_____ MBI6653 Application Note V1.01 - EN_____

Overview

MBI6653 is a constant current, step-down DC/DC converter with high efficiency to driver high power LED. The Hysteretic PFM control scheme enhances the efficiency at light load condition. The output current is controlled by an external resistor. MBI6653 also features under-voltage-lock-out (UVLO), over current protection (OCP), over temperature protection (OTP), open-/short circuit protection to protect IC from being damaged. In addition, MBI6653 has three dimming methods including digital dimming, analog dimming, and digital-to-analog dimming. The built-in MOSFET can reduce the size of PCB to effectively reduce the overall cost.

Hysteretic PFM Control Scheme

The key feature of the MBI6653 is its Hysteretic PFM control scheme with high side current limit. When the power is on, V_{SEN} is lower than V_H (1.15 times of V_{SEN}), which causes the internal MOSFET of the MBI6653 to turn on and V_{SEN} to increase with I_L. When V_{SEN} is equal to V_H, the MOSFET will turn off and V_{SEN} will decrease with I_L. When V_{SEN} decreases to V_L (0.85 times of V_{SEN}), the internal MOSFET will turn on again and repeat the above actions. However, the inductor current will always work on continuous current mode (CCM) due to the character of the Hysteretic PFM control, which helps to reduce the LED ripple current. Figure 1 below demonstrates the application circuit of the MBI6653. Figure 2 shows the waveform of the Hysteretic PFM control scheme.

The switching frequency of this control scheme varies according to the output loading. The heavy loading will result in low switching frequency. When it is under the same loading condition, the larger inductance will result the lower switching frequency. The lowest switching frequency is limited to 40 kHz to avoid audio noise.

The high side current limit allows users to choose a smaller size and offers lower power consumption resistor than that of low side current limit unit. As a result, MBI6653 can save space and cost.

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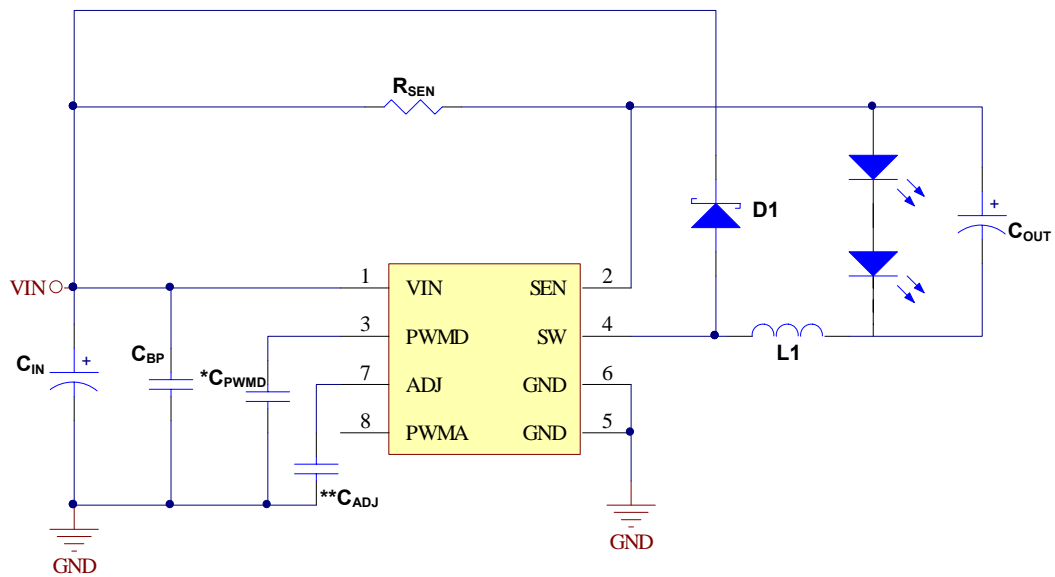
* When the input voltage is higher than 30V, the C_{PWMD} is required. The recommended capacitance is 100pF.

**When the digital-to-analog function is enabled, the C_{ADJ} is necessary, The recommended capacitance is 0.1uF.
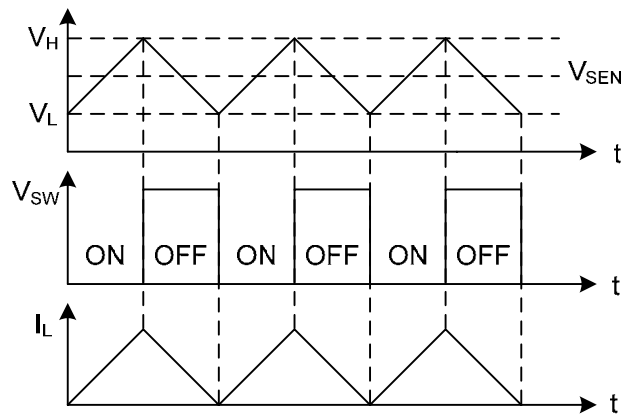
Figure 1. MBI6653 application circuit

Figure 2. Waveform of Hysteretic PFM control scheme

Under Voltage Lock Out (UVLO)

The typical voltage of the MBI6653 UVLO is 5.7V. If the input voltage is lower than 5.7V, the internal MOSFET of the MBI6653 will turn off, and prevent current from going through. Also, the MBI6653 features a hysteretic of UVLO when IC is working. If the input voltage is down to 4.5V again, the internal MOSFET of MBI6653 will turn off.

