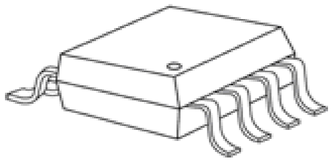
Step-Down, 1A Dimmable LED Driver

Features

- 4.5~65V wide input voltage range
- Maximum 1A constant output current
- Patented fixed frequency analog dimming control
  - PWM-controlled brightness modulation
  - DC voltage-controlled brightness modulation
- Integrated power switch with 0.3ohm low $R_{DS(ON)}$
- Full protections: UVLO/ Soft Start/ OCP/ OTP
- SOP-8L Package
- Package MSL Level : 3

Small Outline Package



GD: SOP8L-150-1.27

Product Description

MBI6653 is a step-down constant-current high-brightness LED driver to provide a cost-effective design solution for interior/exterior illumination applications. It is designed to deliver constant current to light up high power LED with only 6 external components.

The output current of MBI6653 can be programmed by an external resistor and dimmed via pulse width modulation (PWM) through DIM pin. In addition, a novel analog dimming method is proposed and offered by the device. Users can achieve higher efficiency linear current modulation from 5% to 100% of preset current by applying either PWM-controlled or DC voltage-controlled brightness modulation.

MBI6653 features completed protection design to handle faulty situations. The start-up function limits the inrush current while the power is switched on. Under voltage lock out (UVLO), over temperature protection (OTP), and over current protection (OCP) guard the system to be robust and keep the driver away from being damaged which results from LED open-circuited, short-circuited and other abnormal events. MBI6653 provides thermal-enhanced SOP-8 package as well to handle power dissipation more efficiently.

Applications

- Signage and Decorative LED Lighting
- High Power LED Lighting
- Stage Lighting
- Constant Current Source

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Typical Application Circuit

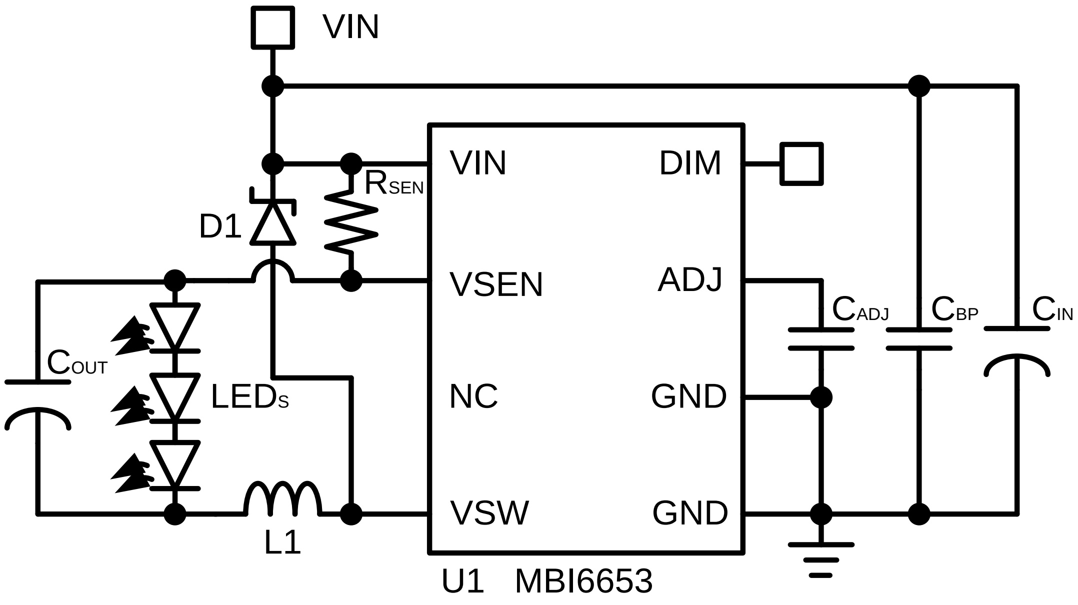


Fig. 1

Functional Diagram

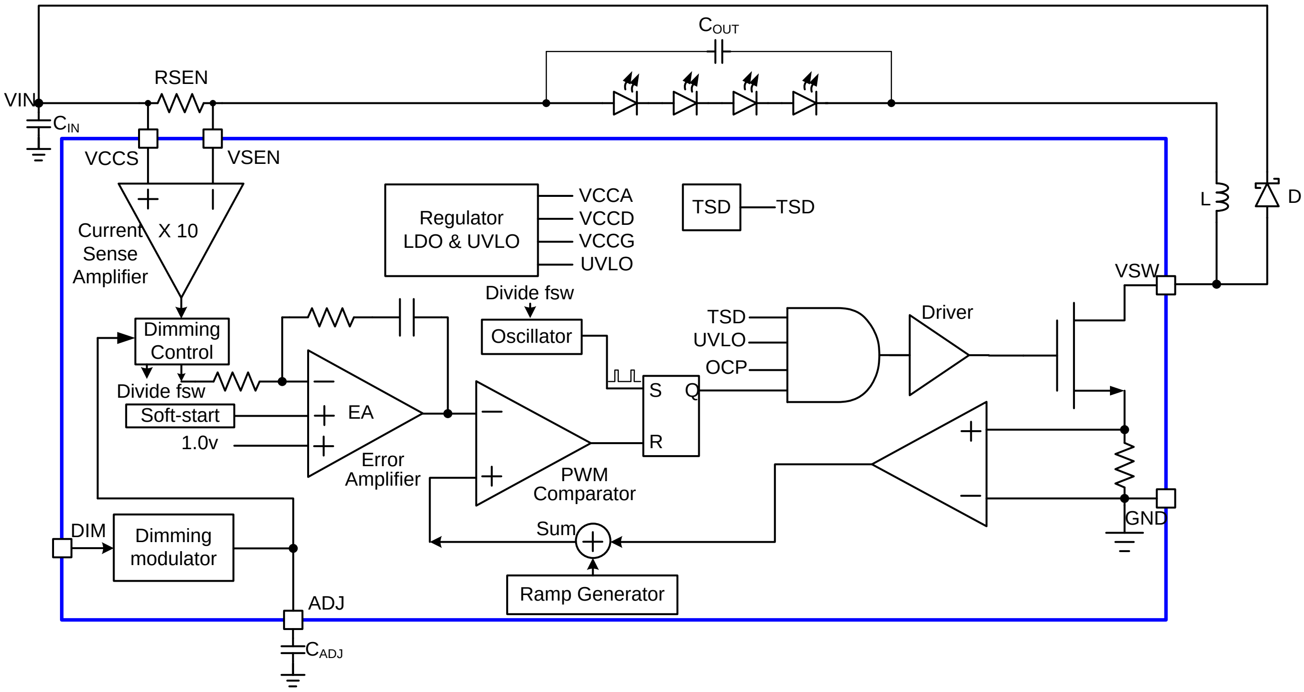
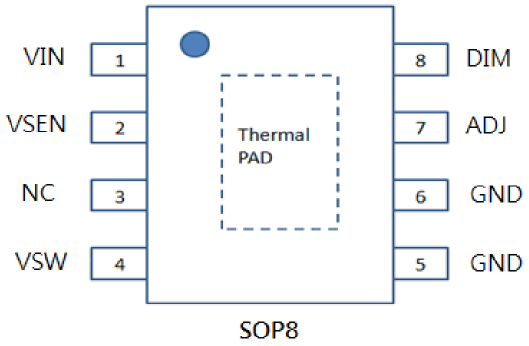


