APPLICATION MANUAL

WLED DRIVER IC with SMBus
TK61224BQ5

CONTENTS

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WLED DRIVER IC with SMBus
TK61224BQ5

1. DESCRIPTION

TK61224BQ5 is a White LED driver IC for medium-sized displays such as Laptop PCs. It can drive up to four to six strings of ten white LEDs in series. Each string has constant current sources and stabilizers to drive up to 25mA. This part contains a boost DC-DC converter to drive the internal power MOSFET, and the switching frequency can be tuned by an outside resistor, from 200kHz to 2MHz allowing the use of a small inductor.
It has over-voltage protection function, over-current protection function and UVLO function.
TK61224BQ5 has two brightness control inputs, PWM and SMBus. It supports Intel DPST (Display Power Saving Technology). The signal for the brightness control modes and brightness level are received via SMBus.

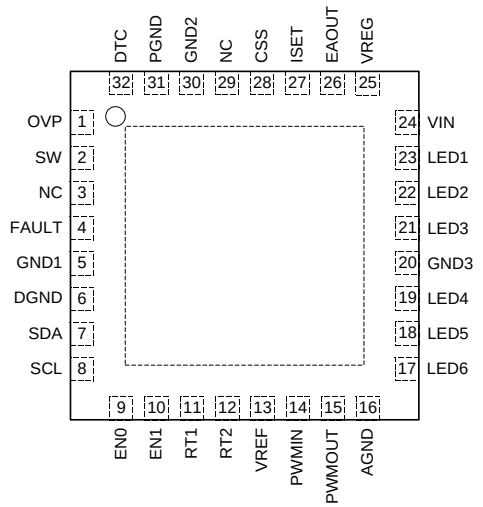
2. FEATURES

- Capable of driving 4 to 6 strings of 10 WLEDs in series
- Internal Switching FET
- Internal six Current Stabilizers (Each up to 10 LEDs at 25mA)
- Internal LDO (Single Input-Voltage)
- Wide Input-Voltage Range (4.25V to 25V)
- Brightness control
  - SMBus mode by SMBus Signal input
  - PWM mode by duty of PWM waveform
  - DPST mode on the basis of SMBus
  - 8 bit accuracy
- Adjustable Oscillation Frequency, Max 2.0MHz
- Over-voltage protection
- Over-current protection
- UVLO
- Thermal protection
- Small 32-pin, 5.0mm × 5.0mm, HQFN Package

3. APPLICATIONS

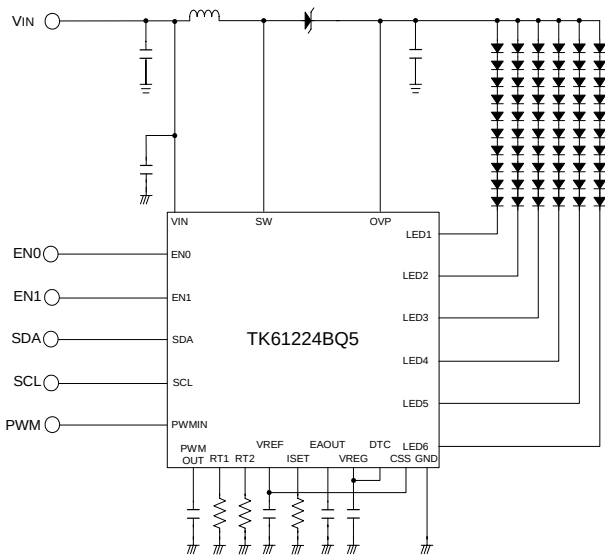
- White LED Backlight for Laptop PC Display
- White LED Backlight for a medium-sized LCD Display
- Lighting installation driver

4. PIN CONFIGURATION



(TOP VIEW)

5. TYPICAL APPLICATION



MODE	EN0	EN1	Active LED Strings
Shut down	L	L	Shut down mode
6 strings	H	L	LED1, LED2, LED3, LED4, LED5, LED6
5 strings	L	H	LED1, LED2, LED3, LED4, LED5
4 strings	H	H	LED1, LED2, LED3, LED4

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6. ABSOLUTE MAXIMUM RATING(*1)

Parameter	Symbol	Rating	Units	Conditions
VIN, FAULT	V_{LDO}, V_{FAULT}	-0.3 to +35	V	
SW, OVP, LED1-6	V_{SW}, V_{OVP}, V_{LED1-6}	-0.3 to +50	V	
SW Current	I_{SW}	2.6	A	
VREG, DTC, EN0, EN1, SCL, SDA, PWMIN	-	-0.3 to +6	V	
VREF	V_{REF}	-0.3 to (V_{REG} + 0.3)	V	
EAOUT, RT1, RT2, CSS, ISET, PWMOUT	-	-0.3 to (V_{REF} + 0.3)	V	
LED1-6 Drive Current	I_{LED1-6}	30	mA	
Continuous Power Dissipation	P_D	2500	mW	*2, *3
Storage Temperature Range	T_{STG}	-55 to +150	°C	

Note:
*1. All voltages are with respect to the potential at the GND pins (GND1, GND2, GND3, PGND, DGND, AGND).
*2. P_D must be decreased at the rate of 20mW/°C for operation above 25°C.
*3. TK61224BQ5 operates on the FR-4 type evaluation board(80mm × 90mm).

7. ELECTRICAL CHARACTERISTICS

Recommended Operating Range

Parameter	Symbol	Value	Units	Conditions
Switching Frequency Range	F_{OSC_SW}	0.2 to 2.0	MHz	
PWM Frequency Range of Brightness Control	F_{OSC_DIM}	0.2 to 2.0	kHz	
VIN Input Voltage Range	V_{OP}	4.25 to 25	V	
Operating Temperature Range	T_{OP}	-40 to +85	°C	

Electrical Characteristics

(PWM Mode, VIN=12V, PGND=DGND=AGND=GND1=GND2=GND3=0V, EN0=5V, EN1=0V, RT1=RT2=40kΩ, R_{SET}=61kΩ, PWMIN=2.5V, DTC=0V, T_A=+25°C, unless otherwise noted.)

Parameter	Symbol	Value			Units	Conditions
		MIN	TYP	MAX		
DC-DC CONVERTER						
VIN Quiescent Current (SW OFF)	I_Q		2	4	mA	
VIN Operating Current (SW ON)	I_{DD}		5	10	mA	SMBus Mode
VIN Standby Current	I_{STB}		2	10	µA	EN0=EN1=0V
UVLO Threshold (Falling Edge)	V_{UVLO}	2.6	2.7	2.8	V	UVLO ON, V_{REG}
UVLO Hysteresis	V_{HYS}		0.2		V	UVLO OFF, V_{REG}
Internal Reference Voltage	V_{REF}	2.45	2.5	2.55	V	
Oscillator Operating Frequency of Switching	F_{OSC_SW}	0.94	1.04	1.14	MHz	RT1=40kΩ
		535	600	685	kHz	RT1=75kΩ
Internal Switch Rds-ON	R_{SW}		300	600	mΩ	I_{SW}=+30mA
Internal Switch OFF Leak Current	I_{LEAK}		0.1	1.0	µA	V_{SW}=50V

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Electrical Characteristics (continued)

Parameter	Symbol	Value			Units	Conditions
		MIN	TYP	MAX		
Maximum Duty Cycle	D_{MAX1}	85	90	95	%	F_{OSC_SW}=1.0MHz, DTC=H
	D_{MAX2}	83	88	93	%	F_{OSC_SW}=1.0MHz, DTC=L
CSS Current	I_{CSS}	0.5	1.0	2.0	µA	
EAOUT Output High Voltage	V_{OH_EA}	1.3	1.5		V	I_{EAOUT}= -100µA
EAOUT Output Low Voltage	V_{OL_EA}		0.1	0.3	V	I_{EAOUT}= +10µA
Error Amplifier Gain	A_V		40		dB	
Reference Voltage for Error Amplifier	V_{REF_EA}	760	800	840	mV	
EN0, EN1 Input High Voltage	V_{IH_EN}	1.2			V	
EN0, EN1 Input Low Voltage	V_{IL_EN}			0.3	V	
DTC Input High Voltage	V_{IH_DTC}	0.8 ×V_{REG}			V	*1
DTC Input Low Voltage	V_{IL_DTC}			0.2 ×V_{REG}	V	*1
Current Sink Circuit and Brightness Control						
Maximum LED Current	I_{LED_MAX}	25			mA	R_{SET}=46kΩ
LED Current	I_{LED_TYP1}	19	20	21	mA	R_{SET}=61kΩ $I_{LED\_TYP}(mA) = \frac{I_{LED(1-6)MAX} + I_{LED(1-6)MIN}}{2}$
	I_{LED_TYP2}	9.5	10	10.5	mA	R_{SET}=125kΩ $I_{LED\_TYP}(mA) = \frac{I_{LED(1-6)MAX} + I_{LED(1-6)MIN}}{2}$
LED Current Difference between Channels	Δ I_{LED}		±3		%	R_{SET}=61kΩ, I_{LED_TYP}=20mA $\Delta I_{LED}(\%) = \frac{I_{LED(1-6)MAX} - I_{LED(1-6)MIN}}{I_{LED(1-6)MAX} + I_{LED(1-6)MIN}} \times 100$
LDO						
Output Voltage	V_{REG}	4.5	5.0	5.5	V	V_{IN}=12V, I_{REG}=10mA
Protection						
Over-voltage Protection Threshold (OVP)	V_{OVP1}	38.5	42		V	*2
	V_{OVP2}	44	46	48	V	*3
Maximum Current Limit of Internal Switch	I_{SW_LIMIT}	2.0	2.3	2.6	A	
Soft-Start Time	T_{SS}	50	100	200	µs	C_{SS}=82pF, *4
FAULT Output ON-Resistance	R_{FAULT}			100	Ω	I_{FAULT}=+10mA
BUS INTERFACE & PWM						
Brightness Control PWM Frequency	F_{OSC_DIM}	1020	1120	1220	Hz	RT2=40kΩ
		230	260	290	Hz	RT2=200kΩ
PWMOUT Output Impedance	R_{PWMOUT}	20	40	80	kΩ	
PWMIN Input High Voltage	V_{IH}	2.1			V	
PWMIN Input Low Voltage	V_{IL}			0.7	V	
PWMIN Input Hysteresis	V_{HYS}		0.2		V	
PWMIN Input Bias Current	I_{IN}	-1		+1	µA	

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Electrical Characteristics (continued)

Parameter	Symbol	Value			Units	Conditions
		MIN	TYP	MAX		
PWMIN Input Frequency Range	F_{PWMIN}	5		50	kHz	
PWMIN Brightness Setting		88	90	92	%	PWMIN duty cycle=90%
		48	50	52	%	PWMIN duty cycle=50%
		8	10	12	%	PWMIN duty cycle=10%
SCL, SDA Input High Voltage	V_{IH}	2.1			V	
SCL, SDA Input Low Voltage	V_{IL}			0.7	V	
SCL, SDA Input Hysteresis	V_{HYS}		0.2		V	
SCL, SDA Input Bias Current	I_{IN}	-1		+1	µA	
SDA Output Low Sink Current	I_{L_SDA}	4	8		mA	V_{SDA}=0.4V
SMBus Operating Frequency	F_{SMB}	10		100	kHz	
SMBus Free Time between STOP and START Condition	t_{BUF}	4.7			µs	
SCL Serial Clock High Period	t_{HIGH}	4.0			µs	
SCL Serial Clock Low Period	t_{LOW}	4.7			µs	
START Condition Set-up Time	$t_{SU:STA}$	4.7			µs	
Hold Time after (Repeated) START Condition. After this period, the first clock is Generated.	$t_{HD:STA}$	4.0			µs	
STOP Condition Set-up Time from SCL	$t_{SU:STO}$	4.0			µs	
Data Set-up	$t_{SU:DAT}$	250			ns	
Data Hold time	$t_{HD:DAT}$	300			ns	

Note:
*1. Guaranteed by design, not production tested.
*2. When OVP voltage surpasses V_{OVP1}, the current of all LED branches decrease to one fifth.
*3. When one or more LED current branches are open, the voltage at OVP is controlled to V_{OVP2}.
*4. The voltage of CSS transition time from 0V to 1.2V.

