Application Note
AP2014/A Synchronous PWM Controller

Contents

1. AP2014/A Specification

1.1 Features

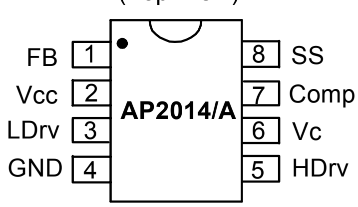
- Synchronous Controller in 8-Pin Package
- Operating with single 5V or 12V supply voltage
- Internal 200KHz Oscillator(400KHz for AP2014A)
- Soft-Start Function
- Fixed Frequency Voltage Mode
- 500mA Peak Output Drive Capability
- Protects the output when control FET is shorted
- SOP-8L/PDIP-8L **Pb-Free** package

1.2 General Description

The AP2014 controller IC is designed to provide a low cost synchronous Buck regulator for on-board DC to DC converter applications. With the migration of today's ASIC products requiring low supply voltages such as 1.8V and lower, together with currents in excess of 3A, traditional linear regulators are simply too consumptive to be used when input supply is 5V or even in some cases with 3.3V input supply. The AP2014 together with dual N-channel MOSFETs provide a low cost solution for such applications. This device features an internal 200KHz oscillator(400KHz for "A" version), under-voltage lockout for both Vcc and Vc supplies, an external programmable soft-start function as well as output under-voltage detection that latches off the device when an output short is detected.

1.3 Pin Assignments

(Top View)

