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Datasheet

4-Channel White LED Driver with Integrated FET for up to 40 LEDs

BD65D00MUV

- **General Description**

  This IC is white LED driver IC with PWM step-up DC/DC converter that can boost max 41V and current driver that can drive max 100mA. The wide and precision brightness can be controlled by external PWM pulse. This IC has very accurate current drivers, and it has few current errors between each strings. So, it will be helpful to reduce brightness spots on the LCD panel. Small package is suited for saving space.
  It can respond to the application according to the application to be abele to switch to external/internal NchFET boosting.

- **Features**
  - ■ High efficiency PWM step-up DC/DC converter (fsw=typ 1.25MHz, 0.60MHz to 1.6MHz)
  - ■ High accuracy & good matching current drivers 4ch (MAX100mA/ch)
  - ■ Integrated 50V power Nch MOSFET
  - ■ Soft Start function
  - ■ Drive up to 10 LEDs in series, 4 strings in parallel
  - ■ Various safety functions
    - Over-voltage protection
    - External SBD open detect / Output Short protection
    - Over current limit
    - CH Terminal open / GND short protect
    - CH over voltage protect / LED short protect
    - Thermal shutdown
    - UVLO
    - ISET short protection
  - ■ PWM dimming(100Hz - 25kHz)Analog Brightness Control

- **Key Specifications**

■ Operating power supply voltage range:	6V to 27V
■ LED maximum current:	100mA/ch
■ Quiescent Current:	1.6µA (typ.)
■ Operating temperature range:	-40℃ to +85℃

- **Package** W(typ.) x D(typ.) x H(Max.)

VQFN028V5050
5.00mm x 5.00mm x 1.00mm

Figure 1.

- **Applications**

  All LCD equipments, Backlight of Notebook PC, Amusement, net book, monitor, TV, Portable DVD player, light source etc.

- **Typical Application Circuit (4 parallel)**

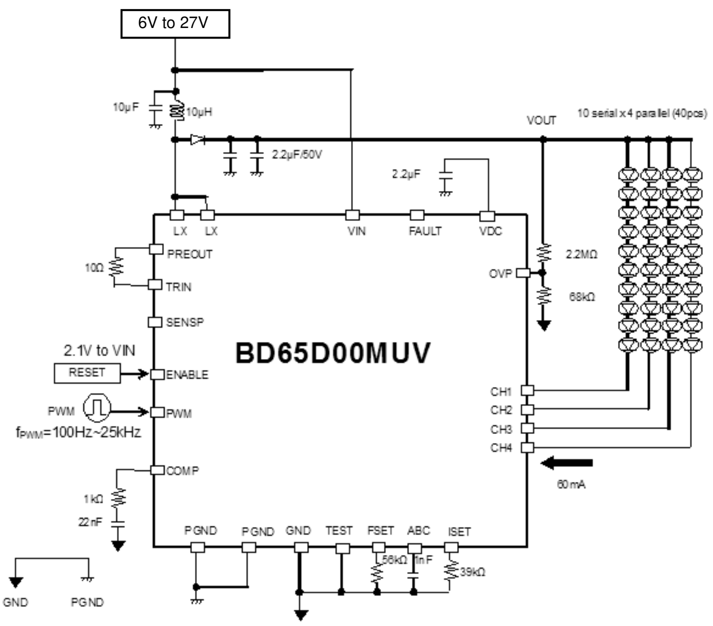


Figure 2. Typical Application Circuit

○ Product structure：Silicon monolithic integrated circuit ○ This product is not designed protection against radioactive rays

- **Absolute Maximum Ratings** (Ta=25℃)

Parameter	Symbol	Ratings	Unit	Conditions
Terminal voltage 1	VMAX1	7	V	VDC, ISET, ABC, COMP, FSET, TEST, FAULT, PREOUT, TRIN, SENSP
Terminal voltage 2	VMAX2	45	V	CH1 to CH4, LX, OVP
Terminal voltage 3	VMAX3	30.5	V	VIN, ENABLE
Terminal voltage 4	VMAX4	15	V	PWM
Power dissipation 1	Pd1	380 *1	mW	
Power dissipation 2	Pd2	880 *2	mW	
Power dissipation 3	Pd3	3264 *3	mW	
Operating temperature range	Topr	-40 to +85	℃	
Storage temperature range	Tstg	-55 to +150	℃	

*1 Reduced 3.0mW/ ℃ With Ta>25℃ when not mounted on a heat radiation Board.
*2 1 layer (ROHM Standard board) has been mounted. Copper foil area 0mm^2, When it's used by more than Ta=25 ℃, it's reduced by 7.0mW/ ℃.
*3 4 layer (JEDEC Compliant board) has been mounted. Copper foil area 1.4layer 20.2mm^2, Copper foil area 2 to 3layers 5505mm^2, When it's used by more than Ta=25 ℃, it's reduced by 26.1mW/℃.
*Power dissipation is calculated by formula : (Storage temperature max - 25℃)/θ ja (ex. Pd1=3.0mW/℃)

- **Recommended Operating Ratings** (Ta=-40℃to +85℃)

Parameter	Symbol	Limits			Unit	Conditions
		Min.	Typ.	Max.		
Power supply voltage	VINL	6.0	12.0	27.0	V	Coil power supply
	VIN	4.5	5	27.0	V	IC power supply

- **Electrical Characteristics**
(Unless otherwise specified, VIN=12V, Ta = +25℃)

Parameter	Symbol	Limits			Unit	Conditions
		Min.	Typ.	Max.		
[General]						
Quiescent Current	Iq	-	1.6	4.4	µA	ENABLE=0V
Current Consumption	Idd	-	3.6	5.4	mA	OVP=0V,ISET=39kΩ
Max. Output Voltage	MOV	-	-	41	V	
Under Voltage Lock Out	UVLO	-	3.7	4.1	V	VIN falling edge
[ENABLE **Terminal]**						
Low Level Input Voltage	EnL	0.0	-	0.8	V	
High Level Input Voltage 1	EnH	2.0	-	VIN	V	
ENABLE Pull down resistor	EnR	100	300	500	kΩ	ENABLE =3V
Output Current	ENIout	-	0	2	µA	ENABLE=0V
[PWM Terminal]						
Low Level Input Voltage	PWML	0.0	-	0.8	V	
High Level Input Voltage 2	PWMH	1.3	-	14.5	V	
PWM Pull down resistor	PWMR	100	300	500	kΩ	PWM=3V
Output Current	PWMIout	-	0	2	µA	PWM=0V
[FAULT]						
Nch RON	FFCR	-	-	3	kΩ	ENABLE=PWM=3V, OVP=2V
[Regulator]						
VDC Voltage	VREG	4.2	5.0	6.0	V	No load, VIN > 6V

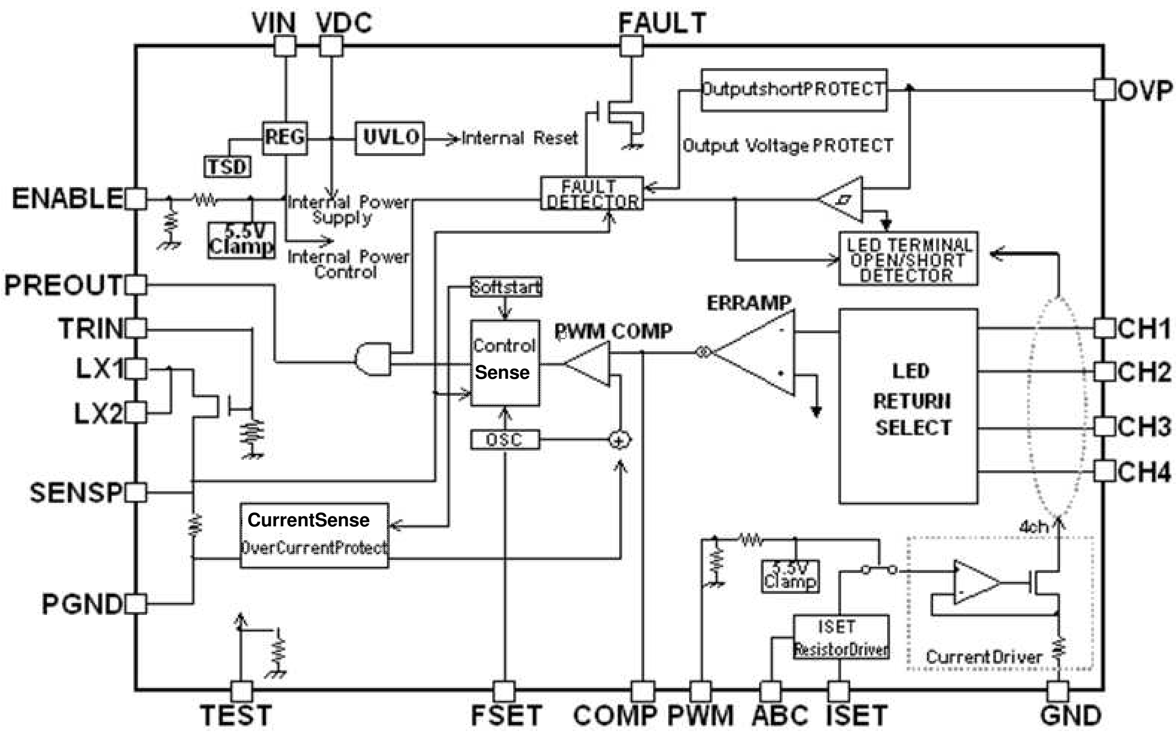
- **Electrical Characteristics - continued**

(Unless otherwise specified, VIN=12V, Ta = +25℃)

Parameter	Symbol	Limits			Unit	Conditions
		Min.	Typ.	Max.		
[Switching Regulator]						
LED Control voltage	VLED	0.64	0.80	0.96	V	
Switching frequency accuracy	Fsw	1.00	1.25	1.50	MHz	FSET=56kΩ
Duty cycle limit	Duty	91.0	95.0	99.0	%	CH1-4=0.3V, FSET=56kΩ
LX Nch FET RON	RON	-	0.3	0.5	Ω	ILX=80mA
[Protection]						
Over Current Limit	Ocp	1.5	2.5	-	A	*1
Over voltage limit Input	OVP	1.16	1.20	1.24	V	Detect voltage of OVP pin
Output Short Protect	OVPfault	0.02	0.05	0.08	V	Detect voltage of OVP pin
OVP leak current	OVIL	-	0.1	1.0	µA	
CH Terminal Over Voltage Protect accuracy	VSC	-15	0	+15	%	VSC=8V
[Current driver]						
LED maximum current	ILMAX	-	-	100	mA	This is current driver's characteristics. This IC may not output current according to application.
LED current accuracy	ILACCU	-	-	±5.0	%	ILED=60mA (39kΩ)
LED current matching	ILMAT	-	-	3.0	%	(Max LED current – Min LED current)/ Ideal current (60mA) ILED=60mA
LED current limiter	ILOCP	-	0	0.1	mA	Current limit value at ISET Resistance 1kΩ setting
ISET voltage	Iset	-	0.733	-	V	
LED current accuracy2	ILACCU2	-	±3.0	-	%	ILED=60mA, ABC=0.733V

*1 This parameter is tested with DC measurement.