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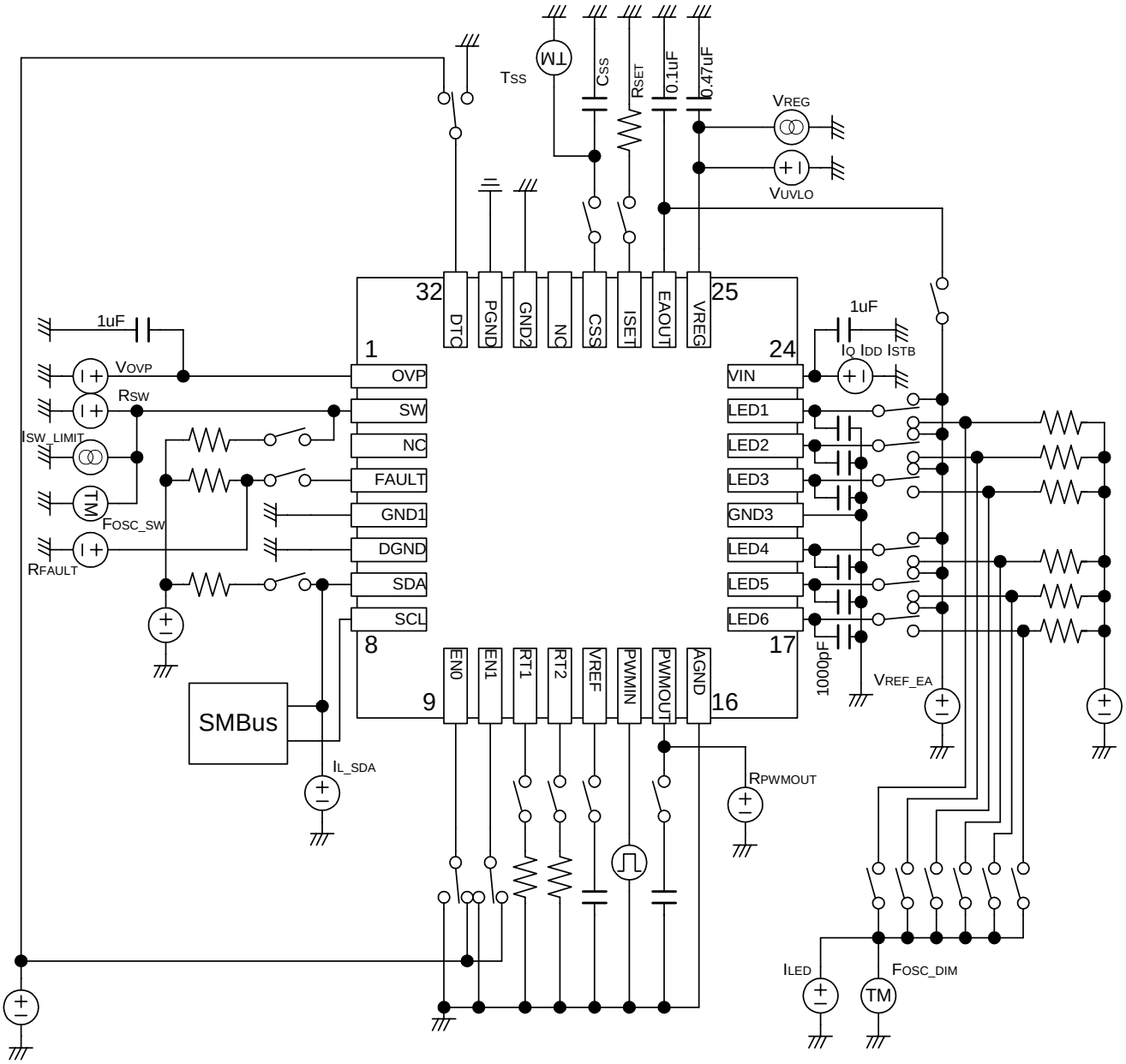
8. TEST CIRCUIT



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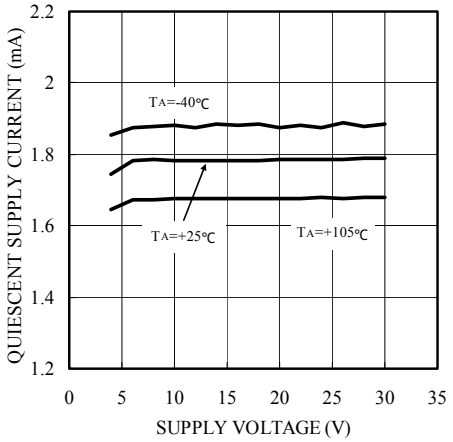
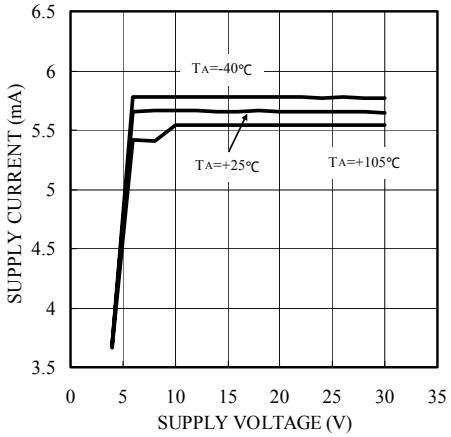
9. TYPICAL CHARACTERISTICS

(PWM Mode, VIN=12V, PGND=DGND=AGND=GND1=GND2=GND3=0V, EN0=5V, EN1=0V, RT1=RT2=40kΩ, RSET=61kΩ, PWMIN=2.5V, DTC=0V, TA=+25°C, unless otherwise noted.)

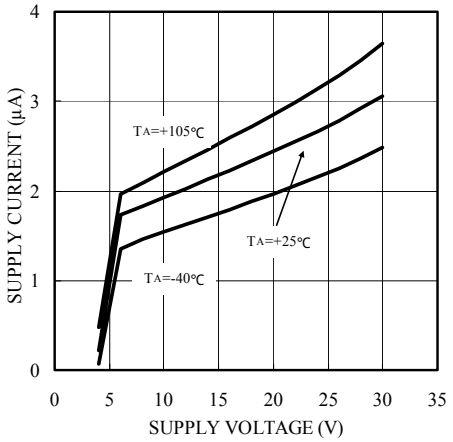
■ Quiescent Supply Current vs. Supply Voltage



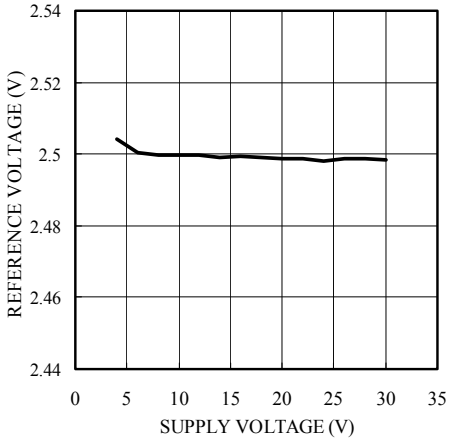
■ Operating Supply Current vs. Supply Voltage



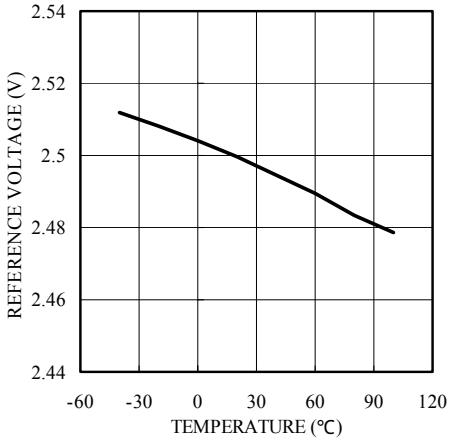
■ Shutdown Supply Current vs. Supply Voltage



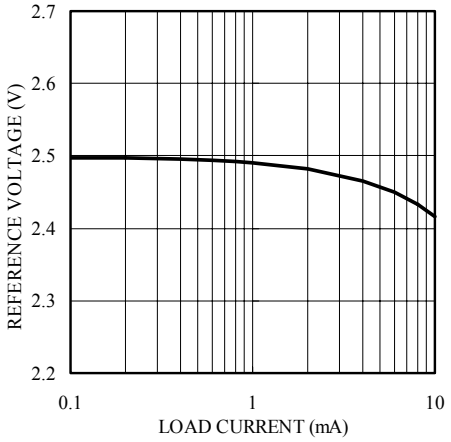
■ Reference Voltage vs. Supply Voltage



■ Reference Voltage vs. Temperature



■ Reference Voltage vs. Load Current



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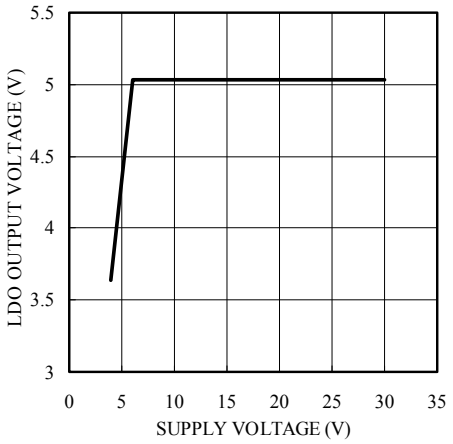
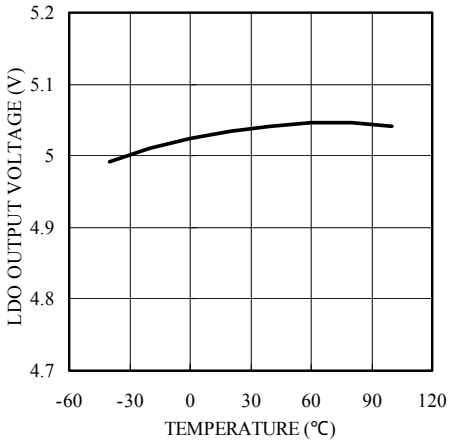
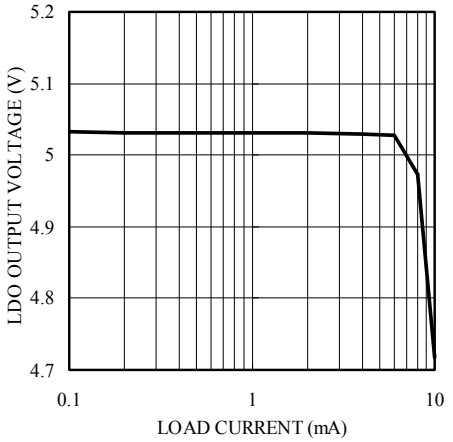
■ LDO Output Voltage vs. Supply Voltage



