

# APPLICATION MANUAL



## CMOS White LED Driver IC TK65600B, B-G

### CONTENTS

1 . DESCRIPTION	2
2 . FEATURES	2
3 . APPLICATIONS	2
4 . PIN CONFIGURATION	2
5 . PACKAGE OUTLINE	2
6 . BLOCK DIAGRAM	3
7 . ABSOLUTE MAXIMUM RATINGS	3
8 . ELECTRICAL CHARACTERISTICS	4
9 . TEST CIRCUIT	5
10 . TYPICAL CHARACTERISTICS	5
11 . PIN DESCRIPTION	8
12 . APPLICATIONS INFORMATION	8
13 . NOTES	16
14 . OFFICES	16



**1. DESCRIPTION**

TOKO TK65600B,TK65600B-G White LED Driver IC has been optimized for battery powered systems where power consumption and size are primary concerns. High efficiency has been optimized for this application.

The miniature Flip Chip package device, together with the miniature Toko Coil D3313FB or Low Profile D412F Coil, further helps system designers reduce the space required to drive the white LEDs.

The IC uses Current-mode PWM (Pulse Width Modulation) method of regulating the current through the string of LEDs. This time-proven method of regulation works at a fixed switching frequency which is preferred in RF systems, because the switching noise RF spectrum is more predictable.

With a switching frequency of 700 kHz the operation of

the IC should not disturb 455 kHz IF subsystem.

The Enable pin can take a PWM signal provided by the user to reduce the display brightness. A PWM signal is preferred to pulse the LEDs with a regulated value of current and to maintain better consistency of chromaticity.

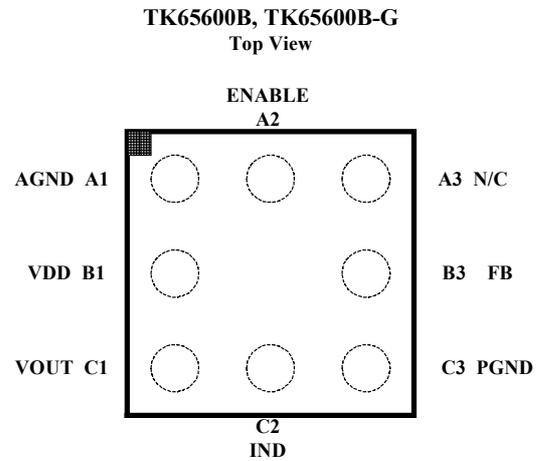
**2. FEATURES**

- Minimum External Components
- Efficiency as High as 80%
- LED Current Regulated
- Internal Synchronous Rectifier
- PWM Signal Intensity Control
- Can Drive Multiple Strings of 3 WLED in Series
- 700 kHz PWM Operation
- Low Supply Current
- Enable Pin
- Short Circuit Protection
- Over Voltage Protection
- 8 Pin Flip Chip Package

**3. APPLICATIONS**

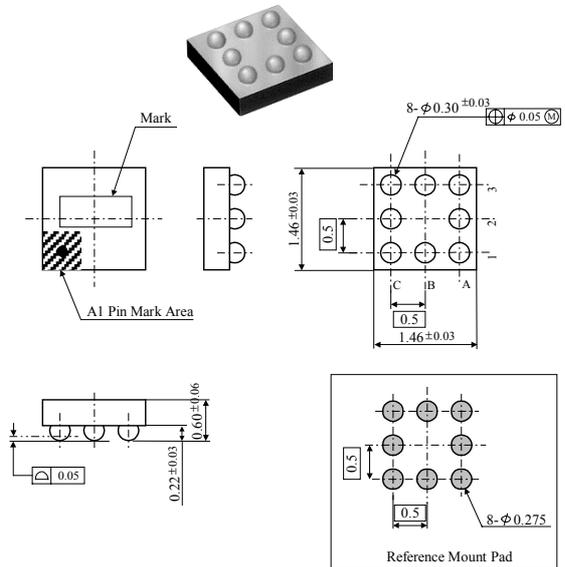
- LCD Modules
- Cellular Telephone
- Battery Powered Systems
- Consumer Electronics

**4. PIN CONFIGURATION**

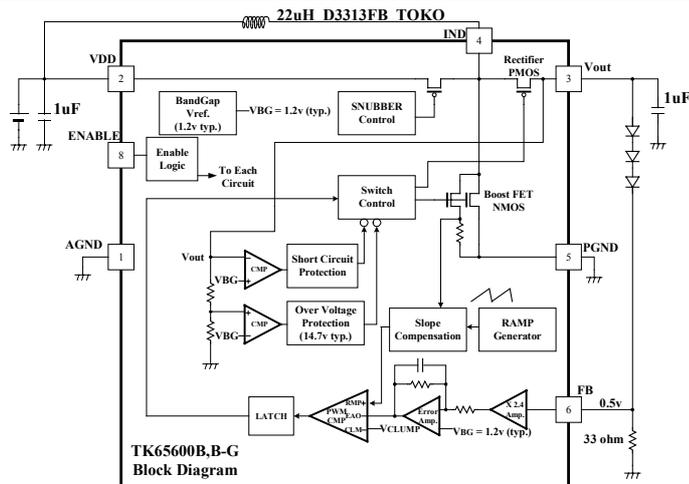


**5. PACKAGE OUTLINE**

- FC-8 (1.46x1.46mm)



## 6. BLOCK DIAGRAM



## 7. ABSOLUTE MAXIMUM RATINGS

 $T_a = 25^\circ\text{C}$ 

Parameter	Symbol	Rating	Units	Conditions
Supply Voltage	$V_{DD}$	6	V	
Mid-voltage pins Voltage	$V_{OUT}$ and $V_{IND}$	16.5	V	$V_{OUT}$ and $V_{IND}$ pins
Power Dissipation	$P_D$	560 (Note 1)	mW	* Internal Limit $T_j = 150^\circ\text{C}$
Storage Temperature Range	$T_{stg}$	-55 ~ +150	$^\circ\text{C}$	
Operating Temperature Range	$T_{OP}$	-30 ~ +85	$^\circ\text{C}$	
Operating Voltage Range	$V_{OP}$	2.7 ~ 5.5	V	
Thermal Resistance	$J_A$	220	$^\circ\text{C}/\text{W}$	Note 1

\*  $P_D$  must be decreased at the rate of 4.545mW/ $^\circ\text{C}$  for operation above 25 $^\circ\text{C}$ .

Note 1: The Absolute Maximum Power Dissipation depends upon the Ambient Temperature and can be calculated using the formula  $P_{DMAX} = (T_{JMAX} - T_A) / (J_A)$

## 8. ELECTRICAL CHARACTERISTICS

 $V_{DD}=3.7V, T_a=T_j=25^{\circ}C$ , unless otherwise specified.

