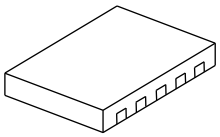
Step-Down, 2.5A Dimmable LED Driver for Automotive Lighting

Features

- 5~45V wide input voltage range
- Open Loop Power Regulator output 5V for Gate Driver
- Support Analog/PWM Dimming (select by EN pin)
- Minimum 5% Analog Dimming
- Minimum 5% PWM Dimming @ 1KHz
- ±3% Output Current Accuracy
- Integrated Low Side Switch w/ Peak Current Limit 3A
- Up to 1MHz Switching Frequency (Adjustable w/ External Resistor through ROSC)
- Fixed Spread Spectrum range for EMI Consideration
- DC-DC Protection: UVLO/Soft-Start/Diode Short/Thermal Foldback(TFB)/Over Current Protection(OCP)/Over Temperature Protection(OTP)

Small Outline Package

GD: SOP8-150-1.27



GDF: DFN-10L 3*3

Product Description

MBI6659 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 PWM control scheme, MBI6659 eliminates external compensation design and makes the design simple.

The output current of MBI6659 can be programmed by an external resistor and dimmed via pulse width modulation (PWM) or DC voltage through EN pin to achieve higher efficiency linear current modulation.

MBI6659 features completed protection design to handle faulty situations. The start-up function limits the inrush current while the power is switched on. Thermal shutdown, Thermal Foldback and Schottky diode short (SDS) 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.

