MBI6661 Application Note

Overview

MBI6661 is a step-down DC/DC converter with high efficiency, and is designed to drive high power LED in constant current. The Hysteretic PFM control scheme is used to enhance the efficiency at light load condition. The LED current can be programmed by an external resistor. The MBI6661 also features Under Voltage Lock Out (UVLO), Over Temperature Protection, Open Circuit Protection and Short Circuit Protection to protect IC from being damage. The embedded peak current limit protects LED form being damage by large current. For dimming control, the output current can be adjusted by connecting a PWM signal to DIM pin of MBI6661.

MBI6661's build-in MOSFET allows saving the PCB space. MBI6661 provides two packages including TO-252 and SOP-8. The TO-252 and SOP-8 packages offer a thermal pad to enhance heat dissipation, and allow MBI6661 to operate safely even in high current applications.

Hysteretic PFM control scheme

The key feature of MBI6661 is its hysteretic pulse-frequency-modulation control scheme. When power is on, V_{SEN} is lower than V_H (115mV), the internal MOSFET of the MBI6661 will be turned on and V_{SEN} increases with I_L. Until V_{SEN} is equal to V_H, the MOSFET turns off and V_{SEN} decreases with I_L. When V_{SEN} decreases to V_L (85mV), the internal MOSFET turns on again, and repeats the above action. However, the inductor current will always work in Continuous Conduction Mode (CCM) due to the characteristics of Hysteretic PFM control. This is helpful in terms of reducing the LED ripple current. Figure 1 demonstrates the application circuit of MBI6661, and Figure 2 shows the waveforms of the hysteretic PFM control.

The switching frequency of this control scheme varies according to the output loading. The heavier load corresponds to the lower switching frequency. The minimum switching frequency of MBI6661 is limited to 40kHz to avoid audio noise interference. Compared to the low side current sensing method, high side current sensing allows users to use smaller size of sensing resistor and thus lower power consumption is achieved. This is helpful in terms of space-saving and cost effectiveness consideration.

Moreover, to ensure normal operation of MBI6661, a dropout voltage between input and output voltage is needed due to the step-down DC/DC converter topology of MBI6661. ***As the input voltage becomes lower than the minimum input voltage, which is the sum of the dropout voltages on each external component and total forward voltage of the cascaded LEDs, the internal MOSFET of MBI6661 will always turn on, and the maximum LED current is limited to 1.15 times of the preset current.*** On the contrary, if the input voltage is higher than the minimum input voltage, or if the total forward voltage of cascaded LEDs decreases due to LED's rising temperature, the output current will resume its nominal one.

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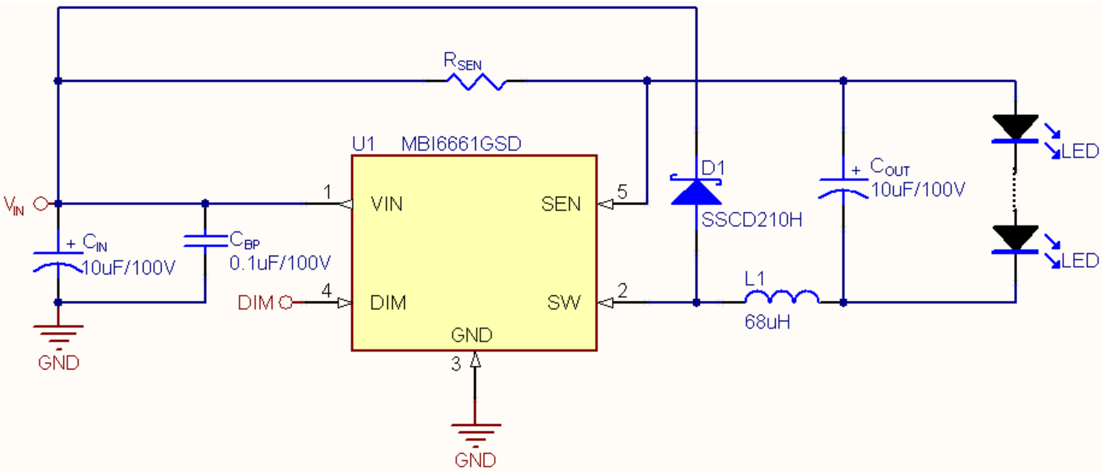

