A704

SWITCHING MODE LED DRIVER

ADDtek
www.addmtek.com

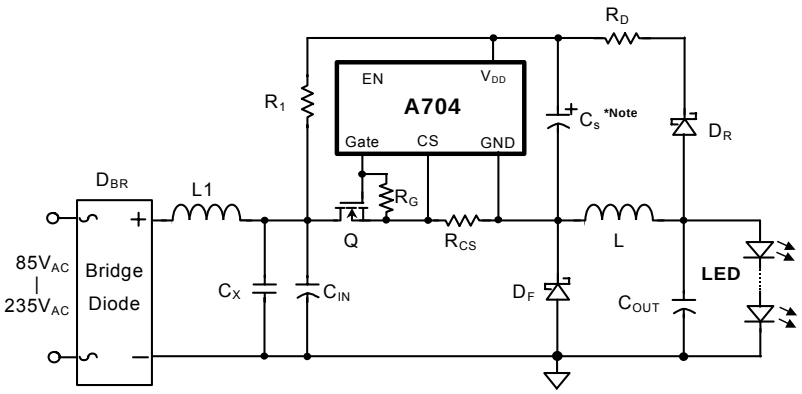
DESCRIPTION

The A704 is a PWM high efficiency LED driver controller. The LED string is driven at constant current rather than constant voltage, thus providing constant light output and enhanced reliability.

FEATURES

- **Low Startup Current (5uA in typical).**
- **Low Operating Current (3mA in typical).**
- **Lead-Edge Blanking.**
- **Internal OVP Detected.**
- **150°C OTP Sensor with Hysteresis.**
- **Under Voltage Lockout (UVLO).**
- **Fixed PWM Frequency.**
- **PFC > 0.9 with Suitable External Components.**

TYPICAL APPLICATION CIRCUIT

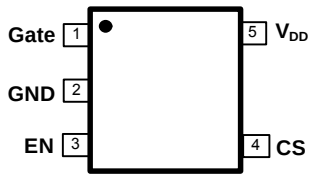


*Note: C_S ***MUST*** be very close to A704's V_{DD} pin and GND pin.
Please refer to ADDtek's reference layout.

APPLICATIONS

- B22, E27 lamp device
- General purpose lighting

PACKAGE PIN OUT



SOT-23-5
(Top View)

Preliminary

ORDER INFORMATION

W	**SOT-23-5**
	5 pin
	A704WFT

Note: The letter "F" is marked for Lead Free parts, and letter "T" is marked for Tape & Reel.

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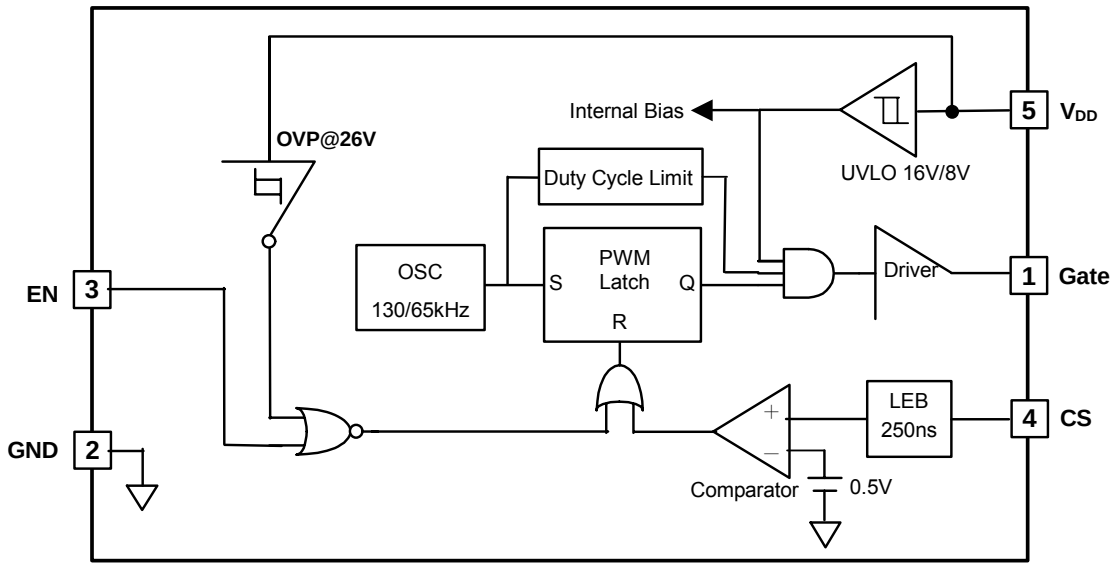
ABSOLUTE MAXIMUM RATINGS (Note)