Applications

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

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Typical Application Circuit

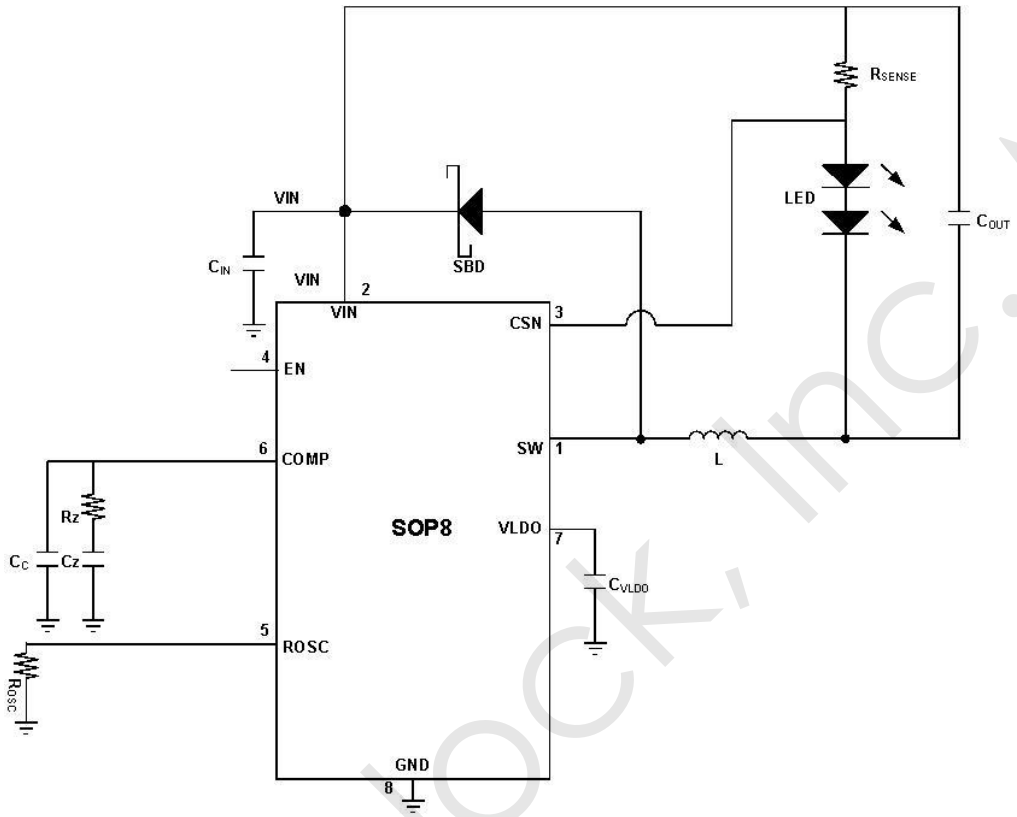


Fig. 1 Application circuit of MBI6659

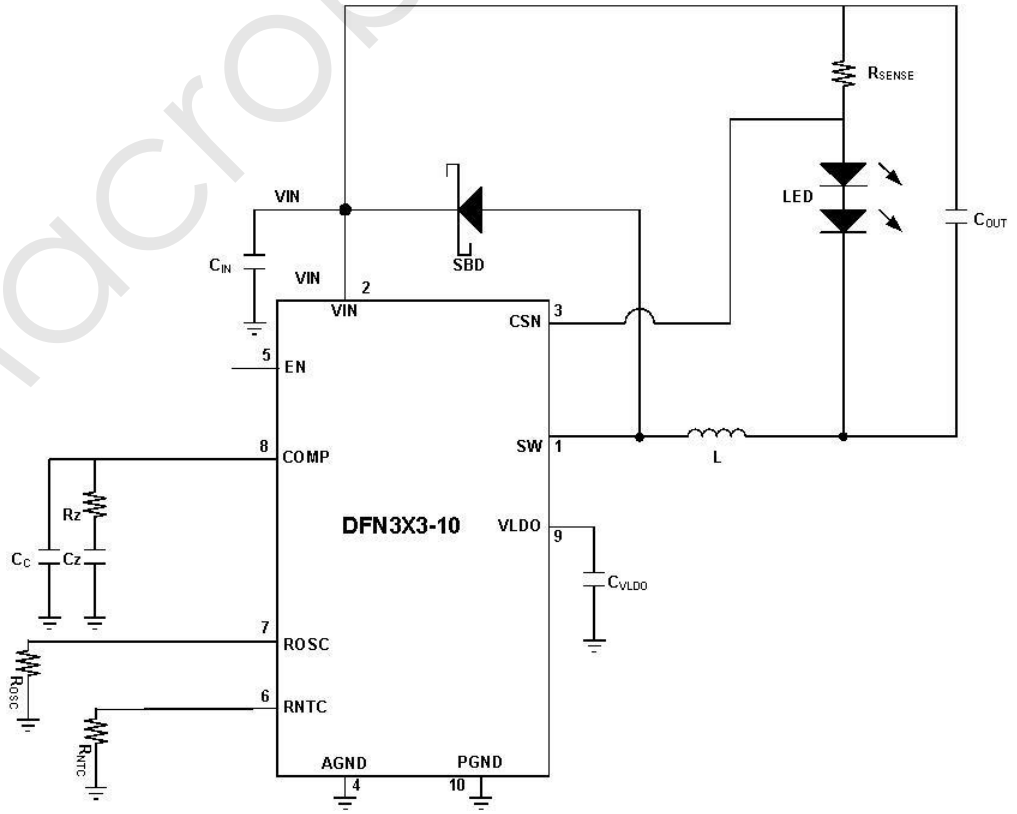


Fig. 2 Application circuit of MBI6659

Functional Diagram

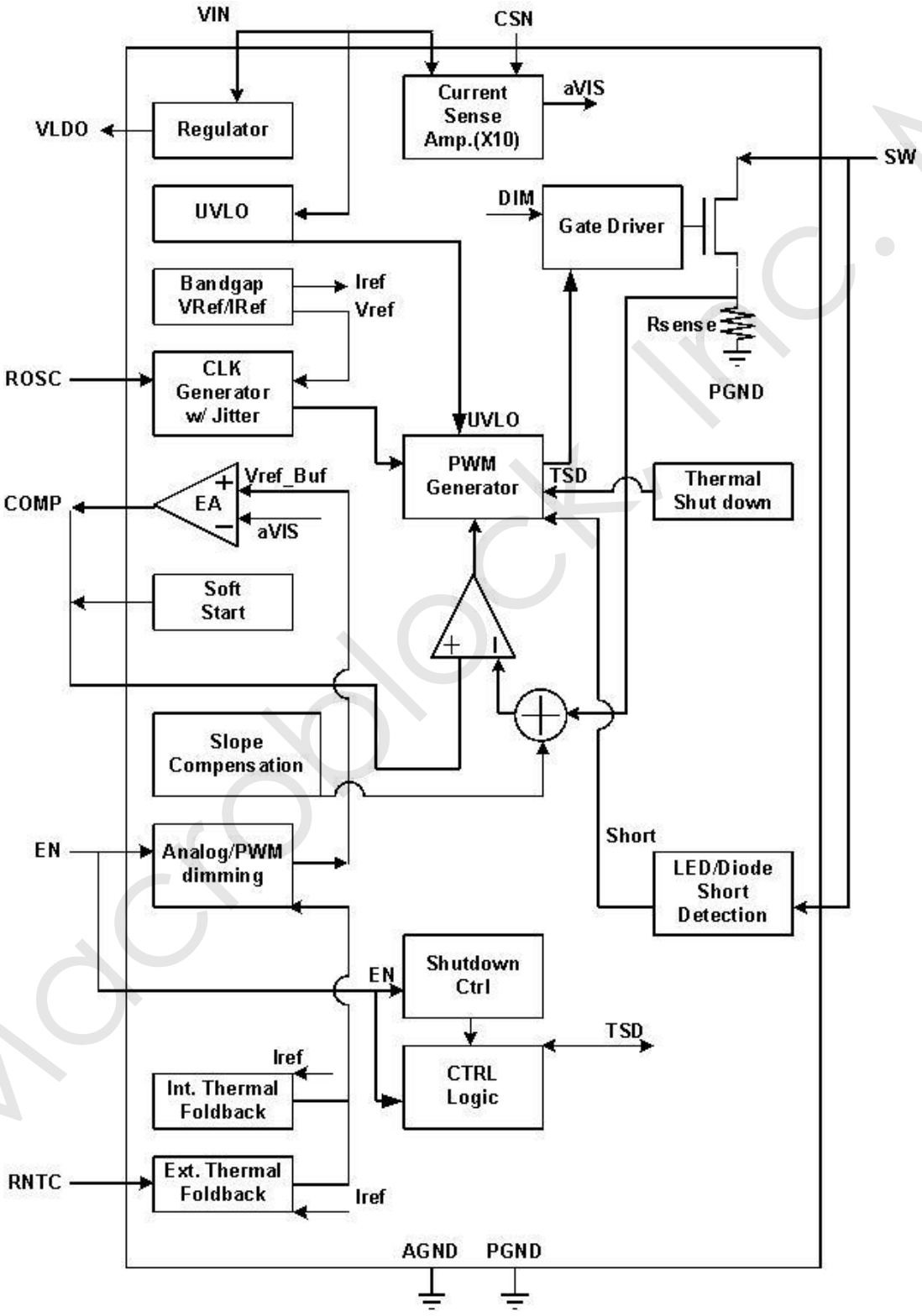
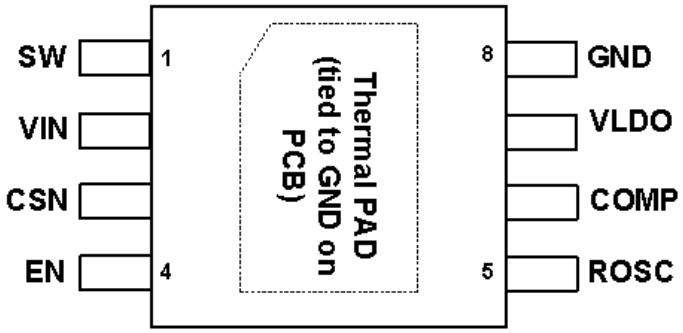
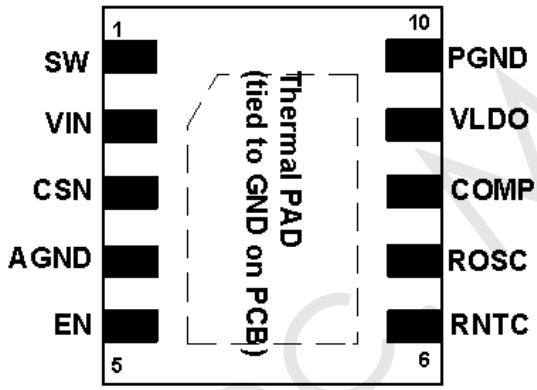


Fig. 3 Function block diagram of MBI6659

Pin Configuration



MBI6659GD (Top View)



MBI6659GDF (Top View)

Pin Description

Pin Name	Function
SW	DC-DC Switch Node
VIN	Power Input
CSN	LED Current Sense Negative node, VIN-CSN<5.5V
AGND	Quiescent and ESD Ground
EN	Chip Enable, Hi Active, default weak pull Lo, Analog/PWM Dimming Decision, Analog Dimming Input
RNTC	Negative Temperature Coefficient Resistor input, disable external NTC function if pin floating
ROSC	DC-DC Switching Frequency Setting
COMP	Error Amplifier Output
VLDO	5.5V LDO Output
PGND	5V LDO output

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}	0~50	V
Sustaining Voltage at EN pin		V_{EN}	-0.3~50	V
Sustaining Voltage at SW pin		V_{SW}	-0.3~50	V
Sustaining Voltage at CSN pin		V_{CSN}	-0.3~50	V
Power Dissipation (On 4-Layer PCB, Ta=25°C)	GD Type	P_D	2.08	W
	GDF type		1.84	
Empirical Thermal Resistance (On PCB, Ta=25°C)**	GD Type	$R_{th(j-a)}$	40	°C/W
	GDF type		43	
Junction Temperature		$T_{j,max}$	150**	°C
Operating Ambient Temperature		T_{opr}	-40~+85	°C
Storage Temperature		T_{stg}	-55~+150	°C
ESD Rating	Human Body Mode (MIL-STD-883G Method 3015.8)	HBM	Class 3A (3KV)	-
	Machine Mode (ANSI/ ESD S5.2-2009)	MM	Class M4 (300V)	-

*The PCB size is 76.2mm*114.3mm in simulation. Please refer to JEDEC JESD51-7 thermal measurement standard.

**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.

Recommended Operating Conditions

Characteristic	Symbol	Rating	Unit
Supply Voltage	V_{IN}	5~45	V
Operating Junction Temperature Range	T_j	-40~+125	°C

Electrical Characteristics

V_{IN}=12V, T_A=25°C; unless otherwise specified.

Characteristics	Symbol	Condition	Min.	Typ.	Max.	Unit
Power Input						
Supply Voltage	V_{IN}		5		45	V
Standby current	$I_{standby}$	VIN=12V, EN=Lo>20ms,		150	300	uA
Quiescent current	I_Q	VIN=12V, EN=Hi, ROSC=39K, SW non-switching		1.5	3	mA
Switching current	I_{Q_SW}	VIN=12V, EN=Hi, ROSC=39K,SW switching		3.5	7	mA
VIN UVLO Threshold	V_{INUVLO}	V_{IN} Falling		4.1		V
V_{IN} Start-Up Threshold	$V_{INSTRUP}$	V_{IN} Rising		4.3		V
V_{IN} UVLO Hysteresis	V_{IN-HYS}			200		mV
LDO						
Output accuracy		EN=Hi, VIN>=7V ,measure V(VLDO),	-10%	5.5	+10%	V
DC-DC Converter						
Internal MOS RON(SW)						
ON Resistance	R_{ON}	VLDO=5.5V		0.25	0.5	Ω
SW Leakage	I_{SW_LEAK}	EN=Lo,V(SW)=45V			1	uA
Current Sense & Current Limit						
Current Sense Voltage	V_{sense}		-3%	0.2	+3%	V
Low Side Peak Current Limit	IL_{peak}	Cycle by cycle current limit		3	3.6	A
ErrorAmp						
COMP Sink/Source Current	Icomp			30		uA
Trans conductance	GM_{EA}			200		uA/V
Oscillator Frequency and Jitter						
Frequency Setting Voltage	V_{ROSC}	ROSC=39KΩ w/o frequency jitter		1		V
Frequency	F_{OSC}	ROSC=39KΩ w/o frequency jitter, in open loop,200K~2MHz	-10.00 %	1	10.00 %	MHz
Max. Duty	D_{MAX}			90		%
Minimum On Time	$V_{MIN\ ON}$			60		ns
Delta Frequency	ΔF_{OSC}	ROSC=39KΩ,		12		%
LED Short Protection						
CSN Leakage Current	$I_{CSPLEAK}$	EN=Lo, V(VIN)=V(CSN)=45V,measure I(CSN)			1	uA
CSN Sink Current	$ICSP_{\_SINK}$	EN=Hi,V(VIN)=V(CSN=45V,measure I(CSN)		5	10	uA
Logic Input EN and Analog/PWM Dimming						
Input High Threshold	VIH_ON		1			V
Input Low Threshold	VIL_OFF				0.4	V
EN Analog Dimming Low Bound				1		V
EN Analog Dimming Hi Bound				2		V

