



## Step-Down, 1A LED Driver

### Features

- Backward compatible with MBI6650 in package
- 1A constant output current
- 96% efficiency @ input voltage 12V, 350mA, 3-LED
- 9~36V input voltage range
- Hysteretic PFM improves efficiency at light loading
- Settable output current
- Integrated power switch with 0.45ohm low Rds(on)
- Full protection: Thermal/UVLO/Start-Up/LED Open-/Short- Circuit
- Only 4 external components required

### Product Description

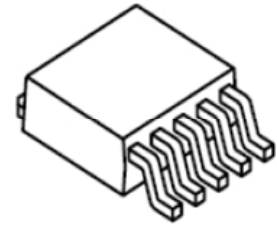
The MBI6651 is a high efficiency, constant current and step-down DC/DC converter. It is designed to deliver constant current to light up high power LED with only 4 external components. With hysteretic PFM control scheme, MBI6651 improves the efficiency of light loading. The output current of MBI6651 can be programmed by an external resistor and LED dimming can be controlled via pulse width modulation (PWM) through DIM pin. In addition, the start-up function limits the inrush current while the power is switch on. The MBI6651 also features under voltage lock out (UVLO), over temperature protection, LED open-circuited protection and LED short-circuited protection to protect IC from being damaged.

Additionally, to ensure the system reliability, the MBI6651 builds thermal protection (TP) function inside. This function protects IC from overheating (165°C) in various application conditions. MBI6651 provides thermal-enhanced packages as well to handle power dissipation more efficiently. MBI6651 is available in TO-252, SOT23-6 and MSOP-8 packages.

### Applications

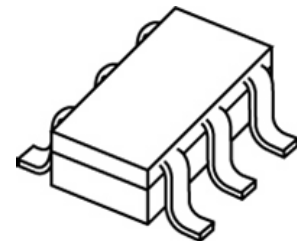
- Signage and Decorative LED Lighting
- Automotive LED Lighting
- High Power LED Lighting
- Constant Current Source

#### Surface Mount Device



GSD : TO-252-5L

#### Small Outline Transistor



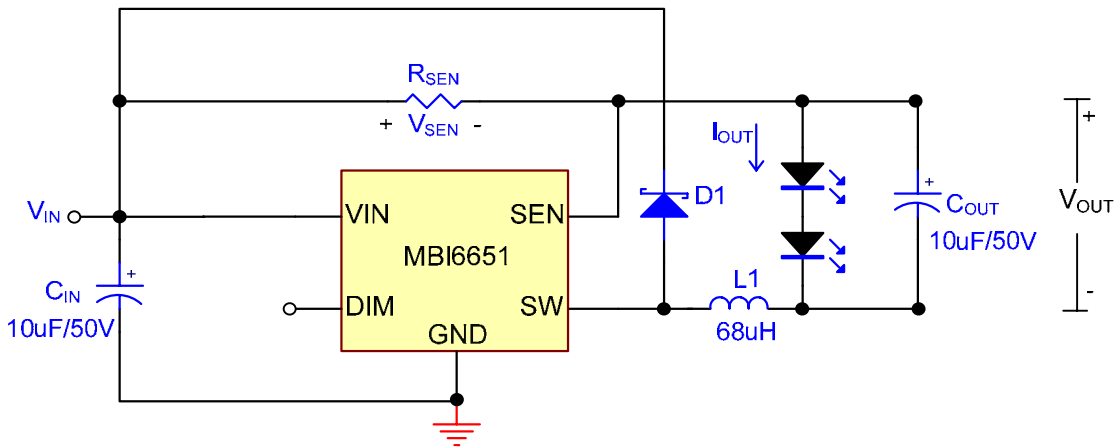
GST: SOT-23-6L

#### Mini Small Outline Package



GMS: MSOP-8L-118mil

Typical Application Circuit



C<sub>IN</sub>: VISHAY, 293D106X9050D2TE3, D case Tantalum Capacitor  
 C<sub>OUT</sub>: VISHAY, 293D106X9050D2TE3, D case Tantalum Capacitor  
 L1: GANG SONG, GSDS106C2-680M  
 D1: ZOWIE, SSCD206

Figure 1

Functional Diagram

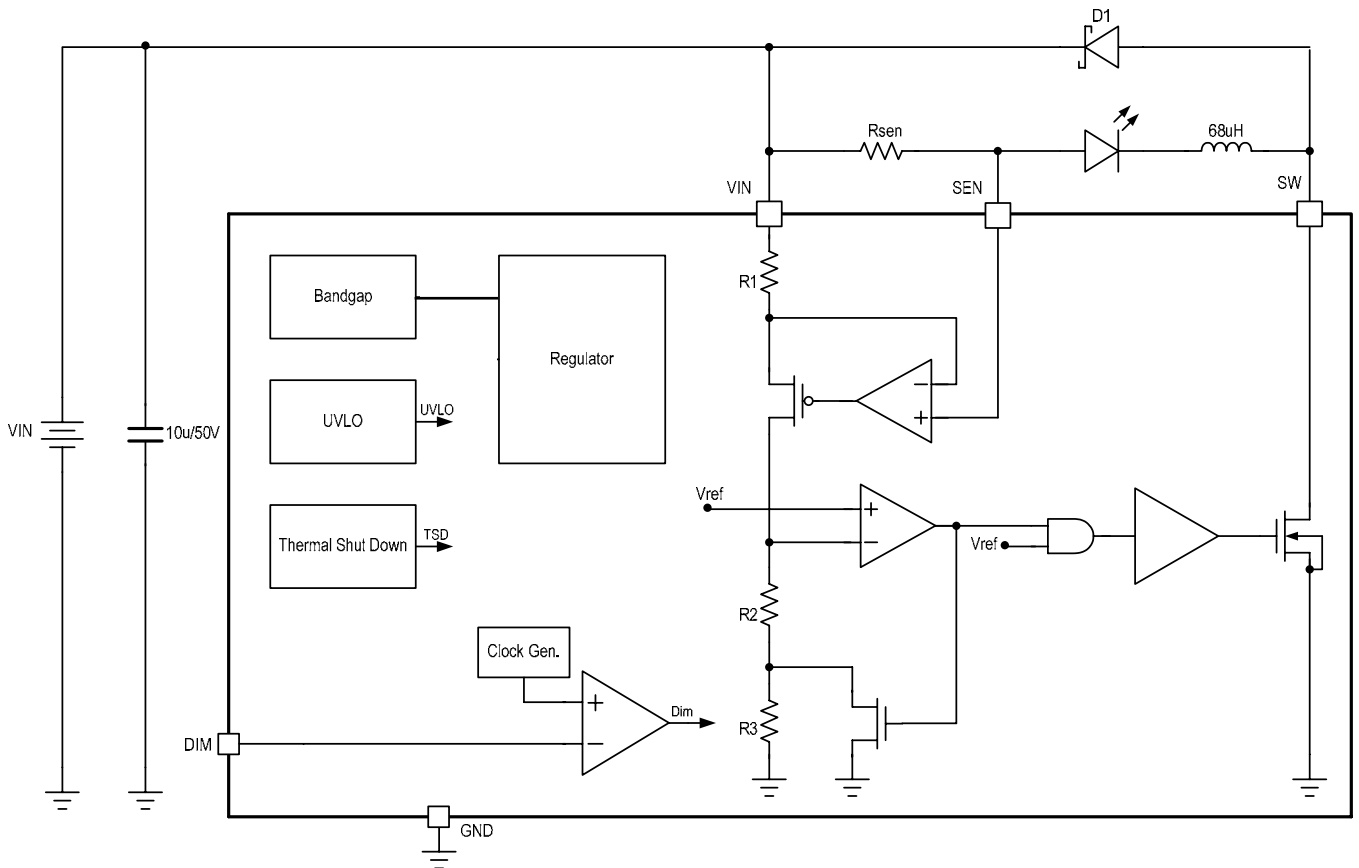
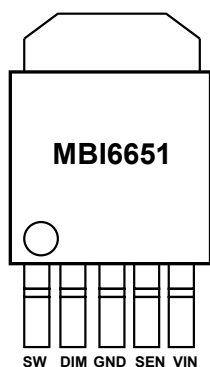
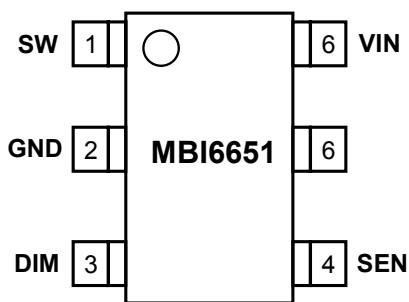


Figure 2

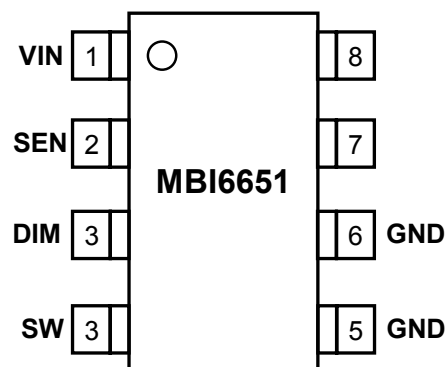
Pin Configuration



TO-252



SOT-23



MSOP-8L

Pin Description

| Pin Name    | Function   |
|-------------|--|
| GND         | Ground terminal for control logic and current sink |
| SW          | Switch output terminal                             |
| DIM         | Dimming control terminal                           |
| SEN         | Output current sense terminal                      |
| VIN         | Supply voltage terminal                            |
| Thermal Pad | Power dissipation terminal connected to GND*       |

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

Maximum Ratings

Operation above the maximum ratings may cause device failure. Operation at the extended periods of the maximum ratings may reduce the device reliability.

| Characteristic   |          | Symbol        | Rating   | Unit          |
|--|----------|---------------|----------|---------------|
| Supply Voltage   |          | $V_{IN}$      | 0~40     | V             |
| Output Current   |          | $I_{OUT}$     | 1.2      | A             |
| Sustaining Voltage at SW pin                               |          | $V_{SW}$      | -0.5~45  | V             |
| GND Terminal Current                                       |          | $I_{GND}$     | 1.2      | A             |
| Power Dissipation<br>(On 4 Layer PCB, $T_a=25^{\circ}C$ )* | GSD Type | $P_D$         | 3.80     | W             |
| Thermal Resistance<br>(By simulation, on 4 Layer PCB)*     |          | $R_{th(j-a)}$ | 32.9     | $^{\circ}C/W$ |
| Empirical Thermal Resistance**                             |          |               | 60.85    |               |
| Power Dissipation<br>(On 4 Layer PCB, $T_a=25^{\circ}C$ )* | GST Type | $P_D$         | 0.51     | W             |
| Thermal Resistance<br>(By simulation, on 4 Layer PCB)*     |          | $R_{th(j-a)}$ | 244      | $^{\circ}C/W$ |
| Empirical Thermal Resistance**                             |          |               | 132.69   |               |
| Power Dissipation<br>(On 4 Layer PCB, $T_a=25^{\circ}C$ )* | GMS Type | $P_D$         | 3.3      | W             |
| Thermal Resistance<br>(By simulation, on 4 Layer PCB)*     |          | $R_{th(j-a)}$ | 37.53    | $^{\circ}C/W$ |
| Empirical Thermal Resistance**                             |          |               | 141.33   |               |
| Operating Junction Temperature                             |          | $T_{j,max}$   | 125      | $^{\circ}C$   |
| Operating Temperature                                      |          | $T_{opr}$     | -40~+85  | $^{\circ}C$   |
| Storage Temperature  |          | $T_{stg}$     | -55~+150 | $^{\circ}C$   |

\*The PCB size is 76.2mm\*114.3mm in simulation.

\*\* The PCB size is 4 times larger than that of IC and without extra heat sink.

