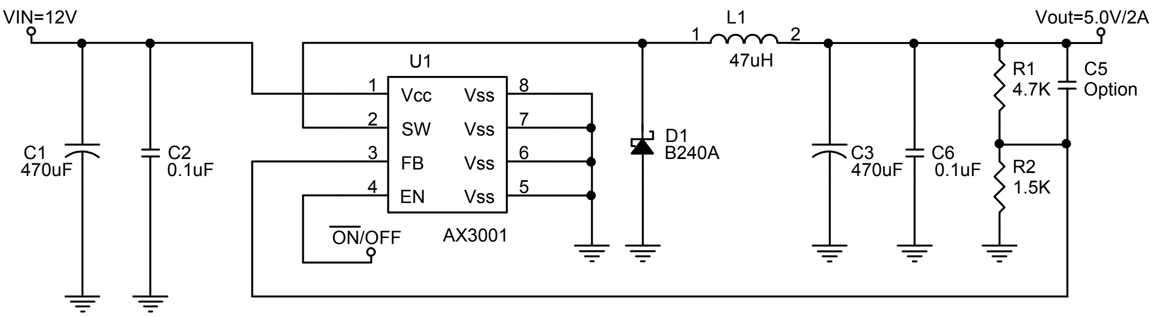
4.1 Introduction

This application note discusses simple ways to select all necessary components to implement a step-down (BUCK) DC/DC Converter and gives a design example. In this example, the AX3001 monolithic IC is used to design a cost-effective and high-efficiency miniature switching buck Converter. For more complete information, pin descriptions and specifications for the AX3001 will not be repeated here, please refer to the datasheet when designing or evaluating with the AX3001.

This demonstration board allows the designer to evaluate the performance of the AX3001 series buck Converter in a typical application circuit. The user needs only to supply an input voltage and a loading. Operation at other voltages and currents may be accomplished by proper component selection and replacement.

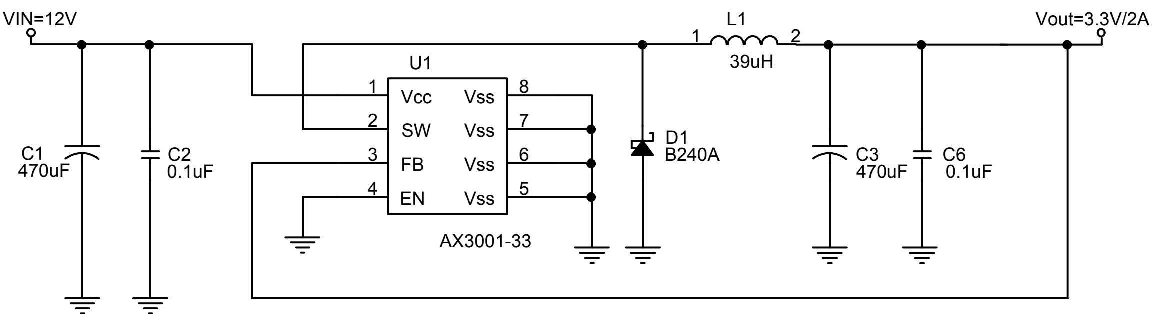
4.2 Demo Board Schematic

A. Adjustable Output Voltage Version



$$Vout = V_{FB} \times (1 + \frac{R1}{R2})$$

B. Fixed Output Voltage Version(For reference)

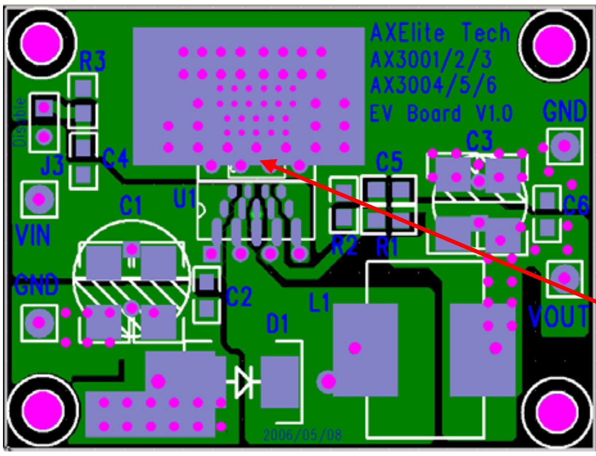


4.3 Board of Materials (V_{IN}=12V,V_{OUT}=5V2A)

Item	Value	Q'ty	Description	Part Number	MFG/Dist.
C1	470uF, 25V	1	Aluminum electrolytic		OST G-LUXON
C2	0.1uF, 25V	1	0805 Ceramic SMD capacitor		Viking
C3	470uF, 10V	1	Aluminum electrolytic		OST G-LUXON
C6	0.1uF, 25V	1	0805 Ceramic SMD capacitor		Viking
D1	20V, 2A	1	Schottky diode	B240A	
J3	Pitch=2.54mm	1	Jumper		
L1	47uH, 2A	1	Inductor	WE-TPC	Wurth elektronik
U1	150KHz, 2A	1	PWM buck converter	AX3001	AXElite
R1	4.7kΩ	1	1% 0805 SMD resistor		Viking
R2	1.5kΩ	1	1% 0805 SMD resistor		Viking

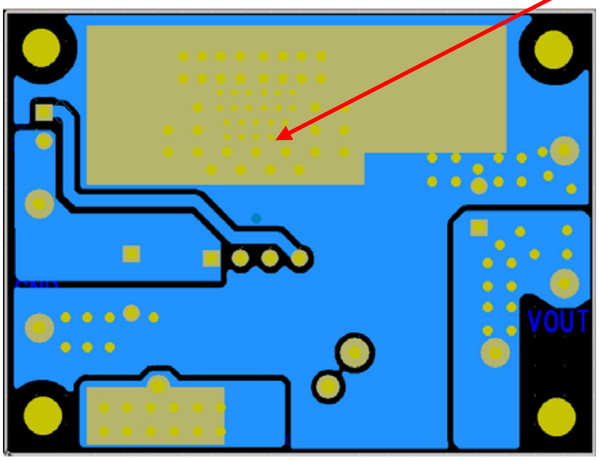
4.4 Demo Board Layout

(1) Top View - General Size (38.1*50.8 mm)



Use many via to conduct the heat into the backside of PCB layer. The PCB heat sink copper area should be solder-painted without masked. This approaches a "best case" pad heat sink.

(2) Bottom View



4.5 Typical PC Board Layout Guide Line

A. Layout is very important in switching regulator design. The heavy current line should be wide printed circuit traces and should be kept as short as possible.

B. The PC board layout should allow for maximum possible copper area at the Output pins of the AX3001. The V_{SS} pins (5~8) on the SOP-8 package are internally connected, but lowest thermal resistance will result if these pins are tightly connected on the PC board. This will also aid heat dissipation at high power levels.

C. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula:

$$PD_{(MAX)} = (TJ_{(MAX)} - TA) / \theta_{JA}$$

Where TJ(MAX) is the maximum operation junction temperature 125°C, TA is the ambient temperature and the θ_{JA} is the junction to ambient thermal resistance. For recommended operating conditions specification of AX3001, where **TJ** (125°C) is the setting maximum junction temperature of the die and **TA** (25°C) is the operation ambient temperature. For SOP-8 packages, the thermal resistance θ_{JA} is **60°C/W** on the Multi-layer 2S demo board. The maximum power dissipation can be calculated by following formula:

$$PD_{(MAX)} = (125°C - 25°C) / 60°C/W = 1.66W$$

The maximum power dissipation depends on operating ambient temperature for fixed TJ(MAX) and thermal resistance θ_{JA}.