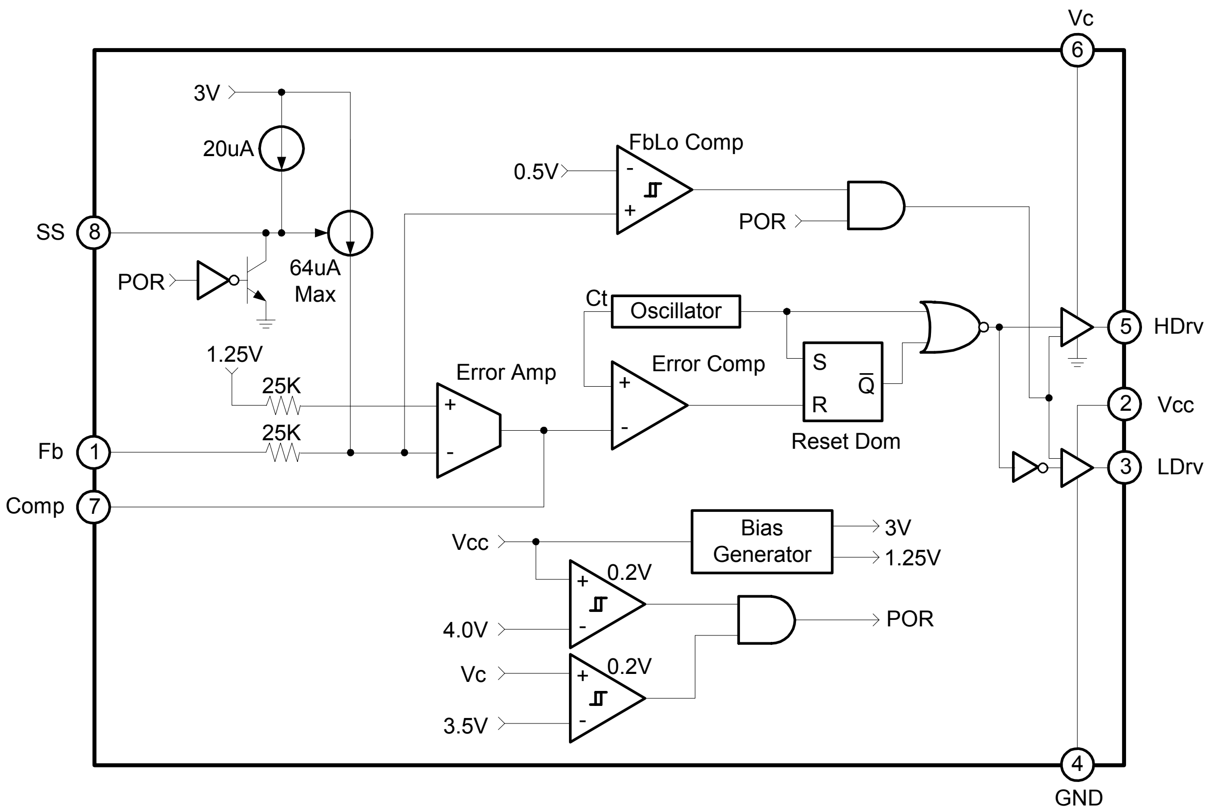


SOP-8L/PDIP-8L

1.4 Pin Descriptions

Pin Name	Pin No.	Description
FB	1	This pin is connected directly to the output of the switching regulator via resistor divider to provide feedback to the Error amplifier.
Vcc	2	This pin provides biasing for the internal blocks of the IC as well as power for the low side driver. A minimum of 1uF, high frequency capacitor must be connected from this pin to ground to provide peak drive current capability.
LDrv	3	Output driver for the synchronous power MOSFET.
GND	4	This pin serves as the ground pin and must be connected directly to the ground plane. A high frequency capacitor (0.1 to 1uF) must be connected from V5 and V12 pins to this pin for noise free operation.
HDrv	5	Output driver for the high side power MOSFET.
Vc	6	This pin is connected to a voltage that must be at least 4V higher than the bus voltage of the switcher (assuming 5V threshold MOSFET) and powers the high side output driver. A minimum of 1uF, high frequency capacitor must be connected from this pin to ground to provide peak drive current capability.
Comp	7	Compensation pin of the error amplifier. An external resistor and capacitor network is typically connected from this pin to ground to provide loop compensation.
SS	8	This pin provides soft-start for the switching regulator. An internal current source charges an external capacitor that is connected from this pin to ground which ramps up the output of the switching regulator, preventing it from overshooting as well as limiting the input current. The converter can be shutdown by pulling this pin below 0.5V.

1.5 Block Diagram



1.6 Absolute Maximum Ratings

Symbol	Parameter	Range.	Unit
V_{CC}	Vcc Supply Voltage	20	V
V_C	Vc Supply Voltage (not rated for inductive load)	32	V
T_{ST}	Storage Temperature Range	-65 to 150	^oC
T_J	Operating Junction Temperature Range	0 to 125	^oC
θ_{JC}	Thermal Resistance Junction to Case(Note1)	7	$^oC/W$
θ_{JA}	Thermal Resistance Junction to Ambient(Note1)	160	$^oC/W$

Note：1.Test conditions for SOP-8L：Device mounted on 2oz copper, minimum recommended pad layout, FR-4 PCB.

2. Hardware

2.1 Introduction

The AP2014 is a fixed frequency, voltage mode synchronous controller and consists of a precision reference voltage, an error amplifier, an internal oscillator, a PWM comparator, 0.5A peak gate driver, soft-start and shutdown circuits (see Block Diagram).

The output voltage of the synchronous converter is set and controlled by the output of the error amplifier; this is the amplified error signal from the sensed output voltage and the reference voltage.

This voltage is compared to a fixed frequency linear saw-tooth ramp and generates fixed frequency pulses of variable duty-cycle, which drives two N-channel external MOSFETs. The timing of the IC is provided through an internal oscillator circuit which uses on-chip capacitor to set the oscillation frequency to 200 KHz (400 KHz for “A” version).

2.2 Description of the built-in function circuit

Under Voltage Lock Out (UVLO)

The under-voltage lockout circuit assures that the MOSFET driver outputs remain in the off state whenever the supply voltage drops below set parameters. Lockout occurs if V_C and V_{CC} fall below 3.3V and 4.2V respectively. Normal operation resumes once V_C and V_{CC} rise above the set values.

Soft-Start and Shutdown

The AP2014 has a programmable soft-start to control the output voltage rise and limit the current surge at the start-up. To ensure correct start-up, the soft-start sequence initiates when the V_C and V_{CC} rise above their threshold (3.3V and 4.2V respectively) and generates the Power On Reset (POR) signal. Soft-start function operates by sourcing an internal current to charge an external capacitor to about 3V. Initially, the soft-start function clamps the E/A’s output of the PWM converter. As the charging voltage of the external capacitor ramps up, the PWM signals increase from zero to the point the feedback loop takes control.

