Application Note
AP1512/A 50KHz, 2A/3A PWM Buck DC/DC Converter

Contents

1.0 Features

- Small Board Size
  - Entire circuit can fit on less than 1 square inch of PCB space
- Low Implementation Cost
  - Fewer than 4 discrete components required
- $\overline{ON}$ /OFF Control
  - Be controlled by external logic level signal
- Thermal Shut-down and Current Limit
  - Built-in function
- Simple Feedback Compensation
  - Lead compensation using external capacitor
- Immediate Implementation
  - Schematic, bill-of-materials and board layout available from DIODES

2.0 Introduction

This application note discusses simple ways to select all necessary components to implement a step-down (BUCK) regulator and gives a design example. In this example, the AP1512/A monolithic IC is used to design a cost-effective and high-efficiency miniature switching buck regulator. For more complete information, pin descriptions and specifications for the AP1512/A will not be repeated here. Please refer to the datasheet when designing or evaluating with the AP1512/A.

This demonstration board allows the designer to evaluate the performance of the AP1512/A series buck regulator in a typical application circuit. The user needs only to supply an input voltage and a load. The demonstration board can be configured to evaluate a fixed output voltage of 3.3V, 5V, 12V, and an adjustable output version of the AP1512/A series. Operation at other voltages and currents may be accomplished by proper component selection and replacement.

3.0 Pin Functions

Number	Name	Function
1	+VIN	Operating Voltage Input
2	Output	Switching Output
3	GND	Ground
4	FB	Output Feedback Control
5	SD	ON/OFF Shutdown Control

+VIN (Pin 1):

This pin is the main power input to the IC. The range of operating voltage is from +4.5V to +60V. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching current's needs by the regulator.

Output (Pin 2):

Internal switch. The voltage at this pin switches between $(+V_{IN} - V_{SAT})$ and approximately -0.55 V, with a duty cycle of approximately V_{OUT}/V_{IN}. To minimize coupling to sensitive circuitry, the PC board copper area connected to this pin should be kept at a minimum.

GND (Pin 3):

Circuit ground for the IC.

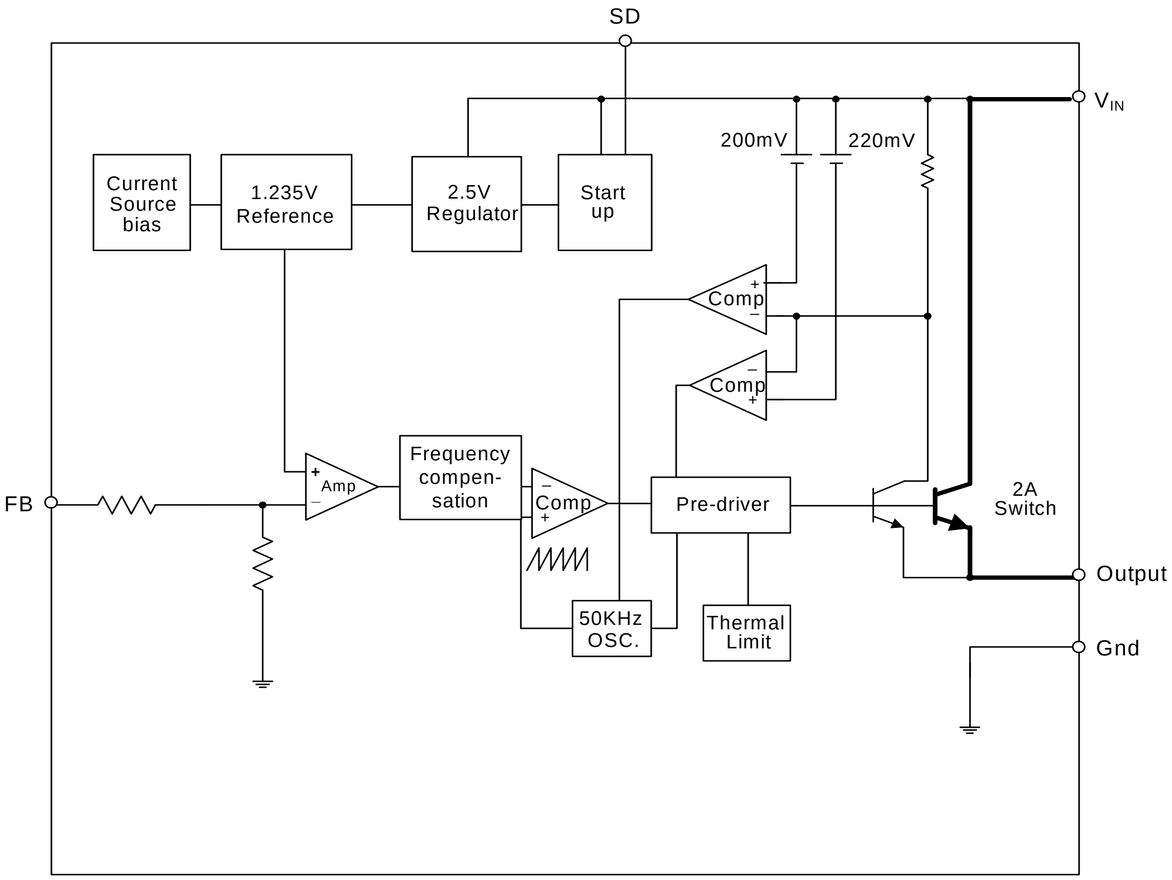
FB (Pin 4):

