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Constant Current LED Drivers

50V 500mA
1ch Source Driver for Automotive

BD83732HFP-M BD83733HFP-M

General Description
BD83732HFP-M and BD83733HFP-M are 50V tolerant LED current drivers. Suitable for Automotive LED applications, it can control light through constant current output with control using PWM.
Having LED open/short detective circuit and LED current de-rating functions integrated, it can deliver high reliability. By utilizing Rohm's patented PBUS function, it is possible to turn OFF all LEDs when a row of LEDs are short/open-circuited if multiple number of the ICs are used
In case the LED connected to the output IOUT terminal has 2 LEDs in serise, BD83732HFP-M has to be used, in case of 3 LEDs in series - BD83733HFP-M (Refer to Page.18 LED Open Detection / Disable LED Open Detection).

Key Specifications
- Input Voltage Range: 4.5V to 42V
- Max Output Current: 500mA (Max)
- Output Current Accuracy: ±5% (Max)
- Operating Temperature Range: -40°C to +125°C

Packages

Packages	W(Typ) x D(Typ) x H(Max)
HRP7	9.395mm x 10.540mm x 2.005mm

HRP7

Features
- AEC-Q100 Qualified
- Variable form Constant-Current Source Driver
- PWM Dimming Function
- LED constant current set by external resistor
- LED Current De-rating Function
- LED Open/Short detection
- Disable LED Open Detection at low power supply
- Temperature Protective
- Abnormal Output Detection and Output Functions (PBUS)

Application
- On-board Exterior Lamp
  (Rear Lamp, Turn Lamp, DRL/Position Lamp, Fog Lamp, etc.)
- On-board Interior Lamp
  (Air Conditioner Lamp, Interior Lamp, Cluster Light, etc.)

Basic Application Circuit

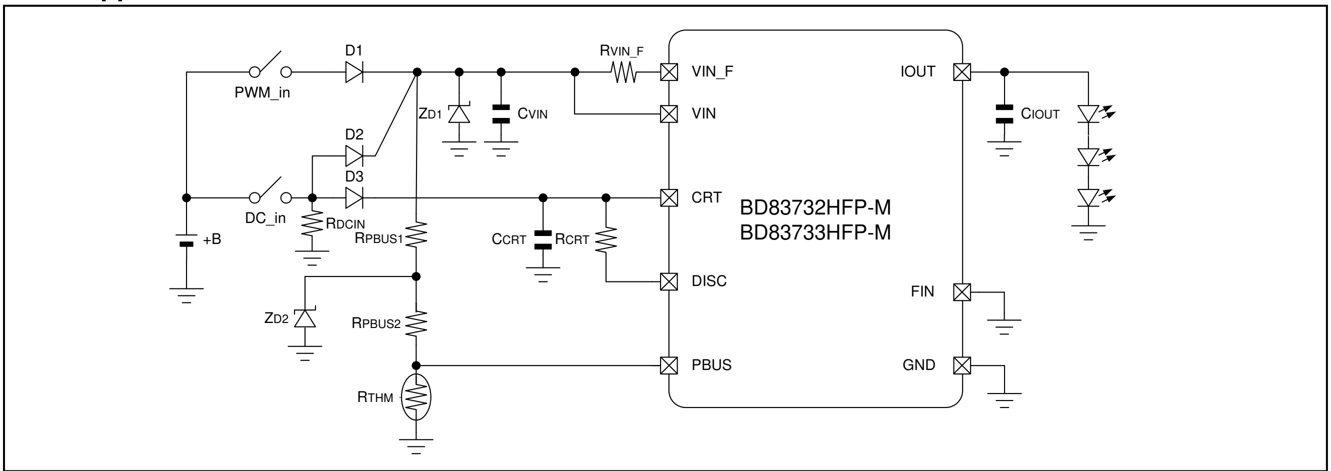


Figure 1. Typical Application Circuit

○Product configuration: Silicon monolithic integrated circuit ○ The product is not designed for radiation resistance.

Pin Configurations

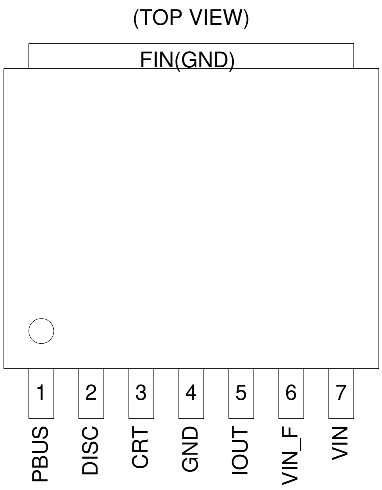


Figure 2. HRP7 Package Pin Configuration

Pin Descriptions

HRP7 Package

Pin No.	Pin Name	Function
1	PBUS	Error detection I/O, LED current de-rating input terminal
2	DISC	Discharge setting pin
3	CRT	Capacitor Resistor Timer setting
4	GND	GND
5	IOUT	Current output
6	VIN_F	Output current detection
7	VIN	Power supply input

If not used DISC should be shorted to GND.

Block Diagram

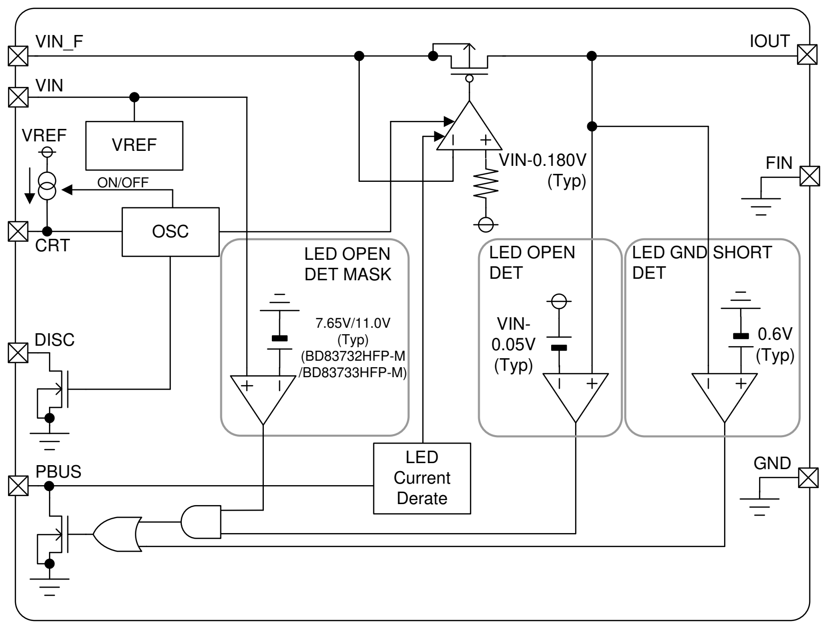


Figure 3. Block Diagram

Absolute Maximum Ratings (Ta=25°C)

Parameter	Symbol	Rating	Unit
Supply Voltage	V_{IN}	-0.3～+50	V
VIN_F,CRT,DISC,IOUT,PBUS Terminal Voltage	V_{VIN_F},V_{CRT},V_{DISC},V_{IOUT},V_{PBUS}	-0.3～VIN	V
Power Dissipation	Pd	2.29(Note1)	W
Operating Temperature Range	Topr	-40～125	°C
Storage Temperature Range	Tstg	-55～150	°C
Junction Temperature	Tjmax	150	°C
IOUT Output Maximum Current	I_{OUT}	500	mA

(Note1) HRP7
De-rate by 18.4mW/°C when operating above Ta=25°C
Please refer to page 21 below.

Caution: Operating the IC over the absolute maximum ratings may damage the IC. The damage can either be a short circuit between pins or an open circuit between pins and the internal circuitry. Therefore, it is important to consider circuit protection measures, such as adding a fuse, in case the IC is operated over the absolute maximum ratings.

Recommended Operating Conditions

Parameter	Symbol	Rating	Unit
Supply Voltage(Note1)	V_{IN}	4.5～42.0	V
Operating Temperature Range	Topr	-40～125	°C
CRTIMER Frequency Range	F_{PWM}	100～5000	Hz
PWM Minimum Pulse Width	T_{MIN}	10	µs

(Note1) Pd, ASO should not be exceeded

Operating Conditions

Parameter	Symbol	Min	Max	Unit
Current Setting Resistor	R_{VIN_F}	0.36	3.6	Ω
Capacitor connecting VIN terminal	C_{vin}	1.0	-	µF
Capacitor connecting IOUT terminal	C_{IOUT}	0.1	0.66	µF
Capacitor connecting CRT terminal	C_{CRT}	0.01	1.0	µF
DC_IN pull-down resistor	R_{DCIN}	-	50	kΩ

Electrical Characteristics (Unless otherwise specified Ta=-40～125°C, V_{IN}= 13V, R_{VIN_F}=0.47Ω, R_{PBUS}=10kΩ)

Parameter	Symbol	Min	Typ	Max	UNIT	Condition
Circuit Current	I_{VIN}	-	2.1	6.0	mA	
IOUT Terminal Output Current Accuracy	I_{OUT}	373	383	393	mA	Ta=25°C
		364	383	402	mA	Ta=-40°C～125°C
VIN – IOUT Drop Voltage	V_{DR_IOUT}	-	0.45	1.0	V	I_{OUT}=383mA
IOUT Terminal OFF Current	I_{IOUT_OFF}	-	-	1	μA	V_{IOUT}=2V, V_{CRT}=0.7V Ta=25°C
IOUT Current at GND Short	I_{IOUT_SHORT}	-	7	40	μA	V_{IOUT}=0V
Current Sense Voltage	$V_{IN\_F\_REF}$	0.171	0.180	0.189	V	$V_{IN\_F\_REF}$=V_{IN}-V_{IN_F}
IOUT Voltage at LED Open Detection	V_{IOUT_OPEN}	V_{IN} -0.080	V_{IN} -0.050	V_{IN} -0.020	V	
IOUT Voltage at LED Short Detection	V_{IOUT_SHORT}	0.20	0.67	1.00	V	
CRT Terminal Charge Current	I_{CRT_SO}	29.75	35.00	40.25	μA	V_{CRT}=0.9V
CRT Terminal Voltage	V_{CRT_CHA}	0.990	1.10	1.21	V	
CRT Terminal Discharge Voltage 1	V_{CRT_DIS1}	2.7	3.0	3.3	V	
CRTIMER Discharge Constant	V_{CRT_CHA} / V_{CRT_DIS1}	0.348	0.367	0.386	V/V	
CRT Terminal Discharge Voltage 2	V_{CRT_DIS2}	3.6	4.0	4.4	V	R_{D1}<->R_{D2} (Note1)
CRT Terminal Charge Resistance	R_{CHA}	51.6	54.3	57.0	kΩ	R_{CHA}=(V_{CRT_DIS1} − V_{CRT_CHA}) / I_{CRT_SO}
DISC Terminal Discharge Resistance 1	R_{D1}	-	50.0	100	Ω	V_{CRT}=3.4V
DISC Terminal Discharge Resistance 2	R_{D2}	2.5	5.0	10	kΩ	V_{CRT}=5V
PBUS Terminal De-rating Input Voltage High	V_{DH_PBUS}	2.3	2.5	2.7	V	⊿$V_{IN\_F\_REF}$ = 2.0mV ⊿$V_{IN\_F\_REF}$ = $V_{IN\_F\_REF(@PBUS = 13V)}$ − $V_{IN\_F\_REF(@PBUS = VDH\_PBUS)}$
PBUS Terminal De-rating Input Voltage Low	V_{DL_PBUS}	0.8	1.0	1.2	V	I_{OUT}<5μA
De-rating Gain	G_D	114	120	126	mV/V	⊿I_{OUT}=G_D × V_{PBUS} V_{PBUS}=1.5V -> 2.0V
PBUS Terminal Low Voltage	V_{OL_PBUS}	-	-	0.7	V	I_{PBUS}=2mA
PBUS Terminal Input Current	I_{IN_PBUS}	-	38.0	100	μA	V_{PBUS}=13V
Disable Open Detection during low power supply voltage						
BD83732HFP-M	V_{M_OPEN}	7.30	7.65	8.00	V	VIN voltage
BD83733HFP-M	V_{M_OPEN}	10.5	11.0	11.5	V	VIN voltage