Figure 1 Application circuit of MBI6661

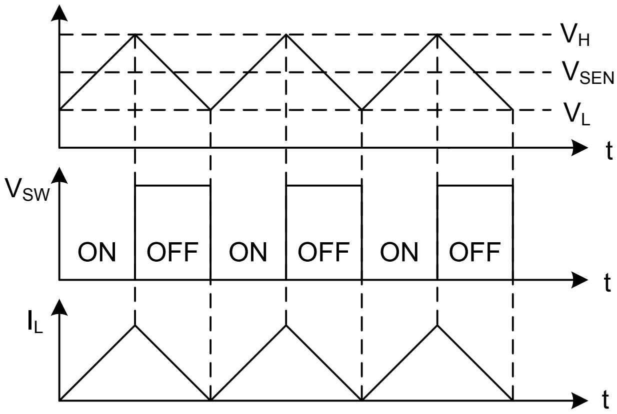

Figure 2 Waveforms of hysteretic PFM control scheme

Design consideration

Switching Frequency

To enhance output current accuracy, the switching frequency should be determined by minimum on/off time of SW waveform. For example, if the duty ratio of MBI6661 is lager than 0.5, the switching frequency should be determined by the minimum off time, and vice versa. When the duty ratio is lager than 0.5, the switching frequency of MBI6661 is

$$f_{SW} = \frac{1}{T_S} = \frac{1}{\frac{T_{OFF,min}}{(1-D)}} \quad (1)$$

When the duty ratio is smaller than 0.5, the switching frequency of MBI6661 is

$$f_{SW} = \frac{1}{T_S} = \frac{1}{\frac{T_{ON,min}}{D}} \quad (2)$$

The switching frequency is related to efficiency (better at low frequency), components size (smaller/cheaper at high frequency), and the magnitude of output ripple voltage and current (smaller at high frequency). The slower switching frequency comes along with the trade off of the lager value of inductor. In many applications, the sensitivity of EMI limits the switching frequency of MBI6661. The recommended switching frequency can be ranged form 40kHz to 1MHz.

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LED Ripple Current

The magnitude of LED ripple current is related to the external components. The lower value of inductor corresponds to the lager LED ripple current. Higher LED ripple current allows the use of smaller inductance, smaller output capacitance and even without any output capacitor. The advantages of higher LED ripple current are to minimize PCB size and reduce cost due to no output capacitor. The advantages of lower LED ripple current are the extension of LED lifetime. The recommended ripple current is from 5% to 20% of preset LED current.

Components Selection

Output Current Setting

The output current of MBI6661 can be programmed by an external resistor, and the relationship between I_{OUT} and R_{SEN} is

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

where R_{SEN} is current sense resistor, which is connected between VIN and SEN of MBI6661. 1% tolerance is recommended for better output current accuracy. V_{SEN} is the voltage across R_{SEN}. The sustaining power dissipation on R_{SEN} 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

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

Where $R_{ds(on)}$ is the on-resistance of the internal MOSFET of MBI6661.

D is the duty ratio of MBI6661, $D = V_{OUT} / V_{IN}$.

f_{SW} is the switching frequency of MBI6661.

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

When selecting an inductor, the inductance is not the only factor to affect the performance of the module, but the saturation current must also be considered. In general, the recommended saturation current of inductor is 1.5 times of the preset LED current. Moreover, the lager inductance provides better line/load regulation. However, with the same inductor size, the inductance and saturation current becomes a trade-off. An inductor with shield is recommended to reduce EMI, but there exists another trade-off with heat dissipation.

In high current applications, the switching frequency becomes the key factor of IC's power dissipation. If IC's temperature exceeds designer's expectation, the larger inductance can be used to reduce the temperature, and furthermore improve the efficiency.

Schottky Diode Selection

MBI6661 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 and fast response time for better efficiency. Two factors determine the selection of Schottky diode. One is the maximum reverse voltage, and

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the recommended rated reverse voltage is at least 1.5 times of the input voltage. The other is the maximum forward current, and the recommended rated forward current is 1.5 times of the output current.

