# The MBI1801/1802/1804/1816 Application Note

## Foreword

The MBI1801/1802/1804/1816 All-Ways-On$^{TM}$ series are LED constant current drivers, which allow product developers to easily set the LED current through an external resister, and the LED brightness can be further adjusted by a PWM signal, which is connected to $\overline{OE}$. The MBI1801/1802/1804/1816 provide 1/2/4/16 output ports respectively, and each port may drive a string of LEDs. The All-Ways-On$^{TM}$ series has a built-in Thermal Protection (TP) function to protect IC from over temperature damage and MBI1802 also features thermal flag and quarter LED current functions.

This article is to provide a design guide for developers when using the MBI1801/1802/1804/1816 All-Ways-On$^{TM}$ series.

## Application Circuit

Figure 1 shows the application circuit of the MBI1801/1802/1804/1816. Product developers usually use only one power source for both LED and IC. However, for the MBI1801/1802/1804/1816, the maximum operating voltage of VDD is 5.5V and the maximum sustaining voltage of VDD is only 7.0V. If the supply voltage of LED ($V_{LED}$) is larger than the maximum sustaining voltage of VDD, $V_{LED}$ and VDD should be separated to avoid IC damage. Alternatively, a resistor (R1) and a zener diode (D1), of which the zener voltage is 5.1V, can clamp input voltage to 5.1V. Following shows the calculation of R1：

$$R1 = (V_{IN}-5.1V) / I_{DD} \quad (1)$$

where $I_{DD}$ is the supply current of IC.

In general application, the $V_{LED}$ is lower than 17V to avoid the voltage exceeding the sustaining voltage of output port of IC. However, sometimes the $V_{IN}$ may be larger than 17V, and then developers need a linear regulator to clamp voltage under 17V. The linear regulator on Figure 1 is a simple Low Dropout Regulator (LDO). Developers can get a suitable $V_{LED}$ by zener diode (D2).

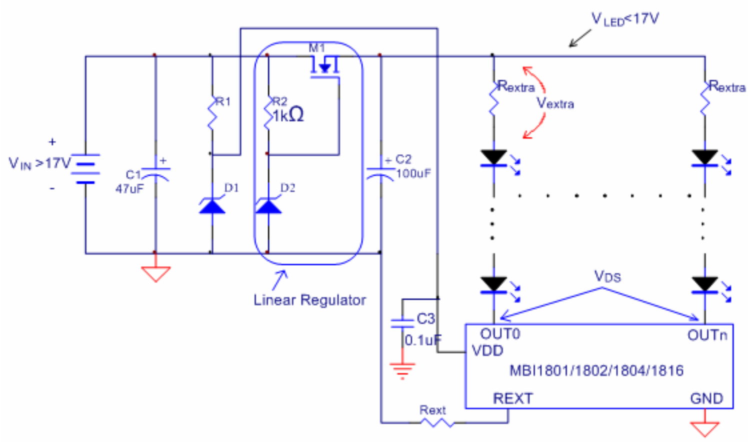


Figure 1. The Application Circuit of the MBI1801/1802/1804/1816


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## Circuit Design

How to decide the $V_{LED}$ is usually a concern for product developers when using MBI1801/1802/1804/1816. If $V_{LED}$ is larger than the one it needed, it will cause the overheat problem. However if there is not sufficient voltage for IC, IC cannot keep constant current. Therefore, the following is the suggestions for circuit design.

1. ***Sorting the forward voltage of LED***

   As above-mentioned, a large $V_{LED}$ may cause the overheat problem. Therefore, reducing the variation of LED forward voltage ($V_F$) is necessary, and the range of variation should be within 0.2V. (e.g. $V_{F,MIN.}$=3.2V，$V_{F,MAX.}$=3.4V)

2. ***Select a suitable $R_{ext}$.***

   The MBI1801/1802/1804/1816 allow developers to set the LED current ($I_{OUT}$) by an external resistor, $R_{ext}$. After developers decide the LED current, developers can get a suitable $R_{ext}$ by the following equations.

