The Introduction to Green Mode PWM Controller AP384XG

1. Introduction

The AP384XG are patented green mode PWM controller series to support "Energy Star" and "Blue Angel" norm. It is designed for off-line AC-DC adapter and battery charger applications where low standby power and high efficiency are especially important. The IC is pin-to-pin compatible with industry standard controller 384X.

This application note includes general description on the overall circuit, detailed explanation of major function, the difference compare between AP384XG and 384X, and notes for typical applications in switching mode power supply (SMPS).

2. General Description

The AP384XG acts as a fixed frequency PWM controller during normal operation, and sets switching frequency with an external resistor and capacitor combination. When output power falls below a given level, the IC automatically enters skip cycle mode to reduce power consumption.

Owing to its proprietary circuitry, the ICs feature low start-up and low standby operating current, which further reduce standby power losses.

AP384XG also provide accurate protection against over-temperature, over-current and maximum output power. Furthermore, a leading edge blanking (L.E.B.) technology is included in AP384XG for noise immunity.

The AP384XG is available in SOIC-8 and DIP-8 packages.

3. Pin Descriptions

COMP (pin 1) This pin is the error amplifier output, it is made available for voltage loop compensation by parallel resistor and capacitor between pin 1 and its inverting input.

FB (pin 2) This is the inverting input of the error amplifier. It is normally connected to optical coupler that receives the feedback signal from the output of SMPS through a resistor divider.

CS (pin 3) In normal operation mode, the input pin receives a voltage proportional to inductor current, and the PWM uses this information to terminate the output switch conduction. In skip cycle mode, an internal 200μA constant current sources from pin 3 to pin 5 (GND) through a series resistor.

R_T/C_T (pin 4) A resistor RT to VREF and capacitor CT to ground will set Oscillator frequency and maximum output duty cycle.

GND (pin 5) The combined control circuitry and power ground.

OUTPUT (pin 6) The PWM output directly drives the gate of a power switch. A series resistor between this pin and the gate of switch can reduce high frequency noise.

VCC (pin 7) A stable source current of 10mA is fed to VCC, and a bypass capacitor to VCC is also needed. In general, auxiliary winding of the transformer provides supply current.

REF (pin 8) Trimmed output voltage of 5V bandgap reference is primarily to supply charging current to the timing capacitor of oscillator. The reference is capable of providing in excess of 20 mA for powering additional control system circuitry. Bypassing V_{REF} to GND with a 0.1μF or larger ceramic capacitor is for better stability.

4. Functional Block Description

The representative block diagram and the pin configuration of AP384XG are respectively shown in Figure 1 and Figure 2.

4.1 UVLO and Start-up

Under voltage lockout (UVLO) section guarantees the AP384XG work normally before the output stage is enabled. The AP384XG can start up only when its supply voltage (VCC) reaches turn-on threshold. A start-up resistor between VCC and rectified line voltage usually actives the IC.