Short-Circuit Protection

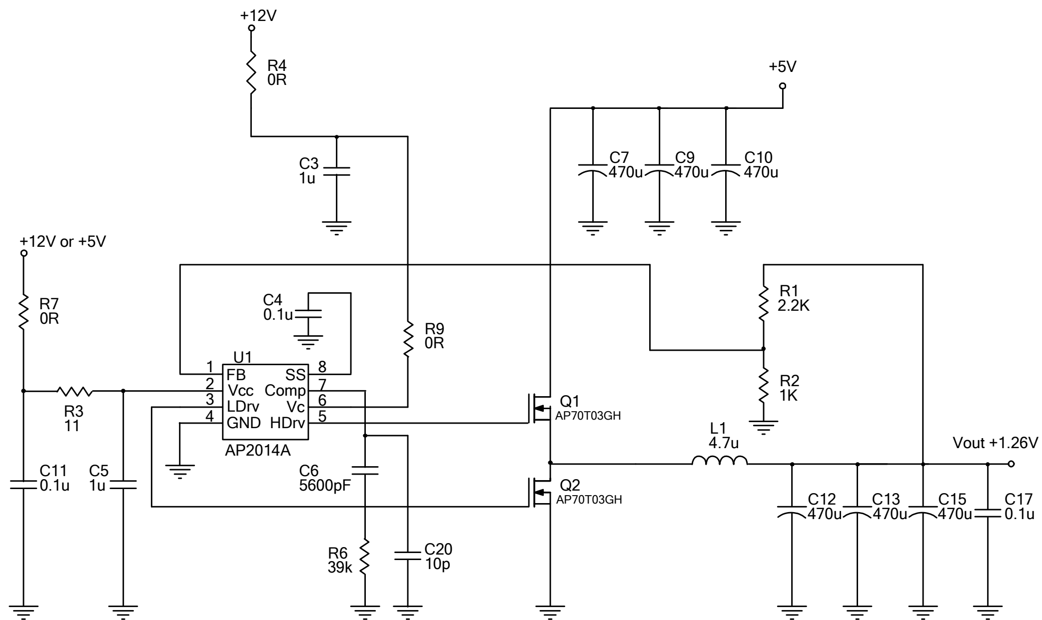
The outputs are protected against the short circuit. The AP2014 protects the circuit for shorted output by sensing the output voltage (through the external resistor divider). The AP2014 shuts down the PWM signals, when the output voltage drops below 0.6V (0.4V for AP2014A).

The AP2014 also protects the output from over-voltage when the control FET is shorted. This is done by turning on the sync FET with the maximum duty cycle.

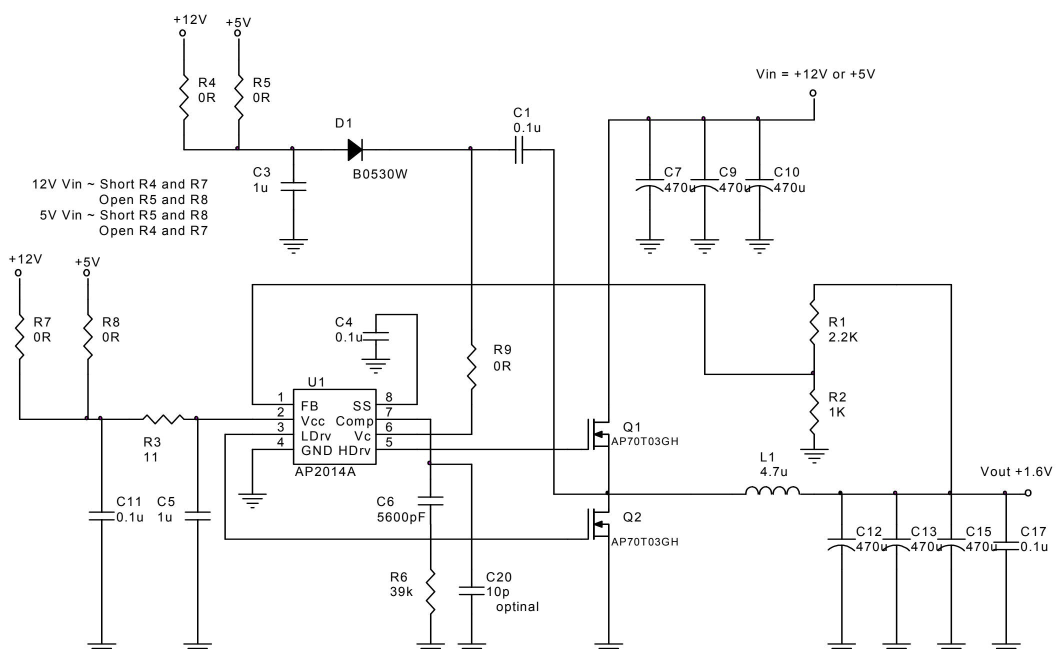
IC Quiescent Power Dissipation

Power dissipation for IC controller is a function of applied voltage, gate driver loads and switching frequency. The IC's maximum power dissipation occurs when the IC operating with single 12V supply voltage (Vcc=12V and Vc≅24V) at 400KHz switching frequency and maximum gate loads.
Show the voltage vs. current in page 10 of data sheet, when the gate drivers loaded with 1500pF capacitors. The IC's power dissipation results to an excessive temperature rise. This should be considered when using AP2014A for such application.

