# 1.25A LED Driver with Internal Switch

## ■ INTRODUCTION

The TB9115 is a high efficiency, constant current, and continuous-mode inductive step-down converter, designed for driving constant current to high power (single or multiple) LED with only 4 external components. The TB9115 operates with input supply between 5V and 36V and provides an externally adjustable output current of up to 1.25A .

The TB9115 is specifically designed with PFM control to enhance the efficiency up to 95%. Its output current can be modified by an external resister and can be adjusted by applying an external control signal to the DIM pin, which will accept a PWM (Pulse Width Modulated) waveform.

Additionally, to ensure the system reliability, the TB9115 is with built-in over temperature protection, and LED open-circuit and short-circuit protection to protect system from being damaged.

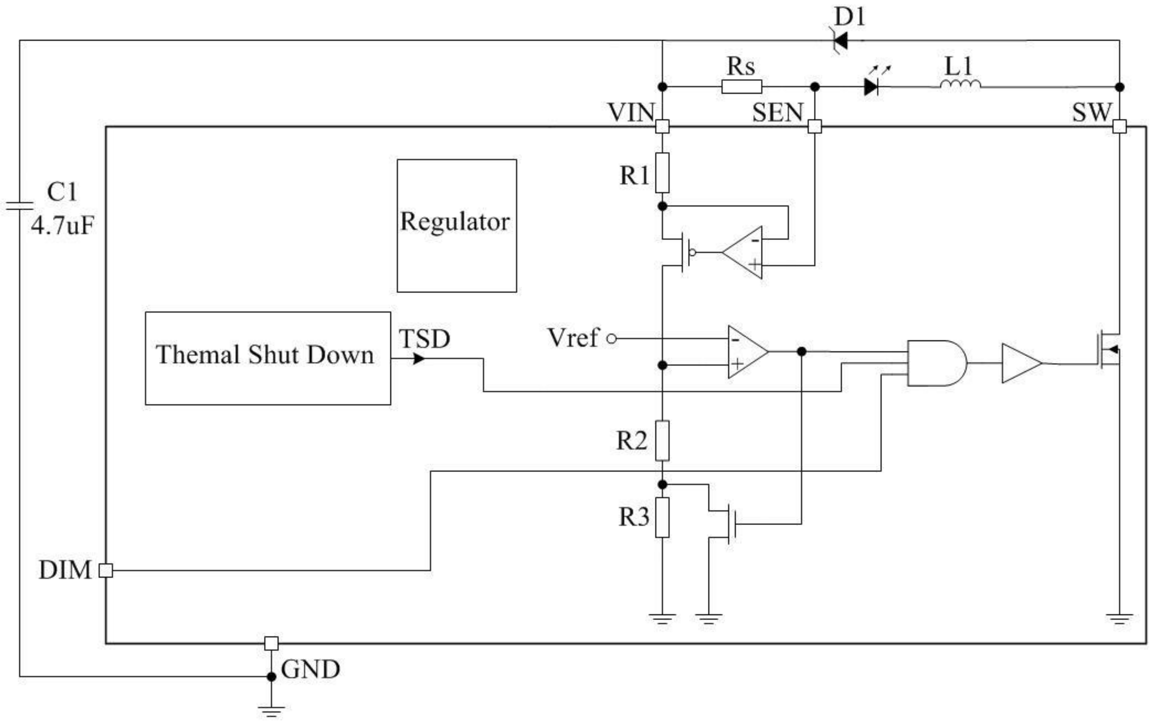
## ■ MAIN APPLICATIONS

- High power LED lighting
- Automotive LED lighting
- Low voltage industrial lighting
- LED back-up lighting
- Constant Current Source

## ■ FEATURE HIGHLIGHTS

- 1.25A output current
- Wide input voltage range: 5V to 36V
- High efficiency (up to 95%)
- Internal NDMOS power switch
- Single pin on/off and brightness control using PWM
- Hysteretic PFM improves efficiency at light loads
- With Thermal/Soft start /LED open-short detect protection
- Only 4 external Components
- Up to 1MHz switching frequency
- Typical 3% output current accuracy

## BLOCK DIAGRAM




## Device Description

The device, in conjunction with the coil (L1) and current sense resistor ($R_S$), forms a self-oscillating continuous-mode buck converter.

## Device Operation

When input voltage $V_{IN}$ is first applied, Vref is set up and finished, the initial current in L1 and $R_S$ is zero and there is no output from the current sense circuit. Under this condition, the (-) input to the comparator is at ground and its output is high. This turns MN on and switches the SW pin low, causing current to flow from $V_{IN}$ to ground, via $R_S$, L1 and the LED(s). The current rises at a rate determined by $V_{IN}$ and L1 to produce a voltage ramp ($V_{SENSE}$) across $R_S$. The supply referred voltage VSENSE is forced across internal resistor R1 by the current sense circuit and produces a proportional current in internal resistors R2 and R3. This produces a ground referred rising voltage at the (-) input of the comparator. When this reaches the threshold voltage (Vref), the comparator output switches low and MN turns off. The comparator output also drives another NMOS switch, which bypasses internal resistor R3 to provide a controlled amount of hysteresis. The hysteresis is set by R3 to be nominally 15% of (Vref).

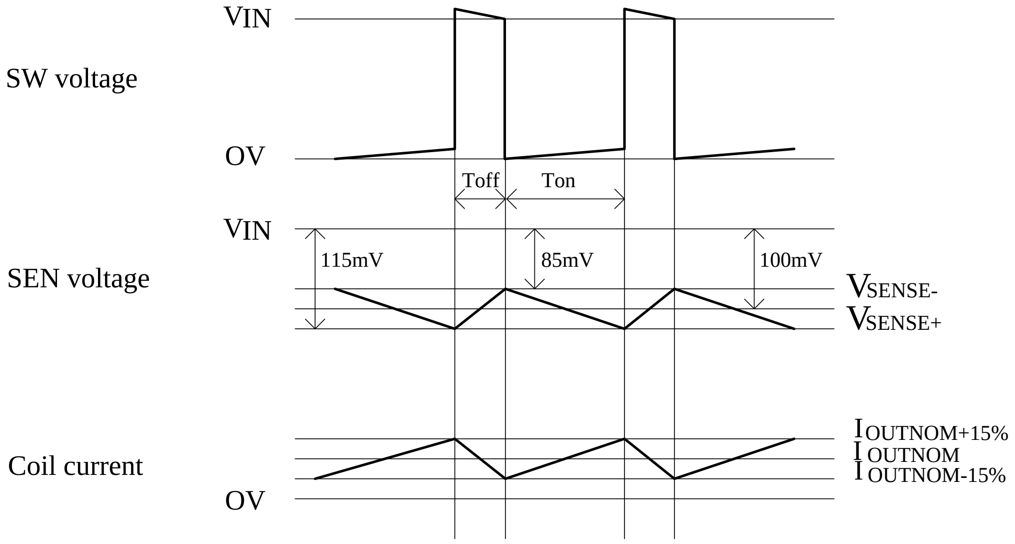
When MN is off, the current in L1 continues to flow via D1 and the LED(s) back to $V_{IN}$. The current decays at a rate determined by the LED(s) and diode forward voltages to produce a falling voltage at the input of the comparator. When this voltage returns to (Vref), the comparator output switches high again. This cycle of events repeats with the comparator input ramping between limits of (Vref) ± 15%.

## Switching Thresholds

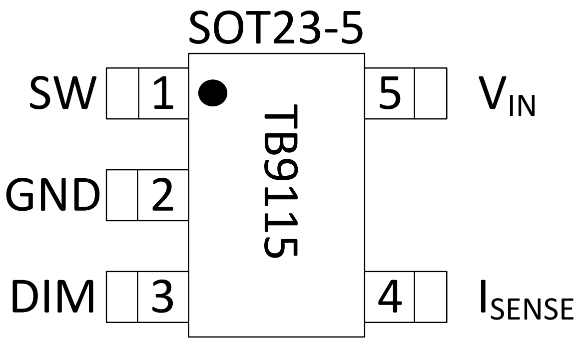
The ratios of R1, R2 and R3 define an average $V_{SENSE}$ switching threshold of 100mV (measured on the SEN pin with respect to $V_{IN}$). The average output current $I_{OUTNOM}$ is then defined by this voltage and $R_S$ according to:

$$I_{OUTNOM} = 100mV/R_S$$

Nominal ripple current is ±15mV/$R_S$.