Peak Current Limit

For normal operation, a dropout voltage between input and output voltage is recommended*.*

When the input voltage becomes lower than the minimum input voltage—which is the

sum of the dropout voltage on each external components and the total forward voltage

of the cascaded LEDs, the internal MOSFET of the MBI6653 will always turn on, and the maximum LED current is limited to 1.15 times of the expected current. On the contrary, if the input voltage is larger than the minimum input voltage, or if the total forward voltage of the cascaded LEDs decreases due to LED's rising temperature, the output current will recover to the preset one.

Introduction of Dimming Function

MBI6653 has three kinds of dimming methods including digital, analog, and digital-to-analog. The depiction of each method is described as below:

Digital Dimming

The LED current can be adjusted by connecting a PWM signal to PWMD pin of the MBI6653. When a low level signal (lower than 0.5V) appears at the PWMD pin, the internal MOSFET will turn off and shut the LED current, and vice versa. The high voltage of PWMD pin is 2.2V. The larger duty cycle of PWM signal will result in higher LED current. To avoid the audio noise caused by low PWM frequency, a smaller inductor value should be considered, but it is a trade-off with the line/load regulation. For linear dimming, the maximum frequency applied to PWMD pin is 1kHz. The C_{PWMD} is required when the input voltage is larger than 30V and capacitance is 100pF in PWMD.
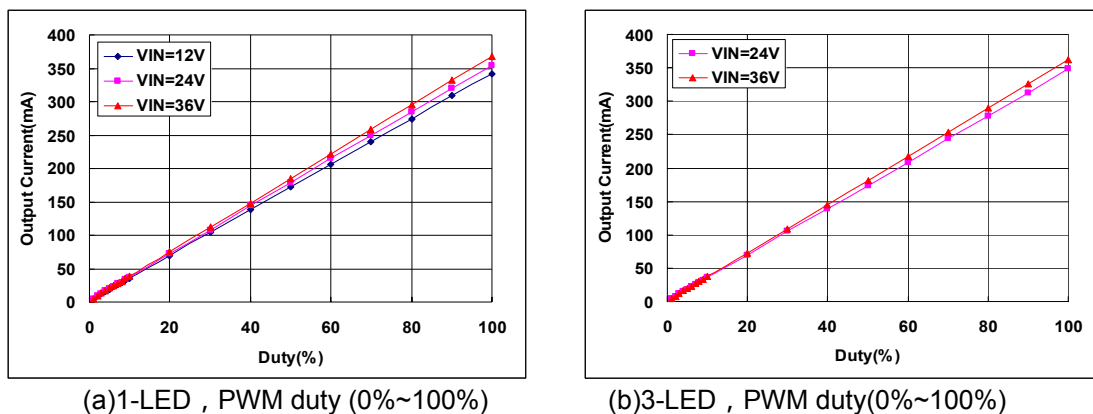

(a)1-LED   PWM duty (0%~100%)   (b)3-LED   PWM duty(0%~100%)
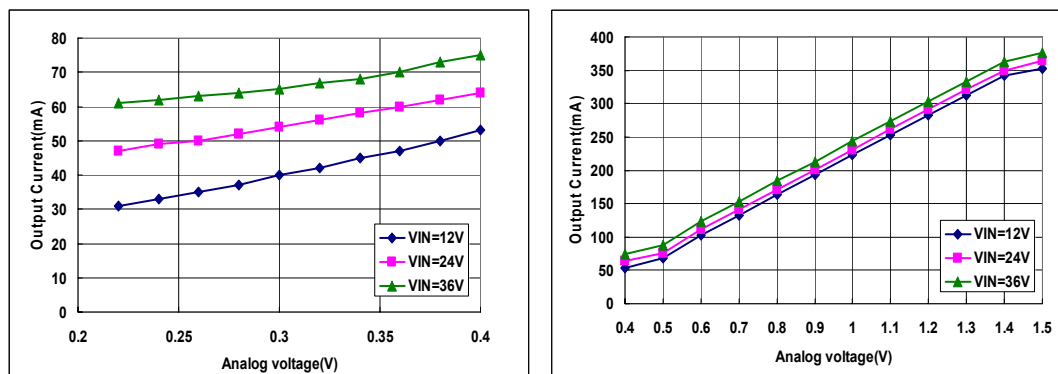Figure 3. The performance of digital dimming (I_{OUT}=350mA)

Analog dimming

Analog dimming functions by means of delivering DC voltage, which range is 0.2V~1.5V, to ADJ pin to control V_{SEN} and furthermore to adjust the output current. The relationship of dimming voltage and V_{SEN} is described as below:

1. If the dimming voltage is higher than 1.5V, the V_{SEN} would be the original value, 100mV. The

V_{SEN} decreases with the decreasing dimming voltage.