2.3 Schematic



Dual Supply 5V and 12V Input



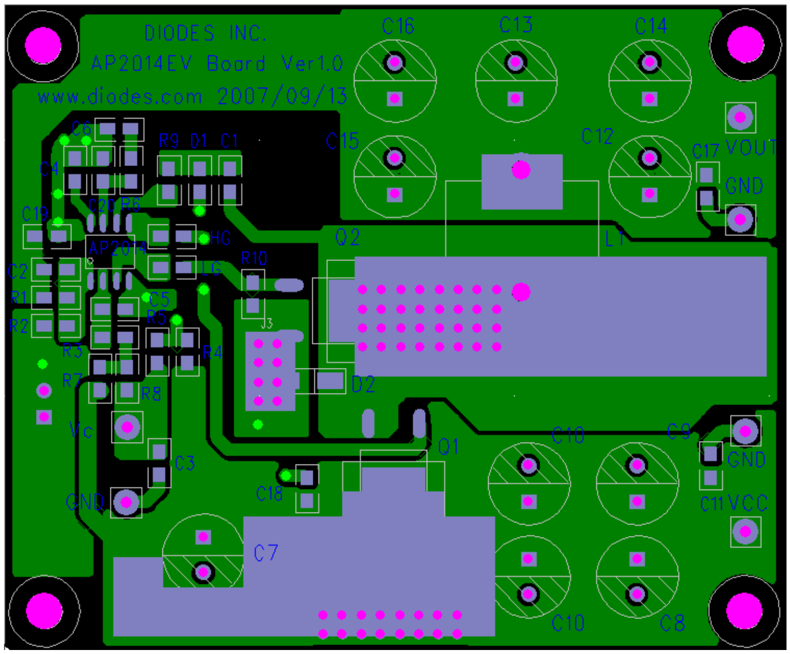
Single Supply, 5V or 12V Input Voltage

2.4 Board of Materials

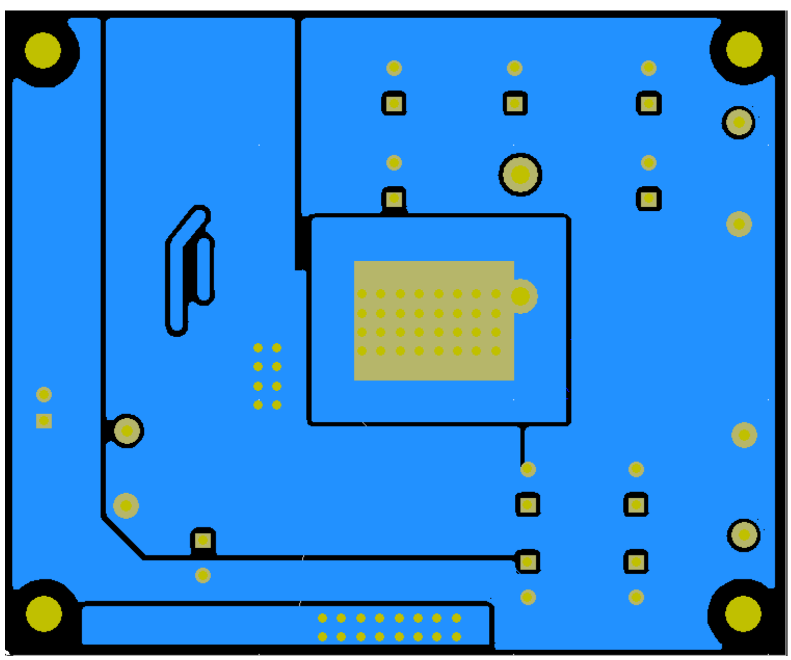
No.	Value	Q'ty	Part Reference	Description	Manufacturers	Part Number
1	AP2014/A	1	U4	AP2014/A	Diodes Inc	AP2014/A
2	0.1uF/50V	4	C1, C4,C11, C17	0805 ceramic SMD capacitor	Viking Tech	
3	470uF/16V	6	C7, C9, C10, C12,C13,C15	Low ESR	OST	
4	1uF/50V	2	C3,C5	0805 ceramic SMD capacitor	Viking Tech	
5	5600pF/50V	1	C6	0805 ceramic SMD capacitor	Viking Tech	
6	10pF/50V	1	C20	0805 ceramic SMD capacitor	Viking Tech	
7	2.2K	1	R1	1% 0805 SMD resistor	Viking Tech	
8	1K	1	R2	1% 0805 SMD resistor	Viking Tech	
9	11Ω	1	R3	1% 0805 SMD resistor	Viking Tech	
10	39K	1	R6	1% 0805 SMD resistor	Viking Tech	
11	0Ω	3	R5,R8,R9	1% 0805 SMD resistor	Viking Tech	
12	0.5A 30V	2	D1	SMD shottky diode	Diodes Inc	B0530W
13	4.7uH	1	L1	ring core inductor 15A	Wurth Elektronik	
14	AP70T03GH	2	Q1, Q2	30V/60A N-MOSFET	Advanced Power Electronics Corp.	