Fig. 2

Pin Configuration



MBI6653GD (Top View)

Pin Description

Pin Name	Function
GND	Ground terminal for control logic and current sink
VSW	Switch output terminal
DIM	Digital dimming control terminal. The PWMD can be floating, if the dimming function is not required.
NC	No Connection
ADJ	Analog dimming control terminal. DC voltage can be applied into the terminal for analog brightness control. The ADJ can be floating, if the dimming function is not required.
VSEN	Output current sense terminal
VIN	Supply voltage terminal
Thermal Pad	Power dissipation terminal connected to GND*

*To improve the noise immunity, the thermal pad is suggested to connect to GND on PCB. In addition, when a heat-conducting copper foil on PCB is soldered with thermal pad, the desired thermal conductivity will be improved.

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_{IN}	-0.3~65	V
Output Current		I_{OUT}	1	A
Sustaining Voltage at DIM pin		V_{DIM}	-0.3~65	V
Sustaining Voltage at ADJ pin		V_{ADJ}	-0.3~7	V
Sustaining Voltage at SW pin		V_{SW}	-0.3~65	V
GND Terminal Voltage		V_{GND}	-0.3~0.3	V
Sustaining Voltage at Current Sense pin		V_{SEN}	V_{IN}+0.3~ V_{IN}-0.6	V
Power Dissipation (On 4-Layer PCB, Ta=25°C)	GD Type	P_D	1.74	W
Thermal Resistance (Measurement on testing PCB)*	GD Type	$R_{th(j-a)}$	72	°C/W
Junction Temperature		$T_{j,max}$	150**	°C
Operating Ambient Temperature		T_{opr}	-40~+85	°C
Storage Temperature		T_{stg}	-55~+150	°C
ESD Rating	HBM(MIL-STD-883H Method 3015.8, Human Body Mode)	-	Class 3A (7KV)	-
ESD Rating	MM (ANSI/ESD S5.2-2009, Machine Mode)	-	Class M3 (400V)	-

*The PCB size is 4 times larger than actual IC size and the measurement test does not use any heatsink. 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

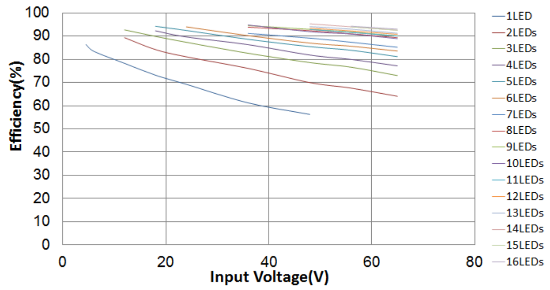
V_{IN}=12V, V_{OUT}=3.6V, L1=47μH, $C_{IN=}$10μF, C_{OUT}=2.2μF, T_A=25°C; unless otherwise specified.

Characteristics	Symbol	Condition	Min.	Typ.	Max.	Unit
INPUT AND OUTPUT						
Supply Voltage	V_{IN}	-	4.5	-	65	V
Supply Current	I_{IN}	V_{IN}=6V~30V	-	2		mA
Output Current	I_{OUT}		0.35		1	A
Start-Up Voltage	V_{SU}			4.3		V
Under Voltage Lock Out Voltage	V_{UVLO}			4.1		V
Current Sensing						
Average of Sense Voltage	V_{SEN_CEN}	V_{IN} -V_{SEN}	95	100	105	mV
Switching Frequency						
Operating frequency	F_{sw}			450	500	KHz
LX Duty Range	D_{LX}		10		90	%
MOS SWITCH						
Switch ON Resistance	$R_{DS(ON)}$			0.3		Ω
Current leakage	$V_{SW\text{-}leak}$	V_{SW} Force 65V		0.1	1	uA
VSW fall time	$T_{F,SW}$	V_{IN}=65V		20		ns
THERMAL OVERLOAD						
Thermal Shutdown Threshold	T_{SD}	-		150		°C
Thermal Shutdown Hysteresis*	$T_{SD\text{-}HYS}$	-		35		°C
Over Current Protection level 1	I_{OCP1}	VREF_ILM=1V		2.5		A
Over Current Protection level 2	I_{OCP2}	VREF_OCP=1.25V		3		A
PWM DIMMING						
PWM Dimming Frequency		C_{adj}=0.1uF		100	300	KHz
Dimming Duty Range(Down)	D_{PWM_DOWN}		19.5		100	%
Dimming Duty Range(Up)	D_{PWM_UP}		23.5		100	%
ANALOG DIMMING						
ADJ Input Voltage for Dimming Saturation	V_{IH}	-		2.5		V
ADJ Dimming-Off	V_{DIM_OFF}		0.395	0.45	0.505	V
ADJ Dimming-On	V_{DIM_ON}		0.485	0.55	0.615	V
ADJ On-Off Hysteresis Voltage				100		mV
Dimming Duty Range(Down)	D_{ADJ_DOWN}		2.5		100	%
Dimming Duty Range(Up)	D_{ADJ_UP}		6.5		100	%

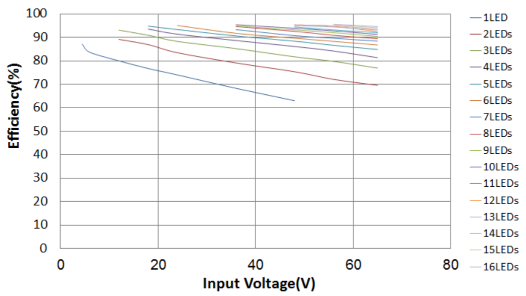
*Parameters are not tested at production. Parameters are guaranteed by design.

Typical Performance Characteristics

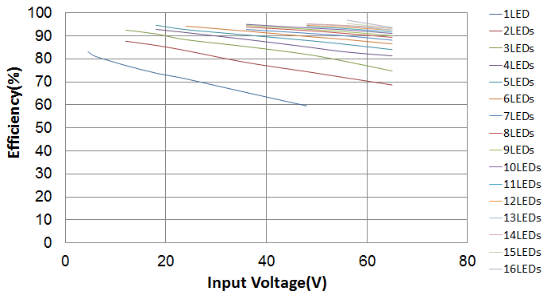
Efficiency vs. Input Voltage at various LED cascaded numbers.