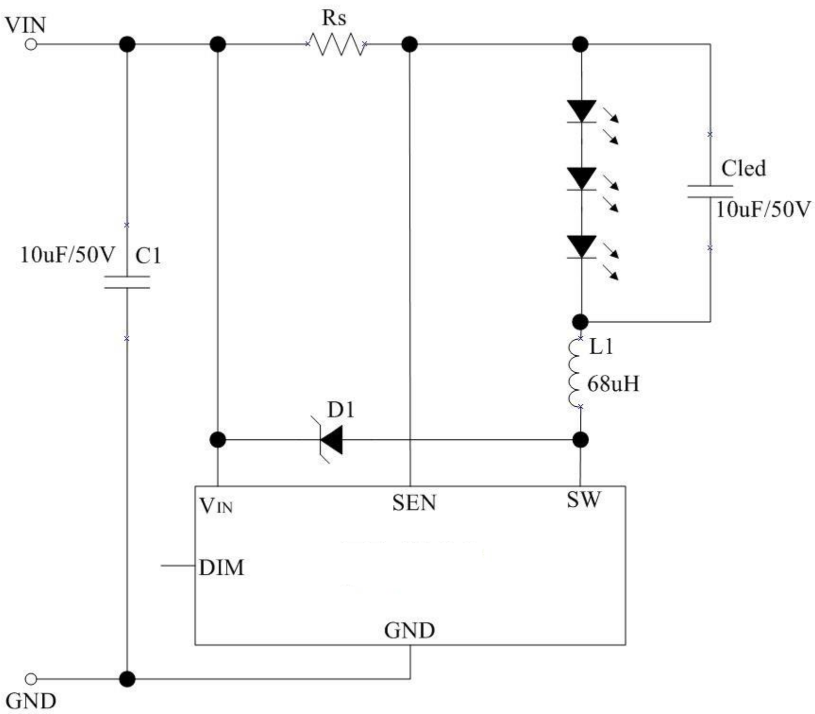
## Pin Description




| Pin # | Pin Name | Description |
|---|---|---|
| 1 | SW | Drain of NDMOS switch |
| 2 | GND | Ground pad |
| 3 | DIM | Dimming control pad |
| 4 | ISENSE | Connect resistor Rs from this pin to $V_{IN}$ to define nominal average output current. |
| 5 | VIN | Power pad. |

## Application

Application Circuit



## Notes in Application

- **SETTING NOMINAL AVERAGE OUTPUT CURRENT WITH EXTERNAL RESISTOR RS**

The nominal average output current in the LED(s) is determined by the value of the external current sense resistor (Rs) connected between $V_{IN}$ and Iout and is given by:

$I_{OUTNOM} = 0.1/ Rs$ [for Rs ≧ 0.1Ω ]

Nominal ripple current is ±15mV/ Rs

The table below gives values of nominal average output current for several preferred values of current setting resistor (Rs) in the typical application circuit above:

| Rs (Ω) | Nominal average output current (mA) |
|---|---|
| 0.1 | 1000 |
| 0.13 | 769 |
| 0.15 | 667 |

- **DIMMING**

A Pulse Width Modulated (PWM) signal with duty cycle DPWM can be applied to the DIM pin. A logic low (below 0.5V) at DIM will disable the internal MOSFET and turn off the current flow to the LED array. An internal pull-high circuit ensures that the TB9115 is ON when DIM pin is unconnected.

- **OPEN / SHORT CIRCUIT LED PROTECTION**

When any LED is open-circuit, the output current will be turned off. When any LED is short-circuit, the output current will be limited to its pre-set value.

- **OVER TEMPERATURE PROTECTION**

When the junction temperature over range. TB9115 will turn off output current.

- **MINIMUM INPUT VOLTAGE**

The Minimum Input Voltage is the sum of the voltage drops on $R_{SEN}$, DCR of L1, Rds(ON) of Internal MOS switch and the total forward voltage of LEDS VLED

- **DESIGN CONSIDERATION:**

**(1) SWITCHING FREQUENCY**

For better output current accuracy, the switching frequency should be determined by Minimum on/off time SW waveform.

$FSW=(1-D)/TOFF_{MIN}$, when the duty cycle > 0.5

or $FSW=D/TON_{MIN}$, when the duty cycle < 0.5,

(D=Vout/Vin)

The switching frequency is related to efficiency (better at low frequency), the size/cost of components, 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. The switching frequency can be ranged from 40KHz to 1.0MHz.

**(2) LED RIPPLE CURRENT**

An LED constant current driver is designed to control the current through the cascaded LEDs, 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 large induce 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 output current.

- **CAPACITOR SELECTION**

A low ESR capacitor should be used for input decoupling, as the ESR of this capacitor appears in series with the supply source impedance and lowers overall efficiency. This capacitor has to supply the relatively high peak current to the coil and smooth the current ripple on the input supply.
A minimum value of 4.7uF is acceptable if the input source is close to the device, but higher values will improve performance at lower input voltages, especially when the source impedance is high. The input capacitor should be placed as close as possible to the IC.

- **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

$$L1>(V_{IN}-V_{OUT}-V_{SEN}-(Rds(ON)x\ I_{OUT}))x\ D/(\ fswx\ \Delta IL)$$

Higher values of inductance are recommended at higher supply voltages in order to minimize errors due to switching delays, which result in increased ripple and lower efficiency. Higher values of inductance also result in a smaller change in output current over the supply voltage range. (See graphs). The inductor should be mounted as close to the device as possible with low resistance connections to the SW and $V_{IN}$ pins.

The chosen coil should have a saturation current higher than the peak output current and a continuous current rating above the required mean output current. The inductor value should be chosen to maintain operating duty cycle and switch 'on'/'off' times within the specified limits over the supply voltage and load current range.

Switch on time:

$$T_{ON} = L\,\Delta I / (V_{IN} - VLED - I_{AVG}\,(R_S + rL + R_{SW}))$$

$$T_{OFF} = L\,\Delta I / (VLED + VD + I_{AVG}\,(R_S + rL))$$

Where

L is the coil inductance

rL is the coil resistance

$R_S$ is the current sense resistance

$I_{AVG}$ is the required LED current

ΔI is the coil peak-peak ripple current {Internally set to 0.3 x $I_{AVG}$}

$V_{IN}$ is the supply voltage

VLED is the total LED forward voltage

$R_{SW}$ is the switch resistance

VD is the diode forward voltage at the required load current.

- **DIODE SELECTION:**

  For maximum efficiency and performance, the rectifier (D1) should be a fast low capacitance Schottky diode with low reverse leakage at the maximum operating voltage and temperature. They also provide better efficiency than silicon diodes, due to a combination of lower forward voltage and reduced recovery time.

  It is important to select parts with a peak current rating above the peak coil current and a continuous current rating higher than the maximum output load current.

  It is very important to consider the reverse leakage of the diode when operating above 85°C. Excess leakage will increase the power dissipation in the device and if close to the load may create a thermal runaway condition. The higher forward voltage and overshoot due to reverse recovery time in silicon diodes will increase the peak voltage on the SW output. If a silicon diode is used, care should be taken to ensure that the total voltage appearing on the SW pin including supply ripple, does not exceed the specified maximum value

## ■ Absolute Maximum Ratings

| Symbol | Parameter | Range | Unit |
|---|---|---|---|
| $V_{IN}$ | Supply Voltage | 0~36 (40V for 0.5 sec.) | V |
| $I_{OUT}$ | Output Current | 1.25 | A |
| $V_{SW}$ | Sustaining Voltage at SW pin | – 0.5~36 (40V for 0.5 sec.) | V |
| $P_D$ | Power Dissipation (See Note 1,2) | 1.2 | W |
| $P_{TH(J-A)}$ | Thermal Resistance | 104.2 | $^oC$/W |
| $T_{OP}$ | Operating Temperature | –40 ~ +85 | $^oC$ |
| $T_{STG}$ | Storage Temperature | –55 ~ +150 | $^oC$ |
| Tj-max | Junction Temperature | 150 | $^oC$ |

**Note:**

(1) 2-layer. The PCB size is 22mm x 20mm.

(2) Power Dissipation depends on PCB layout.

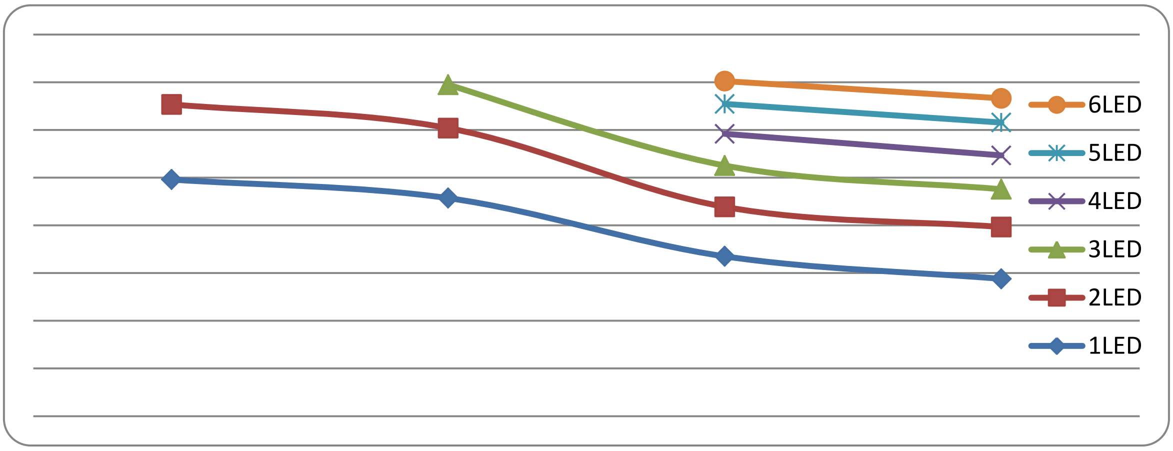
## DC Characteristic

$T_A$=25°C, $V_{IN}$=12V, $V_{OUT}$=3.6V, L1=68uH, $C_{IN}$=$C_{OUT}$=10uF; unless otherwise specified.

