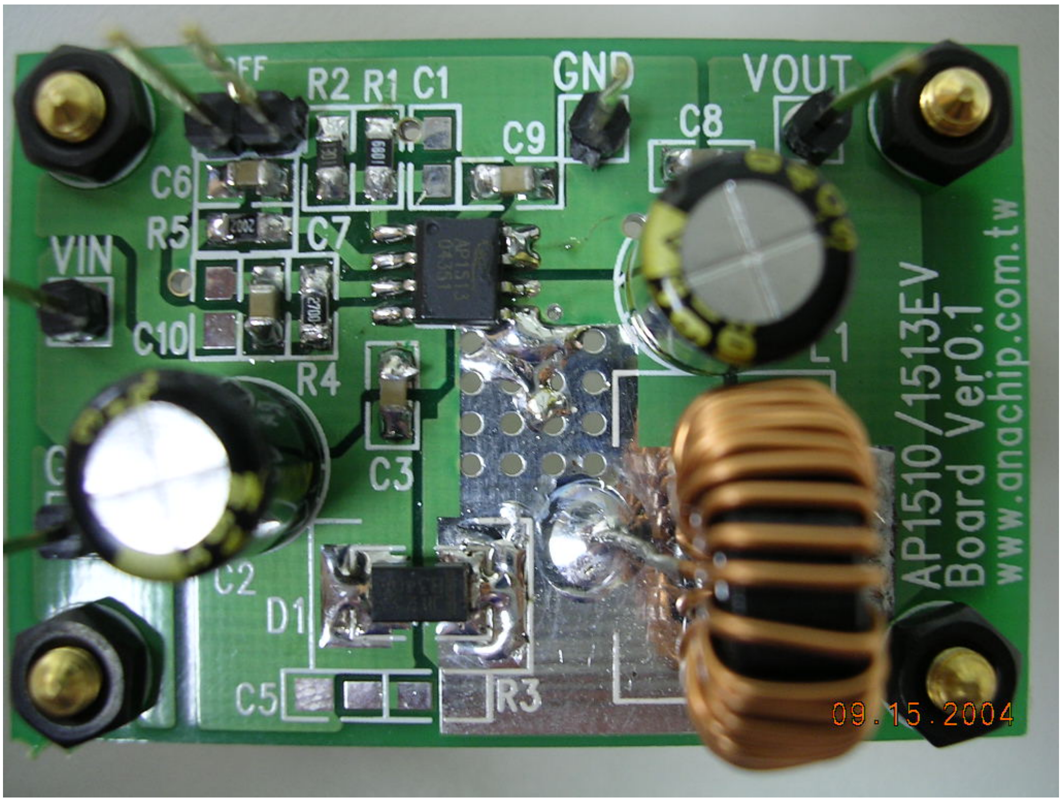
ANP014

Application Note
AP1513 300KHz, 2A High Efficiency PWM Buck DC/DC Converter

Contents



1.0 Features

- Small Board Size
  - Entire circuit can fit in 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
  - Thermal shutdown function built in and current limit level can be set by outside resistor
- Simple Feedback Compensation
  - Lead compensation using external capacitor
- Immediate Implementation
  - Schematic, bill-of-materials and board layout available from Anachip

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 AP1513 monolithic IC is used to design a cost-effective and high-efficiency miniature switching buck regulator. Please refer to the datasheet for more complete information, as pin descriptions and specifications for the AP1513 will not be repeated here.

This demonstration board allows the designer to evaluate the performance of the AP1513 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 adjustable output voltage settings by two resistors. Operation at different voltages and currents may be accomplished by proper component selection and replacement.

3.0 Regulator Design Procedure

3.0 .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 0.6% 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 300 kHz)

3.0.2 Programming Output Voltage (*refer to 4.0.4 Demo Board Schematic P7*)

The output voltage is programmed by selection of the divider R1 and R2. The 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:

$$V_{out} = 0.8 \times (1 + R1 / R2)$$

Select a value for R2 between 0.7KΩ and 5KΩ. The lower resistor values minimize noise pickup in the sensitive feedback pin.