●Typical Performance Curves (Reference Data)
(Unless otherwise specified Ta=25°C, V_{IN}=13V, R_{CRT}=3.9kΩ, C_{CRT}=0.033μF, C_{IOUT}=0.1μF)

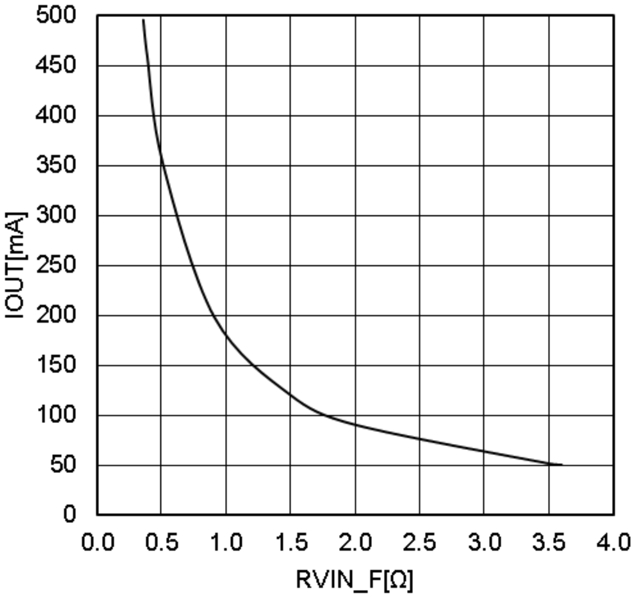


Figure 4. R_{VIN_F} vs I_{OUT}

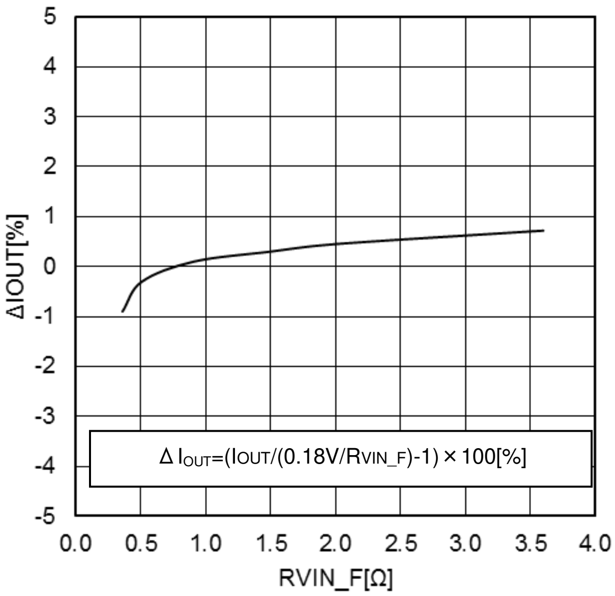


Figure 5. R_{VIN_F} vs ΔI_{OUT}

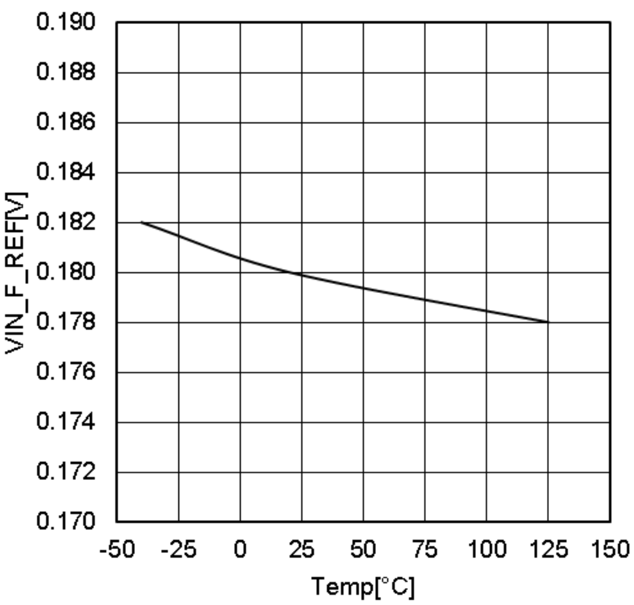


Figure 6.Temperature vs $V_{IN\_F\_REF}$

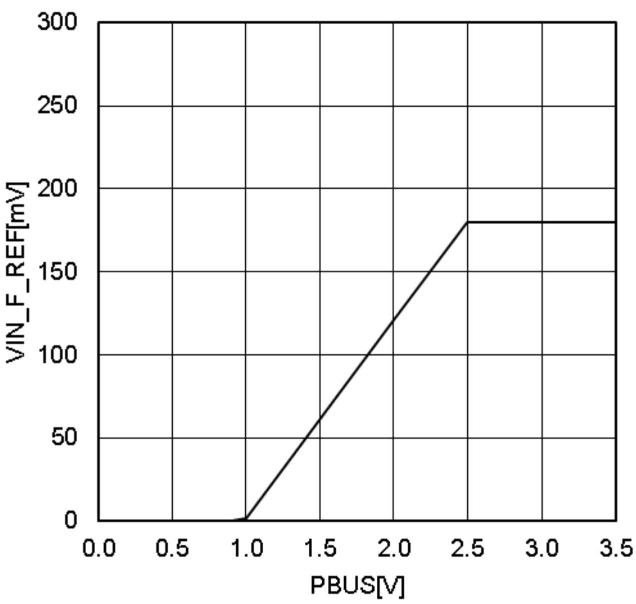


Figure 7. PBUS vs $V_{IN\_F\_REF}$

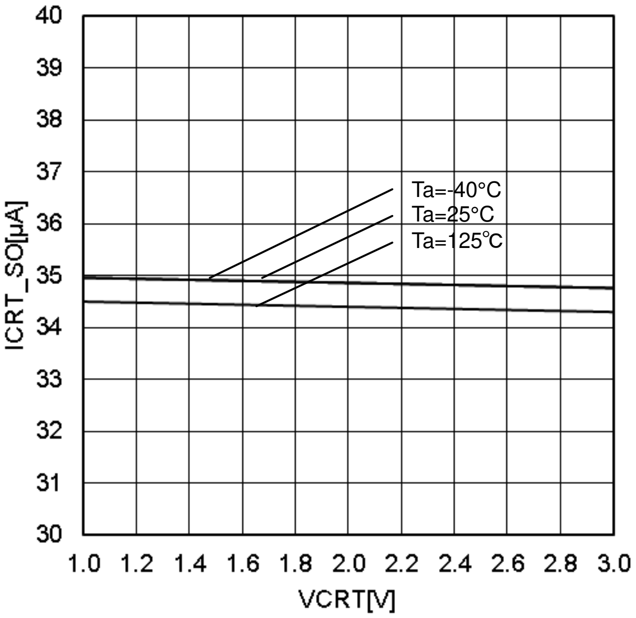


Figure 8. VCRT vs ICRT_SO
(VCRT:CRT Terminal Voltage)