2. MBI6653 features minute current variation when the dimming voltage is ranging from 0.2V to 0.4V to offer better light perception performance in low gray.

3. When the dimming range is 0.4V~1.5V, the output current has good dimming linearity.

4. When the dimming voltage is up to 1.5V, the original setting of V_{SEN} is 100mV. The output current setting is 100%(I_{OUT}=100mV/R_{SEN}) at this moment.

5. The minimum dimming voltage is 0.2V. When the dimming voltage is lower than 0.2V, the V_{SEN} will drop to 0V and shut down the LEDs. Because V_{SEN} is zero, the built-in MOSFET will not switch and thus the power converter will shut down the LED current. As shown in the Figure 4 (a) and (b), the output current has minor variation (the dimming voltage range is 0.2V~0.4V) that operates in low gray. Human eyes for light perception are more sensitive in the low gray. This feature offers more subtle brightness adjustment. If operation in high gray (the dimming voltage range is 0.4V~1.5V), the output current variation is obvious with better linearity performance.

(a) Analog voltag (b) Analog voltage (0.4V~1.5V)

Figure 4. The performance of analog dimming (I_{OUT}=350mA)

Digital-to-Analog Dimming

Digital-to-Analog dimming is implemented through converting a PWM signal, which is connected with the PWMA of MBI6653 to an analog voltage and furthermore adjusts the output current. The larger duty cycle of PWM signal results in the larger output current. If the duty cycle is smaller than 10%, the output current will shut down the LEDs. When using Digital-to-Analog dimming, a ceramic capacitor, C_{ADJ}, with 0.1uF and 6.3V rated voltage is necessary to connect to the ADJ pin of MBI6653. Then through the low pass filter, the PWM signal will be convert to an analog signal and affect the output current. Figure 5 shows the performance of Digital-to-Analog dimming, which is the analog dimming, The minor current variation is implemented in the duty cycle of 11%~20%, and good dimming linearity is in the range of 20%~100%. The LED will be turned off when the duty cycle is under 10%.
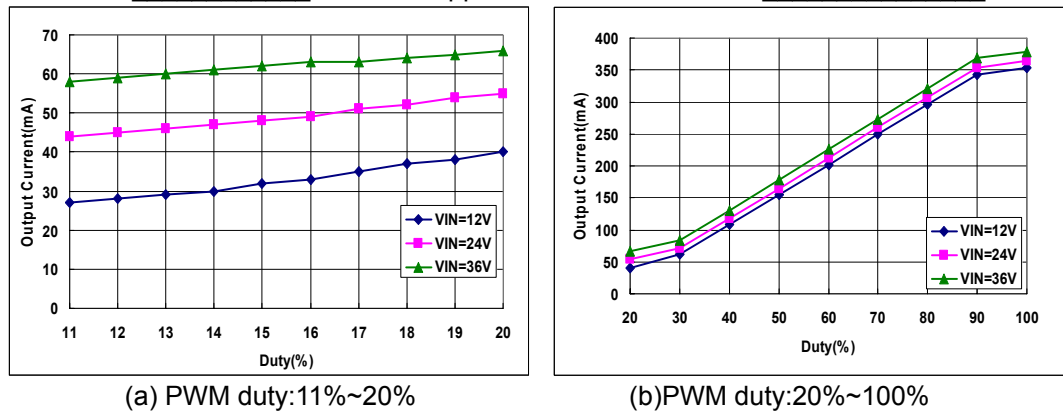
(a) PWM duty:11%~20%   (b)PWM duty:20%~100%

Figure 5. The performance of Analog-to-Digital dimming (I_{OUT}=350mA)

Open-Circuit Protection

The MBI6653 has a built-in open-circuit protection. The internal MOSFET stops switching and remains at turn-off state. There is no current when LED is open-circuited.

Short-Circuit Protection

The MBI6653 offers a short-circuit protection. When LED is short-circuited, the output voltage will drop to zero. However, the internal MOSFET will keep on switching and the output current will be the preset value. In cascaded application, if one or more than one LEDs are short-circuited, the output voltage across the LEDs will decreased, and yet the LED current can maintain at its preset value.

Over Temperature Protection

The MBI6653 offers an over temperature protection at 165 . As junction temperature exceeds 165 , the internal MOSFET will turn off and shut down the LED current. Thus, the junction temperature will start to decrease. As the junction temperature is below 135 , the internal MOSFET will turn on again to switch.

Over current Protection

The MBI6653 offers an over current protection, When the MBI6653 of output current exceeds 1.7A, the internal MOSFET will turn off and shut down the LED current. When the function is activated, it will not be removed until power is reset.

Design Consideration

Switching Frequency

To achieve better output current accuracy, the switching frequency should be determined by minimum on/off time of SW waveform. For example, if the duty cycle of MBI6653 is larger than

0.5, then the switching frequency should be determined by the minimum off time, and vice versa. Thus the switching frequency of MBI6653 is

$$f_{SW} = \frac{1}{T_S} = \frac{1}{\frac{T_{OFF,min}}{(1-D)}} \text{ , when the duty cycle is larger than 0.5} \tag{1}$$

$$\text{or } f_{SW} = \frac{1}{T_S} = \frac{1}{\frac{T_{ON,min}}{D}} \text{ , when the duty cycle is smaller than 0.5.} \tag{2}$$

The switching frequency is related to efficiency (better at low frequency), components size/cost (smaller/cheaper at high frequency), and the amplitude of output ripple voltage and current (smaller at high frequency). The slower switching frequency comes from the large value of inductor. In many applications, the sensitivity of EMI limits the switching frequency of MBI6653. The switching frequency can be ranged from 40kHz to 1MHz.