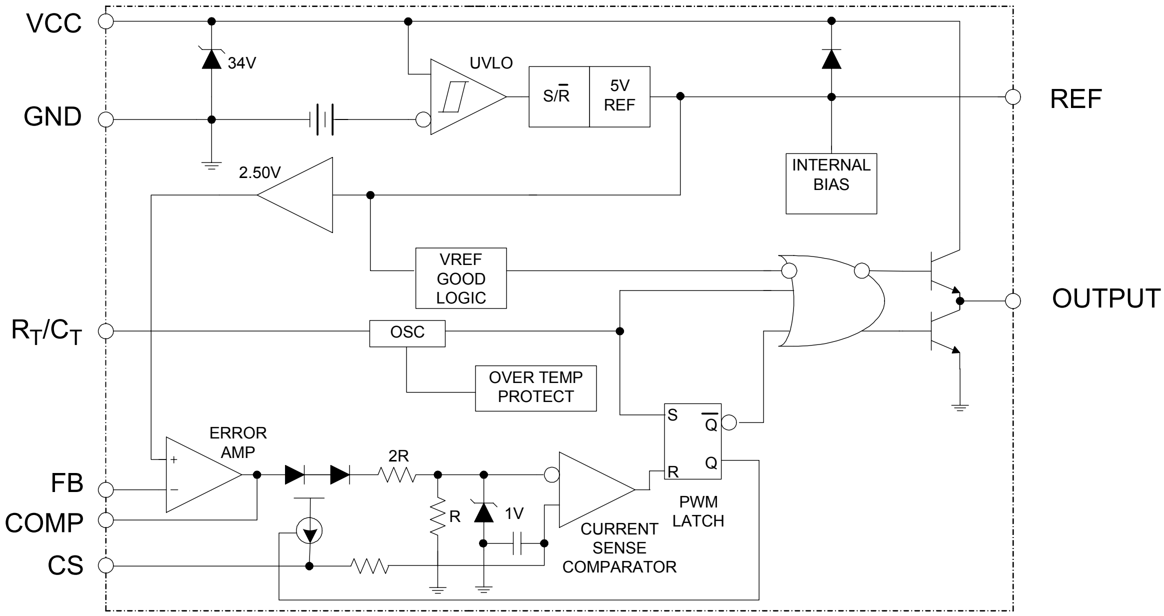


Figure 1. Functional Block Diagram of AP384XG

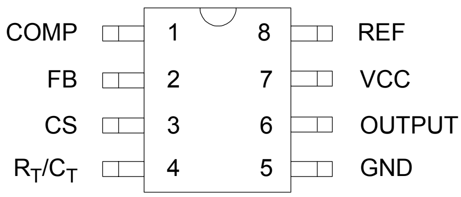


Figure 2. Pin Configuration of AP384XG

4.2 Oscillator

The oscillator frequency is set by the timing components R_T and C_T. In Figure 3, Capacitor C_T is charged from voltage reference of 5V through resistor R_T to approximately 2.8 V and discharged to 1.2 V by an internal current sink. During the discharge of C_T, the oscillator generates an internal blanking pulse that holds the center input of the NOR gate high. This blanks the output to be in a low state, so a controlled amount of output dead time is produced. An internal flip-flop is incorporated in the AP3844G/AP3845G that blanks the output off every other clock cycle by holding one of the inputs of the NOR gate high. Charged and discharged periods are determined by the formula:

$$t_C = 0.531 R_T C_T$$

$$t_D = R_T C_T \ln\left(\frac{0.0105 R_T - 2.2}{0.0105 R_T - 3.9}\right)$$

So, oscillator frequency can be calculated by:

$$f = (t_C + t_D)^{-1}$$

For $R_T \geqslant 5K$,

$f \approx 1.8/(R_T * C_T)$

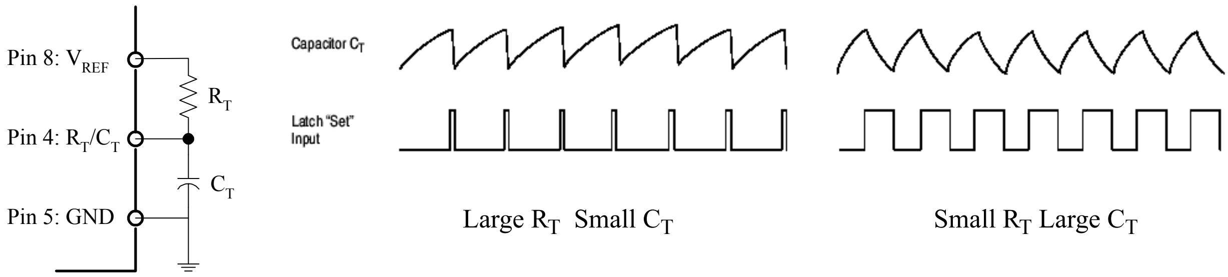


Figure 3. Oscillator Waveforms and Maximum Duty Cycle

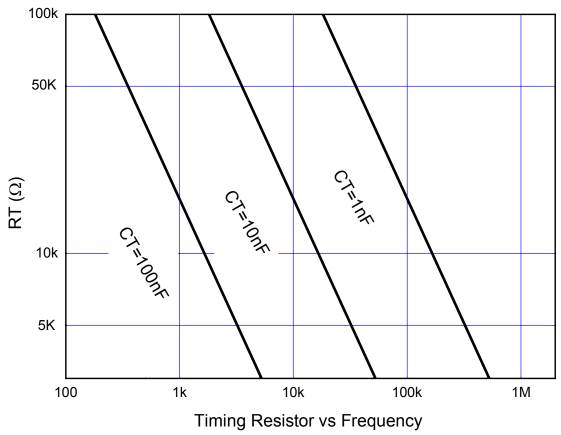


Figure 4. Timing Resistor vs. Frequency

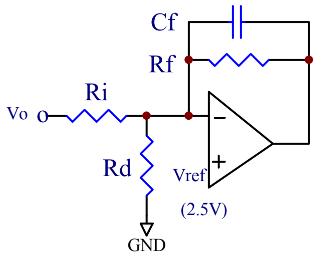


Figure 5. The Compensation Circuit for the Error Amplifier

4.3 Error Amplifier

The non-inverting input is internally biased at 2.5V and is not pinned out. The output voltage of a SMPS converter is typically monitored by the inverting input. The output voltage error equals to the product of the input bias current and the equivalent input divider source resistance. The Error Amp Output (Pin 1) is provided for external loop compensation. The output voltage is offset by two diode drops (1.4V) and divided by three before it connects to the inverting input of the current sense comparator. This guarantees that no drive pulses appear at the output (Pin 6) when Pin 1 is at its lowest state (V_{OL}), and this occurs when the power supply is operating and the load is removed, or at the beginning of a soft start interval. Both the amplifier source current (0.5mA) and the required output voltage (V_{OH}) determines minimum feedback resistor of Error Amp.

Rf (min) =(6V-2.5V)/0.5mA=7kΩ

4.4 Current Sense Comparator and PWM Latch

The current sense comparator and PWM Latch configuration ensures that a single pulse appears at the output for any oscillator cycle. The inductor current is converted to a voltage by inserting the resistor R_S, and R_S is in series with the source of output switch Q. The current sense input always monitors the voltage from resistor R_S and compares it with a level derived from the Error Amp output. The peak inductor current under normal operating conditions is controlled by the voltage at Pin 1 where: $I_{PK}=(V_{PIN1}-1.4)/3R_S$, Under abnormal operating condition, e.g., over-power for heavy load, the level on current sense comparator will be internally clamped to 1.0V. Therefore the maximum peak current is:

$I_{PK,\ MAX}=1/R_S$.

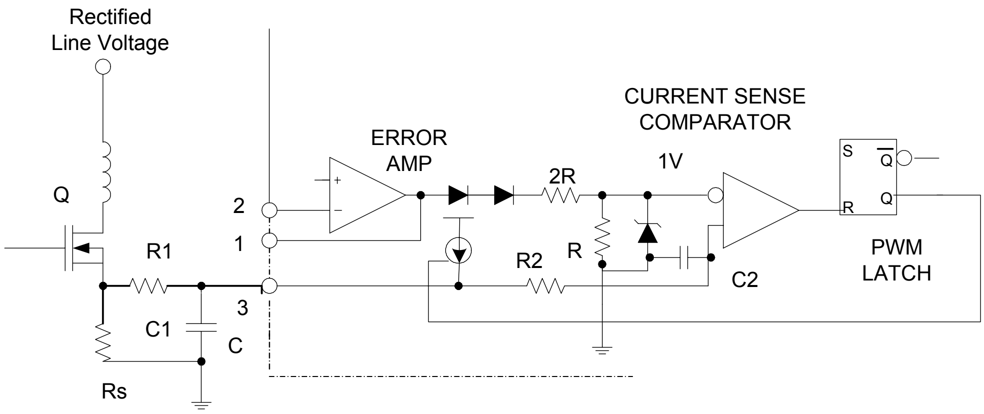


Figure 6. Current Sense Comparator

4.5 Green Mode

The AP384XG automatically enters skip cycle mode when the output power demand drops below a given level. The output power is monitored by sensing the FB pin. In normal operation, the FB pin indicates peak current under certain load current. If the load demand decreases, the internal loop asks for less peak current. When the set point reaches a determined value, the IC prevents the current from decreasing further down and starts to blank the output pulses, the IC then enters the skip cycle mode operation. The power transfer now depends upon the length of the pulse bunches.

Suppose we have the following component values:

L_P, primary inductance = 1mH;

f_S, switching frequency = 70kHz;

I_P = 200 mA

The theoretical power transfer is therefore:

$0.5 \times L_P \times I_P^2 \times f_S$=1.38W.

If this IC enters skip cycle mode with a bunch length of 20 ms over a recurrent period of 100 ms, then the total power transfer is:

1.38×0.2 = 276 mW.