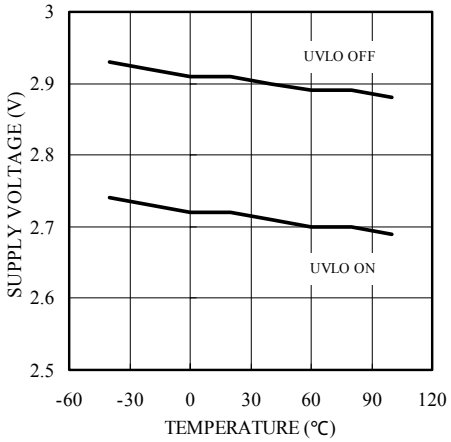
■ LDO Output Voltage vs. Temperature



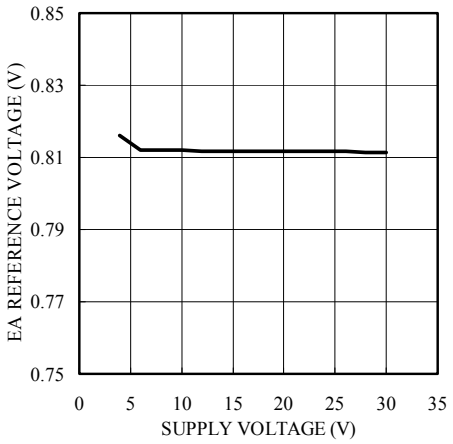
■ LDO Output Voltage vs. Load Current



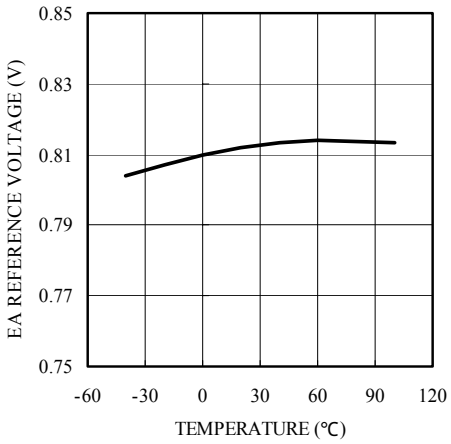
■ UVLO vs. Temperature



■ EA Reference Voltage vs. Supply Voltage



■ EA Reference Voltage vs. Temperature



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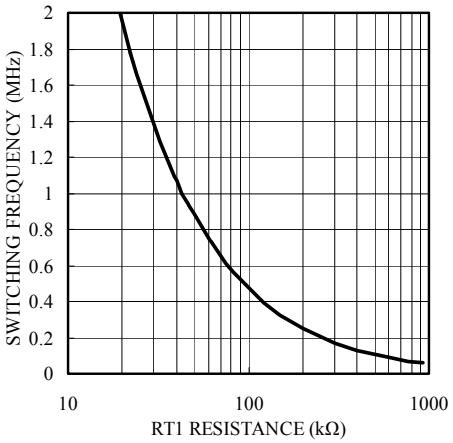
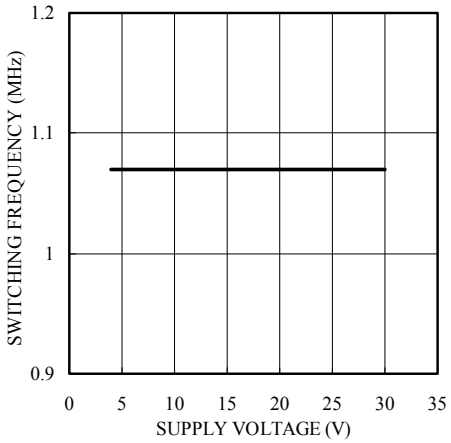
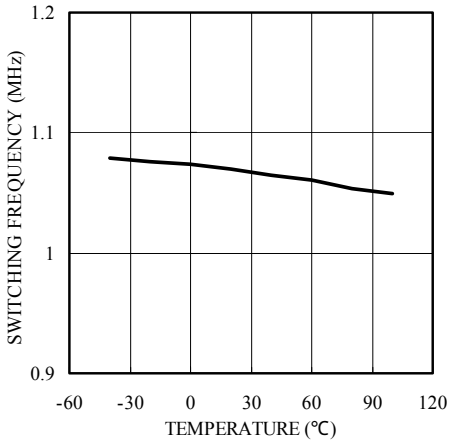
■ Switching Frequency vs. RT1 Resistance



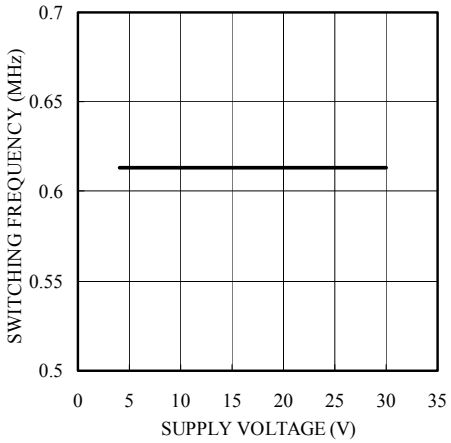
■ Switching Frequency vs. Supply Voltage (RT1=40kΩ)



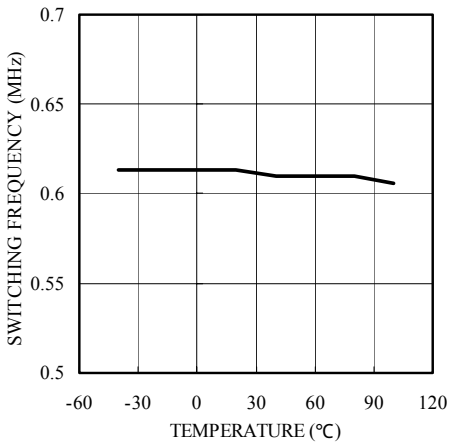
■ Switching Frequency vs. Temperature (RT1=40kΩ)



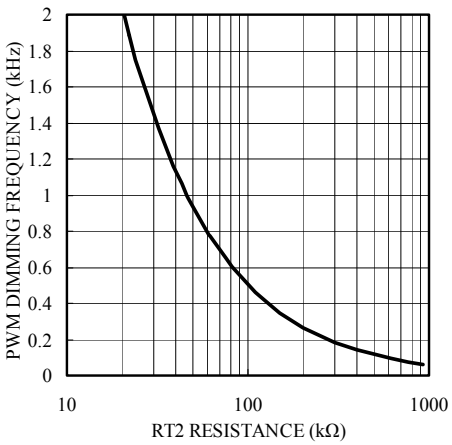
■ Switching Frequency vs. Supply Voltage (RT1=75kΩ)



■ Switching Frequency vs. Temperature (RT1=75kΩ)



■ PWM Dimming Frequency vs. RT2 Resistance



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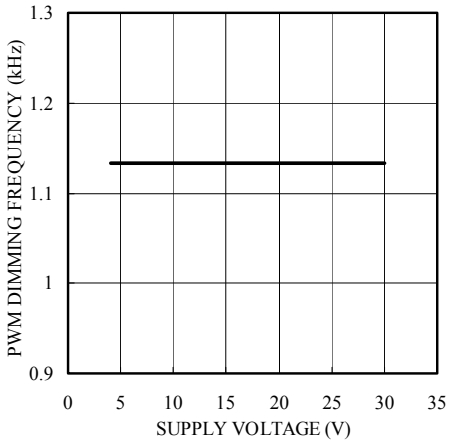
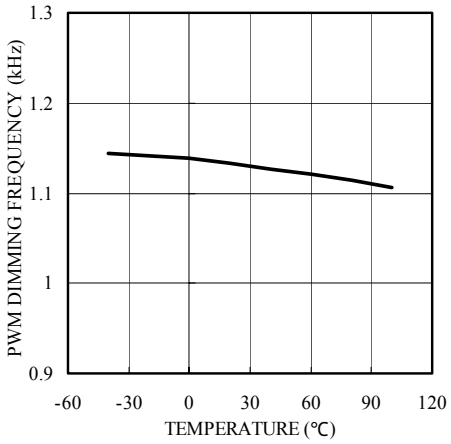
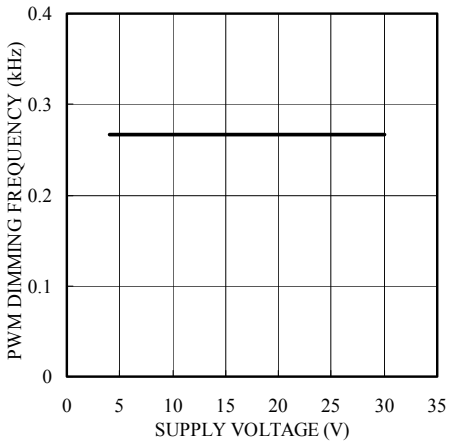
■ PWM Dimming Frequency vs. Supply Voltage (RT2=40kΩ)



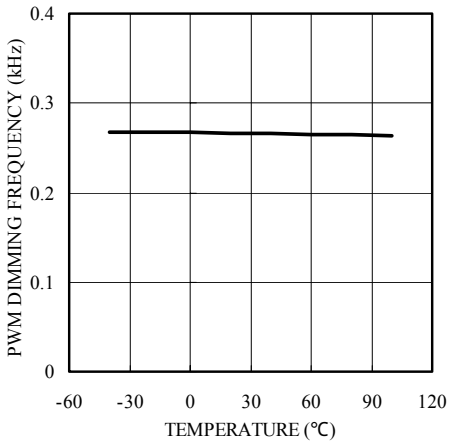
■ PWM Dimming Frequency vs. Temperature (RT2=40kΩ)



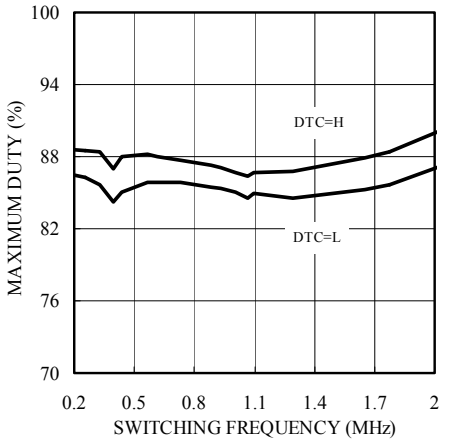
■ PWM Dimming Frequency vs. Supply Voltage (RT2=200kΩ)



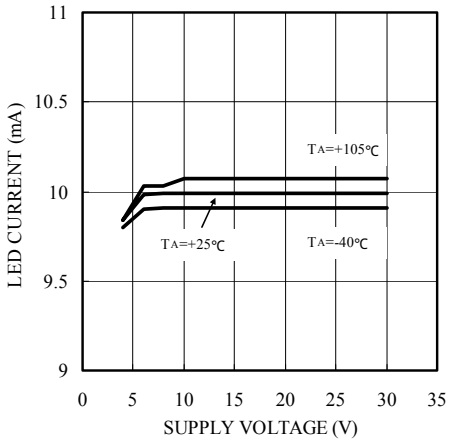
■ PWM Dimming Frequency vs. Temperature (RT2=200kΩ)



■ Maximum Duty vs. Switching Frequency



■ LED Current vs. Supply Voltage (R_{SET}=125kΩ , V_{LED}=0.8V)



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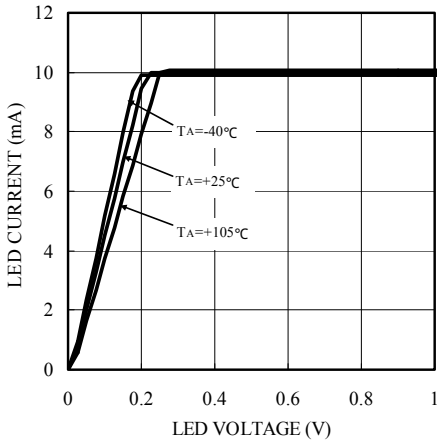
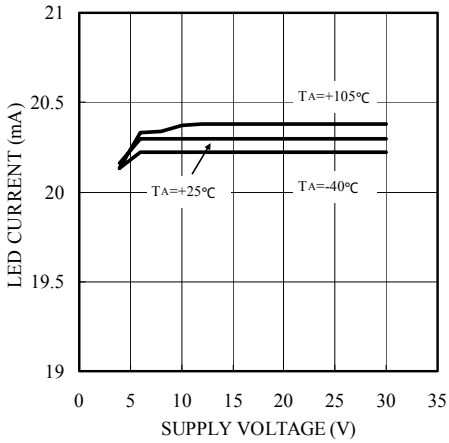
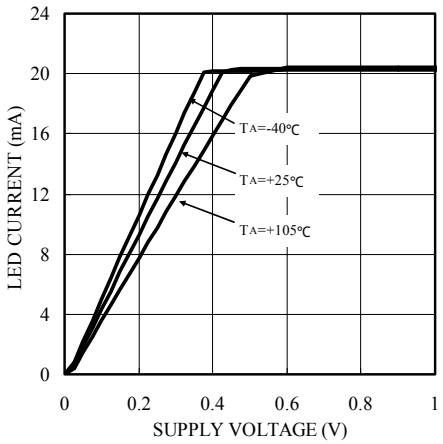
■ LED Current vs. LED Voltage
(RSET=125kΩ)



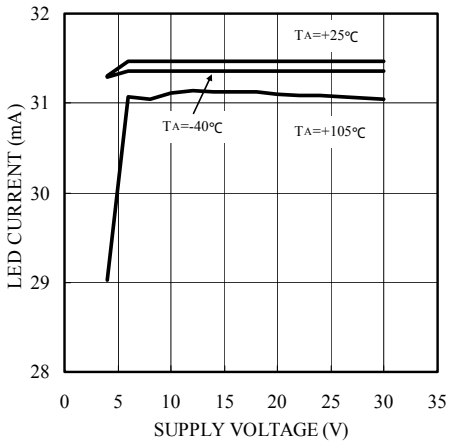
■ LED Current vs. Supply Voltage
(RSET=61kΩ , VLED=0.8V)



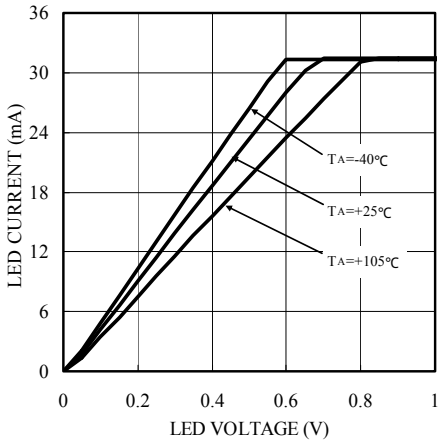
■ LED Current vs. LED Voltage
(RSET=61kΩ)



