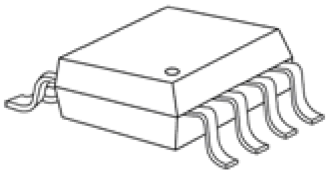
AC/DC LED Controller with 4-step Dimming Capability

Features

- Efficiency> 85% when V_{AC} =110V, I_{LED}=100mA, V_{LED} =80V
- PWM switching control
- 4-step dimming capability
- Operation with active power factor correction
- THD < 15% when V_{AC} =110V, I_{LED}=100mA, V_{LED} =80V
- Full protections: OTP/UVLO/OVP/OCP/LED open-/short-circuit
- Current setting accuracy within ±5%
- Full range line regulation within 1.7%
- Available in SOP-8L package

Small Outline Package



GD: SOP8L-150-1.27

Product Description

MBI6904 is a high efficiency buck-boost AC/DC controller designed to deliver constant output current. The input voltage range of MBI6904 application is universal from 85V_{AC} to 265V_{AC}. It is featured by a PWM control scheme. MBI6904 is designed to operate with active power factor correction (PFC) circuit and is therefore capable of maintaining system power factor greater than 0.9 with proper design. MBI6904 regulates the output current within ±5% of the preset current by well controlling the external MOSFET. In addition, MBI6904 can operate with 4-step dimming. MBI6904 also protects the controller from fault conditions, inclusive of under voltage lock-out (UVLO), over voltage protection (OVP) and over current protection (OCP). To ensure the system reliability, over temperature protection (OTP) is built-in to prevent IC from over temperature (155°C) by turning off the external MOSFET. Once the temperature drops below 125°C, the external MOSFET will resume working. MBI6904 is available in SOP-8L package.

Applications

- T-8 CFL Replacement LED Solution
- E26/E27 Light Bulb Alternative LED Solution
- Flat Panel Lighting Solution
- General Illuminations

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Typical Application Circuit

The component selection is made based on the loading of 80V/100mA for AC input 220V. Different settings may require different component selection accordingly.

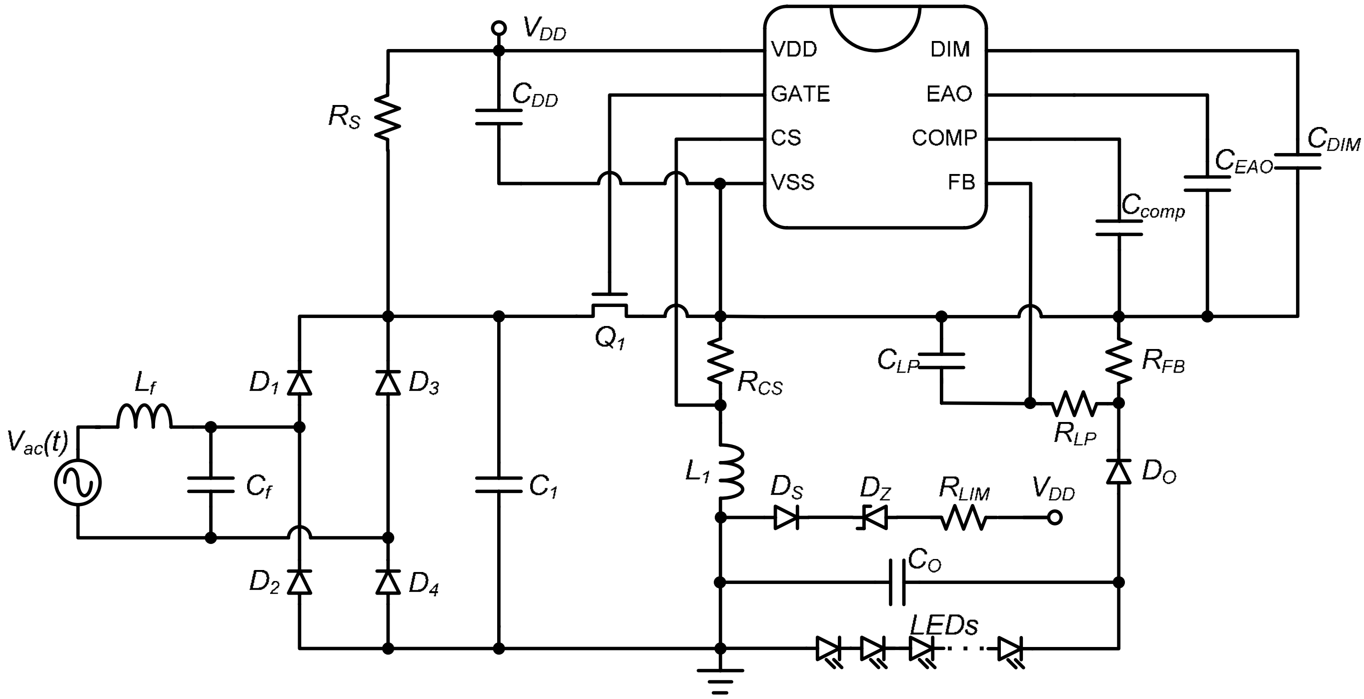


Fig. 1

C_1: 100nF/450V, metal film capacitor
C_O: 47μF/100V, 105°C 8000hrs electrolytic capacitor
D_O: 600V/2A, 35ns superfast diode
D_S: 600V/1A, 35ns superfast diode
D_Z: 51V, 800mW, zener diode
L: 1.5mH, EE13 power inductor
R_S: 1MegΩ, 5% resistor (sustaining voltage at least 400V)
R_{FB}: 2Ω, 1% SMD resistor
R_{CS}: 100mΩ, 1% SMD resistor
R_{LP}: 470Ω, 5% SMD resistor
R_{LIM}: 470Ω, 5% SMD resistor
C_{DD}:2.2μF/50V, X5R, ceramic capacitor
C_{EAO}: 1μF/16V, X7R ceramic capacitor
C_{comp}: 4.7nF/16V, X7R ceramic capacitor
C_{LP}: 1μF/16V, X7R ceramic capacitor
Q1: 600V/5A, N-channel MOSFET
C_{DIM} : 4.7μF/16V, X7R or X5R ceramic capacitor