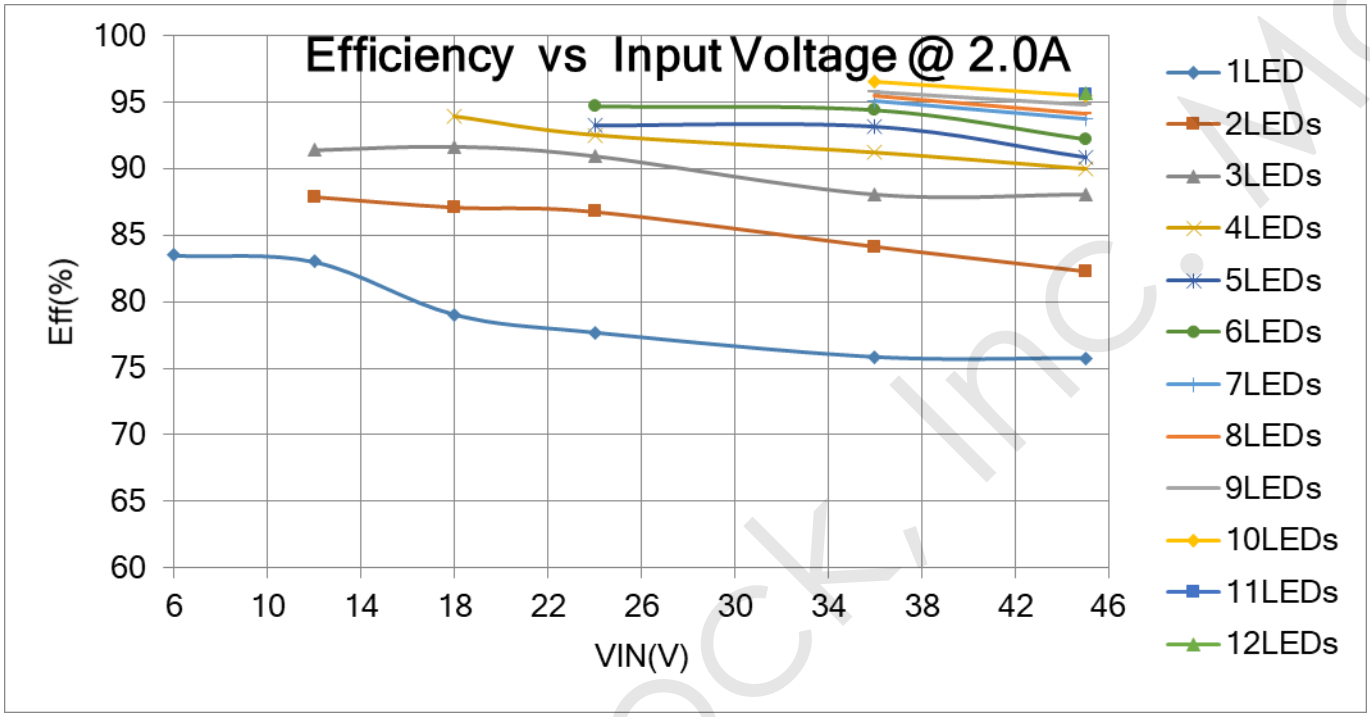
EN PWM Dimming Hi Bound	VIH_PWM		3.2			V
EN Pull up Current	$I_{EN\_Pull\_up}$	EN>1V		19		uA
EN Weak Pull up Resistor	$I_{EN\_Pull\_up}$	EN=0V		150		kΩ
EN shutdown delay time	$T_{shutdown}$		20			ms
Thermal Protection						
Thermal Shutdown Trigger Point	TJ	EN=Hi, COMP=0V, SW non-switching		165		℃
Thermal Shutdown Hystersis	TJ_hys			20		℃
Internal Thermal Foldback Trigger Point	TFBJ			150		℃
Thermal Foldback Slope	TFB_slope			1.5		%/℃
External Thermal Foldback Disable	VIH_TFB		4			V
RNTC Pull Up Current	I_{RNTC}	V_{RNTC}=1V	18	20	22	uA

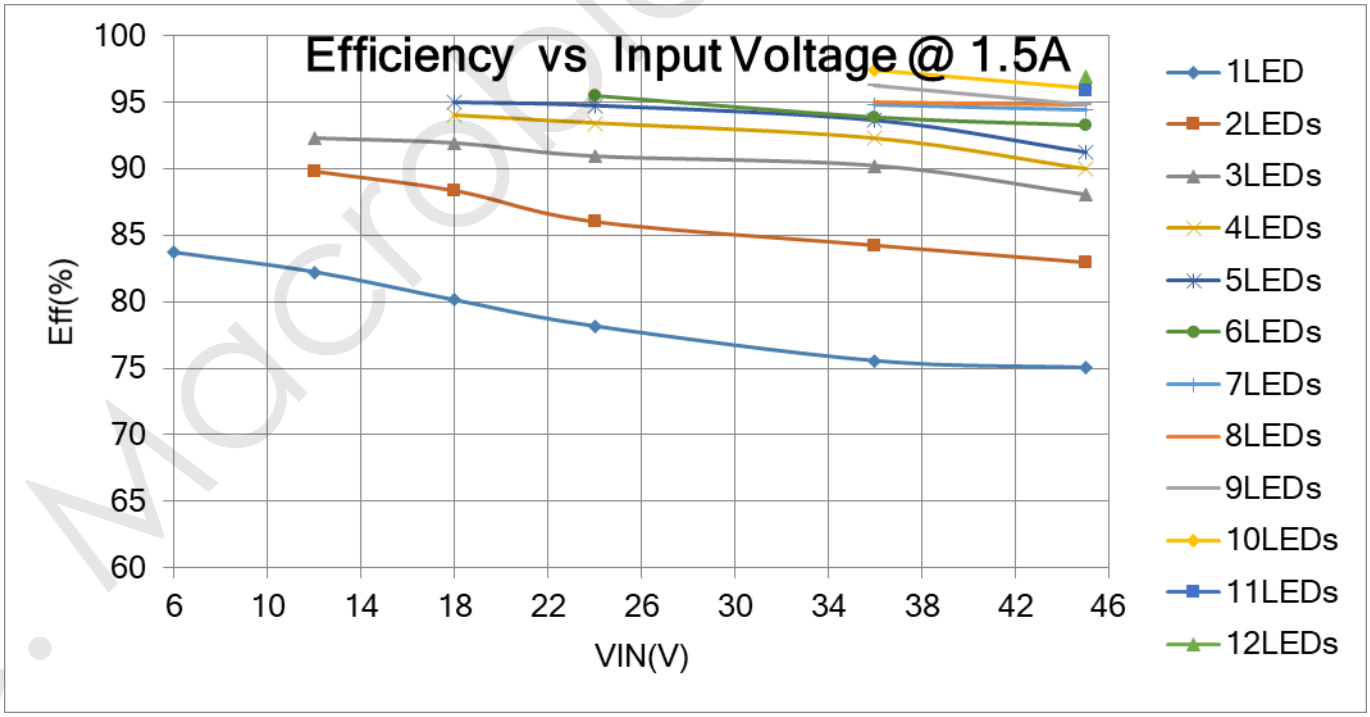
*Parameters are not tested at production. Parameters are guaranteed by design.