- **Block Diagram**



Pin number 22pin

Figure 3. Block Diagram

- **Pin Descriptions**

PIN No.	PIN Name	IO	Function	Terminal diagram
1	VDC	Out	Regulator output / Internal power-supply	C
2	TEST	In	TEST signal (Pull down 100kΩ within IC)	E
3	FSET	In	Resistor connection for frequency setting	A
4	ABC	In	PIN for Analog Brightness Control	C
5	GND	-	GND for Switching Regulator	B
6	COMP	Out	ERRAMP output	A
7	ISET	In	Resistor connection for LED current setting	A
8	CH4	In	Current driver sink for CH4	C
9	NC	-	-	-
10	CH3	In	Current driver sink for CH3	C
11	NC	-	-	-
12	CH2	In	Current driver sink for CH2	C
13	NC	-	-	-
14	CH1	In	Current driver sink for CH1	C
15	NC	-	-	-
16	GND	-	GND for Current Driver	B
17	FAULT	Out	Fault signal	C
18	PREOUT	Out	Signal output pin for internal switching Tr	A
19	TRIN	In	Gate terminal for switching Tr	A
20	SENSP	In	Source terminal for external switching Tr	A
21	PGND	-	PGND for switching Tr	D
22	LX	Out	Switching Tr drive terminal	F
23	LX			
24	NC	-	-	-
25	OVP	In	Detect input for SBD open and OVP	C
26	PWM	In	Input pin for current driver power ON/OFF	E
27	ENABLE	In	Pin for power ON/OFF or Power control	E
28	VIN	In	Battery input	G
-	Thermal PAD	-	Heat radiation PAD of back side Connect to GND	