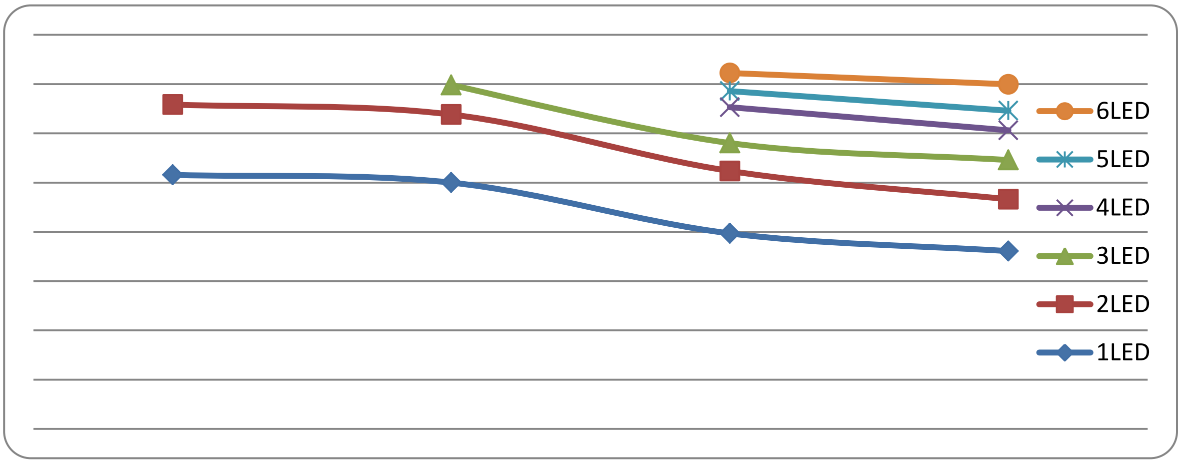
| Symbol | Description | Conditions | Min. | Typ. | Max. | Unit |
|---|---|---|---|---|---|---|
| $V_{IN}$ | Operating voltage |  | 5 | -- | 36 | V |
| $I_{IN}$ | Operating current | $V_{IN}$ = 5V~36V | -- | 1 | 2 | mA |
| $I_{OUT}$ | Output current |  | -- | -- | 1250 | mA |
| $\Delta I_{OUT}$ / $I_{OUT}$ | Output current Accuracy | 150mA ≤ $I_{OUT}$ ≤ 500mA |  | ±3 | ±5 | % |
|  | Efficiency | $V_{IN}$ = 12V, $I_{OUT}$=350mA, $V_{OUT}$=10.8V |  | 95 |  | % |
| $\Delta V_{SW}$ | SW Dropout voltage | $I_{OUT}$=500mA |  | 0.5 |  | V |
| $V_{IH}$ | Input Voltage – High |  | 3.5 |  | 5 | V |
| $V_{IL}$ | Input Voltage – Low |  |  |  | 0.5 | V |
| % / ΔV | Load Regulation | $V_{IN}$=24V, $I_{OUT}$=500mA, 3.6v≤$V_{OUT}$≤18V |  | 0.5 |  | %/V |
| $V_{SENSE\_HYS}$ | Sense threshold hysteresis |  |  | ±15 | -- | % |
| $V_{SENSE}$ | Mean current sense threshold voltage |  | 95 | 100 | 105 | mV |
| $R_{DS}$ (ON) | Switch on resistance | $V_{IN}$=12V, $I_{OUT}$=350mA,$V_{OUT}$=10.8V |  | 0.5 | 1 | Ω |
| $t_{PD}$ | Internal propagation delay |  | 100 | 200 | 300 | nS |
| $t_{ON\_MIN}$ | Minimum switch 'ON' time |  | 100 | 350 | 450 | nS |
| $t_{OFF\_MIN}$ | Minimum switch 'OFF' time |  | 100 | 350 | 450 | nS |
| $t_{SD}$ | Thermal Shutdown Threshold |  | 145 | 160 | 175 | °C |
| $t_{SD\_HYS}$ | Thermal Shutdown Hysteresis |  |  | 20 |  | °C |
| $D_{SW}$ | Recommended duty cycle range of switch |  | 0.2 |  | 0.8 |  |
| $Freq\_{MAX}$ | Maximum operating frequency |  | 400 |  | 1000 | kHz |
| $Duty\_{DIM}$ | Duty cycle range of PWM signal applied to the DIM pin | PWM frequency = 1kHz | 0.01 |  | 1 |  |
| tr | Rise time of output current |  |  | 20 |  | nS |
| tf | Fall time of output current |  |  | 20 |  | nS |

## ■ Typical Performance Characteristics

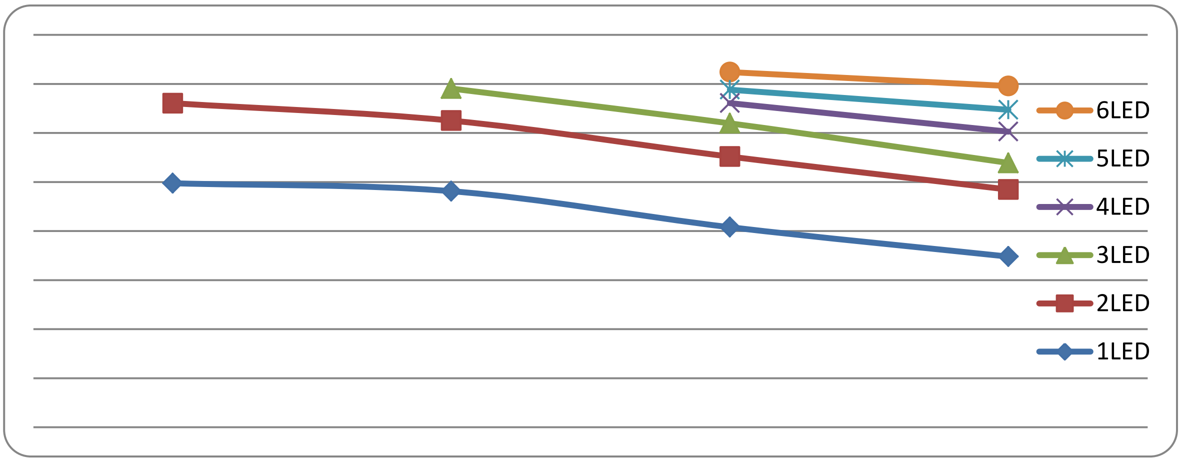
### 1. Efficiency vs. Input Voltage at Various LED Cascaded Number