   $R_{ext}$ = (1.24 / $I_{OUT}$) x 945 For MBI1801 ........................................................................ (2)

   $R_{ext}$ = (1.24 / $I_{OUT}$) x 471 For MBI1802 ........................................................................ (3)

   $R_{ext}$ = (1.24 / $I_{OUT}$) x 236 For MBI1804 ........................................................................ (4)

   $R_{ext}$ = (1.24 / $I_{OUT}$) x 59 For MBI1816 ........................................................................ (5)

3. ***Decide $V_{DS}$.***

   To keep a constant current, a sufficient voltage at output port of IC ($V_{DS}$) is needed. Figure 2 to 5 show the I-V curves of MBI1801/1802/1804/1816 respectively. User can refer to the figures and get a suitable $V_{DS}$. In general, the $V_{DS}$ is slightly greater than the knee voltage.

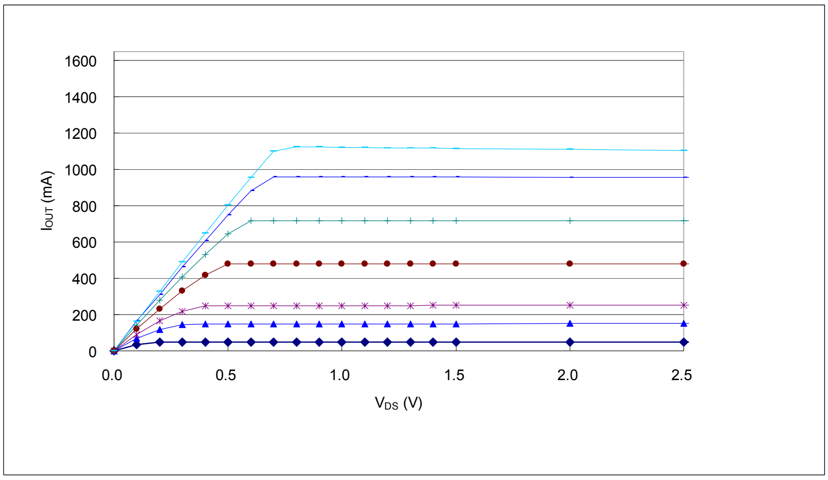


Figure 2. $I_{OUT}$ vs. $V_{DS}$ (MBI1801)

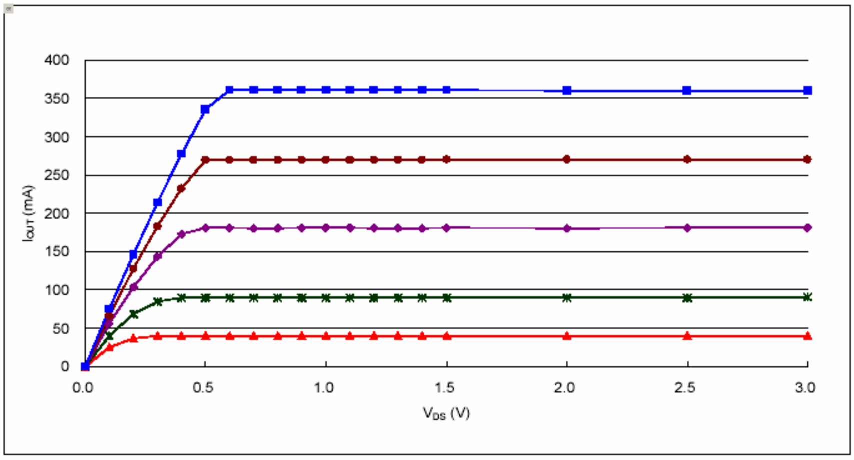


Figure 3. $I_{OUT}$ vs. $V_{DS}$ (MBI1802)