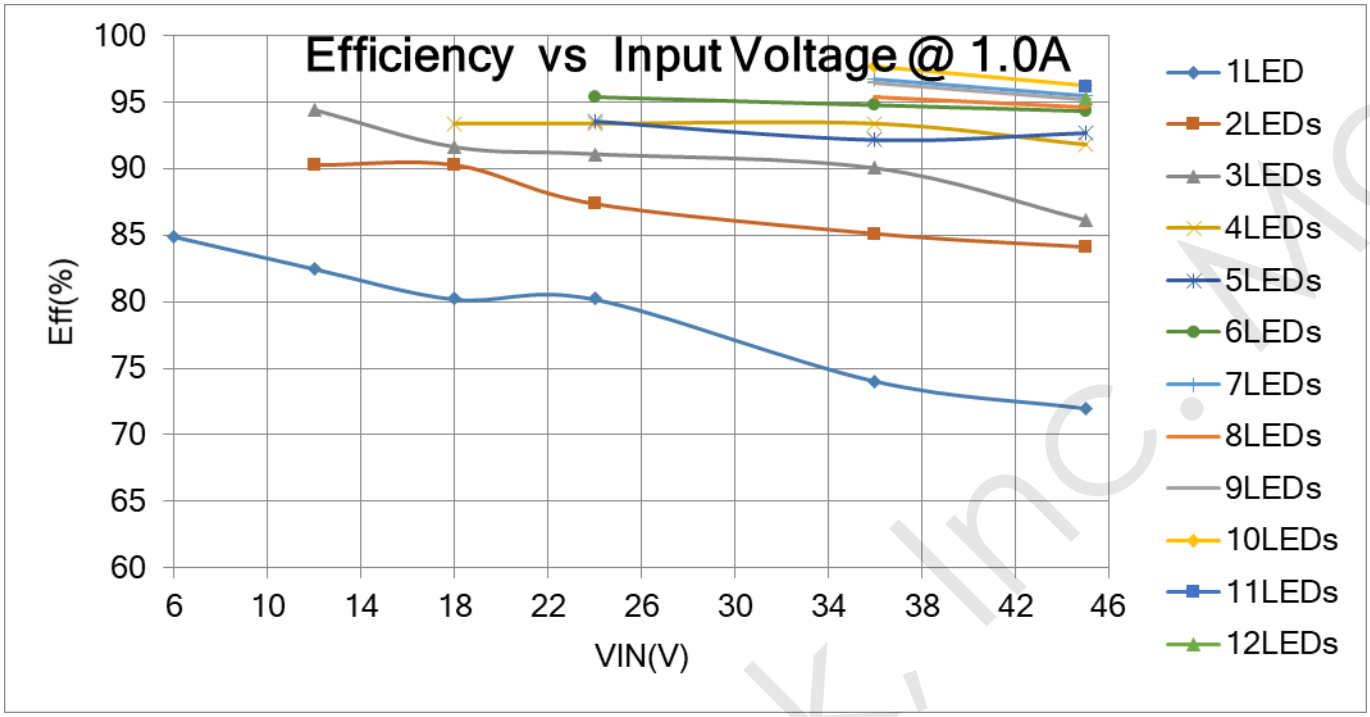
** Schottky diode short protection is not tested at production, it is guaranteed by design.

Typical Performance Characteristic

1. Efficiency vs. Input Voltage at Various LED Cascaded Numbers







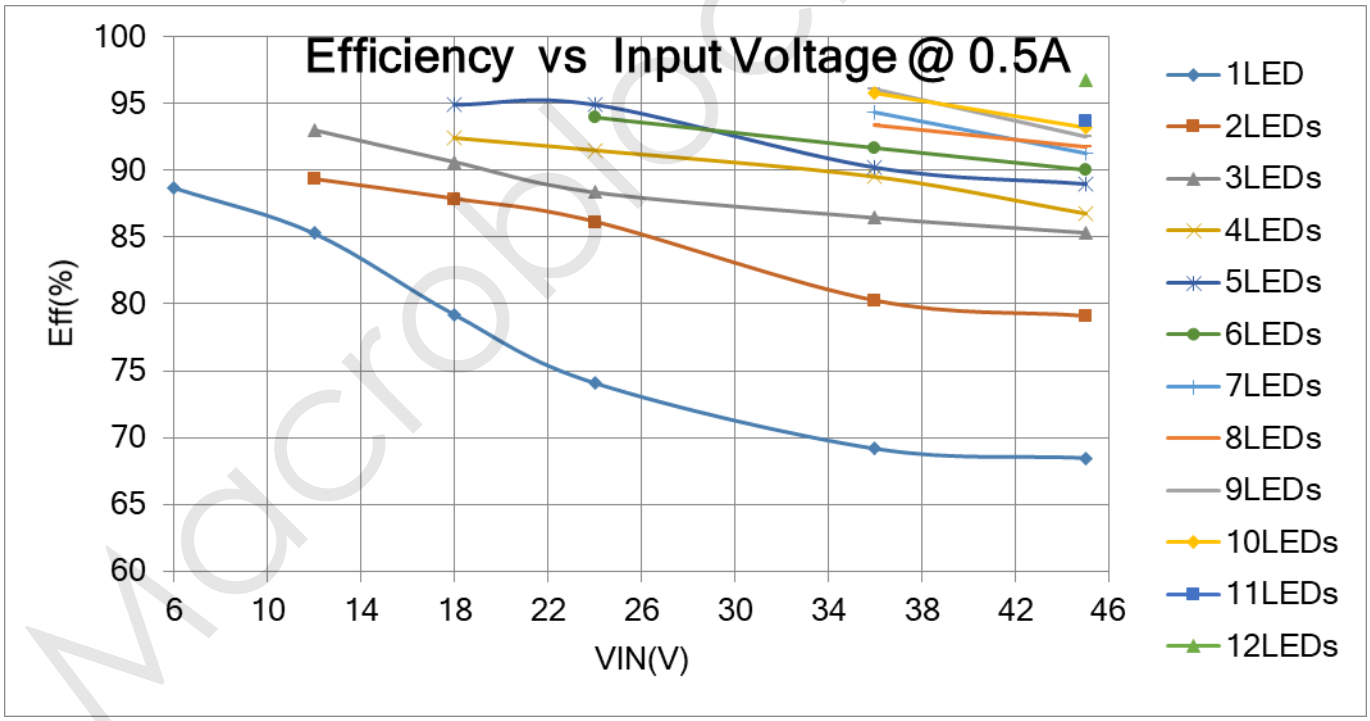


Fig. 4 Efficiency vs. input voltage at I_{OUT} = 2.0A, 1.5A, 1.0A and 0.5A

Application Information

MBI6659 is a simple and high efficient buck converter with fix frequency for high power application, fix frequency control can be set by an external resistor and build in MOSFET would be able simplify the design.

The output current of MBI6659 can be set by an external resistor. The EN pin of MBI6659 provides analog and PWM dimming, besides MBI6659 provides full protection, Soft-start, UVLO, thermal foldback, over temperature protection(OTP) and diode short protection.

Fix frequency PWM mode

MBI6659 is a step-down constant current converter with fixed-frequency PWM control. Comparing with other hysteretic converters, it provides excellent line/load regulations and lower LED output ripple current. Fig. 5 shows the typical application circuit of MBI6659.