Input Voltage, V_{DD}	32V
Operating temperature	-20°C ~85°C
Maximum Operating Junction Temperature, T_J	150℃
Storage Temperature Range	-65°C to 150°C
Lead Temperature (Soldering, 10 seconds)	260°C

Note: Exceeding these ratings could cause damage to the device. All voltages are with respect to Ground. Currents are positive into, negative out of the specified terminal.

BLOCK DIAGRAM



Preliminary

PIN DESCRIPTION

Pin Name	Pin Function
Gate	Drives the gate of the external MOSFET.
GND	Power Ground Pin.
EN	Enable Pin.
CS	Current Sense Pin
V_{DD}	Input Power Supply Pin and Over Voltage Protected Pin.

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THERMAL DATA

Thermal Resistance from Junction to Ambient, θ_{JA}	TBD °C /W

Junction Temperature Calculation: $T_J = T_A + (P_D \times \theta_{JA})$.
The θ_{JA} numbers are guidelines for the thermal performance of the device/pc-board system.
Connect the ground pin to ground using a large pad or ground plane for better heat dissipation.
All of the above assume no ambient airflow.

Maximum Power Calculation:

$$P_{D(MAX)} = \frac{T_{J(MAX)} - T_{A(MAX)}}{\theta_{JA}}$$

$T_J(^oC)$: Maximum recommended junction temperature

$T_A(^oC)$: Ambient temperature of the application

$\theta_{JA}(^oC/W)$: Junction-to-Ambient thermal resistance of the package, and other heat dissipating materials.

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ELECTRICAL CHARACTERISTICS

V_{DD}=20V_{DC}, C_{Load}=1nF, R_{Load}=2.2Ω in series, T_A=25°C, unless otherwise noted.

Description & Conditions	Parameter	Conditions	Min	Typ	Max	Unit
Input Supply Voltage	V_{DD}		6.5		32	V
Input Supply Current	I_{DD}	After start-up, V_{DD}=20V		3	5	mA
Input Quiescent Current	I_{QC}	Before start-up, V_{DD}=15V		5	30	uA
Input Shutdown Current	I_{SD}	V_{DD} pin, after start-up. V_{DD}=20V, V_{EN}=Low		1	2	mA
Under-Voltage Lockout, Turn On	$V_{UVLO,ON}$		16	17	18	V
Under-Voltage Lockout, Turn Off	$V_{UVLO,OFF}$		6		8	V
Over-Voltage Protection	V_{OVP}	V_{DD} pin	26			V
Current Sense Voltage	V_{CS}		485	500	515	mV
Enable Input Logic “High”	V_{IH}		2.2		6	V
Enable Input Logic “Low”	V_{IL}		0		0.8	V
Oscillator Maximum Duty Cycle	D_{MAX}				50	%
Leading Edge Blanking	t_{LEB}		150	200	250	nS
CS to Gate Pin Delay Time	t_{PD}	CS=“1”, Gate=“0”		50	75	nS
Minimum Turn-ON Time	$t_{ON,MIN}$		300			nS
Thermal Shutdown Temperature	T_{SD}		150			°C
Thermal Shutdown Recovery Temperature	T_{REC}		120			°C
Switching Frequency	f_{SW}		50		70	kHz
Gate Pin Source Current	I_{SOURCE}	C_{Load}=1nF		300		mA
Gate Pin Sink Current	I_{SINK}	C_{Load}=1nF		500		mA
Gate Pin Maximum Voltage	V_{Gate}			20		V