Efficiency vs. input voltage @L=22uH, $I_{OUT}$=370mA

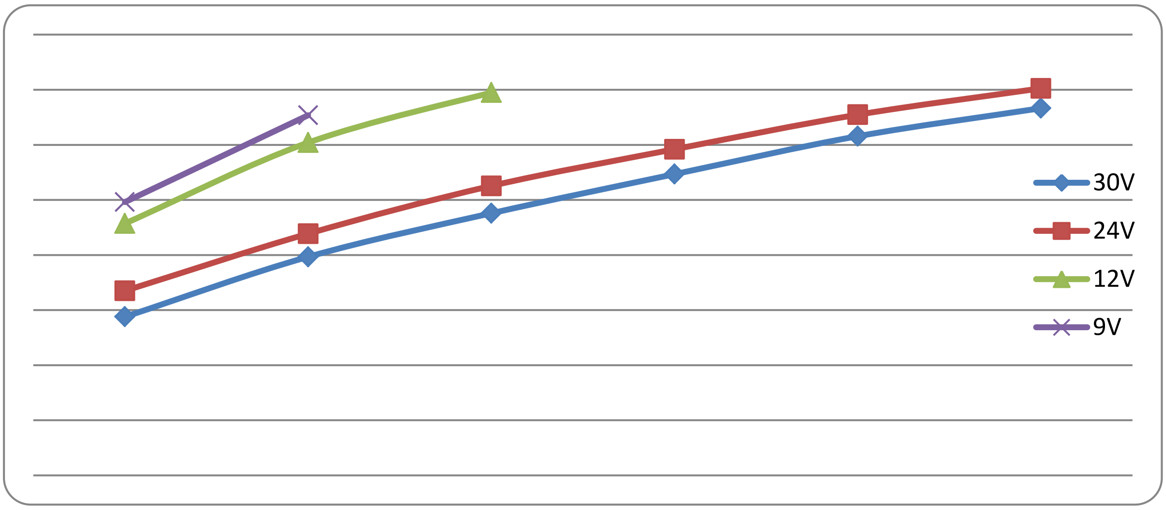



Efficiency vs. input voltage @L=68uH, $I_{OUT}$=370mA

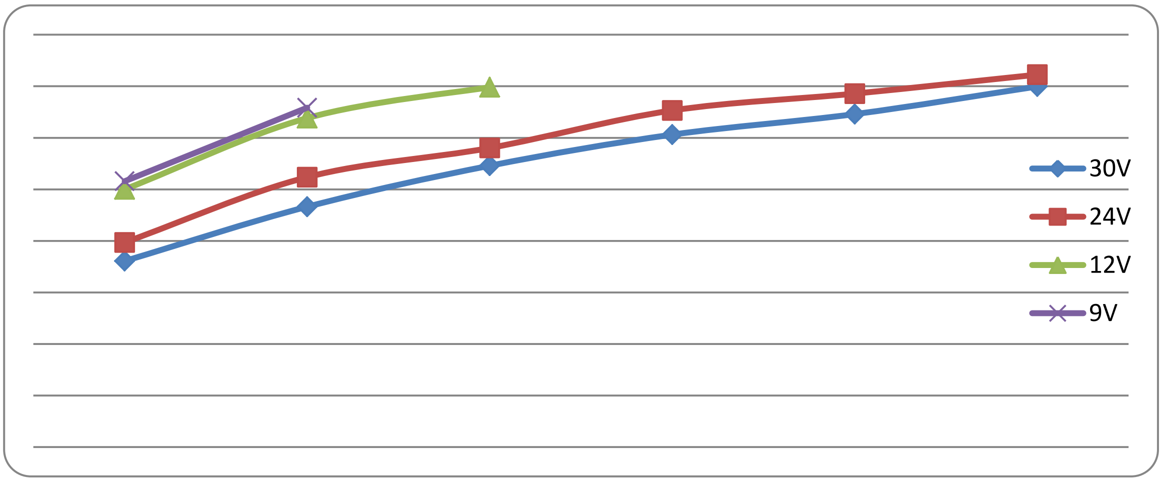



Efficiency vs. input voltage @L=100uH, $I_{OUT}$=370mA

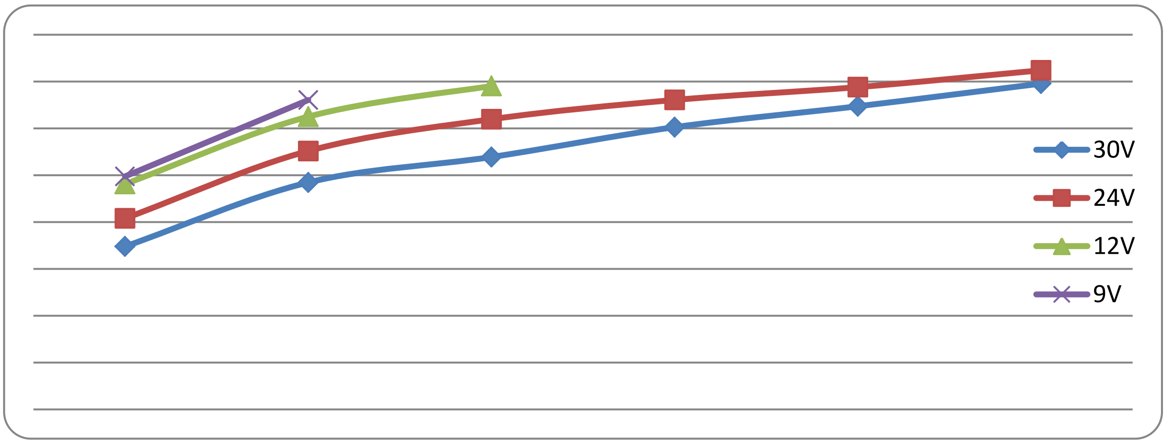
2. **Efficiency vs. LED Cascaded Number at Various Input Voltage**




Efficiency vs. LED cascaded number @L=22uH, $I_{OUT}$=370mA

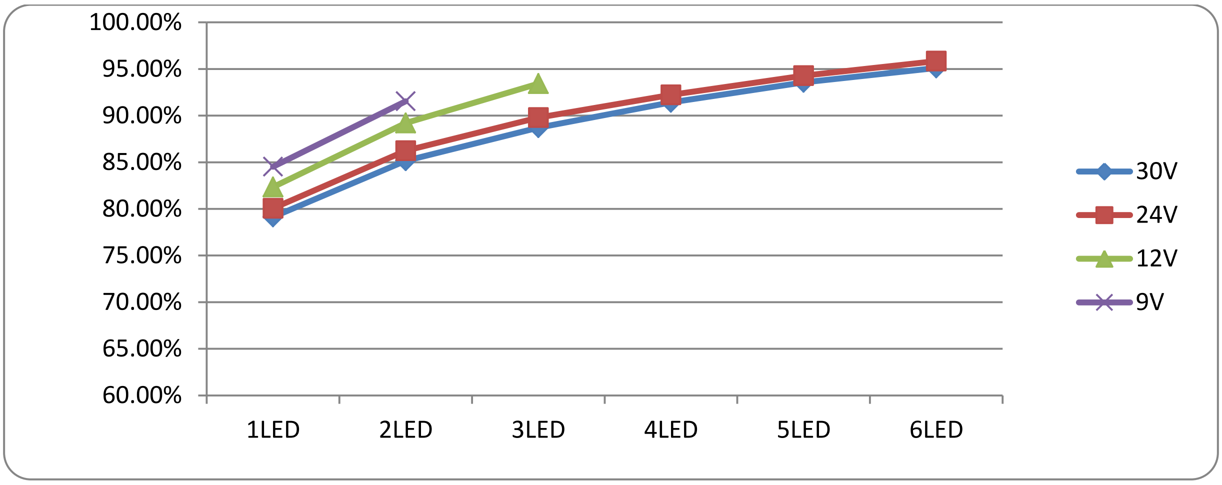



Efficiency vs. LED cascaded number @L=68uH, $I_{OUT}$=370mA

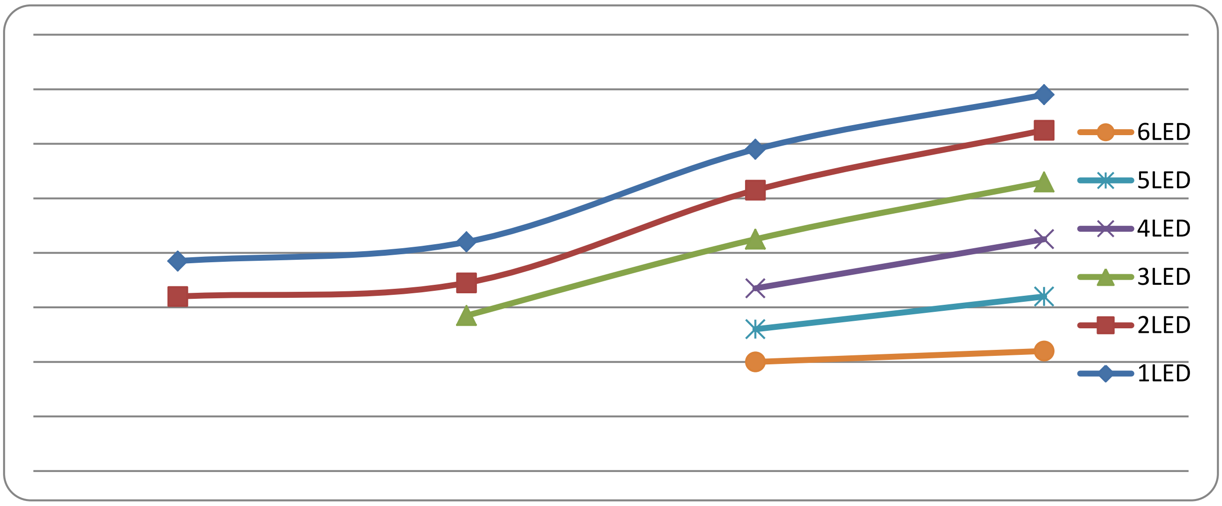



Efficiency vs. LED cascaded number @L=100uH, $I_{OUT}$=370mA

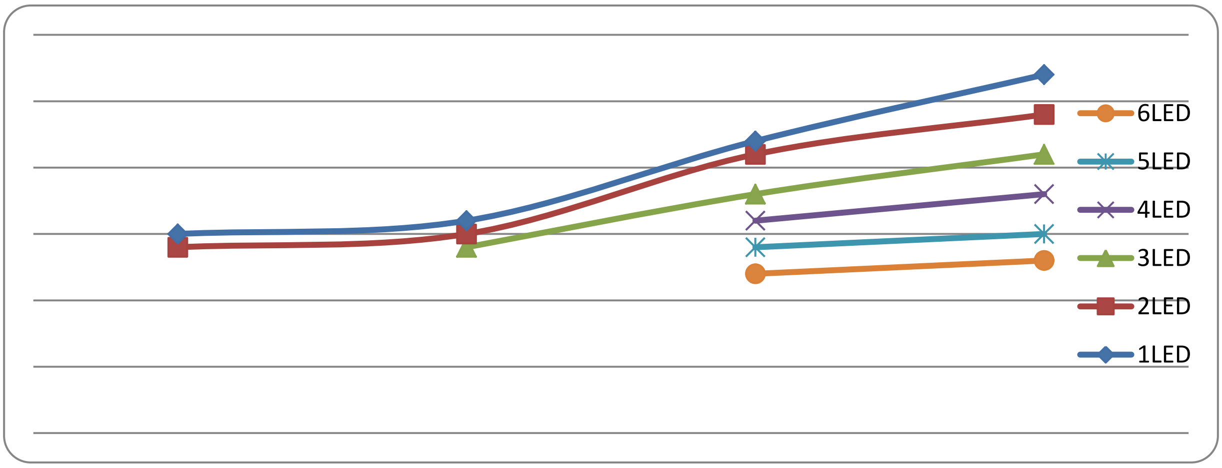
### 3. Output Current vs. Input Voltage at Various LED Cascaded Number