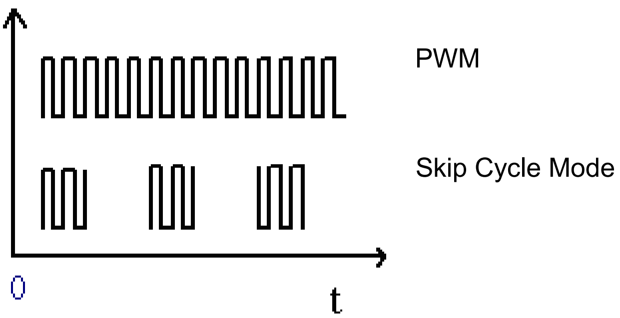


Figure 7. Skip Cycle Mode and PWM Mode

4.6 Leading Edge Blanking (LEB)

This is the enhanced function of AP384XG. Each time the power switch is switched on, a leading edge spike is generated due to parasitic capacitance, which may cause the power supply to exhibit instability, especially when the output is lightly loaded. To avoid premature termination of the switching pulse, a pulse with a time width of 250ns blanks this leading edge spike. During this period, the current-limit comparator is disabled and cannot switch off the gate drive regardless how big the SENSE voltage is. The additions of an RC filter on the Current Sense Input further improve noise immunity.

5. The Differences between AP384XG and 384X

Compared with 384X, AP384XG has built-in adjustable skip cycle function. The total power consumption of SMPS with AP384XG can be considerably reduced under light load.

Furthermore, the start-up current of AP384XG is considerably lower than 384X, resulting less power losses on start-up resistor. The rise time of AP384XG PWM output is 150ns while 384X is 50ns, so a smaller power switch gate driver resistor can be used when using AP384XG to replace 384X in AC-to-DC converters. The leading edge blanking is another enhanced function of AP384XG in order to improve circuit noise immunity. Table 1 gives the main differences between AP384XG and AZ384XA.

Table 1. The differences between AP384XG and AZ384XA

Parameter	Test Conditions	AP384XG			AZ384XA			Units
		Min	Typ	Max	Min	Typ	Max	
Total Standby and UVLO Section								
Start-up Current			40	80		150	300	μA
Standby Operating Current			6			-		mA
Operation Current			8			10		mA
Skip Cycle Section								
Source Current (@CS)	V_{FB}=2.6V	180	200	220	No this function			μA
Current Sense Section								
Leading Edge Blanking Duration			250		No this function			ns
Output Section								
Rise Time			150		50			ns

6. Notes for typical green power applications

The AP384XG can be used to replace 384X directly, and it is suitable for most SMPS adapter kinds where flyback circuits are widely used. The standby power dissipation of the entire power converter can be significantly reduced to typically 0.5W when using AP384XG, and this help to meet both the "Blue Angel" and "Energy Star" standards. When designing these circuits, lowering power dissipation, improving stability and reliability, and realizing short circuit protection should be taken into consideration.

6.1 Selection for Start-up Resistor

Low start-up current (40μA) allows high value start-up resistor to be used for AP384XG. Through a 1.2MΩ start-up resistor R_C, VCC hold up capacitor C_{IN} can be charged up to 9V for 3843G/3845G or 16V for 3842G/3844G even under low line voltage 90Vrms. Power dissipation of such larger resistor R_C would be less than 100mW even under high line voltage (V_{AC} = 250Vrms) conditions. Once the AP384XG begins to work, the IC is supplied from an auxiliary winding of the transformer to provide the operation current. In general, the recommended supply voltage is above 13V for 3842G/ 3844G, and 8.5V for 3843G/ 3845G.