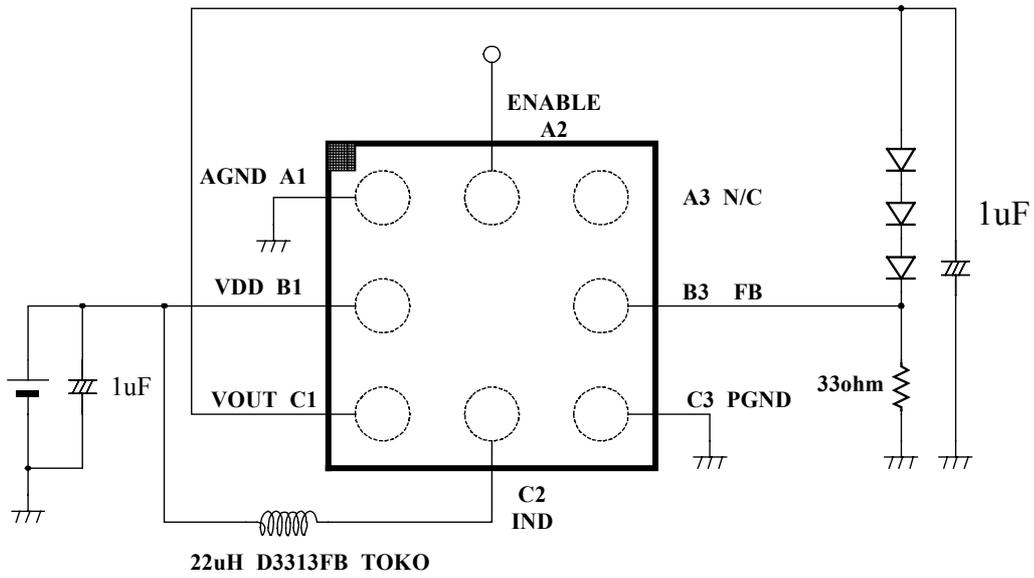
Parameter	Symbol	Value			Units	Conditions
		MIN	TYP	MAX		
Input Supply Range	VDD	2.7	3.7	5.5	V	
Quiescent Current in VDD PIN	IDD		150	500	$\mu A$	VEN>1.2 V
Standby Current	ISTB			2	$\mu A$	VEN < 0.3 V
Enable Full On Voltage	VEN(on)	1.2		VDD +0.3	V	Output on
Enable Off Voltage	VEN(off)	-0.3		0.3	V	Output off
Enable Pin Current	IEN	-5			$\mu A$	
Boost FET Current Limit Setting	ILIM	250		450	mA	VDD=3v
		210		410		Ta=-30 to 85°C
Boost FET On Resistance (Note 3)	RDS(ON)	0.6	1.0	1.5	$\Omega$	VOUT=10.0v
Over Voltage Protection	OVP	14.0	14.7	15.5	V	No Load
		13.8		16.1	V	Ta=-30 to 85°C
Synchronous Rectifier on Resistance (Note 3)	RSYNCH		3.0		$\Omega$	VOUT=10.0v
Feedback Reference Voltage	VFB	0.46	0.5	0.53	V	
		0.43		0.56	v	Ta=-30 to 85°C
Average Current flowing through LED	I LED (SET)	14	15	16	mA	Rsense=33.2 $\Omega$ , 1% VEN>1.2 V
Variation of Average Current through LED (Note 3)	I LED (VAR)	-1.5	I LED (SET)	+1.5	%	2.7V<VDD<5.5V
I LED LINE Regulation (Note 3)	I LED (LINE)			0.161	mA/V	2.7V<VDD<5.5V I LED=15mA
Boost Frequency	F BOOST	575	700	825	kHz	Ta=-30 to 85°C
Boost Maximum Duty Cycle	DC (MAX)		85	95	%	
				95	%	Ta=-30 to 85°C
Output Voltage Ripple (Note 3)	$\Delta V$ OUT		50		mV	(Note 1)
Maximum Power Output (Note 3)	P OUT MAX	324			mW	VDD=3V
		300			mW	VDD=3V, Ta=-30 to 85°C
Boost Converter Efficiency	EFF		78		%	L=27uH D31FB
			72		%	L=22uH D3313FB
Start-Up Setting Time (Note 3)	T START		300		$\mu s$	(Note 1)

Note 1: When using pictured test circuit

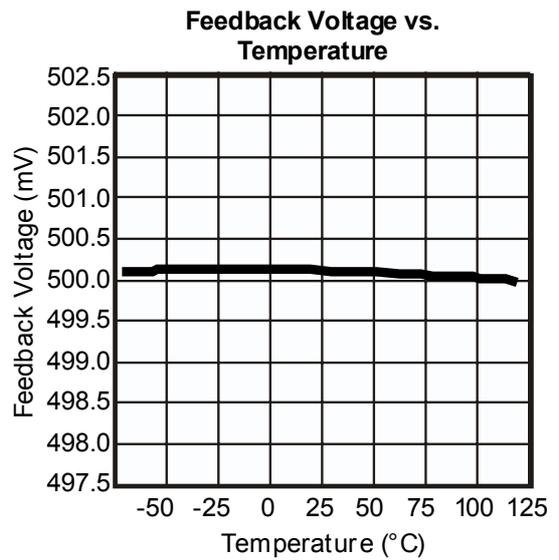
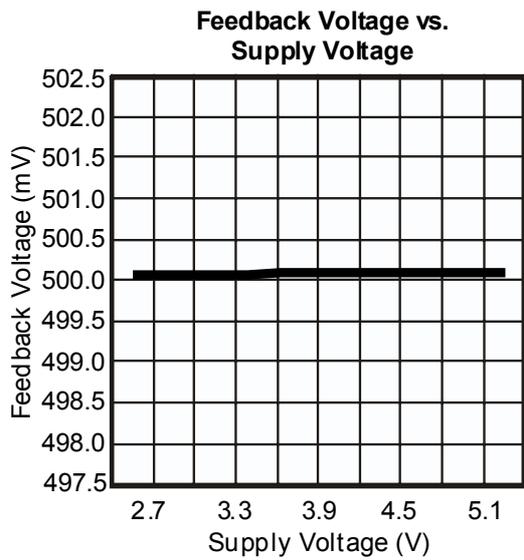
Note 2: Converter efficiency is partly dependent upon the DC resistance of the inductor L

Note 3: Guaranteed by Design. Not Production Tested.