Functional Diagram

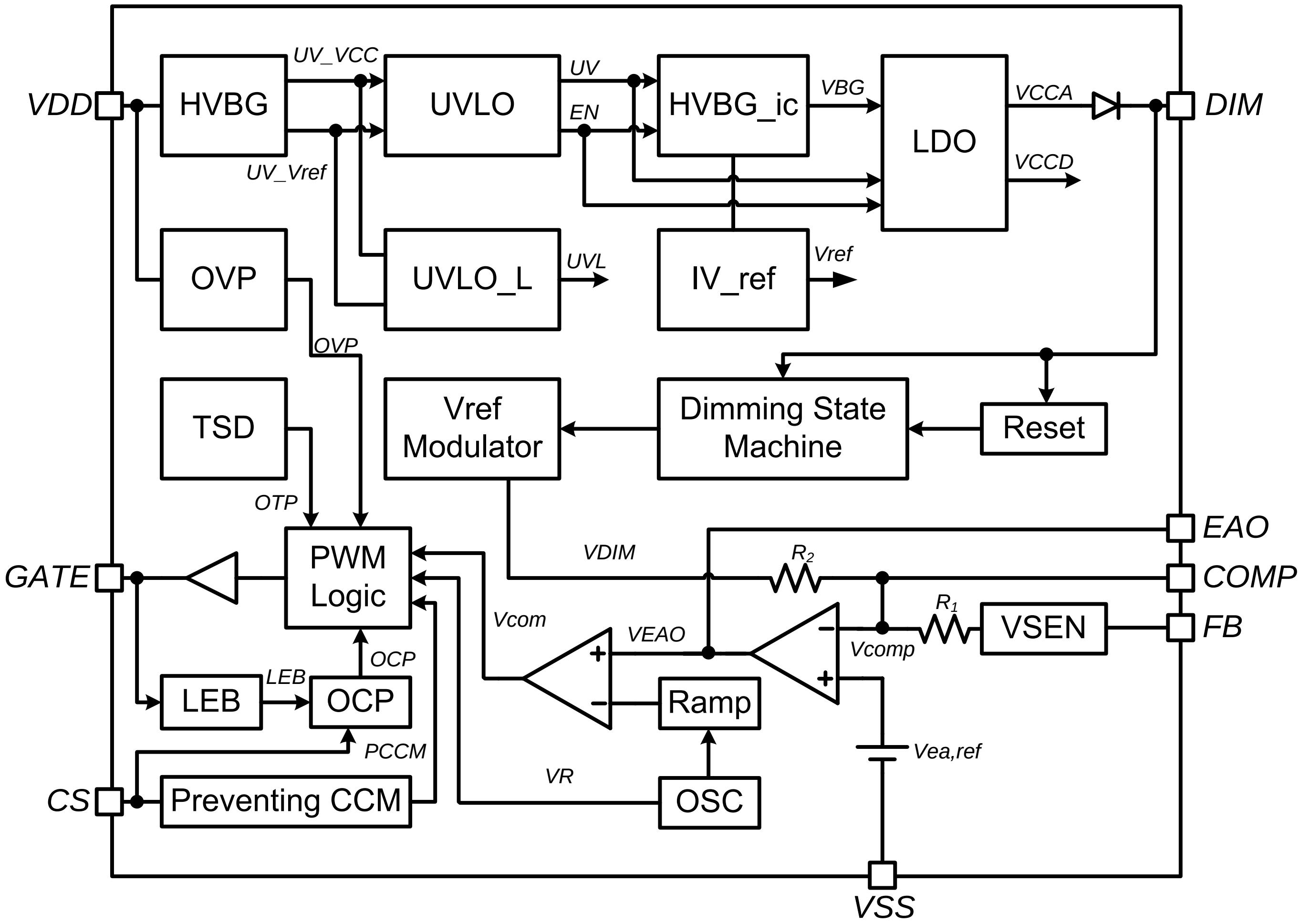
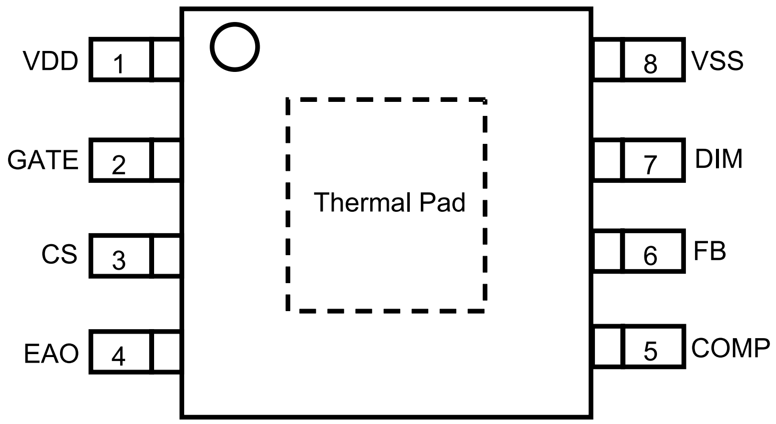


Fig. 2

Pin Configuration



MBI6904GD (Top View)

Pin Description

Pin Name	Pin No.	Function
VDD	1	Supply voltage terminal and terminal to execute the over voltage protection
GATE	2	Terminal to drive the gate of the external MOSFET
CS	3	Terminal to sense LED string current
EAO	4	Terminal to connect a capacitor to enhance the stability of internal error amplifier
COMP	5	Terminal to connect a capacitor to enhance the stability of V_{COMP}
FB	6	Output current feedback
DIM	7	Terminal can be connected with a capacitor for 4-step dimming. If the dimming function is unused, this pin can be kept floating
VSS	8	Ground terminal for control logic and current sink
Thermal Pad	-	Power dissipation terminal connected to GND*

*To eliminate the noise impact, the thermal pad should be connected to VSS (Pin No. 8) on PCB. In addition, a heat-conducting copper foil on PCB soldered with thermal pad will improve thermal conductivity.