- **Pin ESD Type**

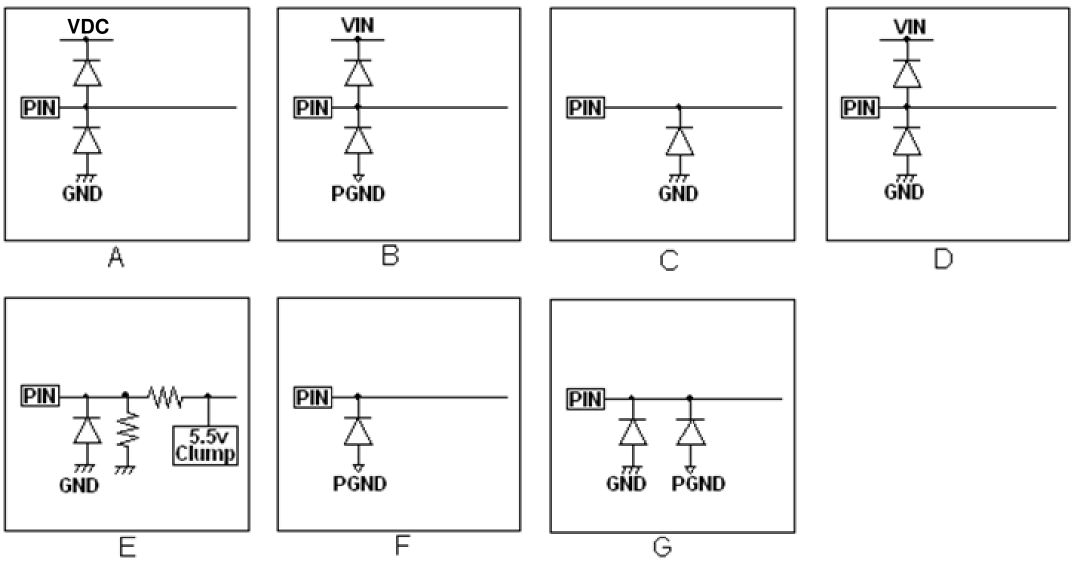


Figure 4. Pin ESD Type

- **Typical Performance Curves**

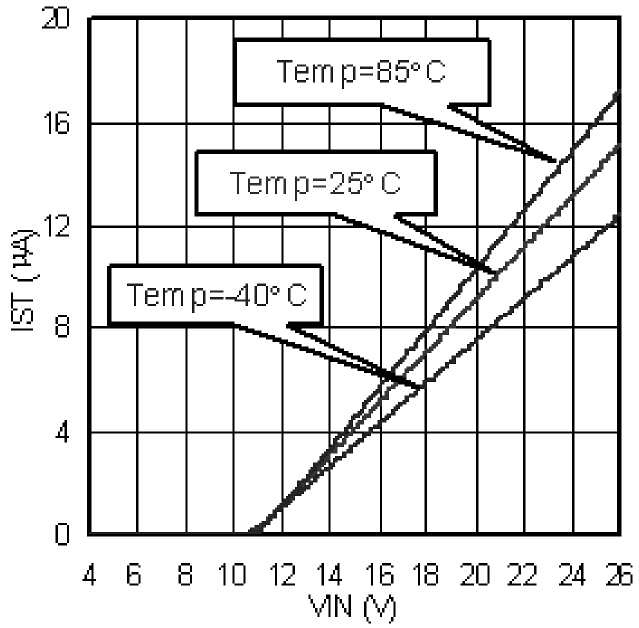


Figure 5. Quiescent Current

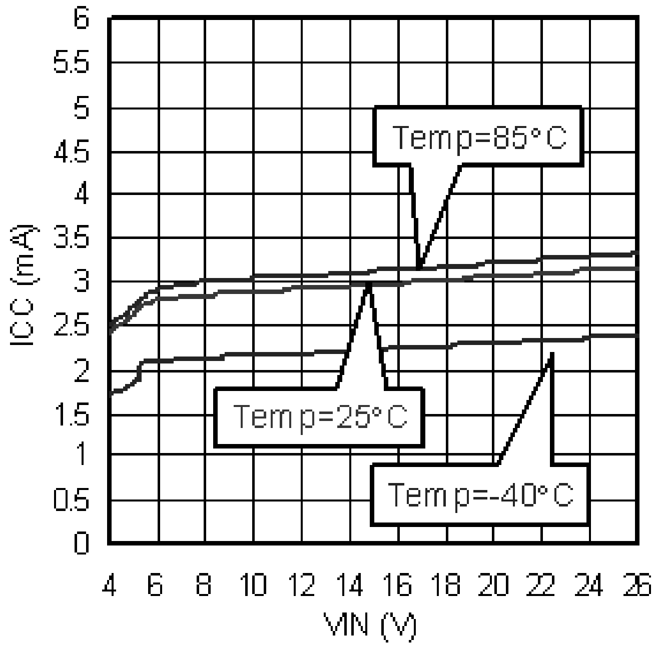


Figure 6. Current Consumption

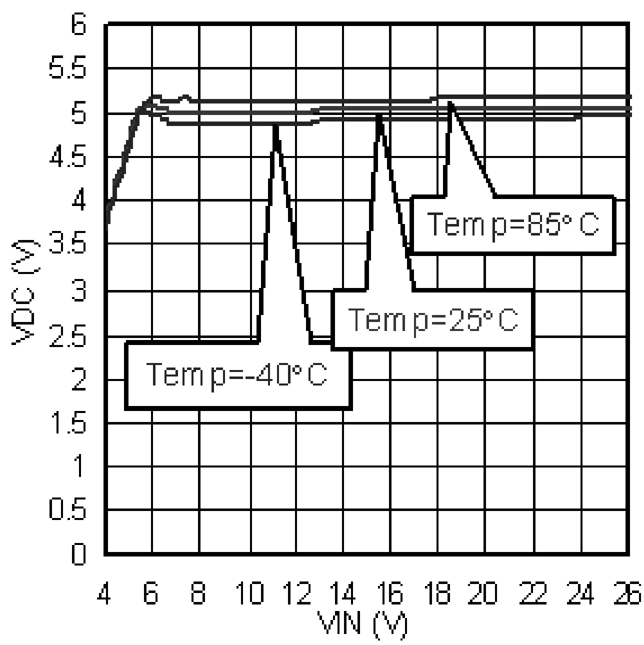


Figure 7. VDC Voltage

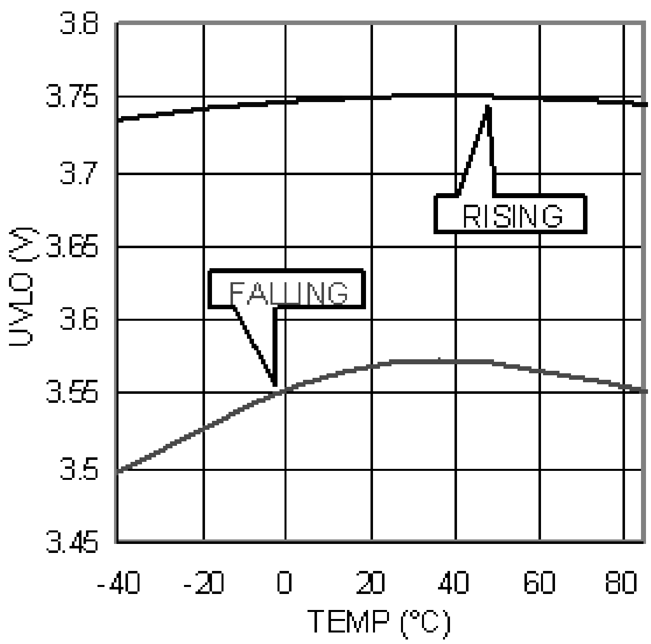


Figure 8. Under Voltage Lock Out

- **Typical Performance Curves**

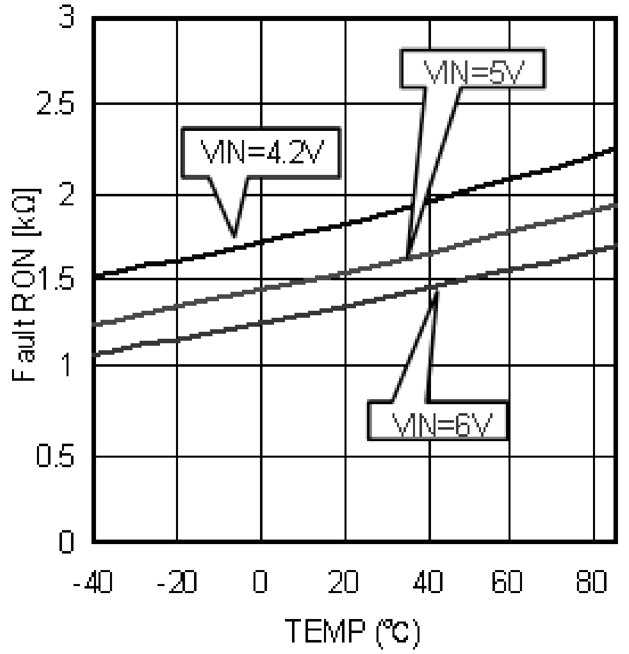


Figure 9. Fault RON

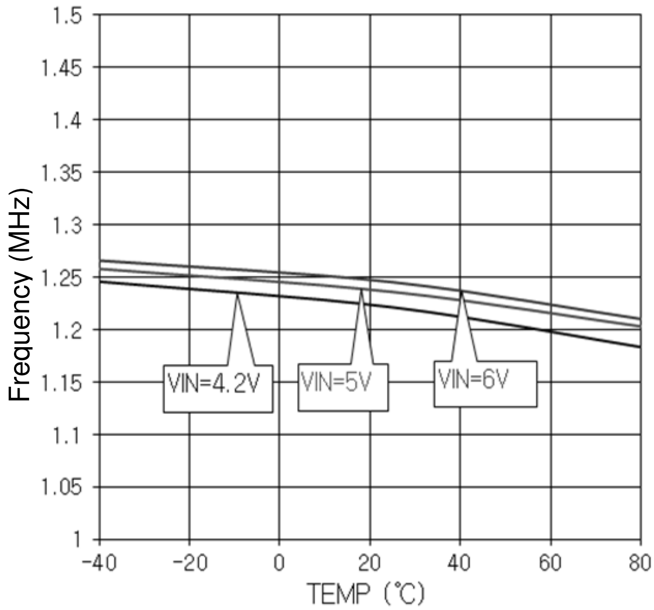


Figure 10. Switching Frequency

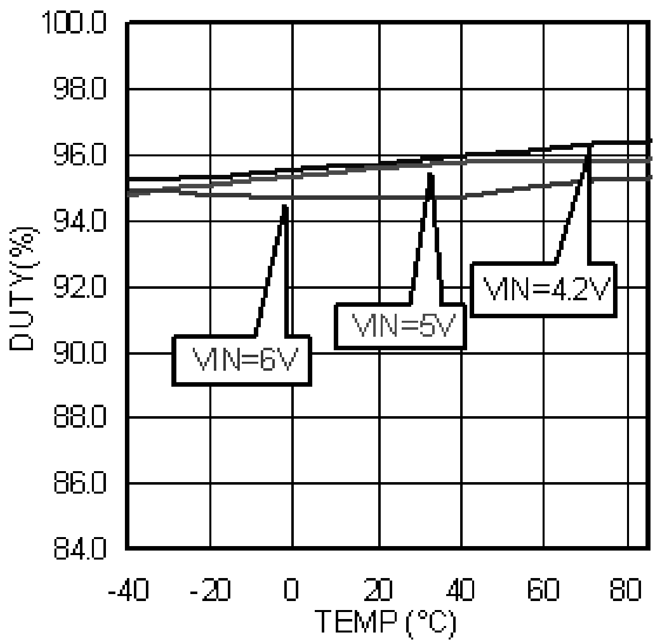


Figure 11. Max Duty

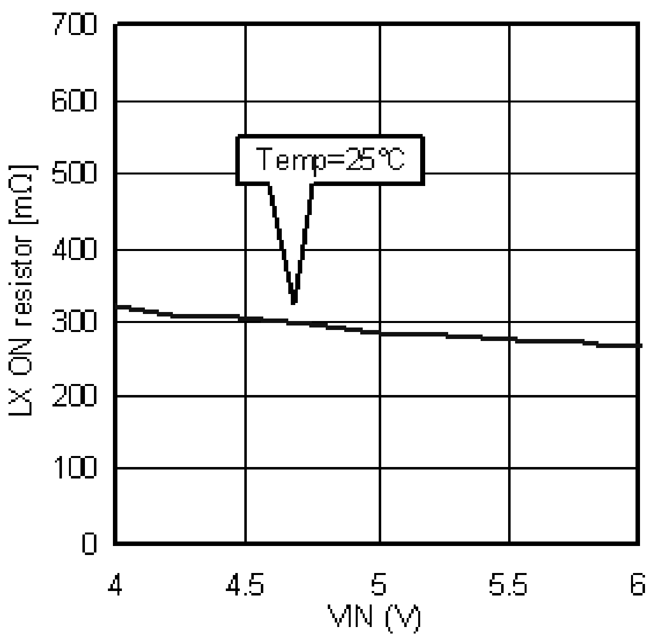


Figure 12. LX NcH RON

- **Typical Performance Curves - continued**

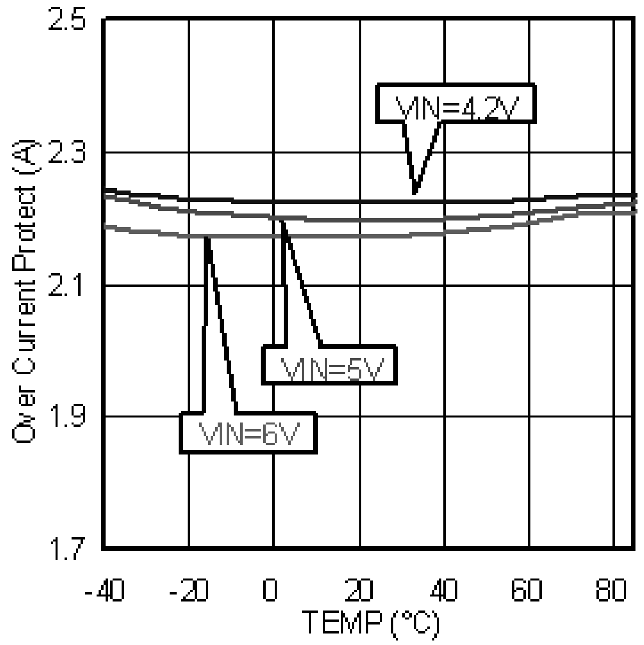


Figure 13. Over Current Limit

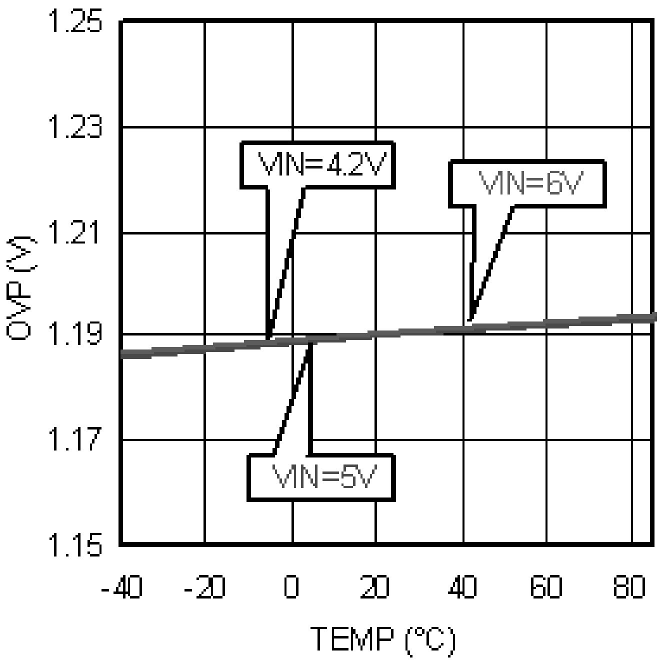


Figure 14. Over Voltage Protect

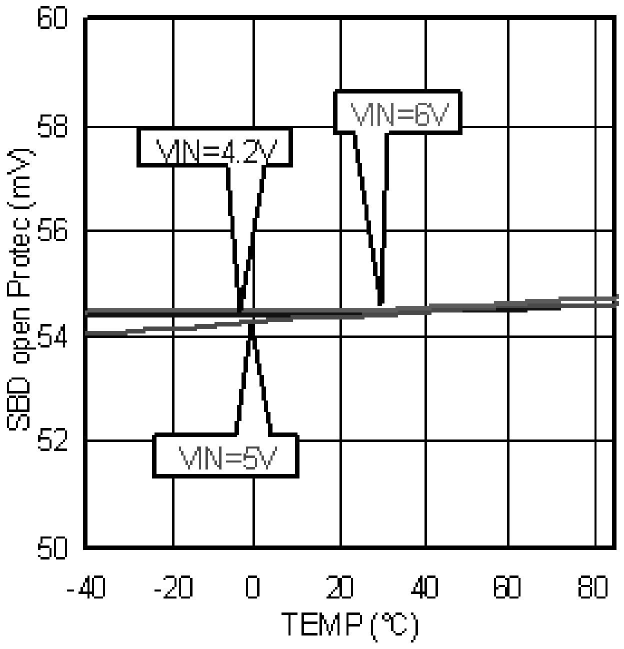


Figure 15. Output Short Protect

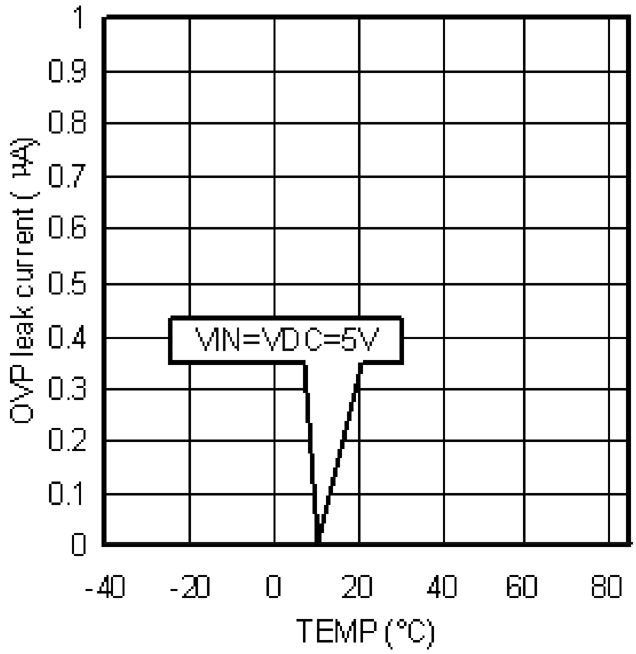


Figure 16. OVP Leak Current

- **Typical Performance Curves - continued**

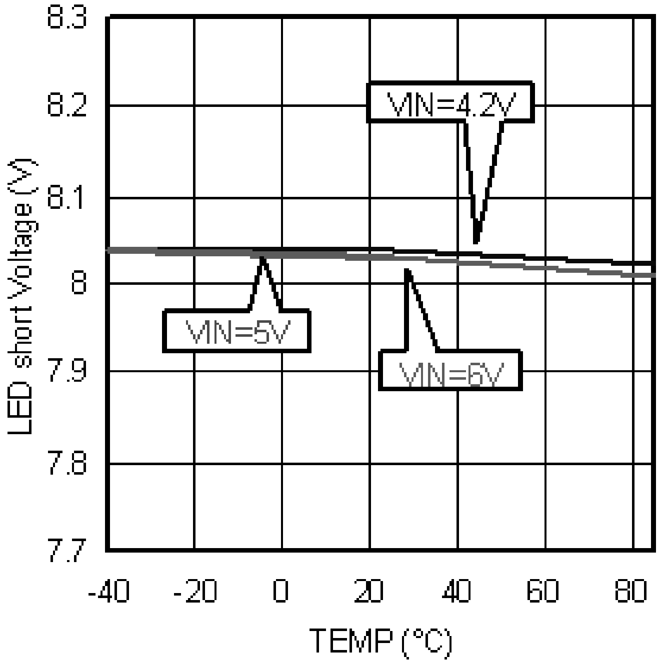


