Application Note
AP1501A Series Step-Down (Buck) Regulator

Contents

ANP006

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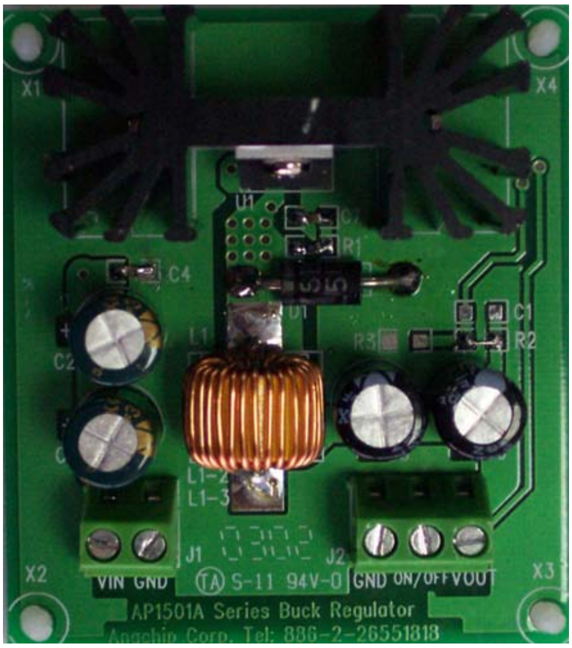
1.0 Features

- Small Board Size
  - Entire circuit can fit on less than 2.5 square inches of PCB space
- Low Implementation Cost
  - Requires Only 10 External Components
- $\overline{ON}$ /OFF Control
  - Be controlled by external TTL logic level signal, low power standby mode
- Thermal Shutdown and Current Limit Protection
  - 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 AP1501A monolithic IC is used to design a cost-effective and high-efficiency miniature switching buck regulator.



This implementation is suitable for LCD TV and PDP TV applications. It can also be used in an off-line post-regulator to convert the AC line voltage down to a DC voltage below 37V for a distributed power system.

This demonstration board allows the designer to evaluate the performance of the AP1501A 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 fixed output voltage of 3.3V, 5V, 12V, and an adjustable output version of the AP1501A 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 +40V. A suitable input bypass capacitor must be present at this pin to minimize voltage transients and to supply the switching current 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.

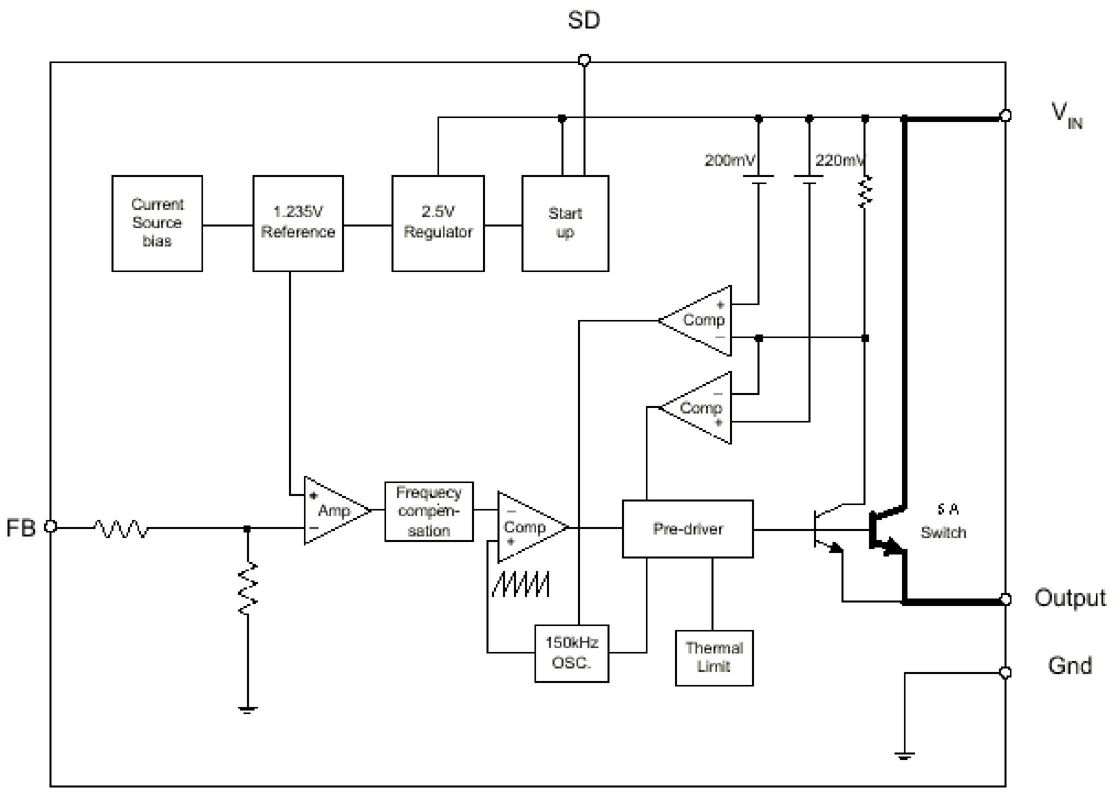
FB (Pin 4):