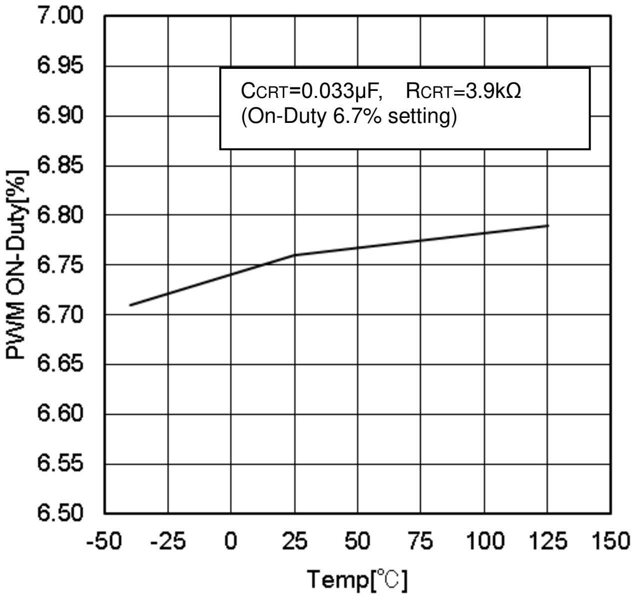


Figure 9. Temperature vs PWM ON Duty

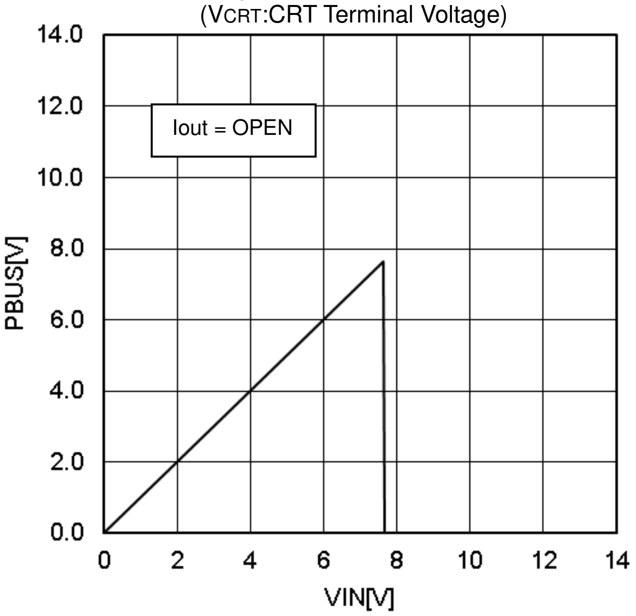


Figure 10. BD83732HFP-M
LED Disable Open Detection voltage

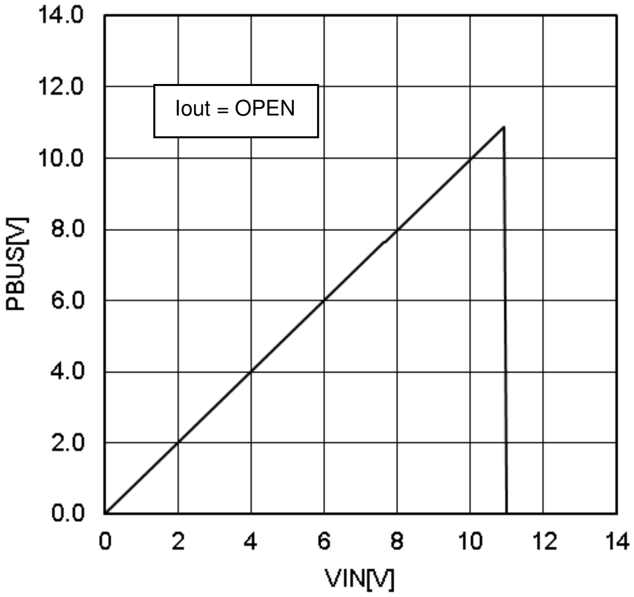


Figure 11. BD83733HFP-M
LED Disable Open Detection voltage

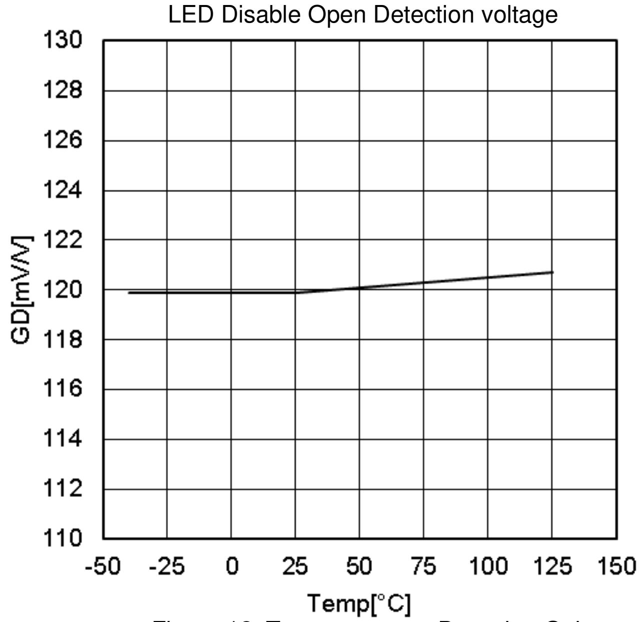


Figure 12. Temperature vs De-rating Gain

Functional Description

(Unless otherwise specified, Ta=25°C, V_{IN}=13V, I_{OUT}=6V and R_{VIN_F}=0.47Ω. Numbers are "Typical" values.)

1. Output Current Setting

LED Current I_{OUT} can be set by value of resistor R_{VIN_F}.

$$I_{OUT} = \frac{(V_{IN} - V_{IN\_F})}{R_{VIN\_F}} = \frac{V_{IN\_F\_REF}}{R_{VIN\_F}} [A]$$

where:
$V_{IN\_F\_REF}$ is 0.18V (Typ)

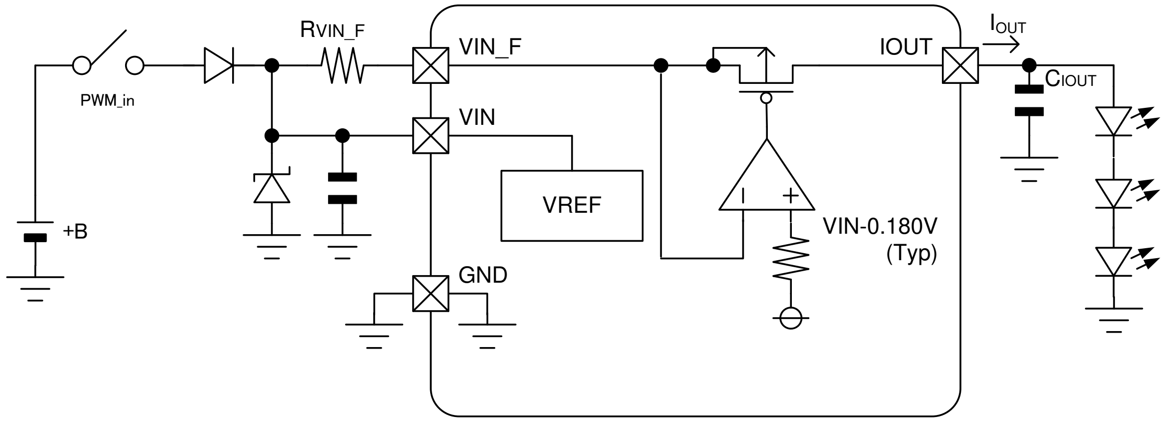


Figure 13. Output Current Setting

2. Table of Operations

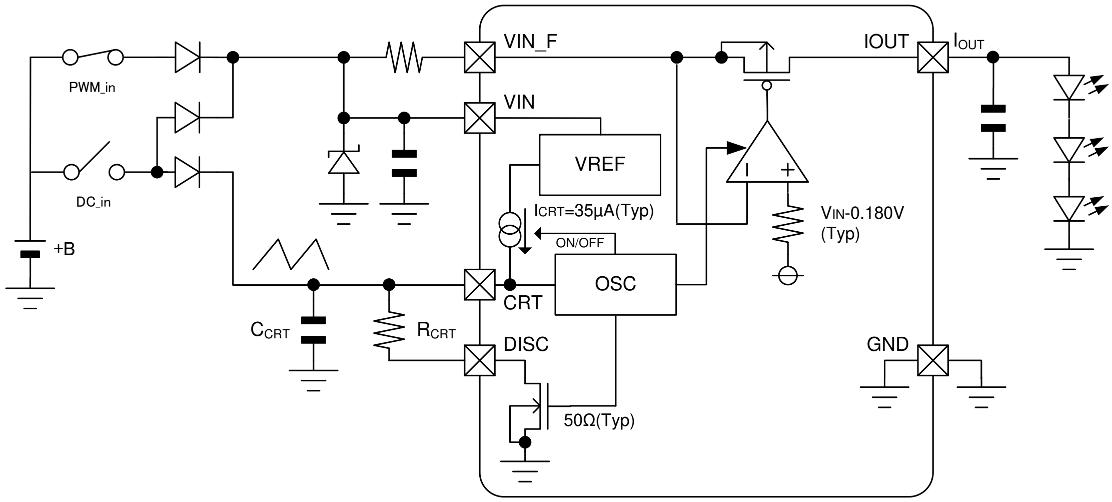
The PWM dimming mode switches to linear control depending on CRT terminal voltage.
When V_{CRT} > V_{CRT_DIS2}(Typ ~ 4.0V), Dimming mode turns to Linear Control, and discharge resistance of DISC terminal changes from R_{D1}(Typ ~ 50 Ω) to R_{D2} (Typ ~ 5k Ω).
When an LED open/short-circuit fault is detected, which depends on IOUT terminal voltage, the output current is turned OFF.
Output current is also turned OFF when PBUS terminal is pulled LOW.

Operation Mode	CRT Terminal	IOUT Terminal Voltage (V_{IOUT})	Output Current (I_{OUT})	PBUS Terminal
Linear Control	4.0V(Typ)≤V_{CRT}	-	50mA～500mA	Hi-Z
PWM dimming	See Features Functional Description, 3. PWM Dimming Operation	-	See Features Functional Description, 3. PWM Dimming Operation	Hi-Z
LED Current De-rating	-	-	See Features Description, 8. LED Current De-rating Function	PBUS<2.5V
LED Open	-	V_{IOUT} ≥ VIN - .050V(Typ)	1μA(Max)	Low Output
LED Short	-	V_{IOUT} ≤ 0.6V(Typ)	40μA(Max)	Low Output
PBUS Control OFF	-	-	1μA(Max)	Low Input

3. PWM Dimming Operation

PWM Dimming is performed with the following circuit.

The CR timer function is activated if DC_in is OPEN. To perform PWM light control of LED current, a triangular waveform is generated at CRT terminal. The **LED current is turned OFF** while CRT voltage is ramping up, and **LED current is turned ON** while CRT voltage is ramping down.
The ramp up/down time of the CRT voltage, and therefore the dimming cycle and Duty, can be set by values of the external components **(C_{CRT}, R_{CRT})**.
Please connect DISC to GND if it is not used.



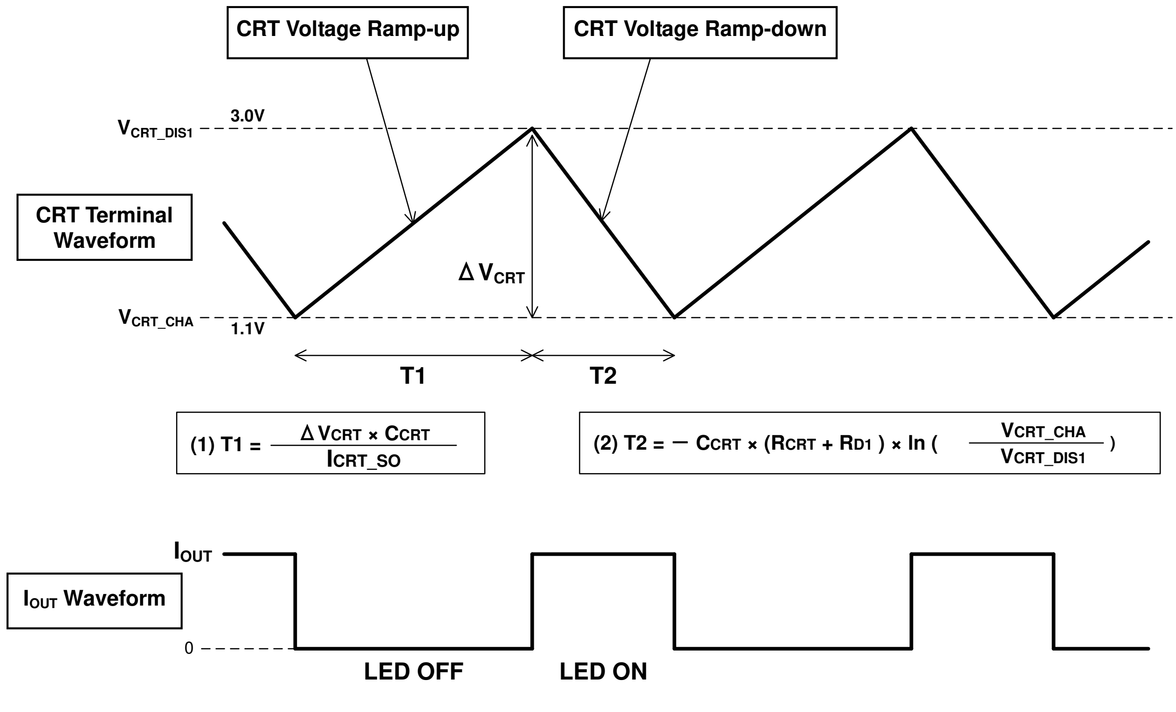


Figure 14. PWM Dimming Operation

(1) CRT Ramp up Time T1
CRT ramp up time can be obtained from the following equations:

$$T1 = \frac{\Delta V_{CRT} \times C_{CRT}}{I_{CRT\_SO}} = R_{CHA} \times C_{CRT}\,[s]$$

where:
I_{CRT_SO} is the CRT Terminal Charge Current 35µA (Typ)
R_{CHA} is the CRT Terminal Charge Resistance 54.3kΩ(Typ)

(2) CRT Ramp down Time T2
CRT ramp down time is defined by the discharge period due to the external capacitor C_{CRT} and resistance (R_{CRT} + R_{D1}). The CRT Terminal Charge Current is OFF at CRT ramp down.
Make sure that T2 is set > pulse width 20μs (Min).

$$T2 = -C_{CRT} \times (R_{CRT} + R_{D1}) \times \ln\left(\frac{V_{CRT\_CHA}}{V_{CRT\_DIS1}}\right) \quad [s]$$

where:
R_{D1} is the CRT Terminal Discharge Resistance 1 50Ω (Typ)
V_{CRT_CHA} is the CRT Terminal Discharge ON Voltage 1.1V (Typ)
V_{CRT_DIS1} is the CRT Terminal Discharge ON Voltage 3.0V (Typ)