I_{OUT}=1A

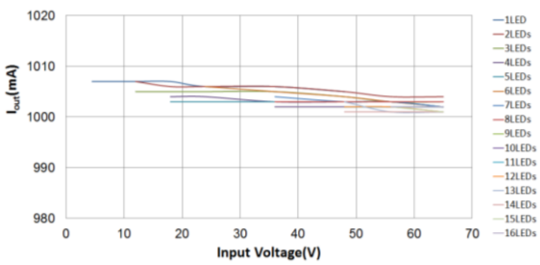


I_{OUT}=0.7A

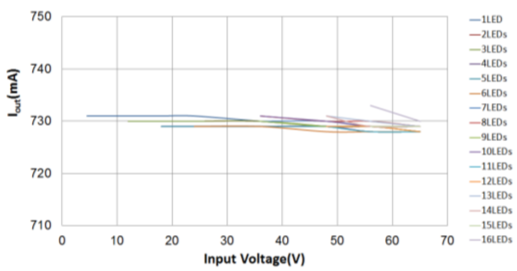


I_{OUT}=0.35A

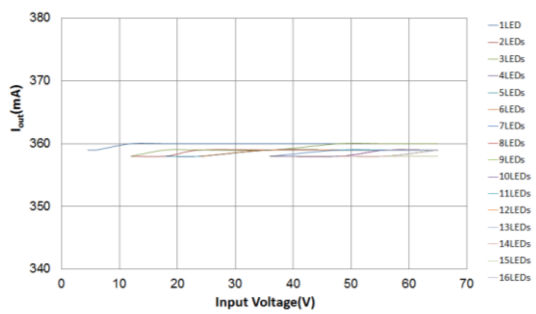
Output Current vs. Input Voltage at various LED cascaded numbers.



I_{OUT}=1A

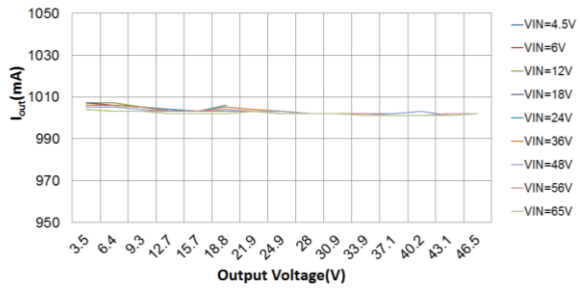


I_{OUT}=0.7A

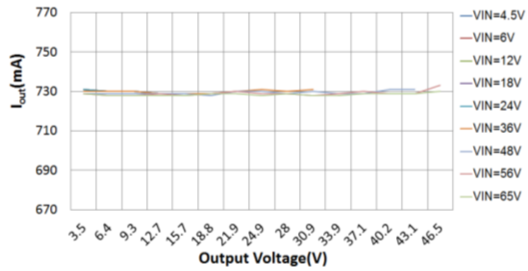


I_{OUT}=0.35A

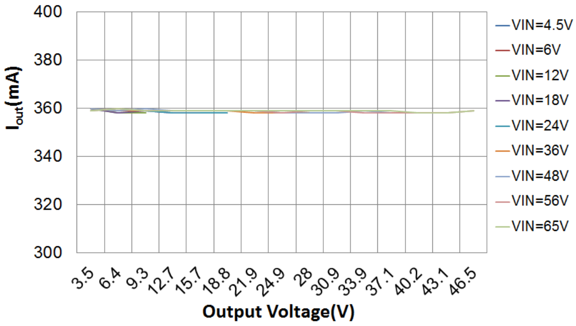
Output Current vs. Output Voltage at various input voltage.



I_{OUT}=1A

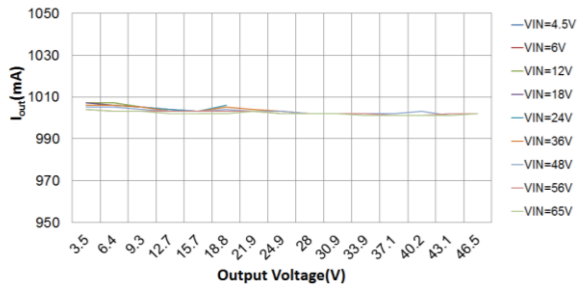


I_{OUT}=0.7A

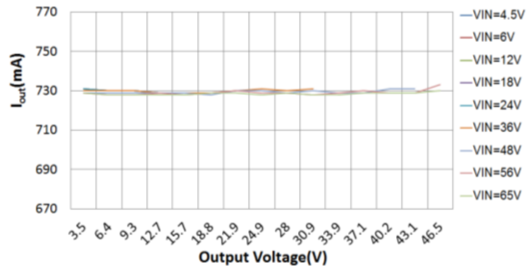


I_{OUT}=0.35A

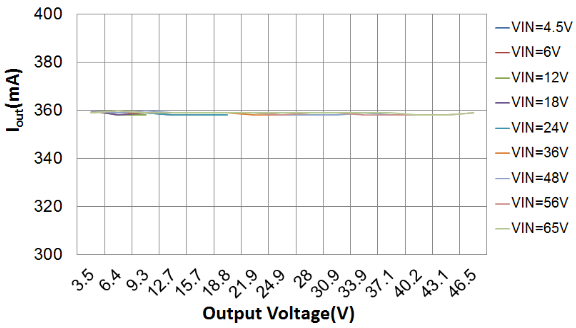
Output Current vs. LED Cascaded Number at Various Input Voltage



I_{OUT}=1A



I_{OUT}=0.7A



I_{OUT}=0.35A

Application Information

MBI6653 is a cost-effective and high efficiency constant current buck converter that is applied for lighting. Due to 500k Hz switching frequency, it would allow users to implement smaller inductor. Besides, with internal MOSFET, PCB space would shrink so largely as to decrease effectively cost.

LED output current of MBI6653 can be programmed by external resistor and dimmed through DC voltage or PWM signal to achieve high resolution. In addition, MBI6653 offers complete protections, including soft-start, Under Voltage Lockout (UVLO), Over Temperature Protection (OTP), Schottky Diode Short-Circuit Protection), output Open-circuit and Short-circuit protection, to prevent system or components from being damaged by any fault conditions.

Fixed-frequency PWM control

MBI6653 is a constant current buck converter with fixed-frequency PWM control. Comparing with hysteretic control, it offers premium Line/Load regulation and lower output ripple current. Figure 3 shows the typical application circuit. The internal control loop is composed of four main circuits: current sense circuit, dimming control circuit, fixed-frequency oscillator and PWM control circuit. The current sense circuit can sense current through resistor R_{SEN} which cause the voltage difference between VIN pin and SEN pin. Under full loading and no analog dimming, the switching frequency is fixed at 500k Hz and can't change with the variation of input voltage and output loading.