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 150uA. 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 25V) 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_{OSC} = Switching Frequency (fixed at a nominal 150KHz)

5.0.2 Programming Output Voltage

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

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R2}{R3}\right) \text{ ------------------------ (1)}$$

Where V_{REF} = 1.235V

$$R2 = R3 \times \left(\frac{V_{OUT}}{V_{REF}} - 1\right) \text{ -------------------------- (2)}$$

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 AP1501A, the formula (1) won't be applied, and then 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
$\frac{T_{ON}}{T_{OFF}}$	$\frac{(V_{OUT} + V_F)}{V_{IN(\min)} - V_{SAT} - V_{OUT}}$
T_{ON}	$\frac{\frac{T_{ON}}{T_{OFF}}}{F_{OSC} \cdot \left(\frac{T_{ON}}{T_{OFF}} + 1\right)}$
$L_{(\min)}$	$\frac{[V_{IN(\min)} - V_{SAT} - V_{OUT}] \times T_{ON(\max)}}{2 \times I_{LOAD(\min)}}$

V_{SAT} = Internal switch saturation voltage of the AP1501A. The saturation voltage increases with the conducting current. Typical value is 1.5 V.

V_F = Output rectifier forward voltage drop. Typical value for SB540 rectifier is 0.55V.

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 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 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 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.

5.0.6 Output Rectifier Selection

A. The output rectifier D1 current rating must be 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 AP1501A 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 manufacturers data sheet must be checked to assure that this current rating is not exceeded.

Calculation	Step-down (buck) regulator
δ	$T_{ON} \cdot F_{OSC}$
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.

5.0.8 Thermal Considerations

Internal Thermal Shutdown circuitry is provided to protect the integrated circuit in the event that the maximum junction temperature is exceeded. When activated, typically at 150°C, the output switch is disabled. This feature is provided to prevent catastrophic failures from accidental device overheating. The maximum IC junction temperature shall not exceed 125ºC to guarantee proper operation and avoid any damages to the IC. The total power dissipated by the IC can be quantified as follows:

$$P_{LOSS} = P_Q + P_{SAT} + P_S \quad \text{--------------------(4)}$$

Where:

P_Q : The power dissipation is due to quiescent current of the IC (10mA maximum).

P_{SAT} : The conduction loss occurs when the power switch turns on, the saturation voltage and conduction current contribute to the power loss of a non–ideal switch.

P_S : The switching loss occurs when the switch experiences both high current and voltage during each switch transition.

The thermal characteristics of AP1501A depend on the following four factors: junction temperature, ambient temperature, IC power dissipation, and the thermal resistance from the die junction to ambient air. The relation between temperature and heat radiation quantity is shown as follows:

$$R_{\theta JA} = \left(T_{J(\max)} - T_{A(\max)}\right) / P_{LOSS} \quad \text{--------------------(5)}$$

The TO-220 package needs a heat sink that effectively increases the surface area of the package to improve the flow of heat away from the AP1501A and into the surrounding air. The total thermal resistance is comprised of three components. These resistive terms are measured from junction to case ($R_{\theta JC}$), case to heat sink ($R_{\theta CS}$), and heat sink to ambient air ($R_{\theta SA}$). The equation is shown as follows:

$$R_{\theta SA} = R_{\theta JA} - R_{\theta JC} - R_{\theta CS} \quad \text{-------------------(6)}$$

Where:

$R_{\theta JC}$: The thermal resistance between the IC chip (junction point) and package backside connecting to the heat sink. The thermal resistance of 5-lead TO-220 package is approximately 2.5ºC/W.