LED Ripple Current

A LED constant current driver, such as MBI6653, is designed to control the current through the cascaded LED, instead of the voltage across it. Higher LED ripple current allows the use of smaller inductance, smaller output capacitance and even without an output capacitor. The advantage of higher LED ripple current is to minimize PCB size and to reduce cost because of no output capacitor. Lower LED ripple current requires larger inductance and output capacitor. The advantage of lower LED ripple current is to extend LED life-time and to reduce heat of LED. The recommended ripple current is from 5% to 20% of normal LED current.

Component Selection
Output Current Setting
The output current can be programmed by an external resistor, the relationship between I_{OUT} and R_{SEN} is

$$R_{SEN} = (V_{SEN} / I_{OUT}) \tag{3}$$

where R_{SEN} is current sense resistor. It is connected between VIN and SEN pin of the MBI6653. 1% tolerance is recommended for better output current accuracy, and V_{SEN} is the voltage across $R_{SEN.}$ The sustaining power dissipation on R_{SEN}, and P_{RSEN}, is

$$P_{RSEN} = (V_{SEN}^2 / R_{SEN}) \tag{4}$$

Inductor Selection
The inductance is determined by two factors: the switching frequency and the inductor ripple current. The calculation of the inductance, L1, can be described as

$$L1 > (V_{IN} - V_{OUT} - V_{SEN} - (R_{ds(on)} \times I_{OUT})) \times \frac{D}{f_{SW} \times \Delta I_L} \qquad (5)$$

where

$R_{ds(on)}$ is the on-resistor of internal MOSFET of MBI6653.

D is the duty cycle of MBI6653, $D = V_{OUT} / V_{IN}$.

f_{SW} is the switching frequency of MBI6653.

I_L is the ripple current of inductor, $I_L = (1.15 \times I_{OUT}) - (0.85 \times I_{OUT}) = 0.3 \times I_{OUT}$.

When selecting an inductor, the inductance is not the only factor to affect the performance of module, but the saturation current also needs to be considered. In general, it is recommended to choose an inductor with 1.5 times of LED current as the saturation current. Also, the larger inductance gains the better line/load regulation and efficiency. However, when at the same inductor size, the inductance and saturation current becomes a trade-off. An inductor with shield is recommended to reduce the EMI interference, but this is another trade-off with heat dissipation.

Schottky Diode Selection

The MBI6653 needs a flywheel diode, D1, to carry the inductor current when the MOSFET is off. The recommended flywheel diode is schottky diode with low forward voltage for better efficiency. Two factors determine the selection of schottky diode. One is the maximum reverse voltage, and the recommended rated voltage of the reverse voltage is at least 1.5 times of input voltage. The other is the maximum forward current, which works when the MOSFET is off. The recommended forward current is 1.5 times of output current. Since the switching characteristics of schottky diode degrades with the rising temperature, the recommended operating temperature is 85 to prevent MBI6653 from being damaged by large leakage current, which caused by schottky diode.

Minimum Input Voltage

The minimum input voltage is the sum of the voltage drops on R_{SEN}, R_S, DCR of L1, $R_{ds(on)}$ of internal MOSFET and the total forward voltage of LEDs. The dynamic resistance of LED, R_S, is the inverse of the slope in linear forward voltage model for LED. This electrical characteristic can be provided by LED manufacturers. ***As the input voltage is smaller than minimum input voltage, which is pointed out by MBI6653 Design Tool, the output current will be larger than the preset output current, and is limited to 1.15 times of preset one.*** The equivalent impedance of the MBI6653 application circuit is shown as in Figure 6. To calculate these voltage drops, the peak LED current must be defined first. As previously mentioned, the peak current is 1.15 times of the preset current, and then the voltage drops on each component can be calculated as below

$$V_{RSEN} = V_{SEN} \times 1.15 \tag{6}$$

$$V_{RS} = R_S \times I_{OUT} \times 1.15 \times n, \text{ where n is the amount of LED.} \tag{7}$$

$$V_{MOSFET} = R_{ds(on)} \times I_{OUT} \times 1.15 \tag{8}$$

$$V_{L1} = DCR \times I_{OUT} \times 1.15 \tag{9}$$

Thus, the minimum input voltage ($V_{IN, MIN}$) can be defined as

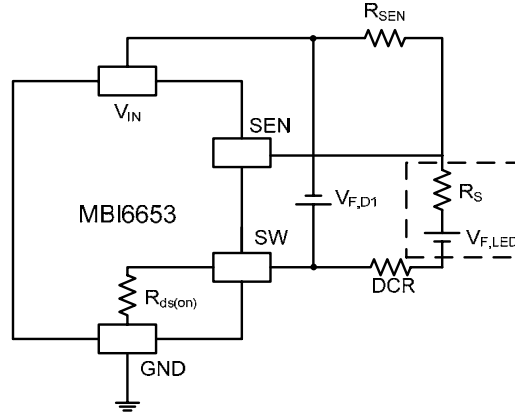$$V_{IN, MIN} = V_{RSEN} + V_{RS} + V_{MOSFET} + V_{L1} + V_{F, LED} \tag{10}$$