(3) Dimming Frequency f_{PWM}
PWM frequency is defined by T1 and T2.

$$f_{PWM} = \frac{1}{T1 + T2} \quad [Hz]$$

(4) ON Duty (D_{ON})
Like the above, PWM ON duty is defined by T1 and T2.

$$D_{ON} = \frac{T2}{T1 + T2}$$

(Example) In case of f_{PWM} = 518Hz and 6.7% Duty (Typ),

From f_{PWM}=518Hz; T1 + T2 = 1 / f_{PWM} = 1 / 518Hz = 1931μs
From ON Duty = 6.7%; CRT ramp up time T1 is T1 = (T1 + T2) × 0.933 = 1801.6μs
External capacity C_{CRT} is;
C_{CRT} = T1 × (I_{CRT} / ΔV_{CRT}) = 1801.6μs × 35μA / 1.9V ≒ **0.033μF**

CRT ramp down time T2 is; T2 = (T1 + T2) × 0.067 = 129μs
External resistance R_{CRT} is;
R_{CRT} = −T2 / (C_{CRT} × ln(V_{CRT_CHA} / V_{CRT_DIS})) − R_{D1} = −129usec / (0.033μF × ln(1.1 / 3.0)) – 50Ω ≒ **3.9kΩ**

PWM Dimming Operation using external signal

An external microcomputer can directly drive the PWM signal for Dimming CRT terminal. In that case, 'High' level voltage of PWM signal should be > V_{CRT_DIS2}(4.4V(Max)) and 'Low' level voltage of PWM signal < V_{CRT_CHA}(0.99V(Min)).

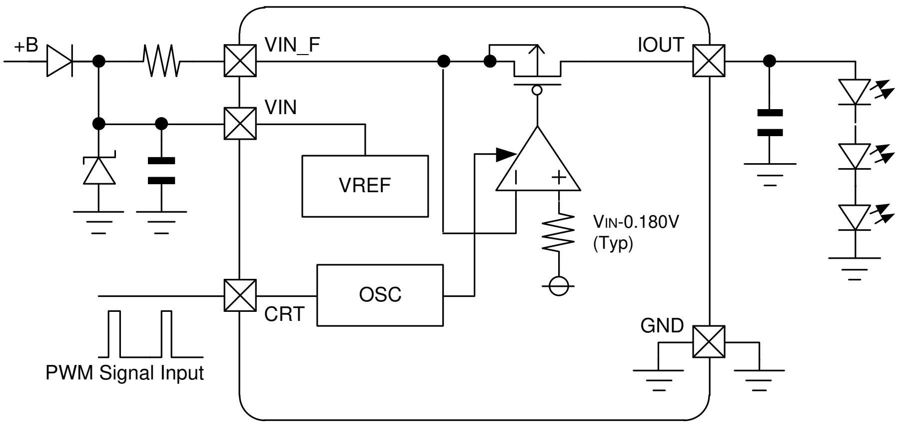


Figure 15. External Input of PWM Signal

About a reverse connection protection diode

In case you apply voltage the CRT over the reverse protection diode (D3) as the figure below (Figure 16), there is a possibility that the CRT rise time and fall time will deviate from the settings due to reverse current of diode (D3) affecting charge and discharge current to capacitance(C3). Reverse current Ir is getting high value with high temperatures, so the diode recommended by ROHM or a diode with reverse current characteristics below max 1µA needs to be considered.
Besides, since reverse current causes also in the recommended diode, **a resistor of about 1kΩ needs to be connected between the A-point and GND**, so that voltage in the A-point doesn't rise.

CRT start-up / fall time　Mechanism of deviation from settings

① During the PWM dimming operation mode, the A-point on Figure.16 becomes Hi-Z
↓
② Reverse current Ir of D2 and D3 goes to the A-point
(Power supply voltage is being input into the cathode of D2, so reverse current of D2 goes to mainly into C1)
⇒Reverse current Ir of D3 is added to the CRT terminal charge current I_{CRT_SO} and discharge current I_{DIS}, so CRT start-up / fall time deviates from the settings.
↓
③ C1 gets charged, voltage in the A-point rises
↓
④ Voltage in the A-point exceeds voltage in CRT terminals of each IC
↓
⑤ Vf occurs in the diodes D3
↓
⑥ D3 circulate forward current If
⇒Forward current If of D3 is added to the CRT terminal charge current I_{CRT_SO} and discharge current I_{DIS}, so CRT start-up / fall time deviates from the settings. ↓
⑦ Repetition ②-⑥

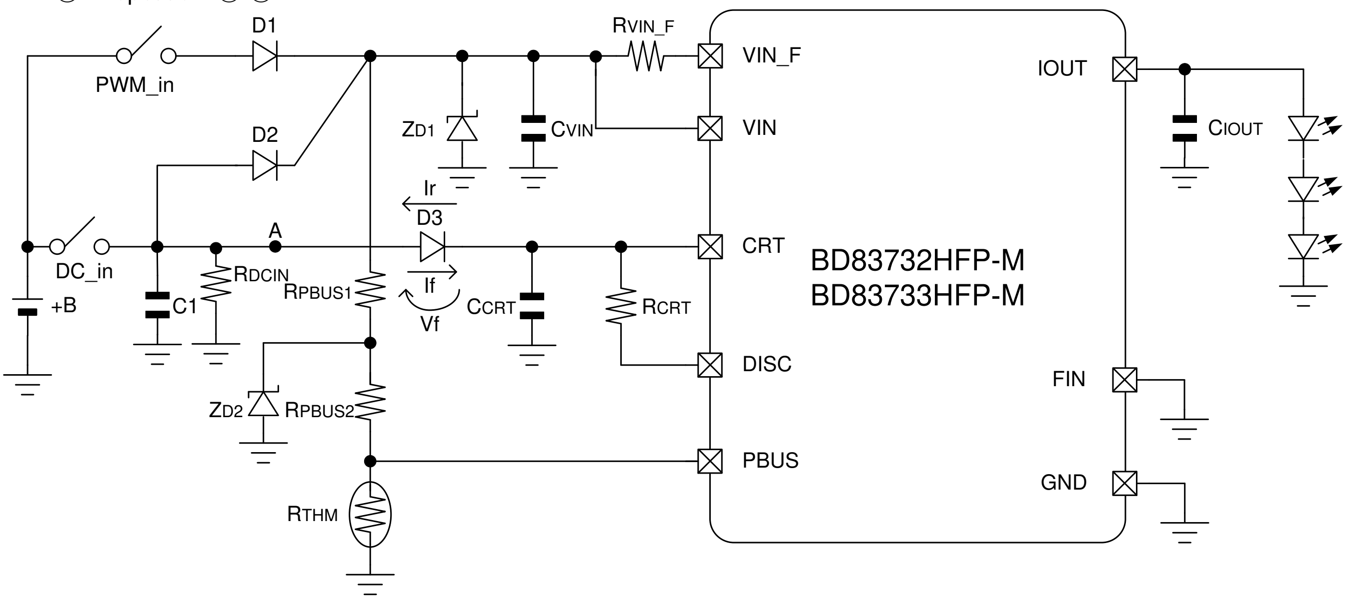


Figure 16. About the mechanism of deviation of CRT start-up / fall time due to the reverse connection prevention diode

4. Setting VIN Range

Number of LED connections N should meet the following conditions:

$$V_{f\_led} \times N \leq +B - V_{f\_diode} - V_{IN\_F\_REF} - V_{DR\_IOUT}$$

where:
+B is the Battery Voltage
V_{f_diode} is the Reverse Connection Preventing Diode Vf
$V_{IN\_F\_REF}$ is the VIN_F Terminal Voltage ($V_{IN} - V_{IN\_F}$)
V_{DR_IOUT} is the IOUT Terminal Drop Voltage
V_{f_led} is the LED Vf (maximum)
N is the Number of LED Levels

Example : If you want to supply constant current to LED at 9V or higher Battery Voltage (+B) (Supposing that V_{f_diode} is 0.5V),

$$V_{f\_led} \times N \leq +B - V_{f\_diode} - V_{IN\_F\_REF} - V_{DR\_IOUT} = 9V - 0.5V - 0.189V(Max) - 1.0V(Max) = 7.311V$$

(Sum of Vf of LED connected to IOUT terminal is set to be 7.311V Max.)

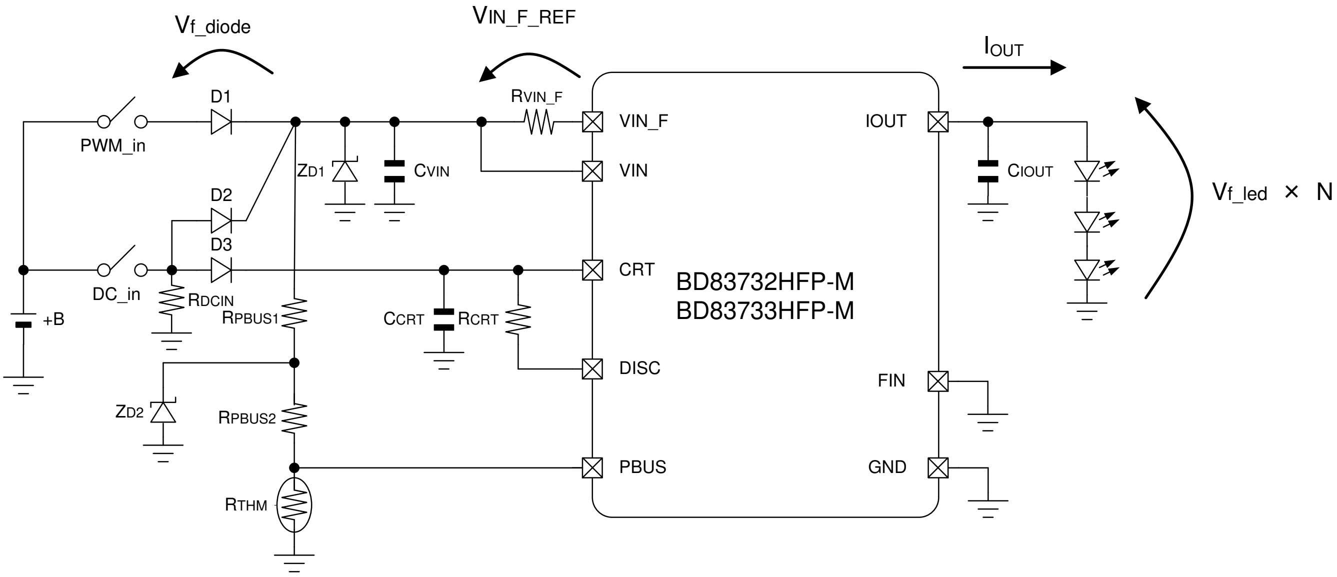


Figure 17. LED Setting Range Schematic

5. Self-protection and PBUS Functionality

This IC includes self-protection from short/open-circuit of LED, and reports abnormal condition at the PBUS terminal.

(1) LED Open Detection Function

When any LED connected to IOUT terminal is open-circuited, it is detected by overvoltage at IOUT terminal ($V_{OUT} > V_{IOUT\_OPEN}$). Then the output current is turned OFF and PBUS terminal is pulled Low.