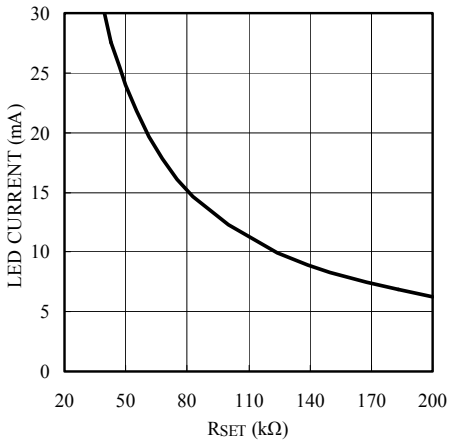
■ LED Current vs. Supply Voltage
(RSET=39kΩ , VLED=0.8V)



■ LED Current vs. LED Voltage
(RSET=39kΩ)



■ LED Current vs. SET Resistance



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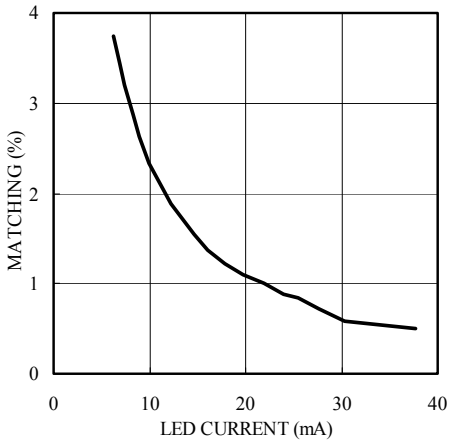
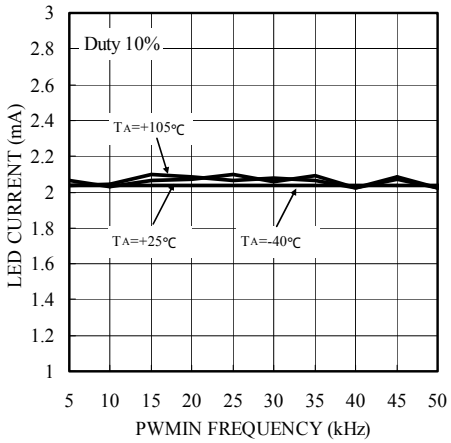
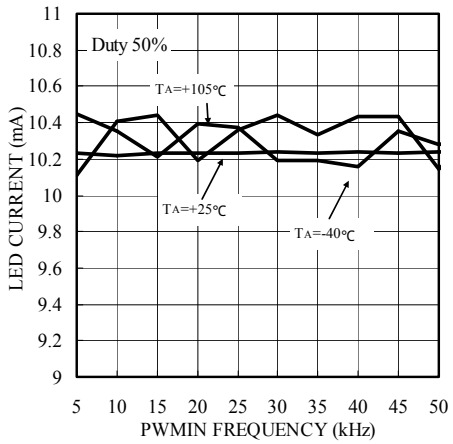
■ LED Current vs. Matching



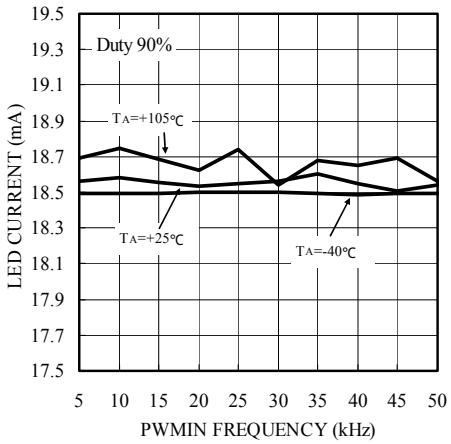
■ LED Current vs. PWMIN Frequency (PWMIN Duty=10%)



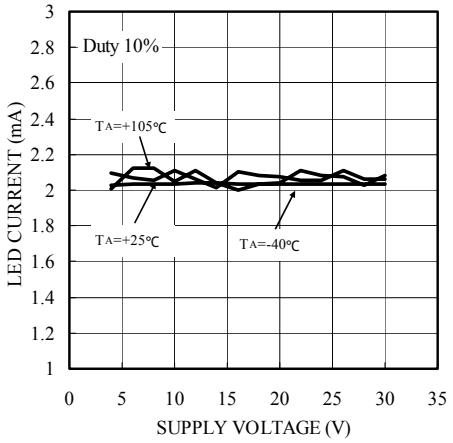
■ LED Current vs. PWMIN Frequency (PWMIN Duty=50%)



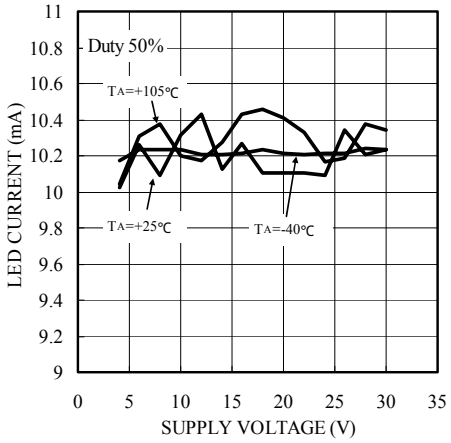
■ LED Current vs. PWMIN Frequency (PWMIN Duty=90%)



■ LED Current vs. Supply Voltage (PWMIN Duty=10%)



■ LED Current vs. Supply Voltage (PWMIN Duty=50%)



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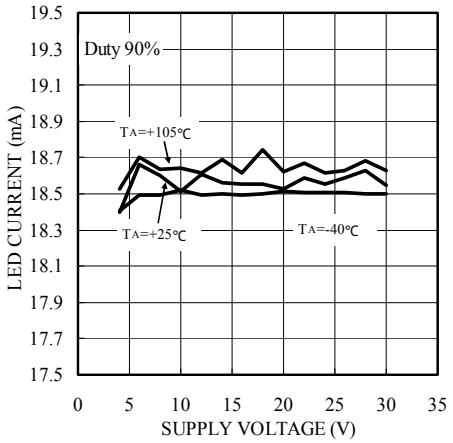
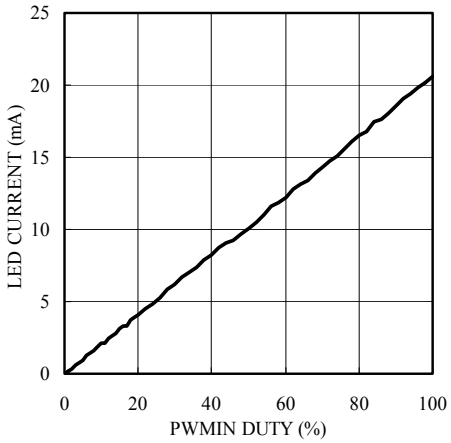
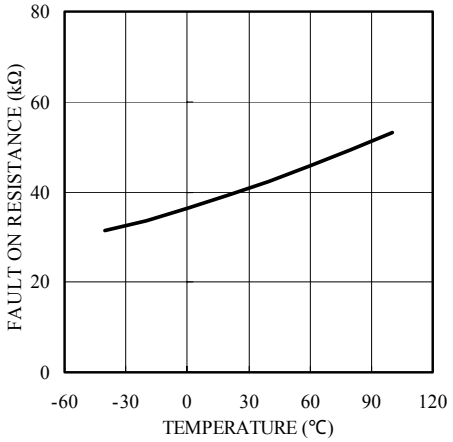
■ LED Current vs. Supply Voltage
(PWMIN Duty=90%)



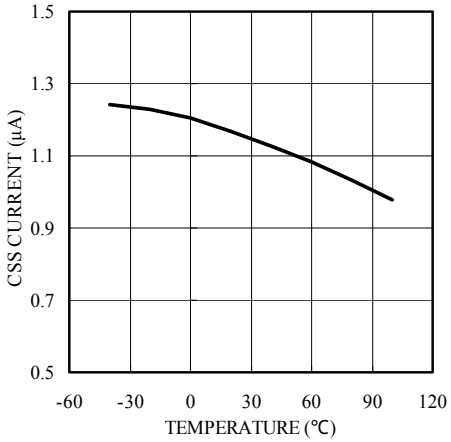
■ LED Current vs. PWMIN Duty
(PWMIN Frequency=10kHz)



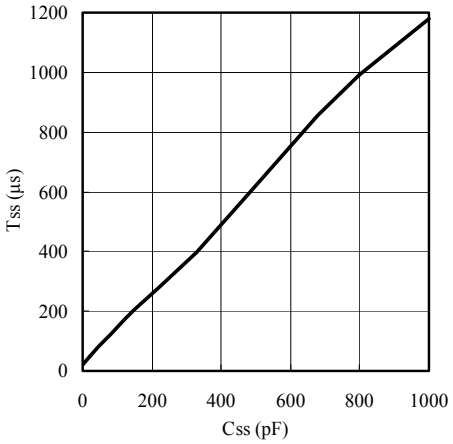
■ CSS Current vs. Supply Voltage



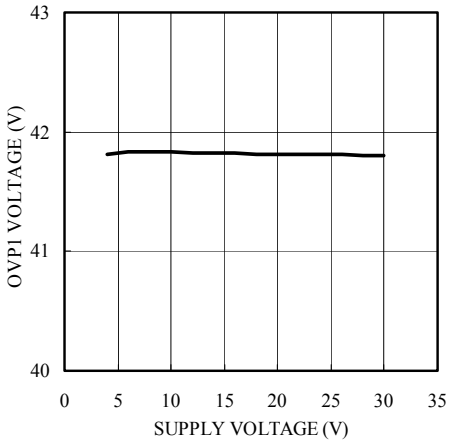
■ CSS Current vs. Temperature



■ Soft Start Time vs. Soft Start Capacitance



■ OVP1 Voltage vs. Supply Voltage



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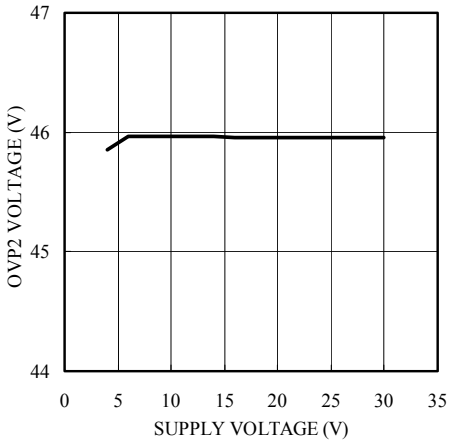
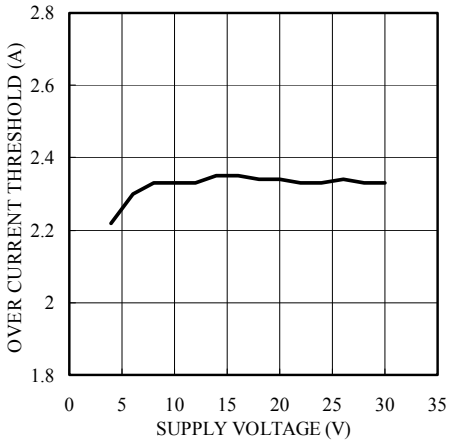
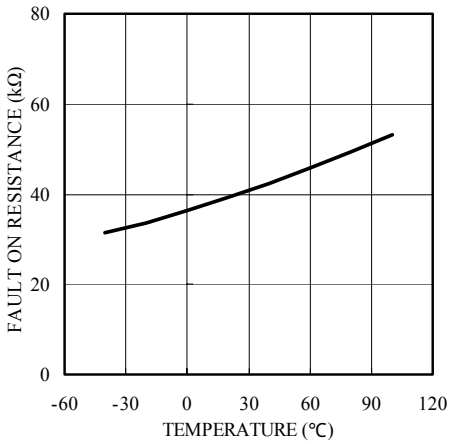
■ OVP2 Voltage vs. Supply Voltage



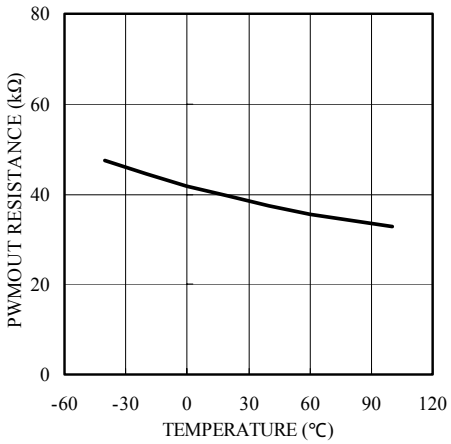
■ Over Current Threshold vs. Supply Voltage