Senses the regulated output voltage to complete the feedback loop.

SD (Pin 5):

Allows the switching regulator circuit to be shutdown using logic level signals thus dropping the total input supply current to approximately 350uA. Pulling this pin below a threshold voltage of approximately 1.3V turns the regulator on, and pulling this pin above 1.3V (up to a maximum of 40V) shuts the regulator down. If this shutdown feature is not needed, the SD pin can be wired to the ground pin or it can be left open, in either case the regulator will be in the ON condition.

4.0 Internal Block Diagram



5.0 Regulator Design Procedure

5.0 .1 Given Power Specification

$V_{IN(max)}$ = 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 50KHz)

5.0.2 Programming Output Voltage

The output voltage is programmed by selection of the divider R2 and R3. The designer should use resistors R2 and R3 with ±1% tolerance in order to obtain the best accuracy of the output voltage. The output voltage can be calculated from the following formula:

$$V_{out} = 1.23 \times (1 + R2 / R3)$$

Select a value for R3 between 240Ω and 1.5KΩ. The lower resistor values minimize noise pickup in the sensitive feedback pin.

If the designer selects a fixed output version of the AP1512/A, the resistor R2 shall be short and R3 shall be open.

5.0.3 Inductor Selection

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

Calculation	Step-down (buck) regulator
$\frac{T_{ON}}{T_{OFF}}$	$\frac{(V_{OUT}+V_F)}{V_{IN(\min)}-V_{SAT}-V_{OUT}}$
$L_{(\min)}$	$\frac{[V_{IN(\min)}-V_{SAT}-V_{OUT}]\times T_{ON(\max)}}{2\times I_{LOAD(\min)}}$

V_{SAT} = Internal switch saturation voltage of the AP1512/A = 1.3V

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 I_{PK} . (I_{PK} = Peak inductor or switch current = $I_{LOAD(\max)} + I_{LOAD(\min)}$)

5.0.4 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:

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

An aluminum electrolytic capacitor's ESR value is related to the capacitance and its voltage rating. In most cases, 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, it results 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.

5.0.5 Compensation Capacitor Selection

For a stable application circuit, an additional capacitor C5 is required. The compensation capacitor C5 provides additional stability for high output voltages, low input-output voltages, and/or very low ESR output capacitors.

5.0.6 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 AP1512/A 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.

5.0.7 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.

Calculation	Step-down (buck) regulator
δ	$T_{on}/(T_{on}+T_{off})$
I_{PK}	$I_{LOAD(\max)}+I_{LOAD(\min)}$
I_m	$I_{LOAD(\max)}-I_{LOAD(\min)}$
ΔI_L	$2\times I_{LOAD(\min)}$
$I_{IN(rms)}$	$\sqrt{\delta\times\left[(I_{PK}\times I_m)+\frac{1}{3}(\Delta I_L)^2\right]}$

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.