6.2 Adjusting the Skip Cycle Level

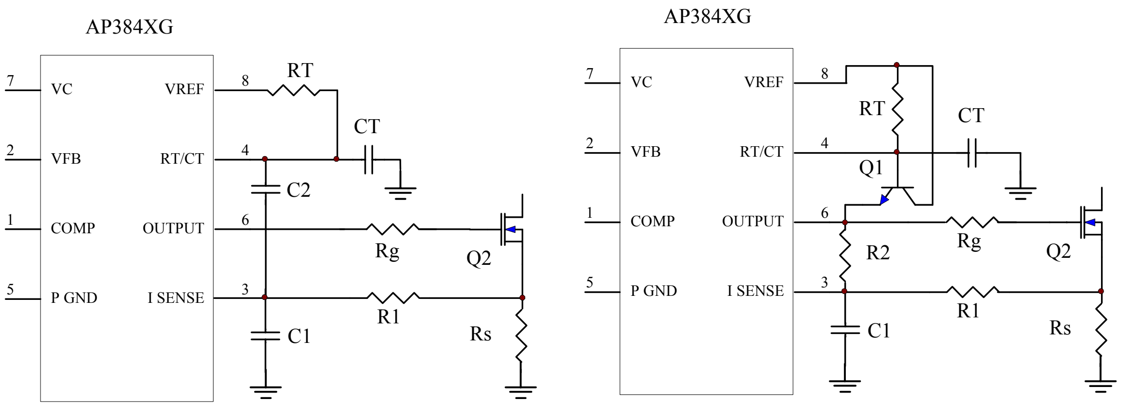
The resistor R1 on pin 3, shown in Figure 6, can be used to adjust skip cycle set point: the larger the resistor, the lower load power required to enter the skip cycle mode. The typical range of the resistor is from 300Ω to 4KΩ.

6.3 Slope Compensation and LEB

Slope Compensation technology is always recommended to keep the system stable when duty cycle is greater than 50%, for example, pulse width jitter of a AC-to-DC converter often happens at low line voltage. Figure 8 gives two methods to perform the function; Figure 8-1 is by adding capacitor C2 between pin 3 and pin 4, Figure 8-2 is by adding transistor Q1. In addition, capacitor C1 is optional if slope compensation is not required, because AP384XG has the enhanced function of LEB.

6.4 Speedup Start-up Circuit

The output set-up time for AC-to-DC adapter with AP384XG is close 2s or longer, and this is especially obvious at lower line voltage. To reduce circuit start-up time, Figure 9 affords a solution.



(8-1) (8-2)

Figure 8. Slope Compensation Methods

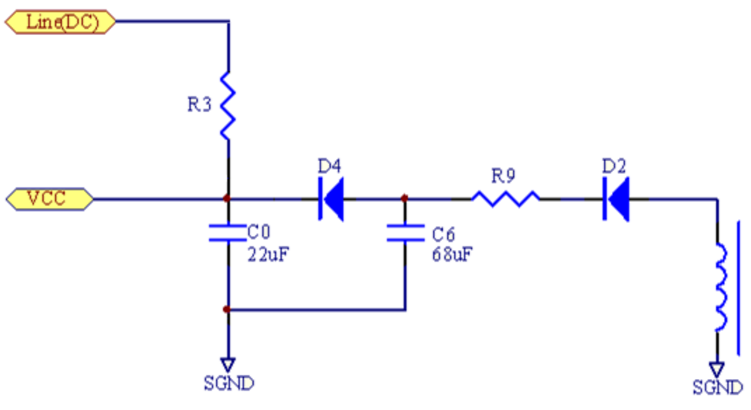


Figure 9. Speedup Startup Circuit

7. Typical Application Circuit 1: 12V/3A AC-to-DC Adapter

Figure 10 is a typical AC-to-DC adapter using AZ3843A or AP3843G (U1). The low standby power dissipation can be easily obtained when using AP3843G to replace AZ3843A, only few components should be adjusted, which are shown in table 2. Table 3 is the bill of materials when using AP3843G, and table 4 is the specifications of the application circuit.

