APPLICATION MANUAL

WHITE LED DRIVER
Step-up DC-DC Converter IC
TK11860B

CONTENTS

MEETING YOUR NEEDS
TOKO, INC.

WHITE LED DRIVER Step-up DC-DC Converter IC
TK11860B

1. DESCRIPTION

The TK11860B is a pulse skipping step-up DC-DC converter IC designed for White LED driver applications with the following built in: a very high current switching transistor (400 mA peak), a schottky diode (300 mA peak) as a rectifier, an inductor current limit detector, a low voltage reference (V_{ref} = 0.515 V), a high speed oscillator, an error comparator, a zener diode for open-circuit protection and an ON/OFF control. The IC works with a very wide operating supply range (2.3 V to 10 V) and the adjustable output voltage can be set as high as 20 V. The device is in the ON state when the En pin is pulled to a high level. Using the very small TK11860B and a few external components, battery powered systems with LCD displays, such as digital cameras and cellular phones, can be effectively backlit with white LEDs. The white LEDs are connected in series and driven at a constant current, resulting in uniform brightness and high efficiency. This IC has an adjustable oscillator, which allows the designer to set the operating frequency by an external capacitor with the output controlled by pulse skipping. The reference voltage is a very low 0.515 V, achieving high efficiency operation with the constant current output. A small coil can be used because the inductor current limit detector circuit limits the peak current (caused by an input voltage increase or the inrush current at start-up) that flows through the coil. The ON /OFF control is built-in and the circuit current can be decreased when the En pin is low (shutdown mode). The white LEDs can be dimmed by applying a PWM signal to the En (ON / OFF control) pin. With this method, the white LED brightness is still controlled by constant current, resulting in constant chromaticity.

The built-in zener diode can be used for open-circuit protection in case the output load is disconnected, such as the string of LEDs opened. The internal zener diode reduces the external component count.

The TK11860B can also be used in other applications as a step-up DC-DC converter.

The TK11860B is available in the 8 bumps flip chip package (FC-8).

2. FEATURES

- Very High Speed Adjustable OSC (800KHz Max)
- Very Wide Operating Voltage Range (2.3 V to 10 V)
- Low Loss Detector (Low Reference Voltage: V_{ref} = 0.515 V)
- Operates with Toko D31FU, D31FB Miniature Coil (Current Limited by Inductor Current Sensor)
- Internal Switching Transistor
- Internal schottky diode
- Open-Circuit Protection (OVP)
- Active High ON / OFF Control
- Available Intensity Control Using EN Pin with PWM Signal
- Low component Count
- Very Small 8 bumps flip chip Package (FC-8)

3. APPLICATIONS

- LED Backlighting and Frontlighting
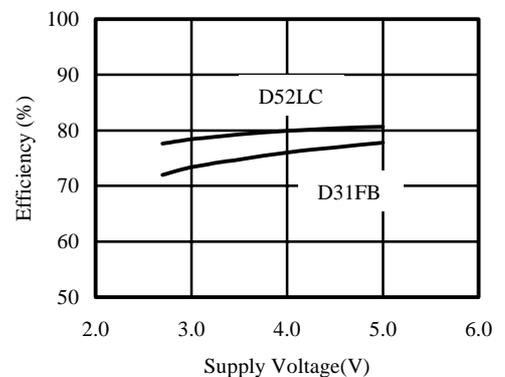- LED Flashlights
- Step-up DC-DC Converters

4. TYPICAL APPLICATION

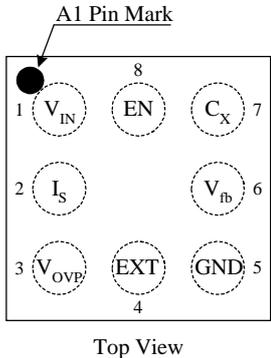### APPLICATION CIRCUIT (3 LEDs in Series)

L: TOKO Part Number D31FB: 984FB-220M
D52LC: A914BYW-220M
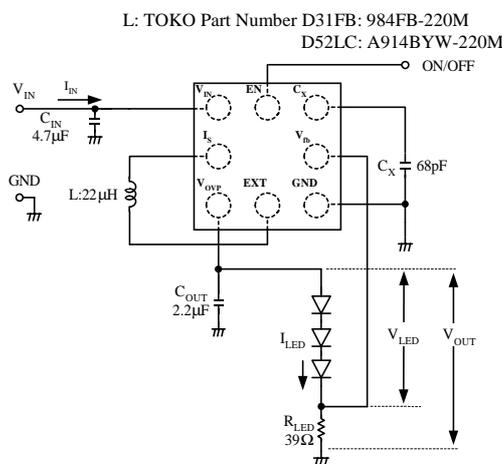
Efficiency vs. Supply Voltage
Efficiency (%) = 100·V_{OUT}·I_{LED}/(V_{IN}·I_{in})

5. PIN CONFIGURATION

A1 Pin Mark

Top View

| Pin No.	SYMBOL	Function
1 (A1)	V_{IN}	Power Supply Voltage Input.
2 (B1)	I_S	Inductor current limit.
3 (C1)	V_{OVP}	Open-Circuit Protection
4 (C2)	EXT	External Inductor.
5 (C3)	GND	Ground.
6 (B3)	V_{fb}	Feedback Voltage.
7 (A3)	C_X	Timing Capacitor.
8 (A2)	EN	Enable (ON/OFF) Input.

6. BLOCK DIAGRAM
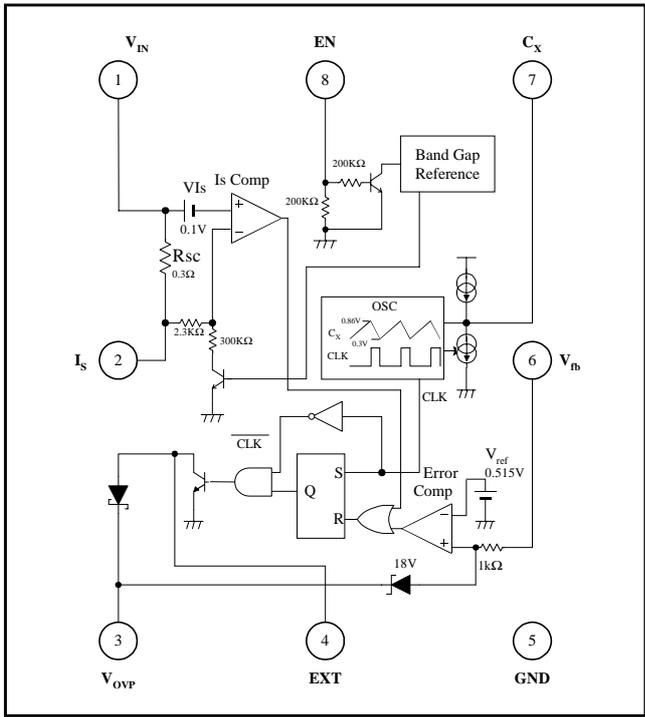
7. STANDARD APPLICATION CIRCUIT

Standard Application circuit for white LED
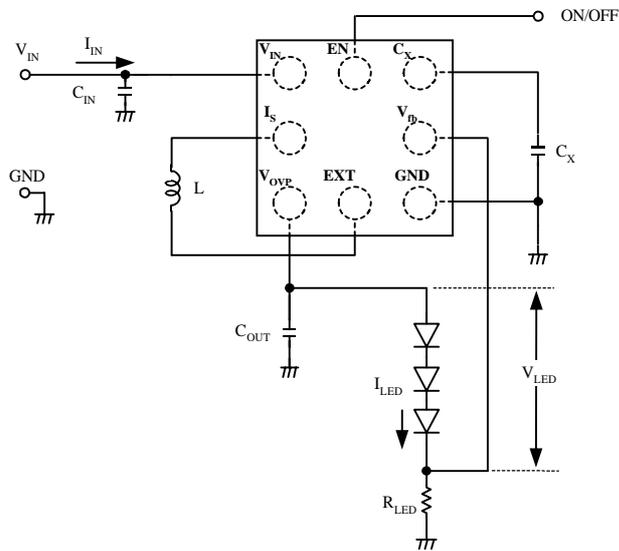
Cin: Input Capacitor
Cout: Output Capacitor
L: Inductor
R_{LED}: LED Current Setting Resistor
C_X: OSC Frequency Setting Capacitor

Standard application circuit for LCD Bias
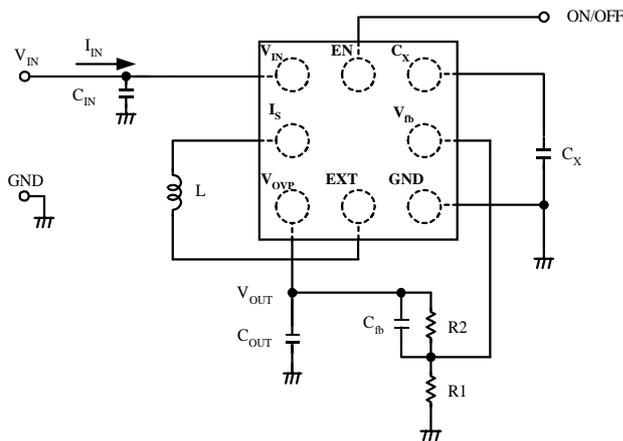
Cin: Input Capacitor
Cout: Output Capacitor
L: Inductor
R1, R2: Output Voltage Setting Resistor
C_{fb}: Compensation Capacitor
C_X: OSC Frequency Setting Capacitor

8. ABSOLUTE MAXIMUM RATINGS

T_a=25°C

PARAMETER	SYMBOL	RATINGS	UNITS	TEST CONDITIONS
Supply Voltage	V_{IN}	20	V	
Operating Voltage Range	V_{OP}	2.3 ~ 10	V	
Switch Voltage	V_{sw}	20	V	
Vovp Pin Voltage	V_{ovp}	-0.3 ~ V_{OVP}	V	
Vfb Pin Voltage	V_{fb}	-0.3 ~ V_{in}	V	
En Pin Voltage	V_{EN}	-0.3 ~ 20	V	
Switch Peak Current	$I_{sw, peak}$	400	mA	
Schottky Diode Forward Peak Current	$I_{D, peak}$	300	mA	
Power Dissipation	P_D	660	mW	*
Storage Temperature Range	T_{stg}	-55 ~ +150	°C	
Operating Temperature Range	T_{OP}	-30 ~ +85	°C	
Maximum Frequency	f_{MAX}	~800	kHz	

P_D must be decreased at the rate of 5.28mW/°C for operation over 25°C on TK11860B's evaluation board.