6.0 Design Example

6.0.1 Summary of Target Specifications

Input Power	$V_{IN(max)}$ = +12V; $V_{IN(min)}$ = +12V
Regulated Output Power	V_{OUT} = + 5V; $I_{LOAD(max)}$ = 2A; $I_{LOAD(min)}$ = 0.6A
Output Ripple Voltage	$V_{RIPPLE} \leq$ 50 mV peak-to-peak
Output Voltage Load Regulation	1% (1/2 full load to full load)
Efficiency	75% minimum at full load
Switching Frequency	F = 50KHz ± 15 %

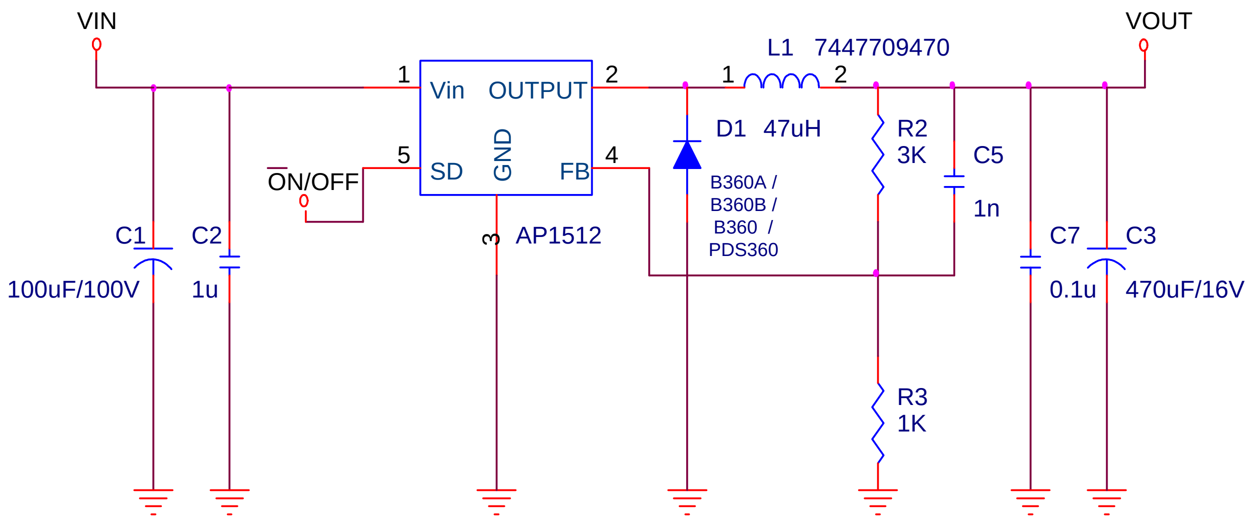
6.0.2 Calculating and Components Selection

Calculation Formula	Select Condition	Component spec.
$V_{out} = V_{ref} \times ((R2/R3) + 1)$	$240\Omega \leq R3 \leq 1.5K\Omega$	R2 = 3KΩ; R3 = 1KΩ
$L_{(min)} \geq \frac{[V_{IN(min)} - V_{SAT} - V_{OUT}] \times T_{ON(max)}}{2 \times I_{LOAD(min)}}$ $I_{PK} = I_{LOAD(max)} + I_{LOAD(min)}$	$L_{(min)} \geq 47uH$ $I_{rms} \geq I_{PK} = 2.6A$	Select = 47uH/3A
$ESR = \left(\frac{V_{RIPPLE}}{2 \times I_{LOAD(min)}} \right)$ $V_{WVDC} \geq 1.5 \times V_{OUT}$	$ESR \leq 62.5m\Omega$ $V_{WVDC} \geq 7.5V$	Select C3 from "JACKCON" 470uF/16V*1pcs
$V_{RRM} \geq 1.25 \times V_{IN(max)}$ $I_{PK} = I_{LOAD(max)} + I_{LOAD(min)}$	$V_{RRM} \geq 15V$ $I_{PK} = 2.6A$	Select D1:SR360 60V/3A
$I_{IN(rms)} = \sqrt{\delta \times \left[(I_{PK} \times I_m) + \frac{1}{3} (\Delta I_L)^2 \right]}$ $V_{WVDC} \geq 1.5 \times V_{IN(max)}$	$I_{ripple} \geq I_{IN(rms)} = 1.74A$ $V_{WVDC} \geq 18V$	Select C1 from "ELCON" 110uF/100V*1pcs