Maximum Ratings

Operation above the maximum ratings may cause device failure. Operation at the extended periods of the maximum ratings may reduce the device reliability.

Characteristic		Symbol	Rating	Unit
Supply Voltage		V_{DD}	-0.4~44	V
Sustaining voltage at VCS pin		V_{CS}	7	V
Sustaining voltage at VFB pin		V_{FB}	7	V
Power Dissipation (On 4-Layer PCB, Ta=25°C)	GD Type	P_D	3.13	W
Thermal Resistance (By simulation, on 4-Layer PCB)*	GD Type	$R_{th(j-a)}$	40	°C/W
Junction Temperature		$T_{j,max}$	150**	°C
Operating Ambient Temperature		T_{opr}	-40~+85	°C
Storage Temperature		T_{stg}	-55~+150	°C

*The PCB size is 76.2mm*114.3mm in simulation. Please refer to JEDEC JESD51.

** Operation at the maximum rating for extended periods may reduce the device reliability; therefore, the suggested junction temperature of the device is under 125°C.

Note: The performance of thermal dissipation is strongly related to the size of thermal pad, thickness and layer numbers of the PCB. The empirical thermal resistance may be different from simulative value. Users should plan for expected thermal dissipation performance by selecting package and arranging layout of the PCB to maximize the capability.

Electrical Characteristics

Test condition: V_{DD}=22.5V, C_{IN}=1μF, C_{OUT}=1nF, T_A=25°C; unless otherwise specified.

Characteristics	Symbol	Conditions	Min	Typ	Max	Unit
Supply Voltage						
Continuous Operating Voltage	V_{OP}	-	9	-	36	V
Turn-on Threshold Voltage (Start-up)	V_{DD-ON}	-	15	16.3	18	V
Turn-off Threshold Voltage (UVLO)	V_{DD-OFF}	-	7	8.2	9	V
V_{DD} Over Voltage Protection	V_{DD-OVP}	-	37	-	44	V
Operating Current	I_{DD-OP}	-	-	2.5	4	mA
Starting Current	I_{DD-ST}	The current before start-up voltage	-	25	40	uA
Feedback Reference Voltage						
V_{FB} Accuracy	V_{FB}	-	0.19	0.2	0.21	V
Oscillator						
Oscillator Frequency	f_{OSC}	@V_{DD}=22.5V	39	42	45	KHz
Max. Duty Ratio	-	-	-	70	-	%
Current Sense						
Propagation Delay to Gate Output(Turn off)*	T_{PD}	V_{DD}=20V	-	300	-	ns
Max. Leading Edge Blanking	$T_{LEB,max}$	-	-	500	-	ns
Threshold Voltage for Current Limit	V_{ocp}	-	0.18	0.2	0.22	V
Gate Driver						
Output Low Voltage	V_{OL}	-	-	-	1.5	V
Output Clamp Voltage	V_{Clamp}	V_{DD}>15V	11	12.5	13.5	V
Rising Time	T_R	V_{DD} >15V, C_L=1nF	-	200	300	ns
Falling Time	T_F	V_{DD} >15V, C_L=1nF	-	80	120	ns
Thermal Shutdown						
Thermal Shutdown Threshold	T_{SD}	-	145	155	175	°C
Thermal Shutdown Hysteresis	T_{SD-HYS}	-	-	30	-	°C
Dimming						
Dimming steps	-	-	-	4	-	-
Minimum dimming step	-	-	-	15	-	%

* Propagation delay can be defined as time from V_{Ramp}=V_{EAO} to Falling edge of V_{PWM}, which excludes the falling time of gate driver