2.5 Board Layout

Top Side



Bottom Side



2.6 Layout Notice

Introduction

When designing a high frequency switching regulated power supply, layout is very important. Using a good layout can solve many problems associated with these types of supplies. The problems due to a bad layout are often seen at high current levels and are usually more obvious at large input to output voltage differentials. Some of the main problems are loss of regulation at high output current and/or large input to output voltage differentials, excessive noise on the output and switch waveforms, and instability. Using the simple guidelines that follow will help minimize these problems.

Inductor

Always try to use a low EMI inductor with a ferrite type closed core. Open core can be used if they have low EMI characteristics and are located a bit more away from the low power traces and components. It would also be a good idea to make the poles perpendicular to the PCB as well if using an open core. Stick cores usually emit the most unwanted noise.

Feedback

Try to put the feedback trace as far from the inductor and noisy power traces as possible. You would also like the feedback trace to be as direct as possible and somewhat thick. These two sometimes involve a trade-off, but keeping it away from inductor EMI and other noise sources is the more critical of the two. It is often a good idea to run the feedback trace on the side of the PCB opposite of the inductor with a ground plane separating the two.

Filter Capacitors

When using a low value ceramic input filter capacitor, it should be located as close to the V_{IN} pin of the IC as possible. This will eliminate as much trace inductance effects as possible and give the internal IC rail a cleaner voltage supply. Sometimes using a small resistor between V_{CC} and IC V_{IN} pin will more useful because the RC will be a low-pass filter. Some designs require the use of a feed-forward capacitor connected from the output to the feedback pin as well, usually for stability reasons. Using surface mount capacitors also reduces lead length and lessens the chance of noise coupling into the effective antenna created by through-hole components.

Compensation

If external compensation components are needed for stability, they should also be placed closed to the IC. Surface mount components are recommended here as well for the same reasons discussed for the filter capacitors. These should not be located very close to the inductor as well.

Traces and Ground Plane

Make all of the power (high current) traces as short, direct, and thick as possible. It is a good practice on a standard PCB board to make the traces an absolute minimum of 20 mils (0.5mm) per Ampere. The inductor, output capacitors, and output diode (In synchronous case, means the low side switch) should be as close to each other possible. This helps reduce the EMI radiated by the power traces due to the high switching currents through them. This will also reduce lead inductance and resistance as well which in turn reduces noise spikes, ringing, and resistive losses which produce voltage errors. The grounds of the IC, input capacitors, output capacitors, and output diode (or switch, if applicable) should be connected close together directly to a ground plane. It would also be a good idea to have a ground plane on both sides of the PCB. This will reduce noise as well by reducing ground loop errors as well as by absorbing more of the EMI radiated by the inductor. For multi-layer boards with more than two layers, a ground plane can be used to separate the power plane (where the power traces and components are) and the signal plane (where the feedback and compensation and components are) for improved performance. On multi-layer boards the use of vias will be required to connect traces and different planes. It is good practice to use one standard via per 200mA of current if the trace will need to conduct a significant amount of current from one plane to the other. Arrange the components so that the switching current loops curl in the same direction. Due to the way switching regulators operate, there are two power states. One state the switch is on and the other the switch is off. During each state there will be a current loop made by the power components that are currently conducting. Place the power components so that during each of the two states the current loop is conducting in the same direction. This prevents magnetic field reversal caused by the traces between the two half-cycles and reduces radiated EMI.