Minimum Input Voltage

The minimum input voltage is the sum of the voltage drops on R_{SEN}, R_S, $R_{L1,DCR}$ of L1, $R_{ds(on)}$ of internal MOSFET and the total forward voltage of cascaded LEDs. The dynamic resistance of LED is provided by manufactures. ***As the input voltage is smaller than the minimum input voltage, the output current will be lager than the preset output current, and is limited to 1.15 times of the preset value***. The equivalent impedance of MBI6661 application circuit is shown as Figure 3. To calculate these voltage drops, the peak LED current must be defined first. As previously mentioned, the peak LED current is 1.15 times of the preset output current, and then the voltages drops on each component can be calculated accordingly as follow.

$$V_{RSEN} = V_{SEN} \times 1.15 \quad (6)$$

$$V_{Rs} = R_S \times I_{OUT} \times 1.15 \times n\text{, where n is the amount of LED} \quad (7)$$

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

$$V_{L1} = R_{L1,DCR} \times I_{OUT} \times 1.15 \quad (9)$$

Thus, the minimum input voltage can be defined as

$$V_{IN,MIN} = V_{Rsen} + V_{Rs} + V_{MOSFET} + V_{L1} + V_{F,LED} \quad (10)$$

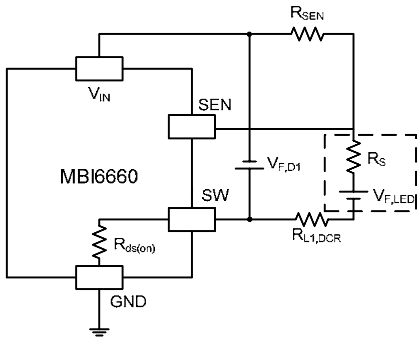

Figure 3. The equivalent impedance of MBI6661 application circuit

Input Capacitor Selection

The input capacitor, C_{IN}, can supply pulses of current for the MBI6661 when the MOSFET is on, and C_{IN}, is charged by input voltage when MOSFET is off. As the input voltage is lower than the minimum input voltage, the internal MOSFET of MBI6661 becomes constantly on, and the LED current is limited to 1.15 times of the preset 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.

Electrolytic capacitor is commonly used due to the convenient acquirement and low cost. The advantage of electrolytic capacitor is large unit capacitance. However, in high temperature application, the electrolyte vaporized easily and the decreased lifetime are concerned. The advantages of ceramic capacitor are high frequency characteristics, small size, low ESR and cost. For design reliability, a ceramic capacitor is recommended to be used. Only if in hot plugging application, a transient voltage suppressor is necessary to suppress the surge which is caused by the parasitical inductor of the power line.

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Moreover, the polymer aluminum solid capacitor with higher rated ripple current and longer lifetime is also recommended for low input voltage application.

The rated voltage and capacitance are not the only concern when selecting the electrolytic capacitor, but also the maximum ripple current should be taken into consideration. If the ripple current exceeds its specification limit, the capacitor and the IC might be damaged. In general, the ripple current is related to the inductor ripple current. The specification of maximum ripple current of capacitor should be lager than 1.3 times of the inductor ripple current. The rated ripple current of ceramic current is very high due to its very low ESR. If the material of the input capacitor is ceramic, this specification could be ignored.

For system stability, it is recommended C_{IN} be placed as close as possible to VIN pin. However, the PCB size might limit this requirement. Therefore, to avoid the noise interference, a bypass capacitor paralleled to C_{IN} and closed to VIN pin is recommended. Whose capacitance range is 0.1uF to 1uF and material is ceramic.

Output Capacitor Selection (Optional)

For reducing the LED ripple current, a capacitor parallel to the cascaded LEDs is recommended. In general, a 10uF capacitor with low ESR is desired, and the recommended rated voltage of output capacitor is 1.5 times of the total LED forward voltage. Note that the output capacitor can alter neither the switching frequency nor the efficiency. The recommended material of output capacitor is electrolytic or ceramic, the specification selection is same as input capacitor's. For the maximum stability over temperature, the input/output capacitor with X7R or X5R dielectric is recommended. A capacitor with Y5V dielectric is not recommended in this application due to worse temperature compensation.