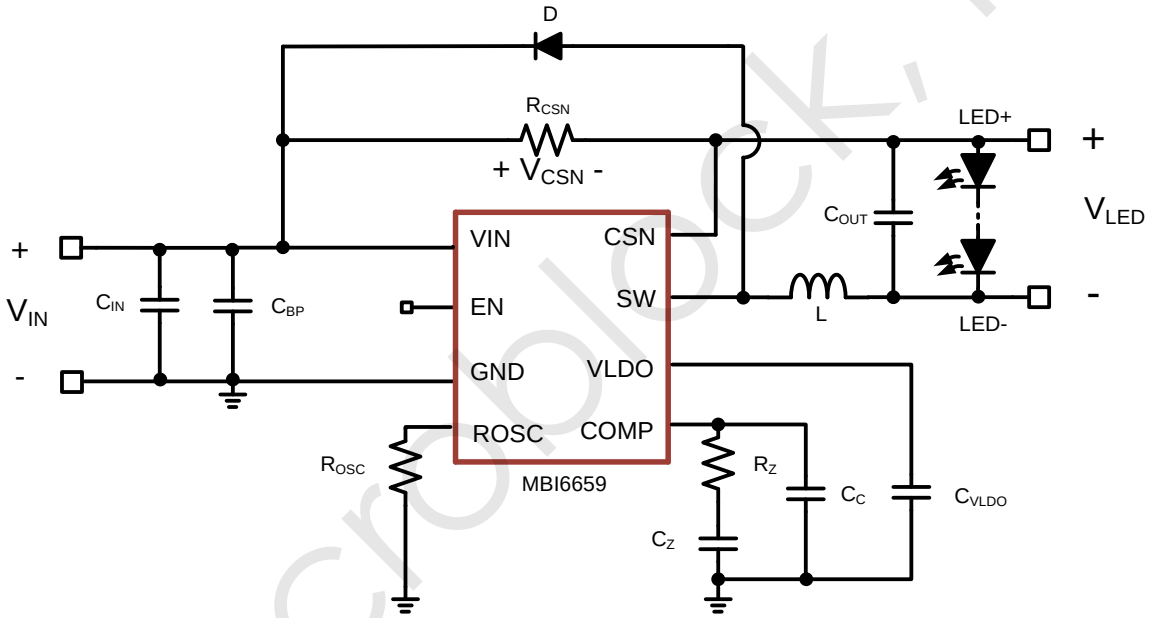


Fig 5. MBI6659 application circuit

Dimming Functions

The EN pin of MBI6659 can be used to achieve both analog and PWM dimming. Fig. 6 is the diagram of dimming function.

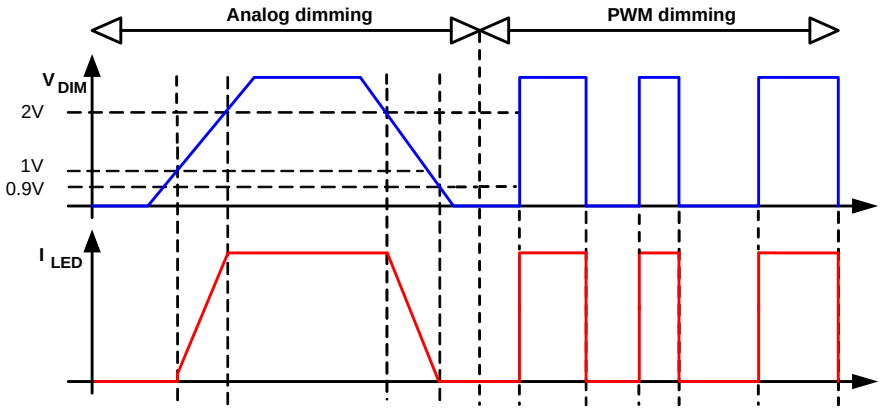


Fig. 6 Dimming waveform diagram

A. PWM dimming

MBI6659 also features digital dimming function, which can be adjusted by a PWM signal at EN pin, as Fig. 7 shows. The output LED current will increase with the increasing DPWM. The high level of VDIM must be larger than 2V to obtain correct dimming current. The dimming range of PWM signal controlled is recommended from 5% to 100%. For dimming linearity, the recommend range of PWM frequency is from 100Hz to 1kHz. The output current is described as Equation (1),

$$I_{LED,PWM} = D_{PWM} \times I_{LED} \quad \text{..... (1)}$$

,where DPWM is the duty cycle of PWM signal.

In PWM dimming application, the dimming resolution is related to the switching frequency, the higher switching frequency leads the higher resolution. In general, the switching frequency should be 10 times larger than the PWM dimming frequency. However, the side effects of high switching frequency are the higher switching loss and case temperature. Consequently, this is a trade-off between switching frequency and dimming resolution.

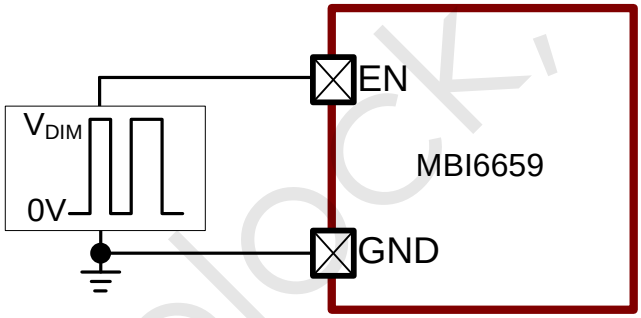


Figure 7. The sketch of digital dimming by PWM signal

Another way to driver EN pin is from the I/O pin of MCU, as shown in Fig. 8, Typically, the I/O pin consists of the open drain circuit to result in a negative spike. Diode and resistor are needed to prevent IC being damaged by the negative spike. The value of R1 is ranged from 1kΩ to 10kΩ depends on actual application.

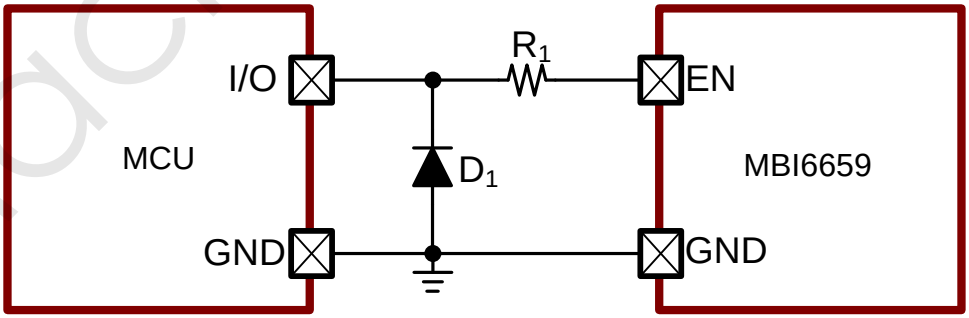


Fig. 8 The sketch of digital dimming by MCU

B. Analog dimming

Users can apply DC voltage directly to EN for modulating LED current. The result is shown in the following figures. The analog dimming function can be achieved easily by applying an external DC voltage (VDIM) at EN pin. To prevent the noise interference, a 0.1uF ceramic capacitor parallel with EN pin is recommended, as shown in Fig. 9 The relationship between ILED,ADIM and VDIM is shown in (2), where ILED is determined by RCSN.

$$I_{LED,ADIM} = I_{LED} \times \frac{V_{DIM} - 1V}{2V - 1V} \quad \text{..... (2)}$$

In analog dimming application, the output LED current (ILED,ADIM) will be increased with the increasing of the voltage (VDIM). The range of VDIM is from 1V to 2V. If VDIM is higher than 2V, the output current will keep at ILED.