Figure 6. The equivalent impedance of MBI6653 application circuit

Input Capacitor Selection

The input capacitor, C_{IN}, can supply pulses of current for the MBI6653 when the MOSFET is on, and C_{IN} is charged by input voltage when the MOSFET is off. As the input voltage is lower than the tolerable input voltage, the internal MOSFET of the MBI6653 becomes constantly "on", and the LED current is limited to 1.15 times of normal current. The recommended value of input capacitor is 10uF for stabilizing the lighting system. The rated voltage of input capacitor should be at least 1.5 times of input voltage.

For system stability, it is recommended to place the C_{IN} to the VIN pin of MBI6653 as close as possible. However, the PCB size might limit this requirement. Therefore, to avoid the noise interference, a bypass capacitor, which capacitance ranges from 0.1uF to 1uF and material is ceramic, parallel with the VIN and GND pins of MBI6653 is recommended. The rated voltage of bypass capacitor should be at least 1.5 times of input voltage.

The rated voltage and capacitance are not the only concerned when selecting capacitors, but also the maximum ripple current. If the specification of maximum ripple current is smaller than the produced, the capacitor might be damaged and furthermore damage IC. In general, the ripple current is related to the inductor ripple current. The specification of maximum ripple current of capacitor should be larger than 1.3 times of the inductor ripple current.

A tantalum or ceramic capacitor can be used as an input capacitor. The advantages of tantalum capacitor are high capacitance and low ESR. The advantages of ceramic capacitor

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are high frequency characteristic, small size and low cost. Compared with the tantalum capacitor, the ceramic capacitor features the lower ESR, so it is not recommended to use in hot plugging application. Users can choose an appropriate one for applications.

Output Capacitor Selection (Optional)

To reduce LED ripple current, a capacitor parallels with the cascaded LED is recommended. Proportionally, the higher capacitor value results in the lower LED ripple current. Usually, a 10uF output capacitor with low ESR is recommended, and the recommended rated voltage of the output capacitor is 1.5 times of total LED forward voltage. Without this paralleled capacitor, the LED ripple current is equal to the inductor current, 0.3 times of LED current. It should be noted that the output capacitor can neither affect the switching frequency nor efficiency. The material of output capacitor can be selected to tantalum or ceramic unit. For stability consideration, the output/input capacitor with X7R or X5R dielectric is recommended. A ceramic capacitor with Y5V dielectric is not recommended in this application due to bad temperature compensation.

Estimated Efficiency

To estimate the efficiency, the power consumption on each current carrying element must be calculated and summed up. The efficiency (η) can be described as

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}} \qquad (11)$$

where

P_{OUT} is the power consumption of LED. The calculation is

$$P_{OUT} = V_{OUT} \times I_{OUT} \qquad (12)$$

The power loss (P_{LOSS}) in step-down DC/DC converter includes

$$P_{LOSS} = P_C + P_{SW} + P_{IC} + P_L + P_{D1} + P_{RSEN} \qquad (13)$$

where

$\mathbf{P_C}$ is conduction loss when the internal MOSFET turns on, $P_C = I_{OUT}^2 \times R_{ds\,(on)} \times D$.

$\mathbf{P_{SW}}$ is the switching loss of the MOSFET during switching, $P_{SW} = V_{IN} \times I_{OUT} \times (t_r + t_f) \times f_{SW}$. t_r and t_f are the rising and falling times of the switching signal.

$\mathbf{P_{IC}}$ is the power consumption of MBI6653, $P_{IC} = I_{DD} \times V_{IN}$. I_{DD} is the supply current of MBI6653 which usually is 1mA.

$\mathbf{P_L}$ is the inductor loss caused by the DC resistance (DCR) of inductor, $P_L = I_{OUT}^2 \times DCR$.

$\mathbf{P_{D1}}$ is the power loss of schottky diode, $P_{D1} = V_{F,\,D1} \times I_{OUT} \times (1-D)$, $V_{F,\,D1}$ is the forward voltage of schottky diode.

$\mathbf{P_{RSEN}}$ is the power loss on R_{SEN}, $P_{RSEN} = V_{SEN} \times I_{OUT}$.

Estimated Junction Temperature

The power loss will cause temperature rising on the MBI6653. When the junction temperature (T_J) reaches 165 , the MBI6653 will enter in thermal protection model and shut down the LED current. Thus, it's important for designers to recognize the relationship between power loss and rising temperature. The relationship can be described as

$$T_J = T_A + P_{LOSS, IC} \times R_{th, JA}$$ (14)

where

T_A is the ambient temperature.