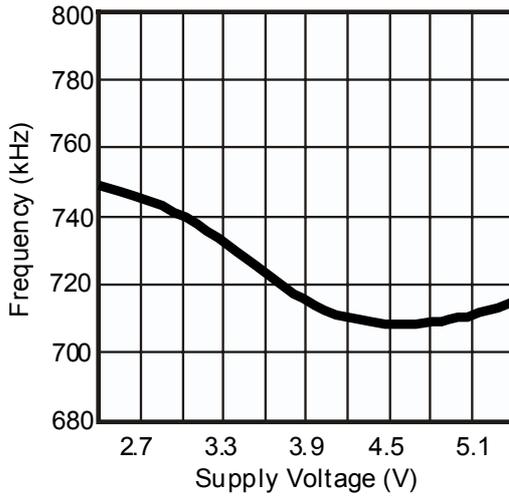
**9. TEST CIRCUIT**



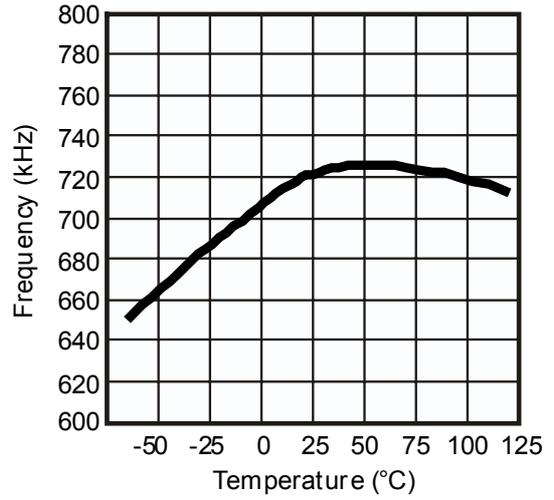
**10. TYPICAL CHARACTERISTICS**



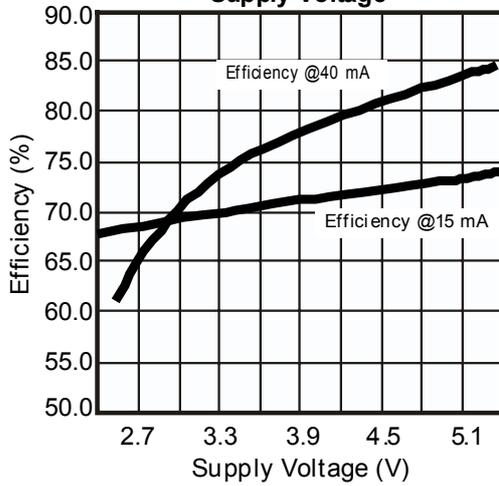
Frequency vs. Supply Voltage



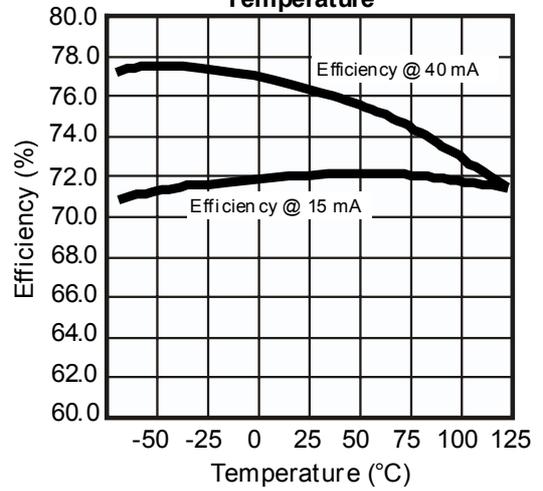
Frequency vs. Temperature



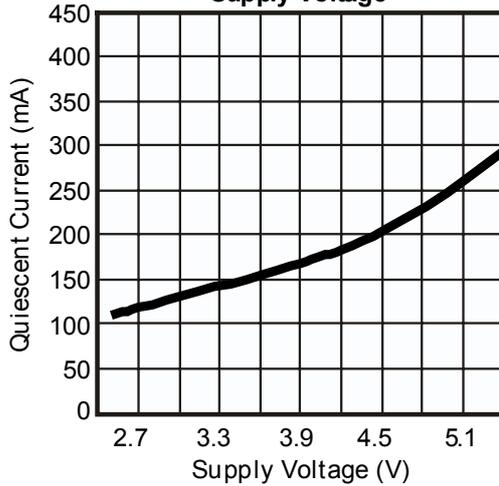
Efficiency (22µH D3313FB Coil) vs. Supply Voltage



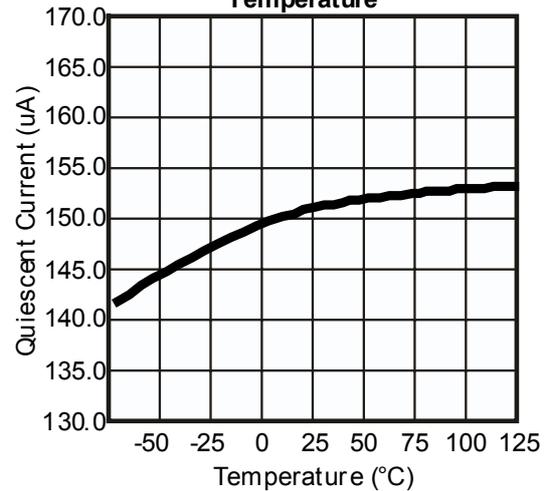
Efficiency (22µH D3313FB coil) vs. Temperature

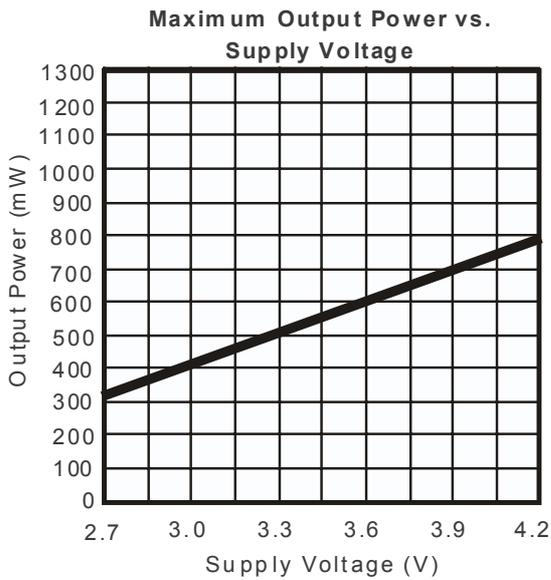
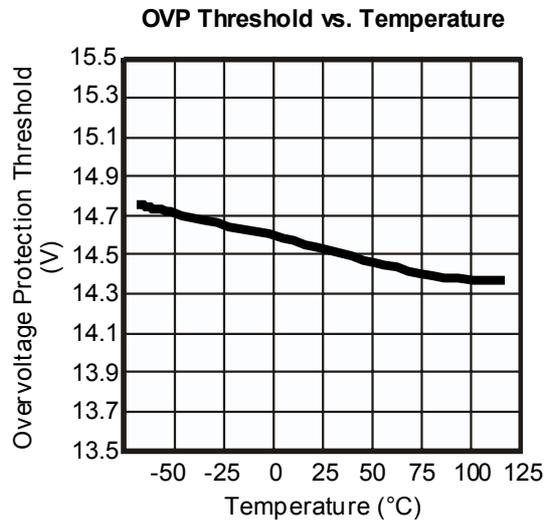
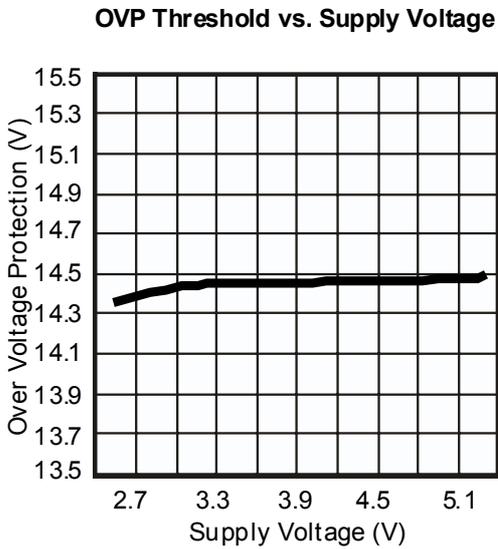
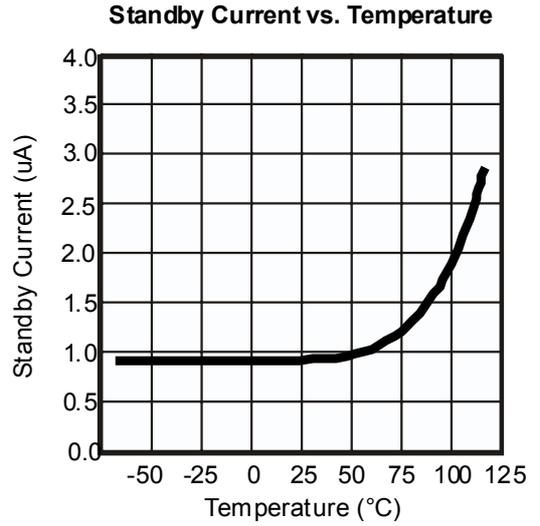
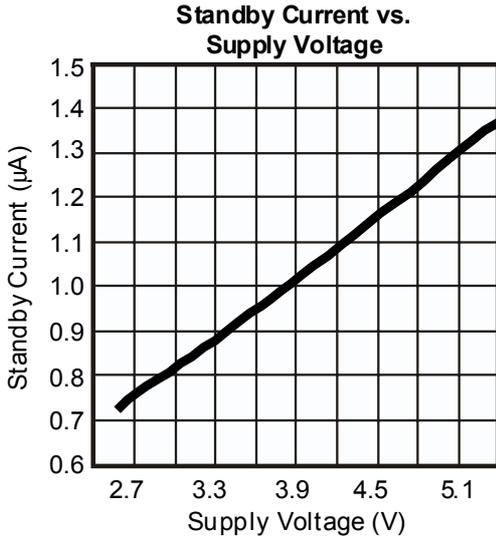


