Application Note
AP1501 Series Step-Down (Buck) Regulator

Contents

1.0 Features

- Small Board Size
  - Entire circuit can fit on less than 1.6 square inch of PCB space
- Low Implementation Cost
  - Fewer than 10 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, board-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 AP1501 monolithic IC is used to design a cost-effective and high-efficient miniature switching buck regulator. This implementation is suitable for LCD monitor application requiring a regulated +5V from an adapter whose output voltage is +12V. For more complete information, pin descriptions and specifications for the AP1501 will not be repeated here, please refer to the datasheet when designing or evaluating with the AP1501.

This demonstration board allows the designer to evaluate the performance of the AP1501 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 AP1501 series. Operation at other 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 1% of the output voltage

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

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

F = Switching Frequency (fixed at a nominal 150kHz)

3.0.2 Programming Output Voltage

The output voltage is programmed by selection of the divider R2 and R5. The designer should use resistors R2 and R5 with ±1% tolerance in order to obtain the best accuracy of the output voltage. The output voltage can be calculated from the following formula:

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R2}{R5}\right) \text{ ------------------------ (1)}$$

Where V_{REF} = 1.235V

$$R2 = R5 \times \left(\frac{V_{OUT}}{V_{REF}} - 1\right) \text{ -------------------------- (2)}$$

Select a value for R5 between 1K and 3K. The lower resistor values minimize noise pickup in the sensitive feedback pin.

If the designer selects a fixed output version of the AP1501, the formula (1) won't be applied, and then the resistor R2 shall be short and R5 shall be open.

3.0.3 Inductor Selection

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

Calculation	Step-down (buck) regulator
$\frac{T_{ON}}{T_{OFF}}$	$\frac{(V_{OUT}+V_F)}{V_{IN(\min)}-V_{SAT}-V_{OUT}}$
$T_{ON}+T_{OFF}$	$\frac{1}{F}$
T_{OFF}	$\frac{(Ton+Toff)}{\left(\frac{Ton}{Toff}+1\right)}$
$L_{(\min)}$	$\frac{[V_{IN(\min)}-V_{SAT}-V_{OUT}]\times T_{ON(\max)}}{2\times I_{LOAD(\min)}}$

V_{SAT} = Internal switch saturation voltage of the AP1501 = 1.16V

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 = $I_{LOAD(\max)}+I_{LOAD(\min)}$)

3.0.4 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 value and its voltage rating. In most cases, higher voltage electrolytic capacitors have lower ESR values. Often, capacitors with much higher voltage ratings may be needed to provide the low ESR values required for low output ripple voltages. 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.

3.0.5 Compensation Capacitor Selection

For output voltage greater than approximately 10V, an additional capacitor C1 is required. The compensation capacitor C1 provides additional stability for high output voltages, low input-output voltages, and/or very low ESR output capacitors.

3.0.6 Output Rectifier Selection

A. The output rectifier D1 current rating 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 AP1501 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 manufacturers datasheet must be checked to assure that this current rating is not exceeded.

Calculation	Step-down (buck) regulator
δ	$\frac{T_{ON}}{(T_{ON}+T_{OFF})}$
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; $I_{LOAD(\max)}$ = 2.5A; $I_{LOAD(\min)}$ = 0.3A
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 = 150kHz ± 15 %

4.0.2 Calculating and Components Selection

Calculation Formula	Select Condition	Component spec.
$R2 = R5 \times \left(\frac{V_{OUT}}{V_{REF}} - 1 \right)$	240Ω ≤ R5 ≤ 1.5KΩ	R5 = 1KΩ; R2 = 3KΩ
$L_{(\min)} \geq \frac{[V_{IN(\min)} - V_{SAT} - V_{OUT}] \times T_{ON(\max)}}{2 \times I_{LOAD(\min)}}$ $I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$	$L_{(\min)} \geq$ 33UH $I_{rms} \geq I_{PK}$ = 2.8A	Select L1 from "FRONTIER" 33UH/2.8A CSS136S-330M
$ESR = \left(\frac{V_{RIPPLE}}{2 \times I_{LOAD(\min)}} \right)$ $V_{WVDC} \geq 1.5 \times V_{OUT}$	ESR ≤ 88mΩ $V_{WVDC} \geq$ 7.5V	Select C4 from "LUXON" 220UF/25V*1pcs LY series, or 470UF/25V*1pcs LZ series, or 470UF/25V*2pcs SM series
$V_{RRM} \geq 1.25 \times V_{IN(\max)}$ $I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$	$V_{RRM} \geq$ 15V I_{PK} = 2.8A	Select D1: 20V/3A SS32
$I_{IN(rms)} = \sqrt{\delta \times \left[(I_{PK} \times I_m) + \frac{1}{3} (\Delta I_L)^2 \right]}$ $V_{WVDC} \geq 1.5 \times V_{IN(\max)}$	$I_{ripple} \geq I_{IN(rms)}$ = 1.94A $V_{WVDC} \geq$ 18V	Select C2 from "LUXON" 680UF/25V*1pcs LY series If the +12V power source that has a large output capacitor enough to supply this current $I_{IN(rms)}$, designer can select another one. 470UF/25V*1pcs SM series