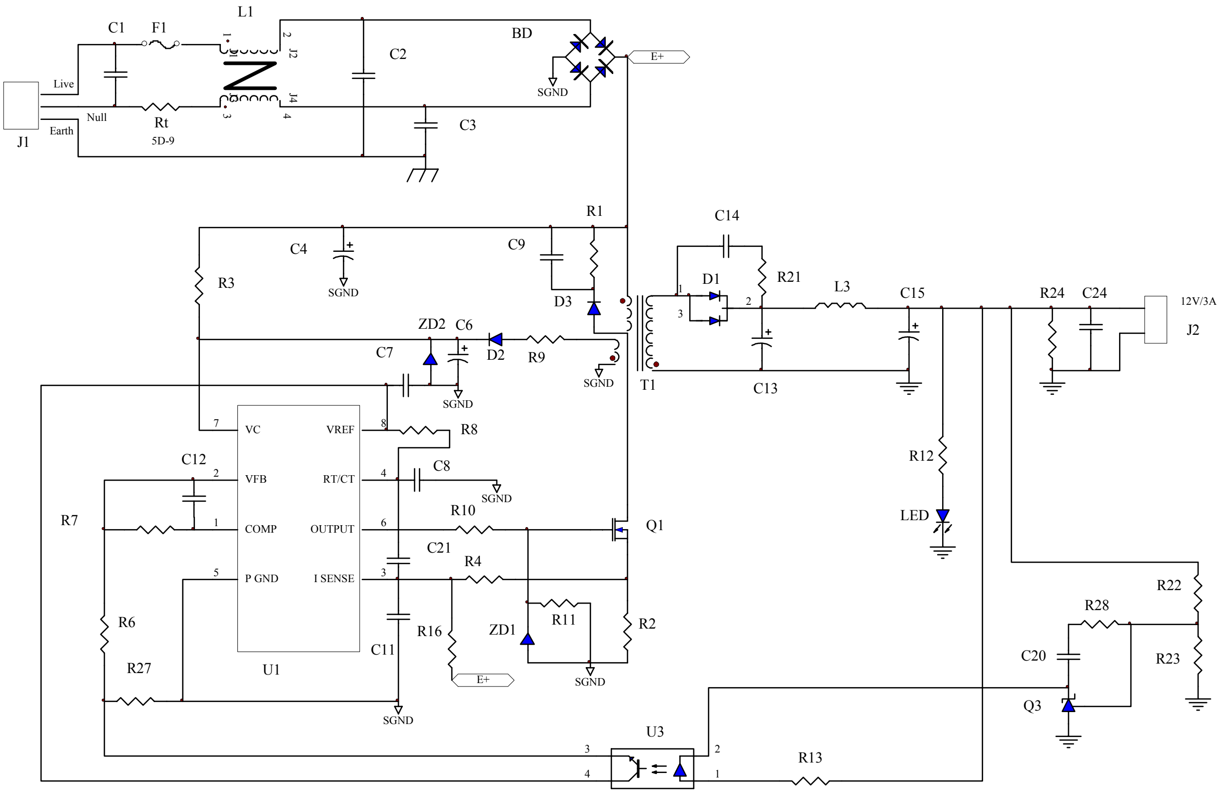


Figure 10. 12V/3A AC-to-DC Adapter

Table 2. Components to be Modified when Using AP3843G to Replace AZ3843A

Components	Reason and Effect
R3	AP3843G has low start-up current (40μA), so increasing R3 is suitable for lowering thermal dissipation on start-up resistor.
R4	For AP3843G, R4 is used to set skip cycle except for reducing narrow spike on the leading edge of the current waveform. Different R4 is used to determine the different output power for AP3843G.
R24	R24 is dummy load, which supplies energy for IC to get high load regulation, lower supply current under standby mode is needed for AP3843G, so it is suitable for AP3843G to use bigger R24 to reduce energy loss.

Table 3. Bill of Materials

Component	Description	Component	Description
R1	Resistor, 24 kΩ, 2W	ZD1	Zener Diode, 1N5819
R2	Resistor, 0.75Ω, 0.5W	ZD2	Zener Diode, 18V/0.5W
R3	Resistor, 560 kΩ, 0.25W	C1	Capacitor, 0.22μF, 275V
R4	Resistor, 430Ω, 0.25W	C2, C3	Capacitor, 2200pF, 250V
R6	Resistor, 22 kΩ, 0.25W	C4	Capacitor, 68μF, 400V
R7	Resistor, 56 kΩ, 0.25W	C6	Capacitor, 47μF, 35V
R8	Resistor, 12 kΩ, 0.25W	C7	Capacitor, 0.1μF
R9	Resistor, 10Ω, 0.25W	C8	Capacitor, 2200p
R10	Resistor, 3Ω, 0.25W	C9	Capacitor, 470p, 1kV
R11	Resistor, 20 kΩ, 0.25W	C11, C12, C21	Capacitor, 100p
R12	Resistor, 4.7 kΩ, 0.25W	C13	Capacitor, 100μF, 100V
R13	Resistor, 3.6 kΩ, 0.25W	C14	Capacitor, 1000p, 100V
R16, open	Resistor, 2MΩ, 0.25W	C15	Capacitor, 2200μF, 16V
R21	Resistor, 10Ω, 0.5W	C20	Capacitor, 0.22μF
R22	Resistor, 9.1kΩ, 0.25W	Q1	MOSFET, K1507
R23	Resistor, 2.4 kΩ, 0.25W	Q3	Voltage Reference, AZ431
R24	Resistor, 2 kΩ, 0.25W	F1	Fuse, 250V/2A
R27	Resistor, 680Ω, 0.25W	LED	Indicator diode
R28	Resistor, 100Ω, 0.25W	T1	Transformer, EI28
D1	Diode, MBR20100CT	U1	Controller, AP3843GM
D2	Diode, 1N4148	U3	Optical coupler, PC817
D3	Diode, FR107	L3	Inductor, 8μH /3A