Quiescent Current vs. Supply Voltage



Quiescent Current vs. Temperature





## 11. PIN DESCRIPTION

Pin No.	Symbol	Description
A1	AGND	Analog Ground pin. This pin provides return current path to low power circuits supplied current through the $V_{DD}$ pin. In the circuit board connect to PGND pin at ground plane.
A2	ENABLE	Enable input pin. This pin turns on the IC to start switching action. Set the Enable pin higher than 1.2V to enable the IC. Set the Enable pin below 0.3V to disable the IC. Do not leave floating.
A3	N/C	No Connection
B1	$V_{DD}$	Power Supply pin. This pin supplies power to low voltage (< 6V) control circuits in the IC.
B3	FB	Feedback Voltage Regulation input pin. A low voltage input that is regulated to 500mV.
C1	$V_{OUT}$	Output Voltage pin. This pin supplies the voltage to drive the White LEDs. It is a high voltage pin (<16.5V) which is protected by an over voltage protect circuit switch stops IC switching if this pin reaches about 14.5V
C2	IND	Inductor Connection pin. This pin is also a high voltage pin and is connected to the internal boost N-channel MOSFET
C3	PGND	Power Ground pin. This pin provides return current path to high currents flowing to ground through the IND and $V_{OUT}$ pins. In the circuit board connect to AGND pin through ground plane.

## 12. APPLICATIONS INFORMATION

### 12-1. Theory of Operation

The TK65600B,TK65600B-G are inductive white LED driver circuits.

The input voltage is 2.7V up to 6V.

The load is represented by white LED's - one or more parallel strings of LED's, each string consisting of two or more LED's connected in series. The absolute maximum voltage allowed at the output pin is 16.5V, dictated by wafer process limits. The forward drop voltage of the LED's dictates how many LED's can be in a string, as the voltage at the output pin is the voltage across the LED's in series in a string, plus the voltage drop across the feedback resistor. The feedback resistor appears in series with the load, connected between the bottom terminal of the LED string(s) and ground.

The minimum input voltage of 2.7V and the maximum output voltage of about 15V requires this

circuit to be a boost circuit - TK65600 is an inductive boost circuit. The circuit regulates the current in the load, as the light intensity of the LED's depends on the current flowing through them. The LED current information is provided by a feedback resistor, connected between the load and ground. A classical current -mode control loop, using pulse width modulation (PWM) at a fixed frequency, regulates the boost circuit output, such as to maintain the current in the LED's constant. As with any classical current -mode control loop PWM, the boost converter has the feature of pulse by pulse current limiting. On the TK65600 that current loop limit is set to

about 400mA. Therefore, the inductor, which is to be used with the TK65600, should have an  $I_{sat}$  above 400mA.

There are a few additional functions the circuit incorporates:

- Disable - allows the circuit to be turned on and off by an external enable signal (off for  $V_{enable} < 0.3V$ , on for  $V_{enable} > 1.2V$ )
- Over-Voltage Protection (OVP) - shunts off the power FET's if the output voltage rises above a predetermined threshold (14.5v Typical.). This is intended to prevent damage to the circuit for an open load condition, for instance, by not allowing the output voltage to rise above the preset limit.
- Short-Circuit Protection (SCP) - if the output sees an unusually high load or a short-circuit, there is circuitry provided that will cut off the current path to the output, wait a predetermined amount of time, then attempt to restart. If the output short-circuit or heavy loading condition at the output disappeared, the circuit will start and function normally. If the short-circuit condition persists, the circuit will wait again the predetermined amount of time, then it will attempt to restart again. The high load or short-circuit condition is identified, for the purpose of this feature, by a low output voltage (less than 1.2V). In order to provide for start-up condition (when the output voltage is inherently low), the SCP circuitry waits for a little while, before asserting the short circuit condition signal. That little while is set now at sixteen (16) clock cycles, while the reset time, that is, the time before the circuit attempts to restart, it is set now at (512) clock cycles. With a clock of 600kHz, these times are approximately 27us for asserting the short circuit condition signal and about 853us between attempts to restart the boost circuit. A classic boost configuration is not able to provide short circuit protection, as the input voltage source can provide current to the load, through the inductor and diode, even if the circuit is disabled.

A synchronous rectifier is required, in order to be able to provide short circuit protection. The synchronous rectifier (Msr) is replacing the diode found in classic boost circuits. The main advantage is eliminating the need for an external component. The second important advantage is the potential for less voltage drop across this device. A serious drawback is the fact that a FET is a non-directional device, unlike the diode it replaces, so, while the diode operated by itself, careful control of the synchronous rectifier operation is required. The synchronous rectifier must be off, at all times when the inductor switch is on - otherwise, shoot-through current from the boost capacitor, through the synchronous rectifier and through the inductor switch, to the ground, can occur - this cannot be allowed to happen, because of its effect on efficiency.

A second issue to consider when driving the synchronous rectifier is the fact that, the FET being a non-directional device, the drive circuitry must ensure that the synchronous rectifier is on only when the boost voltage (output) is smaller than the voltage at the inductor node - otherwise, the boost (output) capacitor will discharge through the synchronous rectifier FET and inductor, to the input voltage source (Vdd).

When the inductor switch is off and the synchronous rectifier it is held off because the inductor voltage is smaller than the boost voltage, both power FET's (Mind and Msr) are off. When this happens, the remaining energy in the inductor may be enough to start ringing, using the inductor and whatever parasitic capacitance can find (both Mind and Msr are large devices, with large parasitic capacitance). The resulting oscillations can be large enough to trigger the hysteresis comparator in the internal synchronous rectifier driver circuitry. Also, this ringing oscillation may cause noise in other parts of the application's system. To avoid these effects, a snubber circuit is used, to short the inductor node not to ground (that would be a loss of energy), but back to Vdd (charging back the source). The snubber circuit must carefully select the moment when Mind and Msr are off, following the current ramp-up in the inductor, and NOT preceding it. The state machine inside the snubber does that. There is another moment when both Mind and Msr are off at the same time - when the inductor switch is cut off, after ramping the current in the inductor, but the synchronous rectifier, Msr, is not yet on (due to delays in circuitry, etc.). At this point in time, the inductor node voltage is highest and no snubber effect is acceptable.

## 12-2. Circuit Board Layout

As with all switching power converters, care should be given to the circuit board layout. The bolded lines, on the schematic in Figure 1, show where the high current paths of switched currents are in the circuit. The circuit board traces for these paths should be short and wide to minimize the power losses and electromagnetic interference generated from the switching currents. Therefore  $C_{in}$ ,  $L$  and  $C_{out}$  should be located close to the IC in the circuit board layout. Also, the circuit board layout should keep the sense resistor close to the IC such that there is no voltage differences in the ground references.