Figure 17. CH Terminal OVP

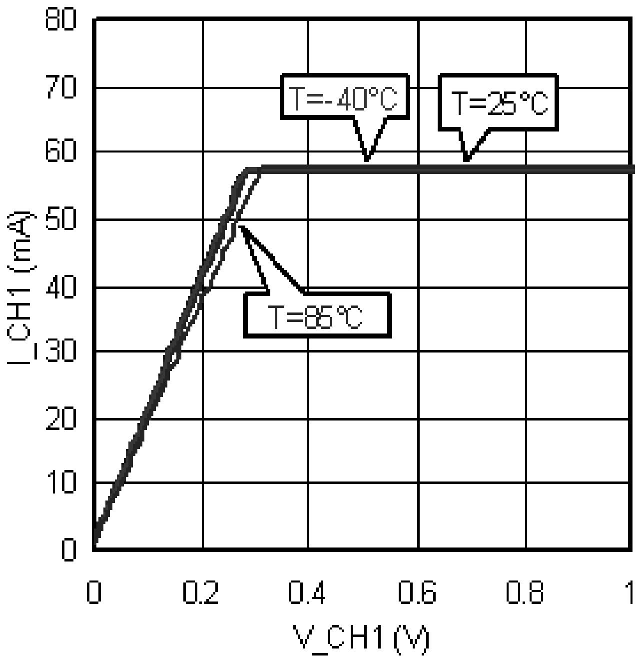


Figure 18. LED Current vs. CH Voltage

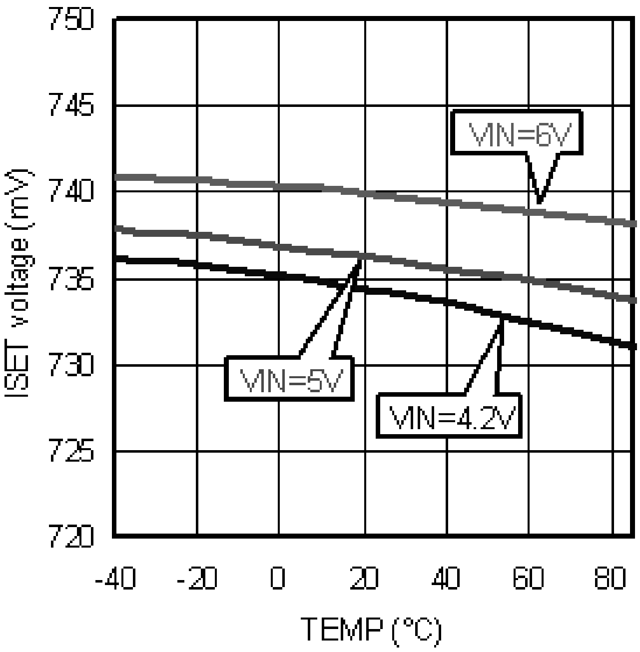


Figure 19. ISET Voltage

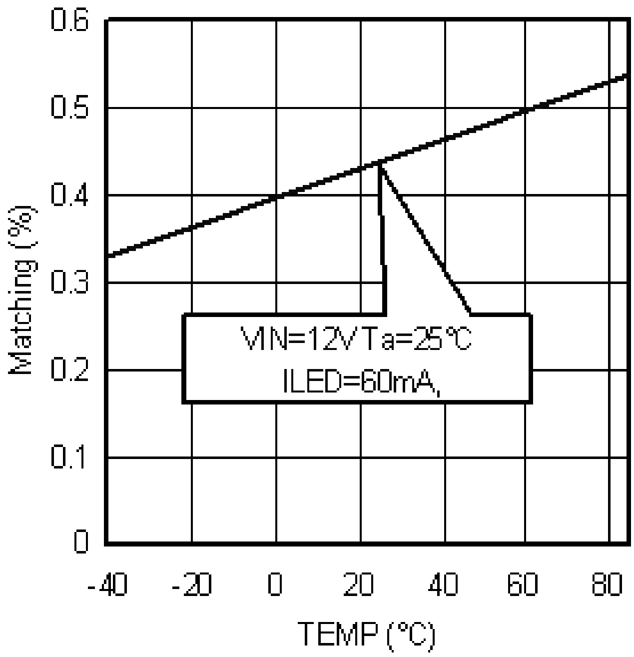


Figure 20. LED Current Matching

- **Typical Performance Curves - continued**

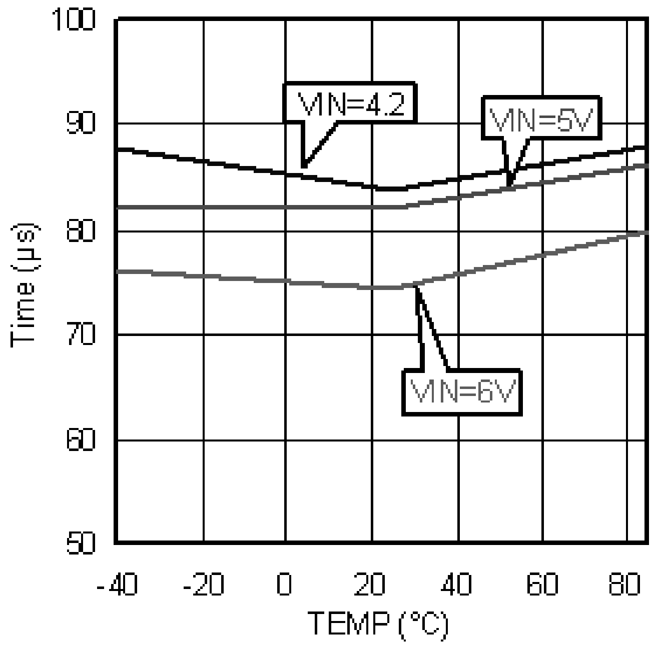


Figure 21. LED Open Time vs. Temp

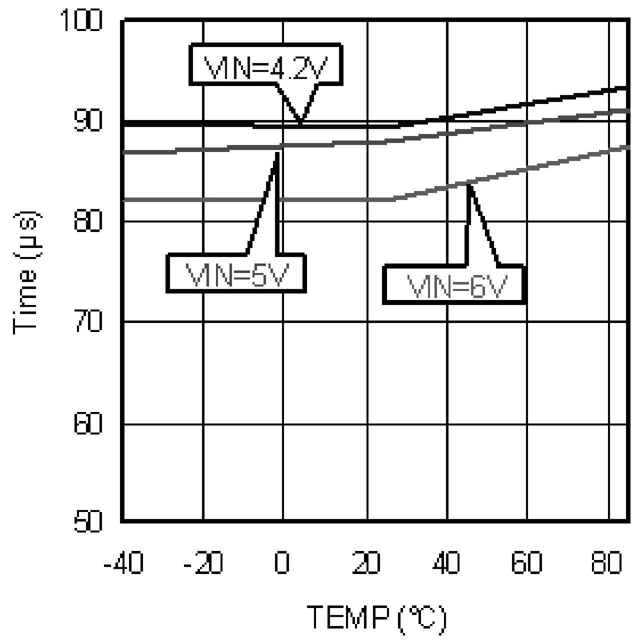


Figure 22. LED Short Time vs. Temp

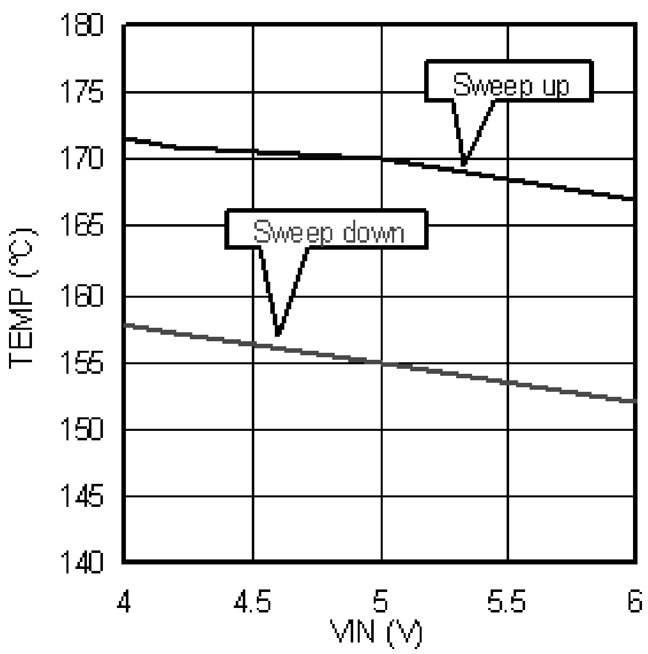


Figure 23. Thermal Shut Down

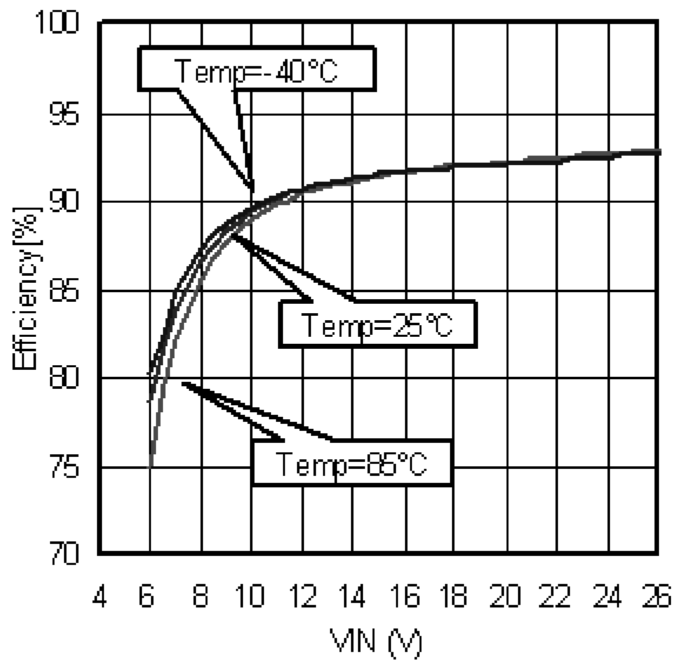


Figure 24. Efficiency 10LEDx4CH
ILED=60mA

- **Typical Performance Curves - continued**

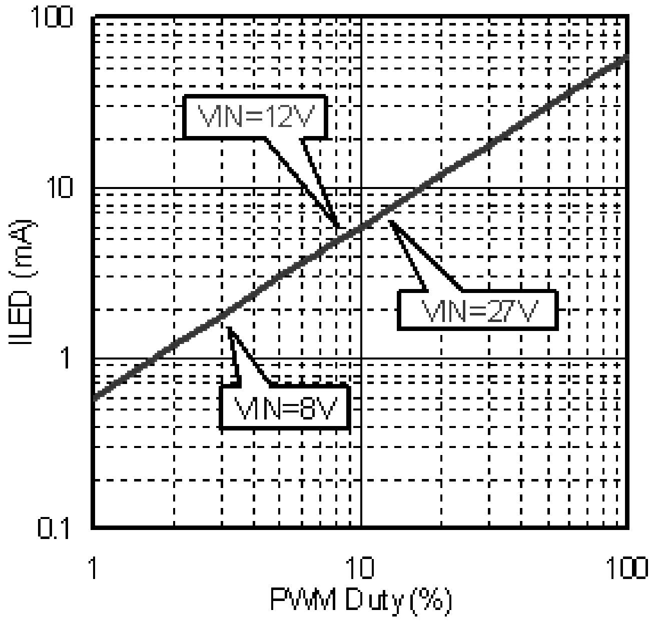


Figure 25. LED Current vs. PWM Duty
PWM Freq=200Hz FSET=56kΩ

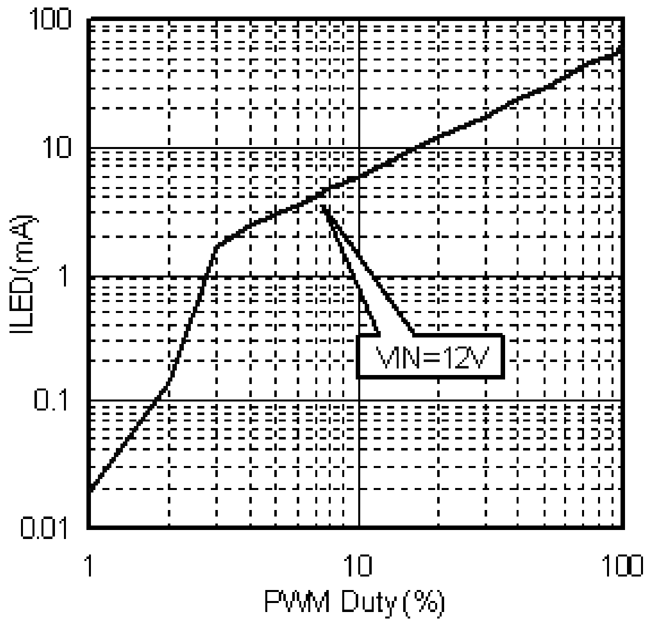


Figure 26. LED Current vs. PWM Duty
PWM Freq=30kHz FSET=56kΩ

- **Application Example**

Figure 27, Figure 28 and Figure 29 are Application examples. Recommended schematics and Layout are shown in page 29, 31.

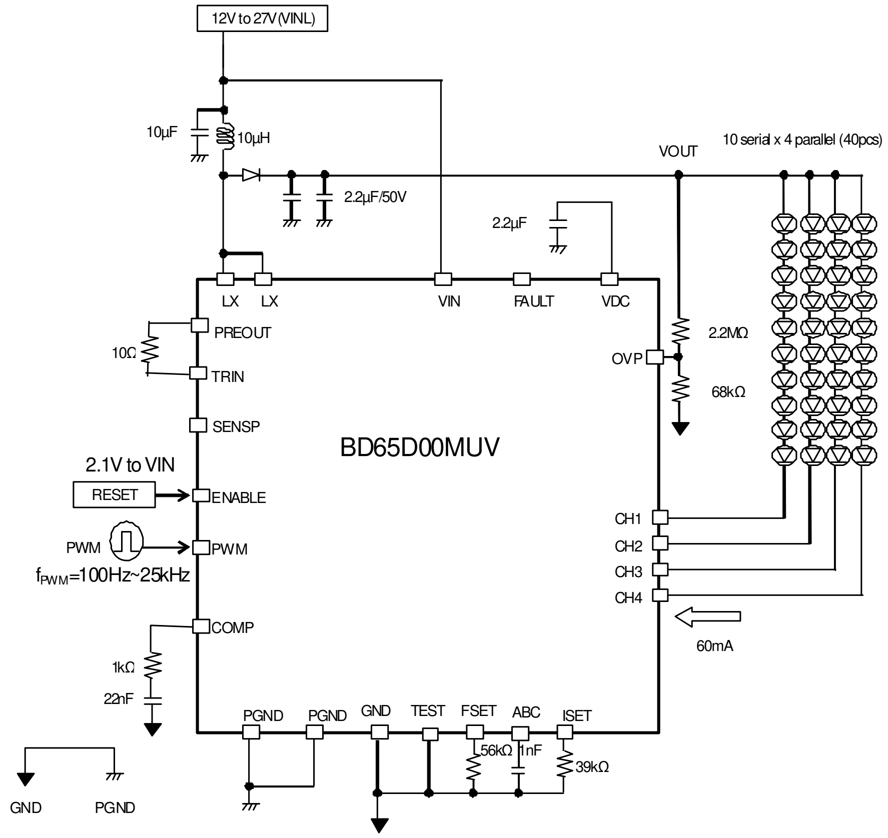


Figure 27. BD65D00 Application example (4 parallel)