$R_{\theta SA}$: The thermal resistance of heat sink. This value depends on the heat sink type.

$R_{\theta CS}$: The thermal resistance between the package backside and the heat sink including the condition of silicon grease and bolt tighten torque. Typical value is 0.5 ºC /W for a 5-lead TO-220 package with a standard silicon/zinc oxide thermal compound has thermal conductivities between 0.7 and 0.9 W/mK. The recommended bolt tighten torque is smaller than 6kg·cm (or 5.3 lb·in) for an M3 screw.

Once these calculations are complete, the maximum permissible value of $R_{\theta SA}$ can be calculated and then select the heat sink whose $R_{\theta SA}$ is smaller than the result of equation (6). For more detail, please refer the thermal resistance value mentioned in the specification of the heat sink supplier.

5.0.9 PCB Layout Considerations

Special care should be taken to separate ground paths from signal currents and ground paths from load currents. All high current loops should be kept as short as possible using heavy copper runs to minimize ringing and radiated EMI. For best operation, a tight component layout is recommended. Input and output capacitors (C2, C3, C5, C6) and all feedback components should be placed as close to the IC as physically possible. It is also imperative that the Schottky diode connected to the Switch Output be located as close to the IC as possible.

6.0 Design Example

6.0.1 Summary of Target Specifications

Input Power	$V_{IN(\max)}$ = +19V; $V_{IN(\min)}$ = +19V
Regulated Output Power	V_{OUT} = + 5V; $I_{LOAD(\max)}$ = 5A; $I_{LOAD(\min)}$ = 0.5A
Output Ripple Voltage	$V_{RIPPLE} \le$ 50 mV peak-to-peak
Operation Temperature	$T_{J(\max)}$ =100℃; $T_{A(\max)}$ = 50℃
Efficiency	75% minimum at full load
Switching Frequency	f = 150KHz ± 15 %

6.0.2 Calculating and Components Selection

Calculation Formula	Select Condition	Component spec.
$L_{(\min)} \geq \frac{\left[V_{IN(\min)} - V_{SAT} - V_{OUT}\right] \times T_{ON(\max)}}{2 \times I_{LOAD(\min)}}$ $I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$	$L_{(\min)} \geq$ 25UH $I_{rms} \geq I_{PK} =$ 5.5A	Select L1 from "FRONTIER" 25UH (@5ADC)
$ESR = \left(\frac{V_{RIPPLE}}{2 \times I_{LOAD(\min)}}\right)$ $V_{WVDC} \geq 1.5 \times V_{OUT}$	ESR ≤ 50mΩ $V_{WVDC} \geq$ 7.5V	Select C5, C6 from "CAPXON" C5: 1000UF/10V GF series, C6: Open Or C5: 1000UF/10V KM series, C6: 1000UF/10V KM series.
$V_{RRM} \geq 1.25 \times V_{IN(\max)}$ $I_{PK} = I_{LOAD(\max)} + I_{LOAD(\min)}$	$V_{RRM} \geq$ 23.75V $I_{PK} =$ 5.5A	Select D1: 40V/5A SB540
$I_{IN(rms)} = \sqrt{\delta \times \left[\left(I_{PK} \times I_{m}\right) + \frac{1}{3}\left(\Delta I_{L}\right)^{2}\right]}$ $V_{WVDC} \geq 1.5 \times V_{IN(\max)}$	$I_{ripple} \geq I_{IN(rms)}$ =2.78A $V_{WVDC} \geq$ 28.5V	Select C2, C3 from "CAPXON" 330UF/35V GF series. If the +19V power source that has a large output capacitor enough to supply this current $I_{IN(rms)}$, designer can select another one. 330UF/50V KM series.
$P_{LOSS} = P_{Q} + P_{SAT} + P_{S}$ $R_{\theta JA} = \left(T_{J(\max)} - T_{A(\max)}\right) / P_{LOSS}$ $R_{\theta SA} = R_{\theta JA} - R_{\theta JC} - R_{\theta CS}$	P_{LOSS} = 5.90W $R_{\theta JA}$ = 8.47□/W, $R_{\theta JC}$ = 2.5ºC /W $R_{\theta CS}$ = 0.5ºC /W $R_{\theta SA} \leq$ 5.47ºC /W	Using current probe and digital oscilloscope to measure P_{LOSS}. Select HS1 from "MEICON" MI-317 type.