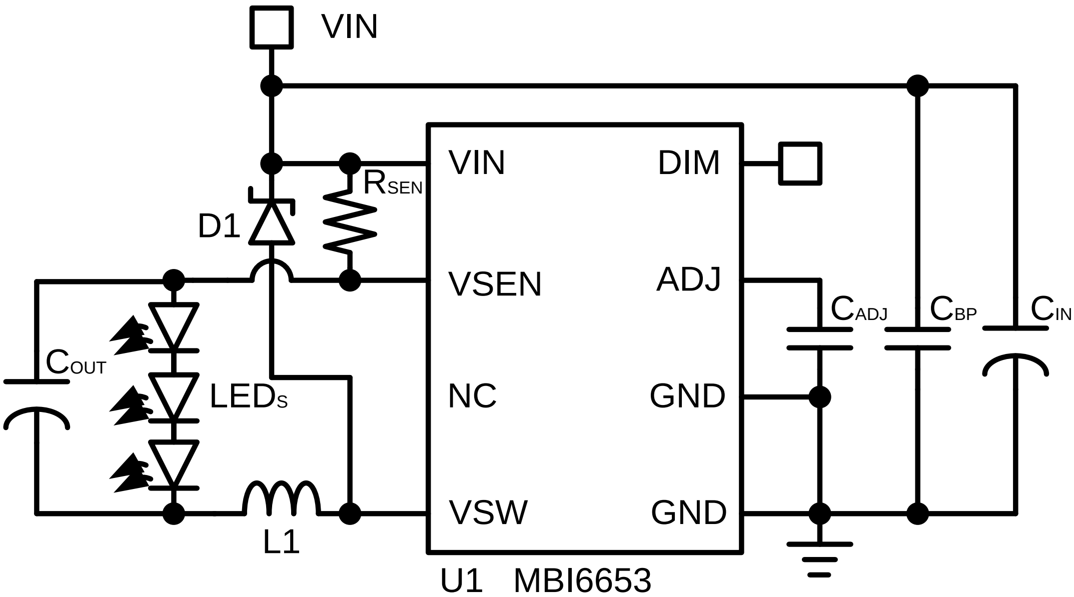


Fig.3 MBI6653's typical application circuit

Soft-start

MBI6653 owns built-in soft-start function to diminish input current spike in order to prevent output overshoot at the moment of power-on. The soft-start function is activated when VIN voltage is more than the start-up voltage. In that time internal PWM control circuit starts to switch with smaller on-time and then gradually increase on-time until normal operation. The soft-start time will change with output current and in other words, the more output current results in longer soft-start duration. Figure 4 shows the operation waveform of soft-start.

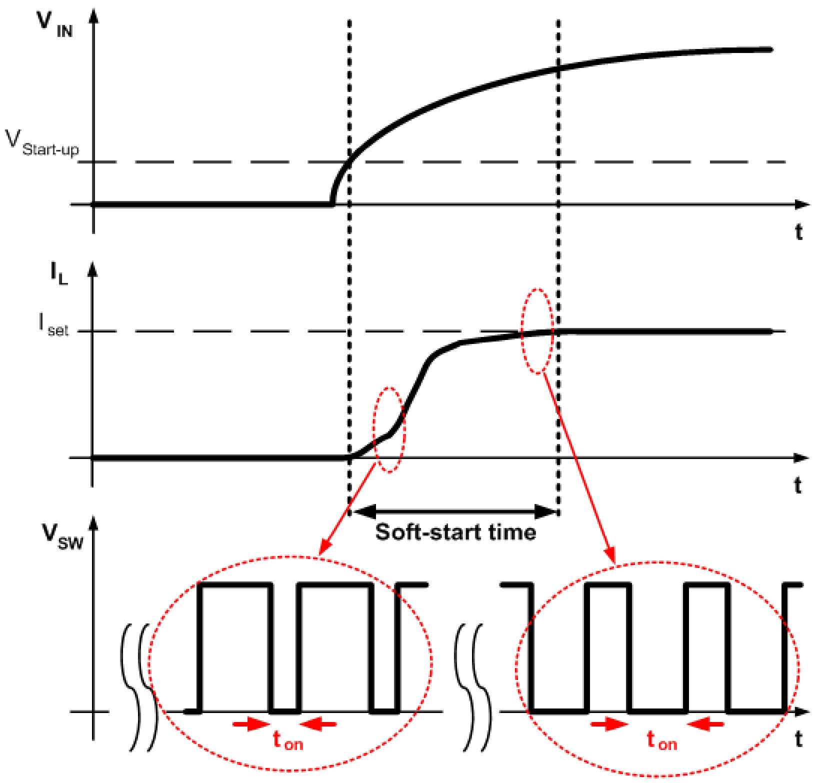


Fig.4 Operation waveform of soft-start

Thermal Protection

When the junction temperature of MBI6653 exceeds the threshold of temperature protection (T_{SD}), the internal MOSFET will be shut down immediately by over temperature protection circuit and reset internal compensated voltage to soft-start voltage. MBI6653 MOSFET will restart to establish inductor current in soft-start way until the internal temperature drops under the hysteretic temperature (T_{SD-HYS}).

Schottky Diodes Short-circuit Protection

MBI6653 built-in current sense circuit can monitor the current through MOSFET and feedback current signal to logic control circuit in order to protect IC against damage from LED short, RSEN resistor short or Schottky diodes short. Once those malfunctions above happen, MBI6653 will suppress the current with internal feedback control loop. If fault current is over the suppressed capability of MBI6653, the converter will be latched off until re-power on.

Dimming Function

The DIM pin of MBI6653 can be used to achieve both analog and PWM dimming. Figure 5 is the diagram of dimming function. It needs to notice that PWM frequency must be more than 1k Hz and high level voltage of PWM signal must be larger than 2.7V.

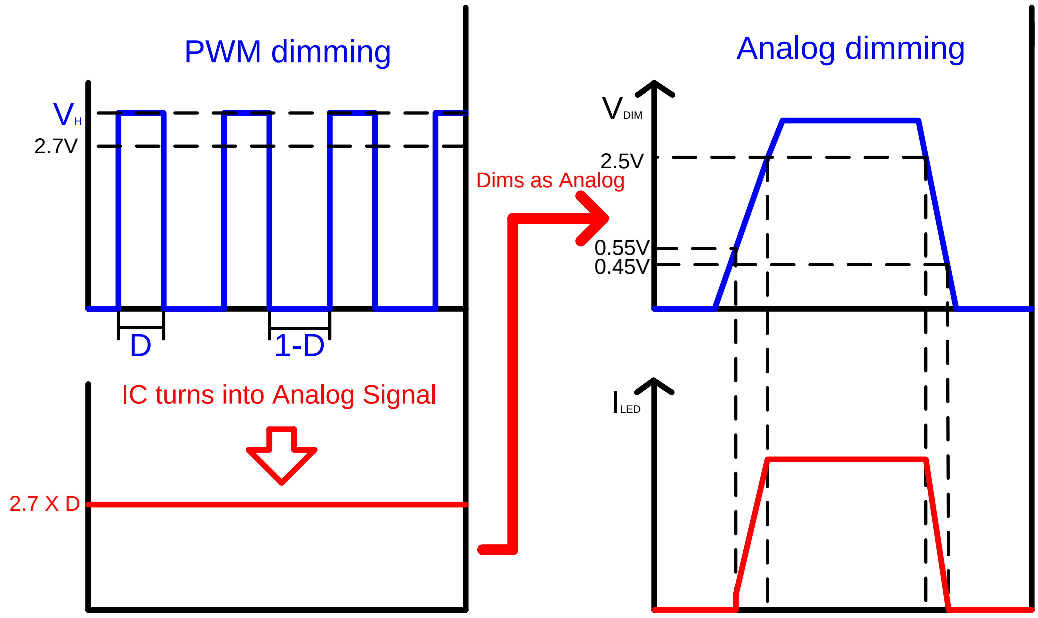


Fig.5 Dimming waveform diagram

Analog Dimming Application

The analog dimming function can be activated by applying an external DC voltage (V_{DIM}) at DIM pin. To prevent the noise interference, it recommends connecting 0.1μF capacitor in parallel to the DIM pin, as shown in Figure 6. In analog dimming application, output dimming current (ILED_ADIM) will rise with VDIM voltage level increasing. Equation (1) shows that $I_{LED\_100\%}$ is programmed by R_{SEN} resistor,

$$I_{LED\_ADIM} = I_{LED\_100\%} \times \frac{V_{DIM} - 0.45}{2.5 - 0.45} \quad \text{.......(1)}$$