**Electrical Characteristics**

Test condition:  $V_{IN}=12V$ ,  $V_{OUT}=3.6V$ ,  $L1=68\mu H$ ,  $C_{IN}=C_{OUT}=10\mu F$ ,  $T_A=25^\circ C$ ; unless otherwise specified. Please refer to test circuit (a) of Figure 3.)

| Characteristics                                   | Symbol             | Condition  | Min. | Typ.    | Max.    | Unit       |
|---|--------------------|--|------|---------|---------|------------|
| Supply Voltage                                    | $V_{IN}$           | -  | 9    | -       | 36      | V          |
| Supply Current                                    | $I_{IN}$           | $V_{IN}=9V\sim 36V$                                | -    | 1       | 2       | mA         |
| Output Current                                    | $I_{OUT}$          | -  | -    | 350     | 1000    | mA         |
| Output Current Accuracy                           | $dI_{OUT}/I_{OUT}$ | $150mA \leq I_{OUT} \leq 1000mA$ ,                 | -    | $\pm 3$ | $\pm 5$ | %          |
| SW Dropout Voltage                                | $V_{SW}$           | $I_{OUT}=1A$                                       | -    | 0.45    | -       | V          |
| Internal Propagation Delay Time                   | $T_{pd}$           |  | 100  | 196     | 300     | ns         |
| Efficiency  | -                  | $V_{IN}=12V$ , $I_{OUT}=350mA$ , $V_{OUT}=10.8V$   | -    | 96      | -       | %          |
| Input Voltage                                     | “H” level          | $V_{IH}$   | -    | 3.5     | -       | V          |
|   | “L” level          | $V_{IL}$   | -    | -       | 0.5     | V          |
| Switch ON Resistance                              | $R_{ds(on)}$       | $V_{IN}=12V$ ; refer to test circuit (b)           | 0.4  | 0.45    | 0.6     | $\Omega$   |
| Minimum Switch ON Time*                           | $T_{ON,min}$       |  | 100  | 350     | 450     | ns         |
| Minimum Switch OFF Time*                          | $T_{OFF,min}$      |  | 100  | 350     | 450     | ns         |
| Recommended Duty Cycle Range of SW*               | $D_{sw}$           |  | 20   | -       | 80      | %          |
| Maximum Operating frequency                       | $Freq_{Max}$       |  | 40   | -       | 1000    | kHz        |
| <b>CURRENT SENSE</b>                              |                    |  |      |         |         |            |
| Mean SEN Voltage                                  | $V_{SEN}$          | $V_{IN}=10V$ , $V1=1V$ , refer to test circuit (c) | 95   | 100     | 105     | mV         |
| <b>THERMAL OVERLOAD</b>                           |                    |  |      |         |         |            |
| Thermal Shutdown Threshold*                       | $T_{SD}$           | -  | 145  | 165     | 175     | $^\circ C$ |
| Thermal Shutdown Hysteresis*                      | $T_{SD-HYS}$       | -  | 20   | 30      | 40      | $^\circ C$ |
| <b>UNDER VOLTAGE LOCK OUT</b>                     |                    |  |      |         |         |            |
| UVLO Voltage                                      | -                  | $T_A=-40\sim 85^\circ C$                           | 7.7  | 8       | 8.3     | V          |
| UVLO Hysteresis                                   | -                  | -  | 0.15 | 0.2     | 0.35    | V          |
| Start Up Voltage                                  | -                  | -  | 7.85 | 8.2     | 8.65    | V          |
| <b>DIMMING</b>                                    |                    |  |      |         |         |            |
| Duty Cycle Range of PWM Signal Applied to DIM pin | $Duty_{DIM}$       | PWM Frequency : 1kHz                               | 1    | -       | 100     | %          |

\*Guaranteed by Design.

Test Circuit for Electrical Characteristics

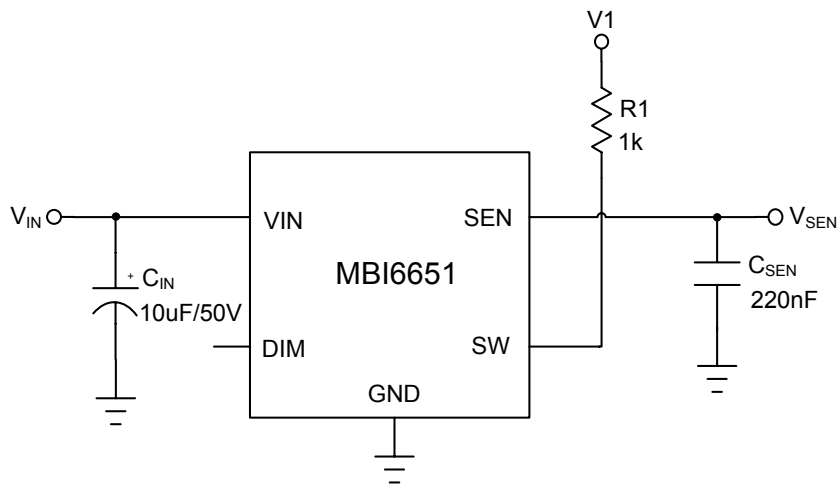
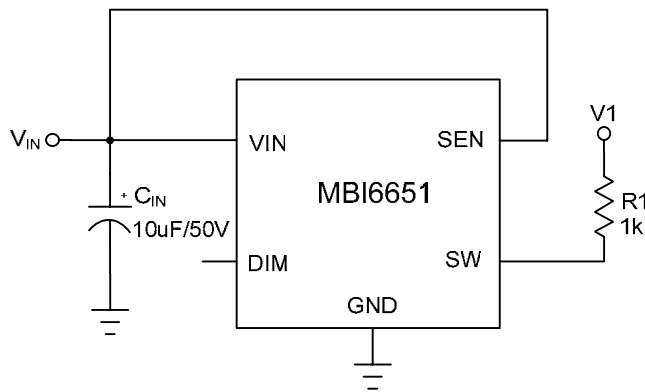
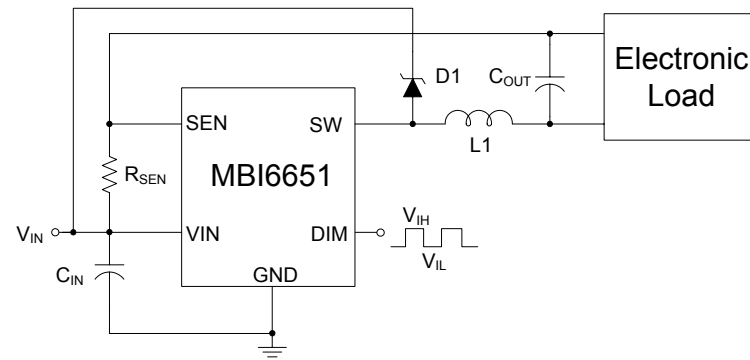


Figure 3

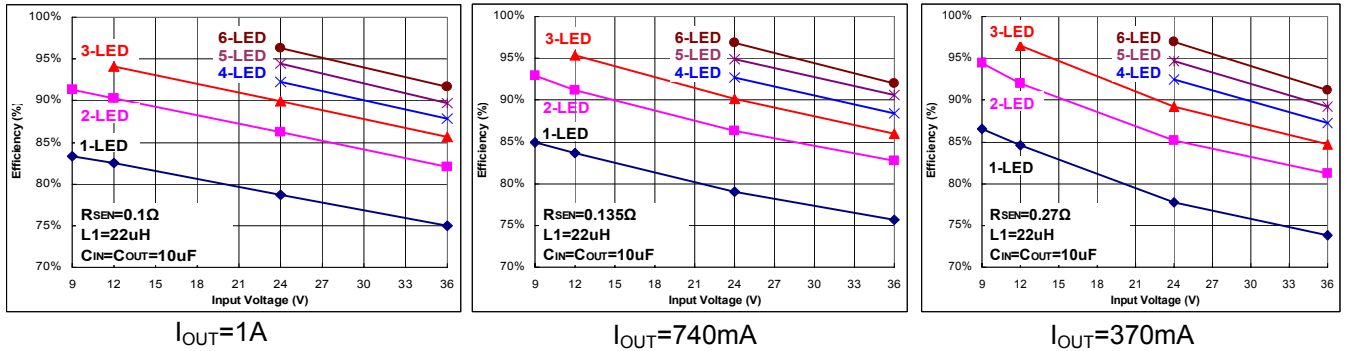
Typical Performance Characteristics

Please refer to Typical Application Circuit,  $V_{IN}=12V$ ,  $L1=68\mu H$ ,  $C_{IN}=C_{OUT}=10\mu F$ ,  $T_A=25^\circ C$ , unless otherwise specified.

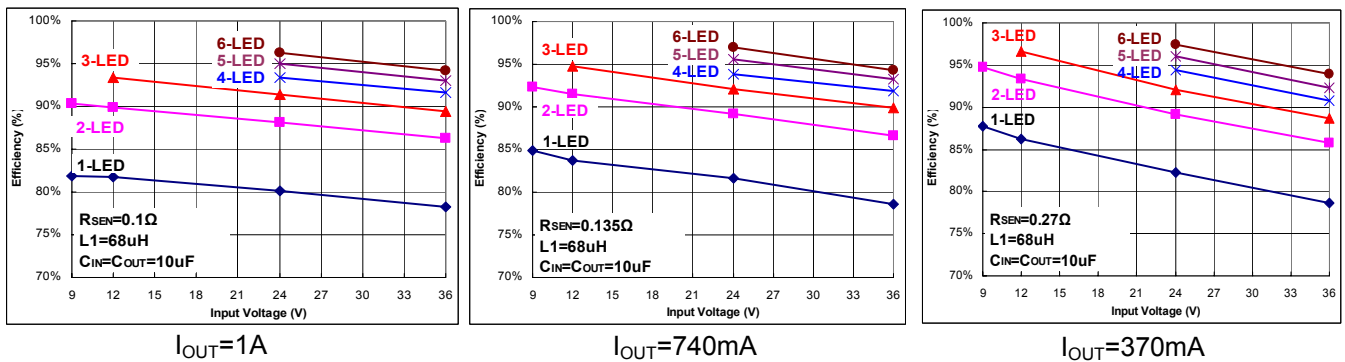
1-LED  $V_F=3.6V$ ; 2-LED  $V_F=7.2V$ ; 3-LED  $V_F=10.8V$ ; 4-LED  $V_F=14.4V$ ; 5-LED  $V_F=18V$

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

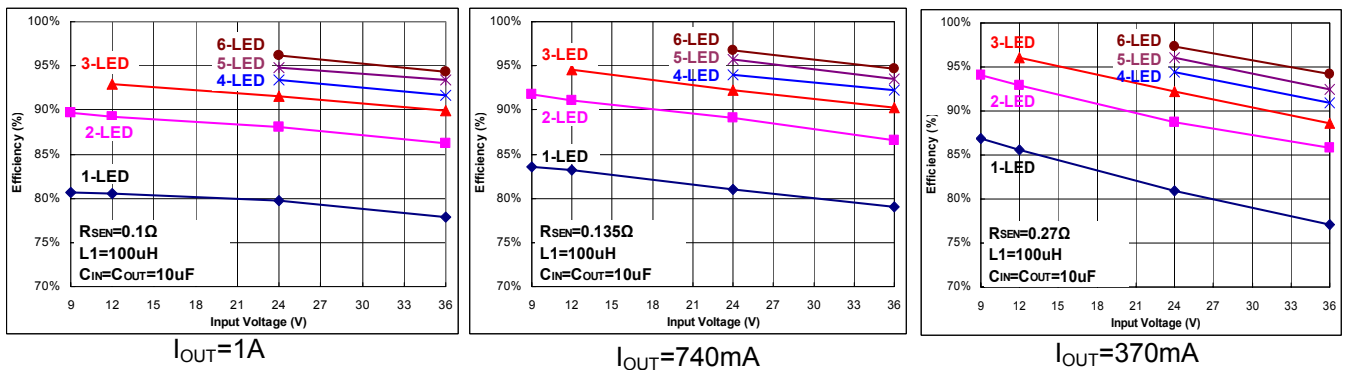
Efficiency vs. input voltage @  $L1=22\mu H$