6.0.3 Parts List (Board of Materials)

Item	Part Number	MFG/Dist.	Description	Value	Quantity
C1				Open	0
C2, C3	GF331M035G160	LUXON	Aluminum Electrolytic*	330uF, 35V	2
C4			Ceramic Capacitor	0.1uF, 50V	1
C5, C6	KM102M010G160	CAPXON	Aluminum Electrolytic*	1000uF, 10V	2
C7			Ceramic Capacitor	2200pF, 50V	1
D1	SB540	HAWYANG	Schottky Diode*	40V, 5A	1
J1			Terminal Block	Pitch=5.08mm, 2pin	1
J2			Terminal Block	Pitch=5.08mm, 3pin	1
L1	3011I56	FRONTIER	Inductor*	25 UH, 5A	1
U1	AP1501A-50T5	Anachip	PWM Buck Converter*	150KHz, 5A	1
R1	Std		Film Chip Resistor	10Ω±5%, 1/8W	1
R2				Short	0
R3				Open	0
HS1	MI-317	MEICON	Heat Sink	W=50.7mm,H=25.2mm	1
	EG-30	E.G-BOND	Silicone Compound	0.9 W/m K	*
X1~X4	MF-005-N2W	Pin Good	Spacer Support	Hole in P.C.B Φ3.5	4

* You should apply a very thin (paper thin) layer on the heat sink before installing AP1501A. Don't use too much - the thinner the layer, the better.