$P_{LOSS, IC}$ is the power loss in MBI6653, $P_{LOSS, IC} = P_C + P_{SW} + P_{IC}$.

$R_{th, JA}$ is thermal resistor of MBI6653 from junction to ambient.

Design Example

The MBI6653GD is designed for table lamp to drive 3 pieces of high power LED. The LED forward voltage is 3.72V. The input voltage is 24V and desired LED current is 1A. The Digital-to-Analog dimming is required. Please calculate the required components.

I_{OUT}, R_{SEN}, D, and f_{SW}

The R_{SEN} can be calculated by (3), R_{SEN} = 0.1V / 1A = 0.1Ω. Here select a 0.1Ω resistor to be R_{SEN}. The sustaining power dissipation is P_{RSEN} = $0.1V^2$ / 0.1Ω = 0.1W. Thus, a 1%, 0.1Ω resistor with 0.5W power dissipation is recommended. The input voltage is 24V, thus the duty cycle of MBI6653 is D = ($V_{F, LED}$ x 3) / V_{IN} = (3.72V x 3) / 24V = 0.465. The switching frequency should be determined by minimum off time, 350ns; thus the switching frequency is f_{SW}=1/(350ns/(0.465))=1.328MHz.

Inductor Selection

From (5), the inductor, L1, can be chosen

$$L1 > (V_{IN} - V_{OUT} - V_{SEN} - (R_{ds(on)} \times I_{OUT})) \times \frac{D}{f_{SW} \times \Delta I_L} = (24V - 11.16V - 0.1V - (0.3\Omega \times 1A)) \times \frac{0.465}{1.328MHz \times 0.3 \times 1A} = 14.51uH$$

The smaller inductance will result in the higher switching frequency. The higher switching frequency will cause the lower efficiency and higher temperature. To prevent MBI6653 from over temperature, the GANG SONG inductor, which part number is GSDS106C2-680M with 68uH, 1.6A saturation current and 150mA DCR, is recommended in this application. And since the inductor changes to 68uH, the switching frequency should be modified as

$$f_{SW} = (24V - 11.16V - 0.1V - (0.3\Omega \times 1A)) \times \frac{0.465}{68uH \times 0.3 \times 1A} = 283.56kHz$$

Schottky Selection

In this application, the recommended schottky diode is SSCD204 with 40V reverse voltage, 2A forward current, and 0.5V forward voltage for the maximum.

Minimum Input Voltage

The minimum input voltage is the sum of voltage drops on each current carrying elements and the forward voltage of LEDs when MOSFET turns on. The voltage drops on each component are

$V_{IN, MIN}$ = V_{RSEN}+V_{Rs}+V_{MOSFET}+V_{L1}+$V_{F, LED}$

=(0.1Vx1.15)+(0.6x1Ax1.15x3)+(0.3Ωx1Ax1.15)+(150mΩx1Ax1.15)+(3.72Vx3)= 13.86V

Input Capacitor Selection

For system stability, a 10uF tantalum capacitor with 50V rated voltage is recommended.

Bypass Capacitor Selection

To avoid the noise interference, a 0.1uF ceramic capacitor with 50V rated voltage is recommended as the bypass capacitor and it should be placed as close to VIN pin as possible.

Output Capacitor Selection

For LED ripple current reduction, an output capacitor paralleling with LED array is required. In this example, the recommended output capacitor is a tantalum unit with 10uF and the rated voltage is 50V.

C_{ADJ} of Capacitor Selection

Since the Digital-to-Analog dimming is required, a ceramic capacitor with 0.1uF and 6.3V rated voltage is necessary to connect to the ADJ pin of MBI6653. The recommended PWM frequency range, which connects to the PWMA pin of MBI6653, is 100Hz~1kHz.

Efficiency

The power consumption on each component can be calculated as

P_{OUT} = V_{OUT} x I_{OUT} = 3 x 3.72V x 1A = 11.16W

P_C = I_{OUT}^2 x $R_{ds(on)}$ x D = (1 A)^2 x 0.3Ω x 0.465 = 139.5mW

P_{SW} = V_{IN} x I_{OUT} x (t_r + t_f) x f_{SW} =24V x 1A x (10ns + 10ns) x 283.56kHz = 136.11mW

P_{IC} = I_{DD} x V_{IN} = 1mA x 24V = 24mW

P_L = I_{OUT}^2 x DCR = (1 A)^2 x 150mΩ =150mW

P_{D1} = $V_{F, D1}$ x I_{OUT} x (1-D) = 0.5V x 1A x (1-0.465) =267mW

P_{RSEN} = V_{SEN} x I_{OUT} = 0.1V x 1A = 100mW

P_{LOSS} = P_C + P_{SW} + P_{IC} + P_L + P_{D1} + P_{RSEN} =0.817W

Thus, the efficiency of this application is

$$\eta\% = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}} = \frac{11.16W}{11.16W + 0.817W} \times 100\% = 93.18\%$$

Estimated Junction Temperature

The estimated junction temperature is

$T_J = T_A + P_{LOSS, IC} \times R_{th, JA}$ = 25 + (0. 299W) x87.38 /W =51.1 .