3.0.3 Programming Current Limit Level (*refer to 4.0.4 Demo Board Schematic P7*)

Select a value for R4 to set the current limit level by using this formula:

$$I_{LOAD} \times R_{DS(on)} = I_{OCSET} \times R_{OCSET}$$

In this application we use R4 to be the R_{OCSET} and in the example we use 3.0K resistor, the $R_{DS(ON)}$ is 100mΩ and the I_{OCSET} is 90uA, so we limit the maximum load current to 2.7A.

3.0.4 Inductor Selection

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

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

V_{SAT} = Internal switch saturation voltage of the AP1513 = $I_{LOAD}\times R_{DS(on)}$ V

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

3.0.5 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:

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

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.

3.0.6 Output Rectifier Selection

A. The current rating of the output rectifier D1 must be greater than the peak switch current I_{PK}. 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 AP1513 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.

3.0.7 Input Capacitor Selection

A. The RMS current rating of the input capacitor can be calculated from the following formula table. The capacitor manufactured by the datasheet 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.

4.0 Design Example

4.0.1 Summary of Target Specifications

Input Power	$V_{IN(\max)}$ = +12V; $V_{IN(\min)}$ = +12V
Regulated Output Power	V_{OUT} = + 5V; $I_{LOAD(\max)}$ = 2A; $I_{LOAD(\min)}$ = 0.2A
Output Ripple Voltage	$V_{RIPPLE} \leq$ 50 mV peak-to-peak
Output Voltage Load Regulation	0.6% (0.2A to 2A)
Efficiency	87% minimum at full load
Switching Frequency	F = 300kHz ± 15 %

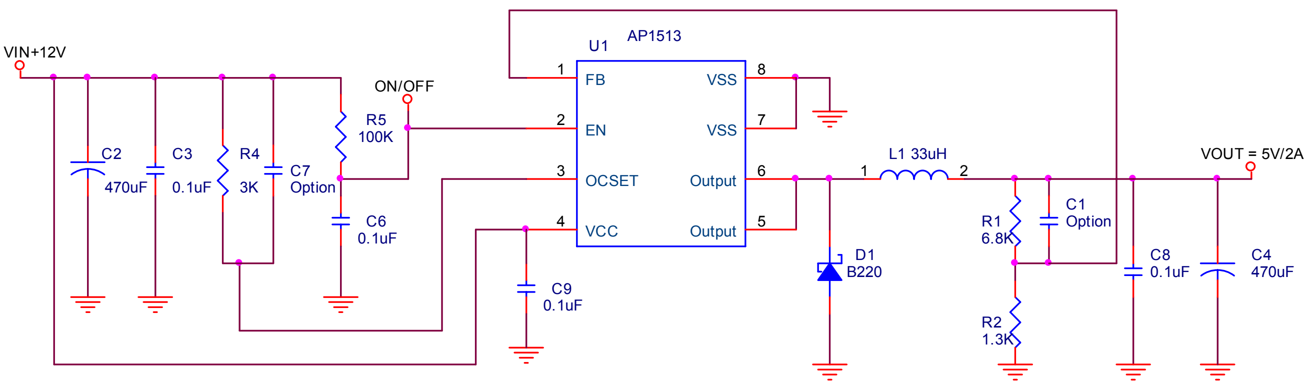
4.0.2 Calculating and Components Selection