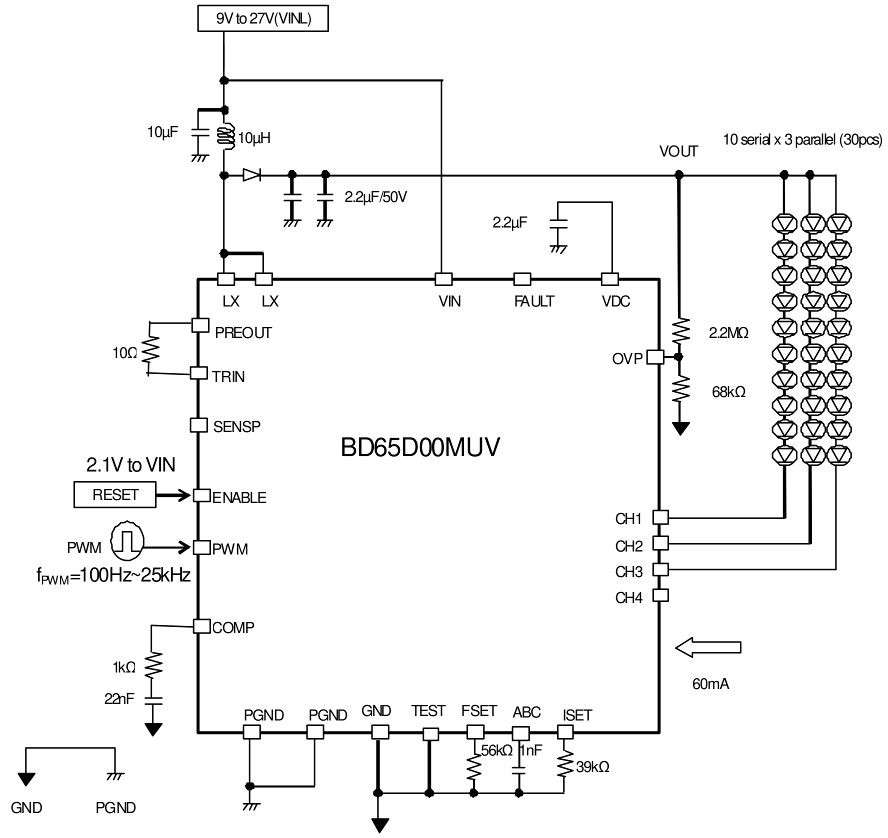


Figure 28. BD65D00 Application example (3 parallel)

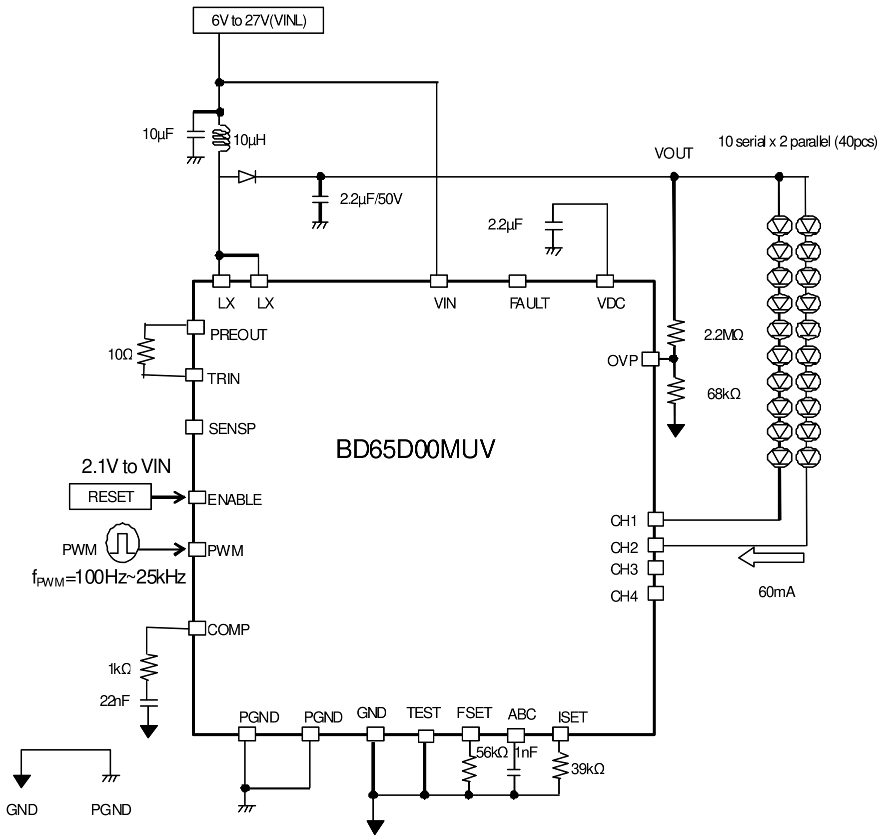


Figure 29. BD65D00 Application example (2 parallel)

- **Functional Descriptions**

1) PWM current mode DC/DC converter
This detects the lowest voltage inside CH 1,2,3,4 pin voltage during power on. PWM duty is decided to be 0.8V and output voltage is kept invariably. As for the input soft the PWM comparator as the feature of the PWM current mode, one is overlapped with error components from the error amplifier, and the other is overlapped with a current sense signal that controls the inductor current into Slope waveform to prevent sub harmonic oscillation. This output controls internal Nch Tr via the RS latch. In the period where internal Nch Tr gate is ON, energy is accumulated in the external inductor, and in the period where internal Nch Tr gate is OFF, energy is transferred to the output capacitor via external SBD.
This IC has many safety functions, and their detection signals stop switching operation at once.

2) Pulse skip control
This IC regulates the output voltage using an improved pulse-skip. In “pulse-skip” mode the error amplifier disables “switching” of the power stages when it detects low output voltage and high input voltage. The oscillator halts and the controller skip switching cycles. The error amplifier reactivates the oscillator and starts switching of the power stages again when this IC detects low input voltage.
At light loads a conventional “pulse-skip” regulation mode is used. The “pulse-skip” regulation minimizes the operating current because this IC does not switch continuously and hence the losses of the switching are reduced. When the error amplifier disables “switching”, the load is also isolated from the input. This improved “pulse-skip” control is also referred to as active-cycle control.

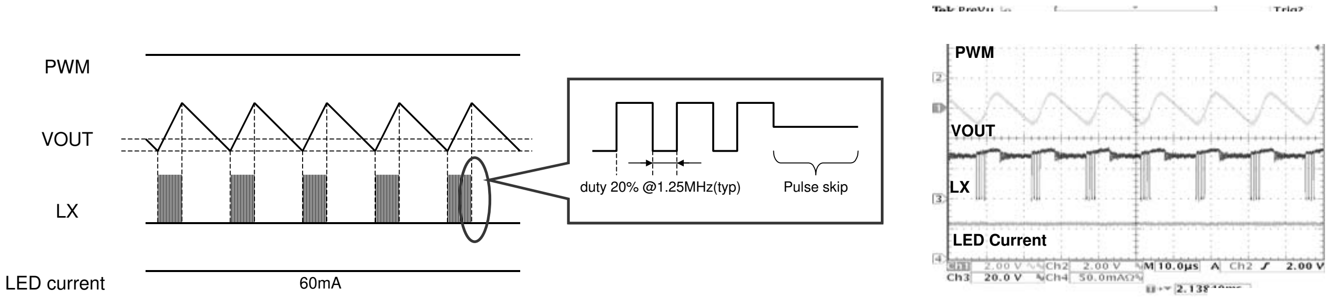


Figure 30. Pulse-skip

3) Soft start
This IC has soft start function.
The soft start function prevents large coil current.
Rush current at turning on is prevented by the soft start function.
The soft start of this IC controls over-current setting hence peak is controlled. Therefore, before switching phenomenon (not pulse-skip phenomenon) occurs, soft start (the phenomenon where-in current flows to the coil) will not start (stop).
Pulse-skip can release soft-start if the switching ON/OFF time is set.
After changing ENABLE pin, PWM pin from ‘L’→ ‘H’, regulator (VDC) voltage increases. Soft start is effective within the period 4.3ms when UVLO is detected and when it exceeds VDC=3.9V (typ.). Once soft start is finished, even if you change PWM from ‘L’ → ‘H’, soft start does not work.

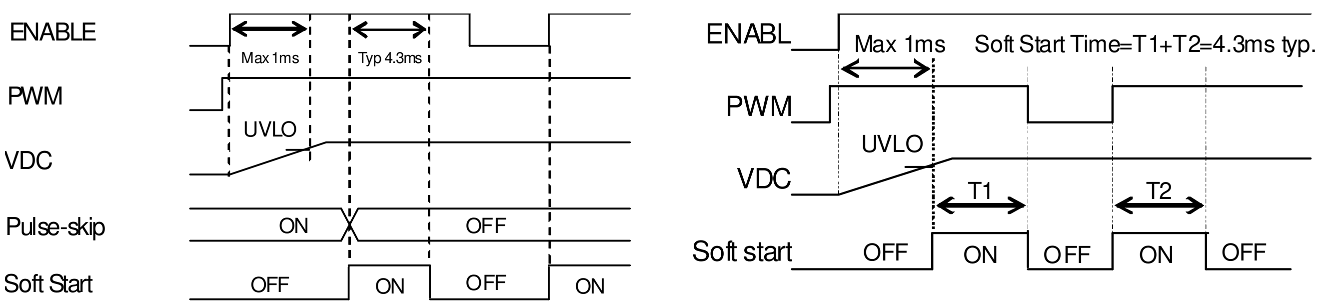


Figure 31. Soft start

4) FAULT

When the error condition occurs, boost operating is stopped by the protection function avoiding error condition. “L” is outputted from FAULT pin when an error occurs. After power-on, until soft start is released, around 4.3ms (typ.), protection functions do not operate (except TSD).
When ENABLE pin is changed to ‘L’, even if output of Fault pin latches, it will still reset to the initial status.

(In pulse-skip state, while the switching is stopped, the mask time of the FAULT pin becomes longer since the soft start is also stopped.) When using 3 parallel connection of LED in less than 4.3ms (typ.), the FAULT pin will output ”L” if the process of the unused pin is not yet finished. Evaluate sufficiently the start up time when the connected capacitor between COMP pin & GND starts up smoothly.

Object of protect function is as shown below.

- Over-voltage protection (OVP)
- Thermal shut down (OTP)
- Over current protect (OCP)
- Output short protect
- LED Short (Latch)
- LED Open (Latch)

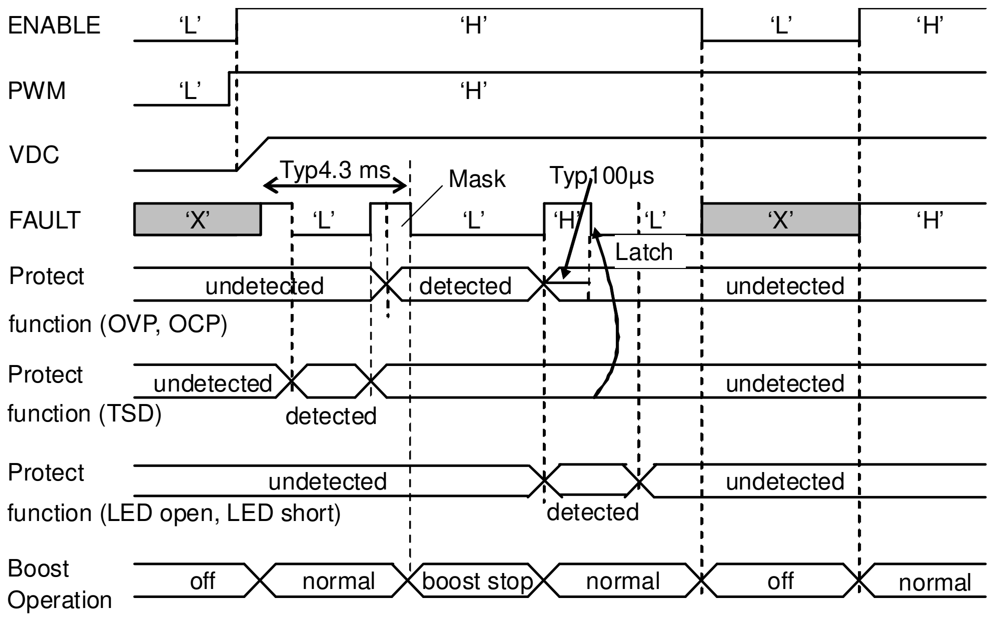


Figure 32. FAULT operating description

- **Protection**

PROTECTION TABLE

CASE	FAILURE MODE	DETECTION MODE	CH1 pin	CH2 to 4 Pin	VOUT Adjustment	FAULT Terminal
1	LED Short (LED CH1 is Short)	CH1 > VSC	LED current stop and DC/DC feedback doesn't return	Normal Burning DC/DC feedbacks at CH2 to CH4	Adjust VF of LED at CH2 to CH4 at the biggest line	'H' → 'L' (Latch)
2	LED OPEN (LED CH1 is Open)	CH1 < 0.2V(typ.) and OVP > 1.2V(typ.)	LED current stop and DC/DC feedback doesn't return	Normal Burning DC/DC feedbacks at CH2 to CH4	Adjust VF of LED at CH2 to CH4 at the biggest line	'H' → 'L' (Latch)
3	VOUT/LX GND SHORT	OVP < 50mV(typ.)	FAULT change from 'H' to 'L', and switching is stopped. When OVP>50mV, FAULT return 'H'		-	'H' → 'L'
4	Output LED stack voltage too high	OVP > 1.2V(typ.)	FAULT change from 'H' to 'L ', and switching is stopped. OVP<1.2V, FAULT returns to 'H ' (does not return when it occurs at the same time with LED open)		-	'H' → 'L'
5	LX current too high	OCP > 2.5A or OTP > 175°C(typ.)	FAULT change from 'H ' to 'L ', and switching is stopped. Fault pin does not returns to 'H ' because IC shutdowns and when ENABLE is from 'H ' to L until 'H '.		-	'H' → 'L'

▪ Over voltage protection (OVP)

When LED is separated it will result to output open and over step-up. When the built-in (external) Tr and OVP pin exceed the absolute maximum rating, the built-in (external) Tr and IC will break down. Thus, OVP pin when more than the detect voltage will turn into over voltage protection status turning off switching and stopping DC/DC.