6.0.3 Parts List (Board of Materials)

Item	Part Number	MFG/Dist.	Description	Value	Quantity
C1			Aluminum Electrolytic	110uF, 100V	1
C2			Ceramic Capacitor	1uF, 25V	1
C3			Aluminum Electrolytic	470uF, 16V	1
C5			Ceramic Capacitor	1nF, 25V	1
C7			Ceramic Capacitor	0.1uF, 25V	1
D1	B360A/B360B/B360 PDS360	DIODES	Schottky Rectifier	60V, 3A	1
L1	7447709470	Wurth Electronik	Inductor	47 uH, 3.8A	1
U1	AP1512/AD	DIODES	PWM Buck Converter	50KHz, 2A	1
R2	Std		Film Chip Resistor	3KΩ±5%, 1/8W	1
R3	Std		Film Chip Resistor	1KΩ±5%, 1/8W	1

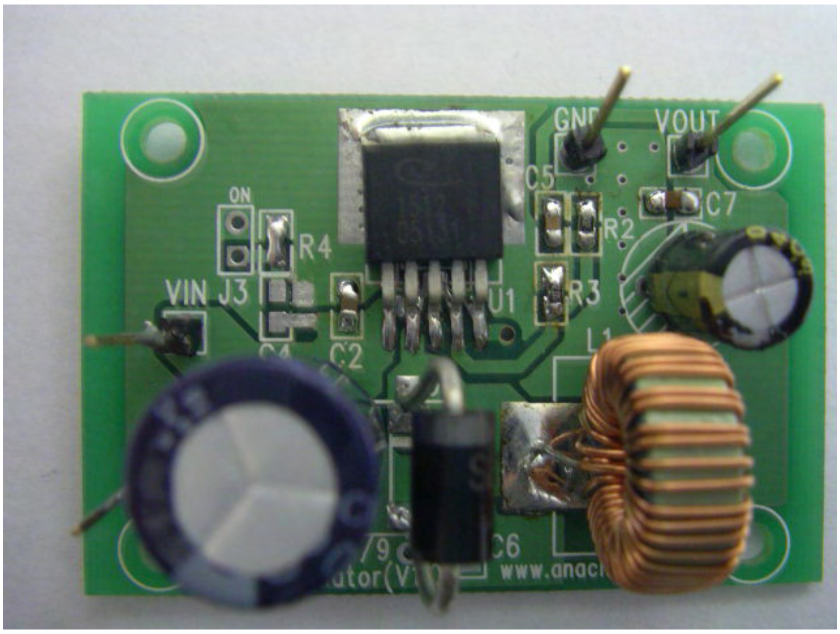
6.0.4 Demo Board Schematic



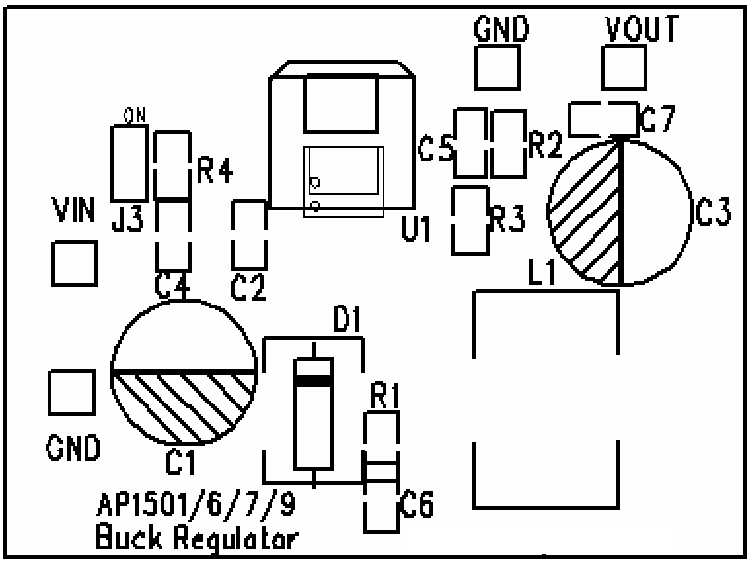
6.0.5 Demo Board Efficiency at V_{in} 60V