4.0.3 Parts List (Board of Materials)

Item	Part Number	MFG/Dist.	Description	Value	Quantity
C1				Open	0
C2	ELY687M025S1A6H20	LUXON	Aluminum Electrolytic*	680uF, 25V	1
C3			Ceramic Capacitor	0.1uF, 50V	1
C4	ELZ477M025S1A6H15	LUXON	Aluminum Electrolytic*	470uF, 25V	1
C5			Ceramic Capacitor	22nF, 50V	1
D1	SS32	HAWYANG	Schottky Diode*	20V, 3A	1
J1			Terminal Block	Pitch = 5.08mm, 2pin	1
J2			Terminal Block	Pitch = 5.08mm, 3pin	1
L1	CSS136S-330M	FRONTIER	Inductor*	33 UH, 2.8A	1
U1	AP1501K5	Anachip	PWM Buck Converter*	150kHz, 3A	1
R1	Std		Film Chip Resistor	10Ω±5%, 1/8W	1
R2	Std		Film Chip Resistor	3KΩ±1%, 1/8W	1
R3				Open	0
R4				Short	0
R5	Std		Film Chip Resistor	1KΩ±1%, 1/8W	1

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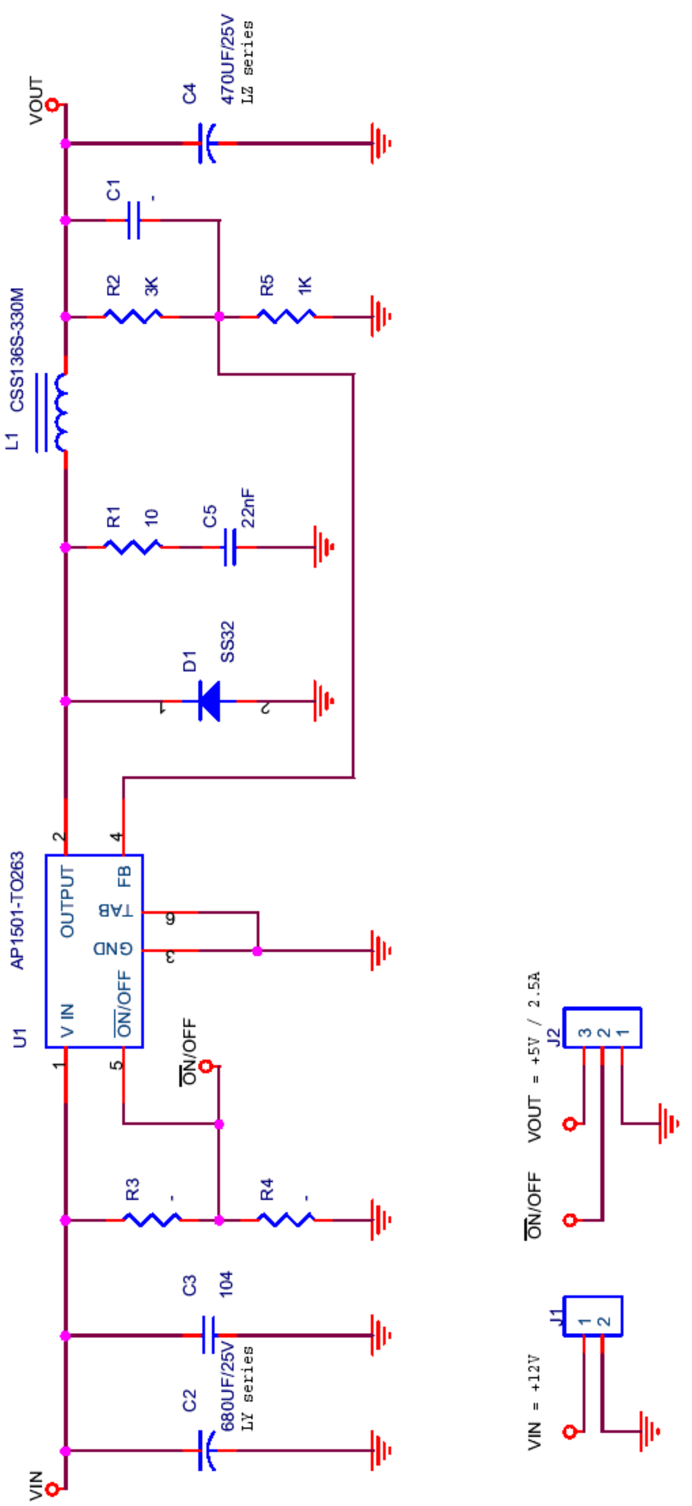
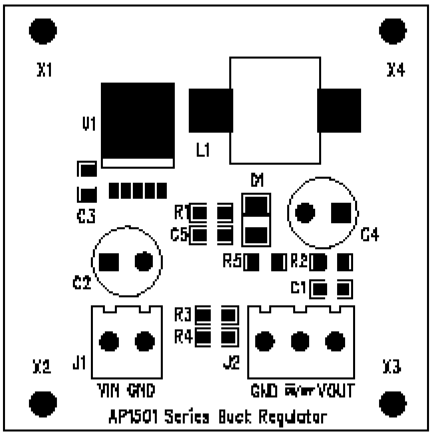
	Website	http://www.luxon.com.tw

4.0.4 Demo Board Schematic

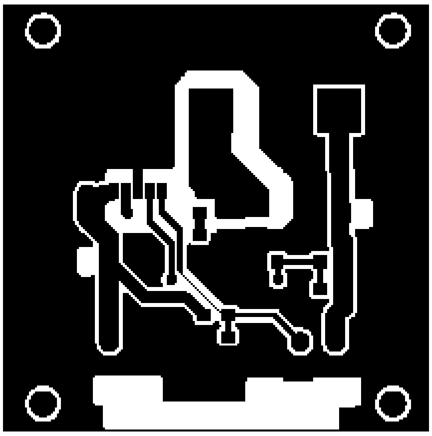


4.0.5 Typical PC Board Layout, Adjustable Output: (1x Size)

(1). Component Placement Guide



(2). Component Side PC Board Layout



(3). Solder Side PC Board Layout