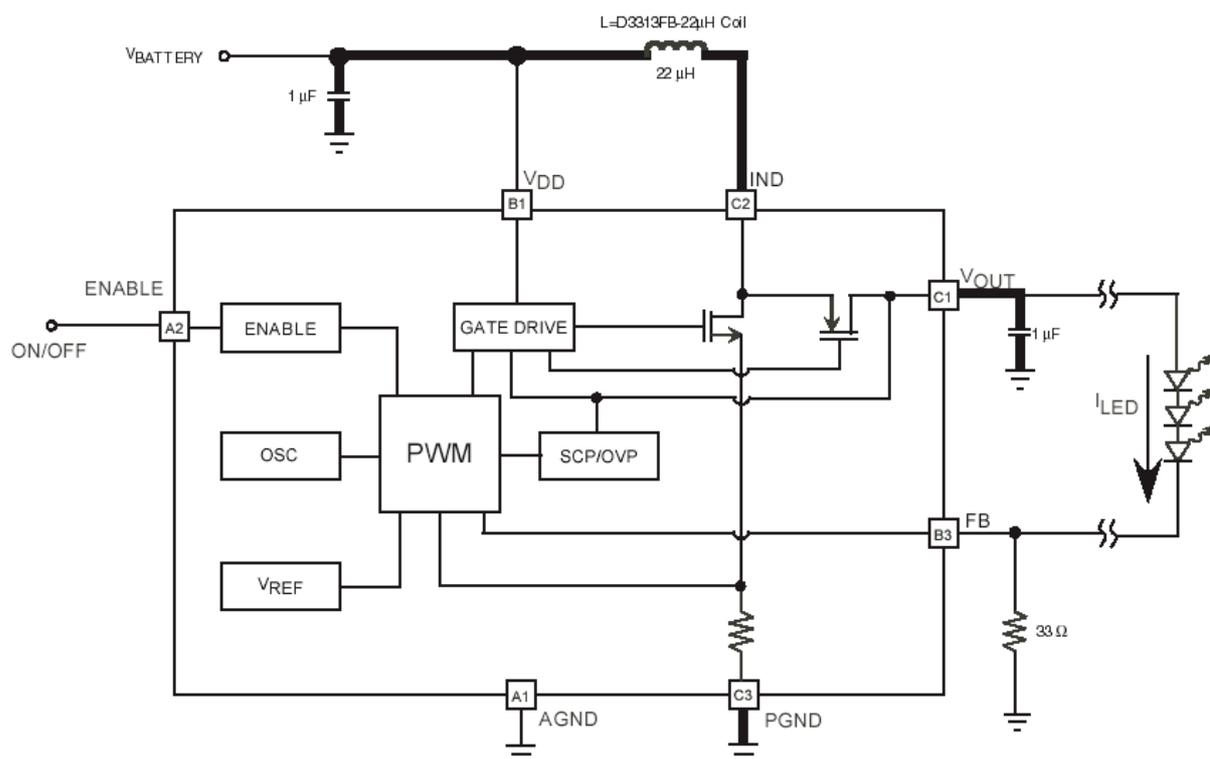


Figure 1: High Current Switching Paths in Step-up Converter

## 12-3. Inductor Selection

The inductor is the main energy storage element used in boosting the output voltage to drive the white LEDs. This requires that the inductor be properly selected to match the output power requirements of the white LEDs to be driven in a given application. Also, selecting an inductor larger than needs be for a given application can be a waste of precious board space in a small mobile product. Presently, a good inductor matched to be used with this IC (except in output power applications over about 480mW) is TOKO's 22uH D3313FU type inductor.

### 12-4. PWM Dimming

Apply a PWM signal to the ENABLE pin (Ball A2). A signal frequency of approximately 200 Hz is adequate. The average brightness 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 above 1.2 V and a low level below 0.3 V, with a driving current over 8μA.

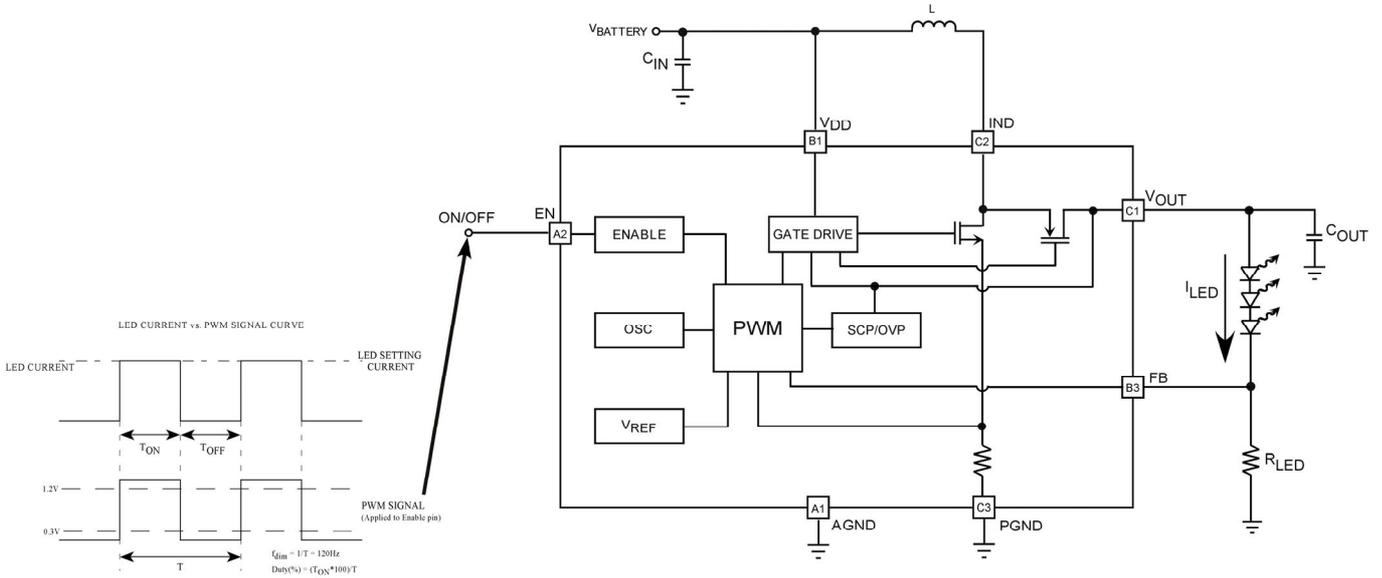
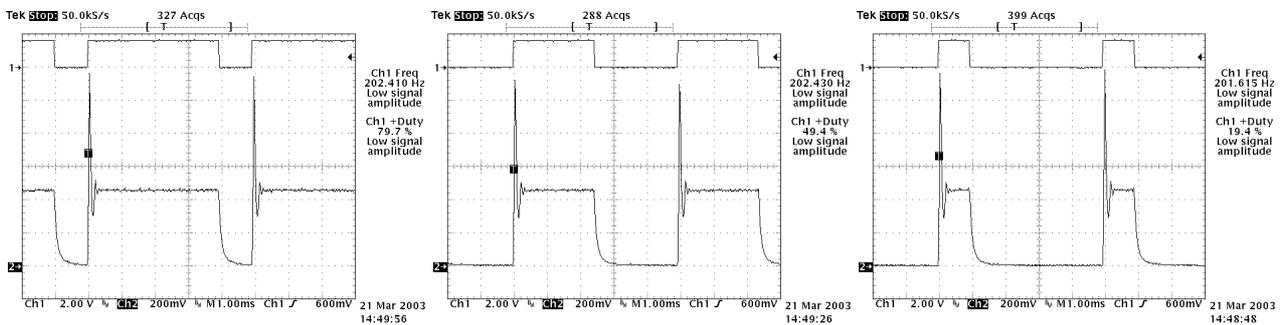


Figure 2: Dimming by PWM signal

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

$$I_{LED(Avg)} = I_{LED(Max)} * \frac{Duty}{100} \quad \text{Where } I_{LED(Max)} = \frac{V_{REF}}{R_{LED}}$$

The graphs below show examples with  $I_{LED(MAX)} = 15mA$  at a Duty Cycle of 80%, 50% and 20%.