9. ELECTRICAL CHARACTERISTICS

V_{IN}=3V, I_S=Open, EXT=Open, V_{OVP}=Open, V_{fb}=GND, C_X=300pF, V_{EN}=V_{IN}, T_A=25°C unless otherwise specified

| Parameter	Symbol	Value			Units	Conditions
		MIN	TYP	MAX		
Oscillator Section (C_X Pin)						
C_X Charging Current	I_{chg}	16	22	30	μA	V_{Cx} =0.1V, V_{fb}=1V
C_X Discharging Current	I_{dis}	35	49	65	μA	V_{Cx} =1.0V, V_{fb}=1V
Charge and Discharge Current Ratio	I_{dis}/I_{chg}		2.2			
C_X Threshold Voltage +	$V_{Cx, High}$	810	860	910	mV	V_{Cx} at I_{chg}=0μA, V_{fb}=1V
C_X Threshold Voltage -	$V_{Cx, Low}$	260	300	340	mV	V_{Cx} at I_{dis}=0μA, V_{fb}=1V
C_X Oscillation Voltage	V_{OSC}	520	560	600	mV	($V_{Cx, High}$)-($V_{Cx, Low}$)
Current Limiting Comparator Section (I_S Pin)						
Inductor Current Limit	I_{LIMIT}	220	260	300	mA	Note 1
Pin 1-2 total Resistance	R_{scext}	300	360	460	mΩ	Measured Between pin 1 and pin 2
Internal effective Resistance for Inductor Current Limit Sense	R_{SC}		300		mΩ	Note 2, Note 3
Output Switch Section (EXT Pin)						
Output Transistor Saturation Voltage	$V_{SW, Sat}$		0.1	0.4	V	V_{CX}=0V, I =200mA
Output Transistor Off Leak Current	$I_{SW, OFF}$		0.01	2	μA	V_{SW}=20V, V_{IN}=V_{fb}=7V
Feedback Comparator Section (V_{fb} Pin)						
Reference Voltage	V_{ref}	0.495	0.515	0.535	V	
Vfb Pin Output Current	$I_{fb, IN}$	-2	-0.3		μA	V_{fb}=0.4V
Shutdown Section (En Pin)						
En Input Voltage +	$V_{EN, High}$	1.2		20	V	On mode
En Input Voltage -	$V_{EN, Low}$			0.3	V	Shutdown mode
En Pin Input Bias Current	$I_{EN, IN}$		25	40	μA	V_{EN}=3V
Open-Circuit Protection Section (V_{OVP} Pin)						
Open-Circuit Voltage	V_{OVP}	17	18.5	20	V	I_Z=0.5mA
Vin Section (Vin Pin)						
Low Voltage Stop	$V_{IN. Low}$	1.7	2.0	2.3	V	
High Voltage Output Stop	$V_{IN, High}$	11.5	13.5	14.5	V	
Shutdown Supply Current	$I_{IN, Off}$		0.01	1	μA	V_{EN}=0.3V
Quiescent Supply Current	$I_{IN, On}$	1	1.5	2	mA	V_{fb}=1V
Schottky Diode Section						
Forward Voltage	V_F	0.5	0.7	0.9	V	I_D 200mA

Note 1 I_{LIMIT}: The value of current source I_L (DC measurement) when the switching operation is stopped by the Is comparator.

Note 2 R_{SC}: Guaranteed by the design equation: $I_{LIMIT} = \dfrac{0.1V - \dfrac{2.3}{300}V_{IN}}{R_{SC}}$

Note 3   Do not connect the output circuit to ground directly, the R_{SC} and Schottky diode might be damaged. (Excessive current passes through R_{SC}, Schottky Diode and Coil)
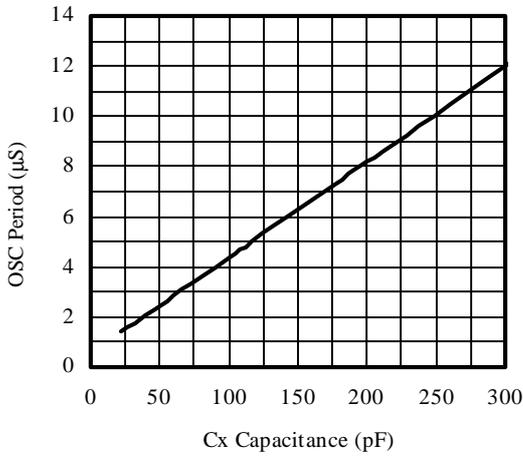
Note 4   When the flip chip device will be exposed to direct sunlight , off mode current (Shutdown Supply Current $I_{IN, Off}$) will be increased . To avoid misoperations, be careful when the TK11860B is exposed to light sources.
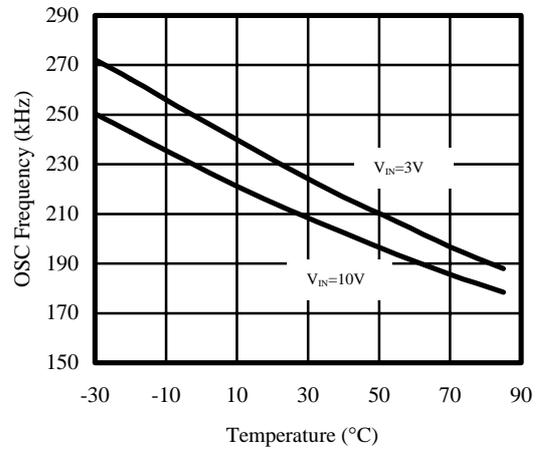
10. TEST CIRCUIT
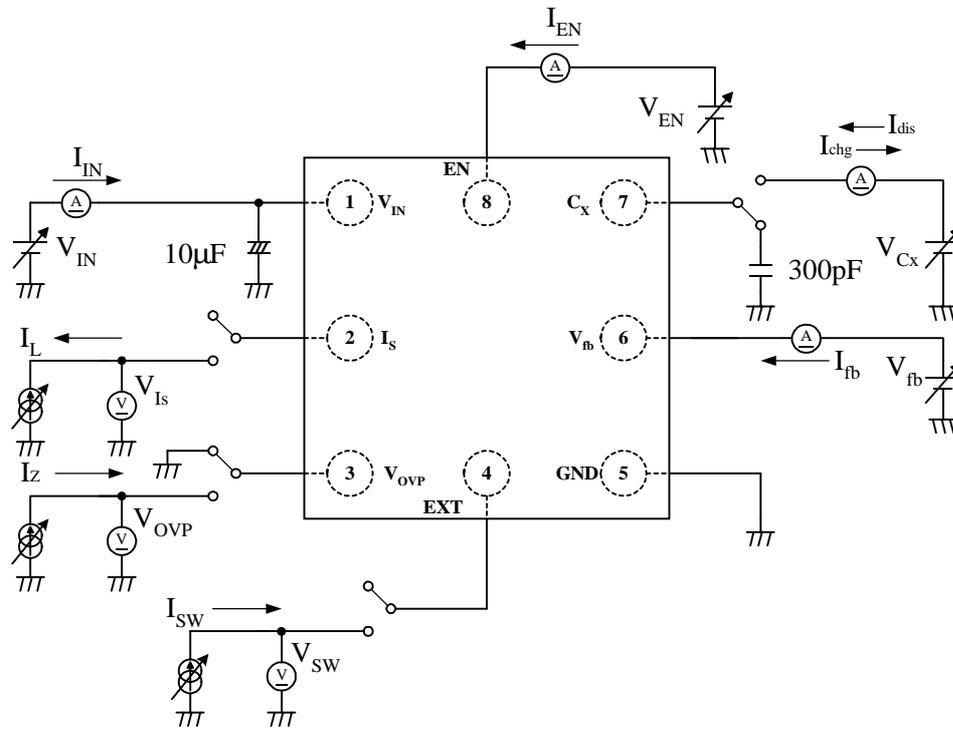
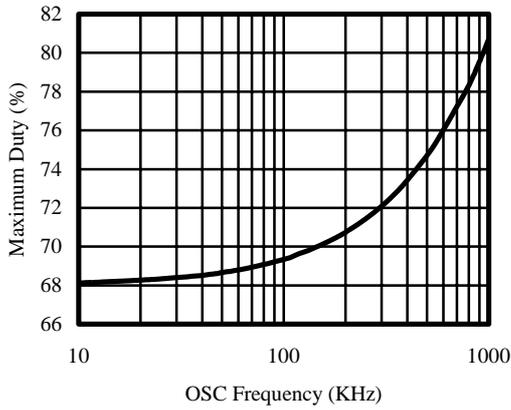## 11. TYPICAL CHARACTERISTICS

OSC Period time vs. C_X Capacitance
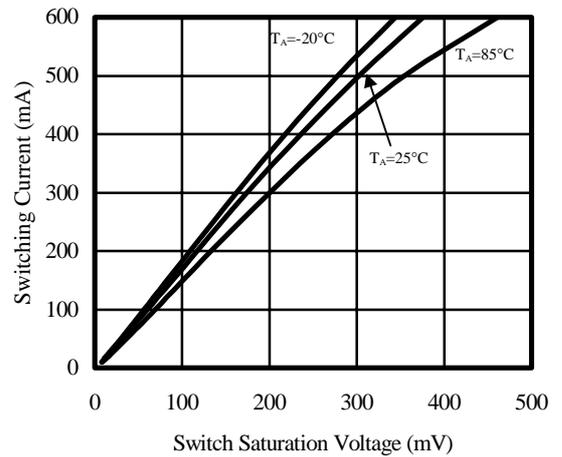$V_{IN}=V_{EN}=3V$, $V_{fb}=0V$

OSC Frequency vs. Temperature
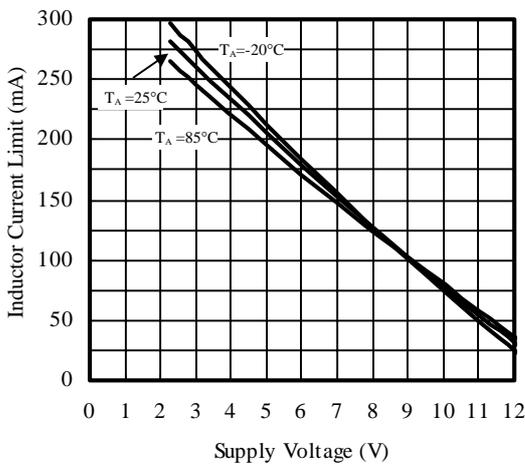$V_{IN}=V_{EN}$, $V_{fb}=0V$, $C_X=100pF$

Maximum Duty vs. OSC Frequency
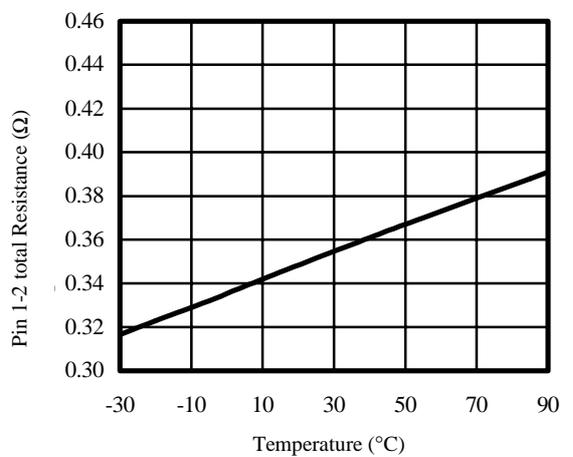$V_{IN}=V_{EN}=3V$, $V_{fb}=0V$