Heat Sinking

When using a surface mount power IC or external power switches, the PCB can often be used as the heat-sink. This is done by simply using the copper area of the PCB to transfer heat from the device. Refer to the device datasheet for information on using the PCB as a heat-sink for that particular device. This can often eliminate the need for an externally attached heat-sink. These guidelines apply for any inductive switching power supply. These include Step-down (Buck), Step-up (Boost), Fly-back, inverting Buck/Boost, and SEPIC among others. The guidelines are also useful for linear regulators, which also use a feedback control scheme, that are used in conjunction with switching regulators or switched capacitor converters.

3. Design Procedure

3.1 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.

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

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.

3.2 Output N-channel MOSFETs Selection

A. The current ability of the output N-channel MOSFETs must be at least more than the peak switch current IPK. The voltage rating V_{DS} of the N-channel MOSFETs should be at least 1.25 times the maximum input voltage.

B. The MOSFETs must be fast (switch time) and must be located close to the AP2014 using short leads and short printed circuit traces. **In case of a large output current, we must layout a copper to reduce the temperature of these two MOSFETs**.

Because of their fast switching speed and low DS(ON) resistor ($R_{DS(ON)}$), the APEC AP70T03GH series provide the best performance and efficiency, and especially in low output voltage applications.

3.3 Input Capacitor Selection

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

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

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. Design Example

4.1 Summary of Target Specifications

Input Power	$V_{IN(\max)}$ = +5V; $V_{IN(\min)}$ = +5V
Regulated Output Power	V_{OUT} = + 1.6V; $I_{LOAD(\max)}$ = 5A; $I_{LOAD(\min)}$ = 0.5A
Output Ripple Voltage	$V_{RIPPLE} \leq$ 50 mV peak-to-peak
Output Voltage Load Regulation	1% (0.2A to 5A)
Efficiency	85% minimum at 5A load.
Switching Frequency	F = 400KHz ± 10 %

4.2 Calculating and Components Selections

Calculation Formula	Select Condition	Component spec.
$V_{OUT} = V_{FB} \times ((R1/R2) + 1)$	$100\Omega \leq R2 \leq 1K\Omega$	R2=1KΩ; R1=2.2KΩ
$L_{(\min)} \geq \frac{\left[V_{IN(\min)} - V_{SAT} - V_{OUT}\right] \times T_{ON(\max)}}{2 \times I_{LOAD(\min)}}$ $I_{PK} = I_{LOAD(\max)} - I_{LOAD(\min)}$	$L_{(\min)} \geq 3.5uH$ $I_{rms} \geq I_{PK} = 4.5A$	Select L1=4.7uH
$ESR = \left(\frac{V_{RIPPLE}}{2 \times I_{LOAD(\min)}}\right)$ $V_{WVDC} \geq 1.5 \times V_{OUT}$	$ESR \leq 50m\Omega$ $V_{WVDC} \geq 2.4V$	Select C12, C13,C15 470uF/16V*2pcs
$I_{IN(rms)} = \sqrt{\delta \times \left[\left(I_{PK} \times I_m\right) + \frac{1}{3}\left(\Delta I_L\right)^2\right]}$ $V_{WVDC} \geq 1.5 \times V_{IN(\max)}$	$I_{ripple} \geq I_{IN(rms)}$=2.83A $V_{WVDC} \geq 7.5V$	Select C7, C9,C10 470uF/16V*2pcs

4.3 Efficiency Calculation

Temperature: room Temperature

★ **Highside nMOS: AP70T03GH :V_{DS}=30V; R_{DS}=9mΩ;I_D=60A**

★ **Lowside nMOS: AP70T03GH :V_{DS}=30V; R_{DS}=9mΩ; I_D=60A**

Vc = 12V

V_{IN}(V)	I_{IN}(A)	V_{OUT}	I_{OUT}(A)	Efficiency	Temp(℃)
5.00	0.019	1.617	0.0	0.00%	45
5.00	0.189	1.616	0.5	85.46%	42
5.00	0.363	1.615	1.0	88.94%	43
5.00	1.085	1.611	3.0	89.01%	44
5.00	1.849	1.606	5.0	86.80%	46
5.00	3.083	1.598	8.0	82.89%	52
5.00	3.965	1.593	10.0	80.34%	56
5.00	4.907	1.588	12.0	77.68%	58
5.00	6.428	1.582	15.0	73.82%	62