**12-5. APPLICATION CIRCUITS**

**12-5-1. APPLICATION CIRCUIT (3 LEDs in Series)**

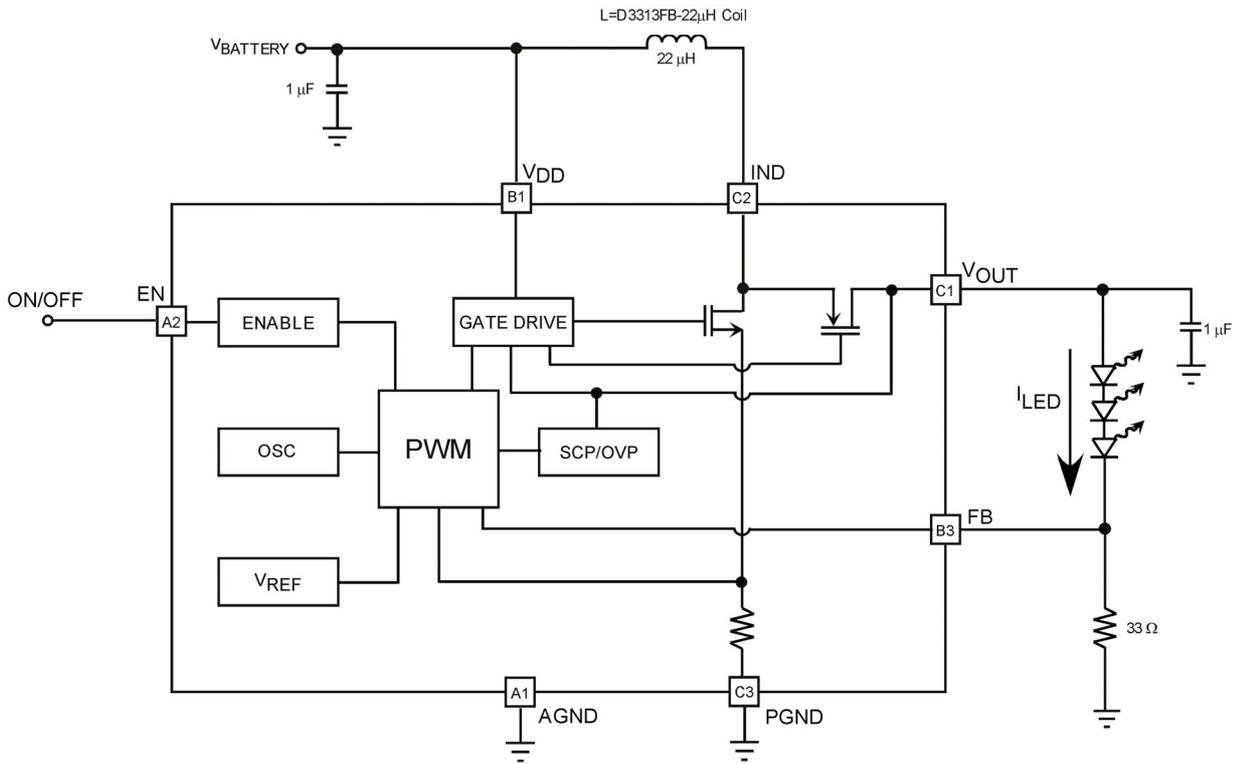
●LED Current: 13mA

L: 22μH

Type D3313FB Toko Sample Number: -220M

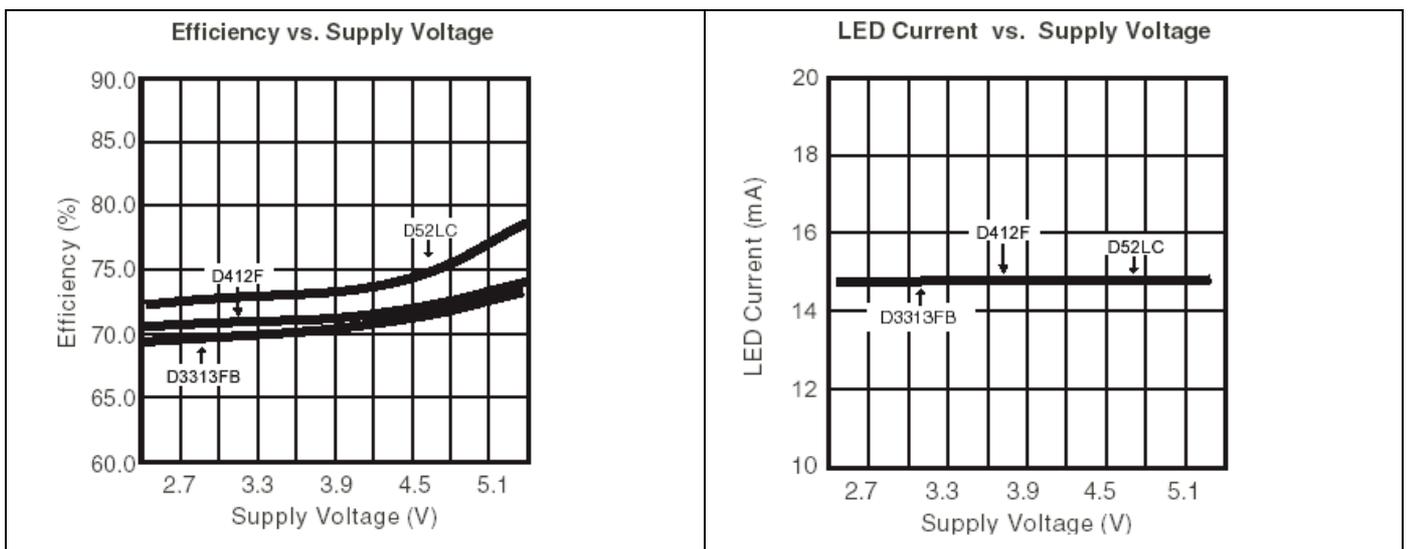
Type D412F Toko Sample Number: 972AS-220M