V_{DIM} dimming range is from 0.45 to 2.54V. If V_{DIM} is higher than 2.5V, the output current will be $I_{LED\_100\%}$ and IC doesn't implement dimming. MBI6653 will reduce switching frequency to remain good dimming linearity.

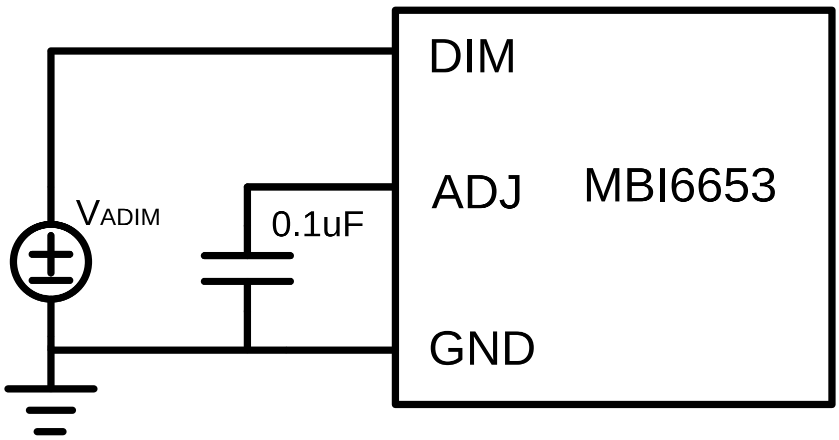


Fig.6 Analog dimming by external DC voltage

PWM Dimming Application

MBI6653 also features PWM dimming function, which can adjust output current through a digital PWM signal. To prevent noise interference, connect a 0.1μF capacitor in parallel to DIM pin is recommended, as shown in Figure 7. The recommended PWM dimming frequency is between 1k Hz and 100kHz. The output current of PWM dimming is described as Equation (2),

$$I_{LED\_PWM} = I_{LED\_100\%} \times \frac{2.7 \times D_{PWM} - 0.45}{2.5 - 0.45} \quad \text{.......................................(2)}$$

where D_{PWM} is duty cycle of PWM signal, and the larger D_{PWM} will result in larger output current.

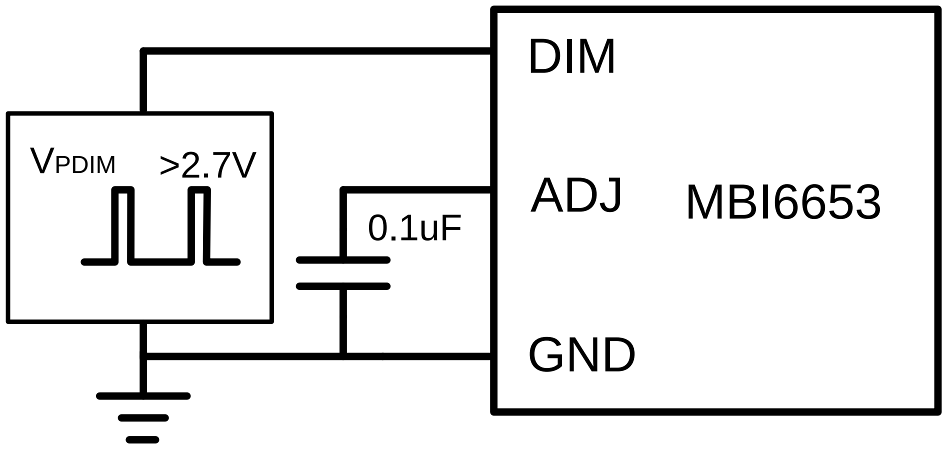


Fig.7 Digital dimming by PWM signal

Design Consideration

Output Current Setup

The output current of MBI6653 can be programmed by an external resistor, and Equation (3) shows the relationship of I_{LED} and R_{SEN},

$$I_{LED} = \frac{V_{SEN}}{R_{SEN}} \quad \text{(3)}$$

where R_{SEN} is the current sense resistor and V_{SEN} is the reference voltage (100mV).

To enhance the accuracy of output current, the R_{SEN} with 1% tolerance is recommended. The power dissipation on R_{SEN} is $P_{Rsen}=(V_{SEN})^2/R_{SEN}$. To prevent the sustaining power dissipation decreases with the rising temperature, the recommended power rating of sense resistor is 1.25 times larger than the calculated, or two resistors in parallel to reduce the effect of rising temperature.

Inductor Selection

Usually, for step-down converter, the current ripple of LED output is approximated to the current ripple of inductor. Since the switching frequency of MBI6653 is fixed, then the inductance can be calculated by Equation (4).

$$L = \frac{V_{out}(1-\frac{V_{out}}{V_{in}})}{F_{SW} \times I_{LED} \times \Delta I_L} \quad \text{(4)}$$

Another consideration in inductor selection is the saturation current, which must be 1.25 times higher than inductor peak current. The minimum inductor saturation current (I_{sat_min}) can be estimated by Equation (5).

$$I_{sat\_min} > 1.25 \times I_{L,PK} \quad \text{(5)}$$

$$I_{L,PK} = I_{LED} + \frac{V_{out}(1-\frac{V_{out}}{V_{in}})}{2 \times F_{SW} \times L} \quad \text{(6)}$$

There is a trade-off between inductance and saturation current in the same volume. To reduce EMI effect, the shielded type inductor is necessary.

Input capacitor selection

Input capacitor provides instant current to MBI6653 when MOSFET turns on, and be charged by input voltage when MOSFET turns off. For system stability, the recommended input capacitance is 10μF and can be adjusted by different spec. The rating voltage of input capacitor should be 1.5 times of input voltage. The advantages of electrolytic capacitor are cheap and accessible; oppositely, the short life time in high temperature is the disadvantage. Small size, low ESR and good high frequency characteristics are the advantages of ceramic capacitor, but in hot plug application, the need of extra transient voltage suppressor (TVS) to suppress the surge current is the drawback.

Another concern to use the electrolytic capacitor is the maximum ripple current. The large ripple current, which exceeds the specification of capacitor, might damage capacitor or IC. To enhance the noise immunity, place a ceramic capacitor closes to the VIN is recommended. The suggested ceramic capacitor is from 0.1μF to 1μF with X7R.