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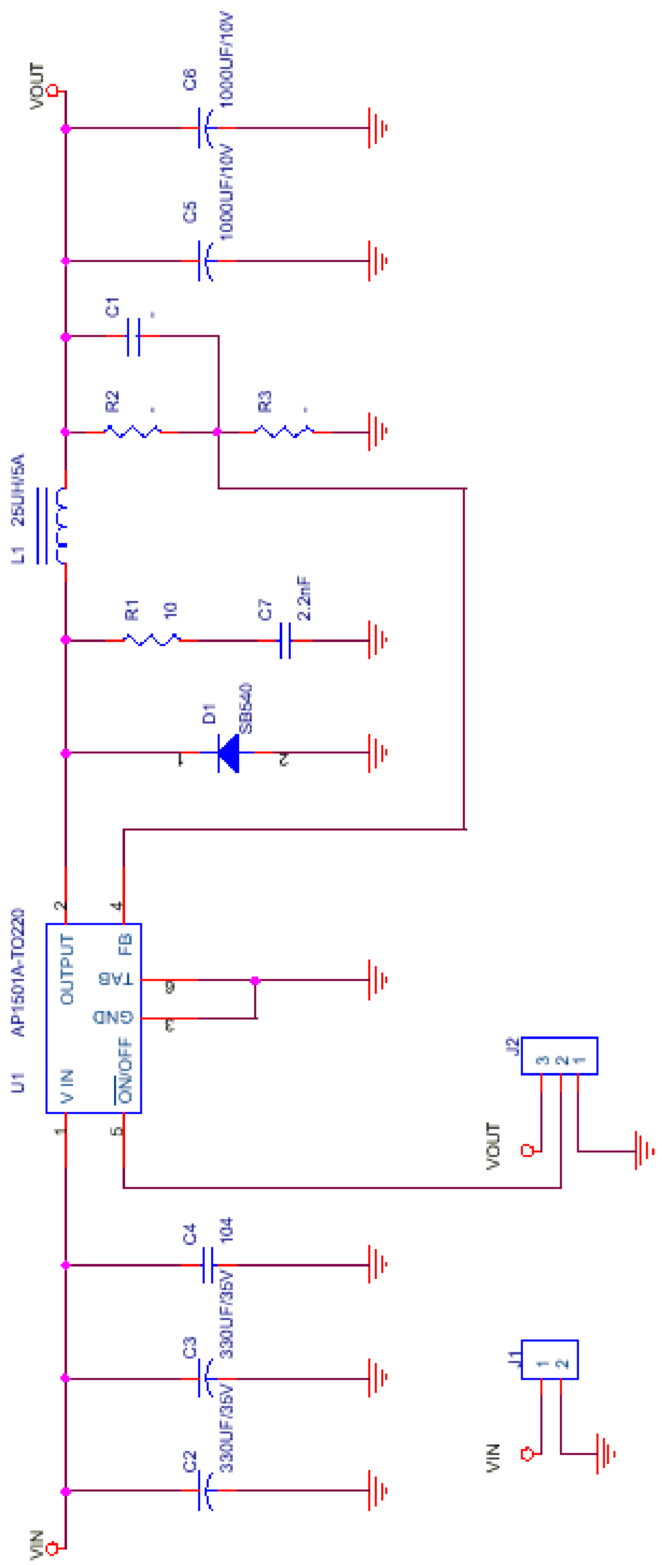
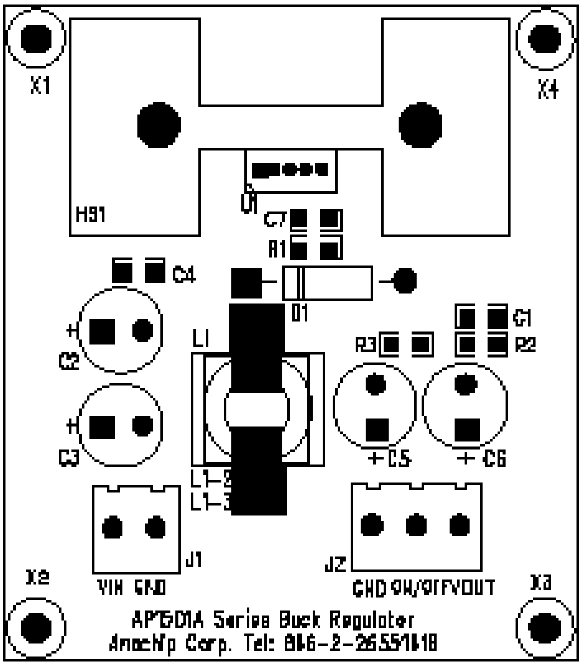
	Fax	+886-2-86926481
	Website	http://www.capxon.com.tw

6.0.4 Demo Board Schematic

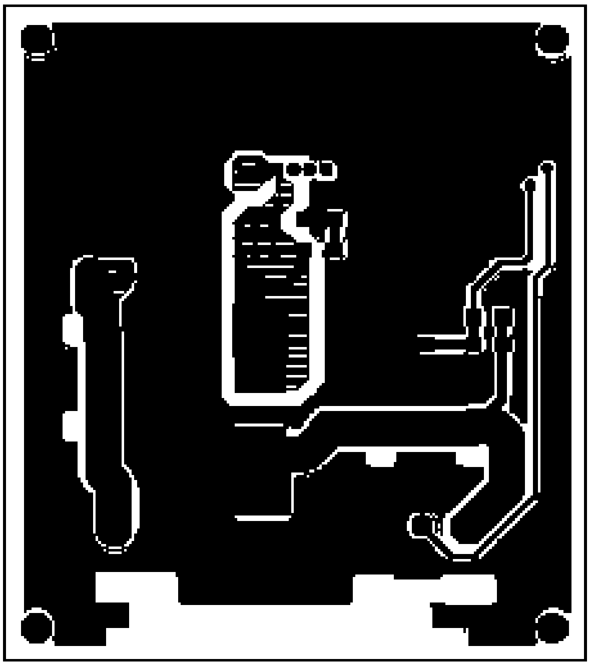


6.0.5 Typical PC Board Layout, Adjustable Output: (1x Size)

(1). Component Placement Guide



(2). Component Side PC Board Layout



(3). Solder Side PC Board Layout