After over voltage protection, as shown in Figure 33, the IC changes from activation into non-activation, and the output voltage goes down slowly. And when the Feedback of CH1 isn't returned, feedback takes place in CH2.

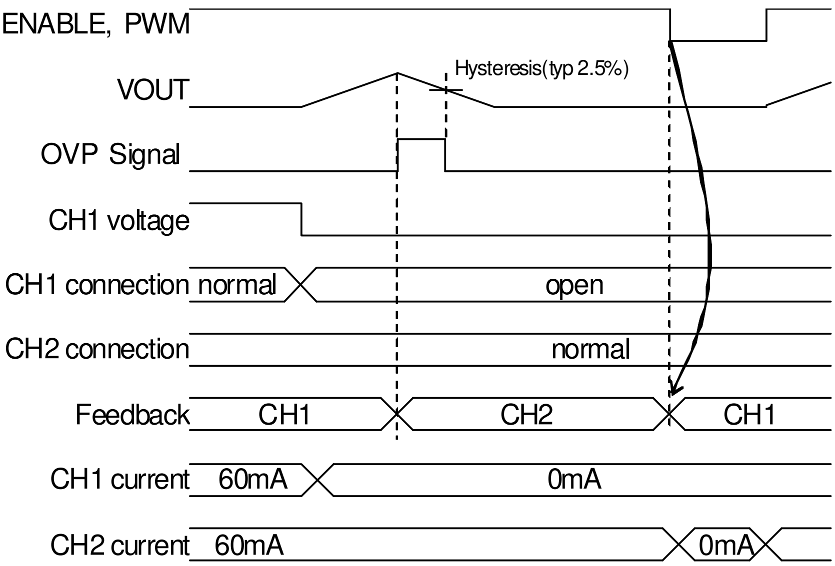


Figure 33. OVP operating description

The value shown in electrical characteristics is used here.

Over voltage limit	min 1.16V	typ 1.20V	max 1.24V
LED control voltage	min 0.64V	typ 0.80V	max 0.96V
LED terminal over voltage protect	min 6.80V	typ 8.00 V	max 9.20V

1. Calculate the condition of the total value of LED VF.
   Example) In the case of serial 8 LEDs with VF=2.9V (min), 3.2V (typ.), 3.5V (max) => 3.5V x 8=28V

2. Then calculate the biggest value of output with the following formula.
   The biggest value of output = the biggest value calculated in #1 + the biggest value of LED terminal voltage. (0.96V)
   Example) The biggest value of output = 28V + 0.96V =28.96V

3. Set the smallest value of over voltage larger than the biggest value of output.
   If over voltage is closer to the total value of VF, it could be occurred to detect over voltage by ripple, noise, and so on.
   It is recommended that some margins should be left on the difference between over voltage and the total value of VF.
   This time around 6% margin is placed.
   Example) Output largest value = 28.96V, the smallest value of over voltage = 28.96V x 1.06 = 30.70V
   Ic over voltage limit min=1.16V, typ=1.20V, max=1.24V
   typ = 30.70V×(1.20V/1.16V) = 31.76V
   max = 31.76V×(1.26V/1.20V) = 33.35V

4. Below shows how to adjust setting resistor value.
   Please fix resistor high between OVP terminal and output and then set over voltage after changing resistor between OVP terminal and GND. If this resistor value is decreased, output voltage will also decrease while PWM is turned OFF, hence ripple of output voltage becomes larger and the sound/noise of output capacitor also increases.

   Example) Selecting OVP resistor (R1 and R2).

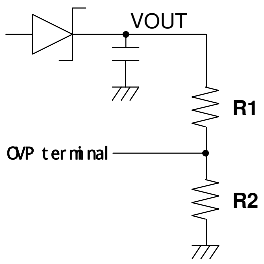
▪ OVP resistor selection

(Example. 1) VF=3.5V max, serial = 7 LED
OVP = 1.2V, R1 = 2.2MΩ, R2 = 95.3kΩ
VOUT = 1.2 × (2.2MΩ + 95.3kΩ)/ 95.3kΩ = 28.90V

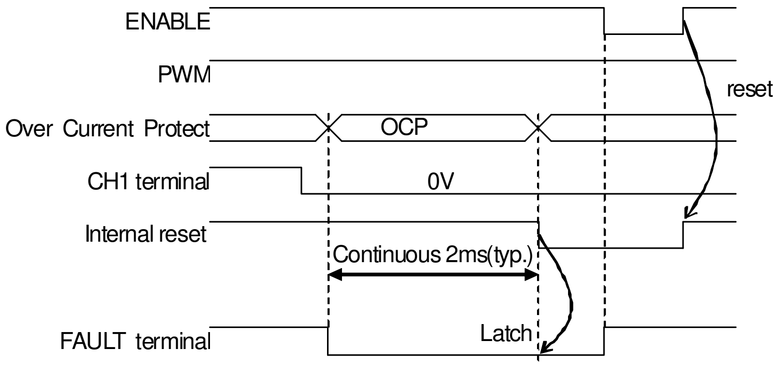
(Example. 2) VF=3.5V max, serial = 8 LED
OVP = 1.2V, R1 = 2.2MΩ, R2 = 82kΩ
VOUT = 1.2 × (2.2MΩ + 82kΩ)/ 82kΩ = 33.40V

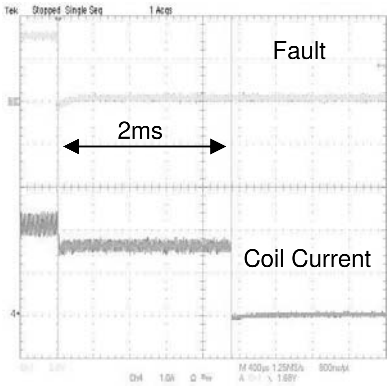
(Example. 3) VF=3.5V max, serial = 9 LED
OVP = 1.2V, R1 = 2.2MΩ, R2 = 73.2kΩ
VOUT = 1.2 × (2.2MΩ + 73.2kΩ)/ 73.2kΩ = 37.27V

(Example. 4) VF=3.5V max, serial = 10 LED
OVP = 1.2V, R1 = 2.2MΩ, R2 = 68kΩ
VOUT = 1.2 × (2.2MΩ + 68kΩ)/ 68kΩ = 40.02V



▪Over Current Protection
Over current flows in current detect resistor that is connected between internal switching Tr source and PGND. When it increases beyond detect voltage, over current protect operates. Over current protect prevents it becoming more than detect voltage by reducing on Duty of switching Tr without stopping boosting operation.
Since the over current detector of this IC detects peak current, more than setting value of over current doesn't flow.
If both PWM=H (boosting condition) and over current situation keep going during continuous 2ms, the IC shuts down. By making ENABLE 'H'->'L'->'H', the IC activates again. The IC might shut down if boosting operation starts with slow speed of power supply activation and also low voltage. Please operate after setting input voltage that is required for application.





▪ External SBD open detect / Output Short protection
If in case external SBD and DC/DC output (VOUT) connection is open, or VOUT is shorted in GND, there is a risk that coil and the internal Tr might break down. Therefore, at such an error as OVP becoming 50mV (typ.) or below, turns off the output Tr, and prevents the coil and the IC from being destructed.

And the IC changes from activation into non-activation, current does not flow to the coil (0mA).

▪ Thermal shut down
This IC has thermal shut down function.
The thermal shut down works at 175°C (typ.) or higher, and the IC changes from activation into non-activation.

- **Operating of the Application Deficiency**

1) When 1 LED or 1string OPEN during the operation

The LED string which became OPEN isn't lighting (e.g. CH1), but other LED strings are lighting.

As shown in Figure 34, when the strings in CH1 are open, CH1 pin become 0V. The lowest voltage is below 0.8V thus the output will boost up to over voltage protection voltage. When over voltage protect is detected, open process starts. Once OPEN, since the pin which is the object of the feedback is excluded, VOUT returns to normal voltage.

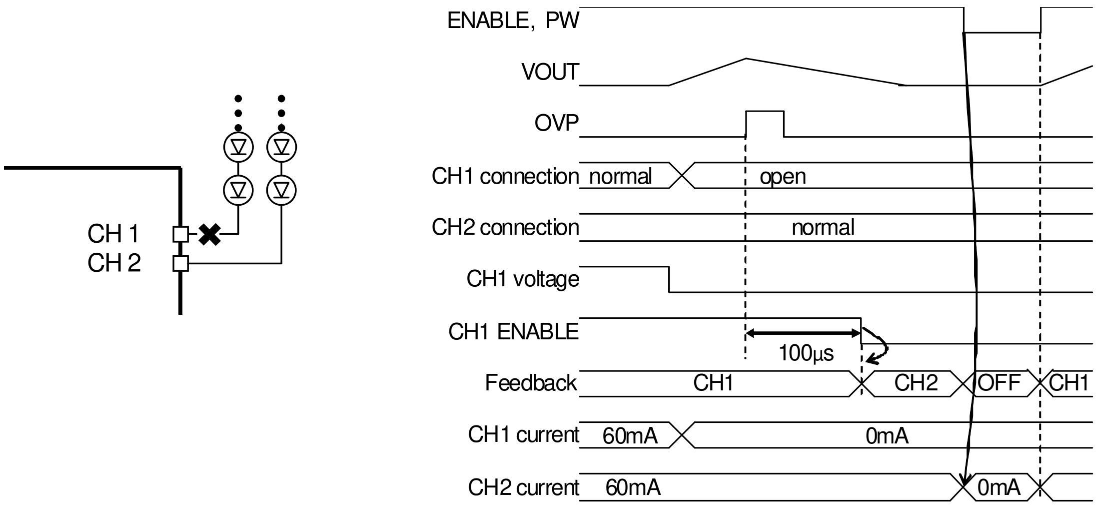


Figure 34. LED open protect

2)When LED short-circuited in multiple

All LED strings are lighted unless CH1 to 4 terminal voltage is more than 8V(typ.).

When it was more than 8V only the strings which short-circuited are turned off, LED current strings of other lines continue to turn on normally. Short line (CH1) current is changed from 60mA to 0.05mA (typ.), so CH1 terminal don't heat.

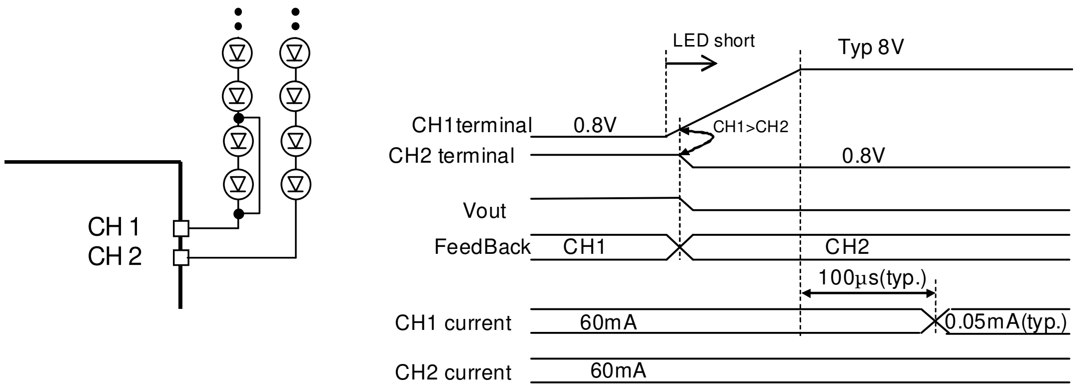


Figure 35. LED short protect

3)When Schottky diode remove

IC breakdown is prevented by stopping boost operation thru Schottky diode protection function (OVP pin <50mV).

- **Control Signal Input Timing**

Timing sequence1

Figure 36. shows the Power ON sequence. ENABLE and PWM signal from ‘L’ to ‘H’ after charging current (VIN ON). Power OFF sequence, on the other hand, is turning OFF power supply (VIN) after ENABLE and PWM Signal turns from H to L.