Efficiency vs. input voltage @  $L1=68\mu H$

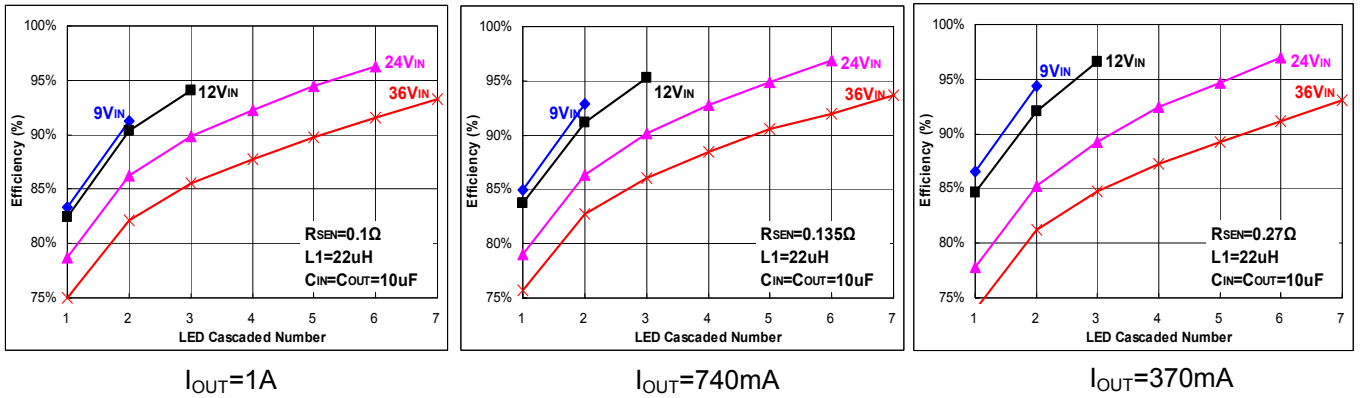


Efficiency vs. input voltage @  $L1=100\mu H$

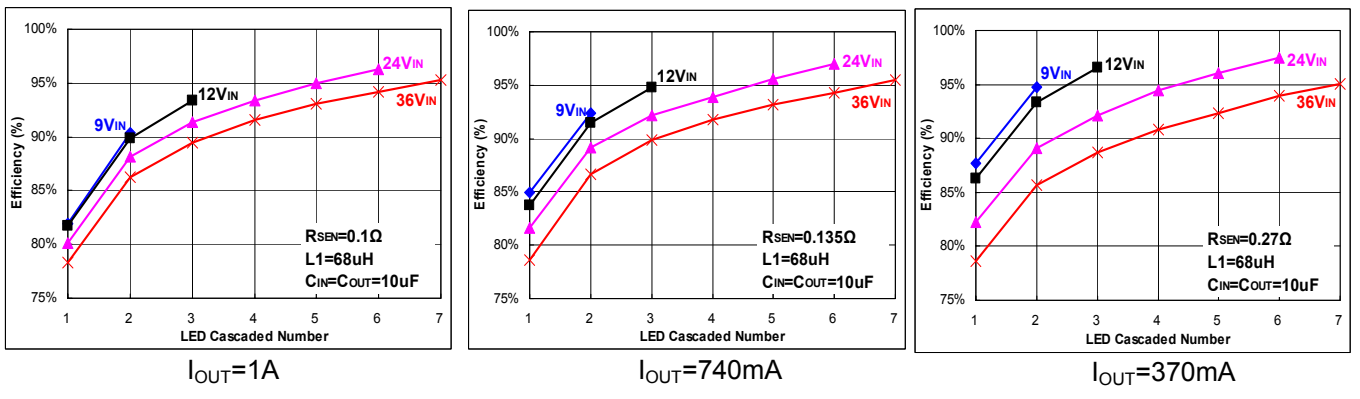


2. Efficiency vs. LED Cascaded Number at Various Input Voltage

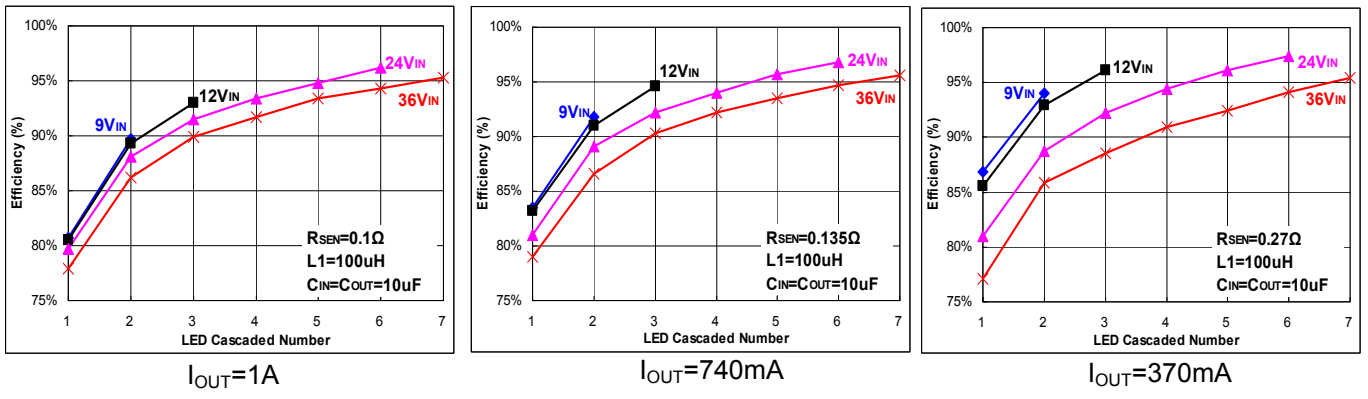
Efficiency vs. LED cascaded number @ L1=22uH



Efficiency vs. LED cascaded number @ L1=68uH



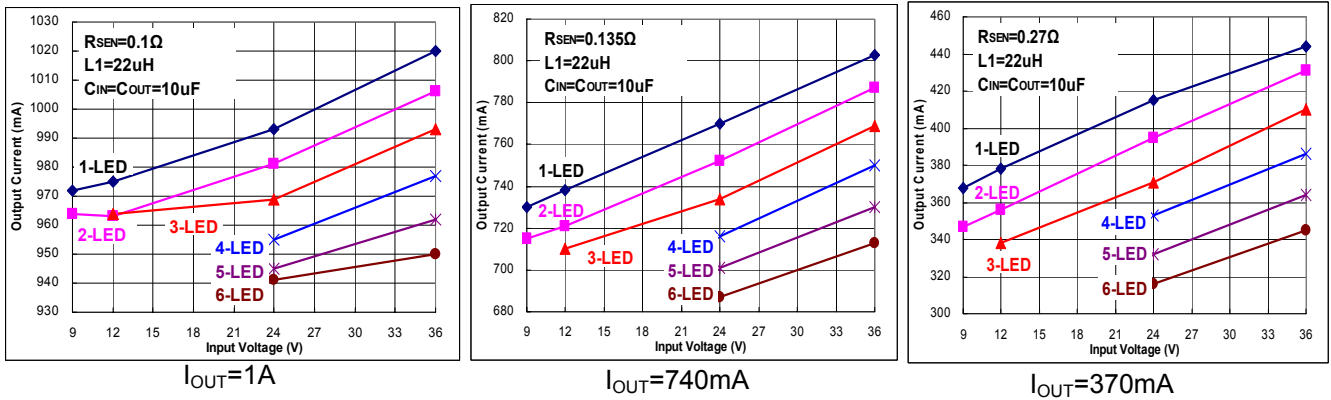
Efficiency vs. LED cascaded number @ L1=100uH



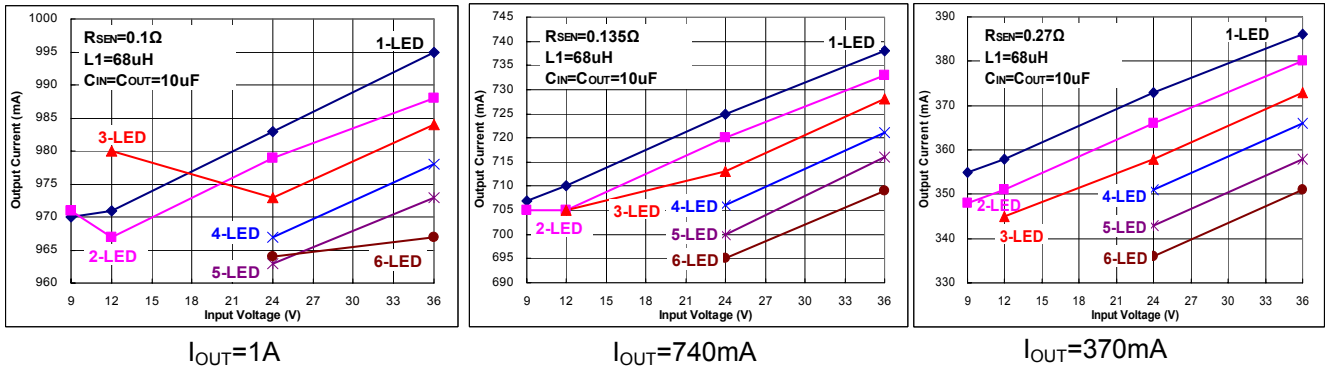


3. Output Current vs. Input Voltage at Various LED Cascaded Numbers

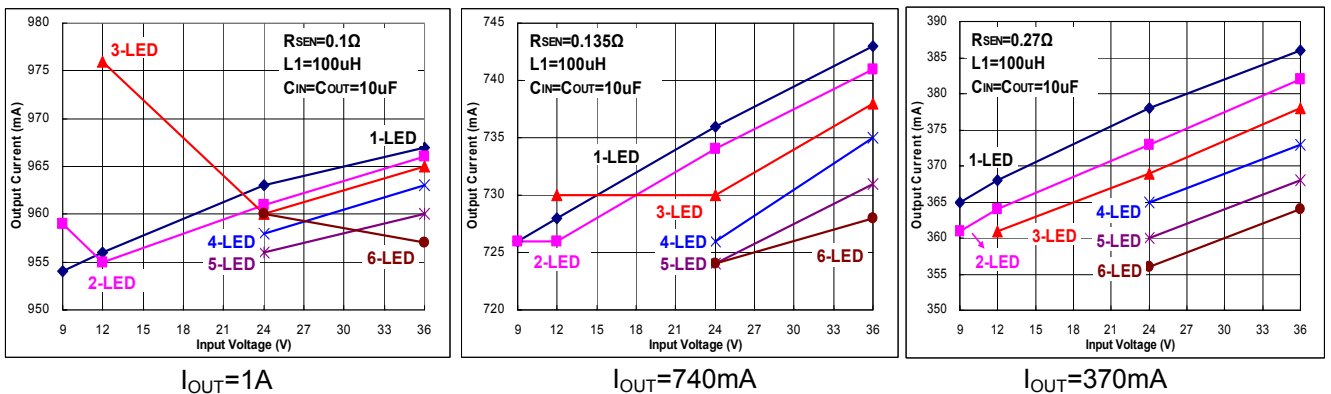
Output current vs. input voltage @ L1=22uH