Switch Current vs. Switch Saturation Voltage
$V_{IN}=V_{EN}=3V$, $V_{fb}=0V$, $V_{Cx}=0V$

Inductor Current Limit vs. Supply Voltage
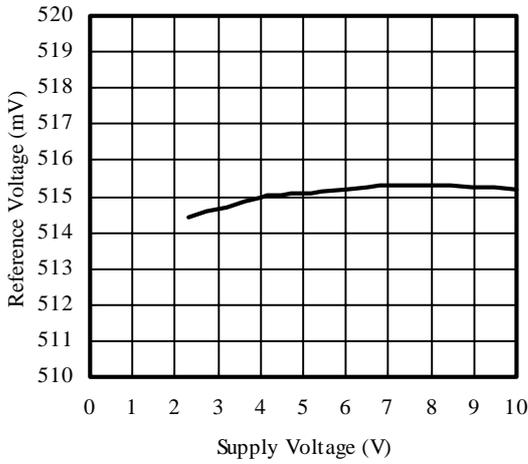$V_{EN}=V_{IN}$, $V_{fb}=0V$, $V_{Cx}=0V$

Pin 1-2 total Resistance vs. Temperature
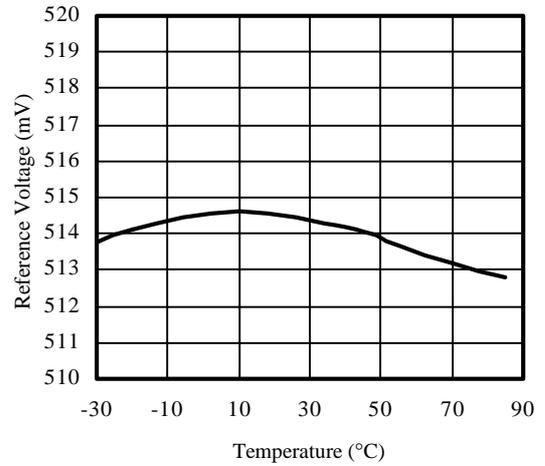$(V_{IN}-V_{Is})/I_L$, $I_L=100mA$

Reference Voltage vs. Supply Voltage
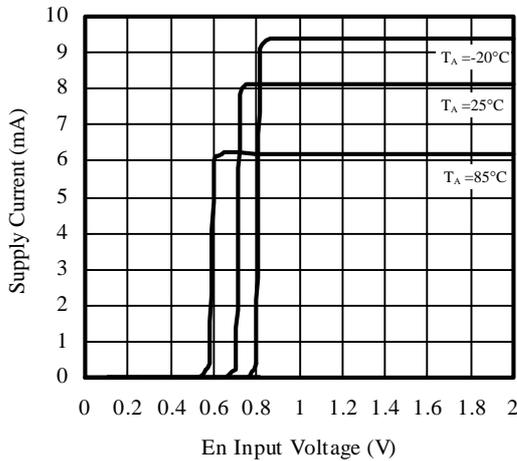$V_{IN}=V_{EN}, V_{Cx}=0V$

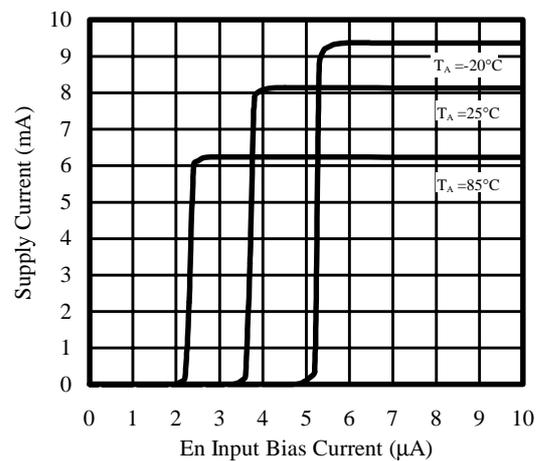### Reference Voltage vs. Temperature
$V_{IN}=V_{EN}=3V, V_{Cx}=0V$

Supply Current vs. En Input Voltage
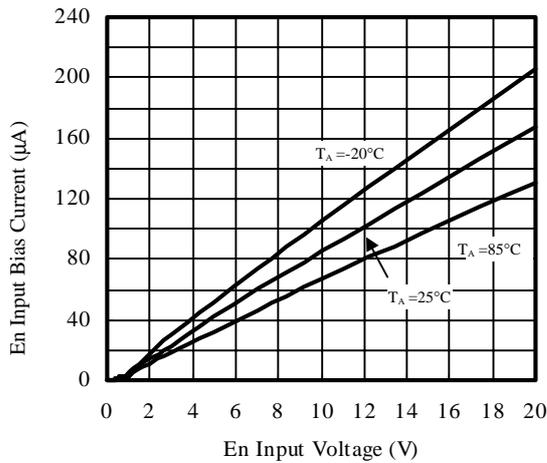$V_{IN}=3V, V_{fb}=0V, C_X=100pF$

Supply Current vs. En Input Bias Current
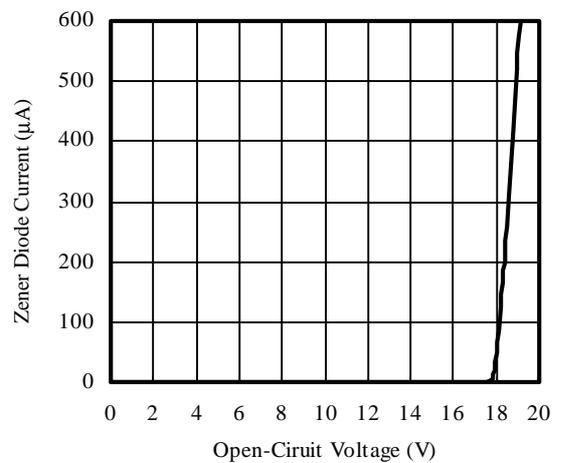(En pin current force) $V_{IN}=3V, V_{fb}=0V, C_X=100pF$

En Input Bias Current vs. En Input Voltage
$V_{IN}=3V, V_{fb}=0V$

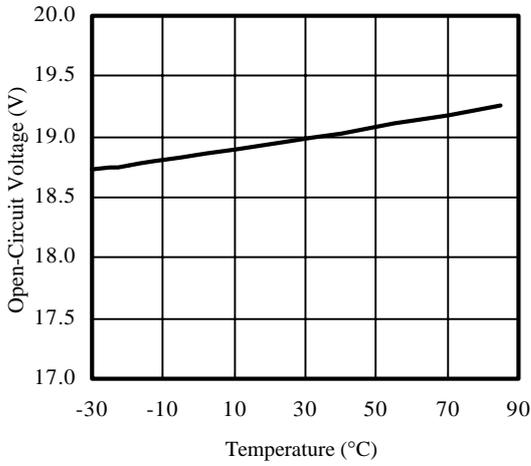### Zener Diode Current vs. Open-Circuit Voltage
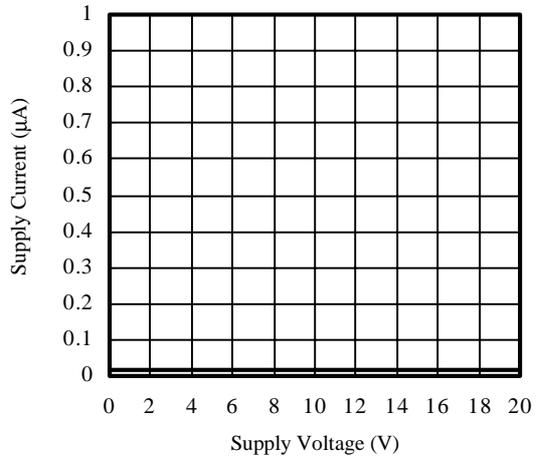$V_{IN}=3V, V_{fb}=0V, V_{EN}=0.3V$

Open-Circuit Voltage vs. Temperature
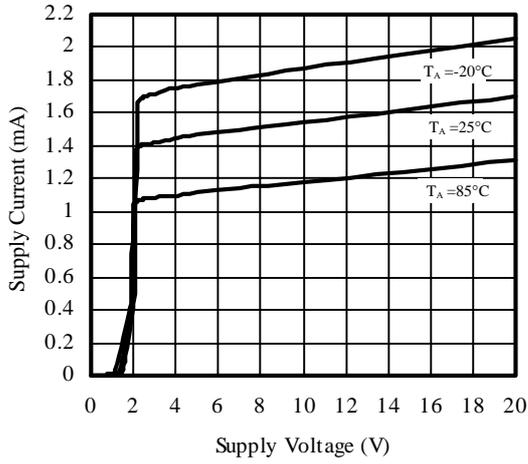$V_{IN}=3V$, $V_{EN}=0.3V$, $I_Z=500\mu A$

Shutdown Supply Current vs. Supply Voltage
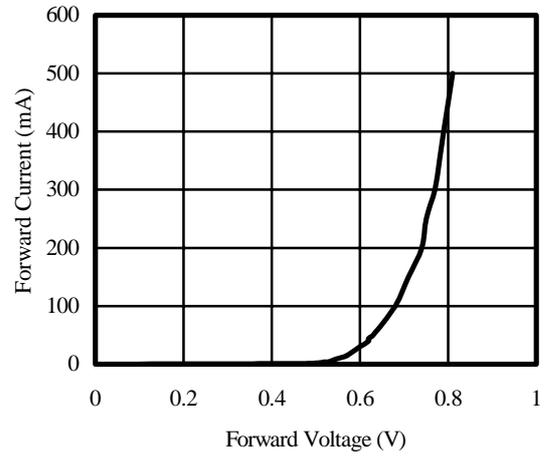$V_{IN}=V_{EN}$, $V_{EN}=0.3V$

Quiescent Supply Current vs. Supply Voltage
$V_{EN}=V_{IN}$, $V_{fb}=1V$, $C_X=100pF$

Schottky diode
 Forward current vs. Forward Voltage

12. PIN DESCRIPTION

PIN No.	SYMBOL	INTERNAL EQUIVALENT CIRCUIT	DESCRIPTION
1	V_{IN}		Power supply voltage input.
2	I_S		The function of this pin is to limit the inductor current associated with the Is comparator. The device contains a sensing resistor referenced as "R_{SC}". The value of R_{SC} is 0.3Ω (typ). Because there is also bump resistance, it will be approximately 0.36Ω when measured between pin1 and pin 2.
4	EXT		This pin is the collector of the internal 20V NPN power switch. The switch transistor has a maximum peak current capability of 400mA and a turn-off delay of 0.2μSec. The internal schottky diode between pin3 and pin4 has a maximum peak current capability of 300mA.
3	V_{OVP}		This pin will work as open-circuit protection. Connect Vovp to Output (Vout) to avoid generating high voltage at the switch pin during open-circuit conditions. The zener voltage is approximately 18V.
6	V_{fb}		Feedback input pin. This pin is the non-inverting input of the error comparator with the inverting input biased with the internal temperature-compensated 0.515V reference. The input bias current of Fb has a typical value of -0.3μA.
5	GND		Ground.
7	C_X		The oscillator frequency is determined by the external timing capacitor C_X and can be set up to 800kHz maximum. The timing capacitor is the only component allowed to be connected to this pin.
8	EN (On/Off)		This is the chip-enable input with a built-in 200kΩ pull-down resistor. Set the En-pin higher than 1.2V to enable the device. Set the En-pin below 0.3V to disable the device.