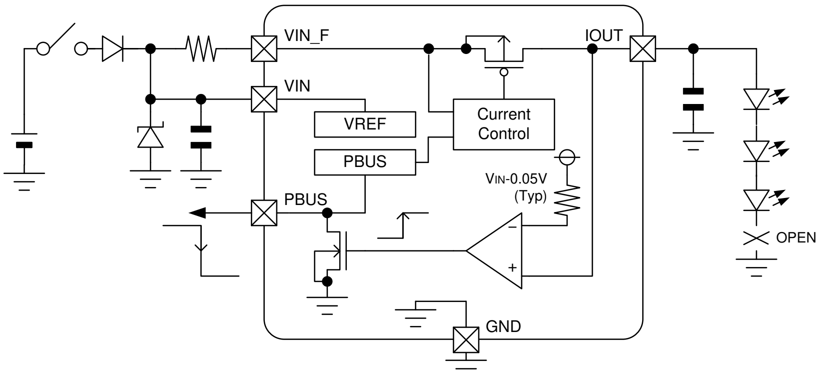


Figure 18. LED Open Detection

(2) LED Short-circuit Detective Function

When the LEDs connected to the IOUT terminal are short-circuited,
it is detected by a low voltage at IOUT terminal ($V_{OUT} < V_{IOUT\_SHORT}$).
Then the output current is turned OFF to prevent thermal destruction of IC, and PBUS terminal is pulled to Low.

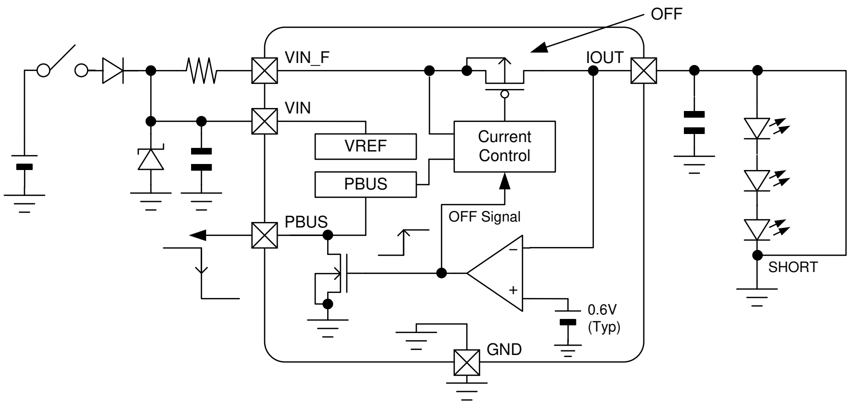


Figure 19. LED Short-circuit Detection

(3) IOUT Current at GND Short(I_{IOUT_SHORT})

In this case, IOUT Current at GND Short(I_{IOUT_SHORT}) flows from IOUT terminal.
The value depends upon V_{OUT}.

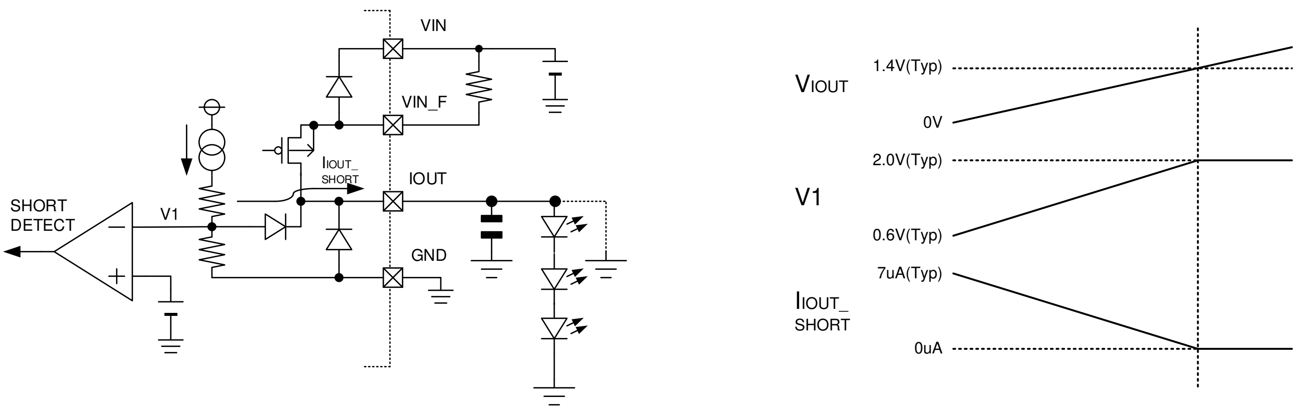


Figure 20. About IOUT Current at GND Short

(4) Prevention of false LED Short Detection during PWM

When in Linear control mode, LED Open & Short Circuit Detection are active continuously.
In PWM Dimming mode, LED Open Detection is active only during the Fall time of V_{CRT}, but LED Short Circuit Detection is active at all time. (Refer to Figure20.)
When IOUT is disabled during PWM, the output will be high impedance ('Hi-Z'). During this time noise (Note1) can couple on to this pin and cause false detection of SHORT condition.

To prevent this **it is necessary to connect a Capacitor(more than 0.1µF(Note2)) between IOUT terminal and GND terminal nearby terminal**
(ROHM Recommended Value : C_{IOUT}=0.1µF GCM188R11H104KA42 murata)

(Note1) Conducted noise, Radiated noise, Interference of connecter and PCB pattern etc…
(Note2) If more than 0.1µF, please evaluate the time of V_{IN} on to I_{IOUT} on. (See Page 14 evaluation example)

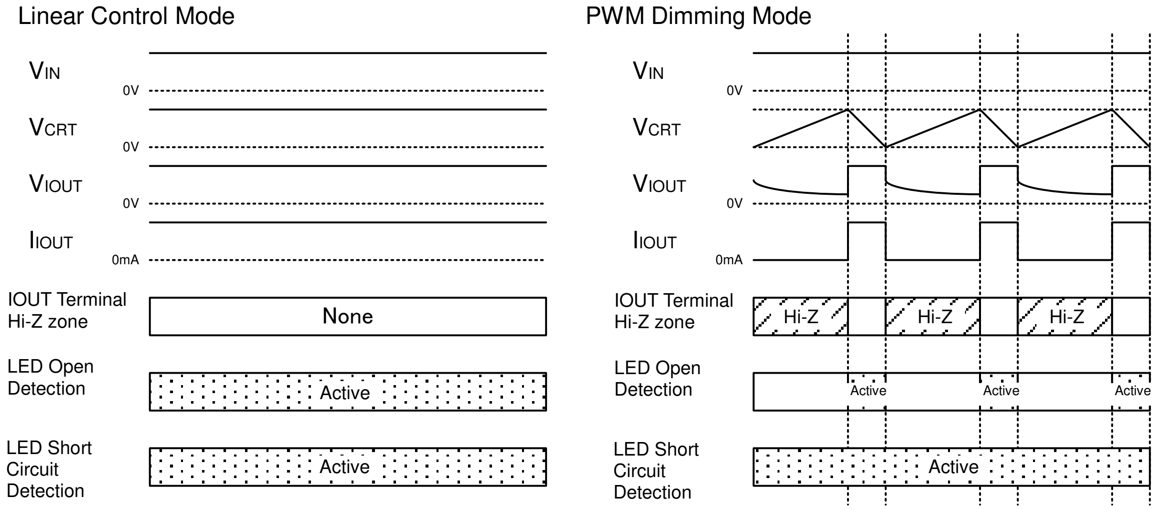


Figure 21. Timing of LED Open & Short Circuit Detection Function and IOUT Terminal Hi-Z zone

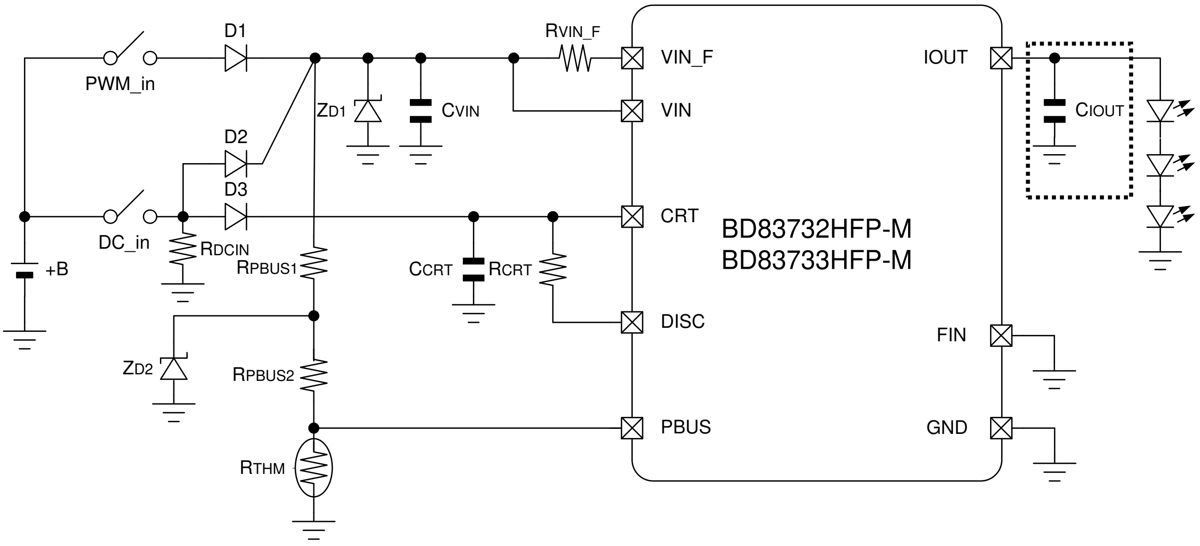
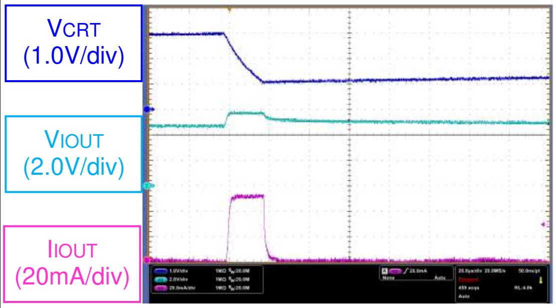
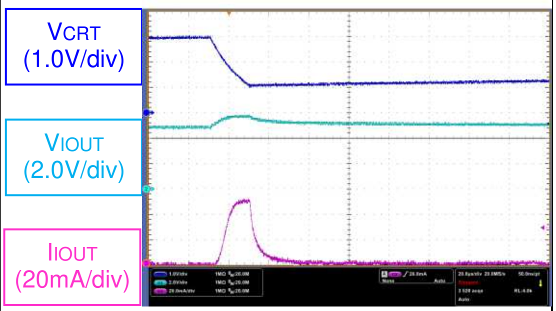
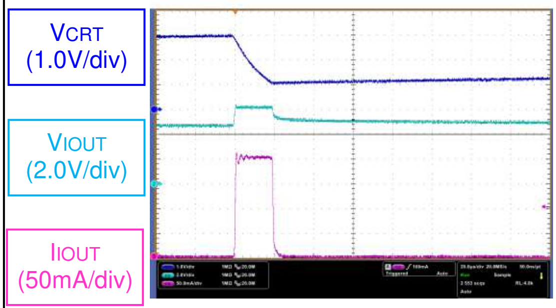
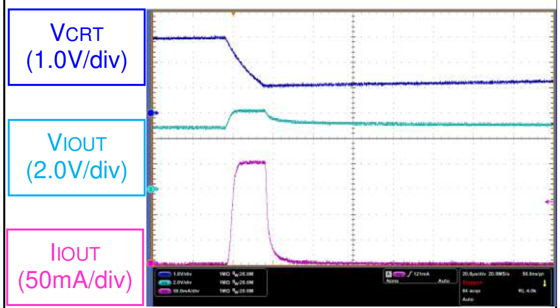