Table 4. 12V/3A Power Supply Specification

Parameters	Results	Unit	Parameters	Results	Unit
Input Line Voltage	85 to 265	V	Load Regulation	1.5	%
Output Voltage	12.3	V	Output Ripple	50	mV
Output Current	3	A	Efficiency	85	%
Line Regulation	10	mV	Rated Output Power	37	W
Standby Power Dissipation	0.5	W			

8. Typical Application Circuit 2: 5V/3A DC-to-DC Converter

Figure 11 is a DC-to-DC converter using AP3843G in buck topology.

Table 5 is the bill of materials, and table 6 is its specifications.

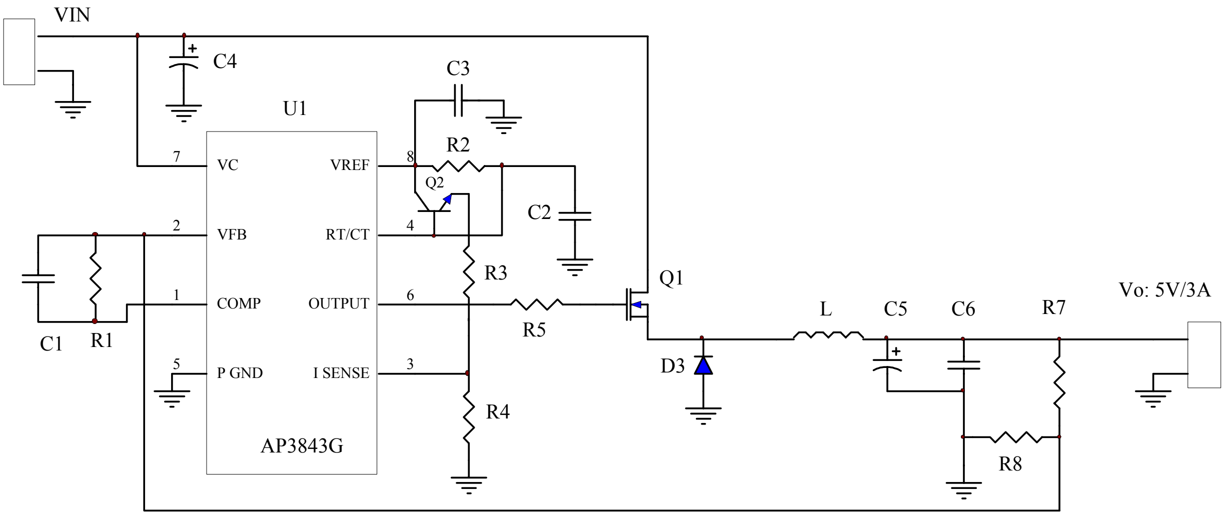


Figure 11. 5V/3A AC-to-DC Adapter

Table 5. Bill of Materials

Component	Description	Component	Description
R1	Resistor, 56 kΩ, 0.25W	C3	Capacitor, 0.1μF
R2	Resistor, 2.4kΩ, 0.25W	C4	Capacitor, 1000μF, 35V
R3	Resistor, 27kΩ, 0.25W	C5	Capacitor, 2200μF, 10V
R4	Resistor, 10kΩ, 0.25W	C6	Capacitor, 1μF
R5	Resistor, 4.7Ω, 0.25W	U1	PWM Controller, AP3843G
R7, R8	Resistor, 1kΩ, 0.25W	Q1	MOSFET, FDB7030
C1	Capacitor, 220p	D3	Diode, 20TQ045
C2	Capacitor, 2200p	Q2	Transistor, 9013

Table 6. 5V/3A Power Supply Specification

Parameters	Values	Unit
DC Input Voltage	8 to 25	V
Output Voltage	5	V
Output Current	3	A
Switching Frequency	280	KHz
Efficiency@ 3A	74 to 82	%
Load Regulation	2	%
Line Regulation	4	%
Ripple Voltage	50	mVpp