13. CIRCUIT DESCRIPTION
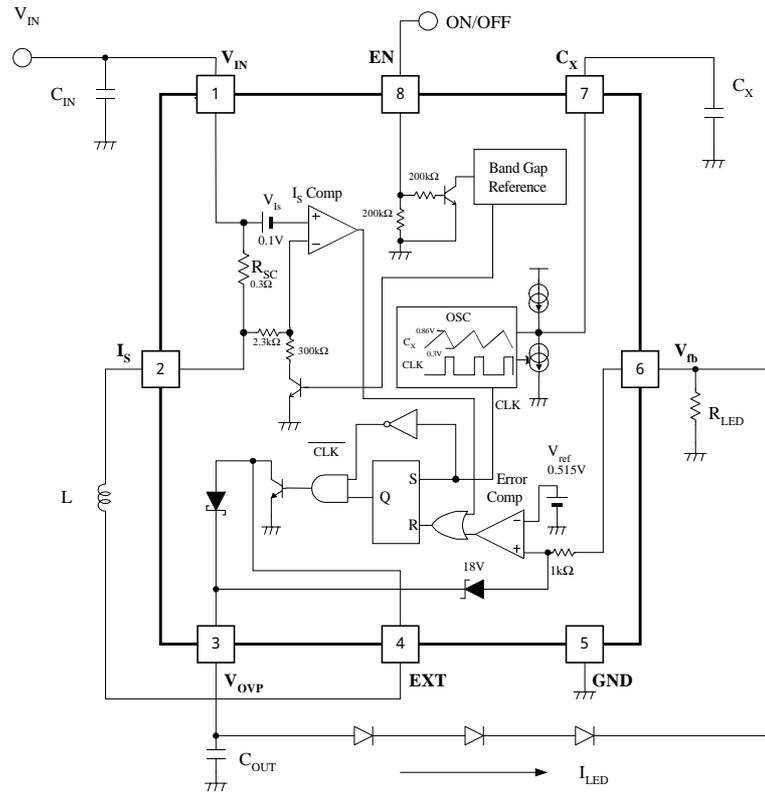
TK11860B Block Diagram

13-1. Constant-Current
(Charge and discharge type) Oscillator.

The oscillator operates by charging and discharging the timing capacitor C_X. This generates the linear ramp waveform across C_X and the internal squarewave signal of the IC. The period time T of the oscillator is determined by the choice of the timing capacitor C_X and is set according to the following equation.

$$T_{(\mu sec)} = 0.038(C_X + 15)_{(pF)} \qquad (1)$$

The oscillator output signal "CLK" is a fixed-duty-cycle pulse train, whose on-off time is fixed internally at a ratio of 2.2:1

$$\frac{t_{chg}}{t_{dischg}} \approx 2.2 \qquad (2)$$

The period time of the oscillator is the period of one full cycle of operation.

$$T = t_{chg} + t_{dischg} \qquad (3)$$

$$f_{osc} = \frac{1}{T} \qquad (4)$$

The oscillator frequency can be set up to 800kHz.

The internal squarewave (CLK) is logical high during the t_{dischg} of ramping down and is low during the t_{chg} of ramping up. When CLK goes high and the AND gate output is low, the switch transistor will be forced off. At the same time, the R-S flip-flop is set to prepare for the next on cycle. When CLK goes low, the inverting signal ($\overline{CLK}$) and the output Q of the flip-flop enters the AND gate; then the AND gate output is high and the switch transistor will be on.
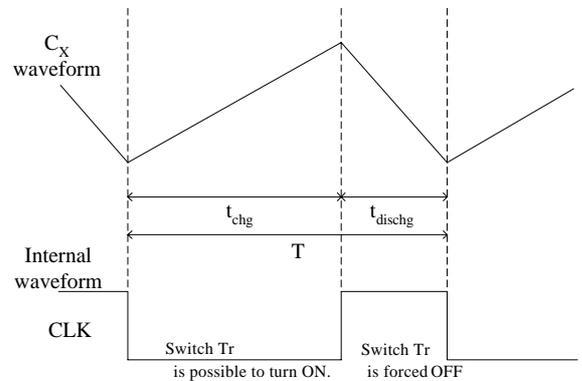

Figure 1: OSC Waveforms

13-2. Inductor Current Limit

The Inductor current-limit function associated with the Is comparator is accomplished by sensing the inductor current by means of the voltage drop across the internal resistor R_{sc}.

The voltage drop across R_{sc} is compared with the equivalent reference voltage of the Is comparator (V_{LIMIT}). If the inductor peak current exceeds the limit, the Is comparator output resets the flip-flop and the switch transistor will be forced off.

The limited value of the inductor peak current can be expressed as

$$I_{Lpk,LIMIT} = \frac{V_{LIMIT}}{R_{sc}} + \frac{V_{IN} - V_{SAT}}{L} t_d$$

(5)

Where

V_{LIMIT} : Equivalent reference voltage of Is comparator.

R_{SC} : Effective current-sense resistor, which is set to 0.3Ω.

V_{IN} : Supply input voltage.

V_{SAT} : Switch transistor saturation voltage.

L : Inductor value.

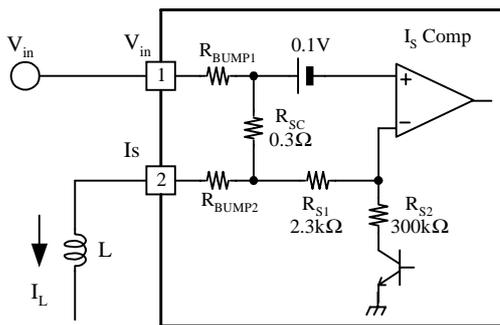t_d : Turn-off delay of switch transistor, which is 0.2μsec.

Figure 2: Schematic of the Inductor Current Limit

In the right side of the equation, the 1st term expresses the limitation by the Is comparator and the 2nd term is an additional inductor current caused by the turn-off delay of the switch transistor. The internal equivalent reference voltage of the Is comparator V_{LIMIT} depends on the supply voltage Vin with resistors R_{S1} and R_{S2}, and can be written as

$$V_{LIMIT} \approx 0.1V - \frac{2.3}{300} V_{in} \qquad (6)$$

Therefore, the inductor current limitation I_{LIMIT} from the 1st term can be given as

$$I_{LIMIT} = \frac{V_{LIMIT}}{R_{SC}} = \frac{1}{R_{SC}}\left(0.1V - \frac{2.3}{300} V_{IN}\right)$$

(7)

(As an example, I_{LIMIT}=257mA at V_{IN}=3V)

When the voltage drop across R_{sc} reaches the V_{LIMIT}, the switch transistor will be forced off, but there is turn-off delay of the switch transistor (t_d=0.2μSec); the additional inductor peak current is expressed as the 2nd term of equation (5).

As an example
   t_d=0.2μSec, V_{IN}=3V, L=22μH, V_{SAT}=0.3V
$$\Delta I_{Lpk} = \frac{V_{IN} - V_{SAT}}{L} t_d = 24mA$$

As a result, the total amount of inductor peak current is limited by equation (5).

For Example
   t_d=0.2μSec, V_{IN}=3.0V, L=22μH, V_{SAT}=0.3V
$I_{Lpk,LIMIT}$=257mA (1st term)+24mA (2nd term)=281mA

The equations (5), (6) and (7) shows that a higher supply voltage Vin will reduce the peak inductor current. This function will allow the use of an inductor with a physically smaller inductor core under a wide operating voltage range. When the supply voltage is higher than 13.5V, the Is comparator output keeps the flip-flop reset (through the OR gate) and the switch transistor will turn-off constantly.

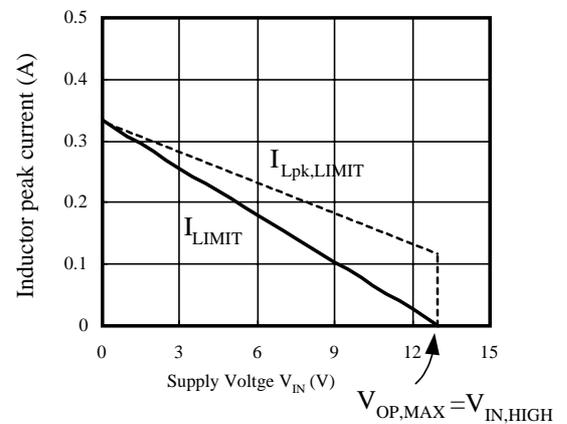Figure 3: Inductor current limit
As a function of Supply input voltage
(R_{SC}=0.3Ω, L=22μH, V_{SAT}=0.3V)

To increase the inductor peak current

If it is necessary to get more output power, add the external resistor R_{scout} between pin 1 and pin 2 in parallel with the internal resistor R_{sc} to increase the inductor peak current. Then, the inductor current limit can be expressed as

$$I_{Lpk,LIMIT} = \left(1 + \frac{R_{SCEXT}}{R_{SCOUT}}\right) I_{LIMIT} + \frac{V_{IN} - V_{SAT}}{L} t_d$$

(8)
Where
R_{SCEXT}: Internal resistor measured pin 1-pin 2.
$\qquad (R_{SCEXT} = R_{BUMP1} + R_{BUMP2} + R_{sc} = 0.36\Omega)$
R_{SCOUT} : External resistor.
I_{LIMIT} : defined in equation (7).
$\dfrac{V_{IN} - V_{SAT}}{L} \cdot t_d$: Defined as the 2nd term in equation (5).