Schottky Diode Selection

The inductor and free-wheeling diode will form a discharge current loop to keep the LED current loop when MOSFET turn-off. To improve efficiency, the Schottky diode with low forward voltage and fast response time is recommended. There are two factors need to be considered in Schottky diode selection, one is the maximum reverse voltage (V_R), which 1.5 times larger than input voltage is recommended, and another is the maximum forward current (I_F), which should be 1.25 times larger than inductor peak current ($I_{L,PK}$). The inductor peak current can be calculated by Equation (6).

$$I_F > 1.25 \times I_{L,PK} \quad (7)$$

$$V_R > 1.5 \times V_{in} \quad (8)$$

Output Capacitor Selection

To avoid system stability be affected, the 2.2μF output capacitor, which can be electrolytic or ceramic type, is recommended. In low input voltage and high output current application, the amplitude of output voltage ripple is large, thus the valley of input voltage ripple might be lower than V_{UVLO} and trigger the UVLO protection. To prevent this malfunction, the output capacitor can be increased to 4.7μF. The recommended rated voltage of output capacitor should be 1.5 times larger than the input voltage.

PCB Layout Guideline

A good PCB layout is very helpful to improve efficiency and system stability; followings are layout guidelines for users.

1. To improve the output current accuracy, the R_{SEN} should be placed as close as possible to SEN and VIN of IC with short and wide trace.
2. The input capacitor should be placed to the VIN pin as close as possible. If the PCB size is not allowed, a 0.1 μF ceramic capacitor should be paralleled to the VIN and GND as a bypass capacitor.
3. To prevent the noise interference from the switched MOSFET, please reduce the area which consists of SW pin, Schottky diode and inductor.
4. In order to eliminate parasitic elements, the path with larger current should be short and wide.

PCB Layout Guideline of Multi-Module Dimming

1. For the multi-module dimming application, the input voltage traces of dimmer and converter should be separated. (Please refer to the 1st point in Figure 8)
2. For the multi-module dimming application, to prevent the noise interference, the ground planes of dimmer and converter should be separated, and connected by a 0Ω resistor with 0603 package. (Please refer to the 2nd point in Figure 8)
3. For the multi-module application, the ground system of each module should be independent of each other, and

then connect together to the ground of I/O connector. (Please refer to Figure 9)

4. The trace with large current should go into the input capacitor first, and then the power module. (Please refer to the 3rd point in Figure 8)
5. The trace flows large current should be kept wide and short to enhance the conversion efficiency. (Please refer to the 4th point in Figure 8)
6. The trace flows large current is not allowed to conductor through via. (Please refer to the 5th point in Figure 8)
7. To prevent the noise interference, the bottom of sensitive trace, such as SW and SEN, allows the GND trace only. (Please refer to the 6th point in Figure 8)