Figure 22. About the capacitor of connecting IOUT terminal

Evaluation example (I_{IOUT} pulse width at PWM Dimming operation)

Condition : +B=13V
Ta=25°C
LED 3Strings
R_{CRT}=560Ω
C_{CRT}=0.033μF
PWM Dimming Mode

	C_{IOUT}=0.1μF	C_{IOUT}=0.47μF
R_{VIN_F}=3.6Ω (I_{IOUT}=50mA)	 VCRT (1.0V/div) VIOUT (2.0V/div) IIOUT (20mA/div)	 VCRT (1.0V/div) VIOUT (2.0V/div) IIOUT (20mA/div)
R_{VIN_F}=0.91Ω (I_{IOUT}=198mA)	 VCRT (1.0V/div) VIOUT (2.0V/div) IIOUT (50mA/div)	 VCRT (1.0V/div) VIOUT (2.0V/div) IIOUT (50mA/div)

(5) About the maximum value of the capacitor connected to the output

In case a capacitor exceeding the recommended range (above 0.66μF) is connected to the IOUT terminal, there is a possibility that delay time of start-up will reach about several hundred ms, so special attention is needed. Below an evaluation example is mentioned as reference data.

Measurement conditions : V_{IN}=13V , Ta=25°C, R_{VIN_F}=3.6Ω , LED 3 steps, linear control mode

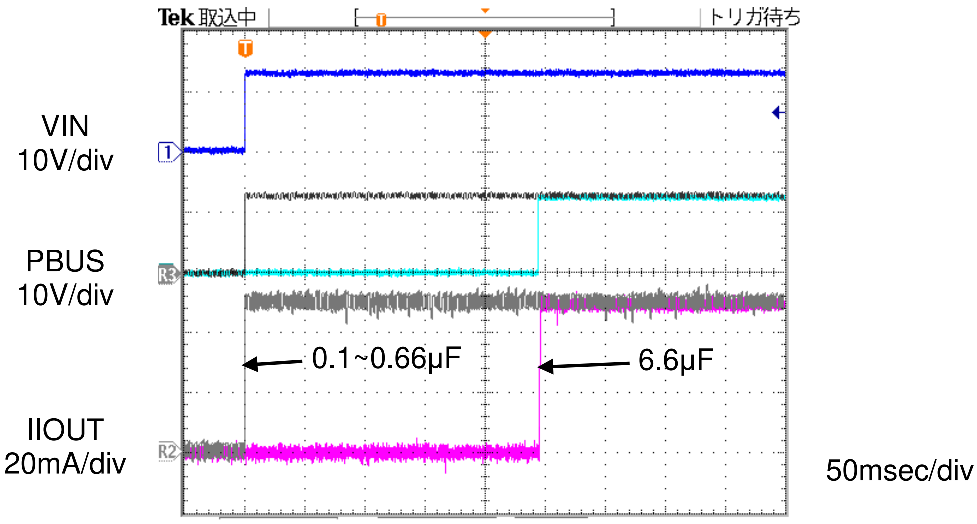


Figure 23. About the capacitor connected to the IOUT terminal

6. PBUS Function

The PBUS terminal is an input/output terminal for outputting trouble and inputting trouble detection.
When an LED open/short-circuit occurs, the PBUS terminal output is pulled LOW (Note1).
It is possible to turn output current OFF by pulling the PBUS terminal Low.

(Note1) PBUS terminal is an open drain terminal. It should always be pulled up(10kΩ) to power supply voltage.

When multiple ICs are used to drive multiple LEDs, as shown in the drawing below, it is possible to turn off all rows of LEDs if only some LEDs are short/open-circuited by connecting PBUS terminal of each IC.

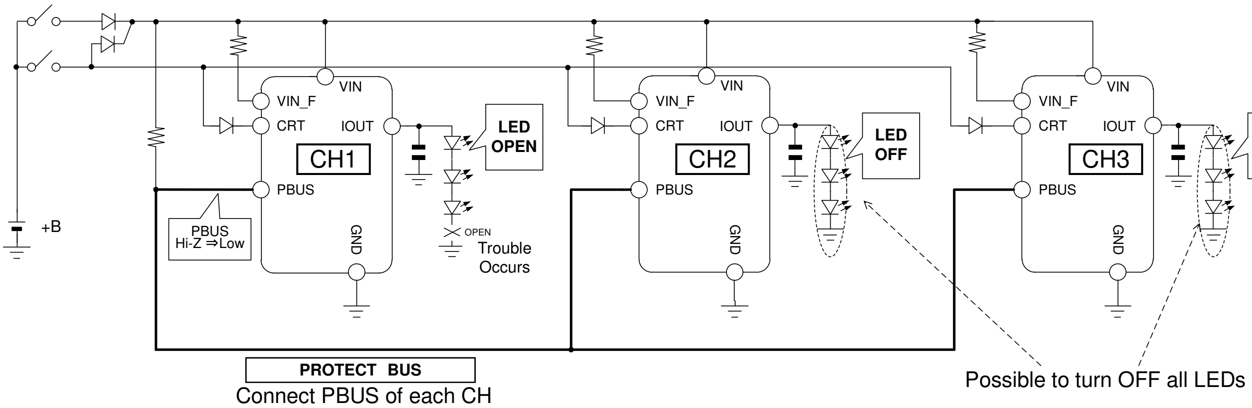


Figure 24. PBUS Function

▼Example of Protective Operation due to LED Open Circuit

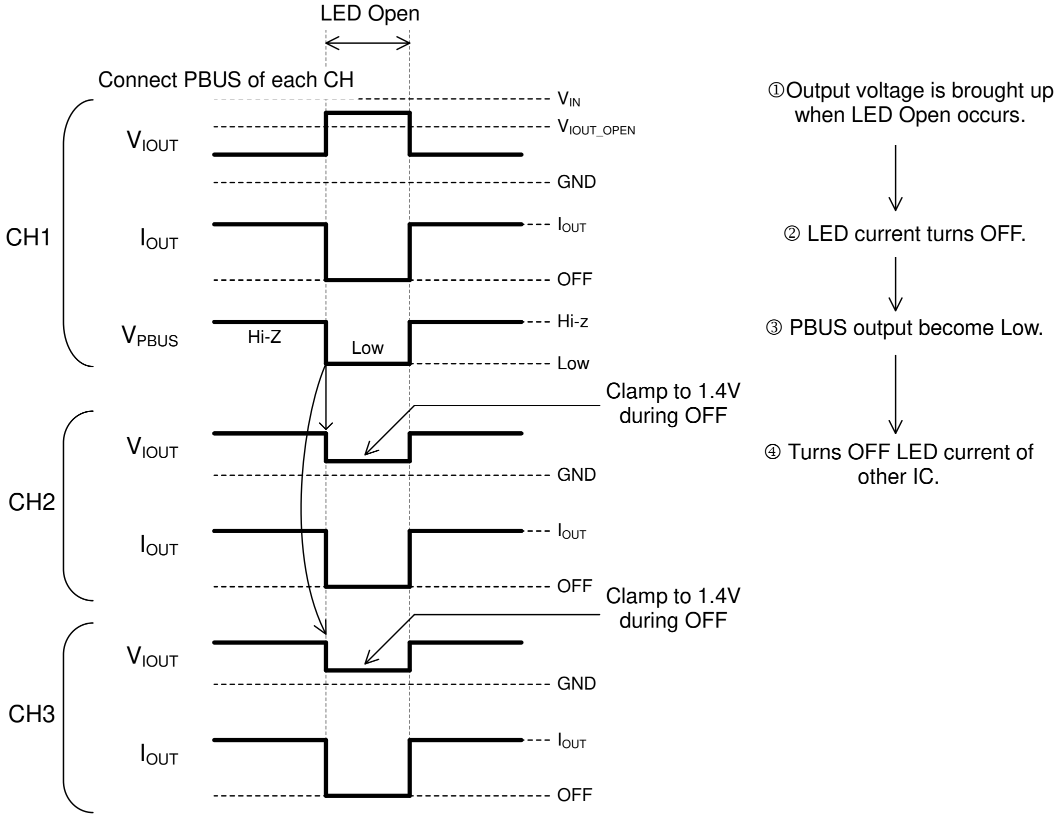


Figure 25. Example of Protective Operation

If LED OPEN occurs, PBUS of CH1 is switched from Hi-Z to Low output. As PBUS becomes Low, LED drivers of other CH detect the condition and turns OFF their own LEDs. VIOUT clamps to 1.4V (Typ) during the OFF period, in order to prohibit ground fault detection.

7. Caution when using multiple IC with different power supplies

Each Input terminal has a built- in ESD protection diodes. (Refer to I/O equivalence circuits)
If the VIN terminal is not supplied and other Input terminals are supplied voltage, the IC may malfunction(abnormal operation mode, abnormal LED lighting) due to arise VIN terminal voltage .

The Application Example of accidental operation is below.

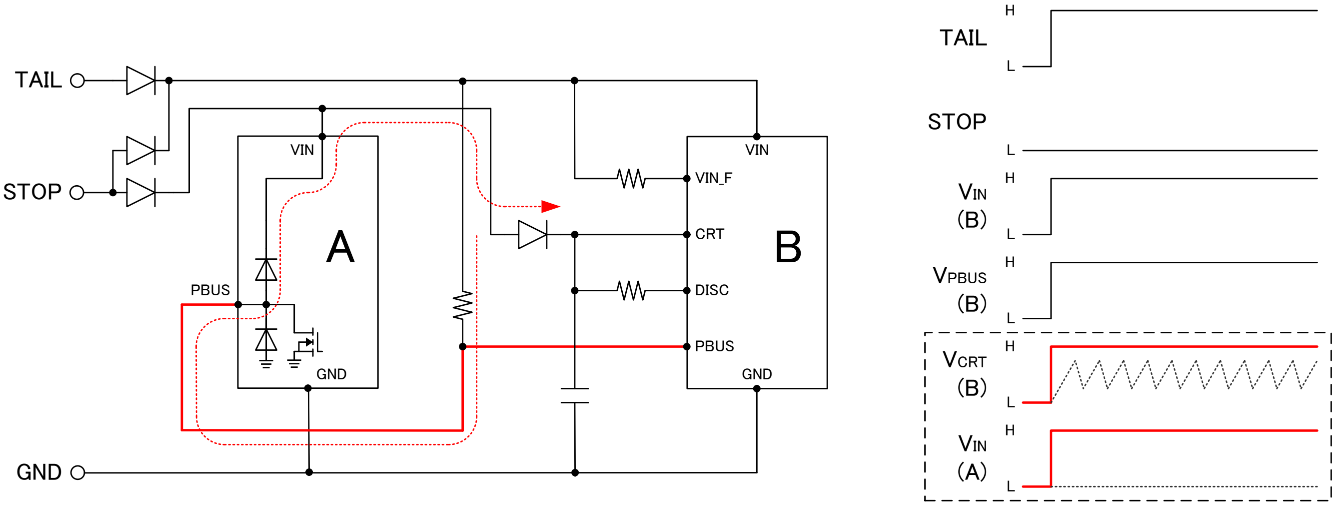


Figure 26. Application Example

(Operational Explanation)
Only input Tail : Arise VIN terminal voltage of IC A from ESD protection Diode between VIN terminal and PBUS terminal of IC A.
Due to connect VIN terminal of IC A and CRT terminal of IC B across Diode,
DC voltage inputs CRT terminal of IC B, so it is possible to operate IC B DC mode.