As an example
$\qquad R_{SCOUT} = 2.2\Omega$, $V_{IN} = 3.0V$, $L = 22\mu H$
$\qquad V_{SAT} = 0.3V$, $t_d = 0.2\mu Sec$
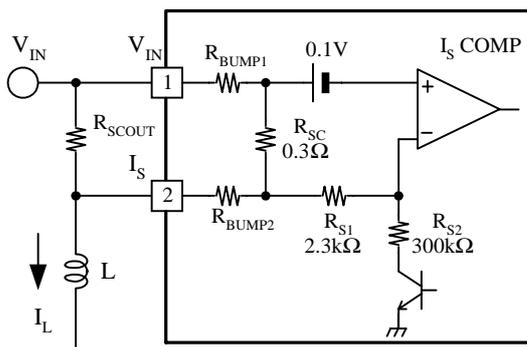$\quad I_{Lpk,LIMIT} = 323mA$

Figure 4: Increased inductor current limit with R_{scout}

An external schottky diode must be put between pin3 and pin4 in parallel with the internal schottky diode when Rscout is added in order to increase the current limit as above mentioned.

That is why the peak current capability of the internal schottky diode is 300mA maximam.

13-3. En (On/Off)

Set the En pin higher than 1.2V to enable the device. Set it below 0.3V to disable the device; that is, shutdown mode. During shutdown, the supply current drops to 1μA or less. The internal 200kΩ pull-down resistor ensures the shutdown mode when the En pin remains open. The En pin can be pulled up to 20V, regardless of the supply voltage and output voltage. The relationship between control current (I_{EN}) and En pin voltage (V_{EN}) is

$$I_{EN} = \frac{V_{EN}}{R_{DOWN}} + \frac{V_{EN} - V_{BE}}{R_{EN}} \qquad (9)$$

Where $R_{DOWN} = R_{EN} = 200k\Omega$, $R_{ENOUT} = 0\Omega$
If the voltage applied to the En pin is too high, put R_{EnOUT} in series with the En pin to reduce its bias current.
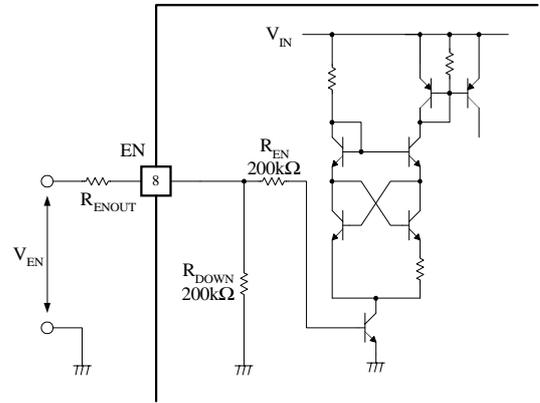

Figure 5: Internal equivalent circuit of EN pin

The EN pin is also used to provide LED-dimming (see DIMMING).

13-4. Operating supply voltage range

When the supply voltage falls below 2.0V ($V_{IN,LOW}$), the TK11860B stops switching operation to avoid malfunction. The level of $V_{IN,LOW}$ is determined by the internal circuit. When the supply voltage is above 13.5V ($V_{IN,HIGH}$), the TK11860B also stops switching operation because of the limitation from equation (7).
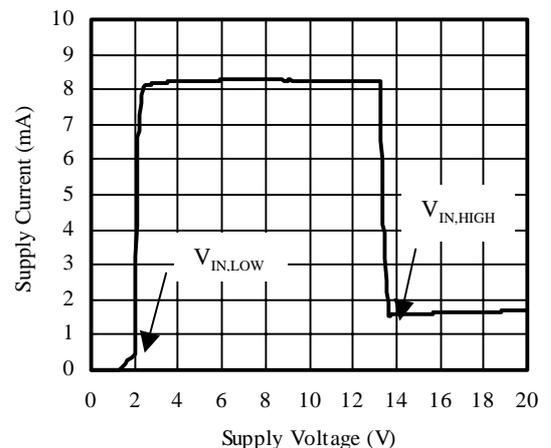However, the maximum rating for the supply voltage is as high as 20V.

Figure 6: Operating supply voltage range
($V_{EN} = V_{IN}$, $V_{fb} = 0V$, $C_X = 100pF$)

13-5. Error comparator, Vfb

The error comparator section of the circuit compares the output feedback voltage Vfb with the 0.515V internal reference and generates a reset signal which inhibits the oscillator output from turning the switch transistor on whenever the output voltage is too high (see block diagram). In this manner, the drive to the switch transistor is essentially an intermittent pulse train, as a result of the pulse skipping operation.

This architecture allows the series-connected white LEDs to be driven with a constant current. The LED current (I_{LED}) is set by an external resistor (R_{LED}) connected between the feedback pin and GND (see Figure 7).

The current of each LED is

$$I_{LED} = \frac{V_{ref}}{R_{LED}} \qquad (10)$$

Where V_{ref} : the feedback reference voltage 0.515V

Output voltage Vout is given by

$$V_{OUT} = n \cdot V_f + V_{ref} \qquad (11)$$

Where V_f : LED forward voltage drop
         n : Number of LEDs connected in series

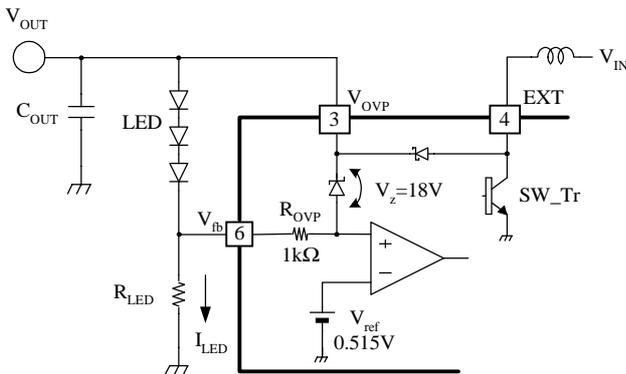The maximum number of LEDs connected in series (n) is four.

Figure 7: Setting constant current through LED

To obtain a regulated output voltage for most common step-up regulator applications, connect a voltage divider from the output (Vout) to Vfb (see Figure 8). The regulated output voltage is determined by

$$V_{OUT} = V_{ref}\left(1 + \frac{R2}{R1}\right) \qquad (12)$$

Vout can be set from Vin to 16.5V, (Note that maximum Vout is limited to an internal open-circuit protection voltage 16.5V.)
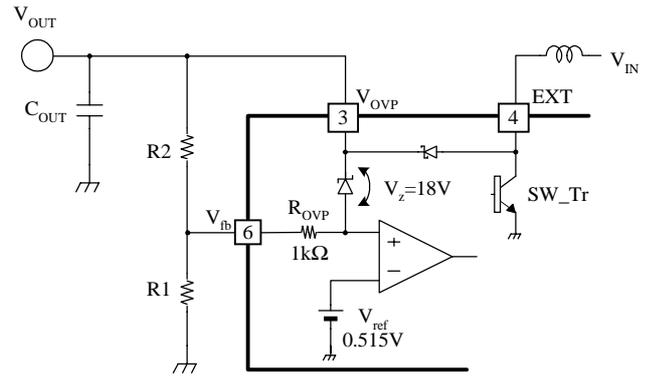

Figure 8: Setting output voltage

13-6. Open-Circuit Protection

The TK11860B has open-circuit protection internally. When the main feedback loop is opened, the internal zener diode will work as another path of the feedback loop. This prevents the switch node from generating high voltage. The voltage level at Vout is clamped at

$$V_{OUT} = V_{OVP} = V_Z + V_{ref} = 18.5V$$

Where V_Z=18V   zener voltage
       V_{ref}=0.5V   error comparator reference voltage.

During open-circuit, the current of zener diode Iz is

$$I_Z = \frac{V_{ref}}{R_{OVP} + R_{LED}} \approx \frac{V_{ref}}{R_{OVP}} < 0.5mA \qquad (13)$$

Where R_{OVP}=1kΩ, $R_{OVP} \gg R_{LED}$

The clamped level of Vout is enough to drive 4 white LEDs connected in series.

13-7. Relationship between Supply input voltage and Inductor peak current

The TK11860B is a pulse skipping step-up DC-DC converter where the inductor peak current is limited by the period time of the oscillator and the inductor current limit circuit. From the equation (1), the period time (T) of the oscillator is

$$T_{(\mu sec)} = 0.038(C_X + 15)_{(pF)} \qquad (1)$$

Also, the switch on time derived from oscillator equation (1) through equation (3) is

$$t_{ON} = t_{chg} + t_d = \frac{2.2}{3.2}T + t_d \qquad (14)$$

Then, the inductor peak current from the oscillator circuit is written as

$$I_{Lpk} = \frac{V_{IN} - V_{SAT}}{L}\left(\frac{2.2}{3.2}T + t_d\right) \qquad (15)$$

This equation (15) shows that when Vin increases, I_{Lpk} will increase linearly. If I_{Lpk} (given by equation (15)) reaches the value of the inductor current limit, the inductor peak current limited by the inductor current limit circuit is expressed as equation (5).

$$I_{Lpk,LIMIT} = \frac{V_{LIMIT}}{R_{sc}} + \frac{V_{IN} - V_{SAT}}{L}t_d$$
$$= \frac{1}{R_{sc}}\left(0.1V - \frac{2.3}{300}V_{IN}\right) + \frac{V_{IN} - V_{SAT}}{L}t_d$$

(5)

Equation (5) shows that when Vin increases, I_{Lpk} will decrease linearly.

As a result, the inductor peak current can be plotted in Fig(10) over a wide range of supply voltage input.
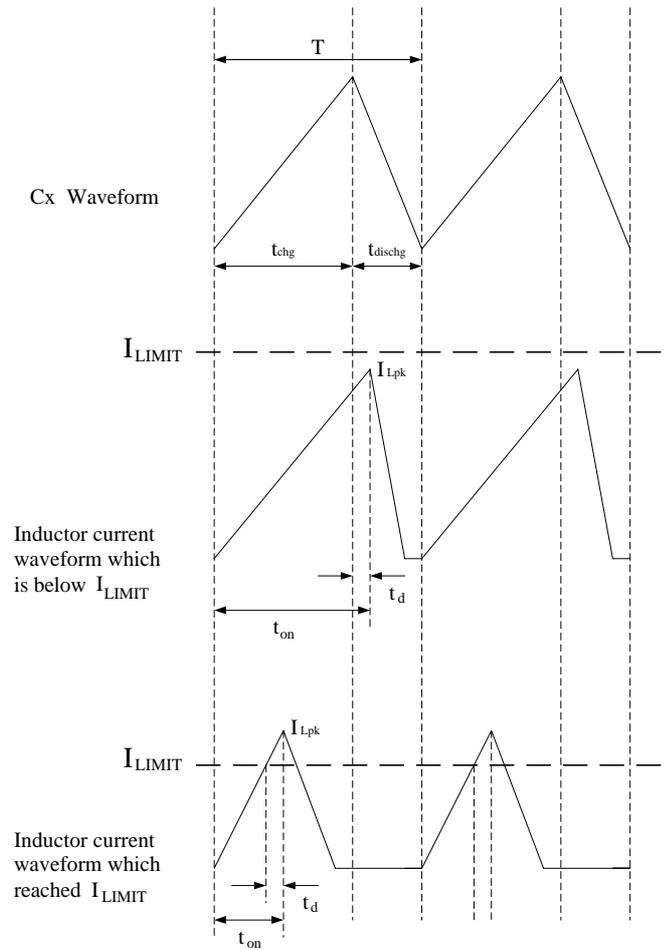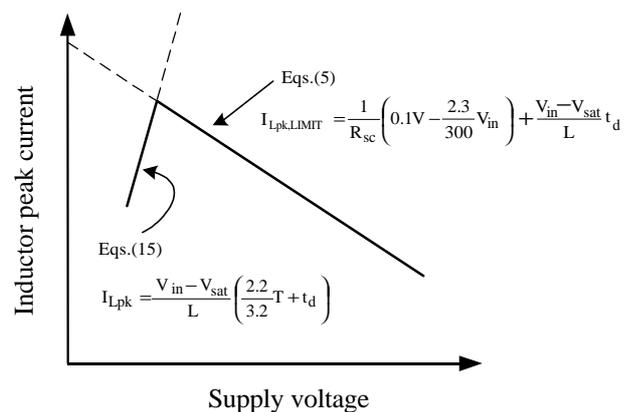

Figure 9: Inductor current waveform

Figure 10: Plot of Inductor peak current as a function of supply voltage

13-8. DIMMING

The following are 3 kinds of methods.