Type D52LC Toko Sample Number A914BYW-220M



**LED Current and Efficiency Characteristics**

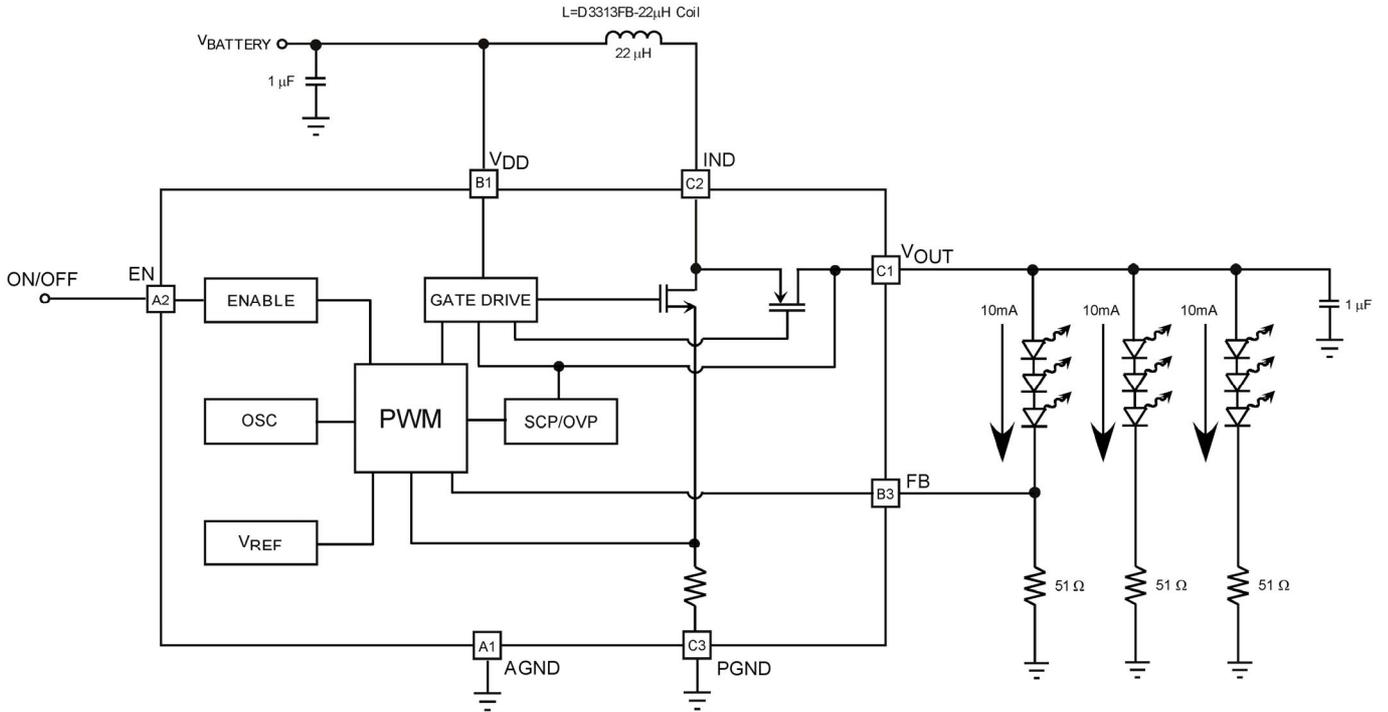
$$\text{Efficiency (\%)} = 100 * V_{\text{OUT}} * \frac{I_{\text{LED}}}{V_{\text{IN}} * I_{\text{IN}}}$$



**12-5-2. APPLICATION CIRCUIT (9 LEDs in 3 x (3branches))**

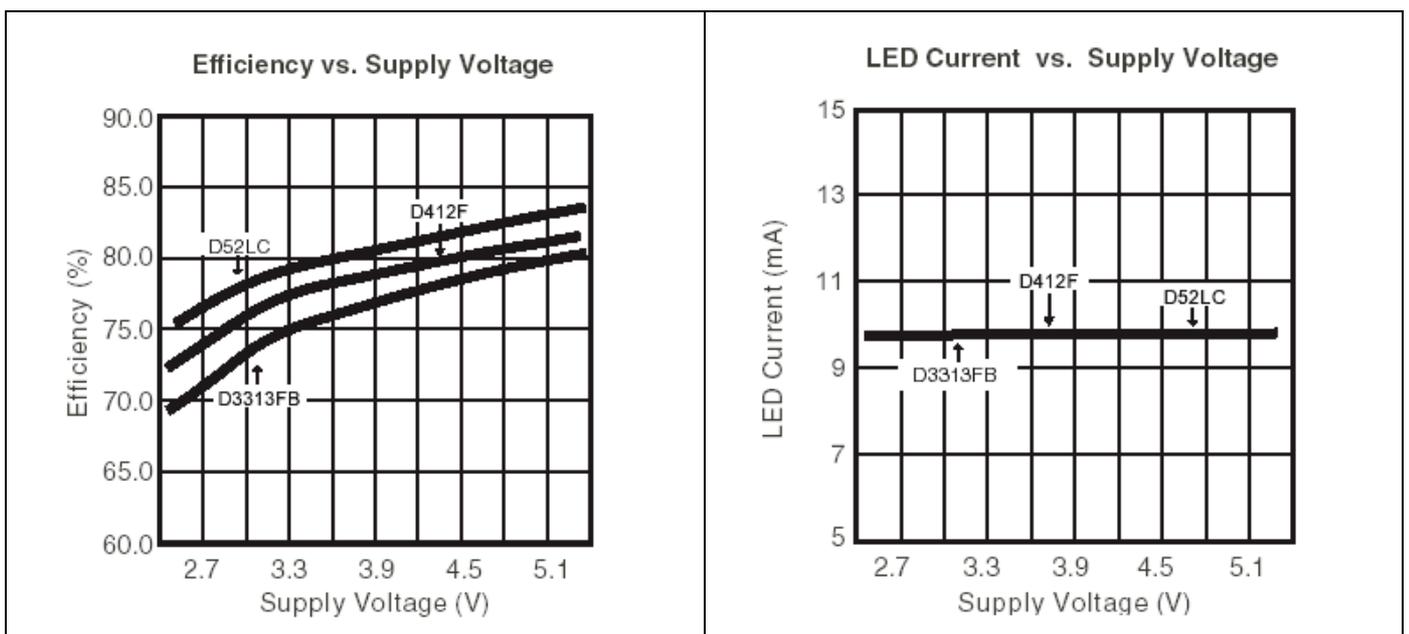
●LED Current: 10mA

L: 22μH Type D3313FB Toko Sample Number: -220M  
 Type D412F Toko Sample Number: 972AS-220M  
 Type D52LC Toko Sample Number A914BYW-220M



**LED Current and Efficiency Characteristics**

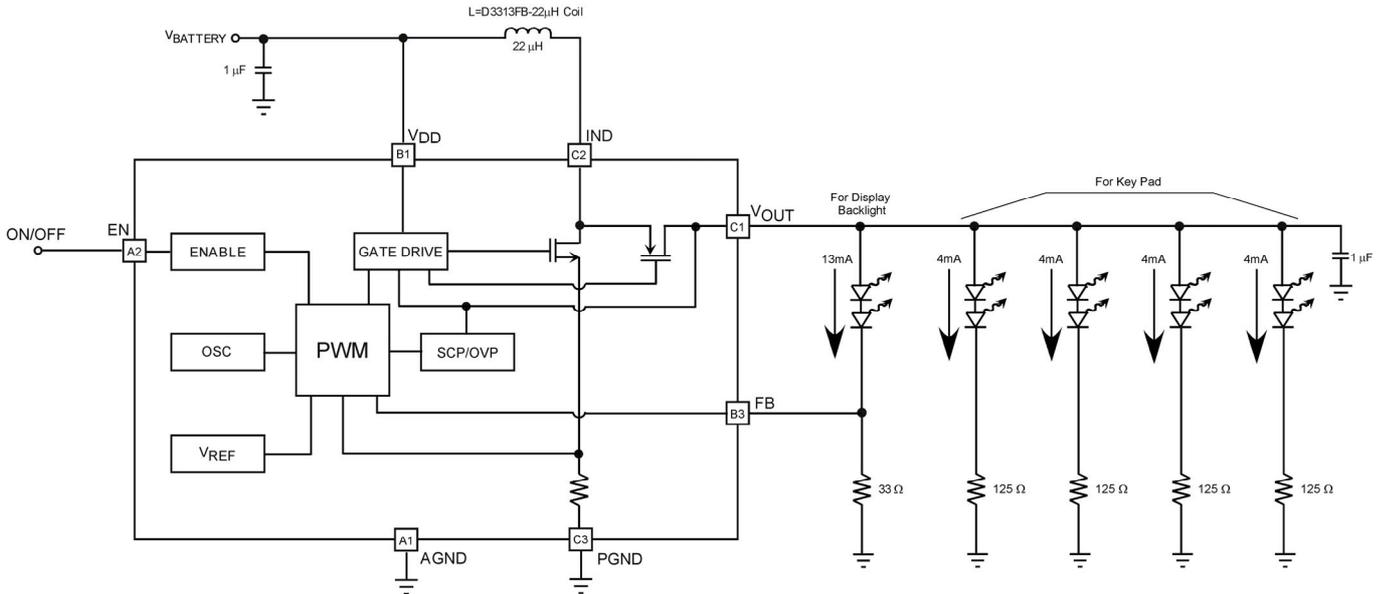
$$\text{Efficiency (\%)} = 100 * V_{\text{OUT}} * \frac{I_{\text{LED}}}{V_{\text{IN}} * I_{\text{IN}}}$$