8. LED current de-rating function

BD83733/32 has an LED current de-rating functionality. When the PBUS terminal voltage falls below 2.5V(Typ), LED current output decreases with VIN_F_REF voltage reduction. In order to eliminate oscillating of the output current, a capacitor is required at the PBUS terminal.

Besides, in case of connecting the PBUS terminals between the series model BD8371XXX/BD8372XXX/BD8374XXX and the BD83733/32HFP-M, the series model except BD83733/32 will be turned off during the de-rating operation.

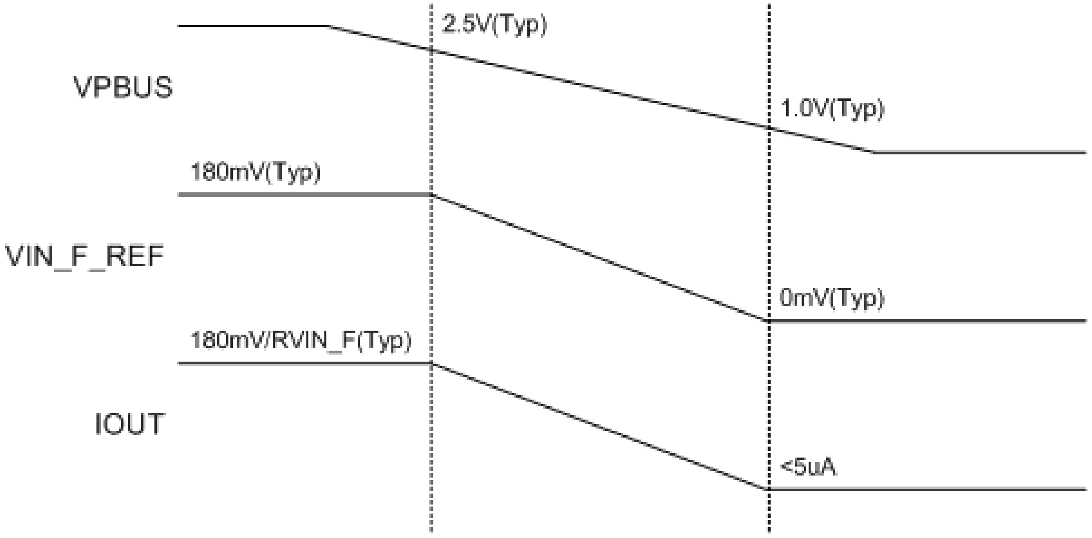
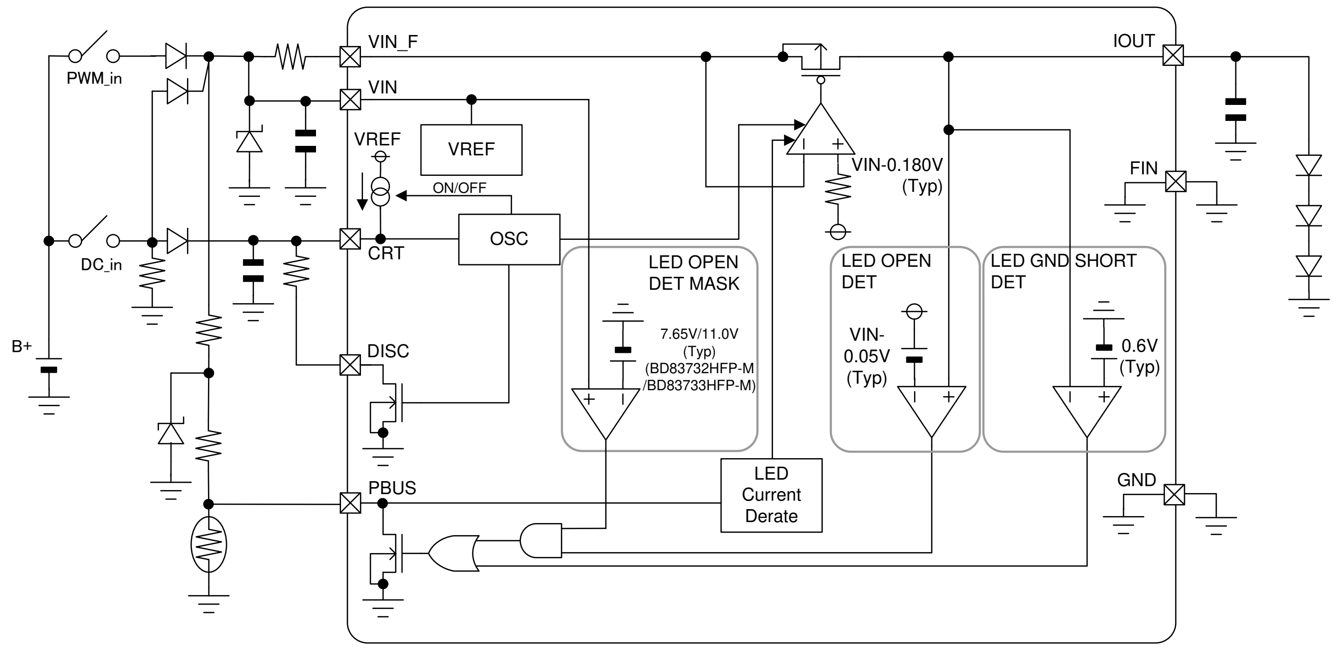


Figure 27. LED Current De-rating Function Characteristics

Timing Chart



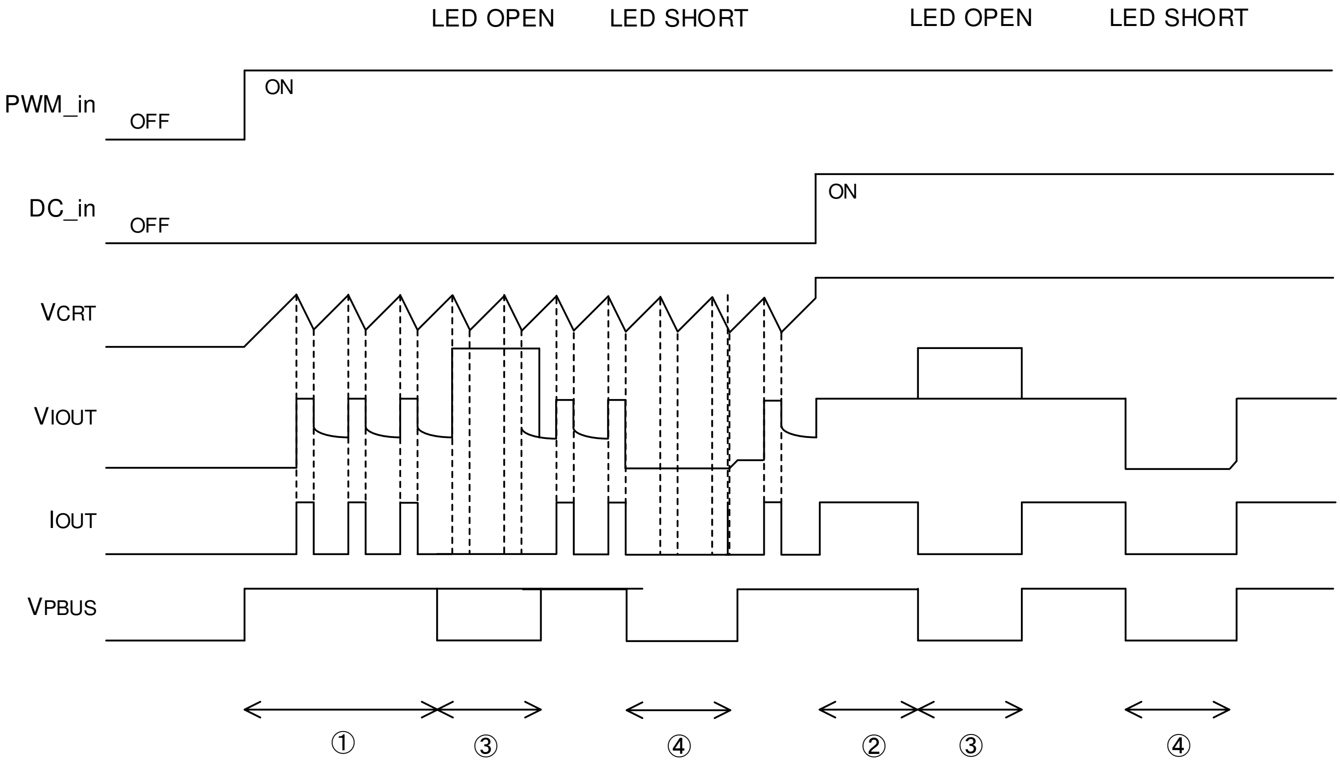


Figure 28. Timing Chart

① If PWM_in is switched ON, V_{CRT} will start oscillation, and LED current I_{OUT} will follow this waveform. (PWM light control mode)

② If DC_in is switched ON, V_{CRT} will be pulled High (V_{IN}-Vf). LED current I_{OUT} will be continuous. (Linear control mode)

③ If LED becomes OPEN, LED current I_{OUT} will stop. At the same time, V_{PBUS} goes Low.

④ If LED is short-circuited to GND, LED current I_{OUT} will stop. At the same time, V_{PBUS} goes Low.

Operation Range of Constant Current Control

Operation range of constant current control can be obtained from the following equation:

Operation range of constant current control
$V_{IN} \geq V_{f\_led} \times N + V_{IN\_F\_REF} + V_{DR\_IOUT}$ [V]

Where:
V_{IN} is the VIN Terminal Voltage
V_{f_led} is the LED Vf
N is the: Number of LED Levels
$V_{IN\_F\_REF}$ is the VIN_F Terminal Voltage (V_{IN} - V_{IN_F})
V_{DR_IOUT} is the IOUT Terminal Drop Voltage

LED Open Detection / Disable LED Open Detection range
This feature is implemented to detect a significant power supply voltage drop at start-up and shut-down, and to disable LED open detection. In case of low power supply (VIN) close to LED forward voltage (VIOUT), the device disables the diagnostic function of LED open to avoid any false open load detection.
At enough power supply higher than the V_{M_OPEN} (threshold of disable LED open detection), when the IOUT terminal (V_{IOUT}) exceeds the V_{IOUT_OPEN} (LED open detection threshold) by actual LED open load , the PBUS output will be Low.
The LED forward voltage has to be set lower than the V_{M_OPEN} as following equation.