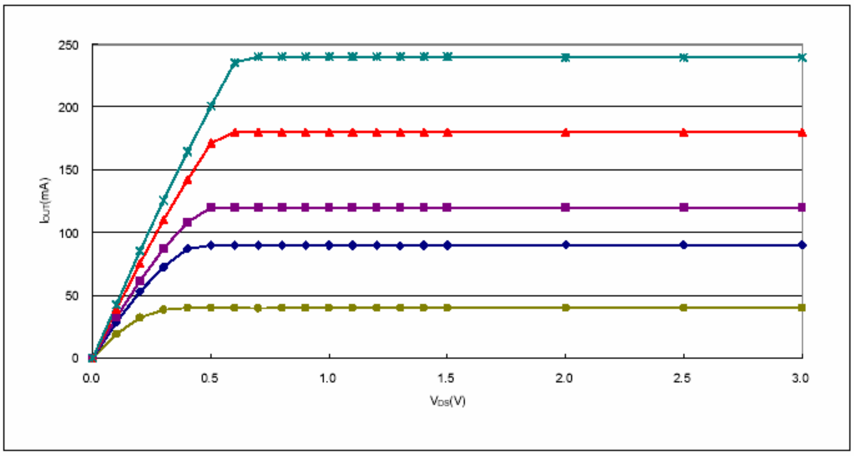


Figure 4. $I_{OUT}$ vs. $V_{DS}$ (MBI1804)

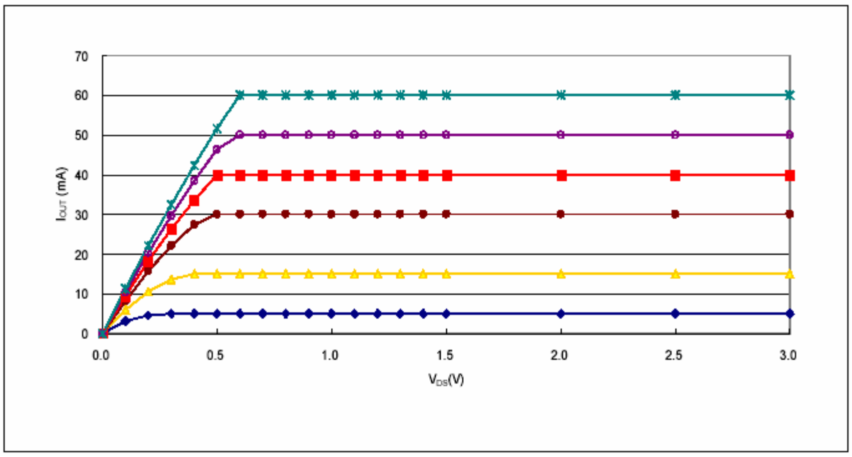


Figure 5. $I_{OUT}$ vs. $V_{DS}$ (MBI1816)



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***4. Decide $V_{LED,MIN.}$***

After the above conditions are set, the minimum $V_{LED}$ ($V_{LED,MIN}$) can be determined by the following equation (6).

$V_{LED,MIN.} = (V_{F,MAX.} \times n) + V_{DS}$ ........................................................................................ (6)

where $V_{F,MAX}$ represents the maximum forward voltage of LED, and n is the cascaded LED count.

If the $V_{LED}$ is an integer voltage (ex. the voltage of transformer is usually an integer one), the extra voltage ($V_{extra}$) needs to be consumed by the resistor cascaded with LEDs ($R_{extra}$ as shown in Figure 1). The value of the resistor can be calculated by following equations

$V_{extra} = V_{LED} – (V_{F,MAX.} \times n) - V_{DS}$ (7)

$R_{extra} = V_{extra} / I_{OUT}$ ........................................................................................ (8)

***5. Decide D2.***

After deciding $V_{LED}$, the breakdown voltage of the zener diode (D2) can be calculated as below

$V_{Z\text{-}D2} = V_{LED} + Vth$........................................................................................ (9)

where the $V_{Z\text{-}D2}$ is the breakdown voltage of D2; Vth is the threshold voltage of MOSFET.

***6. Decide M1***

To select the MOSFET M1, the current of M1 should be larger than the current of LED, and the sustaining voltage of M1 should be larger than that of $V_{IN}$.

***7. Power Dissipation / Heat Dissipation***

In general applications, power dissipation is the major factor to cause temperature rising on the IC. The greater power dissipation causes the higher temperature. The power dissipation can be calculated by the following equation (10).

$P_D = (V_{DD} \times I_{DD}) + (V_{DS} \times I_{OUT}) \times m$ ........................................................................................ (10)

where m represents the number of the output ports of IC, and then the temperature on IC can be approached by the following equation (11).