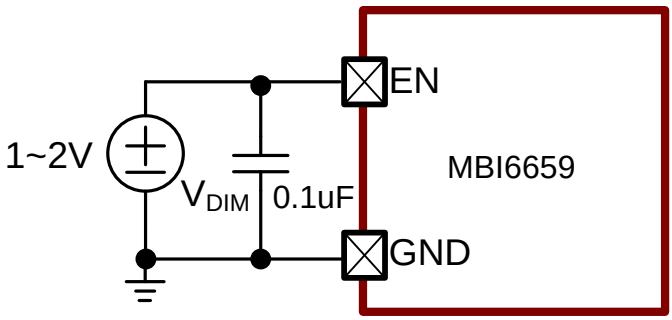


Fig. 9 Analog dimming by external DC voltage

Soft Start

The MBI6659 contains a soft-start function to decrease input inrush current and avoid output overshoot at the transient of power-on. The soft-start function starts when the input voltage is higher than the start-up voltage $V_{START-UP}$, and then the internal circuit will gradually increase on-time until the normal operations. The duration of soft-start is related to the output current, the larger output current results the longer soft start time.

Under-Voltage Lockout

When the input voltage (V_{IN}) is higher than the startup voltage ($V_{START-UP}$), driver starts working and causes a voltage drop on V_{IN} ; if there is no UVLO, the switching components might be damaged by abnormal power on/off. MBI6659 features an under-voltage lockout with 200mV hysteresis range (V_{UVLO}=V_{START}-200mV) to avoid this problem.

Thermal Foldback

When the juction temperature of MBI6659 reaches the thermal foldback point (T_{FB}), the output current will be decreased with a negative slope of -1.5%/℃, and the luminous intensity of LED will be decreased accordingly. If the junction temperature keeps rising to the thermal shutdown point (T_{SD}), the internal MOSFET of MBI6659 will be turned off to prevent being damaged by overheat. Once the IC temperature falls below the thermal foldback point (T_{FB}), LED current will return to the preset current. Additionally, the LED temperature can be detected by external thermistor at NTC pin in DFN3X3-10L package. Once the voltage of V_{NTC} falls below 1V, the output current will be decreased to prevent LED being damaged by overheat. It shows the relationship between V_{NTC} and R_{NTC} in (3).

$$V_{NTC} = 18uA \times R_{NTC} \quad \text{..... (3)}$$

,where 18uA is the internal current source of the NTC pin and R_{NTC} is the resistance of the thermistor.

Diode short protection

To prevent IC from being damaged by abnormal operation, MBI6659 is built in Diode short protection. When the diode is shorted, MBI6659 will be turned off and latched off until V_{IN} power on reset.

Component Selection

A. Output current setting

The output current of MBI6659 can be programmed by an external resistor, and relationship of ILED and RCSN is given by (4).

$$I_{LED} = \frac{V_{CSN}}{R_{CSN}} \quad \text{..... (4)}$$

,where RCSN is current sense resistor and VCSN is the reference voltage 200mV.

The resistor with 1% tolerance, which can enhance the output current accuracy, is recommended to be the RCSN. The power dissipations of RCSN is equal to PCSN=(VCSN)2/RCSN. To prevent the sustaining power decreased with the rising temperature, 2.5 times of PCSN is recommended to be the rating of the resistor. If the power rating is not enough, paralleled resistors are suggested.

Switching frequency setting

The switching frequency of MBI6659 can be programmed by an external resistor, and relationship of ROSC and switching frequency is given by (5).

$$f_S = \frac{39}{R_{OSC}} \quad \text{..... (5)}$$

,where f_s is switching frequency (MHz), and ROSC is switching frequency setup resistor.
The resistor with 1% tolerance, which can enhance the switching frequency accuracy, is recommended to be the ROSC. The recommended switching frequency is ranging from 50kHz to 1MHz. For high power application, the recommended switching frequency is 350kHz to get better efficiency. For high digital dimming resolution, the switching frequency should be higher than 500kHz, but the side effect is poor efficiency. Additionally, MBI6659 is built in jitter function for improve EMI performance. The range of jitter is fixed at 20% (±10%).

Inductor Selection

The switching frequency of MBI6659 is fixed, then the inductance can be calculated by (6).

$$L = \frac{(V_{IN} - V_{LED}) \times \frac{V_{LED}}{V_{IN}}}{\Delta I_L \times f_s} \quad \text{..... (6)}$$

,where fS is the switching frequency, L is the inductance and △IL is the inductor ripple current.

In general, inductor ripple current of MBI6659 should be kept under 30%, and then inductor peak current can be calculated by (7).

$$I_{L(PK)} = I_{LED} + \frac{\Delta I_L}{2} \quad \text{..... (7)}$$

The peak current of inductor must be under the current limit of power MOSFET to avoid IC damage in a fault condition. The current limit of power MOSFET is 3.0A.

As switching frequency is determined, substituting fs into (6) to get proper inductance. However, inductance is not the only concern in inductor selection, the saturation current also needs to be considered. The recommended saturation current should be larger than 1.25 times of inductor peak current (IL(PK)). In order to reduce the LED ripple current and power loss, the recommended inductance is 47uH to ensure operation mode of MBI6659 is

continuous conduction mode (CCM). However, the larger inductance is a trade-off with saturation current in the same volume. Furthermore, the inductor with shielding is recommended for EMI consideration.

Input Capacitor Selection

Input capacitor provides instant current to MBI6659 when MOSFET turns on, and charged from input voltage when MOSFET turns off. For system stability, the recommended input capacitor is 10uF and can be adjusted by different application. The rating voltage of input capacitor is 1.5 times of input voltage. Small size, low ESR and good high frequency characteristic 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. To enhance the noise immunity, place a ceramic capacitor close to the VIN is recommended. The suggested ceramic capacitor is from 0.1uF to 1uF with X7R.

Schottky Diode Selection

When MOSFET turns off, the inductor discharges energy through free-wheeling diode and LED to form a current loop. The schottky diode with low forward voltage and fast response time is recommended to be the free-wheeling diode. There are two factors need to be concerned as schottky diode. One is the maximum reverse voltage, whose rating is 1.5 times of input voltage; and the other is the maximum forward current with 1.25 times of inductor peak current IL(PK) is recommended.

Output Capacitor Selection

The output capacitor is used to reduce the output ripple current. The larger capacitance results the smaller ripple current. The recommended capacitance is 10uF and the rating voltage is 1.5 times of output voltage. The output capacitor also affects the dimming resolution, in the application of high dimming resolution, the output capacitor is not allowed.

COMP Compensation Selection

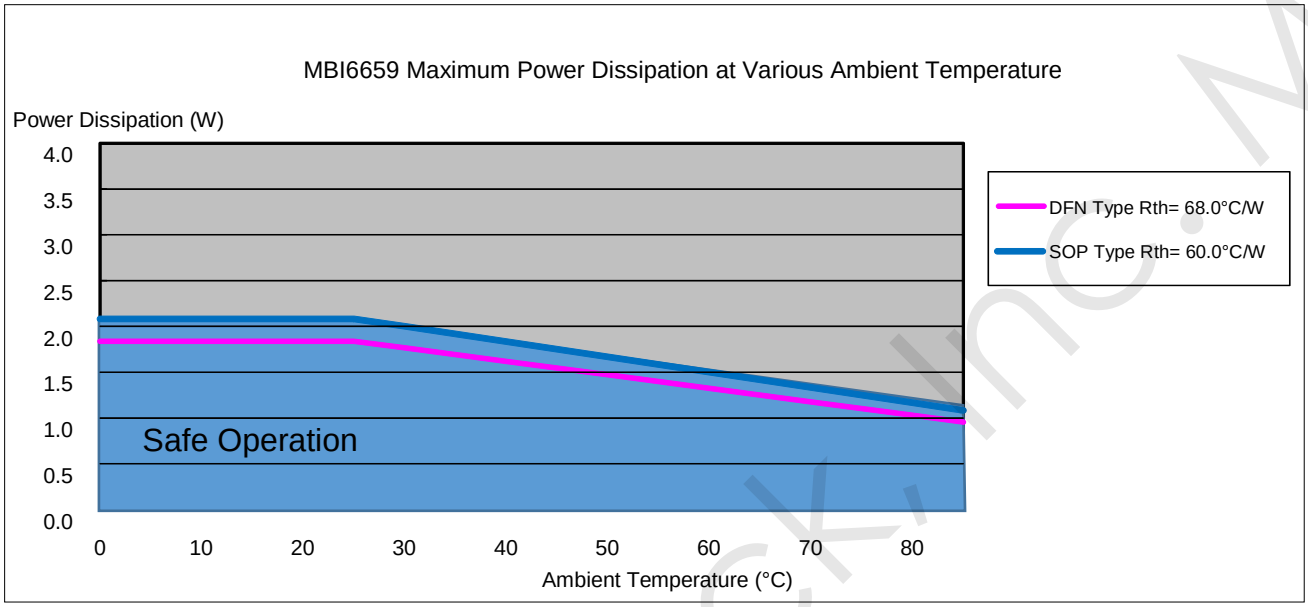
For system stability, the compensator components RZ、CZ and CC¬ are necessary. In general, a 1.1KΩ resistor to be RZ, and a 22nF(X7R) ceramic capacitor to be CZ and CC are recommended and it can be adjusted based on the actual electric circuit situation.