Estimated Efficiency

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

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

where P_{OUT} is the total power consumption of the cascaded LEDs. The calculation is

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

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

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

P_{IC} is the static power consumption of MBI6661, $P_{IC} = I_{DD} \times V_{IN}$. I_{DD} is the quiescent current of MBI6661 with a maximum value of 2mA.

P_L is the inductor loss of the DC resistance (DCR) of inductor, $P_L = I_{OUT}^2 \times R_{L1,DCR}$.

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

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

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Estimated Junction Temperature

The power losses will cause temperature of MBI6661 to rise accordingly. When the junction temperature (T_J) reaches 155°C, MBI6661 will enter thermal protection mode and shut the internal MOSFET off. Thus it is important for users to recognize the relationship between power losses and temperature increment. The relationship can be described as

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

where T_A is the ambient temperature.

$P_{LOSS,\ IC}$ is the power loss of MBI6661, $P_{LOSS,\ IC} = P_C + P_{SW} + P_{IC}$.

$R_{th,\ JA}$ is the thermal resistor of MBI6661 from junction to ambient.

When the estimated junction temperature is higher than 125°C, the inductance must be increase to reduce the power loss of the internal MOSFET and the junction temperature.

Design Example

To design a LED driver with MBI6661 to light up 10 pieces of white LED, the forward voltage of LED is 3.72V/pcs and the dynamic resistance is 0.5Ω. The desired LED current is 1A, and the input voltage is 48V.

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

The R_{SEN} can be calculated by (3), R_{SEN} = 0.1V / 1A = 0.1Ω. Here, R_{SEN} is chosen to be 0.1Ω. The sustaining power dissipation is $P_{RSEN} = 0.1V^2 / 0.1\Omega = 0.1W$. Thus a 1%, 0.1Ω resistor with 0.25W power dissipation is recommended.

Since the duty ratio of MBI6661 is D = (3.72V x 10) / 48V = 0.775, the switching frequency should be determined by the minimum off time. Thus the switching frequency is f_{SW} = 1 / (350ns / (1 - 0.775)) = 642.86kHz.

Inductor Selection

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

L1 > [48V – (3.72 x 10) – 0.1V – (0.35Ω x 1A)] x [0.775 / (642.86kHz x 0.3 x 1A)] = 41.59uH

Consider to the high current applications, the temperature of the IC is higher. Thus, we choose a 100uH (GDK-126-101M) with saturation current of 1.5A and 170mΩ DCR manufactured by GOTREND. Since the inductor is 100uH, the switching frequency should be modified as

f_{SW} = [48V – (3.72 x 10) – 0.1V – (0.35Ω x 0.5A)] x [0.775 / (100uH x 0.3 x 1A)] = 267.38kHz

Schottky Diode Selection

In this application, the recommended selection of Schottky diode is SSCD210H manufactured by ZOEWIE with 100V reverse voltage, 2A forward current, and 0.5V forward voltage as its rated maximum.

Minimum Input Voltage

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

V_{RSEN} = 0.1V x 1.15 = 0.115V

V_{Rs} = 0.5Ω x 1A x 1.15 x 10 = 5.75V

V_{MOSFET} = 0.4Ω x 1A x 1.15 =0.4025V

V_{L1} = 0.17Ω x 1A x 1.15 = 0.1955V

Thus the minimum input voltage is $V_{IN, MIN}$ = 0.1125V + 5.75V + 0.4025V + 0.1955V + 37.2 = 43.66V.

Input Capacitor Selection

To ensure system safety, a 10uF electrolytic capacitor with 100V rated voltage is recommended. To avoid the noise interference, a 0.1uF ceramic capacitor with 100V rated voltage is recommended as the bypass capacitor.

Output Capacitor Selection

For LED ripple current reduction, an output capacitor must be paralleled to the LED array. In this example, the recommended output capacitor is a 10uF electrolytic capacitor with 63V rated voltage.