Test Circuit for Electrical Characteristics

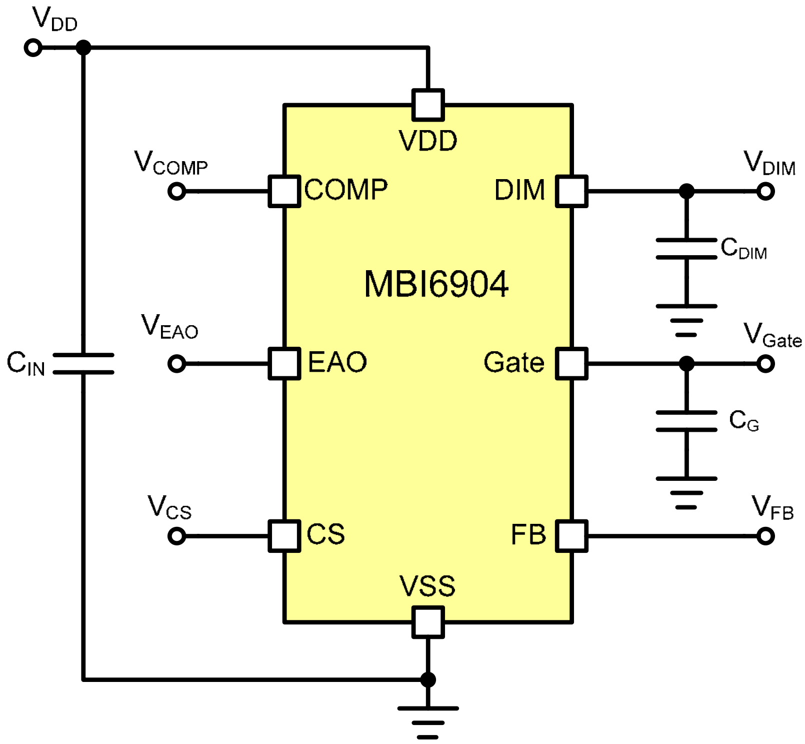


Fig. 3

Application Information

MBI6904 is a universal ac input AC/DC constant current LED driver designed for high power LED applications. This application operates with a buck-boost topology, which provides more flexibility in different input/output design combination to its users with active PFC control. In the application circuit, there are distinct grounds, namely the system ground and VSS. VSS is the reference ground for internal circuit while the system ground is the earth ground. Users should be aware that the system ground and VSS CAN NOT be directly connected together to avoid IC damage and system malfunction.

Start-Up and UVLO (Under Voltage Lock-Out)

When power is on, the voltage imposed on C_{IN} will charge C_S, which is parallel to MBI6904, through R_S. The time for charging up C_S to $V_{Start\text{-}up}$ is the start-up time. The $V_{Start\text{-}up}$ is designed as 16.3V. MBI6904 is also equipped with UVLO protection. When V_{DD} is below the UVLO threshold of 8.2V (typ.), UVLO starts working and MBI6904 will be disabled, as shown in Fig. 4. The hysteresis of UVLO is 8.2V. Once the input voltage reaches $V_{Start\text{-}up}$ again, MBI6904 resumes working and starts regulating the output current to its preset value.

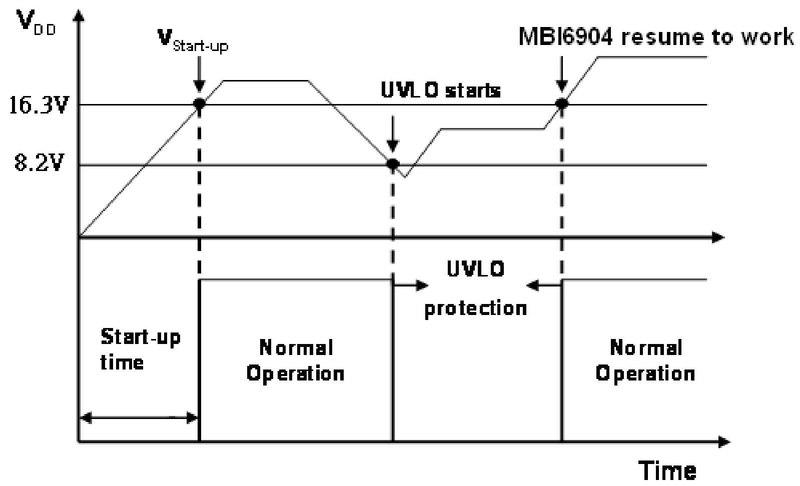


Fig. 4

Setting Output Current

The output current of MBI6904, I_{LED}, can be set via an external resistor, R_{FB}. The relationship between I_{LED} and R_{FB} is as below:

$R_{FB} = (V_{FB} / I_{LED}) = 0.2 / I_{LED}$ (1)

where V_{FB} is the voltage across R_{FB}, and 0.2V typically.

To enhance the output current accuracy, 1% tolerance is recommended for R_{FB}.

The sustaining power dissipation of R_{FB} is

$P_{RFB} = (V_{FB}^2 / R_{FB}) = (0.2)^2 / R_{FB}$ (2)

Power Switch Dimming

MBI6904 features power switch dimming, altering the output current by toggling the input voltage within a short period of time. It utilizes UVLO threshold and voltage level of C_{DIM} capacitor (capacitor from V_{DIM} pin to VSS pin) to achieve the function. External component of C_{DIM} forms a holding and discharging circuitry and connect to VDIM.

When the input voltage is switched off and falls below UVLO threshold, MBI6904 changes the internal dimming memory state. At this time, voltage on C_{DIM} maintains power dimmable circuit active until the voltage discharged further to make memory circuit incapable of operation. It is known as a "memory effect" to keep the function active. In the active moment, a step dimming is completed when the driver is powered again and input voltage rises above UVLO threshold. There is a proportion of output current reduction from original current setting when any single step dimming completes. Repeat above operation results in sequential dimming status change in following ways 100% → 70%→ 40%→ 15%→ 100%.

However, the "memory effect" will be lost, if the voltage on C_{DIM} fails to maintain normal operation of power dimmable circuit during low input voltage period. Without the "memory", no step dimming behavior happens when the input voltage rises above UVLO threshold again.