CVLDO Selection

The recommended capacitance of CVLDO is 0.1uF(X7R) ceramic capacitor.

Package Power Dissipation (P_D)

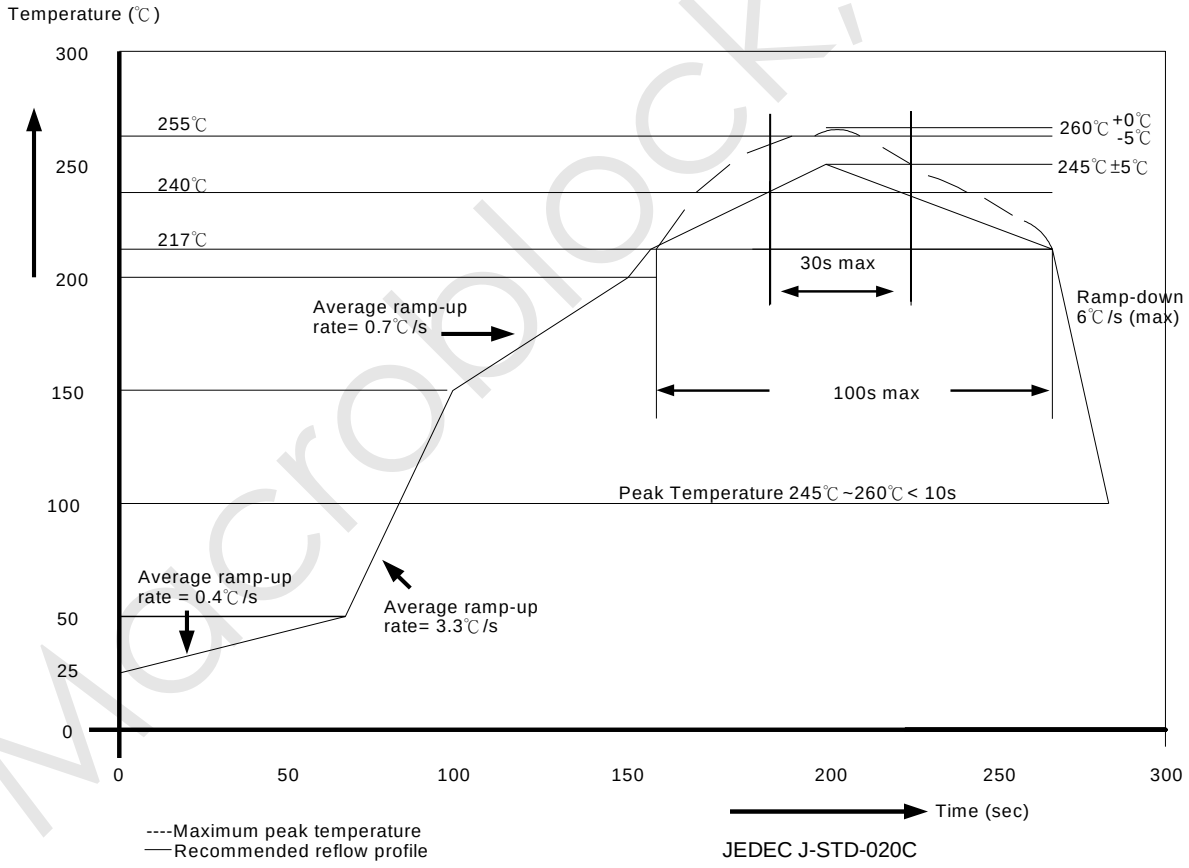
The maximum power dissipation, $P_D(max)=(Tj–Ta)/R_{th(j-a)}$, decreases as the ambient temperature increases.



Soldering Process of "Pb-free" Package Plating*

Macroblock has defined "Pb-Free & Green" 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.

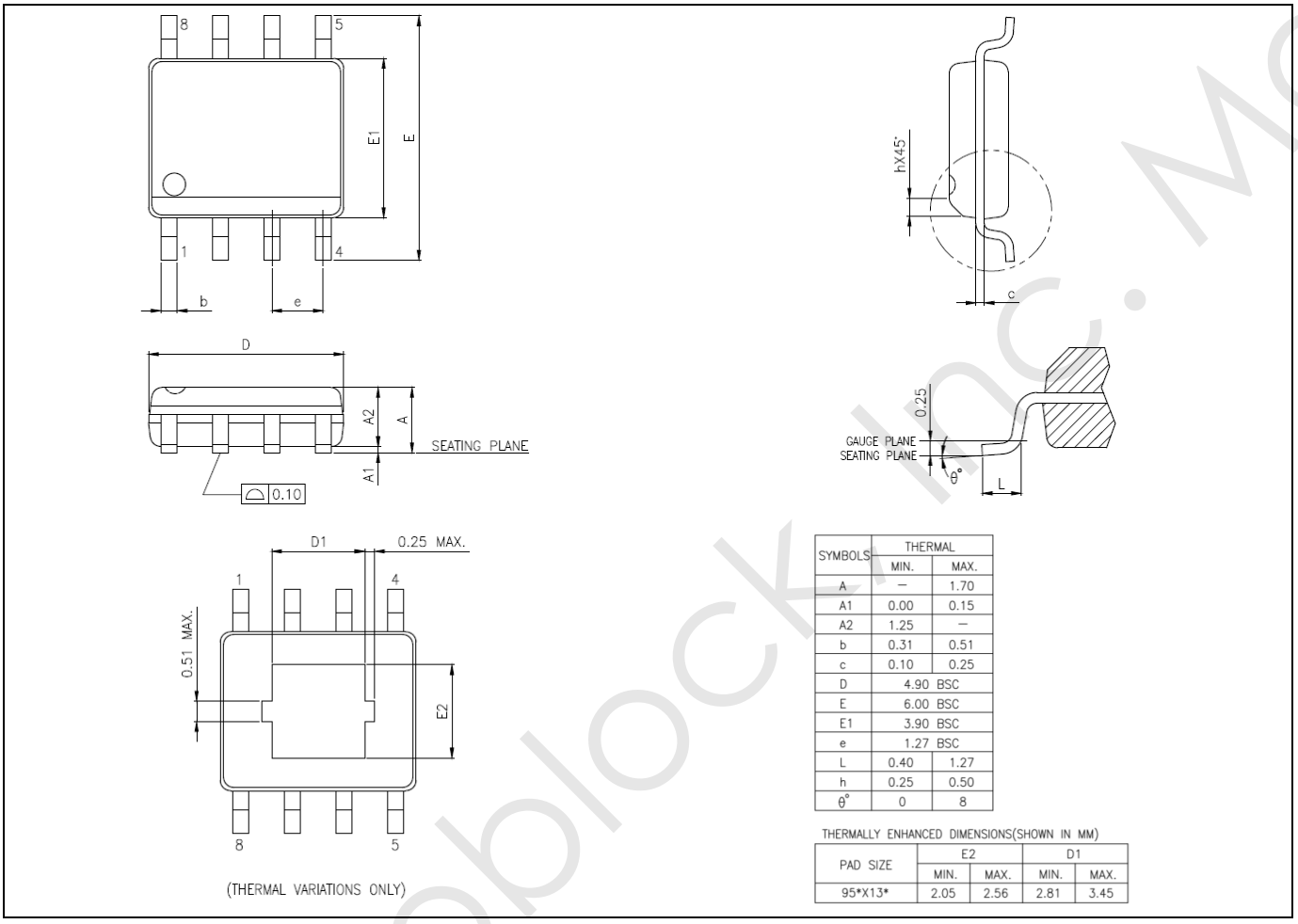
For managing MSL1 Package, it should refer to JEDEC J-STD-020C about floor life management & refer to JEDEC J-STD-033C about re-bake condition while IC's floor life exceeds MSL1 limitation.