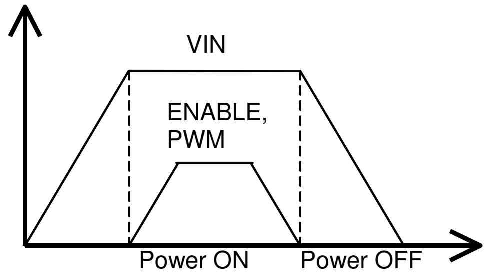
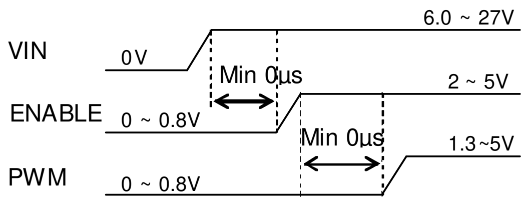


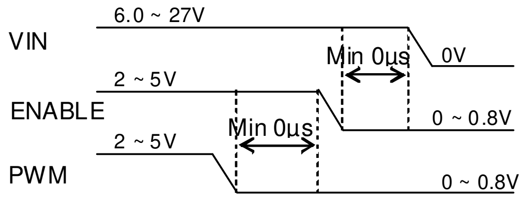
Figure 36. Timing sequence1

LED IC Timing Sequence for PWM Control Turn-on



*other signals are inputted after signals are turned on.

LED IC Timing Sequence for PWM Control Turn-off



*other signals are inputted after signals are turned off.

Timing sequence2

Figure 37. shows the Power ON sequence. Power Supply charge (VIN ON), ENABLE signals from L to H, then PWM signal from L to H. Power OFF sequence, on the other hand, is turning OFF power supply (VIN)and ENABLE, PWM signal from H to L.

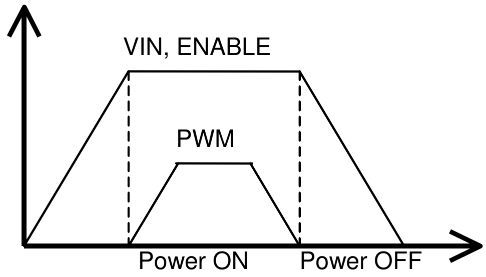
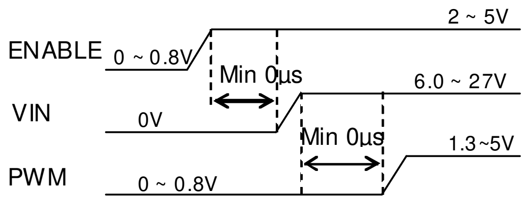


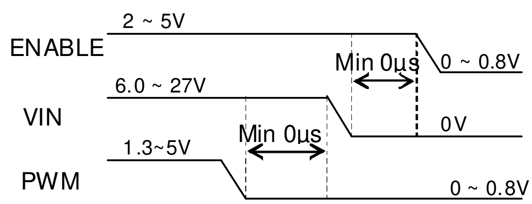
Figure 37. Timing sequence2

LED IC Timing Sequence for PWM Control Turn-on



*other signals are inputted after signals are turned on.

LED IC Timing Sequence for PWM Control Turn-off



*other signals are inputted after signals are turned off.

Timing sequence3

Figure 38.shows Power ON sequence. Power supply charge (VIN ON), PWM from L to H, then afterwards ENABLE signal from L to H. Power OFF sequence is power supply (VIN) OFF, PWM signal from H to L then ENABLE signal from H to L.

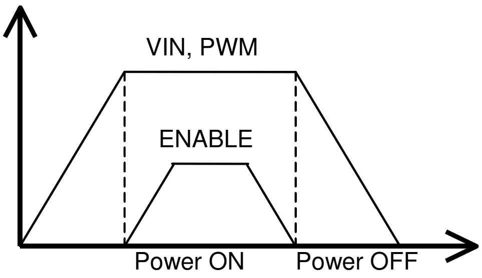
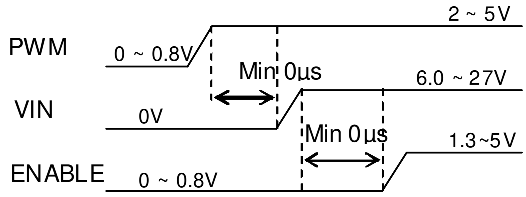


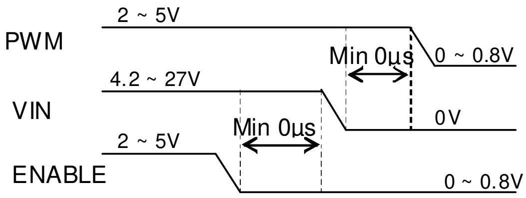
Figure 38. Timing sequence3

LED IC Timing Sequence for PWM Control Turn-on



*other signals are inputted after signals are turned on.

LED IC Timing Sequence for PWM Control Tn



*other signals are inputted after signals are turned off.

VIN wake up speed

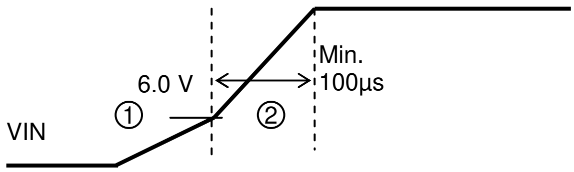


Figure 39. Control Signal timing

In case there is PWM OFF status (min: 10ms) during operation, ENABLE is reset ('H' to 'L') as shown in Figure 40.
If PWM stops and VOUT voltage is dropped, this IC will be in current limiter state when PWM starts (no soft start).
If soft start is not necessary, there is no need also to reset.

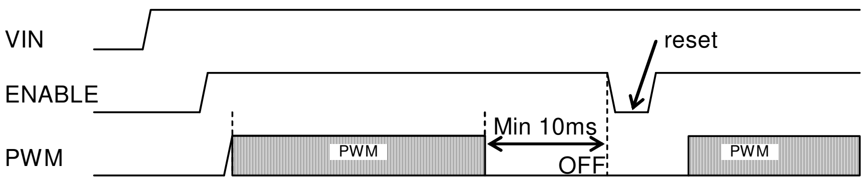


Figure 40. PWM stop and ENABLE turn "off"

● How to Activate

Pay attention to the following when activating.

- Regulator (VDC) is operated after ENABLE=H. Inner circuit is operated after releasing UVLO. When boosting after releasing UVLO, soft start function is operated. Soft start circuit needs t_{15} (more than 5µs) such as Figure 41. Soft start is operated during Tsoft time. Set PWM width "H" until soft start finishes.

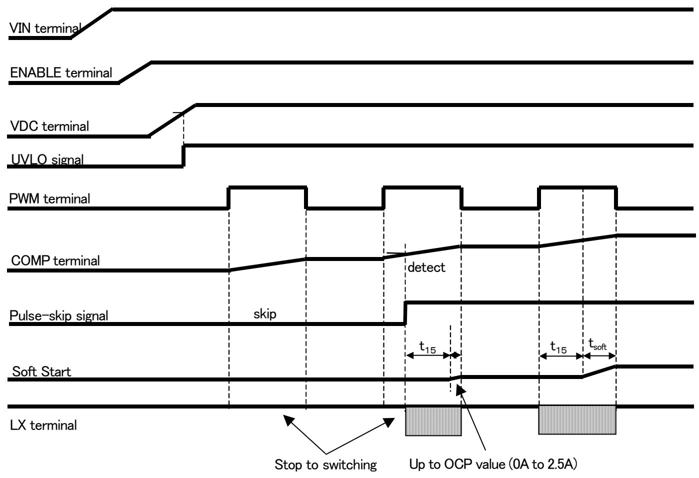


Figure 41. Soft Start

Example: Time until soft start finishes at PWM frequency 25kHz and PWM=H time is 6µs

By soft start time typ 4.3ms

tsoft = 6µs - 5µs = 1µs

Soft start time / tsoft / PWM frequency = 4300µs / 1µs / 25kHz = 172ms

At dimming with PWM terminal (after soft start finishes)

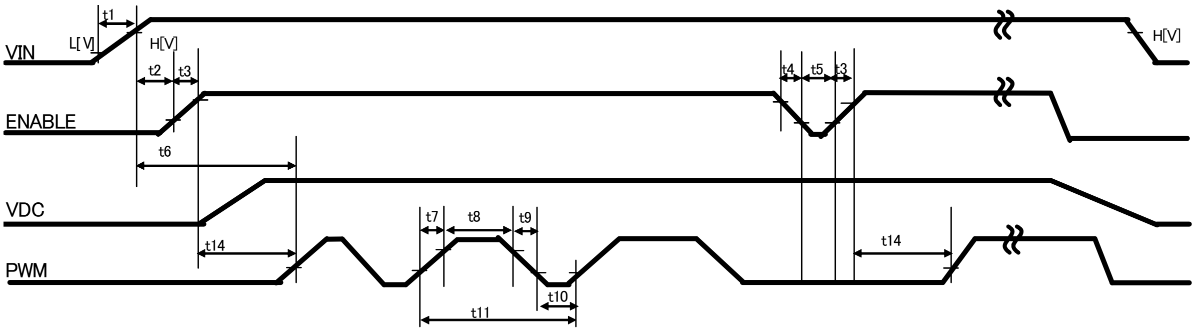


Figure 42. Timing Input (after soft start)

	Name	Unit	Min.	Typ.	Max.
t1	Power Supply Rise Time	µs	100	-	-
t2	Power Supply - ENABLE Rise Time	µs	0	-	-
t3	ENABLE Rise Time	µs	0	-	100
t4	ENABLE Fall Time	µs	0	-	100
t5	ENABLE Low Width	µs	50	-	-
t6	Power Supply - PWM Time	µs	0	-	-
t7	PWM Rise Time	µs	0	-	100
t8	PWM High Width	µs	5	-	-
t9	PWM Fall Time	µs	0	-	100
t10	PWM Low Width	µs	5	-	-
t11	PWM Cycle	µs	40	5000	10000
t12	ENABLE(H)->PWM(H) Time	µs	0	-	-
t13	ENABLE(L)->PWM(L) Time	µs	0	-	-
t14	PWM(L)->ENABLE(L) Time	µs	0	-	-
t15	Soft Start Set Up Time	µs	5	-	-
H	Operation Voltage	V	4.2	12	27
L	No Operation Voltage	V	-	-	4.2

- **How to Select the Number of LED Strings of the Current Driver**

In order to reduce the number of strings of current driver, open unnecessary CH1 to 4 pins for them not to be selected. When using 2 strings, open the unnecessary 2 strings.

During VOUT wake up in an open state, VOUT boost up until OVP voltage. Once IC detect OVP, VOUT don't boost up until OVP from next start up. If ENABLE set to 'L,' IC resets CH4 status as shown Figure 43.   Also during VOUT wake up, CH4 (open terminal) and CH1 are selected as shown Figure 44.