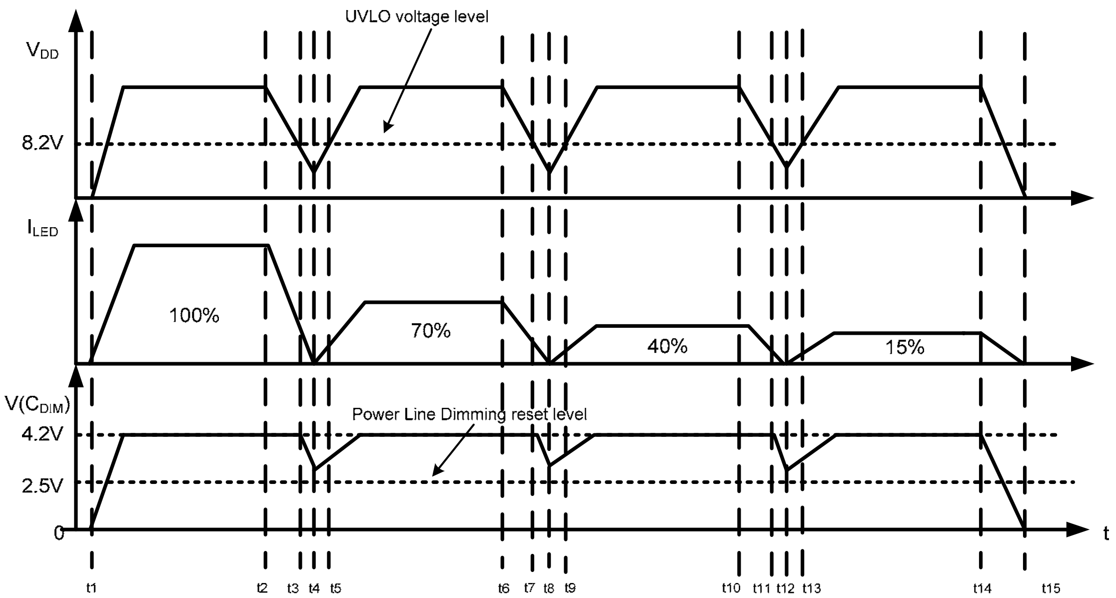


Fig. 5: The output current altering due to power switch dimming function

OVP (Over Voltage Protection)

When V_{DD} rises above the OVP threshold of 40V (Typ.), GATE is forced low to turn off the external power MOSFET. GATE will not be pulled high until V_{DD} falls below UVLO voltage. This function prevents the driver from suffering high voltage stress and also protects LEDs. The threshold also limits the V_{LED} headroom and LED numbers that can be lit up.

LED Open-Circuit Protection

When any LED connected to MBI6904 is open-circuited, it will trigger OVP to turn off the external power MOSFET, and therefore, no current is supplied to LEDs.

MBI6904 provides LED open circuit protection through preventing output voltage accumulating. At the beginning of an open circuit situation, output voltage may go high, as the voltage feeding into VDD also rises. When VDD voltage reaches the OVP threshold voltage, MBI6904 will disable the gate signal to avoid output voltage from going up further. After VDD voltage drops under UVLO level, the gate signal will resume to function. To further protect LED and MBI6904 from the voltage surge caused by LED open circuit, a TVSo device connected parallel to the output capacitor is also recommended.

LED Short-Circuit Protection

When any LED connected to MBI6904 is short-circuited, MBI6904 adaptively regulates the output current according to the new loading.

When the cascaded LEDs are short-circuited and the output voltage drops toward 0V, VDD will also start to drop. Once VDD voltage is below UVLO threshold voltage, the gate signal will stop working to prevent MOSFET from further switching.

Over Temperature Protection (OTP)

When the junction temperature exceeds the threshold T_{SD} of 155°C, MBI6904 turns off the external power MOSFET. Thus, the junction temperature starts to decrease. Once the junction temperature drops below 125°C, the external power MOSFET will resume its normal operations.

Design Example

The sample design is based on the following specifications.

To light up 22 pieces of high power white LEDs, the forward voltage of each LED is 3.2V. The desired LED current is 100mA, and the input line voltage is 220V_{AC}. Users should calculate the required components. (The LED is chosen from NICHIA, NS2W123BT)

Output LED Current (I_{LED})

The LED current can be set by R_{FB}. R_{FB} = 0.2 / $\mathbf{I_{LED}}$ = 0.2 / 100mA = 2Ω. The power dissipation of R_{FB} can be eliminated, and it is equal to P_{RFB} = 0.2 × 100mA =0.02W. Therefore, a 1%, 2Ω resistor with 125mW power dissipation is recommended.

Inductor (L_1)

The inductor (L_1) can be designed by the follow equation:

$$L_1 = \frac{\eta \cdot V_{IN,MAX}^2 \cdot D^2}{4 \cdot P_{LED} \cdot f_S}$$

where

η is the assumed conversion efficiency,

$V_{IN,MAX}$ is the peak value of input voltage,

D is the duty ratio, P_{LED} is the total output power, and

f_S is the switching frequency.

Since the input line voltage is 220V_{AC}, the peak value of the input voltage ($V_{IN,MAX}$) is 311V. Assume the conversion efficiency is 80%, the total output power (P_{LED}) is 7W, the switching frequency is 42KHz, and the duty ratio is 18%. According to the above equation and specifications, the L_1 inductance can be calculated, which is equal to 2.13mH.

Also the maximum current ($I_{L1,MAX}$) of L_1 can be estimated by:

$$I_{L1,MAX} = \frac{V_{IN,MAX} \cdot t_{on}}{L_1} = \frac{V_{IN,MAX} \cdot D \cdot T_S}{L_1}$$

where

t_{on} and **T_S** are the switching-on time and switching period, respectively.

To choose a 2mH inductor to be L_1, such that $I_{L1,MAX}$ is equal to 0.67A. In this application, the 1A saturation current is recommended to keep a 50% safety margin.

Inductor Current Sensing Resistor (R_{CS})

MBI6904 features the cycle-by-cycle inductor current limit through an inductor current sensing resistor (R_{CS}). To set the over-current-protect level at 1A (I_{OCP}=1A), the R_{CS} can be calculated by:

R_{CS} = 0.2 / I_{OCP} = 0.2 / 1 = 0.2 Ω

In this application, a 1%, 2Ω resistor with 125mW power dissipation is recommended.

Power MOSFET (Q1)

In this sample design, the recommended rating voltage of Q_1 is $(V_{IN,MAX} + V_{LED}) \times 1.2 = 457.68$ V, and the recommended rating current of Q_1 is 1A x 1.2 = 1.2A, individually. Thus, the STD4NK60Z-1 that manufactured from ST with 600V rating voltage, 4A rating current, and 1.76Ω $R_{ds(on)}$ is selected.