$T_{IC} = T_A + Rth \times P_D$........................................................................................ (11)

where $T_{IC}$ means the temperature on IC; $T_A$ is the ambient temperature; and Rth represents the thermal resistance from junction to ambient temperature.


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Following is an example explaining the design process.

***Example:***

For lighting 8 pieces of high-power white LEDs, the sorted forward voltage ranges from 3.2V to 3.4V; and LED current is set to 350mA. If we use MBI1802 to be the LED constant current driver, and each port has 4 pieces of LED in cascade. Therefore,

1. ***Select the $R_{ext}$***

   From equation (3), $R_{ext}$ = (1.24V / 350mA) x 471 = 1668.69Ω, a resistor with 1.69 kΩ/0.25W is selected for $R_{ext}$. Thus, $I_{OUT}$ = (1.24V / 1.69kΩ) x 471 = 346mA.

2. ***Decide $V_{DS}$***

   As shown in Figure 3, the knee voltage is 0.6V when $I_{OUT}$ is 360mA. Therefore, when the $I_{OUT}$ is 346mA, the $V_{DS}$ can be set as 0.6V.

3. ***Decide $V_{LED,MIN.}$***

   After the above conditions are set, $V_{LED,MIN}$ can be calculated by equation (6)

   $V_{LED,MIN.}$ = (3.4V x 4) + 0.6V = 14.2V, and thus, the selected $V_{LED}$ must be greater than 14.2V.

4. If the $V_{LED}$ is set as 15V, we need to add a resistor, $R_{extra}$, to consume the extra voltage drop. The value of the resistor can be calculated by equations (7) and (8):

   $V_{extra}$ = 15V – (3.4V x 4) – 0.6V = 0.8V

   $R_{extra}$ = 0.8V / 346mA = 2.31Ω; thus, we select $R_{extra}$=2.2Ω

   The sustaining power of $R_{extra}$ is $P_{Rextra}$ = $(346mA)^2$ x 2.2Ω = 0.263W; thus, the recommended $R_{extra}$ is 2.2Ω/0.5W.

5. ***Select R1***

   According to the datasheet of MBI1802, when $R_{ext}$=2.4kΩ and 1.8kΩ, $I_{DD,MAX}$ is 10mA. Therefore, when $R_{ext}$=1.6kΩ, the $I_{DD,MAX}$ can also be considered as 10mA. From equation (1), R1 is calculated as below:

   R1 = (15V – 5.1V) / 10mA = 990Ω; thus, we select R1=1kΩ. The sustaining power of R1 is $P_{R1}$ = $(10mA)^2$ x 1kΩ = 0.1W ; thus, the recommended R1 is 1kΩ/0.25W.

6. In this example, under the worst case, the $V_{DS}$ is

   $V_{DS}$ = $V_{IN}$ - $V_{extra}$ - $V_{F,MIN.}$ x n = 15V - 0.8V - 3.2V x 4 = 1.4V

   where $V_{F,MIN.}$ represents the minimum forward voltage of LED. Thus, the power dissipation of one IC can be calculated by equation (10) as below:

   $P_D$ = ($V_{DD}$ x $I_{DD}$) + ($V_{DS}$ x $I_{OUT}$) x m =(5.1V x 10mA) + (1.4V x 346mA) x 2 ≒1.02W

   And the temperature on IC can be approached as below:

   $T_{IC}$ ≒ $T_A$ + Rth x $P_D$ = 25℃ + (125℃/W x 1.02) ≒ 152.5℃

   where Rth=125℃/W is the thermal resistance of IC with thermal pad where the heat sink area on PCB layout is 4 times bigger than IC's area. (Please refer to page 4 of the datasheet of MBI1802).

Figure 6 shows the application circuit of this example.

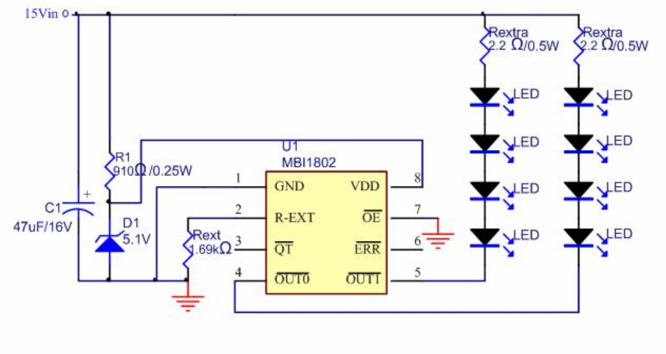


Figure 6. The application circuit using only one MBI1802

The previous example shows the design process by using only one MBI1802, the IC's temperature is 152.5℃. If the temperature is too high for developers, developers may use two ICs as a solution for that. The following shows the example of using two MBI1802.