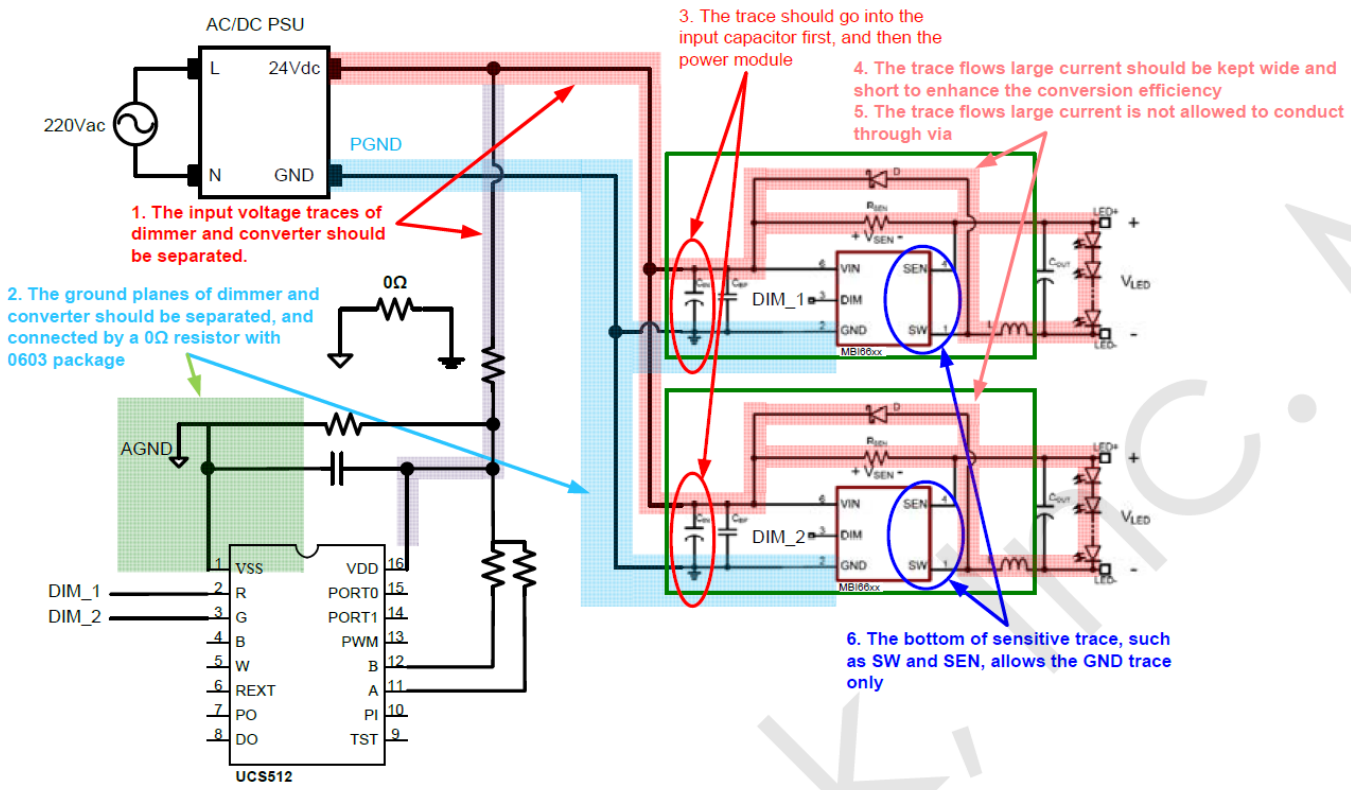


Fig.8 The layout guideline of multi-module dimming application

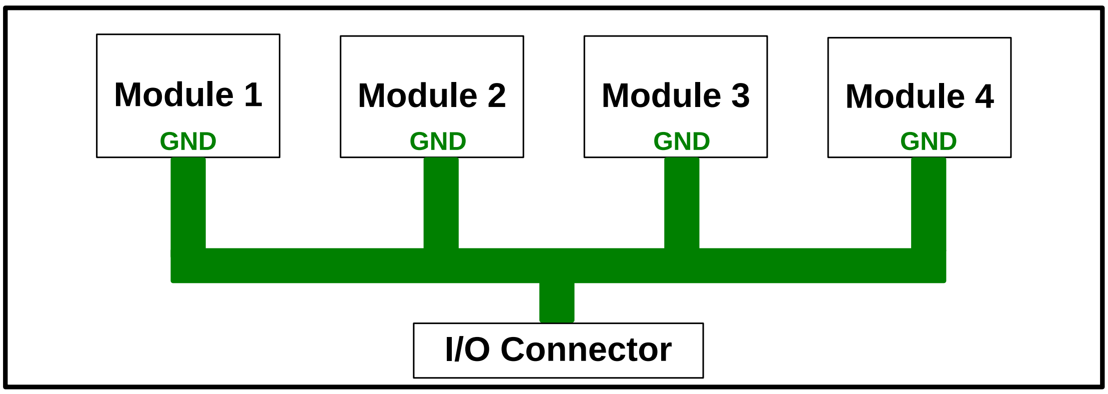
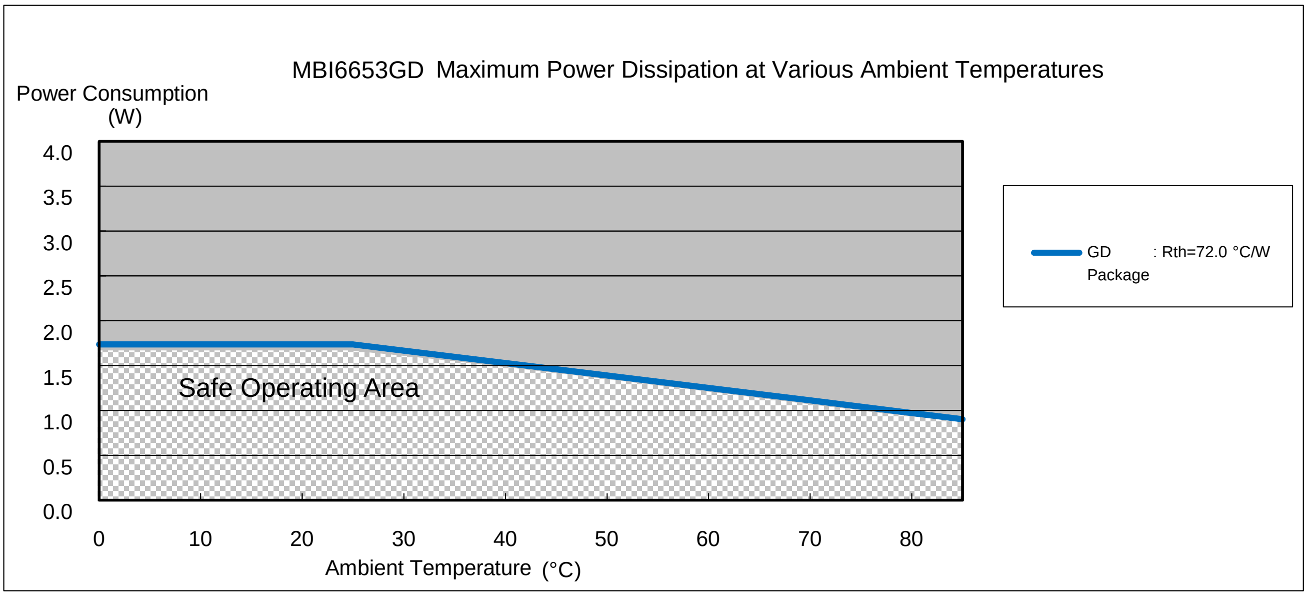


Fig.9 The grounding system of multi-module dimming application

Package Power Dissipation (P_D)

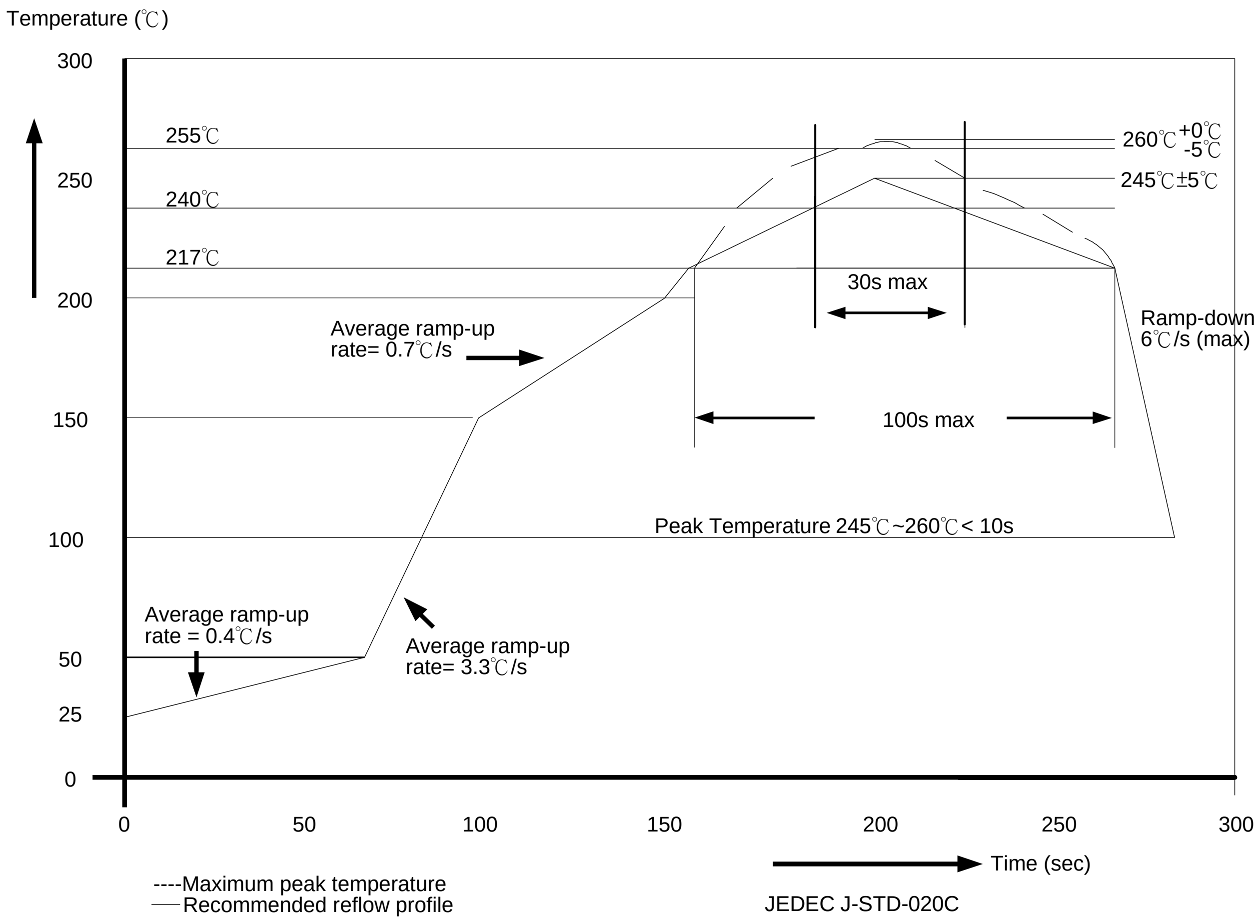
The maximum power dissipation, $P_D(max)=(Tj–Ta)/R_{th(j-a)}$, decreases as the ambient temperature increases.