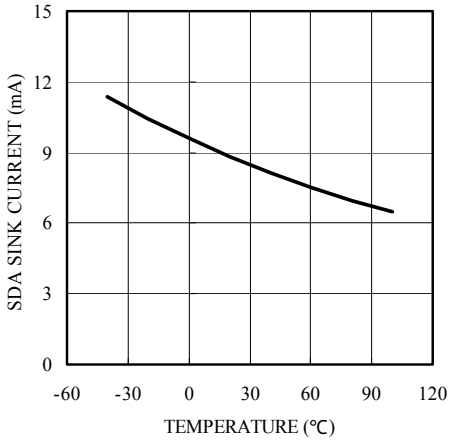
■ FAULT ON Resistance vs. Temperature (I_{FAULT}=+10mA)



■ PWMOUT Resistance vs. Temperature



■ SDA Sink Current vs. Temperature



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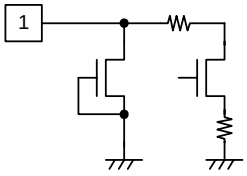
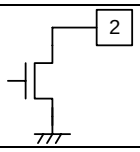
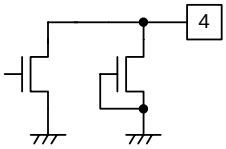
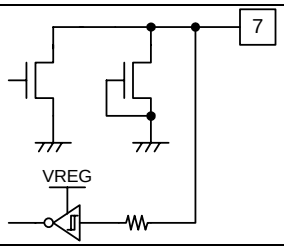
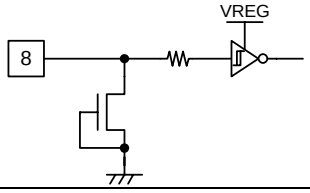
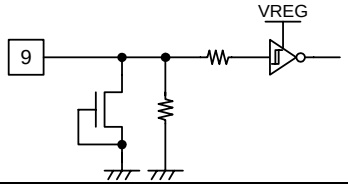
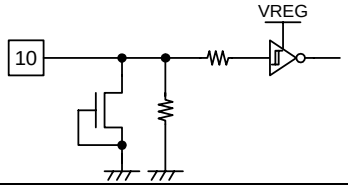
10. PIN DESCRIPTION

No.	Name	Equivalent Circuit	Description
1	OVP		Over-voltage protection threshold. When the output voltage is connected to OVP pin, it is possible to control that OVP pin does not exceed the voltage which is set by IC. When the voltage at OVP surpasses V_{OVP1}, the current of all LED branches decrease to one fifth. If greater than V_{OVP1}, the voltage at OVP is controlled to V_{OVP2}.
2	SW		Internal Power MOSFET, Open Drain Output.
3	NC	-	NC Pin. This pin should be connected to GND.
4	FAULT		FAULT is a N-channel MOSFET open drain output. This pin is "ON" during normal operation of the IC. When the timer latch-type protection circuit stops the switching operation of the IC, this pin switches "OFF". An input voltage ON/OFF switch providing stronger protection can be added by connecting a P-channel FET to this pin. This pin should be connected to GND if not used.
5	GND1	-	Ground for the predriver that drives the internal power MOSFET
6	DGND	-	Ground for digital circuit block
7	SDA		SMBus serial data input
8	SCL		SMBus serial clock input
9	EN0		Chip enable 0. Internal 1MΩ pull-down resistor.
10	EN1		Chip enable 1. Internal 1MΩ pull-down resistor.

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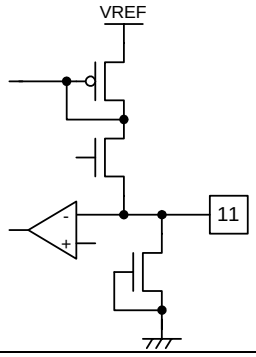
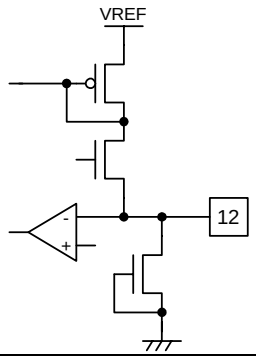
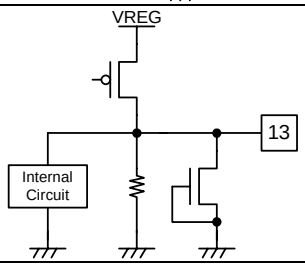
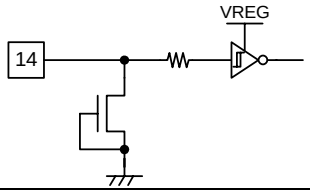
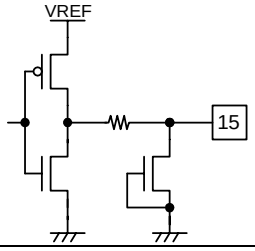
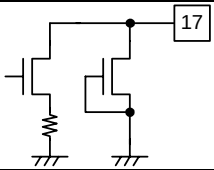
No.	Name	Equivalent Circuit	Description
11	RT1		High frequency oscillator Timing resistor for operating frequency. Connect a resistor that adjusts the frequency between RT1 and GND. RT1-connected oscillator provides the switching frequency.
12	RT2		Equivalent to RT1. RT2-connected oscillator is related to the PWM dimming frequency.
13	VREF		Voltage reference for the linear regulator that powers internal circuits with regulated 2.5V (typ.). Bypass to GND with a 1.0µF ceramic capacitor.
14	PWMIN		PWM control input
15	PWM OUT		PWM buffer output. Connect a 1.0µF ceramic capacitor between PWMOUT and GND. The capacitor forms a low-pass filter with an internal 40kΩ (typ.) resistor for filtering the PWM signal.
16	AGND	-	Ground for the analog to digital converter
17	LED6		White LED current stabilizer output. LED6 supplies LED string with constant current. Connect the cathode of the LED string to LED6. Please do not connect anything if not used.

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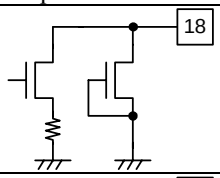
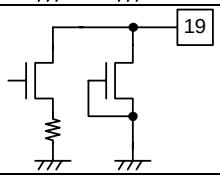
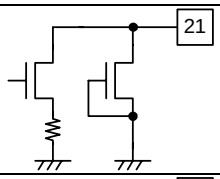
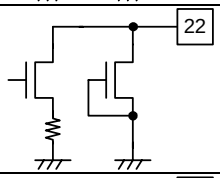
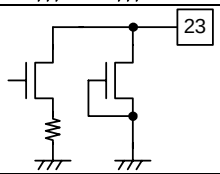
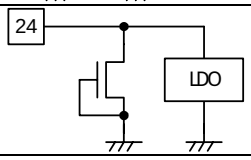
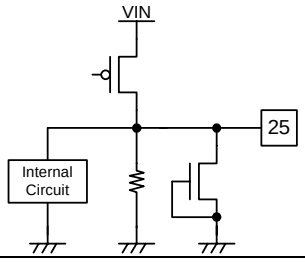
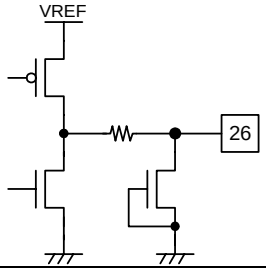
No.	Name	Equivalent Circuit	Description
18	LED5		Equivalent to LED6
19	LED4		White LED current stabilizer output. LED4 supplies LED string with constant current. Connect the cathode of the LED string to LED4.
20	GND3	-	Ground for LED current sink of the stabilizer
21	LED3		Equivalent to LED4.
22	LED2		Equivalent to LED4
23	LED1		Equivalent to LED4
24	VIN		Supply input. VIN is the input to the internal 5.0V LDO that powers the device. Bypass to GND with a 1.0µF ceramic capacitor.
25	VREG		LDO output. The LDO powers internal circuits with regulated 5V (typ.). Bypass to GND with a 1.0µF ceramic capacitor. If this pin is connected to GND, IC restricts to the load current of internal LDO to approximately 30mA(typ.).
26	EAOUT		Error amplifier output. Connect a resistor and /or a capacitor as a phase compensator. When EAOUT voltage is over 2.0V(typ.), internal FET and EA circuit turn off. After that, when EAOUT voltage is under 2.0V(typ.), IC turns on and resumes normal operation.

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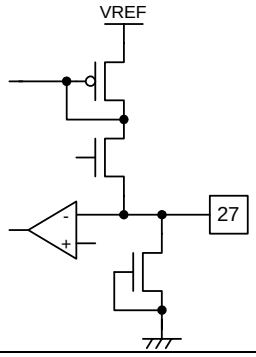
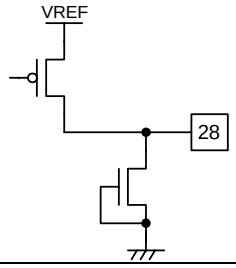
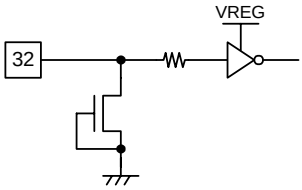
No.	Name	Equivalent Circuit	Description
27	ISET		Maximum LED current setting pin. A resistor should be connected between this pin and GND. The resistor sets the LED current.
28	CSS		Soft-start time setting pin. It reduces inrush current at start state and PWM dimming state. To perform the soft-start operation, connect a capacitor between this pin and GND. When performing PWM dimming at high speed, it is not used, and this pin should be connected to VREF.
29	NC	-	NC Pin. This pin should be connected to GND.
30	GND2	-	Ground for analog circuit block
31	PGND	-	Power ground for internal switching FET
32	DTC		Maximum duty cycle set pin. DTC low mode: Maximum duty cycle of 88% (typ.) at oscillation frequency 1.0MHz when this pin is connected to GND. DTC high mode: Maximum duty cycle of 90% (typ.) at oscillation frequency 1.0MHz when this pin is connected to VREG.