Output current vs. input voltage @L=22uH, $I_{OUT}$=370mA

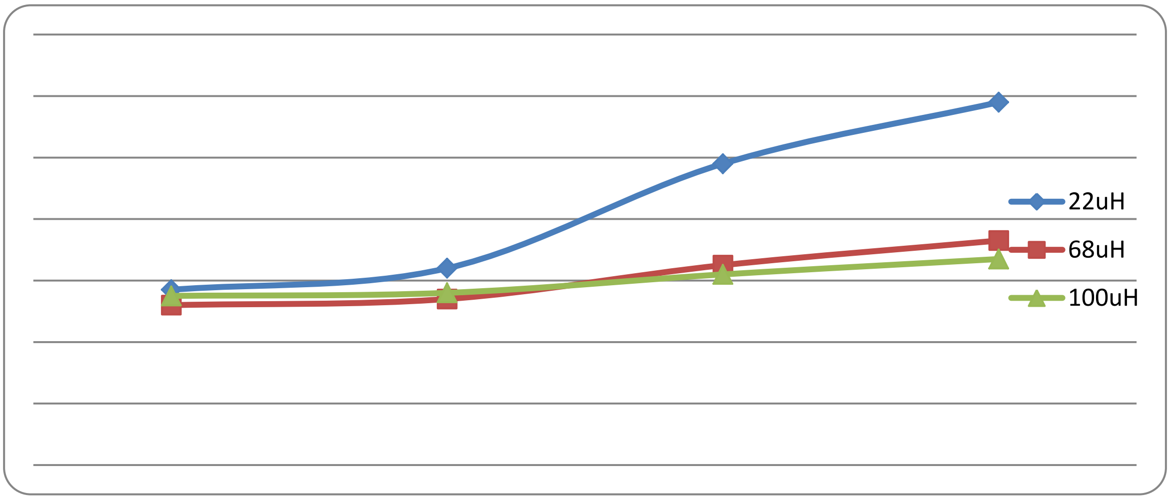



Output current vs. input voltage @L=68uH, $I_{OUT}$=370mA

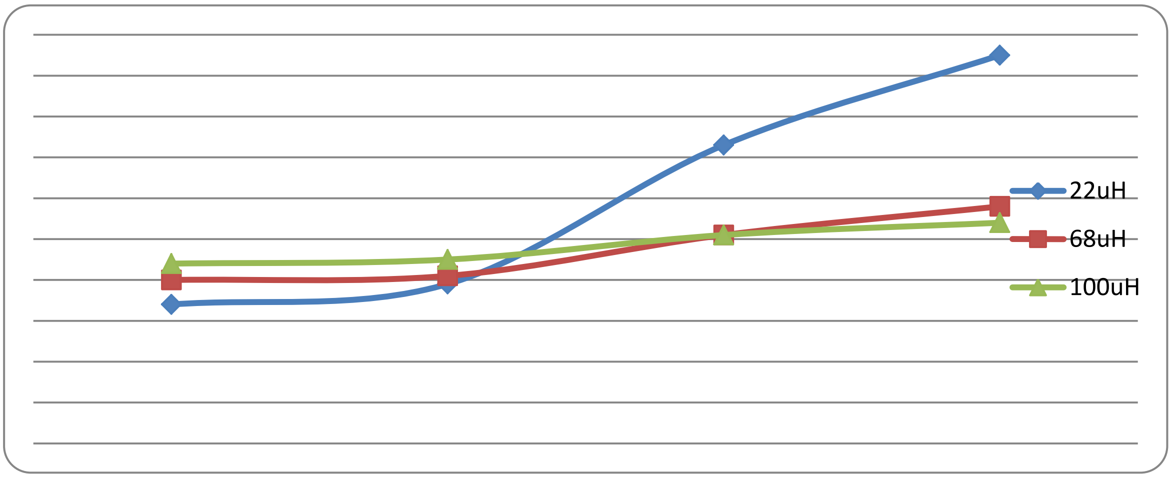



Output current vs. input voltage @L=100uH, $I_{OUT}$=370mA

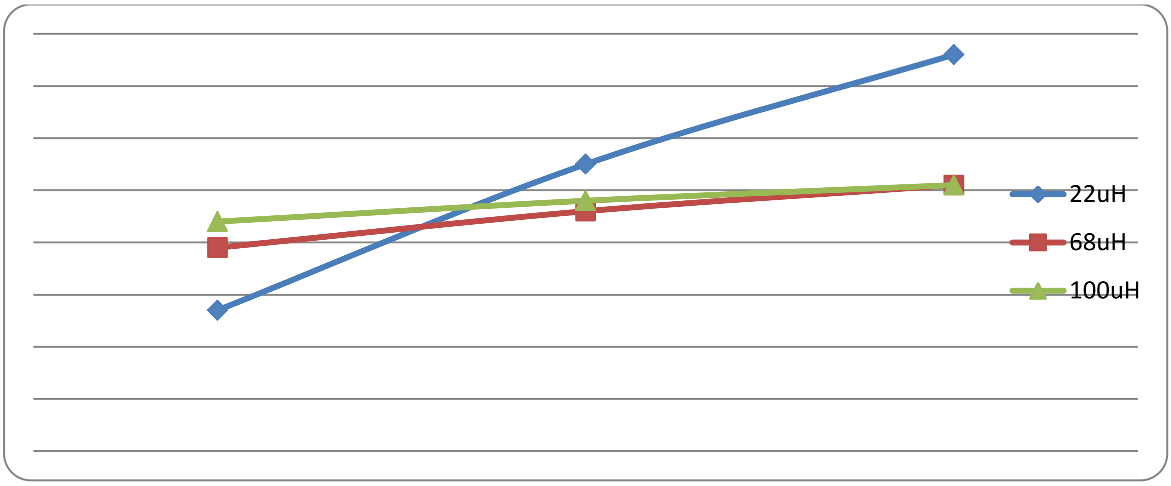
4. **Output Current vs. Input Voltage at Various Inductor**