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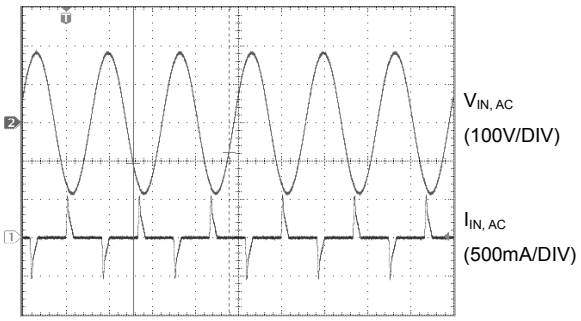
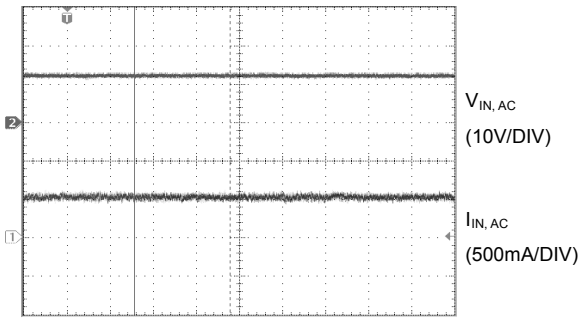
CHARACTERISTIC CURVES

AC Input Voltage and Current



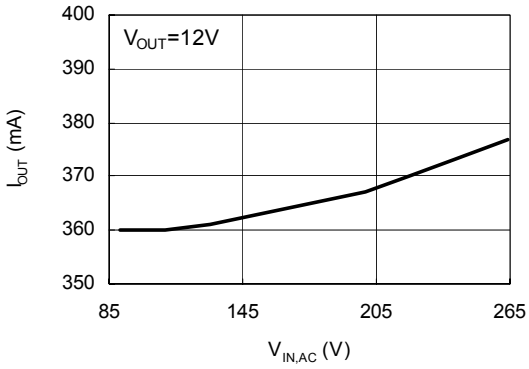
TIME= 10ms/DIV

Output Voltage and Current

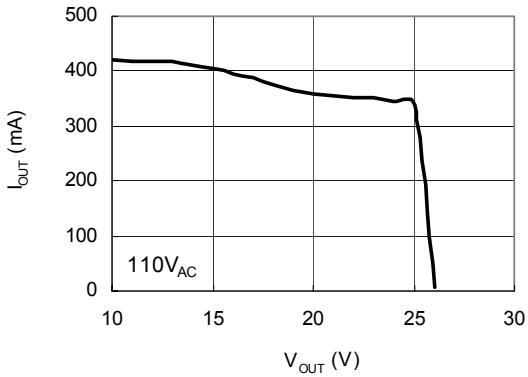


TIME= 10ms/DIV

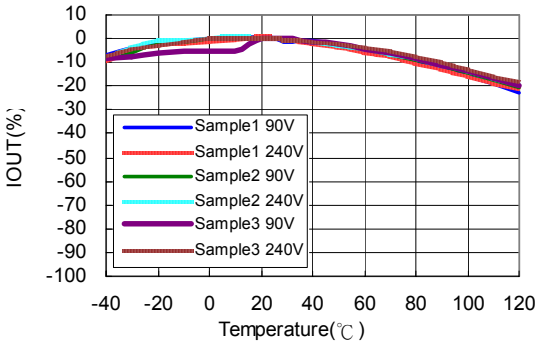
Line Regulation



Load Regulation



Sample to Sample Offset vs. Temperature



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APPLICATION INFORMATION

The A704 PWM controller is a monolithic integrated circuit, design for High Brightness LED application, provides the necessary feature to implement LED driver with a minimal external component needed. Internally implemented function include, a low start up current and operating current reducing the power dissipation on start-up resistor, Built-in OVP and UVLO function detected the LED output whether open and short circuit occur, SOT-23 package can save your PCB layout spaces and easy design into place you want, …etc.

Application Circuit:

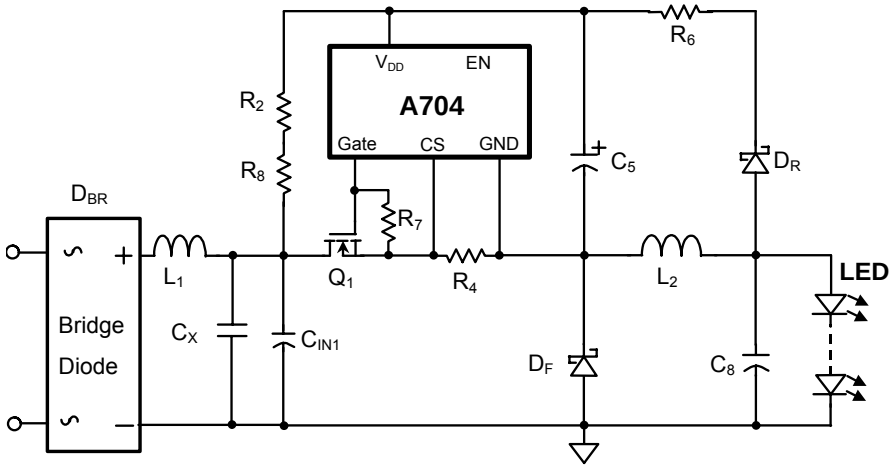

Fig. 1 - Typical Application circuit

Circuit Topology

A Buck converter is an excellent choice for LED driver in off line application provides a constant LED current. A peak current controlled buck converter can give reasonable LED current variation over a wide input rang and LED voltage when the converter is implemented in continuous conduction mode. The A704 is a "Buck" or Step-Down Converter controller and its typical application circuit was shown as Fig.1. Simplify Fig. 1, its basic schematic can be seen in Fig.2.

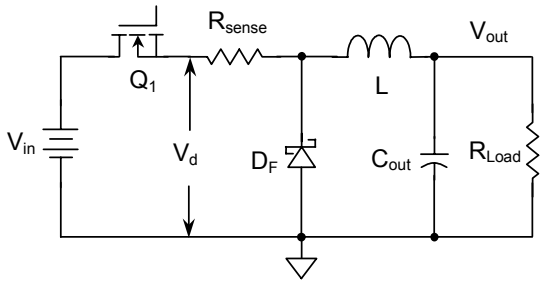

Fig 2. Basic Buck converter

The operation of this regulator topology has two distinct time periods. The first one occurs when the series switch is "on", the input voltage is connected to the input of the inductor. The output of the inductor is the output voltage, and the rectifier (or catch diode) is reverse biased. During this period, since there is a constant voltage source connected across the inductor, the inductor current begins to linearly ramp upwards, as described by the following equation:

$$I_{L(on)} = \frac{(V_{in} - V_{out}) \times t_{on}}{L}$$

During this "on" period, energy is stored within the core material in the form of magnetic flux. If the inductor is properly designed, there is sufficient energy stored to carry the requirements of the load during the "off" period.

The next period is the "off" period of the power switch. When the power switch turns off, the voltage across the inductor reverses its polarity and is clamped at one diode voltage drop below ground by the catch diode. The current now flows through the catch diode thus maintaining the load current loop. This removes the stored energy from the inductor. The inductor current during this time is:

$$I_{L(off)} = \frac{V_{out} \times (T_s - t_{on})}{L}$$

This period ends when the power switch is once again turned on. Regulation of the converter is accomplished by varying the duty cycle of the power switch. It is possible to describe the duty cycle as follows:

$$D = \frac{t_{on}}{T_s}$$

Where, T_s is period of switching, and t_{on} is " turn on" time of Q_1.

For the buck converter with ideal components, the duty cycle can also be described as: Figure 3 shows the buck converter, idealized waveforms of the catch diode voltage and the inductor current.

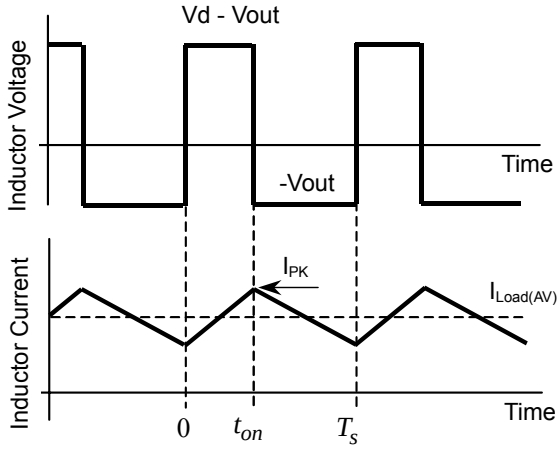

Fig 3. Basic Buck converter

Component Selection

This application note discusses the design of a buck-based LED driver using A704 with the help of an off-line application example. . In this example, Vin= 90~240Vac & LED string voltage= 12V are used. Anyway, the same procedure can be used to design LED drivers with wide AC voltage input & DC voltage output.

1. Maximum output voltage consideration ($V_{o,\max}$)

The first design criterion to meet is that the maximum LED string voltage $V_{o,\max}$ is should be less than half the minimum input voltage to avoid having to implement a special loop compensation technique. For this example, the minimum input voltage $V_{in,dc}$ should be:

$$V_{in,dc\_\min} = 2 \times V_{o,\max}$$

Where, $V_{in,dc\_\min}$ is the minimum voltage of bridge diodes

For example, the $V_{in,dc\_\min}$ in the circuit of this application note is about 100V. So the $V_{o,\max}$ (LED string voltage) should < 50V.