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11. BLOCK DIAGRAM

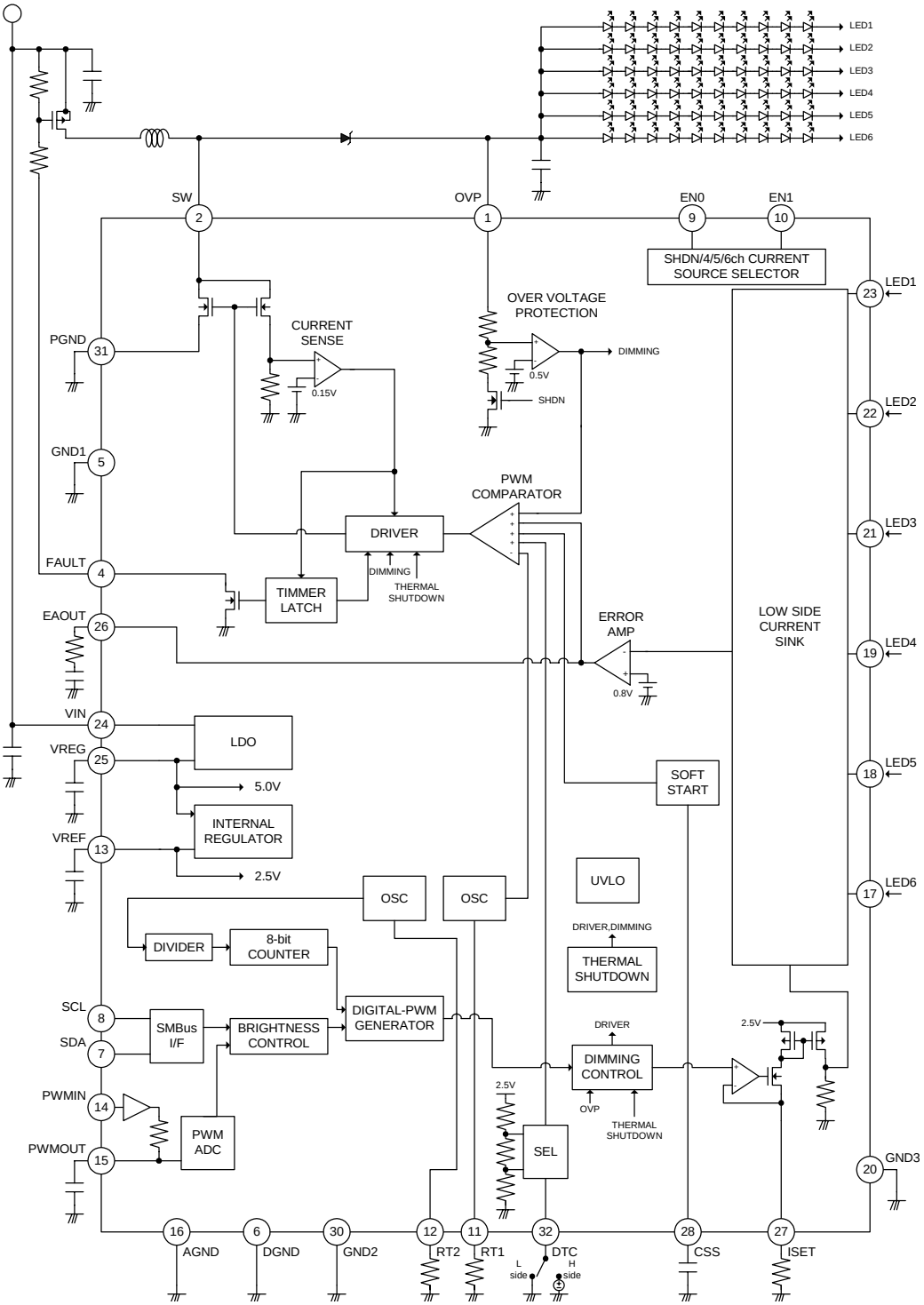

Fig. 1. TK61224BQ5 Block Diagram

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12. DETAIL DESCRIPTION

TK61224BQ5 is a White LED (WLED) driver for LCD display backlight source. It contains an inductive step-up DC-DC converter, a MOSFET switch, 5V low drop-out regulator (LDO), and six current sinks (Fig. 1). It drives up to 60 WLEDs (an array of 6-string by 10 LEDs). The LED current, switching frequency and brightness control PWM frequency are selectable by external resistors. Their ranges are up to 25mA a string, from 200kHz to 2MHz, and from 600Hz to 2kHz, respectively. The range of the input voltage is from 4.25V to 25V wide. The accuracy of current regulation between strings is ± 3.0%.

TK61224BQ5 also supports an SMBus compatible interface. It is used to communicate with a host, in order to receive information about brightness control and to send the driver status or faults etc. The brightness control is achieved through a PWM duty cycle of 256-step. There are three operation modes of brightness control, SMBus mode, PWM mode and SMBus mode with DPST. Also, BL_CTL bit in the device control register, written via SMBus, defines backlight ON and OFF.

TK61224BQ5 protects itself from fault conditions of the LED over-current, the LED string over-voltage and under-voltage of the internal linear regulator and self-heating of the chip. When LED string open occurs or the output voltage exceeds the OVP1 voltage, the LED current decreases to one fifth and the output voltage is controlled under 46V (typ.). These faults set the corresponding flags in the Fault/Status Register and the flags are read via SMBus.

12-1. Stabilizer for LED current

LED current control system consists of the voltage control type step-up DC-DC converter and six matched current sinks. The lowest LEDn(n=1,2,,,, 6) pin voltage is automatically selected and applied to an error amplifier.

The 40dB amplifier amplifies the difference between the lowest voltage and a reference voltage of 0.8V(Fig. 1). The amplified error signal appears on EAOUT pin, and is compared to the triangle wave that is internally generated. The comparator output signal controls the internal MOSFET switching. During EAOUT being higher, the comparator output is HIGH and the MOSFET switch is ON. During EAOUT being lower, the comparator output is LOW and the MOSFET switch is OFF. This regulation provides the stable output voltage.

Self-regulated current sink always measures the LED current and automatically keeps it constant.

12-2. Brightness Control

Two inputs are provided to the backlight controller for brightness control of the LCD panel; SMBus and System PWM.

The backlight LED current is adjustable with an external resistor (between ISET pin and GND).

The backlight brightness is controlled by turning LED current ON and OFF with a PWM. The PWM is digitally generated, and its frequency is tuned by external resistor (RT2). The frequency range is from 600Hz to 2kHz.

The backlight brightness is proportional to the PWM duty cycle of 256-step resolution between 100% and 0%.

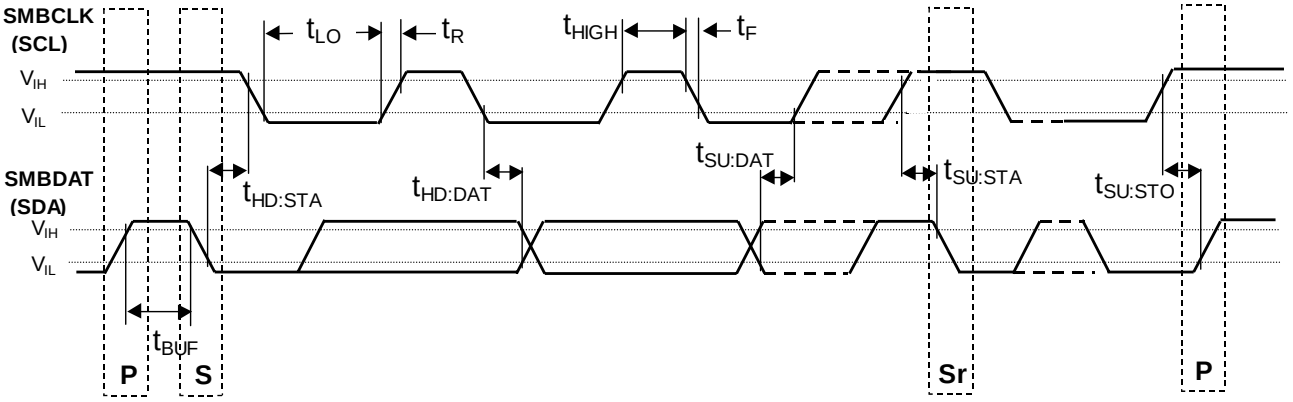
TK61224BQ5 provides three operation modes of brightness control by using two inputs mentioned above. The combination of PWM_MD bit and PWM_SEL bit of the device control register defines one of the three.

12-2-1. PWM mode

PWM_SEL=1

Internal PWM that has same duty cycle as PWMIN input sets the backlight brightness.

The frequency range on PWMIN input is from 5kHz to 50kHz when a capacitor of 1µF is connected between PWMOUT pin and GND.



S: START Condition
Sr: Repeated START Condition
P: STOP Condition

Fig. 2. SMBus Timing Diagram

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When a PWM mode is selected, the brightness control register (0x00) reflects the current brightness value.

12-2-2. SMBus mode

PWM_SEL=0 & PWM_MD=1

The backlight brightness is set by only the 8-bit brightness control register value written via SMBus. The register values 0xFF, 0x80 and 0x00 are corresponding to the brightness level of the maximum 100% duty, the middle level 50% duty and the minimum level 0% duty respectively.
When an SMBus mode is selected, the brightness control register (0x00) reflects the last value written to it.

12-2-3. SMBus mode with DPST

PWM_SEL=0 & PWM_MD=0

The register value written via SMBus is modified by the PWMIN input data, and the modified value sets the backlight brightness. The PWMIN input reflects a percentage change in the current brightness (i.e. DPST mode) and should follows the following equation:

$$\text{DPST brightness} = \text{BRTcurrent} \times D_{PWM}$$

where BRTcurrent is the current brightness setting from SMBus without influence PWMIN input, and D_{PWM} is the duty cycle of the PWMIN input signal. For example, if the current brightness level is 90% of 256 steps and PWMIN input duty is 70%, then the internal PWM of 63% duty is generated and the DPST mode brightness level is set to 63% of 256 steps.
When an SMBus mode with DPST is selected, the brightness control register (0x00) reflects not the current brightness level but the original value via SMBus. In case of the above example not 63% but 80% (0xCD) is read via SMBus.

12-3. SMBus Interface

TK61224BQ5 uses an SMBus™-compatible 2-wire digital interface.
SCL pin is the clock input and SDA pin is the data input/output (bi-directional). These are correspond to SMBCLK and SMBDATA of the SMBus respectively (Fig. 2).
TK61224BQ5 receives instructions and information for backlight control such as LED-ON/OFF, Operation mode for brightness control and brightness level from a master device via SMBus. TK61224BQ5 sends information about the device current status and any fault conditions to a master device via SMBus.
Two SMBus wire SMBCLK and SMBDATA are connected to SCL pin and SDA pin respectively.
TK61224BQ5 uses only the SMBus read byte protocol and the SMBus write byte protocol. It does not use any other SMBus protocols. SMBus protocols are available at http://sbs-forum.org/.

12-3-1. Start condition and Stop condition

One data bit is transferred during each clock pulse. The data on the SMBDATA line must be stable during the HIGH period of the clock. The HIGH or LOW state of the data line can only change when the clock signal on the SMBCLK line is LOW. Data on the SMBDATA line is sampled at the rising edge of the SMBCLK clock.
A HIGH to LOW transition on the SMBDATA line while SMBCLK is HIGH indicates a START condition.
A LOW to HIGH transition on the SMBDATA line while SMBCLK is HIGH defines a STOP condition.
Every byte consists of 8 bits. Each byte transferred on the bus has to be followed by an acknowledge bit. Bytes are transferred with the most significant bit (MSB) first.

12-3-2. Read Byte

As shown in the Fig. 3, the four byte long Read Byte protocol starts out with the slave address followed by the "command code" which translates to the "register index". Then the bus direction turns around with the re-broadcast of the slave address with bit 0 indicating a read ("Rd") cycle. The fourth byte contains the data being returned by the backlight controller. That byte value in the data byte should reflect the value of the register being queried at the "command code" index. Blue colored is used on cycles during which the backlight controller "owns" or "drives" the Data line. All other cycles are driven by the "host".

SMBus is a trademark of Intel Corp.

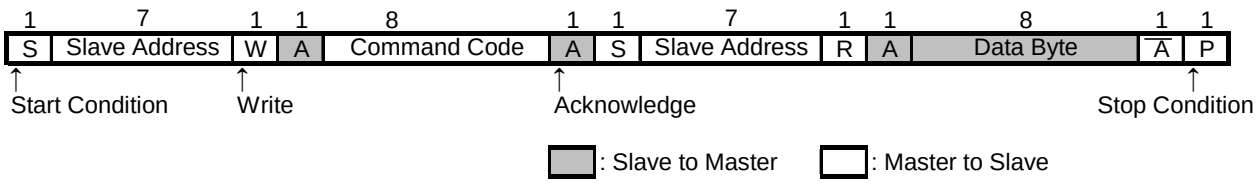

Fig. 3. Read Byte Protocol

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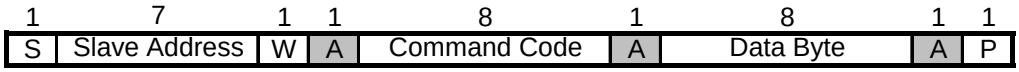

Fig. 4. Write Byte Protocol

12-3-3. Write Byte

The Write Byte protocol is only three bytes long (Fig. 4). First byte starts with the slave address again followed by the "command code" which translates to the "register index" being written. The third byte contains the data byte that must be written into the register selected by the "command code".
Blue colored means same as above.

12-4. Device Address

TK61224BQ5 is a slave-only device.
The SMBus address of TK61224BQ5 is that:
0b0101100(0x2C) /7-bit expression excluding the R/W bit of the address cycle.
0b01011000(0x58) /8-bit expression including the R/W bit of the address cycle.

12-5. SMBus Register definitions

All five registers in TK61224BQ5 are Byte wide and accessible via the Read/Write_Byte protocols mentioned above. Their bit assignments are provided in the following sections with reserved bits containing a default value of "0" (Table 1).

12-5-1. Brightness Control Register Command Code=0x00 POR=0XFF

The granularity of the Brightness control register is 256 steps (Fig. 5).
An SMBus Write Byte cycle to register 0x00 sets the brightness level if the backlight controller is in SMBus mode. A Write Byte cycle to register 0x00 has no effect when the backlight controller is not in SMBus mode. An SMBus Read Byte cycle to register 0x00 returns the current brightness level regardless of the value of PWM_SEL.
An SMBus setting of 0xFF for register 0x00 sets the backlight controller to the maximum brightness output. An SMBus setting of 0x00 for register 0x00 sets the backlight controller to the minimum brightness output.
Default value for register 0x00 is 0xFF.

12-5-2. Device Control Register Command Code=0x01 POR=0X00

This register has two bits that control the operating mode of the backlight controller, and a single bit that controls the BL ON/OFF state. The remaining bits are reserved for future use (Fig. 6).
All reserved bits returns a "0" when read. All reserved bits are ignored by the backlight controller when written. All defined control bits returns their current, latched value when read.
Default value for register 0x01 is 0x00.