Output current vs. input voltage @ L1=68uH

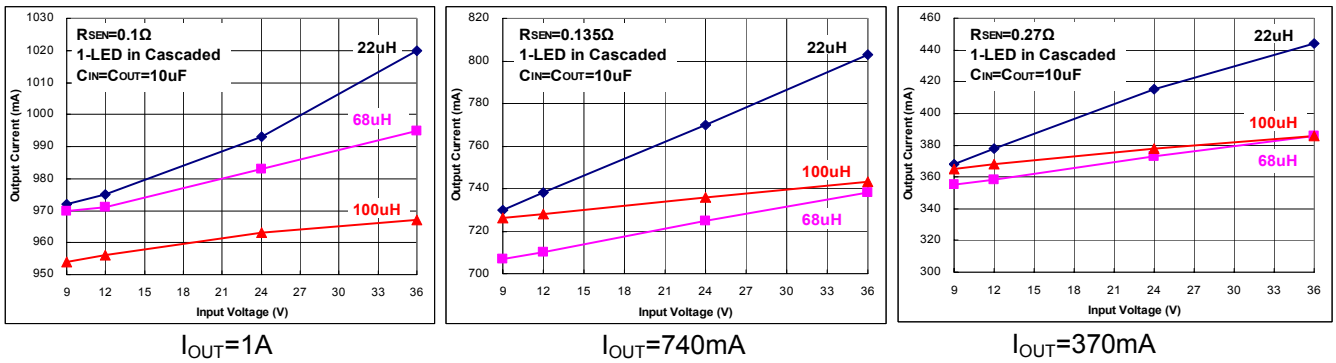


Output current vs. input voltage @ L1=100uH

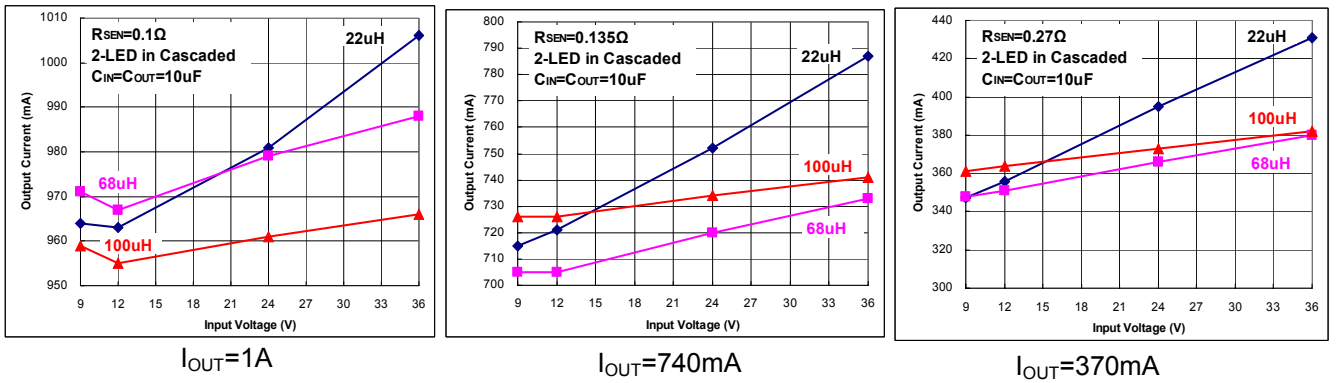


4. Output Current vs. Input Voltage at Various Inductors

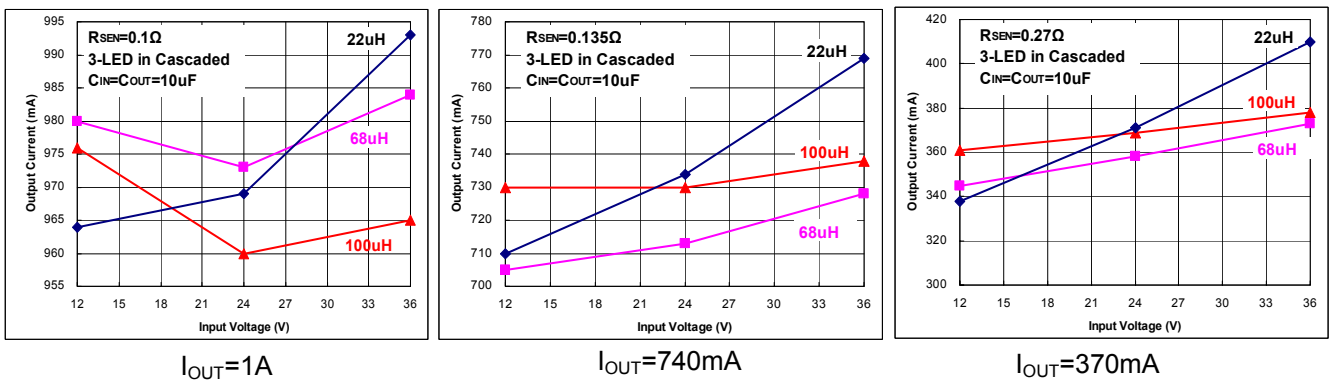
Output current vs. input voltage @ 1-LED in cascaded



Output current vs. input voltage @ 2-LED in cascaded

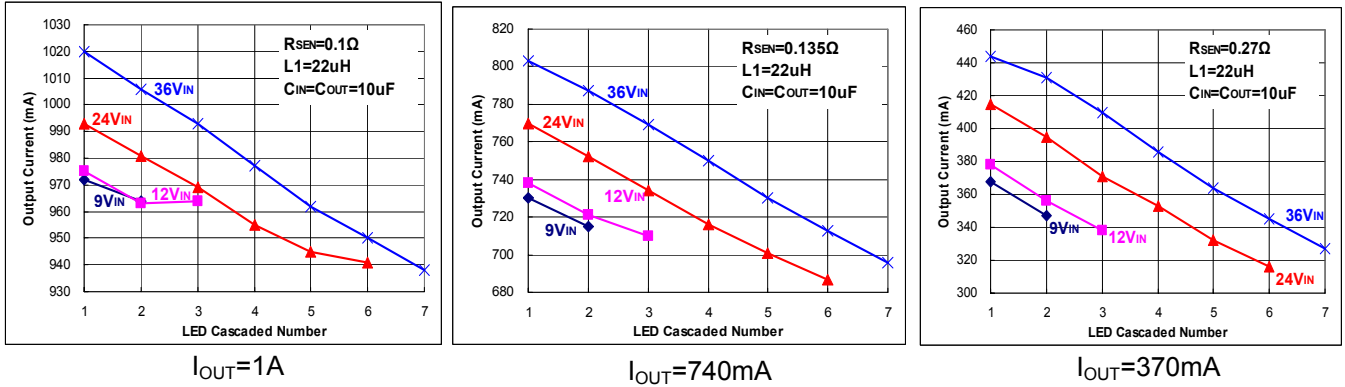


Output current vs. input voltage @ 3-LED in cascaded

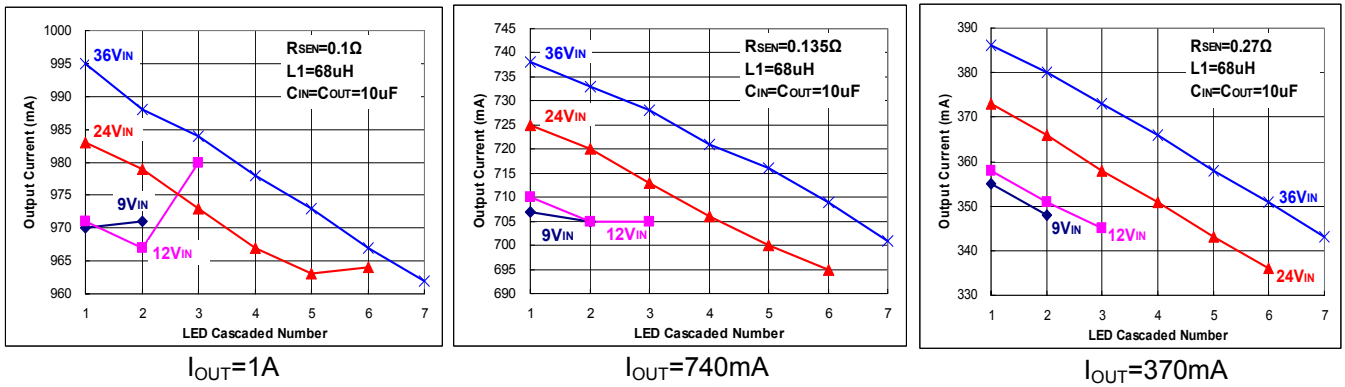


5. Output Current vs. LED Cascaded Number at Various Input Voltage

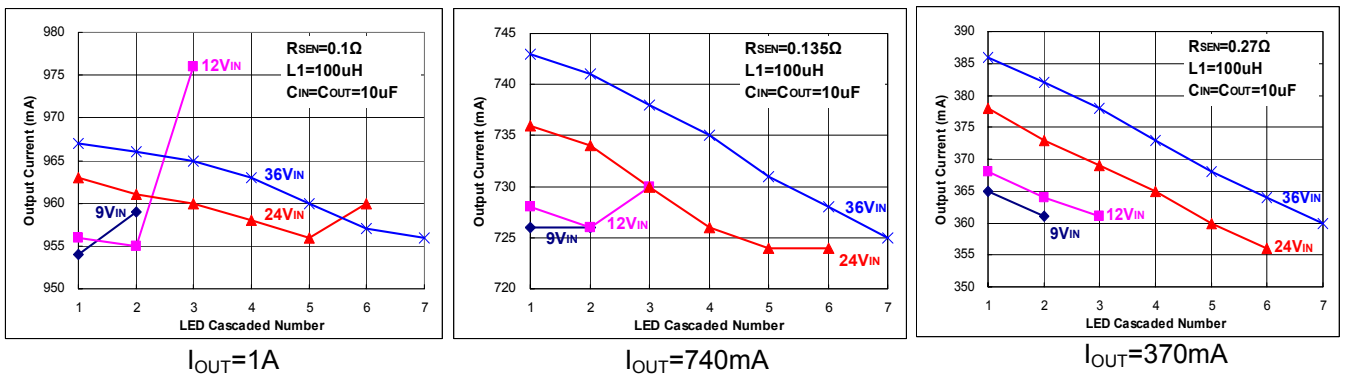
Output current vs. LED cascaded number @ L1=22uH