Followings figure shows the application circuit and BOM for reference.
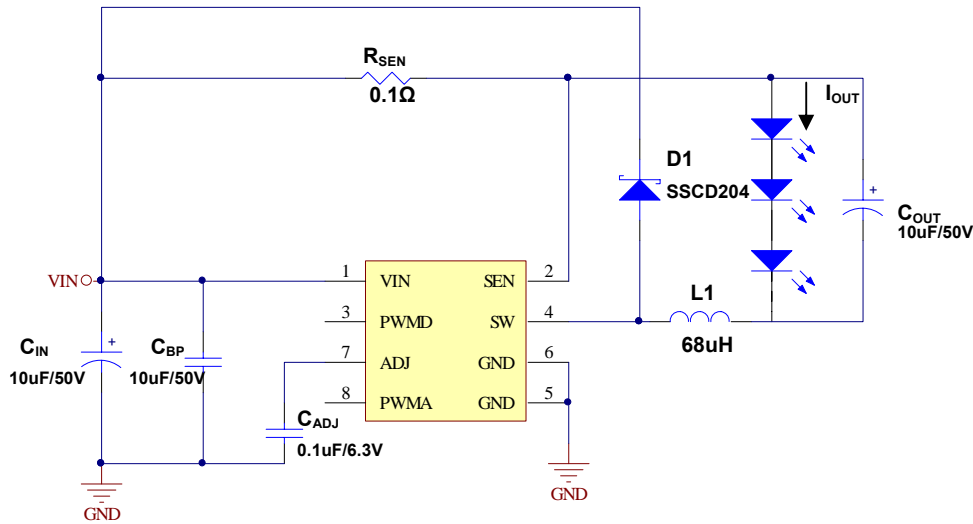
Figure7. MBI6653 Application circuit

Table 2 The BOM of example 2

Designator	Part Type	Description	Vendor	Contact Window
C_{IN}	10uF/50V	293D 106X9050 D2TE3,D caseTantalum Capacitor	VISHAY	+886-3-593-2808 ext:60
C_{OUT}	10uF/50V	293D 106X9050 D2TE3,D caseTantalum Capacitor	VISHAY	+886-3-593-2808 ext:60
C_{BP}	0.1uF/50V	0603,X7R ,MC03FTB500104, SMD ceramic capacitor	VIKING	+886-3-597-2931
C_{ADJ}	0.1uF/6.3V	0603,X7R , MC03FTB6V3105, SMD ceramic capacito	VIKING	+886-3-597-2931
D5	SSCD204	40V/2A Surface Mount Schottky Barrier Rectifier	ZOEWIE	+886-2-2219-5533
L1	68uH	GSDS106C2-680M	GANG SONG	+886-2-2218-2357
R_{SEN}	0.1Ω	1206 SMD Resistor ,CS06FTEVR100	VIKING	+886-3-597-2931
U1	MBI6653	Step-Down,1A LED Driver ,SOP8	MBI	+886-3-579-0068

PCB Layout Consideration

To enhance efficiency and stabilize the system, it is essential to keep a careful printed circuit layout. There are several notes that need to be taken.

1. A complete ground area is helpful to eliminate the switching noise.

2. Keep the IC's GND pin and the ground leads of input and output filter capacitors less than 5mm.

3. To maximize output power efficiency and minimize output ripple voltage, it is suggested to use a ground plane and solder the IC's GND pin directly to the ground plane.

Preliminary

4. To stabilize the system, the heat sink of the MBI6653 is recommended to connect to ground plane directly.

5. To enhance the heat dissipation, the area of ground plane, which IC's heat sink is soldered on, should be as large as possible.

6. The components placement should follow the sequence of the input capacitor, the input bypass capacitor, R_{SEN} and VIN pin. The components layout path should not be spread out. In other words, the components should be placed on the same path.

7. The input and bypass capacitors should be placed to IC's VIN and GND pins as close as possible.

8. To avoid the parasitic effect of trace, the R_{SEN} should be placed to IC's VIN and SEN pins as close as possible.

9. The area, which is composed of IC's SW pin, schottky diode and inductor, should be wide and short.

10. The path, which flows large current, should be wide and short to eliminate the parasite element.

11. To stabilize the system, when the input voltage is over 30V and capacitance is 100pF in PWMD

12. To stabilize the system, do not put the inductor right under the IC

13. To avoid the unexpected damage of malfunction to the driver board, users should pay attention to the quality of soldering in the PCB by checking if cold welding or cold joint happens between the pins of IC and the PCB.

14. Shown in Figure 8, in order to suppress radiated EMI interference can return path diode in series Bead

15. Shown in Figure 8, in order to suppress radiated EMI interference in SW pin to GND pin parallel RC Snubber (Note: When add RC Snubber circuit, make sure the temperature of the various components and circuit efficiency, so poorly designed RC component values, resulting in low efficiency of the circuit or component overheating problems have occurred.)

16. Shown in Figure 8, in order to suppress the interference radiated EMI in diode parallel RC Snubber . (Note: When add RC Snubber circuit, make sure the temperature of the various components and circuit efficiency, so poorly designed RC component values, resulting in low efficiency of the circuit or component overheating problems have occurred.)