Supply Capacitor (C_{DD}) and Charging Resistor (R_S)

For general applications, a 4.7μF ceramic capacitor with 50V rating voltage (X7R or X5R) for C_{DD} is recommended. To consider the sustaining voltage of R_S, it is recommended to use two 510kΩ resistors in series as R_S.

Supply Current Limiter (R_{LIM})

In this application, the recommended resistance of R_{LIM} is 100Ω.

Freewheeling Diode (D_O) and Supply Diode (D_S)

In this application, the recommended maximum reverse voltage of D_O is $(V_{IN,MAX} + V_{LED}) \times 1.2 = 457.68$ V, and recommended rating current of D_O is 1A x 1.2 = 1.2A, individually. The recommended maximum reverse voltage of D_S is$(V_{IN,MAX} + V_{DD,OVP}) \times 1.2 = (311 + 44) \times 1.2 = 426$V, and the recommended rating current of D_s is 100mA. Therefore, the ER2J that manufactured from PANJIT with 600V rating voltage and 2A rating current for both D_O and D_S is selected.

Bridge Diode (D_1, D_2, D_3, and D_4)

In this application, the recommended maximum reverse voltage of the bridge diode is $V_{IN,MAX} \times 1.2 = 373.2$ V, and the recommended rating current of the bridge diode is 42.20mA.Therefore, the B6S that manufactured from PANJIT with 600V rating voltage and 0.5A rating current is selected.

Zener Diode (Z_{DD})

In general, the 43V and 500mW zener diode is recommended.

Compensator Capacitors (C_{EAO} and C_{COMP})

In this application, a 1μF ceramic capacitor (X7R or X5R) for C_{EAO} and a 4.7nF ceramic capacitor (X7R or X5R) for C_{EAO} are recommended.

Zener Diode (Z_{D1})

The Z_{D1} is to shift the OVP threshold of MBI6904 for applications that the output voltage is above 37V. The zener voltage of Z_{D1} is $V_{IN,MAX} \leqq V_{LED,MIN} - V_{DS,MAX} - 25 = 44$V. Therefore, a 43V zener diode is selected.

Output Transient Voltage Suppressor (TVS_O)

To protect the LED, the output transient voltage suppressor (TVS_O) is needed. The breakdown voltage of TVS_O is $V_{DR,MIN} \geqq V_{LED,OVP} = V_{LED} + V_{DD,OVP} - 25 = 81.4$ V. Therefore, an 81V TVS is selected.

Output Capacitor (C_{OUT})

In this application, a 47μF electrolytic capacitor with 250V rating voltage for C_{OUT} is recommended.

Input Filter Capacitor (C_1)

In this application, a 0.1μF metal-film capacitor with 450V rating voltage for C_1 is recommended.

Gate Discharging Resistor (R_{GS})

In this application, the recommended resistance of R_{GS} is 20kΩ.

Low-Pass Filter (R_{LP} and C_{LP})

In this application, a 100Ω R_{LP} and a 4.7μF C_{LP} are selected.

Dimming Capacitor (C_{DIM}) (Optional)

In general, a 4.7μF ceramic capacitor (X7R or X5R) for C_{DIM} is recommended.

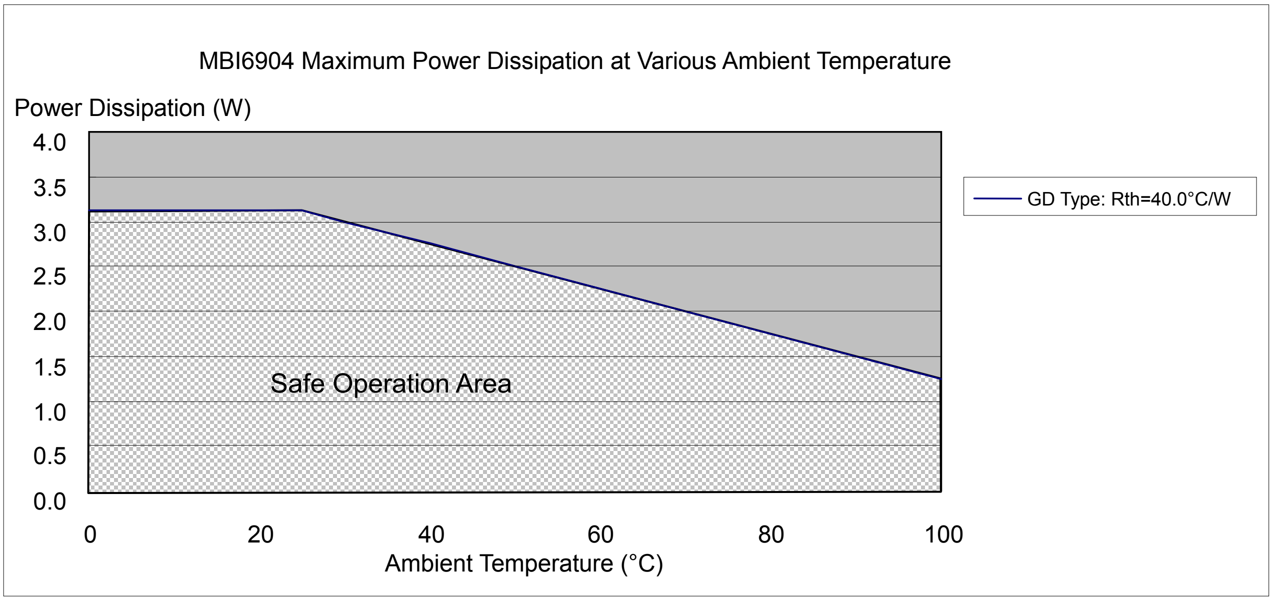
PCB Layout Consideration

To enhance the efficiency and stabilize the system, careful considerations of PCB layout is important. The following several factors should be considered:

1. A complete ground area is helpful to eliminate the switching noise.
2. To stabilize the system, a complete V_{SS} area is recommended.
3. To avoid the parasitic effect, all component pins should be placed as short as possible.
4. High current paths should be as wide and short as possible to eliminate the parasite element.
5. To avoid the parasitic effect of trace, please place the C_{DD} as close to the V_{DD} and V_{SS} pins as possible.
6. To avoid the parasitic effect of trace, please place the C_{EAO} as close to the EAO pin as possible.
7. To avoid the parasitic effect of trace, please place the C_{COMP} as close to the COMP pin as possible.
8. To avoid the parasitic effect of trace, please place the C_{DIM} as close to the DIM pin as possible.
9. To avoid the parasitic effect of trace, please place the R_{CS} as close to the CS pin as possible.
10. To avoid the parasitic effect of trace, please place the low-pass filter $R_{LP\ and}$ C_{LP} as close to the FB pin as possible.
11. Besides VSS area, please do not place any components or other electricity trace under the thermal pad of MBI6904.

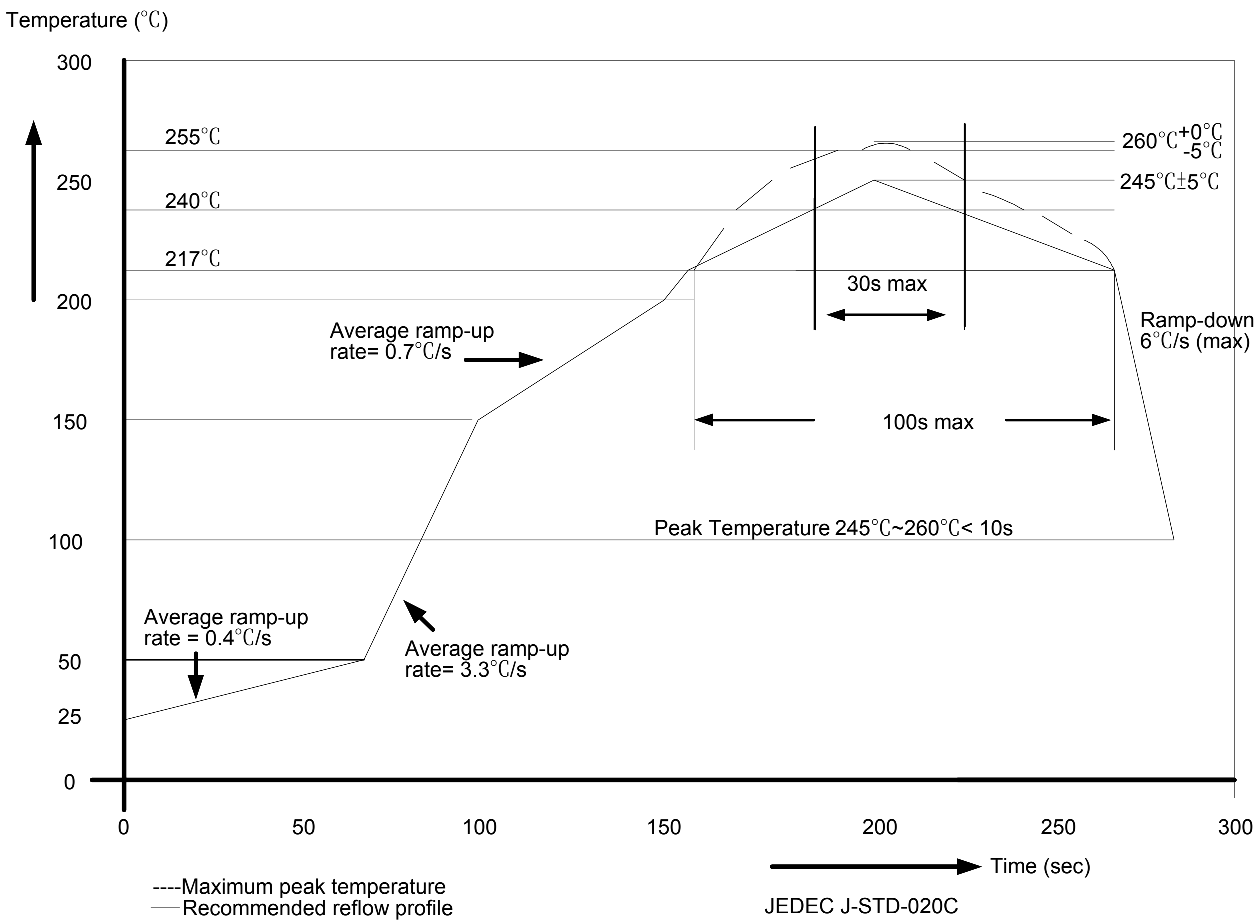
Package Power Dissipation (PD)

The maximum power dissipation, PD(max)=(Tj–Ta)/Rth(j-a), decreases as the ambient temperature increases.