2. Choose the Input Diode Bridge (D_{BR})

The voltage rating of the bridge diode V_{bridge} will depend on the maximum value of the input voltage. The current rating will depend on the maximum average current drawn by the converter.

$$V_{bridge} = 1.25 \times (\sqrt{2} \times V_{\max,ac}) \ldots (1)$$

Where, $V_{\max,ac}$ is the maximum input voltage RMS value.

The 1.25 factor in equation (1) is used for a safety margin.

For this design, the V_{bridge} should be exceed than (1.25* 1.414* $V_{\max,ac}$)= (1.25*1.414* 240)=425 V. A 600V, 0.5A bridge diode is chosen in the example.

3. Choose the Input inductor and input Capacitors

Placing an inductor (L1) in series with input bridge rectifier reduces input current rejection to input source. At this times, utilizing the equivalents series resistance (ESR) of L1 to limit the inrush current charge to input bulk capacitor C1. The ESR should limit the inrush current not more than the Maximum Peak forward Surge Current (I_{FSM}) of the bridge rectifier specification as given by equation (2), assuming maximum voltage is applied. The required resistance is:

$$ESR \geq \frac{V_{bridge}}{I_{FSM}} \qquad (2)$$

In this design, the V_{bridge} is 425 V and I_{FSM} is 30A. So the ESR of the chock should > (425/30)=14.1Ω. If the power loss of such high ESR chock is too high, the designer can replace the high ESR chock with a low ESR chock and add a negative-temperature-coefficient (NTC) resistor to limit the inrush current. As long as the (NTC (hot) resistance + low ESR Chock resistance) is lower than the resistance of the high ESR chock, the efficiency of the A704 DC-DC can be improved.

The hold-up and input filter capacitor required at the diode bridge output have to be calculated at the minimum AC input voltage. The minimum capacitor value can be calculated as:

In this design, $C1 \geq \frac{V_{o,\max} \times I_{o,\max} \times (1 - 2 \times freq \times t_c)}{(2 \times V_{\min,ac}^2 - V_{\min,dc}^2) \times \eta \times freq}$

Where, $freq$ is the AC input frequency, as a rule, $freq$ is 50 ~ 60Hz.

η is efficiency of the system , and t_c is the conduction angle of the AC input, use 45° conduction angle if unknown.

$$C1 \geq \frac{12 \times 0.35 \times (1 - 0.5)}{(2 \times 90^2 - 90^2) \times 0.8 \times 60} \geq 5.4uF$$

The voltage rating of the capacitor should be at least 1.15 times greater than the peak input voltage for a safety margin. For example, the input 220Vac input, the input capacitor voltage should exceed than as:

$$V_{\max,cap} \geq 1.15 \times \sqrt{2} \times V_{\max,ac} \Rightarrow V_{\max,ac} \geq 360V$$

Choose a 400V/ 10μF electrolytic capacitor in the example.

Such electrolytic capacitor has sizable ESR component. The large ESR of these capacitors makes it inappropriate to absorb the high frequency ripple current generated by the buck converter. Thus, adding a small MLCC capacitor in parallel with the electrolytic capacitor is recommended.

4. Choose the power choke

The inductor selection should make the Buck converter work in CCM; the inductor value depends on the ripple current in the LEDs. For example, assume a +/- 30% ripple current in the LEDs. Then, the inductor can be calculated as:

$$L = \frac{V_o(1 - D)T_S}{0.6I_o \times \eta}$$

In this design example, T_S is 16.6μs, D=0.12, Vo=12V_{dc}, η=0.8, Io=0.35

$$L = \frac{12 \times (1 - 0.12) \times 16.6\mu}{0.6 \times 0.35 \times 0.8} = 1.05mH$$

Choose the power choke inductance is 1mH.