Output current vs. LED cascaded number @ L1=68uH

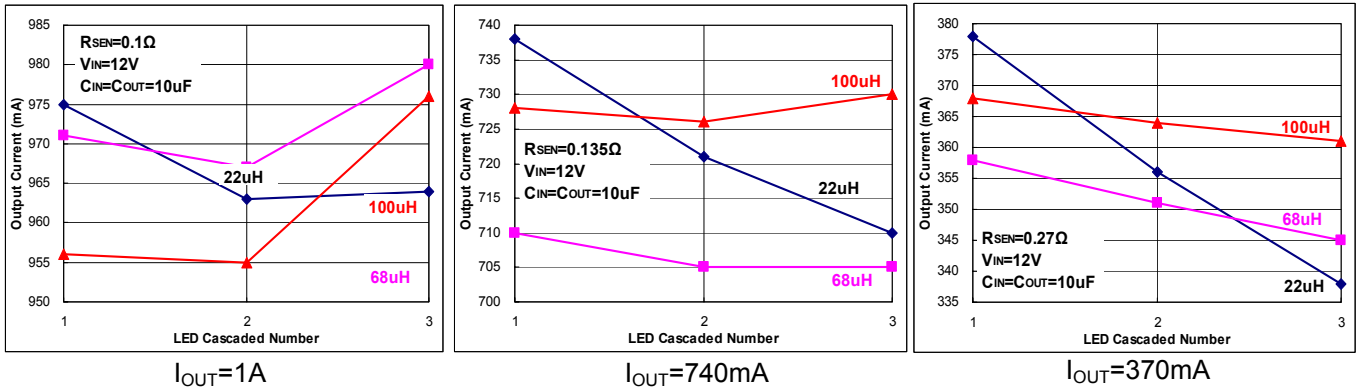


Output current vs. LED cascaded number @ L1=100uH

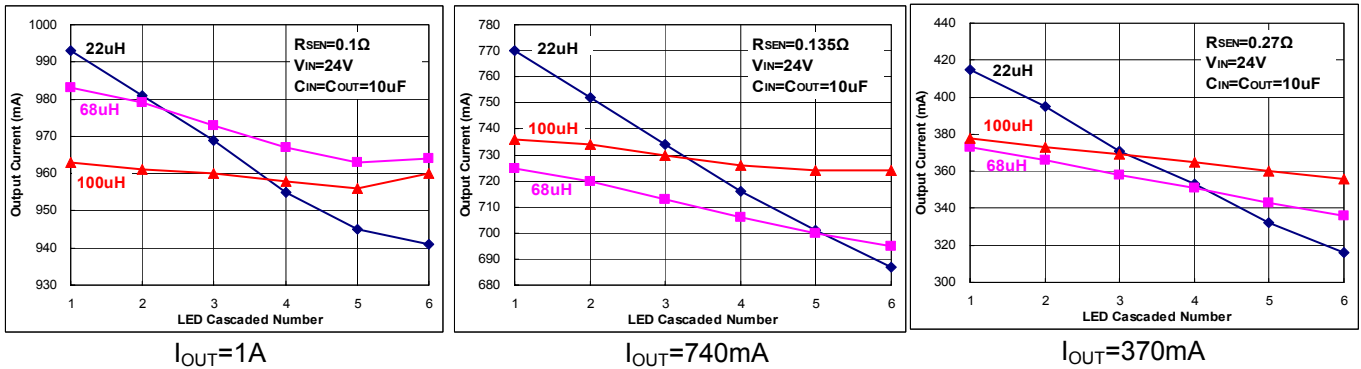


6. Output Current vs. LED Cascaded Number at Various Inductor

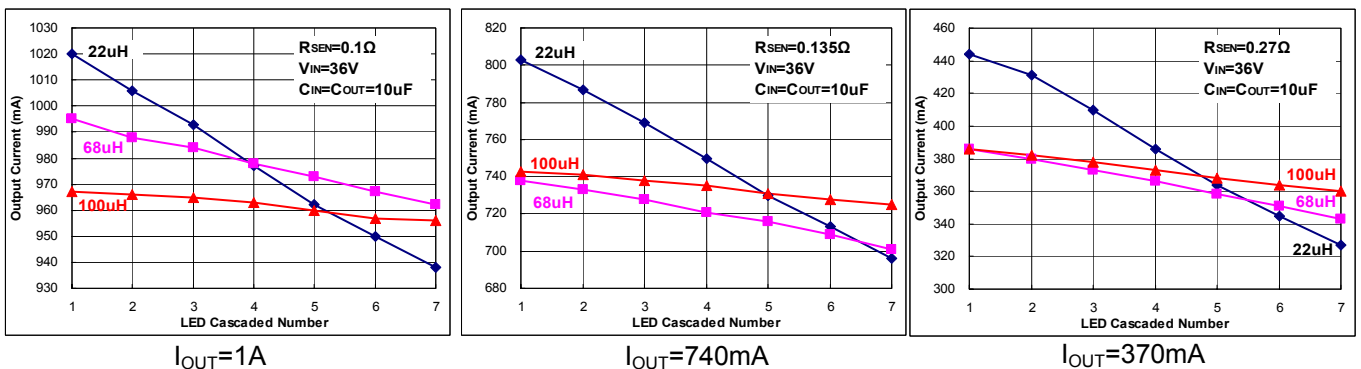
Output current vs. LED cascaded number @  $V_{IN}=12V$



Output current vs. LED cascaded number @  $V_{IN}=24V$

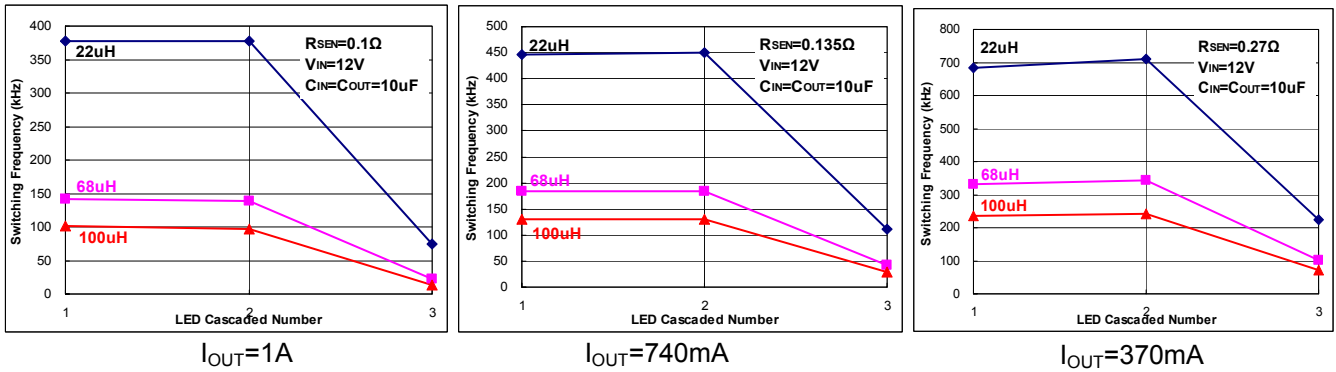


Output current vs. LED cascaded number @  $V_{IN}=36V$

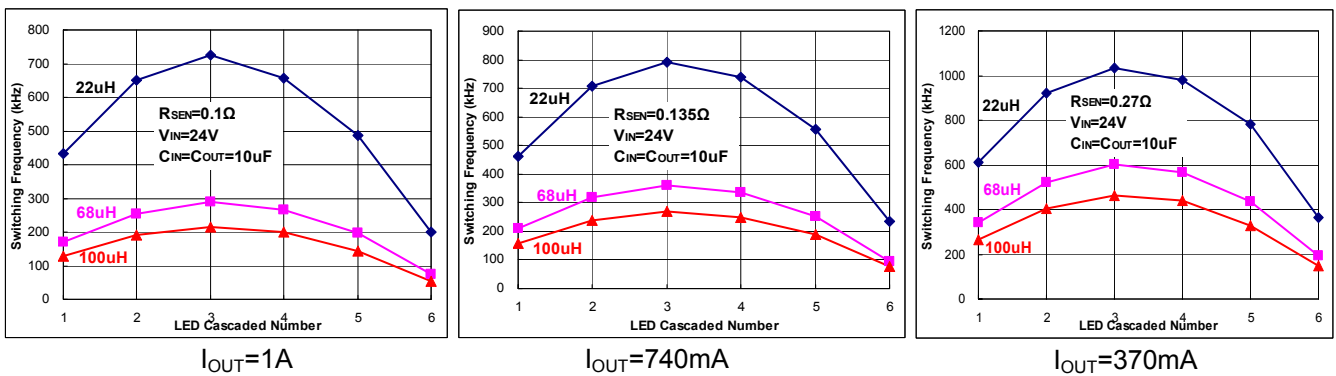


7. Switching Frequency vs. LED Cascaded Number at Various Inductor

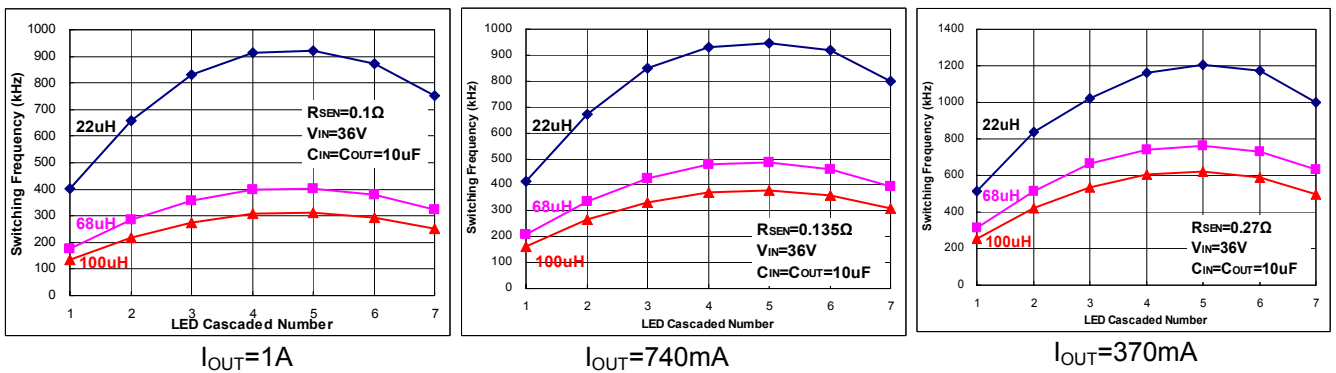
Switching frequency vs. LED cascaded number @  $V_{IN}=12V$



Switching frequency vs. LED cascaded number @  $V_{IN}=24V$

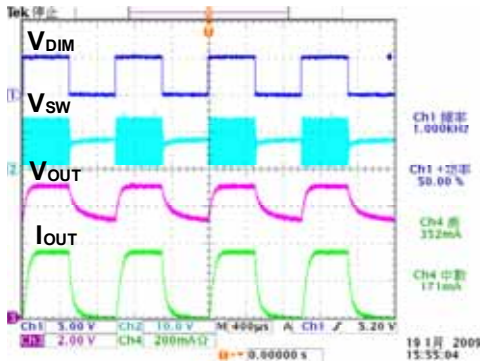


Switching frequency vs. LED cascaded number @  $V_{IN}=36V$

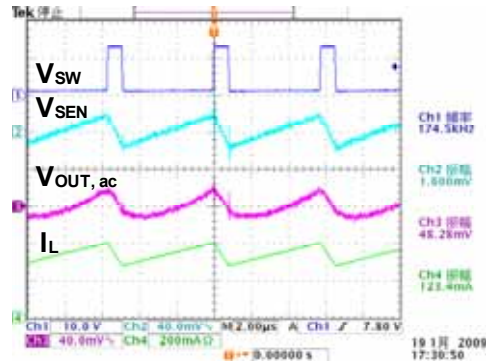


8. Miscellaneous

(a) Dimming and switching waveforms



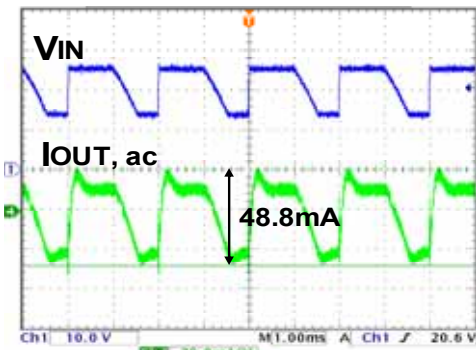
Dimming waveform  
( $V_{IN}=12V$ ,  $R_{SEN}=0.27$  , 2-LED)



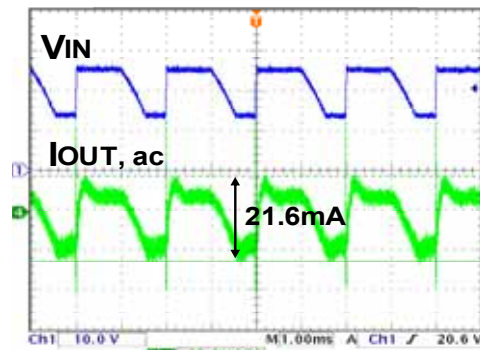
Switching waveform  
( $12V_{IN}$ ,  $3.6V_{OUT}$ ,  $R_{SEN}=0.27$  )

(b) Line transient response

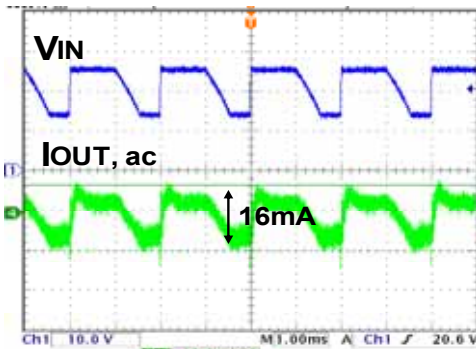
Line transient response @  $V_{IN}=13V \leftrightarrow 24V$ ,  $V_{OUT}=10V$ ,  $R_{SEN}=0.27$