1. ***Select the $R_{ext}$***

   In this solution, each IC lights up 4 LED in cascade and the LED current flowing into each port is 175mA. From equation (3), $R_{ext}$ = 3337Ω. Therefore a resistor with 3.3kΩ/0.25W is selected for $R_{ext}$, and the LED current is $I_{OUT}$ = (1.24V / 3.3kΩ) x 471 = 177mA.

2. ***Decide $V_{DS}$***

   As shown in Figure 3, the knee voltage is 0.5V when $I_{OUT}$ is 180mA. Therefore, when the $I_{OUT}$ is 177mA, the $V_{DS}$ can be set as 0.5V.

3. ***Decide $V_{LED,MIN.}$***

   After the above conditions are set, $V_{LED,MIN}$ can be calculated by equation (6)

   $V_{LED,MIN.}$ = (3.4V x 4) + 0.5V = 14.1V, and thus, the selected $V_{LED}$ must be greater than 14.1V.

4. If the $V_{LED}$ is set as 15V, we need to add a resistor, $R_{extra}$, to consume the extra voltage drop. The value of the resistor can be calculated by equations (7) and (8):

   $V_{extra}$ = 15V – (3.4V x 4) – 0.5V = 0.9V

   $R_{extra}$ = 0.9V / 177mA = 5.08Ω; thus, we select $R_{extra}$=5.1Ω

   The sustaining power of $R_{extra}$ is $P_{Rextra}$ = $(177mA)^2$ x 5.1Ω = 0.16W; thus, the recommended $R_{extra}$ is 5.1Ω/0.5W.

5. ***Select R1***

   According to the datasheet of MBI1802, when $R_{ext}$=2.4kΩ and 1.8kΩ, $I_{DD,MAX}$ is 10mA. Therefore, when $R_{ext}$=3.3kΩ, the $I_{DD,MAX}$ can also be considered as 10mA. Since we use two IC in this example, the current can be considered as 20mA. From equation (1), R1 is calculated as below

   R1 = (15V – 5.1V) / 10mA = 990Ω; thus, we select R1=1kΩ. The sustaining power of R1 is $P_{R1}$ = $(10mA)^2$ x 1kΩ = 0.1W ; thus, the recommended R1 is 1kΩ/0.25W.



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***6.*** In this example, under the worst case, the $V_{DS}$ is

$V_{DS.} = V_{IN} - V_{extra} - V_{F,MIN.} \times n$ = 15V - 0.9V - 3.2V x 4 = 1.3V

where $V_{F,MIN.}$ represents the minimum forward voltage of LED. Thus, the power dissipation of one IC can be calculated by equation (10) as below:

$P_D = (V_{DD} \times I_{DD}) + (V_{DS} \times I_{OUT}) \times m$ =(5.1V x 10mA) + (1.3V x 177mA) x 2 ≒0.51W

And the temperature on IC can be approached as below:

$T_{IC} ≒ T_A + Rth \times P_D$ = 25℃ + (125℃/W x 0.51) ≒ 88.75℃

where Rth=125℃/W is the thermal resistance of IC with thermal pad where the heat sink area on PCB layout is 4 times bigger than IC's area. (Please refer to page 4 of the datasheet of MBI1802)

Figure 7 shows the application circuit by using two MBI1802.