Calculation Formula	Select Condition	Component spec.
$V_{out} = V_{ref} \times ((R1/R2) + 1)$	$0.7K\Omega \le R2 \le 5K\Omega$	$R2 = 1.3K\Omega$; $R1 = 6.8K\Omega$
$L_{(\min)} \ge \frac{[V_{IN(\min)} - V_{SAT} - V_{OUT}] \times T_{ON(\max)}}{2 \times I_{LOAD(\min)}}$ $I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$	$L_{(\min)} \ge 24uH$ $I_{rms} \le I_{PK} = 2.2A$	Select L1 = 33uH
$ESR = \left(\frac{V_{RIPPLE}}{2 \times I_{LOAD(\min)}}\right)$ $V_{WVDC} \ge 1.5 \times V_{OUT}$	$ESR \le 125m\Omega$ $V_{WVDC} \ge 7.5V$	Select C4: 470uF/10V*1pcs
$V_{RRM} \ge 1.25 \times V_{IN(\max)}$	$V_{RRM} \ge 15V$	Select D1: 20V/2A
$I_{IN(rms)} = \sqrt{\delta \times \left[(I_{PK} \times I_m) + \frac{1}{3}(\Delta I_L)^2\right]}$ $V_{WVDC} \ge 1.5 \times V_{IN(\max)}$	$I_{ripple} \ge I_{IN(rms)} = 1.293A$ $V_{WVDC} \ge 18V$	Select C2: 680uF/25V*1pcs
$I_{LOAD} \times R_{DS(on)} = I_{OCSET} \times R_{OCSET}$	$2A \times 100m\Omega = 90uA \times R_{OCSET}$ $R_{ocset} \ge 2.3k$	Select: R4 = 3.0K

4.0.3 Parts List (Board of Materials)

Item	Part Number	MFG/Dist.	Description	Value	Quantity
C1	0805 cap (optional)	Viking	Ceramic Capacitor	1nF, 25V	1
C2		OST	Aluminum Electrolytic	470uF, 25V	1
C3	0805 cap	Viking	Ceramic Capacitor	0.1uF, 25V	1
C4		OST	Aluminum Electrolytic	470uF, 10V	1
C6	0805 cap	Viking	Ceramic Capacitor	0.1uF, 25V	1
C7	Optional				
C8	0805 cap	Viking	Ceramic Capacitor	0.1uF, 25V	1
C9	0805 cap	Viking	Ceramic Capacitor	0.1uF, 25V	1
D1	B220		Schottky Diode	20V, 2A	1
L1		WE	Inductor	33uH, 2A	1
U1	AP1513	Anachip	PWM Buck Converter	300kHz, 2A	1
R1	0805 reg	Viking	Film Chip Resistor	6.8KΩ	1
R2	0805 reg	Viking	Film Chip Resistor	1.3KΩ	1
R4	0805 reg	Viking	Film Chip Resistor	3KΩ	1
R5	0805 reg	Viking	Film Chip Resistor	100KΩ	1

4.0.4 Demo Board Schematic



4.0.5 Demo Board Efficiency and Temperature

V_{in} (V)	I_{in} (A)	V_{out} (V)	I_{out} (A)	Efficiency (%)
12.08	0.165	3.37	0.5	84.54
12.03	0.323	3.37	1	86.73
12.06	0.644	3.37	2	86.78

V_{in} (V)	I_{in} (A)	V_{out} (V)	I_{out} (A)	Efficiency (%)
12.09	0.245	5.33	0.5	89.97
12.01	0.483	5.33	1	91.88
12.07	0.962	5.32	2	91.63