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

* For details, please refer to Macroblock's "Policy on Pb-free & Green Package".

Outline Drawing



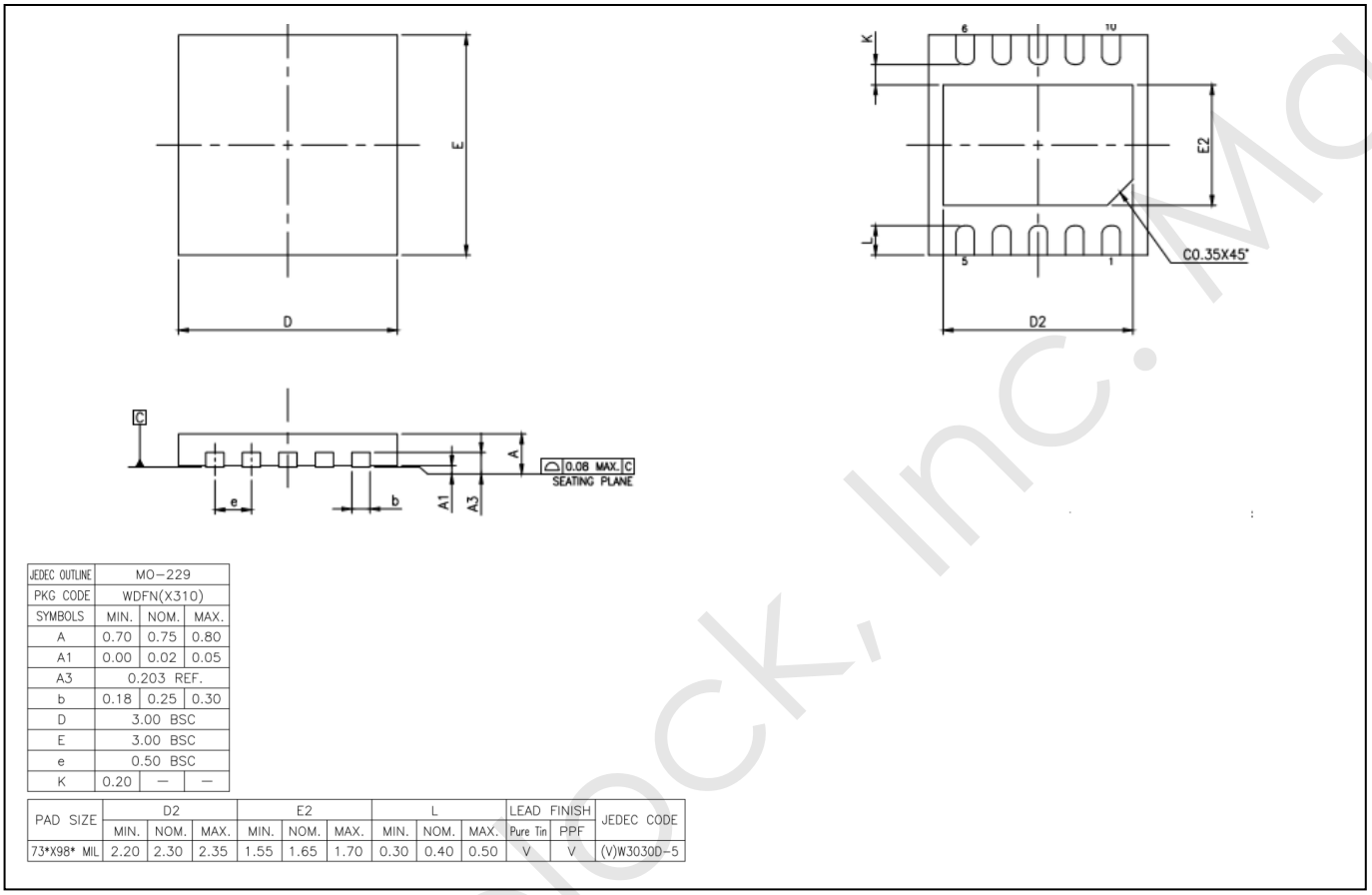
SYMBOLS	THERMAL	
	MIN.	MAX.
A	—	1.70
A1	0.00	0.15
A2	1.25	—
b	0.31	0.51
c	0.10	0.25
D	4.90 BSC	
E	6.00 BSC	
E1	3.90 BSC	
e	1.27 BSC	
L	0.40	1.27
h	0.25	0.50
θ°	0	8

THERMALLY ENHANCED DIMENSIONS(SHOWN IN MM)

PAD SIZE	E2		D1	
	MIN.	MAX.	MIN.	MAX.
95*X13*	2.05	2.56	2.81	3.45

MBI6659GD Outline Drawing

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



JEDEC OUTLINE	MO−229		
PKG CODE	WDFN(X310)		
SYMBOLS	MIN.	NOM.	MAX.
A	0.70	0.75	0.80
A1	0.00	0.02	0.05
A3	0.203 REF.		
b	0.18	0.25	0.30
D	3.00 BSC		
E	3.00 BSC		
e	0.50 BSC		
K	0.20	—	—

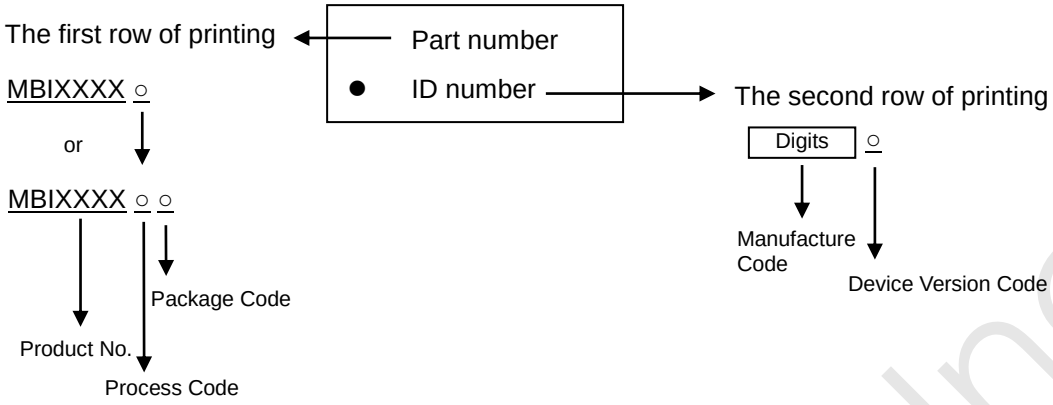
PAD SIZE	D2			E2			L			LEAD FINISH		JEDEC CODE
	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	MIN.	NOM.	MAX.	Pure Tin	PPF	
73*X98* MIL	2.20	2.30	2.35	1.55	1.65	1.70	0.30	0.40	0.50	V	V	(V)W3030D−5

MBI6659GDF Outline Drawing

Note: Please use the maximum dimensions for the thermal pad layout. To avoid the short circuit risk, the bias 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
V1.01	A

Product Ordering Information

Product Ordering Number*	RoHS Compliant Package Type	Weight (g)
MBI6659GD	SOP8L-150-1.27	0.079
MBI6659GDF	DFN-10L 3*3	0.02165

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

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