1. Dimming by R$_{LED}$

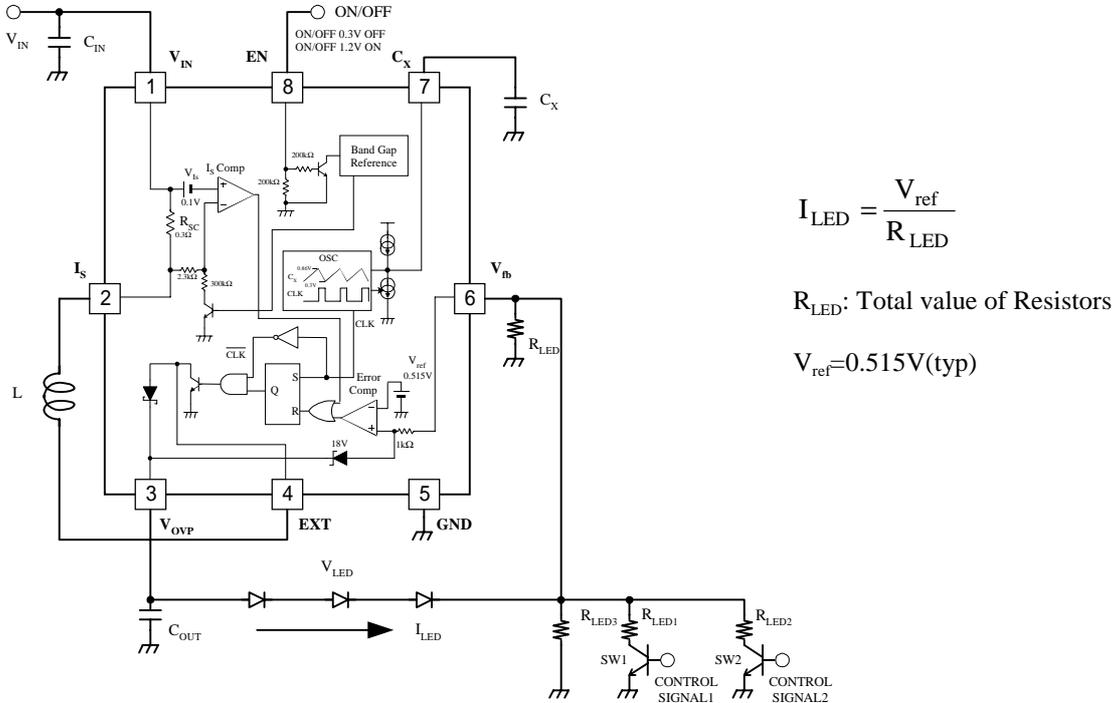The current of the LED (I$_{LED}$) is determined by R$_{LED}$, which can be set by switches such as transistors.

$$I_{LED} = \frac{V_{ref}}{R_{LED}}$$

R$_{LED}$: Total value of Resistors

V$_{ref}$=0.515V(typ)

Figure 11: Example of 3LEDs with a 4 brightness level circuit

The current of the LED can be approximated as

	SW 1	SW 2	I$_{LED}$
1	ON	ON	$\dfrac{V_{ref}}{R_{LED\,1} /\!/ R_{LED\,2} /\!/ R_{LED\,3}}$
2	ON	OFF	$\dfrac{V_{ref}}{R_{LED\,3} /\!/ R_{LED\,1}}$
3	OFF	ON	$\dfrac{V_{ref}}{R_{LED\,3} /\!/ R_{LED\,2}}$
4	OFF	OFF	$\dfrac{V_{ref}}{R_{LED\,3}}$
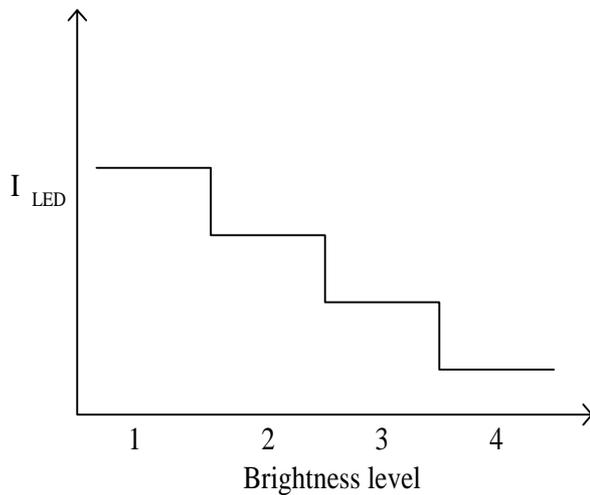
2. Dimming by DAC (D/A Converter) output

Dimming is achievable by applying a DAC output to the V_{fb} terminal with addition of $R_{DAC\,1}$ and $R_{DAC\,2}$
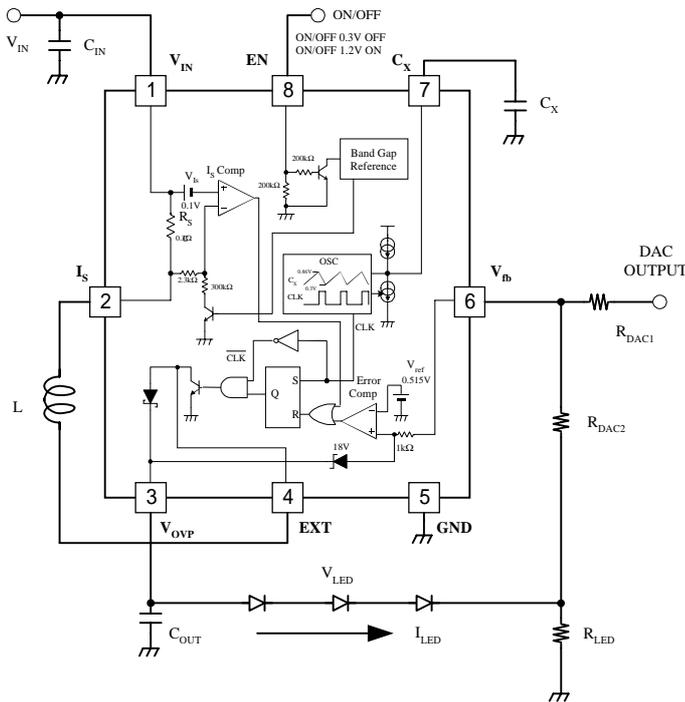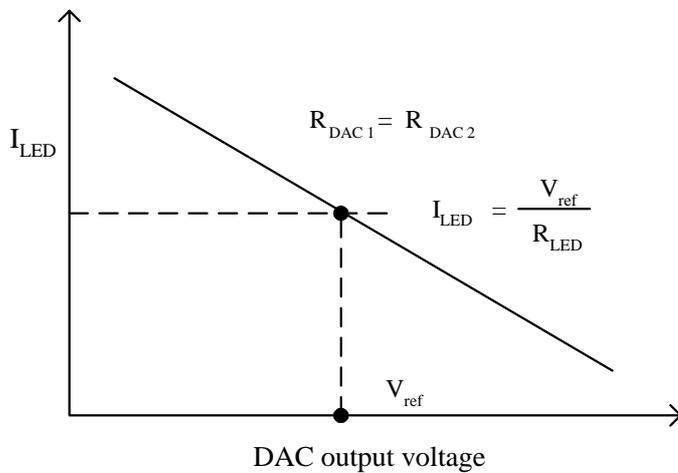

Figure 11: Dimming by DAC (D/A Converter) output

The current of the LED can be given as

$$I_{LED} = \frac{1}{R_{LED}}\left\{ V_{ref} - \frac{R_{DAC2}}{R_{DAC1}}(V_{DACOUT} - V_{ref}) \right\} \qquad \text{Where } V_{ref}=0.515V(typ)$$

$$= \frac{1}{R_{LED}}(2V_{ref} - V_{DACOUT}) \qquad \text{Where } R_{DAC1}=R_{DAC2} \text{ is assumed}$$

3. PWM Dimming

Apply the PWM signal to the EN terminal; (Pin no.8). In this case, a signal frequency of approximately 120 Hz is adequate. The average current of the LED changes due to the ON/OFF cycle of the IC, which follows the duty cycle of the PWM signal.