12-5-2-1. BL_CTL

A value of 1 written to BL_CTL turns on the backlight quickly. A value of 0 written to BL_CTL turns off the backlight immediately.

12-5-2-2. PWM_SEL

The PWM_SEL bit determines whether the SMBus or PWMIN input should control brightness.
When PWM_SEL = 1, internal PWM that has same duty cycle as PWMIN input sets the backlight brightness (PWM mode).
When PWM_SEL = 0, a value of the brightness control register written via SMBus is used to set the backlight brightness. In case of PWM_SEL = 0 & PWM_MD = 1, the backlight brightness is determined by only the brightness control register value (SMBus mode).

DATA -REGISTER	SMBus PROTOCOL	COMMAND CODE	POR STATE	DATA-REGISTER BIT ASSIGNMENT							
				BIT7 (MSB)	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0 (LSB)
BRIGHTNESS CONTROL	Read and Write	0x00	0xFF	BRT7	BRT6	BRT5	BRT4	BRT3	BRT2	BRT1	BRT0
DEVICE CONTROL	Read and Write	0x01	0x00	Reserved	Reserved	Reserved	Reserved	Reserved	PWM_MD	PWM_SEL	BL_CTL
FAULT /STATUS	Read Only	0x02	N/A	Reserved	Reserved	2_CH_SD	1_CH_SD	BL_STAT	OV_CURR	THRM_SD	FAULT
ID	Read Only	0x03	0x01	LED PANEL	TOKO ID				REV2	REV1	REV0
				1	1	0	0	0			

Table 1. SMBus Register Table

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Bit 7 (R/W)	Bit 6 (R/W)	Bit 5 (R/W)	Bit 4 (R/W)	Bit 3 (R/W)	Bit 2 (R/W)	Bit 1 (R/W)	Bit 0 (R/W)
BRT 7	BRT 6	BRT 5	BRT 4	BRT 3	BRT 2	BRT 1	BRT 0

Fig. 5. Brightness Control Register

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2 (R/W)	Bit 1 (R/W)	Bit 0 (R/W)
Reserved	Reserved	Reserved	Reserved	Reserved	PWM_MD	PWM_SEL	BL_CTL

PWM_MD:PWM mode select bit(1=absolute brightness,0=%change)
PWM_SEL:Brightness control select bit(1=PWMIN,0=SMBus value)
BL_CTL:LED ON/OFF(1=ON,0=OFF)

Fig. 6. Device Control Register

In case of PWM_SEL = 0 & PWM_MD = 0, a value of the brightness control register written via SMBus is modified by PWMIN input, and the modified value sets the backlight brightness (SMBus mode with DPST).

12-5-2-3. PWM_MD

The PWM_MD bit selects the manner in which the PWM input (PWMIN) is to be interpreted. When this bit is 0, the PWMIN reflects a percentage change in the current brightness (i.e. DPST mode) and should follows the following equation:

$$\text{DPST brightness} = \text{BRTcurrent} \times D_{PWM}$$

where BRTcurrent is the current brightness setting from SMBus without influence PWMIN input, and D_{PWM} is the duty cycle of the PWMIN input signal. For example, if the current brightness level is 80% of 256 steps and PWMIN duty is 70%, then the DPST mode brightness level becomes 56% of 256 steps.
When PWM_MD bit is 1, the PWMIN input has no effect on the brightness setting unless the backlight controller is in PWM mode. When operating in PWM mode, this bit is a don't care.
The relationships among these 2 control bits (PWM_MD and PWM_SEL) can be thought of as specifying an operating mode for the backlight controller. The defined modes are shown in Table 2. X means "don't care".

PWM_MD (Bit 2)	PWM_SEL (Bit 1)	Operation Mode
X	1	PWM mode
1	0	SMBus mode
0	0	DPST mode (Default)

Table 2. LED Driver Operation Mode

12-5-2-4. Behavior of Brightness Control Register and Operation mode

The behavior of register 0x00 (Brightness Control Register) is affected by certain combinations of the control bits as shown in Table 2 operating mode selected by device control register Bits 1 and 2.
When an SMBus mode is selected, register 0x00 reflects the last value written to it. But, when any non-SMBus mode is selected register 0x00 reflects the current brightness value based on the current mode operation, with the exception of SMBus mode with DPST. When SMBus mode with DPST is selected register 0x00 reflects the last value written to it from SMBus.
When a write to register 0x01 causes the backlight controller to transition to SMBus mode, the brightness of the backlight does not change. When a write to register 0x01 causes the backlight controller to transition to a non-SMBus mode, the brightness of the backlight changes as appropriate for the new mode.

12-5-3. Fault/Status Register

Command Code=0x02 POR=0X00

This register has six status bits that allow monitoring the backlight controller's operating state (Fig. 7). Bit 0 is a logical "OR" of all fault codes to specify error detection. Not all of the bits in this register are fault related --- bit 3 (BL_STAT) is a simple backlight status indicator. The remaining bits are reserved for future use. All reserved bits return a "0" when read & ignore the bit value when written. All of the bits in this register a read-only. A Write Byte cycle to register 0x02 has no effect.
All reserved bits return a "0" when read.
Default value for register 0x02 is 0x00.

Bit Field Definitions:

2_CH_SD : Two LED output channels are shut down (1 = shut down, 0 = OK).

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Bit 7	Bit 6	Bit 5 (R)	Bit 4 (R)	Bit 3 (R)	Bit 2 (R)	Bit 1 (R)	Bit 0 (R)
Reserved	Reserved	2_CH_SD	1_CH_SD	BL_STAT	OV_CURR	THRM_SD	FAULT

Fig. 7. Fault/Status Register

Bit 7 (R)	Bit 6 (R)	Bit 5 (R)	Bit 4 (R)	Bit 3 (R)	Bit 2 (R)	Bit 1 (R)	Bit 0 (R)
LED Panel	Toko's vendor ID				Rev2	Rev1	Rev0
1	1	0	0	0			

Fig. 8. Identification Register

1_CH_SD : One LED output channel is shut down. (1 = shut down, 0 = OK)

BL_STAT : Backlight status (1 = BL ON, 0 = BL OFF)

OV_CURR : LED Over-current (1 = Over-current condition, 0 = Current OK).

THRM_SD : Thermal shut down (1 = Thermal Fault, 0 = Thermal OK)

FAULT : Fault occurred (Logic "OR": THRM_SD + OV_CURR + 1_CH_SD + 2_CH_SD)

A Read Byte cycle to register 0x02 indicates the current backlight On/OFF status in BL_STAT (1 if the backlight is ON, 0 if the backlight is OFF).
A Read Byte cycle to register 0x02 returns FAULT as the logical OR of THRM_DN, OV_CURR, 1_CH_SD and 2_CH_SD.
THRM_SD is 1 when the backlight controllers shuts down due to a thermal event. In all other cases the value of THRM_SD is 0.
The value of OV-CURR is 1 when the backlight controller is shut down due to an LED over-current event. In all other cases the value of OV_CURR is 0.
The value of BL_STAT is 1 whenever the backlight is ON. The value of BL_STAT is 0 whenever the backlight is OFF.
Write 0 to BL_CTL bit (bit 0) of the Device Control Register to clear all fault-related bits

12-5-4. Identification Register

Command Code=0x03 POR=0X00

The identification register contains three bit fields to denote the backlight source, the manufacturer and the silicon revision (Fig. 8).
All of the bits in this register a read-only. A Write Byte cycle to register 0x02 has no effect.
Bit Field Definitions:

Backlight source : 1 = LED backlight

Manufacturer ID: The vendor ID for Toko is 8

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13. APPLICATION INFORMATION

13-1. Enable

The combination of EN0 and EN1 sets the active LED strings. If both EN0 and EN1 are LOW, all LEDs turn to OFF (Table 3).

Table 3. Active Strings Mode

MODE	EN0	EN1	Active LED strings
SHDN	L	L	Shut down mode
6 strings	H	L	LED1, LED2, LED3, LED4, LED5, LED6
5 strings	L	H	LED1, LED2, LED3, LED4, LED5
4 strings	H	H	LED1, LED2, LED3, LED4

13-2. Internal MOSFET Switch

TK61224BQ5 is equipped with a N channel power MOSFET for switching. It's On-resistance is 300mΩ (typ.).

13-3. Soft Start

Soft-start prevents in-rush current at start-up and brightness PWM ON/OFF. An external capacitor CSS between CSS and GND provides the function. Soft-start time, which means CSS voltage transition time from 0V to 1.2V, is approximately as follows;.

$$T_{SS}(\mu s) = 1.2 \times \frac{C_{SS}(pF)}{1.0(\mu A)}$$

13-4. Switching Frequency

An internal oscillator provides the switching frequency. An external resistor RT1 between RT1 and GND activates the oscillator and its frequency is approximately as follows;

$$F_{OSC\_SW}(MHz) = \frac{10^{-6}}{21.16(pF) \times RT1(k\Omega) + 80(ns)}$$

13-5. Brightness Control PWM Frequency

An internal oscillator provides the brightness control PWM frequency. An external resistor RT2 between RT2 and GND activates the oscillator and its frequency is approximately as follows;

$$F_{OSC\_DIM}(kHz) = \frac{0.977 \times 10^{-6}}{18.4(pF) \times RT2(k\Omega) + 80(ns)}$$

13-6. LED Current

An external resistor R_{SET} between ISET and GND defines LED1-6 currents. The value of each string is approximately as follows;

$$I_{LED}(mA) = \frac{1250}{R_{SET}(k\Omega)}$$

13-7. Under-voltage Lockout(UVLO)

When the LDO output voltage is under 2.7V (typ.), it prevents the malfunction of the internal circuitry and turns off the internal circuitry except the LDO. After that, when the LDO output voltage is again over 2.9V (typ.) , the IC turns on and resumes normal operation.

13-8. Timer Latch

The over-current protection output is connected to a timer latch and it counts 1/ F_{OSC_SW}×1920 times. Reset is accomplished by BL_CTL=0 by way of SMBus or reapplying the supply voltage and EN0/EN1 pin.

13-9. FET Over-current Protection

TK61224BQ5 built in internal FET's over-current protection restricts the maximum current of the FET. When the current of the internal FET is over 2.3V (typ.), the internal FET turns off. Simultaneously, the timer latch starts counting. When the FET current is under 2.3A (typ.) within the count time, the internal FET turns on. When the count times exceeds 1/ F_{OSC_SW}×1920, the disable signal of the FET is latched, the internal FET turns off completely.
But, when the output voltage shorts to GND, this protection has no effect because the over-current is flowing through the schottky diode. To protect against this, an input voltage ON/OFF switch can be added by connecting a P-channel FET to the FAULT pin. When the disable signal of the FET for timer latch is latched, the FAULT pin becomes high impedance and the P-channel FET turns off, the current route to GND is cut off (Fig. 9).

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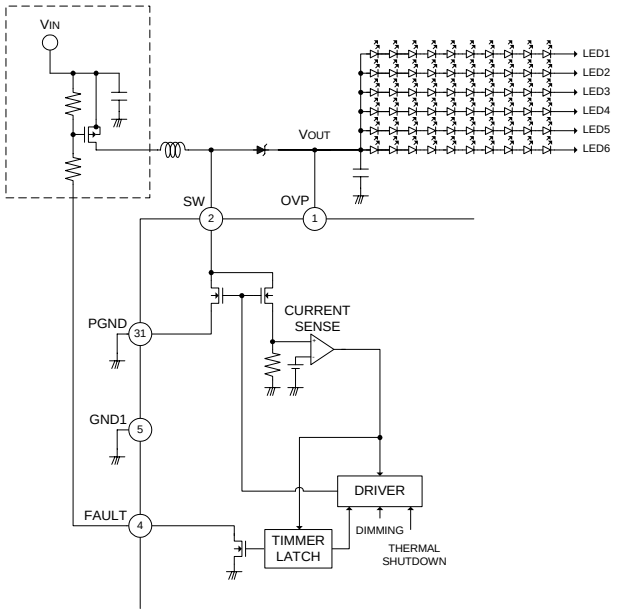

Fig. 9. Protection for short circuit of output voltage and GND

13-10. Over-voltage Protection

TK61224BQ5 has built in over-voltage protection and monitors the output voltage separately from a LED control loop. When the output voltage is connected to the OVP pin, it is possible to control that the OVP pin does not exceed the voltage, which is set by the IC. The OVP function of TK61224BQ5 reacts to 2 types of voltage fault conditions. First when the voltage at the OVP pin exceeds V_{OVP1}=42V (typ.), the LED current decreases to one fifth and the maximum current of the internal FET is restricted to two thirds of 2.3A (typ.). Next when the voltage at the OVP pin exceeds V_{OVP2}=46V (typ.), the voltage at the OVP pin is controlled to V_{OVP2}. Reset is accomplished by BL_CTL=0 by way of SMBus or reapplying the supply voltage and EN0/EN1 pin.