$L1=22\mu H$

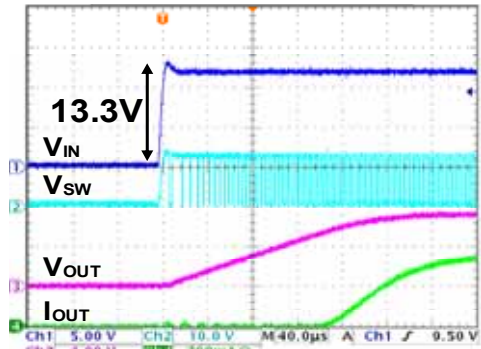


$L1=68\mu H$

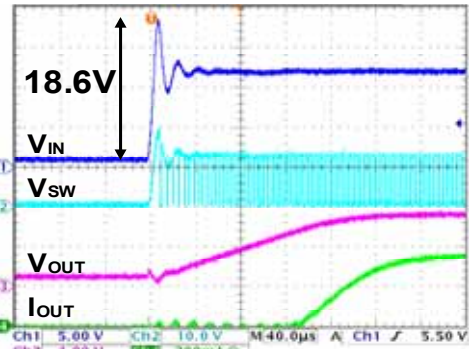


$L1=100\mu H$

(c) Power supply hot plug-in waveforms

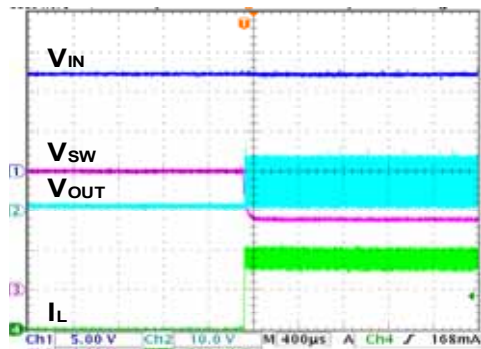


$C_{IN}=C_{OUT}$ =Tantalum capacitor (10uF/50V)

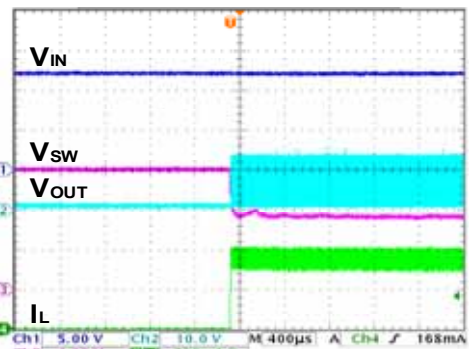


$C_{IN}=C_{OUT}$ =Ceramic capacitor (2 x 4.7uF/35V)

(d) LED hot plug-in waveforms

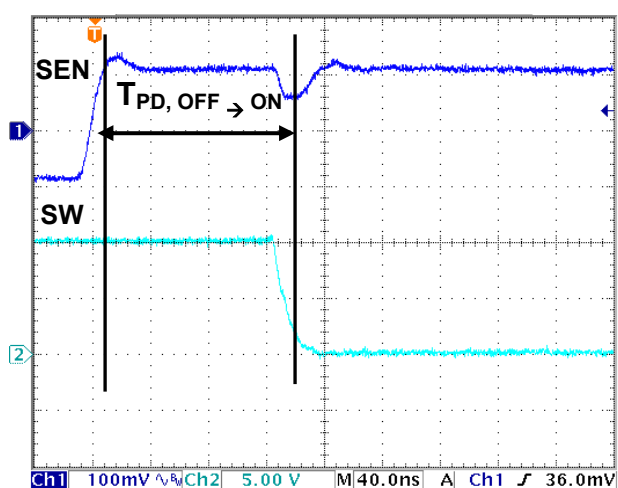
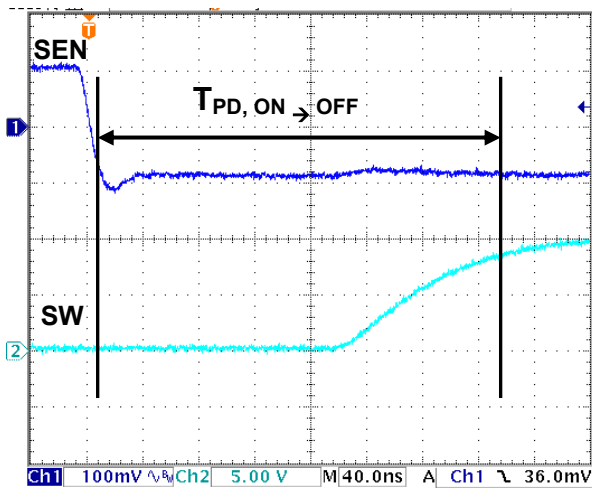


$C_{IN}=C_{OUT}$ =Tantalum capacitor (10uF/50V)



$C_{IN}=C_{OUT}$ =Ceramic capacitor (2 x 4.7uF/35V)

(e) Internal Propagation Delay Time



**Application Information**

The MBI6651 is a simple and high efficient buck converter with capability to drive up to 1A of loading. The MBI6651 adopts hysteretic PFM control scheme to regulate loading and input voltage variations. The hysteretic PFM control requires no loop compensation bringing very fast load transient response and achieving excellent efficiency at light loading.

**Setting Output Current**

The output current ( $I_{OUT}$ ) is set by an external resistor,  $R_{SEN}$ . The relationship between  $I_{OUT}$  and  $R_{SEN}$  is as below;

$$V_{SEN}=0.1V;$$

$$R_{SEN}=(V_{SEN}/I_{OUT})=(0.1V/I_{OUT});$$

$$I_{OUT}=(V_{SEN}/R_{SEN})=(0.1V/R_{SEN})$$

where  $R_{SEN}$  is the resistance of the external resistor connecting to SEN terminal and  $V_{SEN}$  is the voltage of external resistor. The magnitude of current (as a function of  $R_{SEN}$ ) is around 1000mA at 0.1Ω.

**Minimum Input Voltage and Start-up Protection**

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. The equivalent impedance of the MBI6651 application circuit is shown in Figure 4. As the input voltage is smaller than minimum input voltage such as start-up condition, the output current will be larger than the preset output current. Thus, under this circumstance, the output current is limited to 1.15 times of preset one as shown in Figure 5.

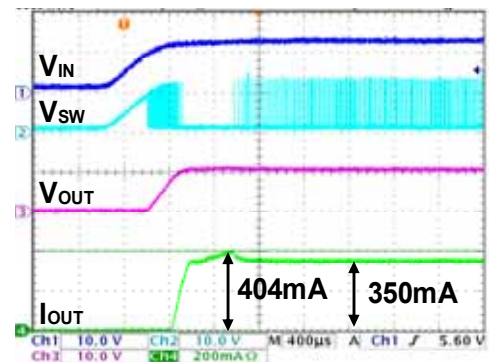
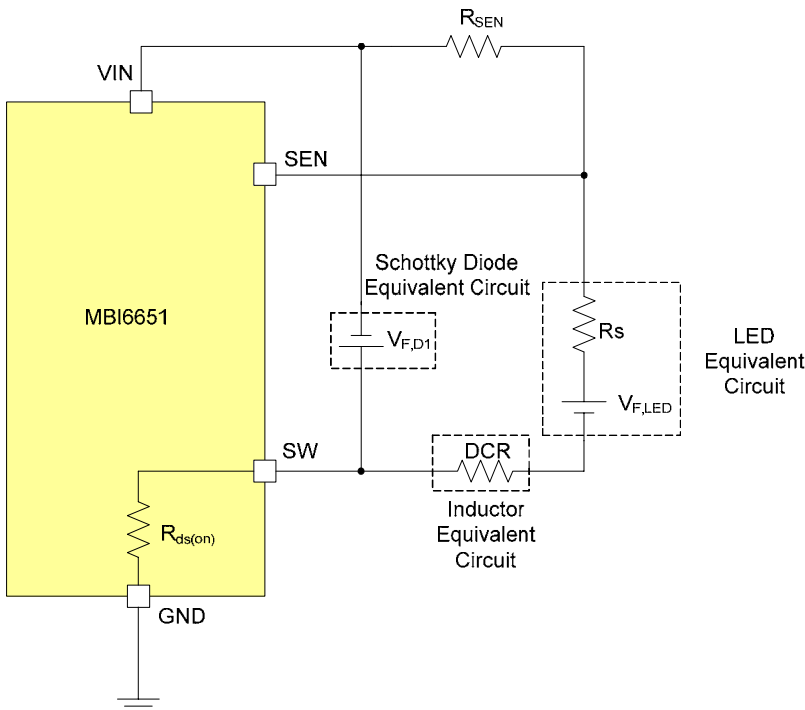


Figure 5. The start-up waveform @  $V_{IN}=12V$ ,  $V_{OUT}= 10.8$ ,  $R_{SEN}=0.27$

Figure 4. The equivalent impedance in a MBI6651 application circuit

**Under Voltage Lock Out Protection**

When the voltage at VIN of MBI6651 is below 8.0V, the output current of MBI6651 will be turned off. When the VIN



voltage of MBI6651 resumes to 8.0V, the output current of MBI6651 will be turned on again.

### Dimming

The dimming of LEDs can be performed by applying PWM signals to DIM pin. A logic low (below 0.5V) at DIM will disable the internal MOSFET and shut off the current flow to the LED array. An internal pull-up circuit ensures that the MBI6651 is ON when DIM pin is unconnected. Therefore, the need for an external pull-up resistor will be eliminated. The following Figure 6 and 7 show good linearity in dimming application of MBI6651.

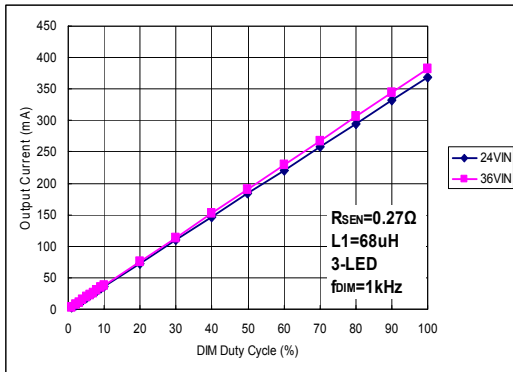


Figure 6. DIM duty cycle: 1% ~ 100%

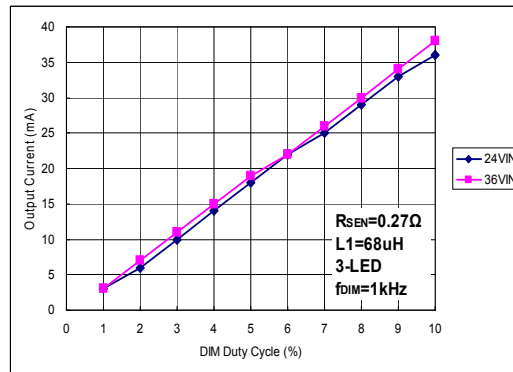


Figure 7. DIM duty cycle: 1% ~ 10%

### LED Open-Circuit Protection

When any LED connecting to the MBI6651 is open-circuited, the output current of MBI6651 will be turned off. The waveform is shown in Figure 8.

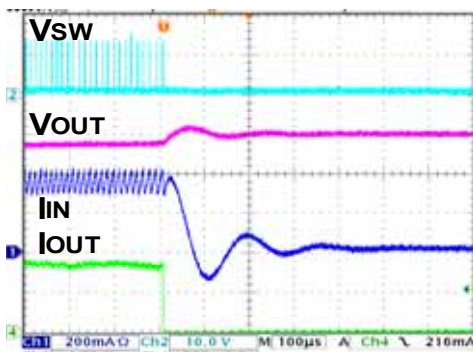


Figure 8. Open-circuited protection

### LED Short-Circuit Protection

When any LED connecting to the MBI6651 is short-circuited, the output current of MBI6651 will still be limited to its preset value as shown in Figure 9.