Efficiency Estimated

The power consumption on each component can be calculated as

$P_{OUT} = V_{OUT} \times I_{OUT} = 10 \times 3.72V \times 1A = 37.2W$

$P_C = I_{OUT}^2 \times R_{ds(on)} \times D = (1A)^2 \times 0.35\Omega \times 0.775 = 271.25mW$

$P_{SW} = V_{IN} \times I_{OUT} \times (t_r + t_f) \times f_{SW} = 48V \times 1A \times (20ns + 40ns) \times 267.38kHz = 770.05mW$

$P_{IC} = I_{DD} \times V_{IN} = 2mA \times 48V = 96mW$

$P_L = I_{OUT}^2 \times R_{L1,DCR} = (1A)^2 \times 0.17\Omega = 170mW$

$P_{D1} = V_{F, D1} \times I_{OUT} \times (1\text{-}D) = 0.5V \times 1A \times (1 - 0.775) = 112.5mW$

$P_{RSEN} = V_{SEN} \times I_{OUT} = 0.1V \times 1A = 100mW$

$P_{LOSS} = P_C + {}_{PSW} + P_{IC} + P_L + P_{D1} + P_{RSEN} = 1.5198W$

Thus, the efficiency in this application is

$$\eta = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}} = \frac{37.2W}{37.2W + 1.5198W} \times 100\% = 96.07\%$$

Estimated Junction Temperature

The junction temperature can be estimated by

$T_J = T_A + P_{LOSS, IC} \times R_{th, JA}$ = 25°C + (271.25mW + 770.05mW + 96mW) x 54.2°C/W = 86.64°C.

The application circuit and BOM of reference are listed as follows.

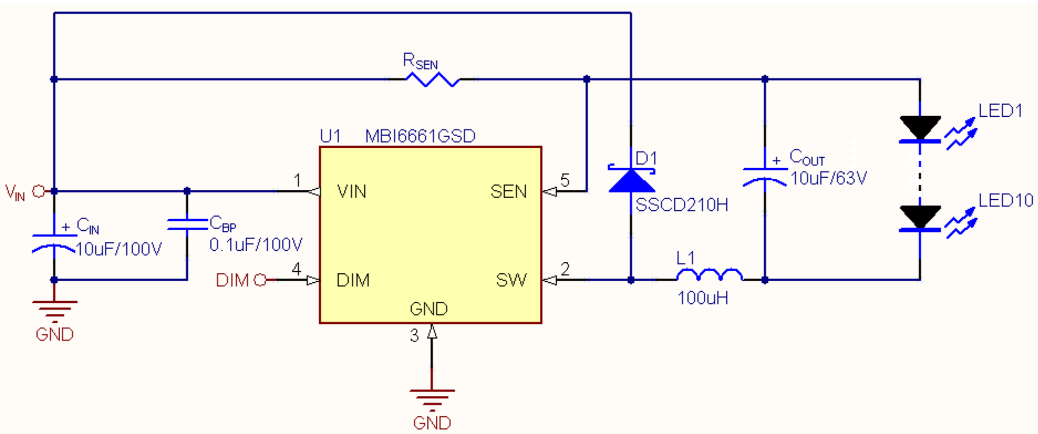

Figure 4. The application circuit of design example

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Table 1. The BOM of design example

Designator	Part Type	Description	Vendor	Contact Window
C_{IN}	10uF/100V	EKY-101ETD100F11D, Electrolytic Capacitor	J. C. TALLY	+886-3-564-6696, ext.12
C_{BP}	0.1uF/100V	GRM21BR72A104KAC4L, X7R, 0805, Ceramic Capacitor	Murata	+886-2-3343-3939
C_{OUT}	10uF/63V	EKY-630ETD100F11, Electrolytic Capacitor	J. C. TALLY	+886-3-564-6696, ext.12
D1	SSCD210H	100V/2A, Schottky diode	ZOEWIE	+886-2-2219-5533
L1	100uH	GDK-126-101M	GOTREND	+886-2-8252-6199
R_{SEN}	0.1Ω	RS05FL70R1, 1%, 0805, SMD Resistor	VIKING	+886-3597-2931, ext.5818
U1	MBI6661GSD	Step-Down, 1A LED Driver, TO252	MBI	+886-3-579-0068

PCB Layout Guideline

With the goal of enhancing efficiency and stabilizing the system, it is essential to abide to a careful printed circuit board layout rules. There are several rules to be noted.