Output current vs. input voltage @1-LED in cascaded, $I_{OUT}$=370mA

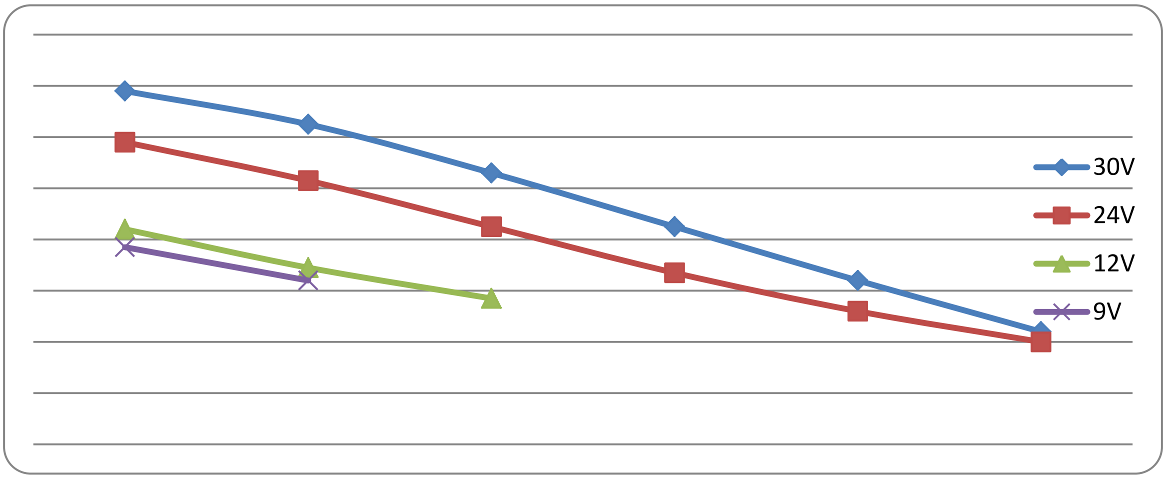



Output current vs. input voltage @2-LED in cascaded, $I_{OUT}$=370mA

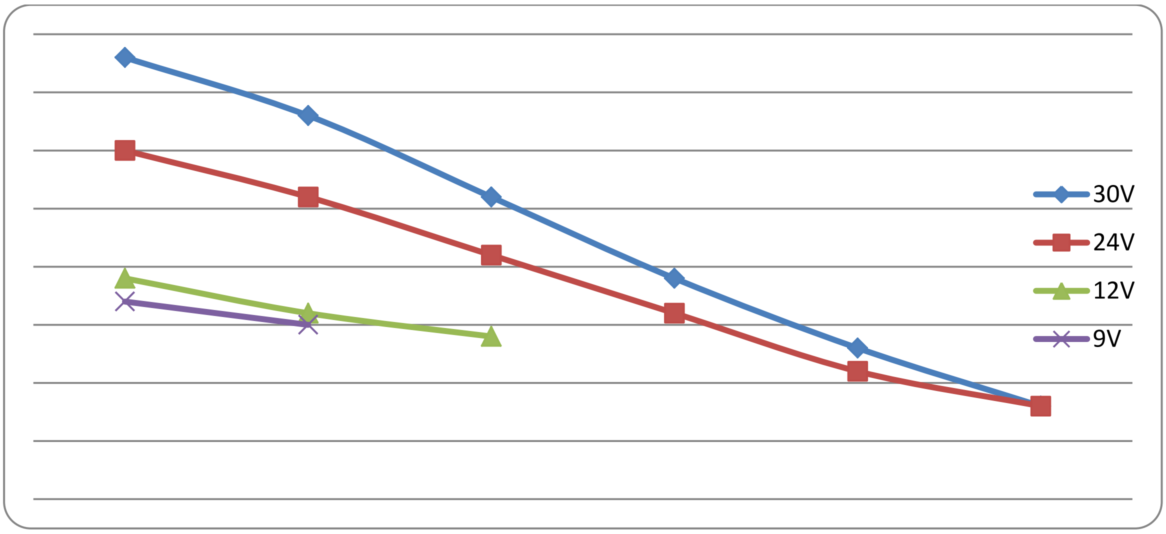



Output current vs. input voltage @3-LED in cascaded, $I_{OUT}$=370mA

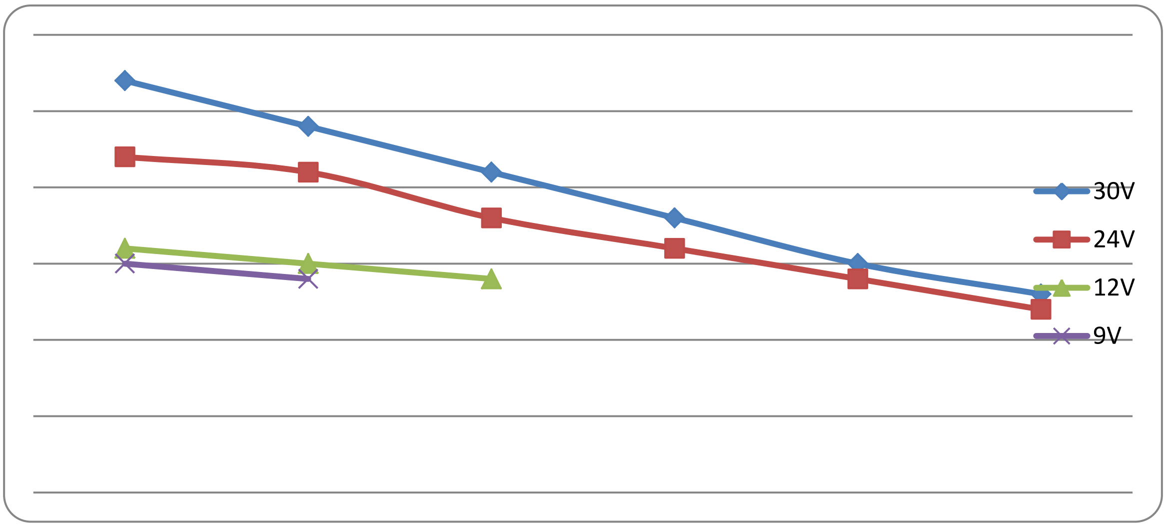
5. **Output Current vs. LED Cascaded Number at Various Input Voltage**




Output current vs. LED cascaded number @L=22uH, $I_{OUT}$=370mA

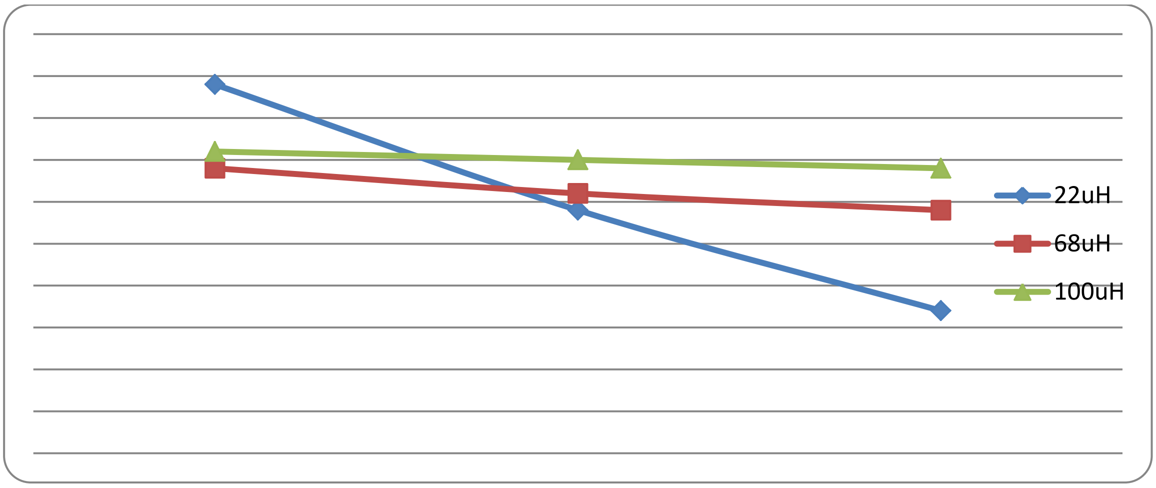



Output current vs. LED cascaded number @L=68uH, $I_{OUT}$=370mA

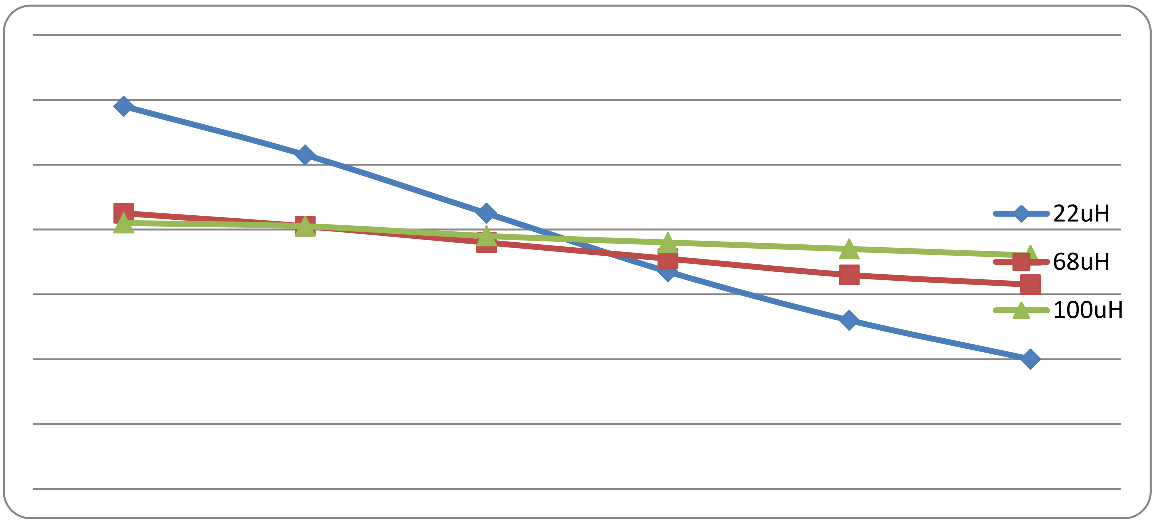



Output current vs. LED cascaded number @L=100uH, $I_{OUT}$=370mA

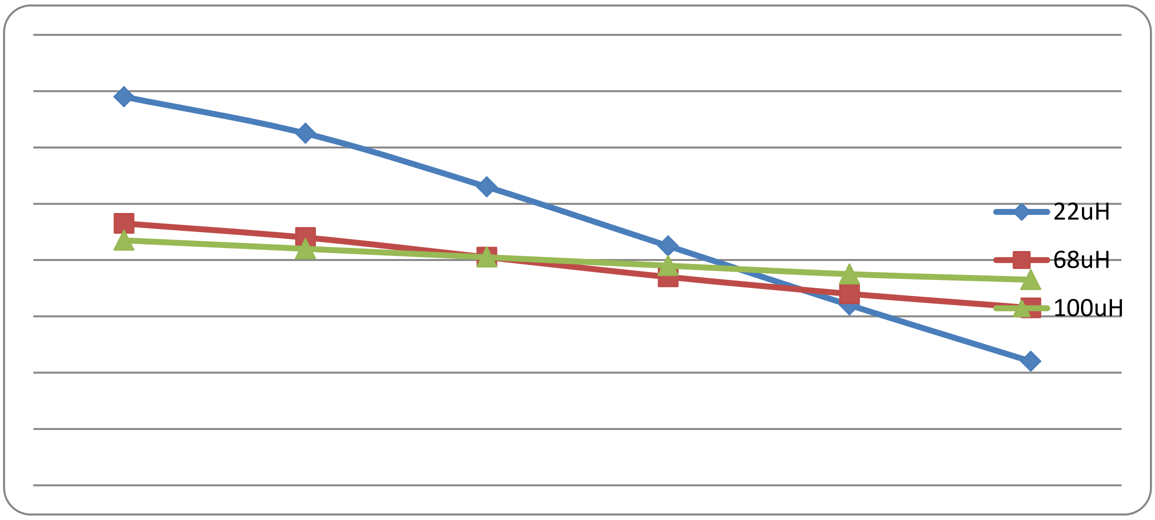
6. **Output Current vs. LED Cascaded number at Various Inductor**