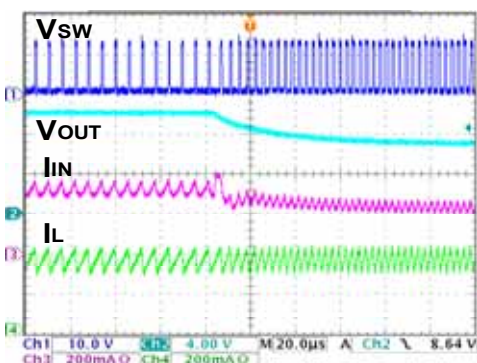


Figure 9. Short-circuited protection

**TP Function (Thermal Protection)**

When the junction temperature exceeds the threshold,  $T_x$  (165°C), TP function turns off the output current. The waveform can refer to Figure 10. The SW stops switching and the output current will be turned off. Thus, the junction temperature starts to decrease. As soon as the temperature is below 135°C, the output current will be turned on again. The switching of on-state and off-state are at a high frequency thus the blinking is imperceptible. The average output current is limited and therefore, the driver is protected from being overheated.

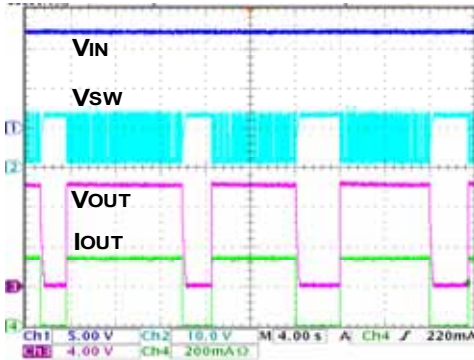


Figure10. Thermal protection

**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 MBI6651 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 MBI6651 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), the size/cost of components (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 MBI6651. The switching frequency can be ranged from 40kHz to 1.0MHz.

**LED Ripple Current**

A LED constant current driver, such as MBI6651, 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 advantages of higher LED ripple current are to minimize PCB size and reduce cost because of no output capacitor. Lower LED ripple current requires larger inductance, and output capacitor. The advantages of lower LED ripple current are to extend LED life time and to reduce heating of LED. The recommended ripple current is from 5% to 20% of normal LED current.

Component Selection

**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

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

where

$R_{ds(on)}$  is the on-resistance of internal MOSFET of the MBI6651. The typical is 0.45Ω at 12V<sub>IN</sub>.

$D$  is the duty cycle of the MBI6651,  $D=V_{OUT}/V_{IN}$ .

$f_{SW}$  is the switching frequency of the MBI6651.

$I_L$  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, not only the inductance but also the saturation current that should be considered as the factors to affect the performance of module. 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. However, the inductance and saturation current become a trade-off at the same inductor size. An inductor with shield is recommended to reduce the EMI interference, however, this is another trade-off with heat dissipation.

**Schottky Diode Selection**

The MBI6651 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. 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. And the recommended forward current is 1.5 times of output current. Users should carefully choose an appropriate schottky diode which can perform low leakage current at high temperature.

**Input Capacitor Selection**

The input capacitor, C<sub>IN</sub>, can supply pulses of current for the MBI6651 when the MOSFET is ON. And C<sub>IN</sub> 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 MBI6651 remains constantly ON, and the LED current is limited to 1.15 times of normal current. The recommended value of input capacitor is 10uF to stabilize the lighting system.

The rated voltage of input capacitor should be at least 1.5 times of input voltage. 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 are high frequency characteristic, small size and low cost. Due to low ESR characteristic of ceramic capacitor, please do not use hot plugging. Users can choose an appropriate one for their applications.

**Output Capacitor Selection (Optional)**

A capacitor paralleled with cascaded LED can reduce the LED ripple current and allow smaller inductance.

**PCB Layout Consideration**

To enhance the efficiency and stabilize the system, careful considerations of PCB layout is important. There are several factors should be considered.

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, use a ground plane and solder the IC's GND pin directly to the ground plane.
4. To stabilize the system, the heat sink of the MBI6651 is recommended to connect to ground plane directly.
5. 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 input capacitor should be placed to IC's VIN pin as close as possible.
7. To avoid the parasitic effect of trace, the  $R_{SEN}$  should be placed to IC's VIN and SEN pins as close as possible.
8. The area, which is composed of IC's SW pin, schottky diode and inductor, should be wide and short.
9. The path, which flows large current, should be wide and short to eliminate the parasite element.
10. 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 11.

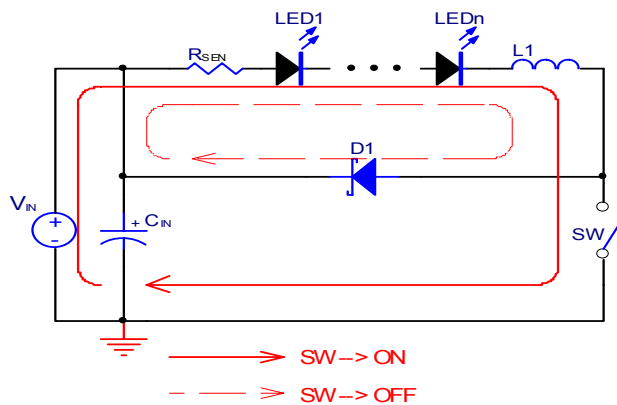


Figure 11. Power loop of MBI6651

**PCB Layout**

Figure 12 is the recommended layout diagram of the MBI6651 GSD package.

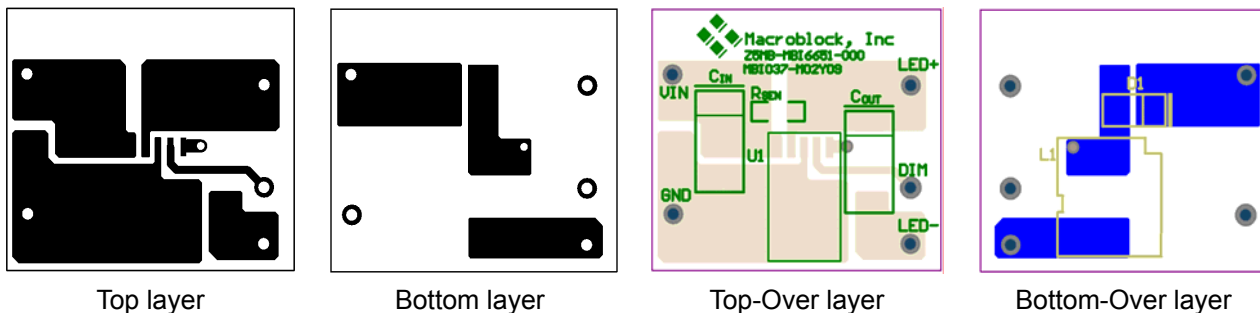
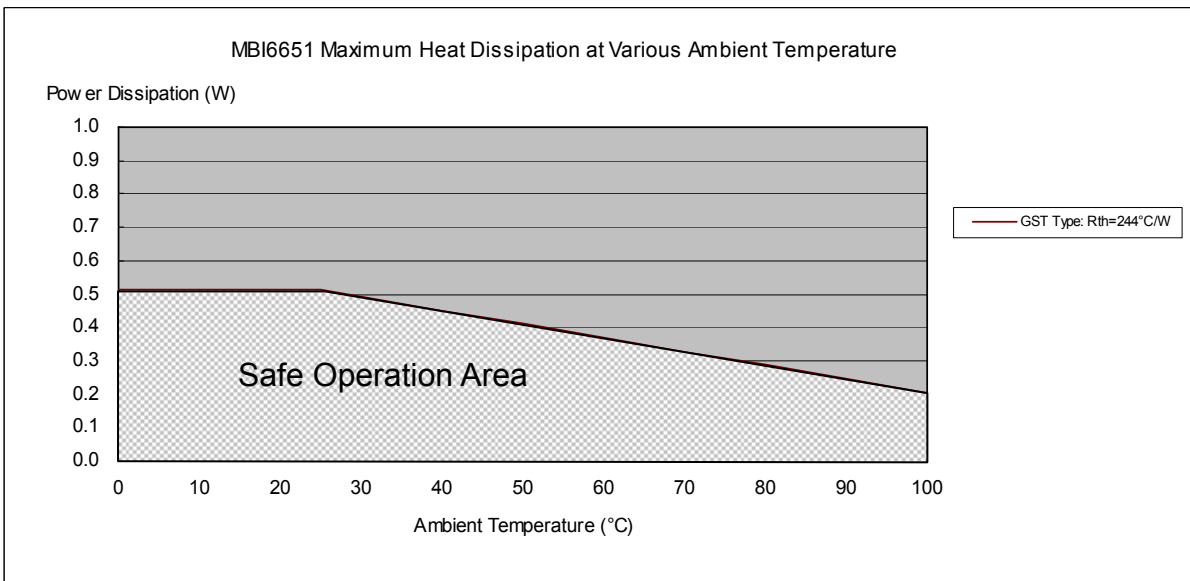
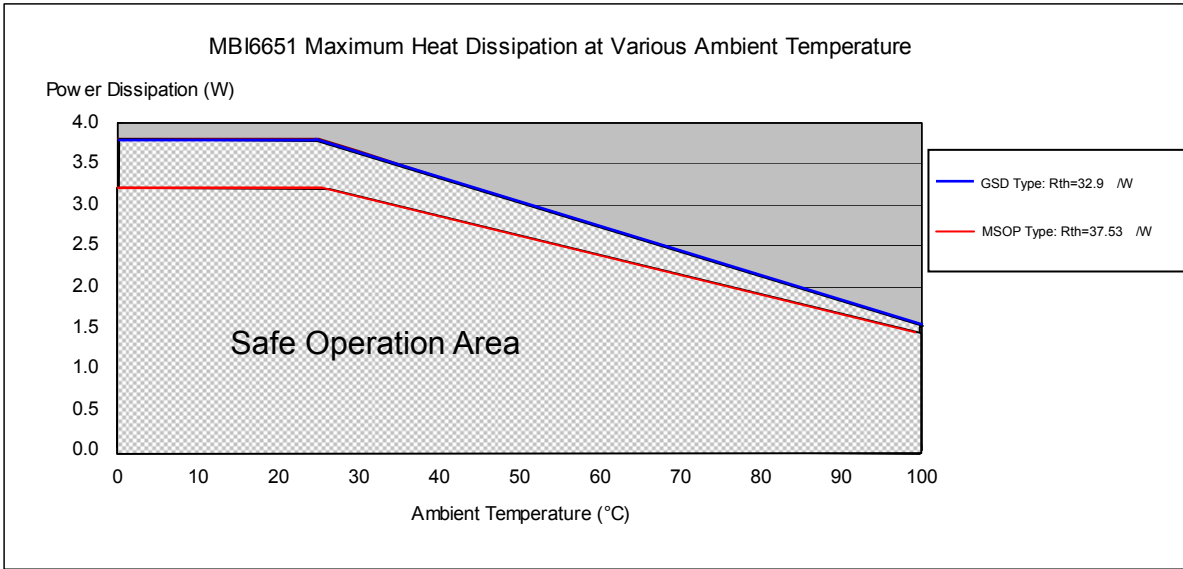