Load	V_{out} = 5V
1A	70.83%
2A	76.84%
3A	74.25%

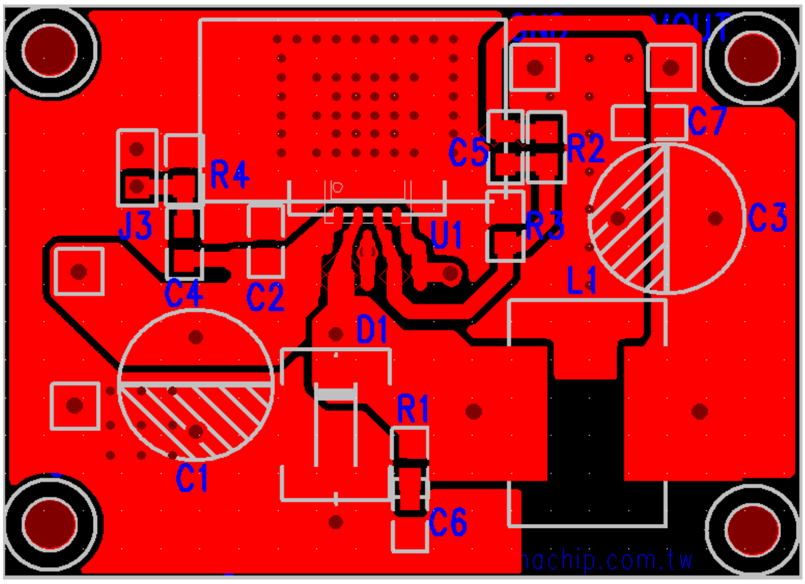
6.0.6 Typical PC Board Layout



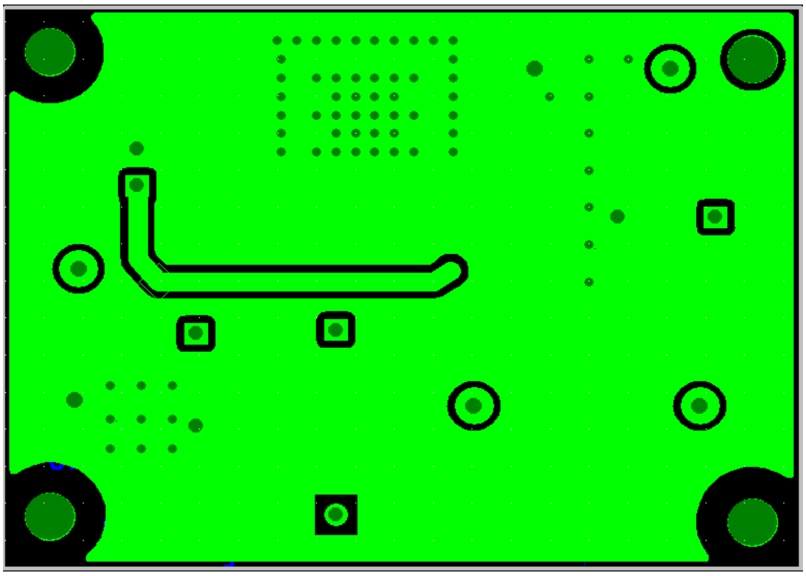
(1). Component Placement Guide



(2). Component Side PC Board Layout



(3). Solder Side PC Board Layout



6.0.7 Heatsink Layout Guide Line

The heatsink is dependent on the maximum power dissipation and maximum ambient temperature of the application.

For example:
12V to 5V/2A

Layout	Top Copper Area (mm*mm)	Bottom Copper Area (mm*mm)	Through Hole	IC Body Temperature	Gnd Pin Temperature
2	15*10	12*20	1mm*48	67	75

12V to 3.3V/2A

Layout	Top Copper Area (mm*mm)	Bottom Copper Area (mm*mm)	Through Hole	IC Body Temperature	Gnd Pin Temperature
2	15*10	12*20	1mm*48	61	68

60V to 5V/2A

Layout	Top Copper Area (mm*mm)	Bottom Copper Area (mm*mm)	Through Hole	IC Body Temperature	Gnd Pin Temperature
2	15*10	12*20	1mm*48	84	90

60V to 3.3V/2A

Layout	Top Copper Area (mm*mm)	Bottom Copper Area (mm*mm)	Through Hole	IC Body Temperature	Gnd Pin Temperature
2	15*10	12*20	1mm*48	78	84