Set the PWM signal at a high level 1.2V and a low level 0.3V, with a driving current over 8μA
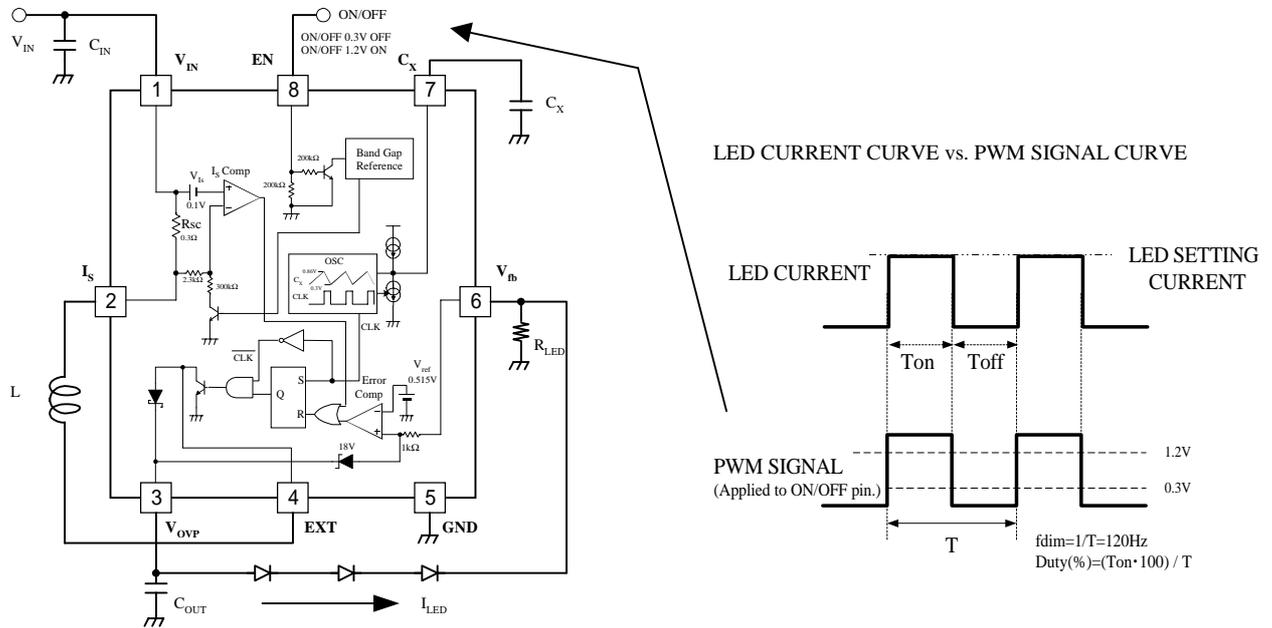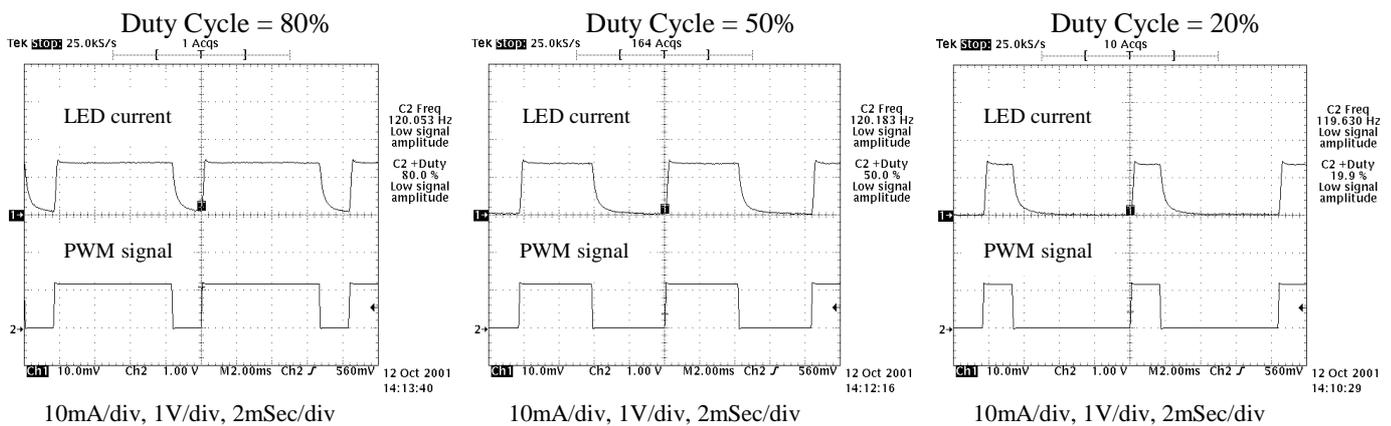

Figure 12: Dimming by PWM signal

The PWM dimming LED current follows the PWM signal. (As shown above)
The average LED current is obtained from the formula below.

$$I_{LED(Avg)} = I_{LED(MAX)} \cdot \frac{Duty}{100} \qquad Where \quad I_{LED(MAX)} = \frac{V_{ref}}{R_{LED}}$$

The graph below shows an example with I_{LED} MAX15mA at a Duty Cycle 80%, 50% and 20%.

Duty Cycle = 80%

LED current

PWM signal

10mA/div, 1V/div, 2mSec/div

Duty Cycle = 50%

LED current

PWM signal

10mA/div, 1V/div, 2mSec/div

Duty Cycle = 20%

LED current

PWM signal
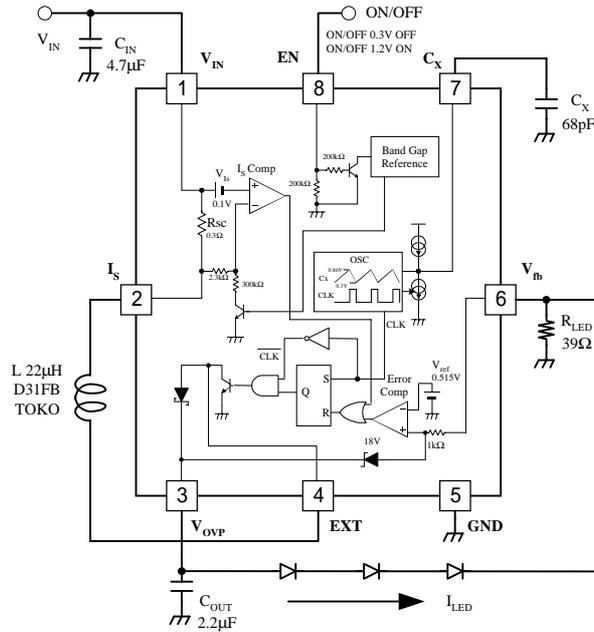
10mA/div, 1V/div, 2mSec/div

Input PWM signal curve vs. LED current curve (ex. Three LEDs, LED current 15mA)

14. WHITE LED APPLICATION

14-1. APPLICATION CIRCUIT (3 LEDs in Series, Internal Schottky Diode)

• LED Current: 13mA

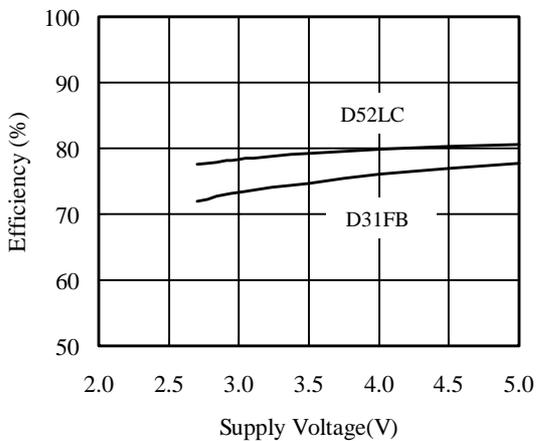L: 22μH   Type D31FB Toko Sample Number: 984FB-220M
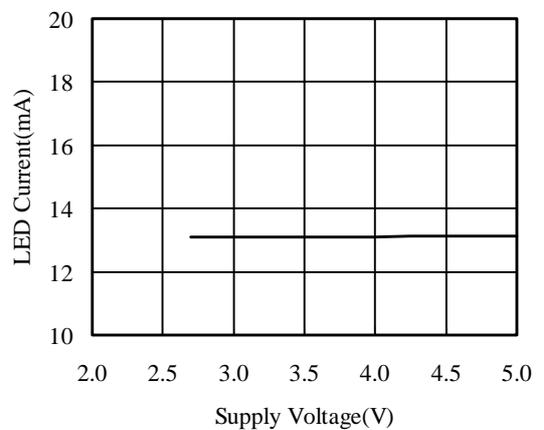   Type D52LC Toko Sample Number A914BYW-220M

LED Current and Efficiency Characteristics

Efficiency $(\%) = 100 \cdot V_{out} \cdot I_{LED} / (V_{IN} \cdot I_{IN})$
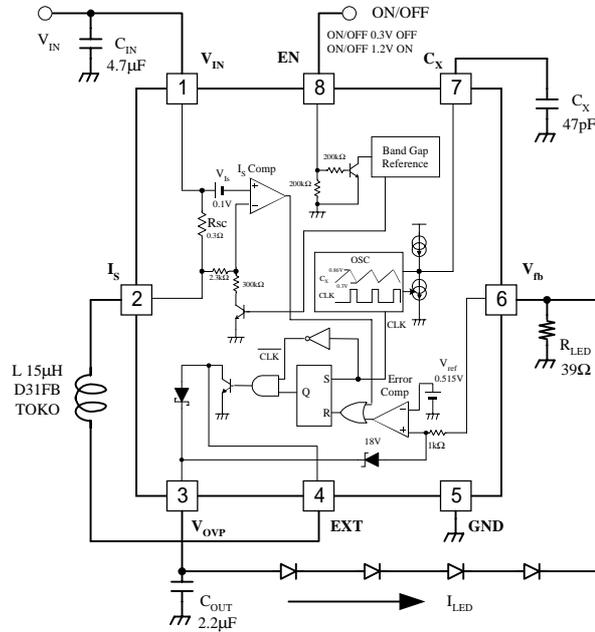
Efficiency vs. Supply Voltage

LED Current vs. Supply Voltage

14-2. APPLICATION CIRCUIT (4 LEDs in Series, Internal Schottky Diode)
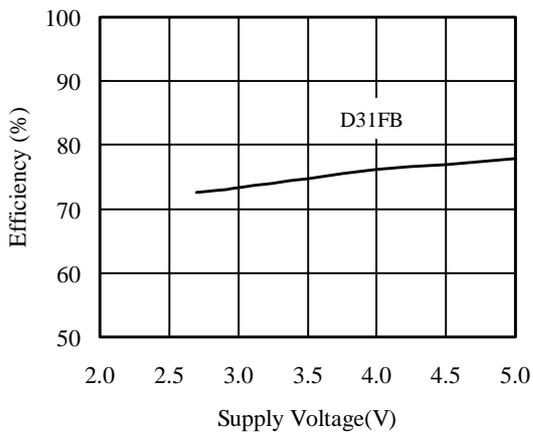
•LED Current: 13mA

L: 15μH   Type D31FB Toko Sample Number: 984FB-150M
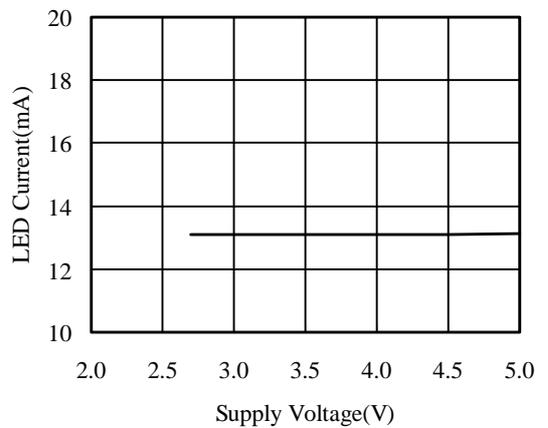   Type D52LC Toko Sample Number: A914BYW-150M