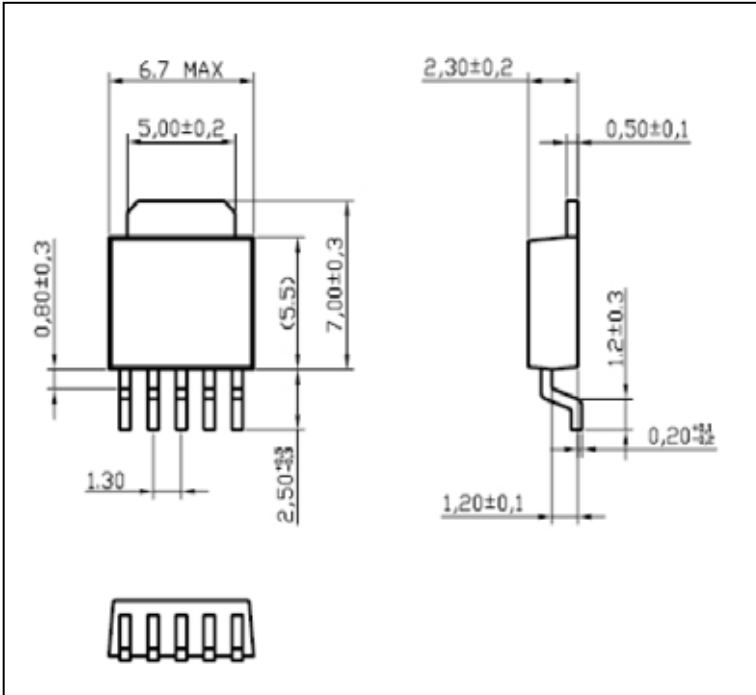
Figure 12. The layout diagram of the MBI6651 GSD

Package Power Dissipation (PD)

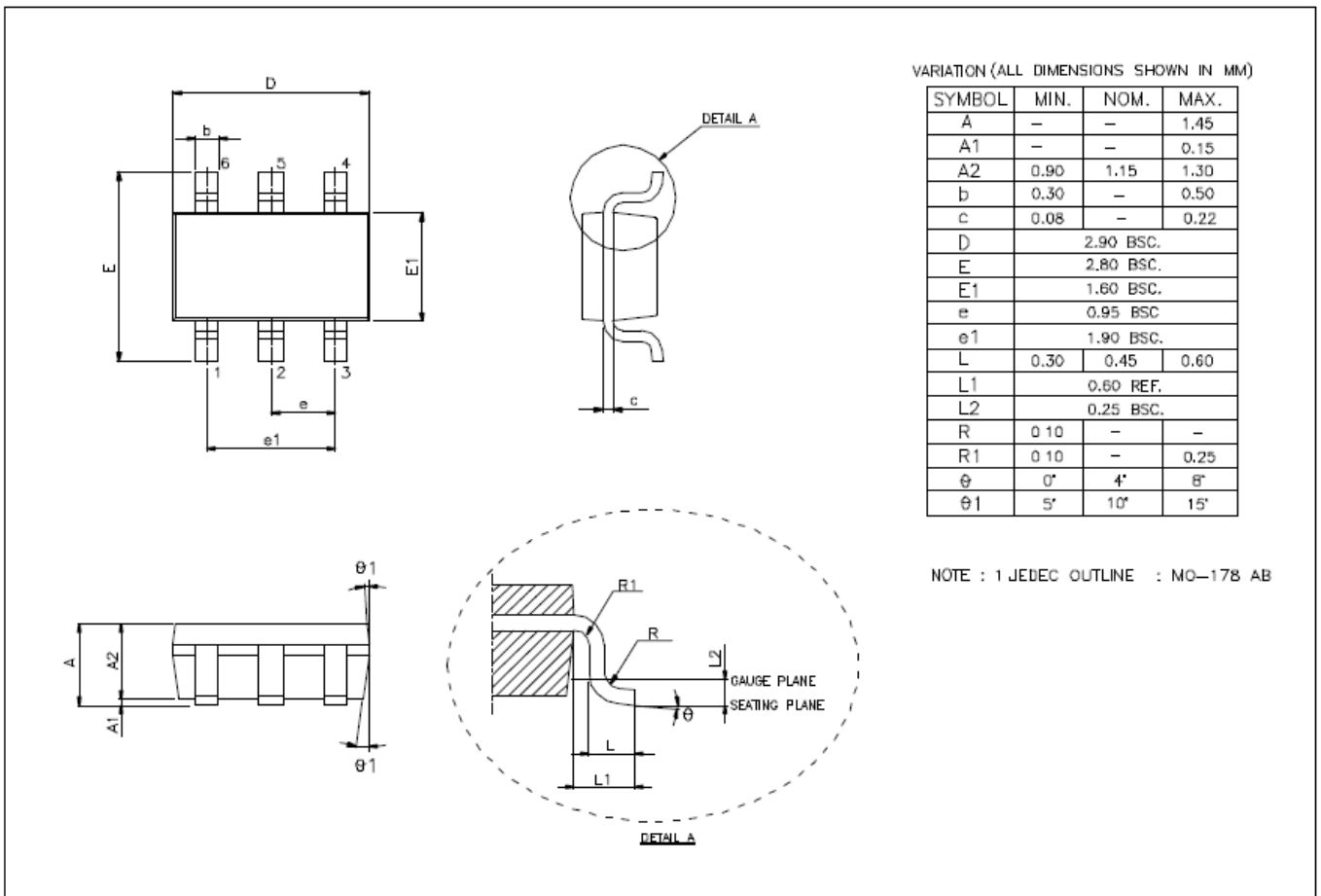
The maximum power dissipation,  $P_D(max)=(T_j-T_a)/R_{th(j-a)}$ , decreases as the ambient temperature increases.



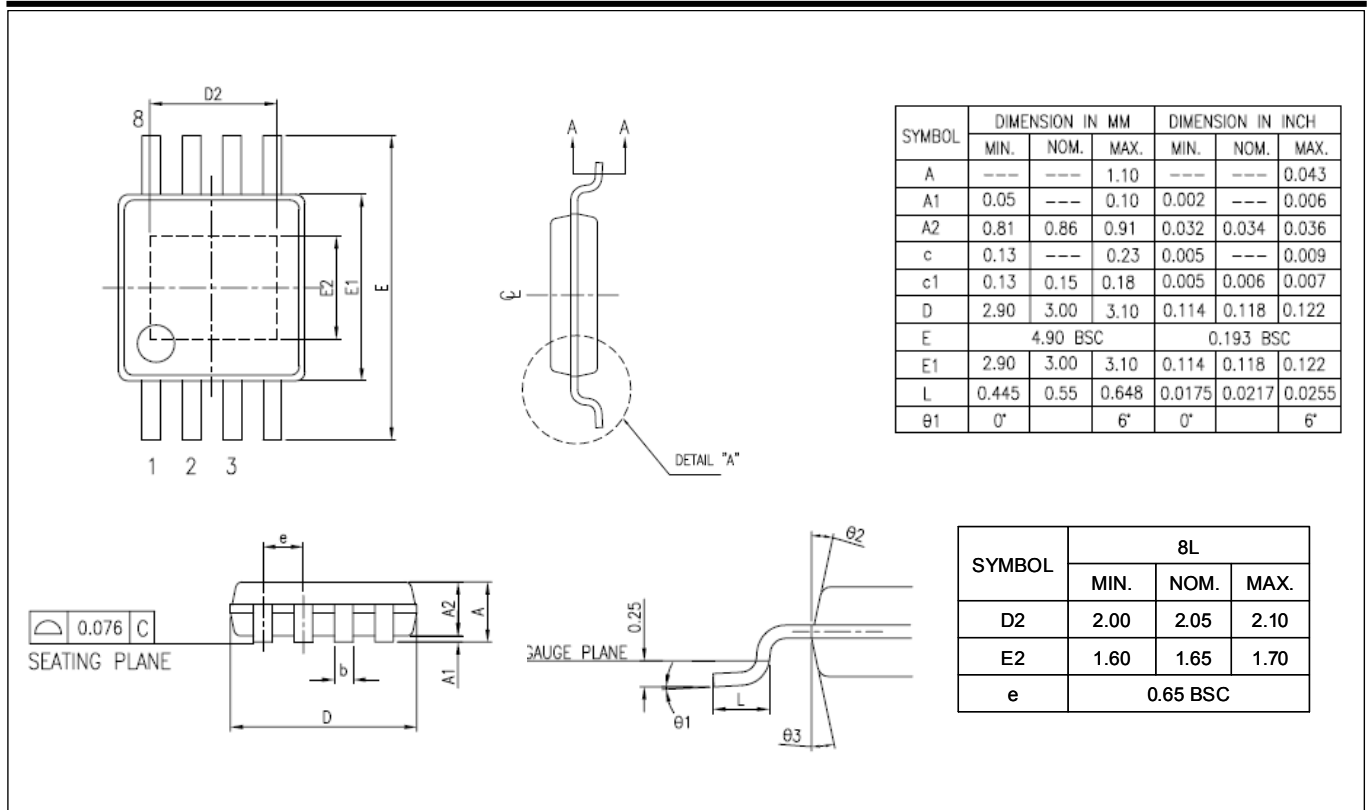
Outline Drawing



MBI6651GSD Outline Drawing



MBI6651 GST Outline Drawing

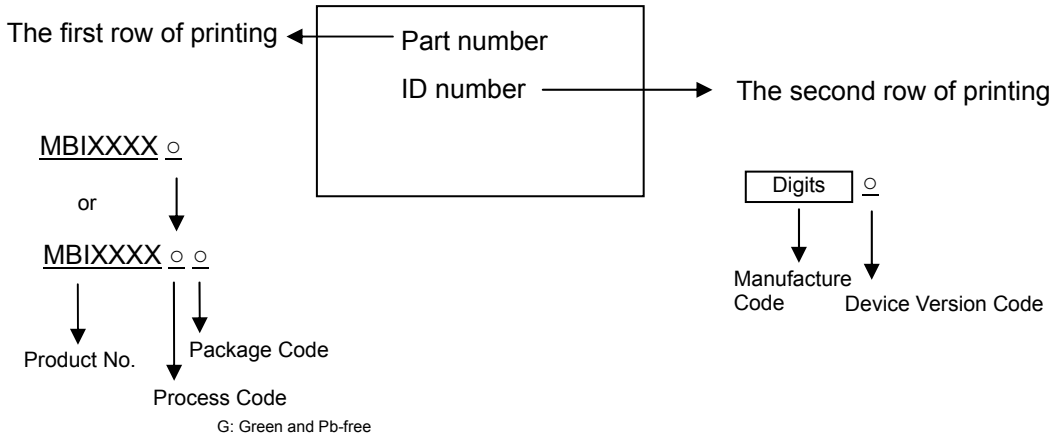


MBI6651 GMS Outline Drawing

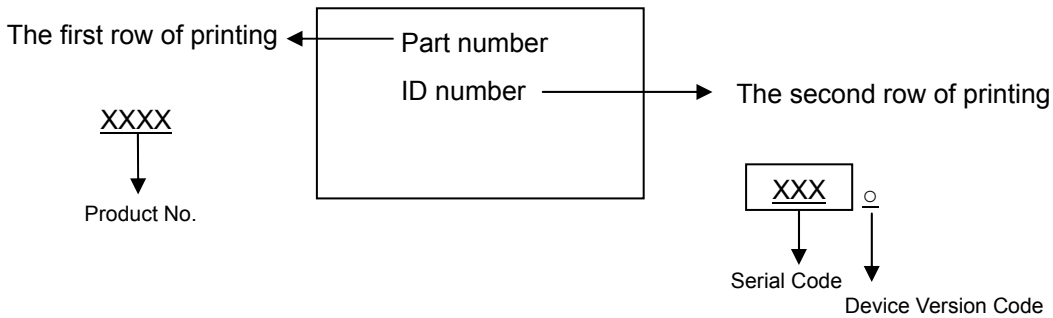
Note: The unit for the outline drawing is mm.

Product Top Mark Information

**GSD(TO-252)/GST(SOT-23)**



**GMS(MSOP-8L)**



Product Revision History

|                   |                     |
|-------------------|---------------------|
| Datasheet version | Device Version Code |
| V1.00             | A                   |

Product Ordering Information

| Part Number | “Pb-free” Package Type | Weight (g) |
|-------------|------------------------|------------|
| MBI6651GSD  | TO-252-5L              | 0.3142g    |
| MBI6651GST  | SOT-23-6L              | 0.016g     |
| MBI6651GMS  | MSOP-8L                | 0.0233g    |



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