13-11. Thermal Sensor

When the chip temperature exceeds approximately 150℃, the internal FET turns off. Afterwards, when the chip temperature falls, the internal FET turns on again.

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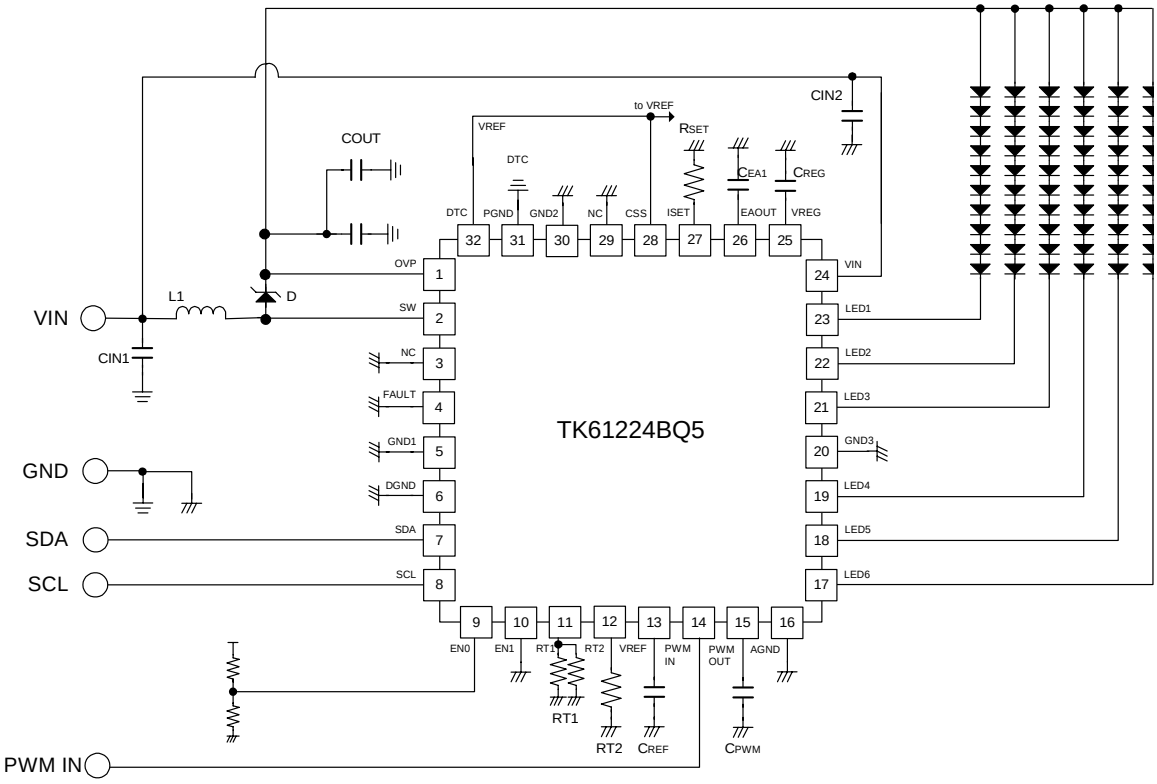
13-13. Application Information

60 White-LEDs Drive

- · Input Voltage : V_{IN}=7V to 21V
- · LED : 10 WLEDs in series(LED Vfmax=3.6V)
- · LED Current : 17mA
- · Peak Current : 1.7Amax
- · Switching Frequency : 780kHz
- · PWM Frequency : 260Hz

13-13-1. Application Circuit



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13-13-2. Component List

Circuit	Symbol	Part Number	Value	Company	Remark
Resistor	RT1		56kΩ ±1%		The switching frequency is 780kHz.
	RT2		200kΩ ±1%		PWM frequency is 260Hz.
	RSET		75kΩ ±1%		LED current is 17mA.
Capacitor	CIN1		Ceramic capacitor, B curve, 4.7μF/25V		Input bypass capacitor
	CIN2		Ceramic capacitor, B curve, 1μF/25V		IC bypass capacitor
	CREG		Ceramic capacitor, B curve, 1μF/6.3V		VREG bypass capacitor
	CREF		Ceramic capacitor, B curve, 1μF/6.3V		VREF bypass capacitor
	CPWM		Ceramic capacitor, B curve, 1μF/6.3V		Low pass filter for DC conversion of an input PWM signal
	CSS		Connecting to VREF		
	CEA1		Ceramic capacitor, B curve, 0.47μF/6.3V		Phase compensation capacitor
	COUT		Ceramic capacitor, low distortion, 1μF/50V×2		Output capacitor
Diode	D	TKS1060ASA	More than VR=60V, IO=1A	Toko	
Inductor	L	1123AS-3R3M	DE4514C 3.3μH	Toko	

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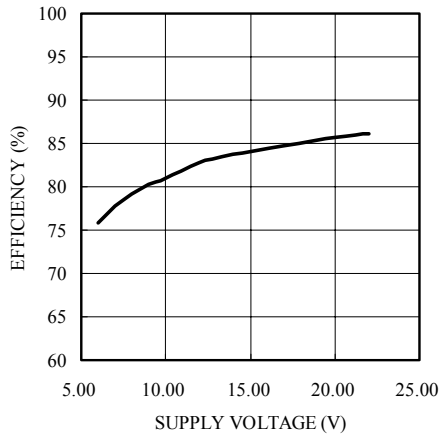
13-13-3. Efficiency

■ Efficiency vs. Input Voltage

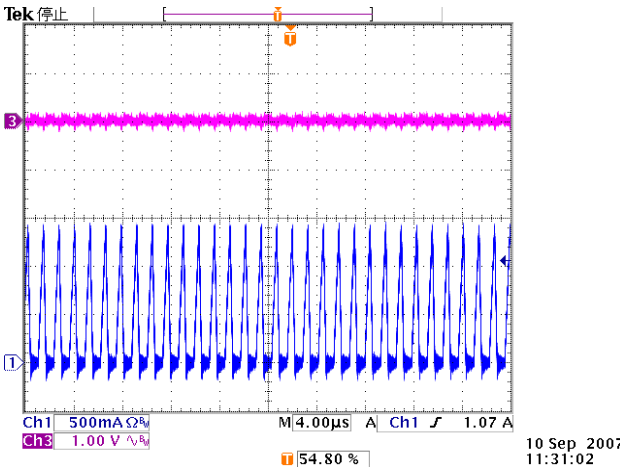


$$\text{Efficiency}(\%) = \frac{V_{OUT} \times I_{LED1-6}}{V_{IN} \times I_{IN}} \times 100$$

13-13-4. Operation Waveform

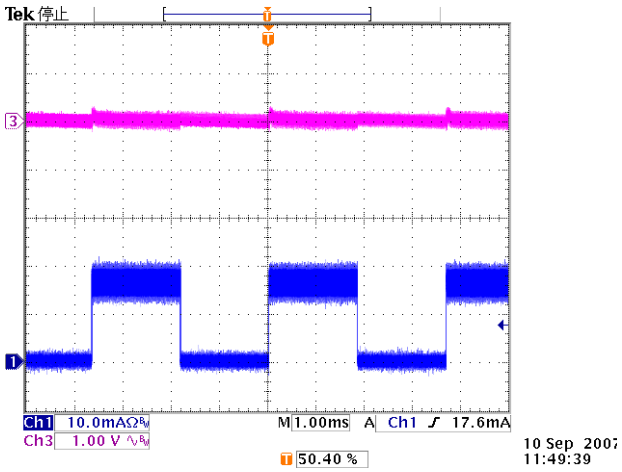
■ Wakeup Waveform at SMBus 100%(SMBus Mode)
V_{IN}=12V

(Top) Output Voltage : 1V/Div
(Bottom) Inductor Current : 500mA/Div



■ Waveform at PWM Dimming(SMBus Mode)
V_{IN}=12V, Duty=50%

(Top) Output Voltage : 2V/Div
(Bottom) Inductor Current : 10mA/Div



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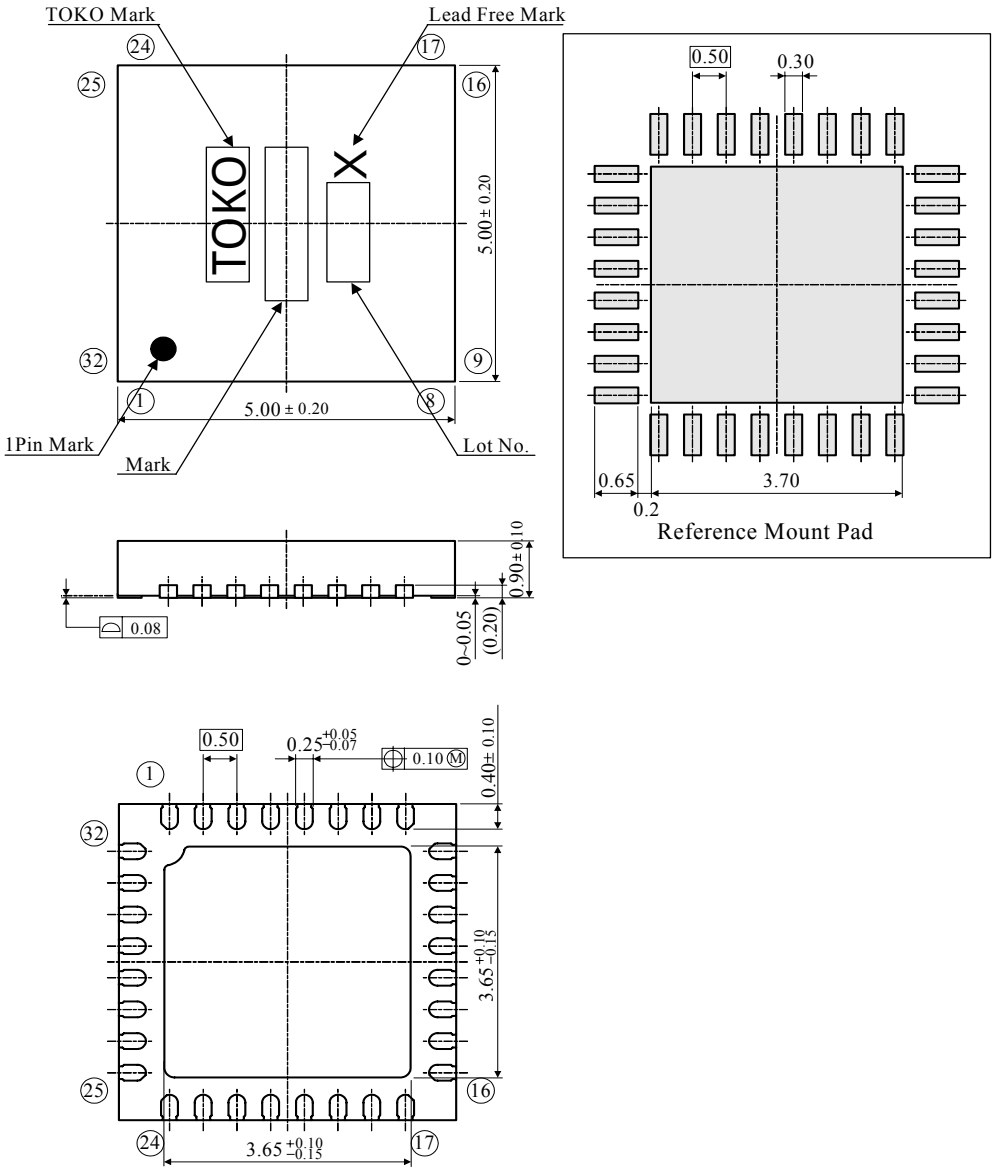
14. PACKAGE OUTLINE

■ 32-lead quad flat non-leaded package with heat sink: HQFN5050-32



Unit : mm

Package Structure and Others

Package Material	:	Epoxy Resin	Mark Method	:	Laser
Terminal Material	:	Copper Alloy	Country of Origin	:	Malaysia
Terminal Finish	:	Lead Free Solder Plating (8~25µm)	Mass	:	0.071g
Solder Composition	:	Sn100%			

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