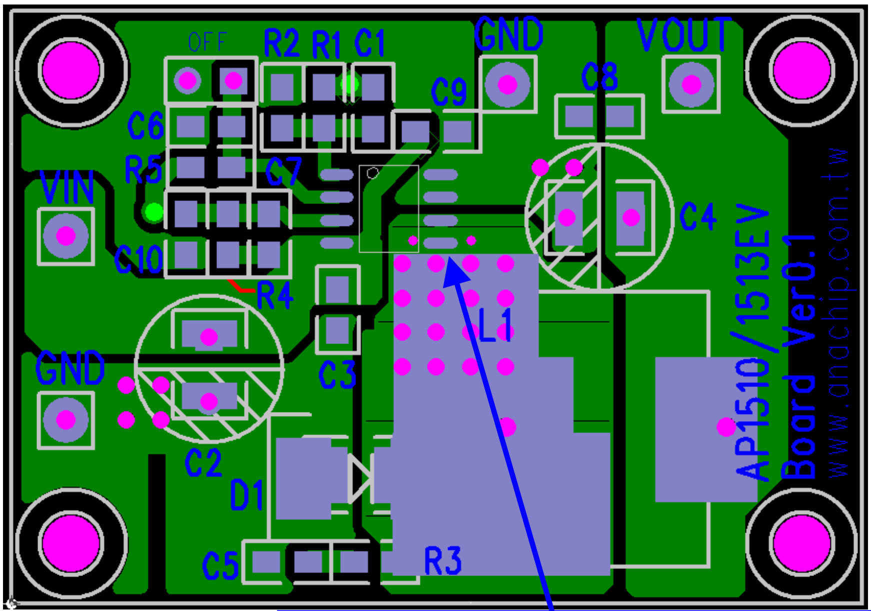
V_{in} (V)	I_{in} (A)	V_{out} (V)	I_{out} (A)	Efficiency (%)
5.00	0.361	3.320	0.5	91.97%
5.00	0.722	3.318	1.0	91.90%
5.00	1.463	3.313	2.0	90.51%

AP1513 Temperature vs. Efficiency

Parameter	Temperature (°C)				
	-20	0	25	50	85
V_{in} (V)	12.03	12.06	12.07	12.14	12.16
I_{in} (A)	0.334	0.327	0.323	0.320	0.318
V_{out} (V)	3.43	3.41	3.39	3.37	3.34
I_{out} (A)	1	1	1	1	1
Efficiency (%)	85.37	86.47	86.95	86.75	86.37

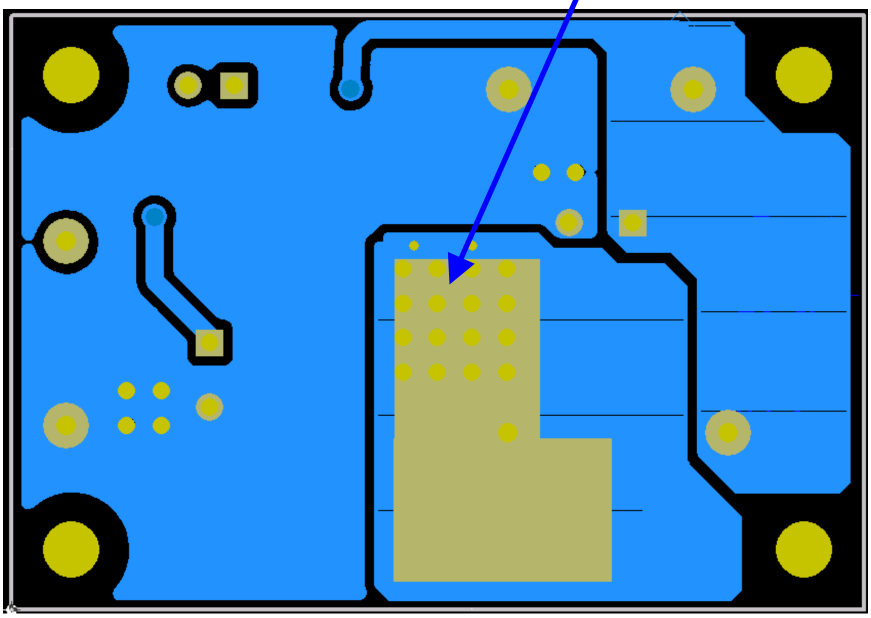
4.0.6 Typical PC Board Layout (refer to ANP016)

(1). Top Side Layout Guide



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

(2). Bottom Side Layout Guide



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