LED Current and Efficiency Characteristics

Efficiency $(\%)=100\cdot V_{out}\cdot I_{LED}/(V_{IN}\cdot I_{IN})$
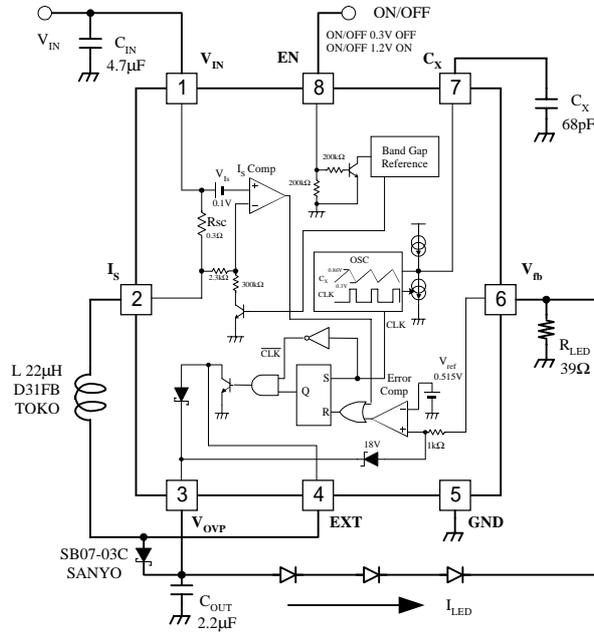
Efficiency vs. Supply Voltage

LED Current vs. Supply Voltage

14-3. APPLICATION CIRCUIT (3 LEDs in Series, External Schottky Diode)
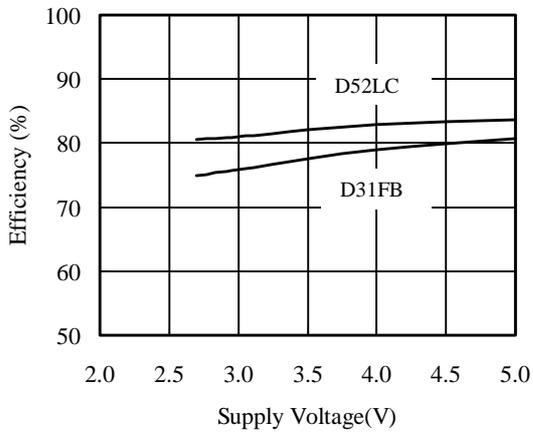
• LED Current: 13mA

L: 22μH   Type D31FB Toko Sample Number: 984FB-220M
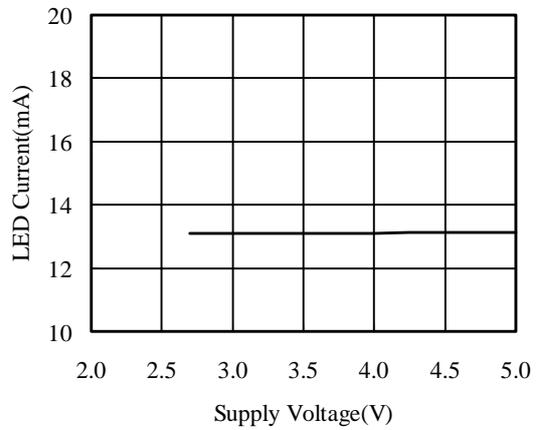   Type D52LC Toko Sample Number A914BYW-220M

LED Current and Efficiency Characteristics

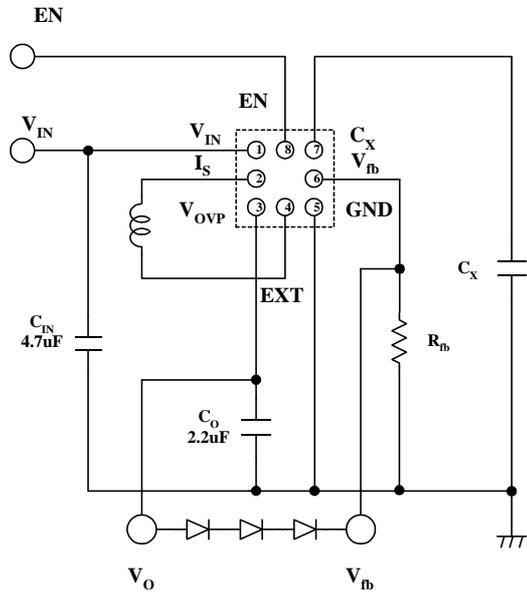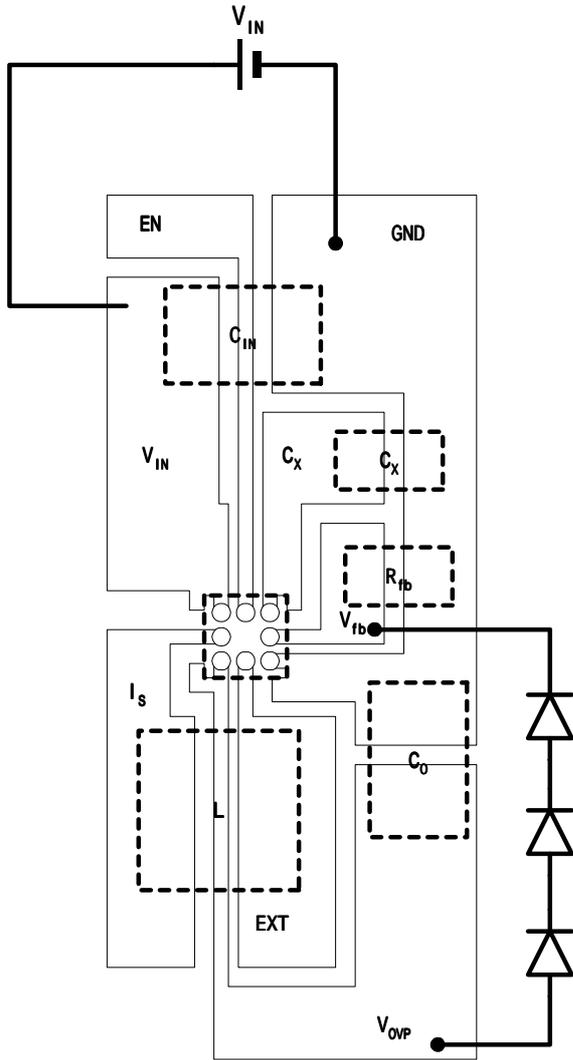Efficiency (%)=100·Vout·I_{LED}/(V_{IN}·I_{IN})

Efficiency vs. Supply Voltage

LED Current vs. Supply Voltage

14-4. TK11860B Evaluation Board Layout

15. PACKAGE OUTLINE

FC-8

Mark

A1 Pin Mark Area

8-ϕ0.30 $^{\pm0.03}$

ϕ 0.05 (M)

1.66 $\pm$0.03

0.5

0.5

1.66 $\pm$0.03

C   B   A

3

2

1

0.60 $\pm$0.06

0.22 $\pm$0.03

0.05

0.5

0.5

8-ϕ0.275

Reference Mount Pad
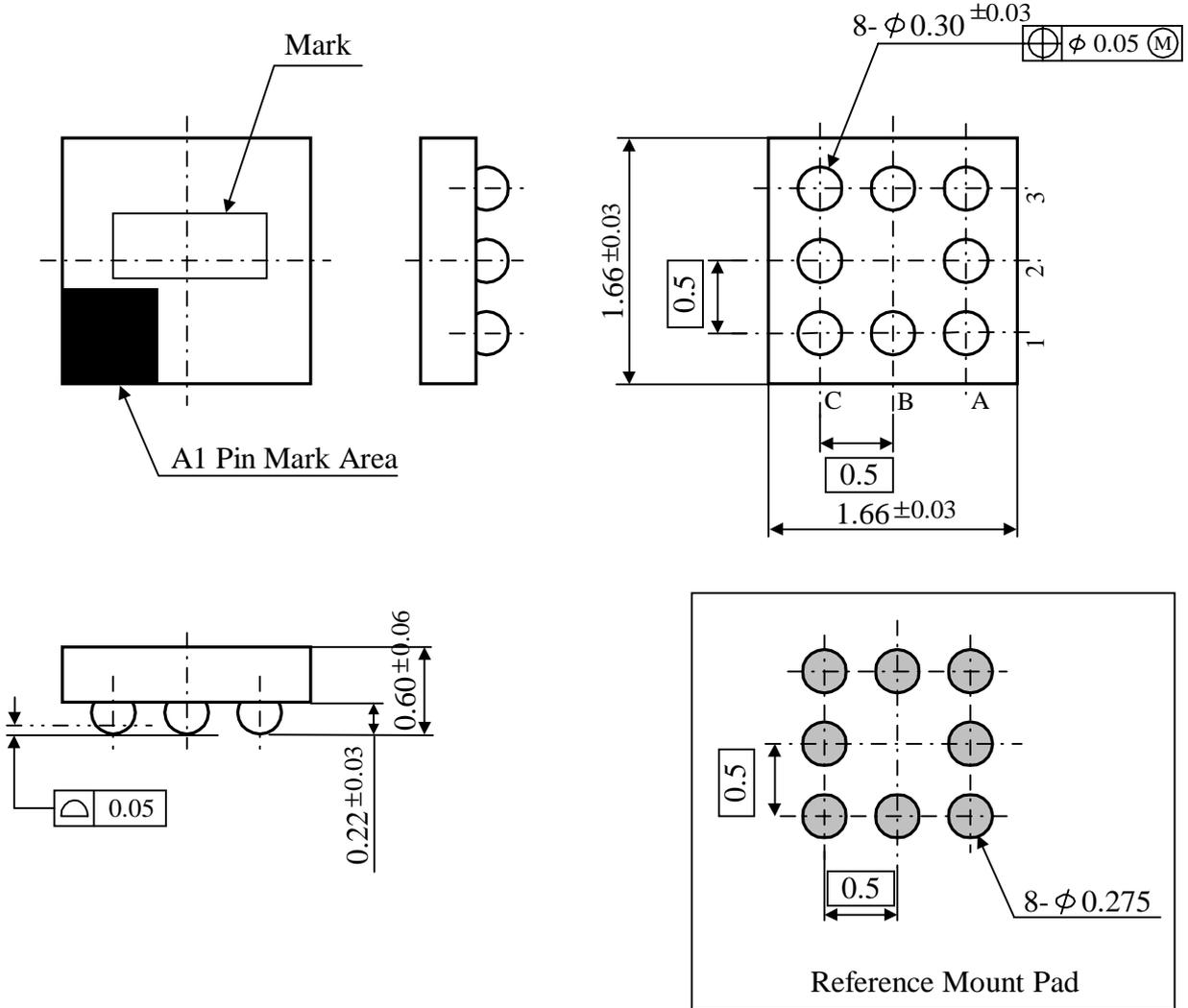
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