**12-5-3. APPLICATION CIRCUIT (10 LEDs in 2 x (5branches))**

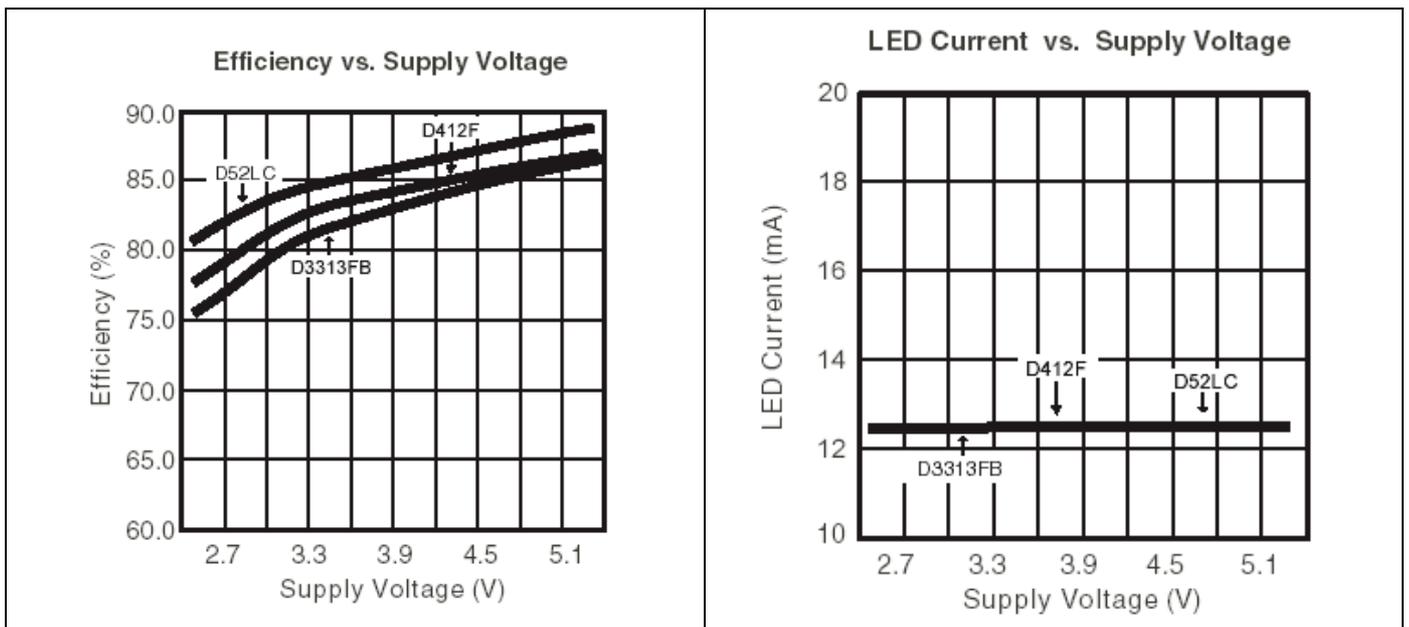
- Display Backlight Current: 13mA
- Keypad Current: Each branch 4mA

L: 22μH      Type D3313FB Toko Sample Number: -220M  
 Type D412F Toko Sample Number: 972AS-220M  
 Type D52LC Toko Sample Number A914BYW-220M



**LED Current and Efficiency Characteristics**

$$\text{Efficiency (\%)} = 100 * V_{OUT} * \frac{I_{LED}}{V_{IN} * I_{IN}}$$



**13. NOTES**

■ Please be sure that you carefully discuss your planned purchase with our office if you intend to use the products in this application manual under conditions where particularly extreme standards of reliability are required, or if you intend to use products for applications other than those listed in this application manual.

- Power drive products for automobile, ship or aircraft transport systems; steering and navigation systems, emergency signal communications systems, and any system other than those mentioned above which include electronic sensors, measuring, or display devices, and which could cause major damage to life, limb or property if misused or failure to function.

- Medical devices for measuring blood pressure, pulse, etc., treatment units such as coronary pacemakers and heat treatment units, and devices such as artificial organs and artificial limb systems which augment physiological functions.

- Electrical instruments, equipment or systems used in disaster or crime prevention.

■ Semiconductors, by nature, may fail or malfunction in spite of our devotion to improve product quality and reliability. In addition, flip chip devices could cause misoperation when they are exposed to direct sunlight or when they are brought very near to light sources like halogen lamps. We urge you to take every possible precaution against sunlight, some light sources, physical injuries, fire or other damages which may cause failure of our semiconductor products by taking appropriate measures, including a reasonable safety margin, malfunction preventive practices and fire-proofing when designing your products.

■ This application manual is effective from May 2004. Note that the contents are subject to change or discontinuation without notice. When placing orders, please confirm specifications and delivery condition in writing.

■ TOKO is not responsible for any problems nor for any infringement of third party patents or any other intellectual property rights that may arise from the use or method of use of the products listed in this application manual. Moreover, this application manual does not signify that TOKO agrees implicitly or explicitly to license any patent rights or other intellectual property rights which it holds.

■ None of the ozone depleting substances(ODS) under the Montreal Protocol are used in our manufacturing process.

**14. OFFICES**

If you need more information on this product and other TOKO products, please contact us.

■ TOKO Inc. Headquarters  
1-17, Higashi-yukigaya 2-chome, Ohta-ku, Tokyo,  
145-8585, Japan  
TEL: +81.3.3727.1161  
FAX: +81.3.3727.1176 or +81.3.3727.1169  
Web site: <http://www.toko.co.jp/>

■ TOKO America  
Web site: <http://www.toko.com/>

■ TOKO Europe  
Web site: <http://www.tokoeurope.com/>

■ TOKO Hong Kong  
Web site: <http://www.toko.com.hk/>

■ TOKO Taiwan  
Web site: <http://www.toko.com.tw/>

■ TOKO Singapore  
Web site: <http://www.toko.com.sg/>

■ TOKO Seoul  
Web site: <http://www.toko.co.kr/>

■ TOKO Manila  
Web site: <http://www.toko.com.ph/>

■ TOKO Brazil  
Web site: <http://www.toko.com.br/>



TO BUILD THE QUALITY RELIED UPON BY CUSTOMERS

**Semiconductor Division**

YOUR DISTRIBUTOR