Soldering Process of “Pb-free” Package Plating*

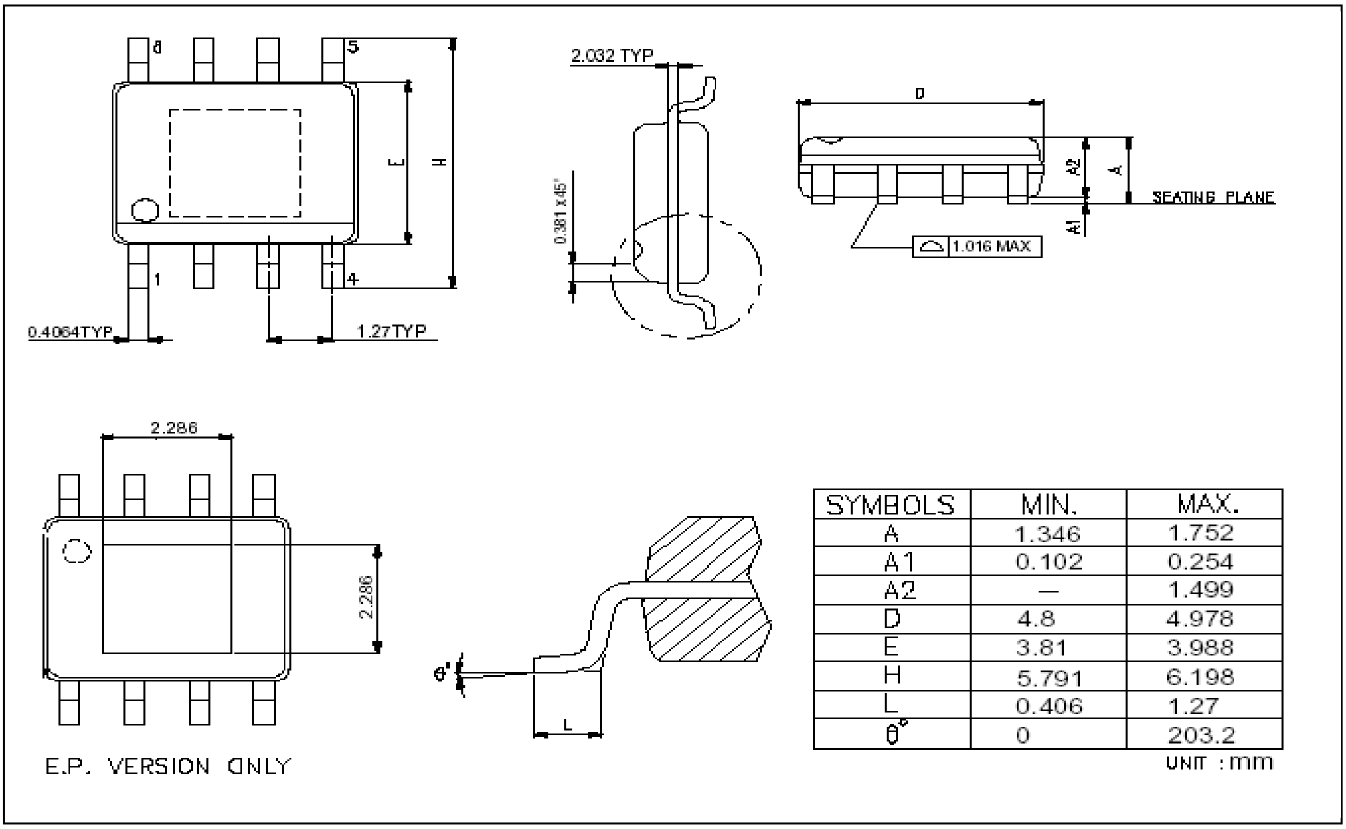
Macroblock has defined "Pb-Free" to mean semiconductor products that are compatible with the current RoHS requirements and selected 100% pure tin (Sn) to provide forward and backward compatibility with both the current industry-standard SnPb-based soldering processes and higher-temperature Pb-free processes. Pure tin is widely accepted by customers and suppliers of electronic devices in Europe, Asia and the US as the lead-free surface finish of choice to replace tin-lead. Also, it adopts tin/lead (SnPb) solder paste, and please refer to the JEDEC J-STD-020C for the temperature of solder bath. However, in the whole Pb-free soldering processes and materials, 100% pure tin (Sn) will all require from 245 °C to 260°C for proper soldering on boards, referring to JEDEC J-STD-020C as shown below.



Package Thickness	Volume mm³ <350	Volume mm³ 350-2000	Volume mm³ ≧2000
<1.6mm	260 +0 °C	260 +0 °C	260 +0 °C
1.6mm – 2.5mm	260 +0 °C	250 +0 °C	245 +0 °C
≧2.5mm	250 +0 °C	245 +0 °C	245 +0 °C

*Note: For details, please refer to Macroblock’s “Policy on Pb-free & Green Package”.

Outline Drawing



SYMBOLS	MIN.	MAX.
A	1.346	1.752
A1	0.102	0.254
A2	—	1.499
D	4.8	4.978
E	3.81	3.988
H	5.791	6.198
L	0.406	1.27
θ°	0	203.2

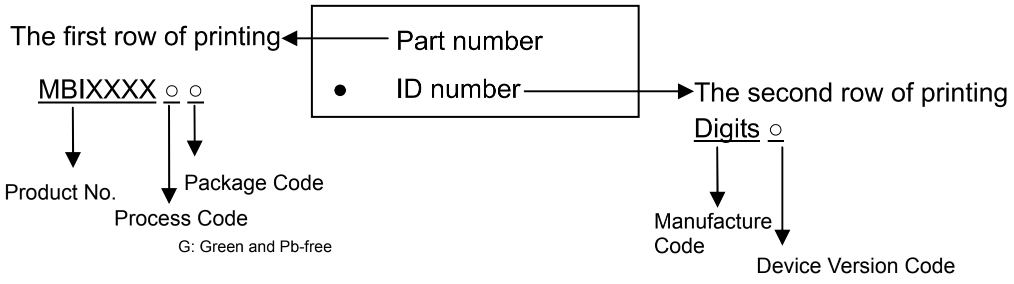
UNIT : mm

MBI6904GD Outline Drawing

Note: Please use the maximum dimensions for the thermal pad layout. To avoid the short circuit risk, the vias or circuit traces shall not pass through the maximum area of thermal pad.

Product Top Mark Information

GD(SOP-8L)



Product Revision History

Datasheet version	Device Version Code
V1.00	A

Product Ordering Information

Part Number	RoHS Compliant Package Type	Weight (g)
MBI6904GD	SOP8L-150-1.27	0.07g

Disclaimer