Output Current vs. LED Cascaded number @$V_{IN}$=12V, $I_{OUT}$=370mA

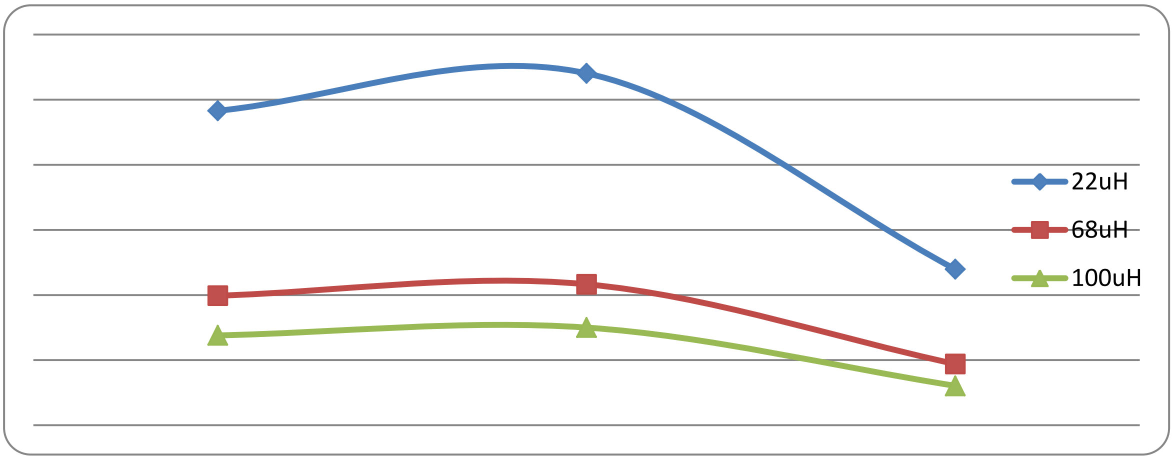



Output Current vs. LED Cascaded number @$V_{IN}$=24V, $I_{OUT}$=370mA

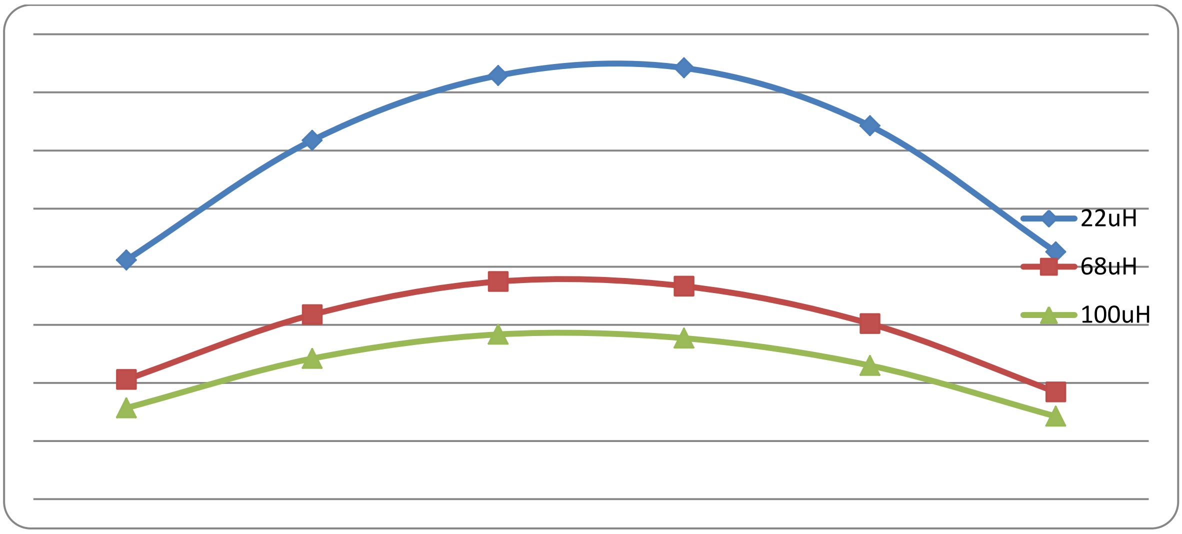



Output Current vs. LED Cascaded number @$V_{IN}$=30V, $I_{OUT}$=370mA

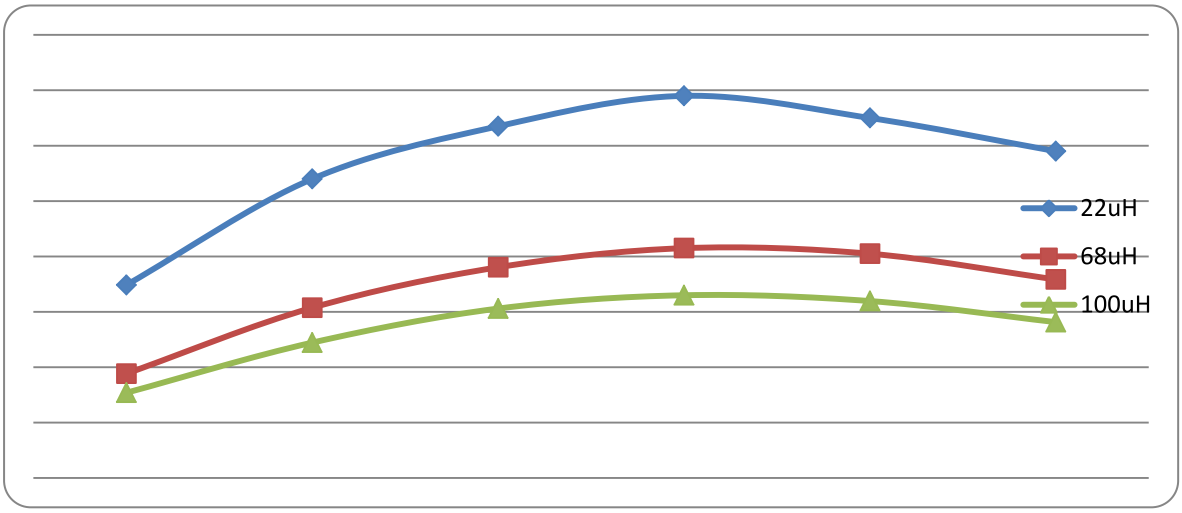
7. **Switching Frequency vs. LED Cascaded Number at Various Inductor**