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.

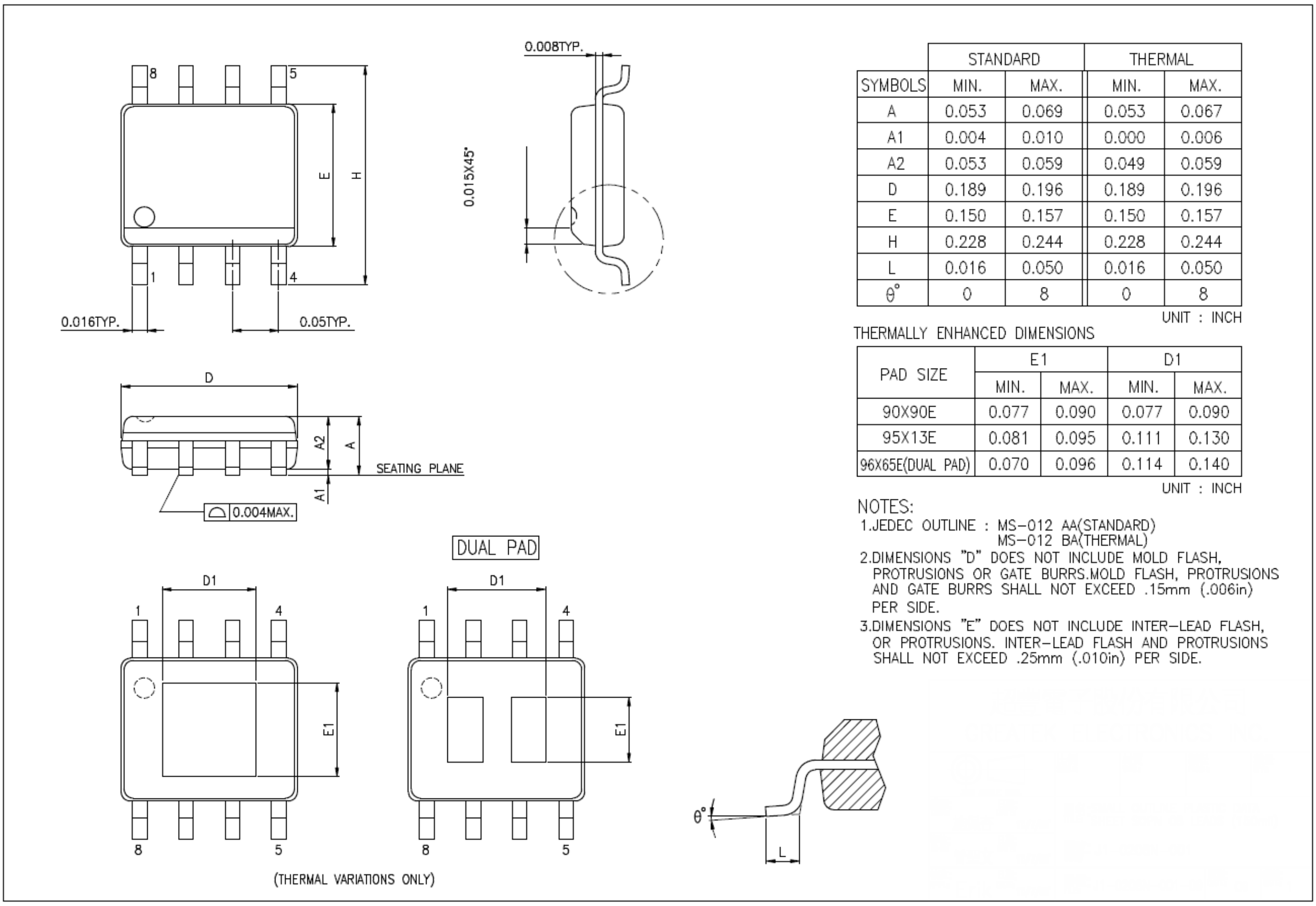
For managing MSL3 Package, it should refer to JEDEC J-STD-020C about floor life management & refer to JEDEC J-STD-033C about re-bake condition while IC's floor life exceeds MSL3 limitation.



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	STANDARD MIN.	STANDARD MAX.	THERMAL MIN.	THERMAL MAX.
A	0.053	0.069	0.053	0.067
A1	0.004	0.010	0.000	0.006
A2	0.053	0.059	0.049	0.059
D	0.189	0.196	0.189	0.196
E	0.150	0.157	0.150	0.157
H	0.228	0.244	0.228	0.244
L	0.016	0.050	0.016	0.050
θ°	0	8	0	8

UNIT : INCH

THERMALLY ENHANCED DIMENSIONS

PAD SIZE	E1 MIN.	E1 MAX.	D1 MIN.	D1 MAX.
90X90E	0.077	0.090	0.077	0.090
95X13E	0.081	0.095	0.111	0.130
96X65E(DUAL PAD)	0.070	0.096	0.114	0.140

UNIT : INCH

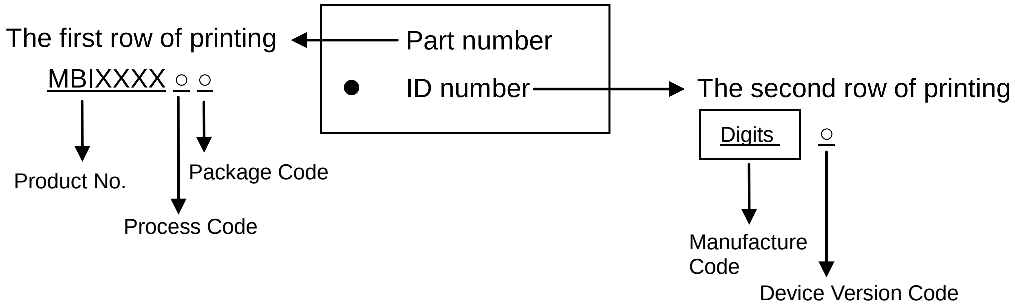
NOTES:
1. JEDEC OUTLINE : MS-012 AA(STANDARD)
   MS-012 BA(THERMAL)
2. DIMENSIONS "D" DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.MOLD FLASH, PROTRUSIONS AND GATE BURRS SHALL NOT EXCEED .15mm (.006in) PER SIDE.
3. DIMENSIONS "E" DOES NOT INCLUDE INTER-LEAD FLASH, OR PROTRUSIONS. INTER-LEAD FLASH AND PROTRUSIONS SHALL NOT EXCEED .25mm (.010in) PER SIDE.

MBI6653GD 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
V2.01	B
VA.00	C

Product Ordering Information

Product Ordering Number*	RoHS Compliant Package Type	Weight (g)
MBI6653GD-B	SOP8L-150-1.27	0.07

*Please place your order with the ***"product ordering number"*** information on your purchase order (PO).

Disclaimer