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Note that the inductance of most chocks drop when the chock current has DC-current components. This inductance drop may cause the actual Io to be lower than the calculation value of Io (please refer the Rcs section of this application note for more detail)

5: Choose the FET (Q1) and Diode (D_F)

Since these power components (diode & MOSFET) maximum peak current exceeds the regulator maximum load current, these components current rating must be at least 1.2 times greater than the maximum load current. And the reverse voltage rating of these components should be at least 1.25 times the maximum input voltage. Therefore, the peak voltage seen by the FET is equal to the maximum input voltage

$$V_{Q1} = 1.25 \times V_{\max,ac} = 1.25 \times (\sqrt{2} \times 240) = 425V$$

Hence, the current rating of the FET is

$$I_{Q1} = 1.25 \times I_{o,pk} = 1.25 \times 1.3 \times 0.35 = 0.57A$$

In the example, choose at least a 500V 2A N-channel MOSFET. A 600V/2A N-channel MOSFET can allow more safety margin.

The peak voltage rating of the diode is as same as the Q1 MOSFET. Hence,

$$V_{DF} = 1.25 \times V_{\max,ac} = 1.25 \times (\sqrt{2} \times 240) = 425V$$

The average current through the diode is:

$$I_{DF} = 1.25 \times I_{o,pk} = 1.25 \times 1.3 \times 0.35 = 0.57A$$

Choose 600V 2A Trr=35nS Fast recovery diode in the example.

6. Choose the Sense Resistor (R4)

Since the output ripple current I_{PP} is design for 0.6 times Io current.

$$I_{pp} = \frac{V_o(1-d)T_s}{L} = 0.6 \times I_o$$

Therefore the Peak current can be given as:

$$I_{pk} = I_o + \tfrac{1}{2} I_{pp} = 1.3 \times I_o$$

Hence, the sense resistor value is given by:

$$R_{cs} = \frac{V_{cs}}{1.3 \times I_o} = \frac{V_{cs}}{I_{pk}}$$

In the design example, use R_{CS} = (0.5V/(1.3*0.35) =1.1Ω. Note that factors like inductor value deviation could cause the actual Io to be higher (or lower) than the ideal value. So we may need to fine-tune the Rcs value for accurate Io.

7. Start-up Circuitry

When the power is turned on, the input rectified voltage $V_{in,dc}$ charges the hold-up capacitor C_5 and the output capacitor *Cout* via a start-up resistor R_{in} as shown in Fig. 4. As the voltage of V_{CC} pin reaches the start threshold voltage $V_{TH(ON)}$, the A704 activates and drives the entire power supply to work.

$$V_{TH(ON)} \cong \frac{C_{out}}{C_{out}+C_5}(V_{in} - I_{DDST} \cdot R_{in})(1 - e^{\frac{-T_D}{R_{in}\cdot(C_5 // C_{out})}})$$

Where I_{DDST} is the start-up current of A704

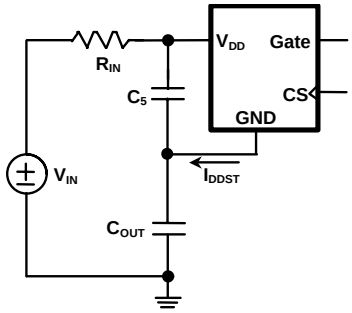

Fig.4. Start-up Circuitry

Since the start-up current I_{DDST} is only 5uA typical, a large R_{IN} such as 2M ohms can be used. Also with a C_5 is 2.2uF/50V, and *Cout* is 22uF/50V, the Start-up delay T_{D_ON} is less than 0.63 sec for 90Vac input.

For example, if the input voltage $V_{in,dc}$ is 310Vdc, output voltage V_o=12Vdc, and start-up resistor R_{in} is 2MΩ，the power dissipation on the R_{in} is:

$$P_{R_{in}} = \frac{V_{in,dc}^2 - 2V_o^2}{R_{IN}} = \frac{310^2 - 2\times 12^2}{2M} = 48mW$$

LAYOUT GUIDELINES

1. PCB Layout consideration：The hold-up capacitor C_5 need closed by the V_{DD} pin of the controller IC。
2. PCB Layout consideration: Please must put these components, (Cin1, Q1, R4, DF) & (Q1,704, R4,R7), as close as possible to each other when in PCB placement (refer to Fig-1, Fig-11 & Fig-12). An A704 DC-DC may not work well if some of these components are placed far away from others.
3. When the MOSFET turned on, a spike, which is induced by the diode reverse recovery and by the output capacitances of the MOSFET and diode, inevitably appears on the sensed signal. Inside A704, a leading edge blanking time about 250nsec is introduced to avoid premature termination of MOSFET by the spike. Therefore, only a small-value RC filter (e.g. 100ohm + 470pF) is required between the SENSE pin and RS.
4. A704 output stage is a totem pole driver stage that can directly drive MOSFET gate. It is also equipped with a voltage clamping circuit to protect MOSFET from damage caused by undesirable over drive voltage. The output voltage is clamped at 20Vmax. An external pull down resistor Rx in the range of 10k to 47k ohm is used to avoid floating state of gate before startup. A gate drive resistor Rg in the range from several to several tens ohm is recommended. This resistor limits the peak gate drive current and provides damping to prevent oscillations at the MOSFET gate terminal.