1. Keep a complete ground area is helpful to eliminate the switching noise.
2. Keep the IC's GND pin and the ground leads of input filter capacitor in less than 5mm.
3. To enhance efficiency and minimizing output ripple voltage, use a ground plane and solder the IC's GND pin directly to the ground plane.
4. To stabilize system, the heat sink of MBI6661 is recommended to connect to ground plane directly.
5. To stabilize system, don't place the inductor on the back of the IC.
6. To enhance heat dissipation, the area of ground plane, which IC's heat sink soldered on it, should be as lager as possible.
7. The input capacitor should be place to IC's VIN pin as close as possible. If the PCB size limits this requirement, place a bypass capacitor, whose capacitance is 0.1uF and material is ceramic, paralleled with V_{IN} and GND is needed.
8. The layout sequence of components please refer to input capacitor→input bypass capacitor→ R_{SEN}→IC's VIN pin. Do not allow the layout path to appear branch on the PCB layout.
9. To reduce the radiation EMI, please don't extend the area, which is comprised by IC's SW pin, Schottky diode and inductor.
10. The path, which flows large current, should be wide and short to eliminate the parasitic element.
11. When switch is on/off, the direction of power loop should keep the same way to enhance efficiency. The sketch is shown as Figure 5. Where the current flows clockwise on the red path during MOSFET turns on; the current flows clockwise on the purple path during MOSFET turns off. Figure 6 is the recommended layout diagram of MBI6661GSD.

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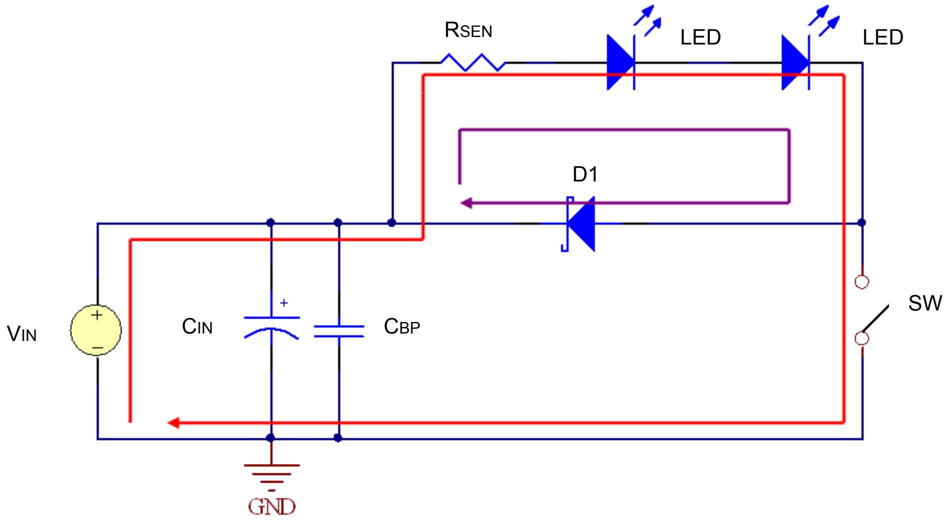
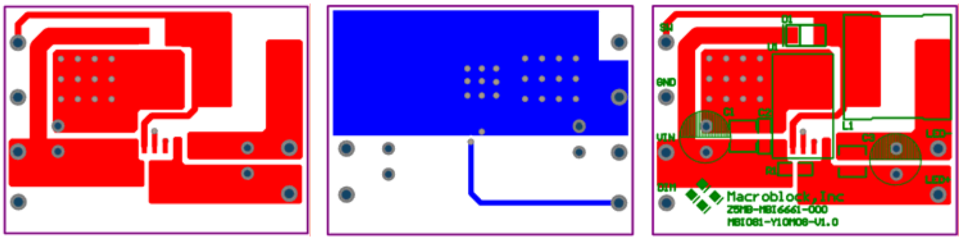


Figure 5. The sketch of power loop



Top layer Bottom layer Top overlay

Figure 6. The layout diagram of MBI6661GSD

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