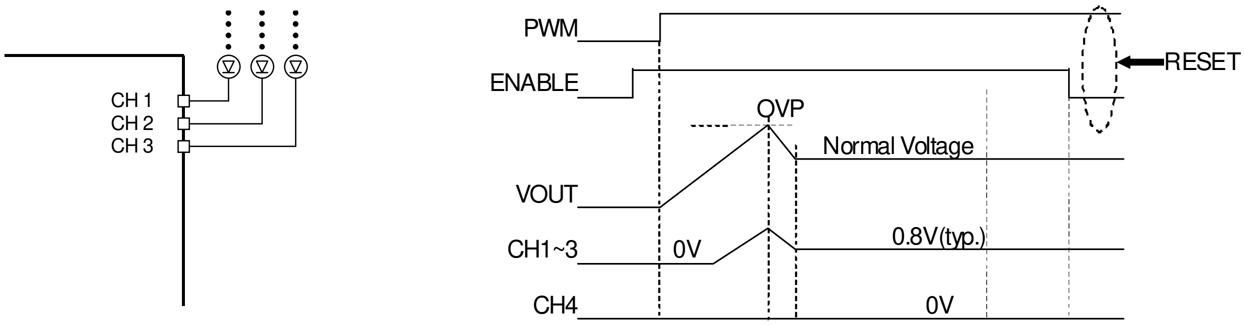


Figure 43. Select the number of CH1 strings

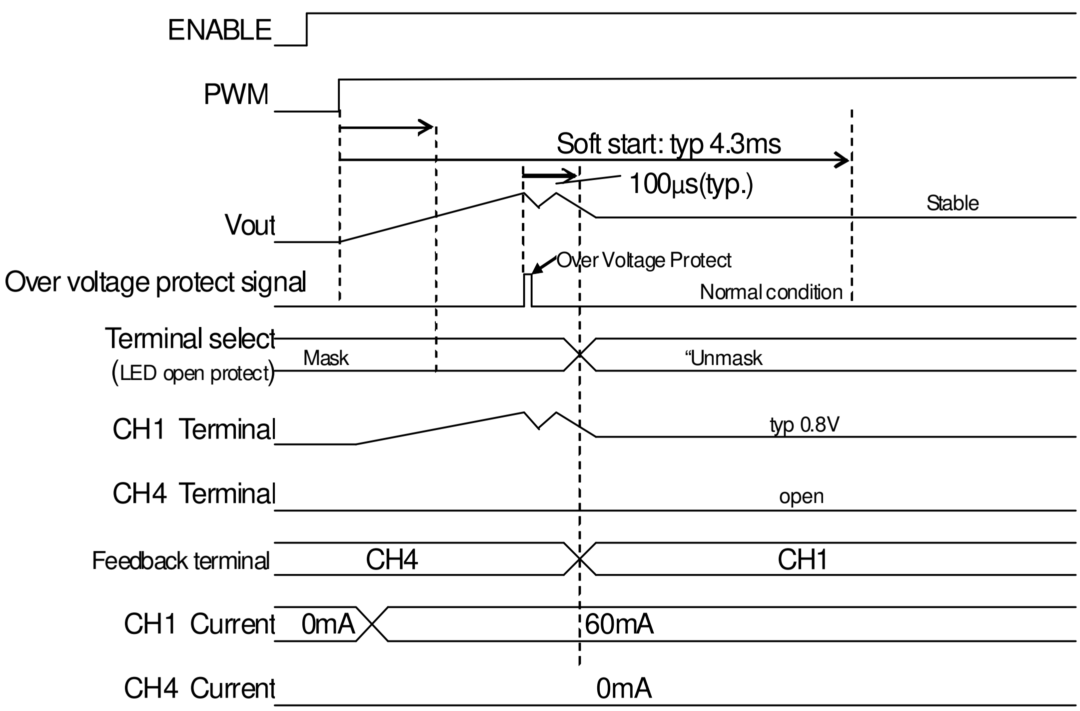


Figure 44. Select the number of CH4 strings (wake up)

- **Start Control (ENABLE) and LED Current Driver Selection (PWM)**

This IC can control the IC system by ENABLE, and IC can power off compulsory by setting 0.8V or below. Also, It powers on ENABLE is at more than 2.0V.
After it's selected to ENABLE=H, When it is selected at PWM=H, LED current decided with ISET resistance flow.
Next, When it is selected at PWM=L, LED current stop to flow.

ENABLE	PWM	IC	LED current
0	0	Off	OFF
1	0	On	OFF
0	1	Off	OFF
1	1	On	Current decided with ISET

- **LED Current Setting Range**

Normal Current setting is done thru resistor (RISET) connected to voltage of ISET.
Setting of each LED current is given as shown below.

RISET = 2340/ILEDmax

Also, Normal current setting range is 30mA to 100mA. LED current becomes a leak current MAX 2µA at OFF setting.

ISET Normal current setting example

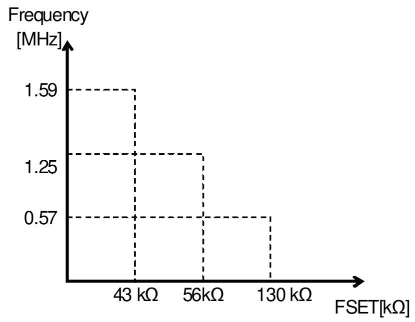
RISET	LED current
24kΩ (E24)	97.5mA
30kΩ (E24)	78.0mA
39kΩ (E24)	60.0mA
43kΩ (E24)	54.4mA
68kΩ (E24)	34.4mA

- **Frequency Setting Range**

Switching frequency can be set by connecting the resistor to FSET pin.
Also, Frequency setting range is 0.60MHz to 1.60MHz.
The below diagrams are the reference data that shows what happens when FSET terminal is connected to resister.

FSET frequency setting example

RFSET	Frequency
130kΩ (E96)	0.57MHz
56kΩ (E24)	1.25MHz
43kΩ (E24)	1.59MHz



Max Duty example

Frequency	Max Duty[%]		
	Min	Typ	Max
600MHz	-	96.0	-
1.25MHz	91.0	95.0	99.0
1.6MHz	-	92.0	-

Min Duty example

Frequency	Min Duty[%]		
	Min	Typ	Max
1.25MHz	-	20	-

- **PWM Dimming**

Current driver PWM control is controlled by providing PWM signal to PWM port, as it is shown Figure 45.
The current set up with ISET is chosen as the H section of PWM and the current is off as the L section. Therefore, the average LED current is increasing in proportion to duty cycle of PWM signal. This method that it lets internal circuit and DC/DC to work, because it becomes to switch the driver, the current tolerance is a few when the PWM brightness is adjusted, it makes it possible to brightness control until 5µs (Min 0.1% at 200Hz). And, don't use for the brightness control, because effect of ISET changeover is big under 1µs ON time and under 1µs OFF time. Typical PWM frequency is 100Hz to 25kHz.

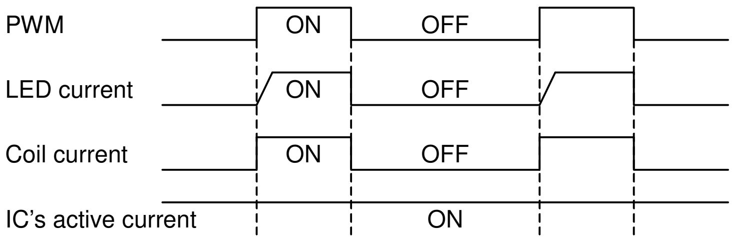


Figure 45. PWM sequence

- **Analog Dimming**

This IC controls LED current thru an analog input (ABC terminal).
LED current is determined thru the resistor connected to ISET.
Normal state is ABC voltage= typ 0.733V.
Decrease LED current to decrease ABC voltage and increase LED current to increase ABC voltage.

In order to get the MAX value of LED current,
follow the setting range of LED current found in page 18.
Be careful that the setting LED current Max value is ABC voltage=0.733V (typ.).
ABC input range is 0.05V ~ 0.9V.
This dimming is effected by ISET tolerance.

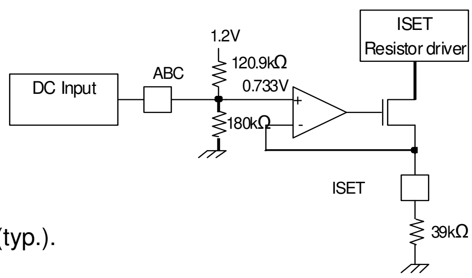


Figure 46. Analog dimming application

When analog dimming is not used, connect capacitor to ABC terminal.
LED current increases until charging of the capacitor at the ABC terminal is finished.
The resistor between 1.2V and ABC terminal is 120.9kΩ.
Take into consideration the charge time before deciding the capacitor value.

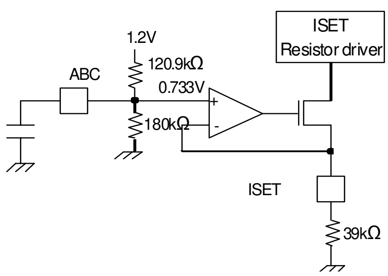


Figure 47. PWM dimming application

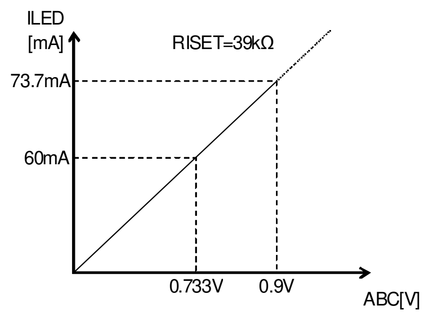


Figure 48. ILED vs. ABC voltage

- **Coil Selection**

The DC/DC is designed by more than 4.7µH. When “L” value sets to a lower value, it is possibility that the specific sub-harmonic oscillation of current mode DC / DC will be happened. Do not let “L” value to 3.3µH or below.
When “L” value increases, the phase margin of DC / DC becomes zero. Please enlarge the output capacitor value when you increase “L” value. Make the resistor component smaller in order to increase the efficiency of DCR Inductor. Please estimate Peak Current of Coil as shown in the examples below.

Peak Current calculation
<Estimate of the current value which is needed for the normal operation>
As over current detector of this IC is detected the peak current, it have to estimate peak current to flow to the coil by operating condition.

In case of,
- Supply voltage of coil = V_{In}
- Inductance value of coil = L
- Switching frequency = fsw (Min=1.0MHz, Typ = 1.25MHz, Max = 1.5MHz)
- Output voltage = VOUT
- Total LED current = I_{LED}
- Average current of coil = Iave
- Peak current of coil = Ipeak
- Cycle of Switching = T
- Efficiency = eff (Please set up having margin)
- ON time of switching transistor = Ton
- ON Duty = D

The relation is shown below:

CCM: $Ipeak = (V_{In} / L) \times (1 / fsw) \times (1-(V_{In} / VOUT))$, DCM: $Ipeak = (V_{In} / L) \times Ton$

$Iave=(VOUT \times IOUT / V_{In}) / eff$

$Ton=(Iave \times (1- V_{In} / VOUT) \times (1/fsw) \times (L/ V_{In}) \times 2)^{1/2}$

Each current is calculated.
As peak current varies according to whether there is the direct current superposed, the next is decided.

CCM: $(1- V_{In} / VOUT) \times (1/fsw) < Ton$ → peak current = Ipeak /2 + Iave

DCM: $(1- V_{In} / VOUT) \times (1/fsw) > Ton$ → peak current = $V_{In} / L \times Ton$

(Example 1)

In case of, V_{In} = 12V, L = 10µH, fsw = 1.25MHz, VOUT = 32V, I_{LED} = 240mA, Efficiency = 88%

Iave = (32 × 240m / 12) / 88% = 0.7273A

Ton = $(0.7273 \times (1 - 12 / 32) \times (1 / 1.25M) \times (10\mu / 12) \times 2)^{1/2}$ = 0.78µs

$(1- V_{In} / VOUT) \times (1 / fsw)$ = 0.5µs < Ton(0.78µs) CCM

Ipeak = (12 / 10µ) × (1 / 1.25M) × (1 - (12 / 32)) = 0.6A

Peak current = 0.6A / 2 + 0.727A = 1.027A

(Example 2)

In case of, V_{In} = 24.0V, L = 10µH, fsw = 1.25MHz, VOUT = 32V, I_{LED} = 120mA, Efficiency = 88%

Iave = (32 × 120m / 24.0) / 88% = 0.1818A

Ton = $(0.1818 \times (1-24 / 32) \times (1 / 1.25M) \times (10\mu / 24) \times 2)^{1/2}$ = 0.17µs

$(1- V_{In} / VOUT) \times (1 / fsw)$=0.20µs > Ton(0.17µs) DCM

Ipeak = V_{In} / L x Ton = 24 / 10µ x 0.17µs = 0.42A

Peak current = 0. 42A

DCM/CCM calculation
Discontinuous Condition Mode (DCM) and Continuous Condition Mode (CCM) are calculated as following.

CCM: $L > VOUT \times D \times (1 - D)^2 \times T / (2 \times I_{LED})$

DCM: $L < VOUT \times D \times (1 - D)^2 \times T / (2 \times I_{LED})$

*D = 1- V_{In} / VOUT

(Example 1)

In case of, V_{In} = 7.0V, L = 10µH, fsw = 1.2MHz, VOUT = 32V, I_{LED} = 240mA

$VOUT \times D \times (1 - D)^2 \times T / (2 \times I_{LED}) = 32 \times (1 – 7 / 32) \times (7 / 32)^2 \times 1/(1.2 \times 10^6) / (2 \times 0.24) = 4.69\mu < L(10\mu H)$

→ CCM

(Example 2)

In case of, V_{In} = 12.0V, L = 10µH, fsw = 1.2MHz, VOUT = 32V, I_{LED} = 60mA

$VOUT \times D \times (1 - D)^2 \times T / (2 \times I_{LED}) = 32 \times (1 – 12 / 32) \times (12 / 32)^2 \times 1/(1.2 \times 10^6) / (2 \times 0.12) = 15\mu > L(10\mu H)$

→ DCM