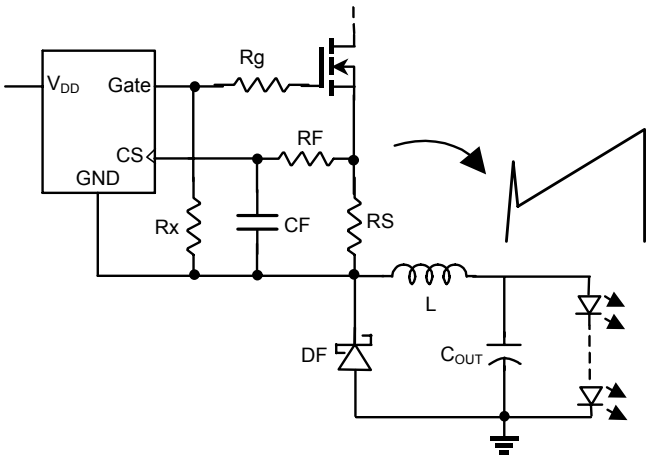

Fig.10. Gate drive

5. The power stage ground and the controller loop ground in this circuit is different, therefore, the measurement equipment need be isolated with device under test (DUT).
6. When output load is open/disconnect, the output voltage would increase the value of the over-voltage protection. However, the start-up circuitry still charges energy to the output capacitor; Placed a dummy load in the range of 10k to 47k ohm in the output is recommended.

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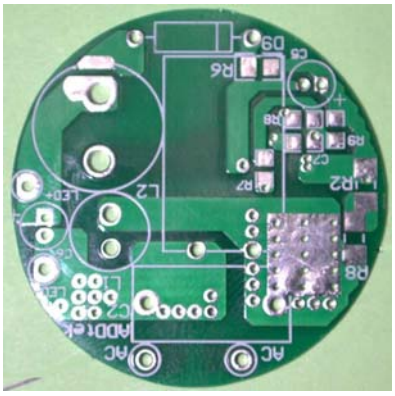

Figure 11. Top layer

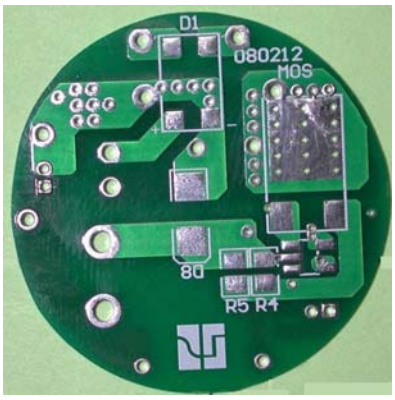

Figure 12. Bottom layer.

Table 1. Bill of Material list

C.R. NO	Q'TY	Description	Vendor	Package
A1	1	A704 control IC	ADD	SOT23-5
Q1	1	Power NMOS 02N60H	APEC	TO-252,
C_{IN1}	1	E.C Cap：10uF/ 400V	NCC	DIP D10x16mm
C_X	1	Cap X1 MPP 0.1uF	Chiefcon	CKX104M
L1	1	IND 2.2mH	GangSong	
L2	1	IND 1mH	GangSong	
DF	1	DIO Super fast 600V 2A,	PANJIT	SMB
DR	1	DIO Fast Diode 600V 1A,	PANJIT	SMA
D_{BR}	1	Bridge Diode 600V 0.5A B6S	PANJIT	MDI
R2, R8	2	1MΩ	relac	SMD 1206
R4	1	1.1Ω	relac	SMD 0805
R6	1	12Ω	relac	SMD 0805
R7	1	47kΩ	relac	SMD 0805
C5	1	E.C Cap：2.2uF/ 50V	NCC	D5x11
C8	1	E.C Cap：22uF/ 50V	NCC	D5x11

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