17. When SW is ON/OFF, the direction of power loop should keep the same way to enhance the efficiency. The sketch is shown as Figure 8. The PCB layout is show as Figure 9
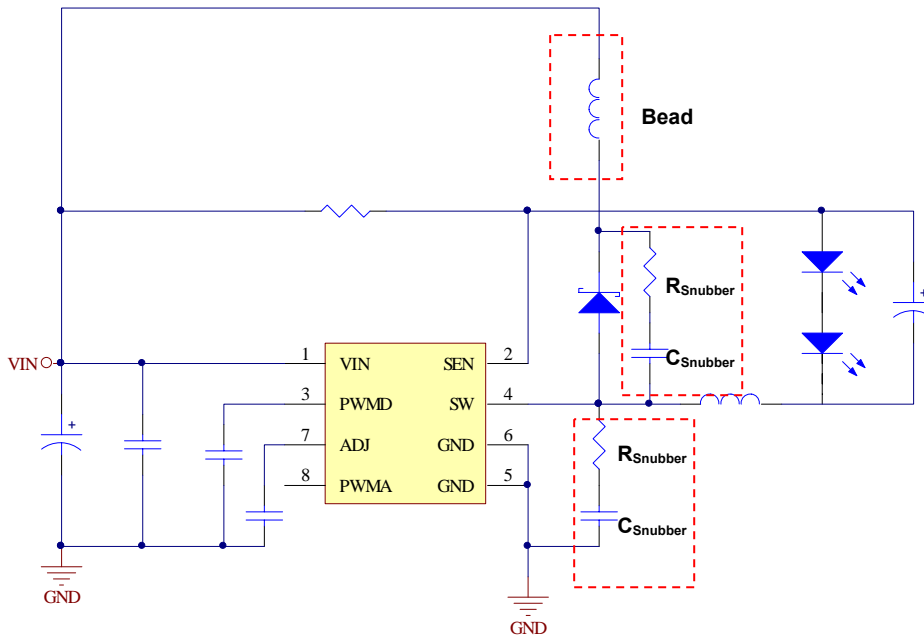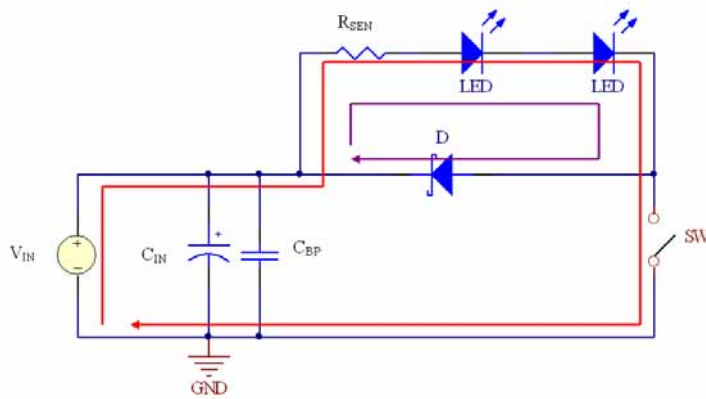
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Figure 8. Radiated EMI solution proposed
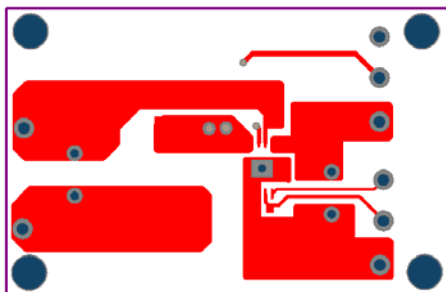

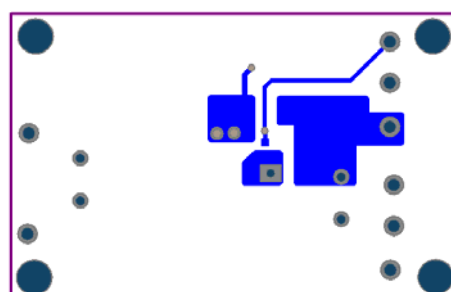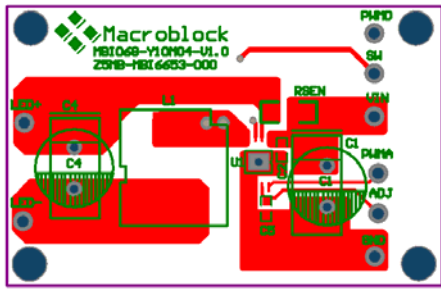Figure9. The sketch of power loop

Top layer   Bottom layer
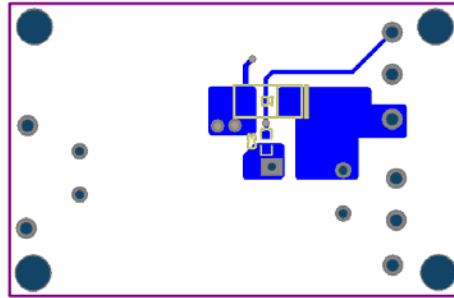
Top over-layer	Bottom over-layer

Figure9. The layout diagram of MBI6653GMS