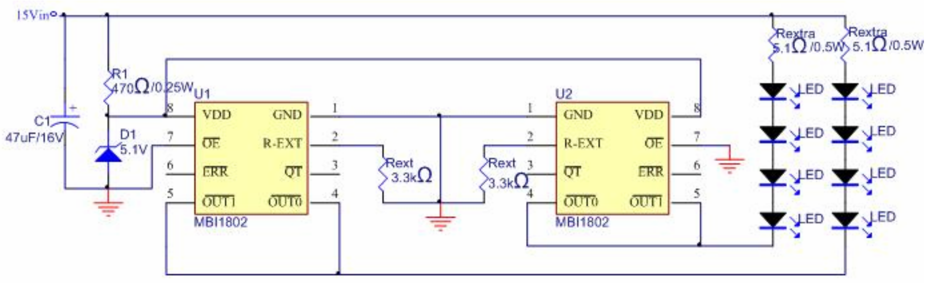


Figure 7. Application circuit using two MBI1802

## Brightness Adjustment

The MBI1801/1802/1804/1816 allow product developers to adjust LED brightness by a 5V PWM signal, whose duty cycle is adjusted by $\overline{OE}$. The less duty cycle results in brighter LED. The fastest frequency of the PWM signal is 1MHz.

## Thermal Protection (TP)

The All-Ways-On™ series features a built-in thermal protection function. When the junction tempereture of IC exceeds 165℃, the thermal protection starts to function and turns off the output current. As soon as the IC cools down below 165℃, the output current will be turned on again. When overheating happens, the peak power dissipation would affect the IC turn on time. The larger peak power dissipation leads to the shorter turn on time, and vice versa. This ensures that IC's junction temperature will not exceed 165℃.

## Thermal Flag

MBI1802 features a thermal flag function by $\overline{ERR}$, which is an open-drain structure. When junction temperature reaches 165℃, $\overline{ERR}$ sends a "low" signal to notify product developers that the thermal protection function has been activated. When the junction temperature is lower than 165℃, the $\overline{ERR}$ will recover to "high". Figure 8 shows the circuit design of thermal flag. When RED LED is lit, the thermal protection function is activated. The recommended resistance of $R_L$ ranges from 5kΩ~10kΩ to ensure the output of $\overline{ERR}$ to deliver an effective "low" signal.



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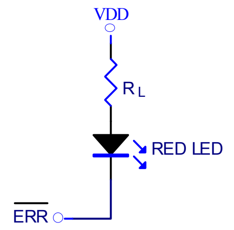


Figure 8. The circuit for the thermal flag

## Quarter of LED Current

When the $\overline{QT}$ pin of the MBI1802 goes to "low", the LED current will drop to 25% of the preset level. $\overline{QT}$ not only provides LED brightness adjustment function but also can be connected to the $\overline{ERR}$ pin for thermal protection. Figure 9 shows the reference circuit design of $\overline{QT}$ and $\overline{ERR}$ for thermal protection. When the thermal protection function is activated, the $\overline{ERR}$ pin will send a "low" signal to Q1 and then turns on Q2, to keep $\overline{QT}$ pin "low", and the LED current will drop to 25% of the original LED current simultaneously. Developers need to re-power-on to recover the pre-set LED current.

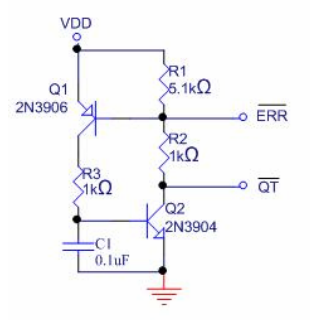


Figure 9. The reference circuit of $\overline{QT}$ for latching the occurrence of $\overline{ERR}$ (For MBI1802 only)

## PCB Layout

Following is the notices for product developers when making the PCB layout of All-Ways-On™ series.

1. To connect a ceramic capacitor with 0.1μF as close to the VDD pin of the IC as possible to avoid the interference from high frequency, and get a stable input voltage.
2. To connect an electrolysis capacitor with 47μF to the input terminal of the LED. It can provide a stable voltage for LED and avoid the oscillation, which is caused by the parasitic inductor of long wire.
3. Rext should be placed as close to IC as possible to avoid the interference of noise, which will result unstable LED current.
4. Increasing the area of IC's heat sink on PCB is helpful to reduce the temperature on IC.
5. To avoid the interference of heat conduction, do not put the heat sink of IC together with LED's.
6. Putting the thermal pad of IC together with GND not only helps reduce the temperature on IC, but also provides a stable ground system to IC.


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