Switching Frequency vs. LED Cascaded Number @$V_{IN}$=12V, $I_{OUT}$=370mA

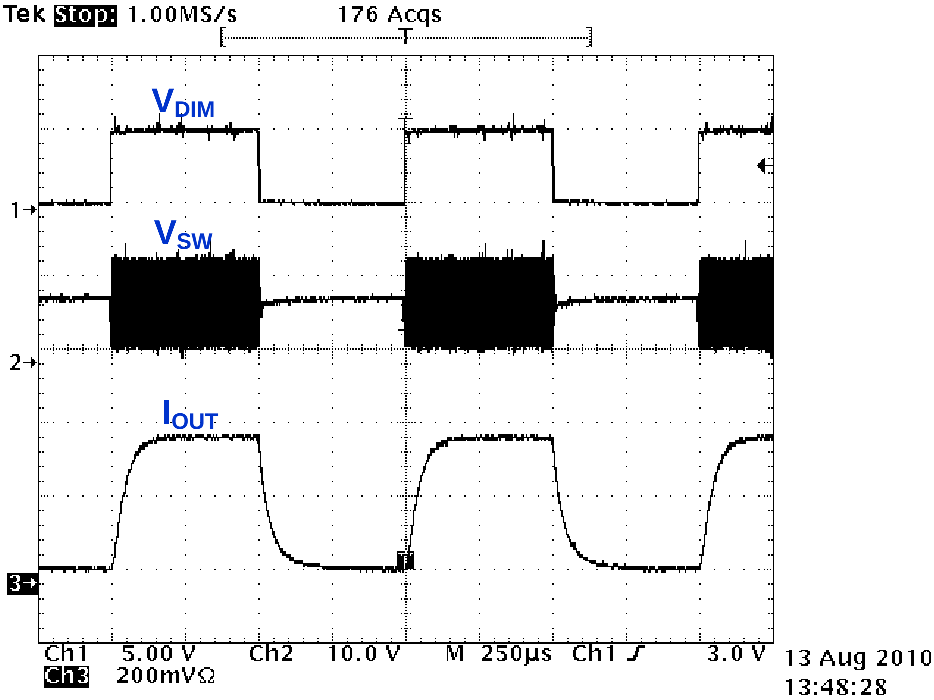



Switching Frequency vs. LED Cascaded Number @$V_{IN}$=24V, $I_{OUT}$=370mA

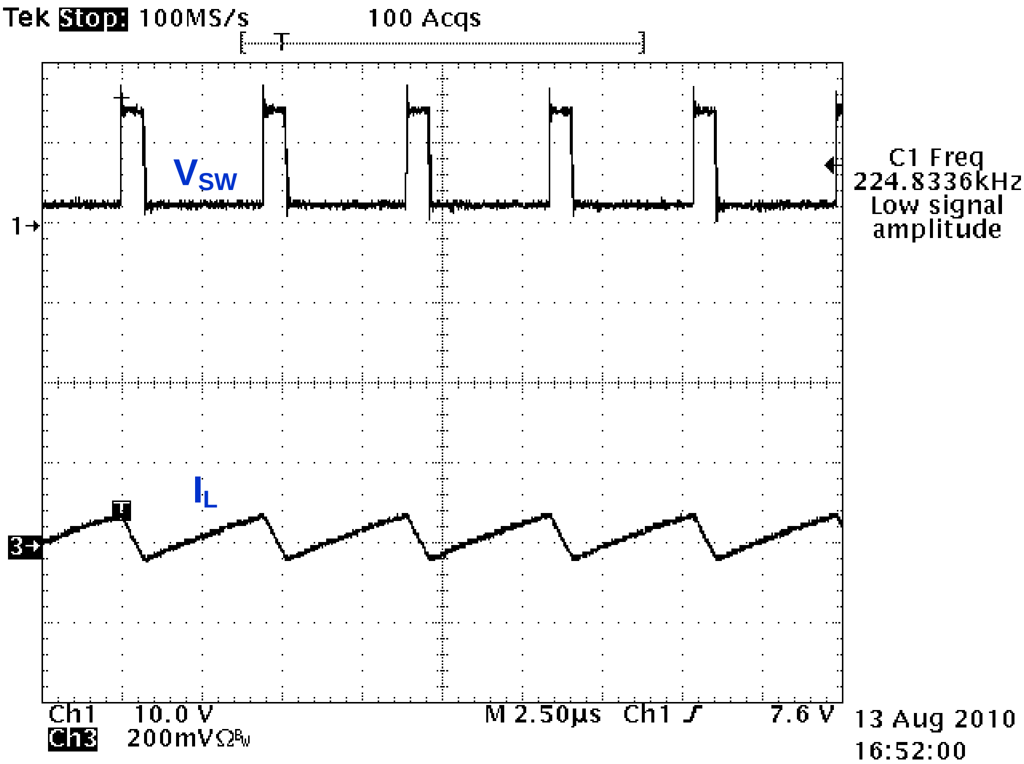



Switching Frequency vs. LED Cascaded Number @$V_{IN}$=30V, $I_{OUT}$=370mA

## 8. Dimming and switching waveforms

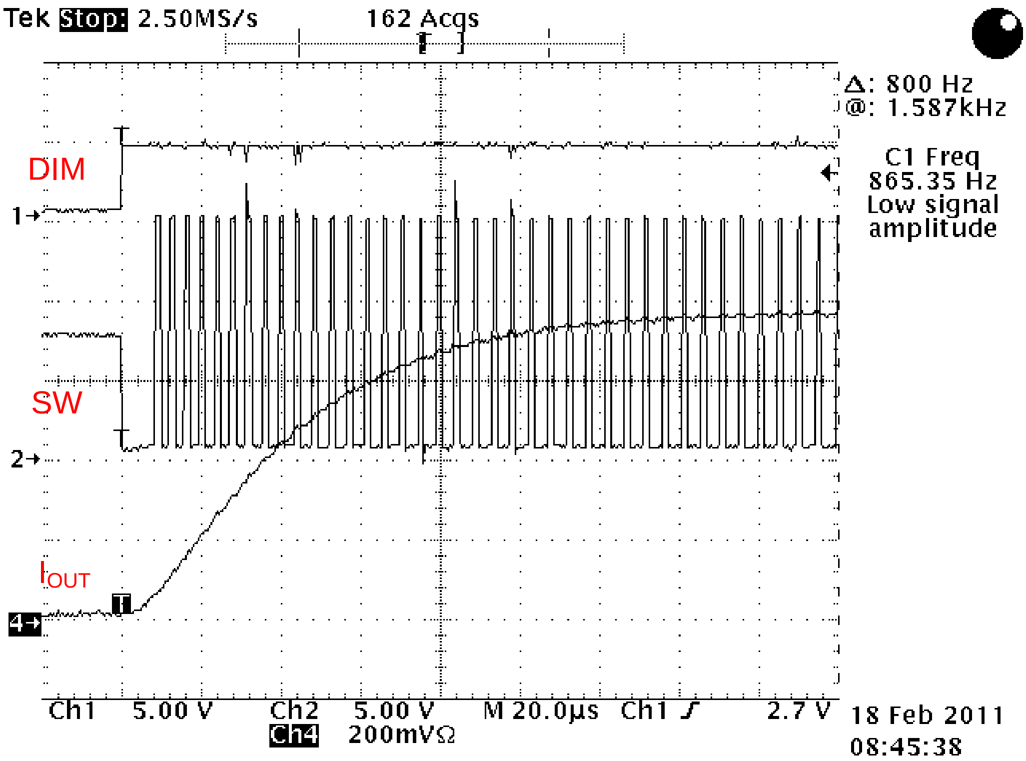



Dimming waveform ($V_{IN}$=12V, $R_{SEN}$=0.27Ω, 3-LED)

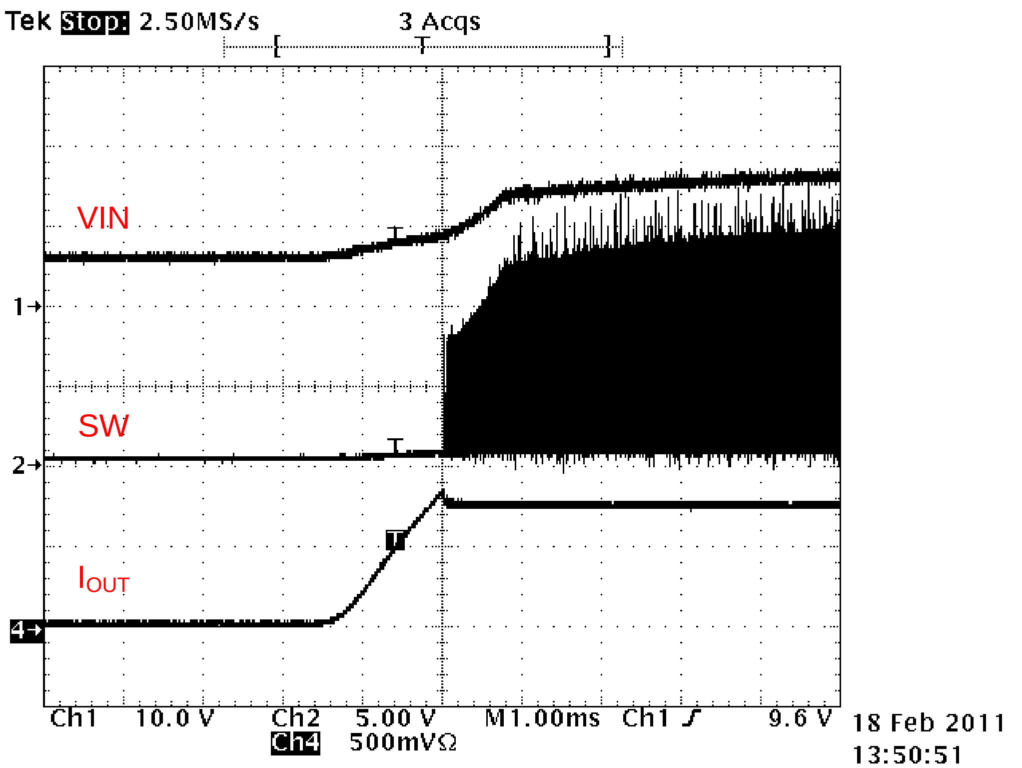



Switching waveform ($V_{IN}$=12V, $R_{SEN}$=0.27Ω, 3-LED)

**9. Start-up waveform**




Start-up waveforms (DIM)




Start-up waveforms ($V_{IN}$)

## ■ Package Information

| SOT23-5 | Unit: mm | | Unit: Inch | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| A | 1.050 | 1.250 | 0.041 | 0.049 |
| A1 | 0.000 | 0.100 | 0.000 | 0.004 |
| A2 | 1.050 | 1.150 | 0.041 | 0.045 |
| b | 0.300 | 0.500 | 0.012 | 0.020 |
| c | 0.100 | 0.200 | 0.004 | 0.008 |
| D | 2.820 | 3.020 | 0.111 | 0.119 |
| E | 1.500 | 1.700 | 0.059 | 0.067 |
| E1 | 2.650 | 2.950 | 0.104 | 0.116 |
| e | 0.950 BSC | | 0.037 BSC | |
| e1 | 1.800 | 2.000 | 0.071 | 0.079 |
| L | 0.300 | 0.600 | 0.012 | 0.024 |
| Θ | $0^{o}$ | $8^{o}$ | $0^{o}$ | $8^{o}$ |