$V_{M\_OPEN} \geq V_{f\_led} \times N + 50mV(typ) + V_{DR\_IOUT}$ [V]

LED Open Detection Voltage at IOUT
$V_{IOUT\_OPEN} = V_{IN} - 50mV(Typ)$

Disable LED Open Detection at VIN voltage
BD83732HFP-M : V_{M_OPEN} = 7.65V (Typ)
BD83733HFP-M : V_{M_OPEN} = 11.0V (Typ)

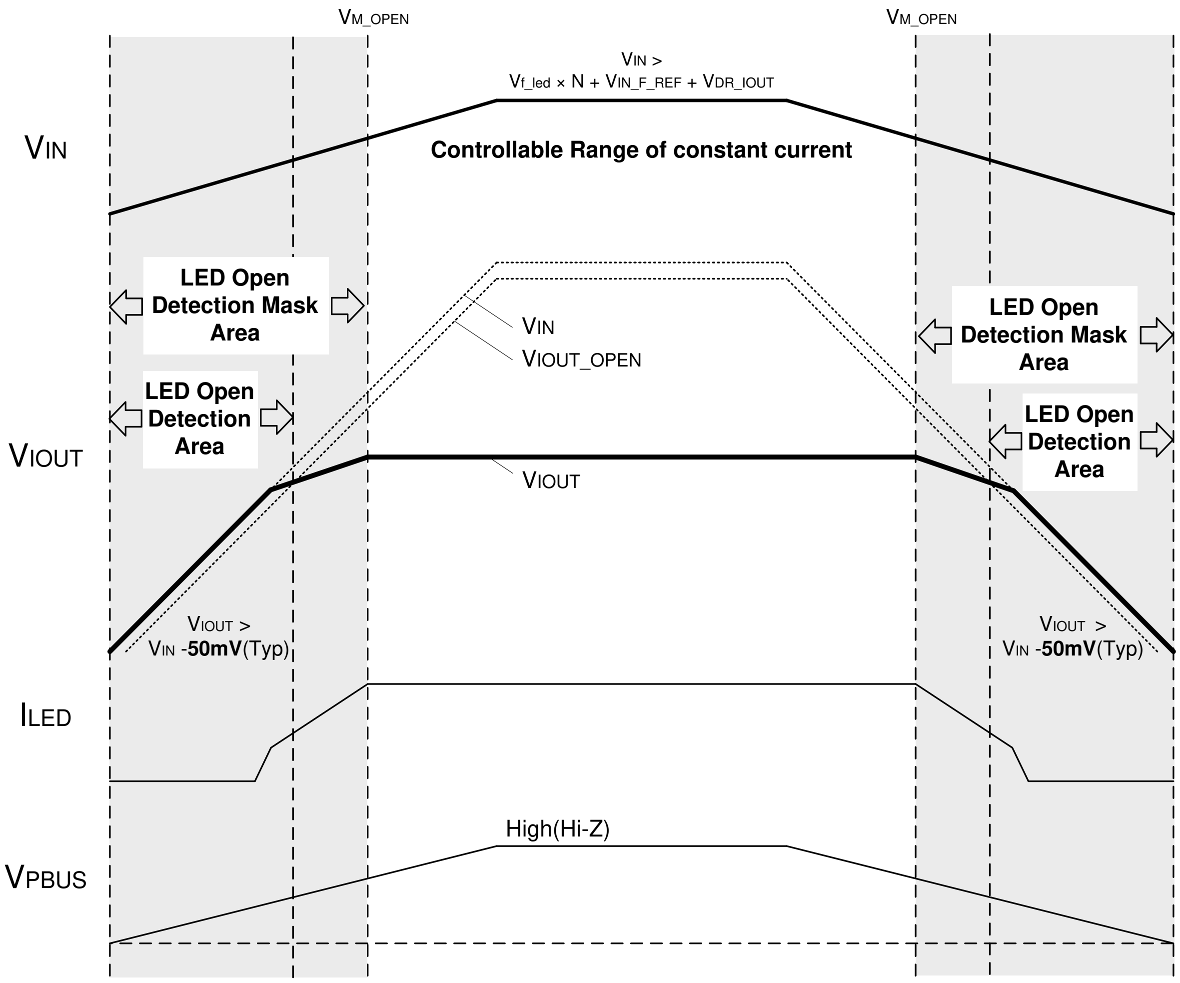


Figure 29. Guaranteed Range of Current Accuracy and LED Open Detection / Disable LED Open Detection range.

How to Connect LED

If multiple rows of LEDs are connected, note that OPEN circuit may not be detected.

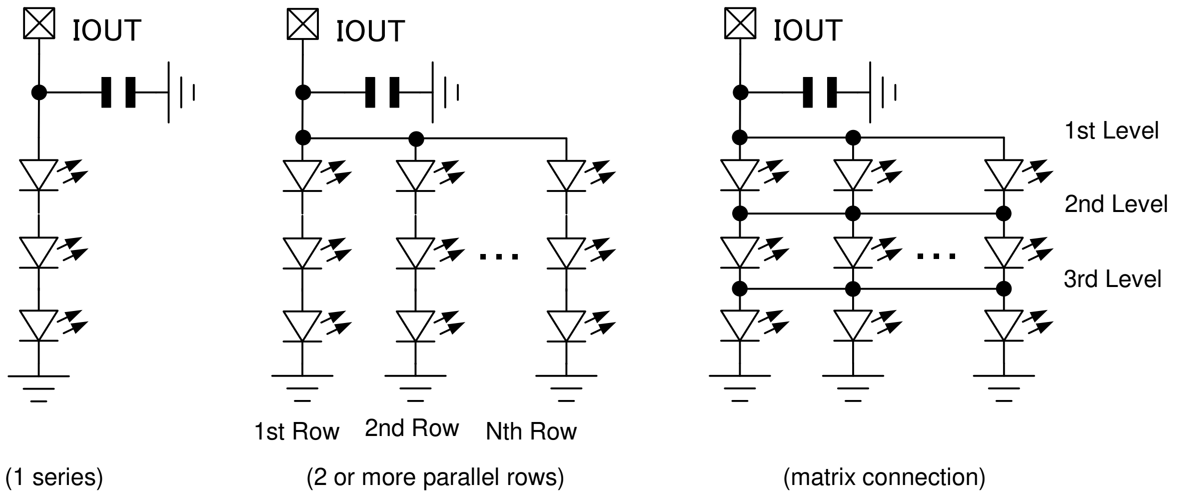


Figure 30. LED Connection Patterns

Connection Pattern	LED Short-circuit Detection (GND short of IOUT terminal)	LED OPEN detection
1 Series	Detectable	Detectable-
2 parallels or more	Detectable	Non-detectable (Note 1)
2 parallels or more (Matrix Connection)	Detectable	Non-detectable (Note 2)

(Note1) : Detectable only when one or more LEDs become open in all rows.
(Note2) : Detectable only when all LEDs on the same level become open.

Recommended Application Circuit

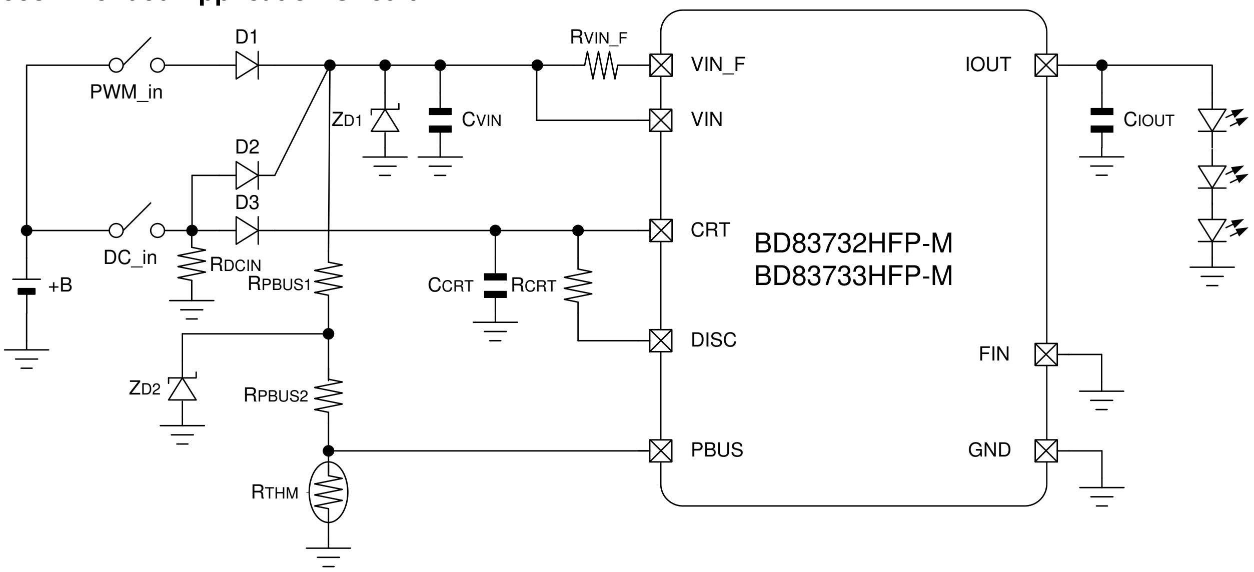


Figure 31. Recommended Application Circuit

No.	Component Name	Component Value	Product Name	Company
1	D1	-	RFN1L6S	ROHM
2	D2	-	RFN1L6S	ROHM
3	D3	-	RFN1L6S	ROHM
4	Z_{D1}	-	TNR12H-220K	NIPPON CHEMICON
5	Z_{D2}	-	FTZ5.6E	ROHM
6	C_{VIN}	4.7µF	GCM32ER71H475KA40	murata
7	R_{VIN_F}	0.91Ω	LTR10 Series	ROHM
8	R_{PBUS1}	1kΩ	ESR03 Series	ROHM
9	R_{PBUS2}	13kΩ	ESR03 Series	ROHM
10	C_{CRT}	0.033µF	GCM188R11H333KA40	murata
11	R_{CRT}	3.9kΩ	MCR03 Series	ROHM
12	C_{IOUT}	0.1µF	GCM188R11H104KA42	murata
13	R_{THM}	150kΩ	NTCG104LH154H	TDK
14	R_{DCIN}	5.1kΩ	ESR03 Series	ROHM

Table 1. BOM List

PWM_in	DC_in	Mode
Low	Low	OFF
High	Low	PWM Dimming Mode (Note1,Note2) (13.25mA 6.7% ON duty@518Hz)
Low	High	Linear Control Mode (Note2) (197.8mA 100% ON duty)
High	High	Linear Control Mode (Note2) (197.8mA 100% ON duty)

(Note1) See Functional Description "3. PWM Dimming Operation."
(Note2) See Functional Description "2. Table of Operations."

Table 2. Table of Operations

○Waveform of PWM Mode

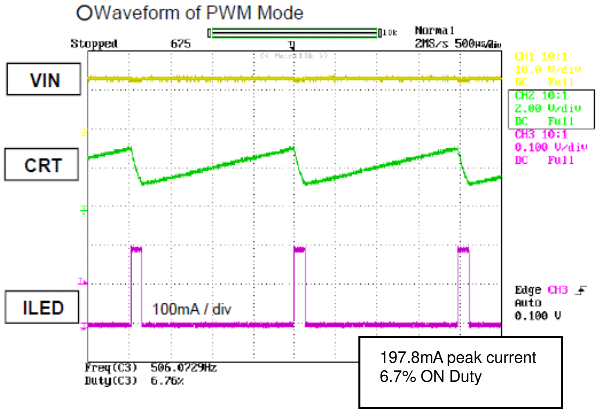


Figure 32. Example of Waveform Measurement

Thermal Loss

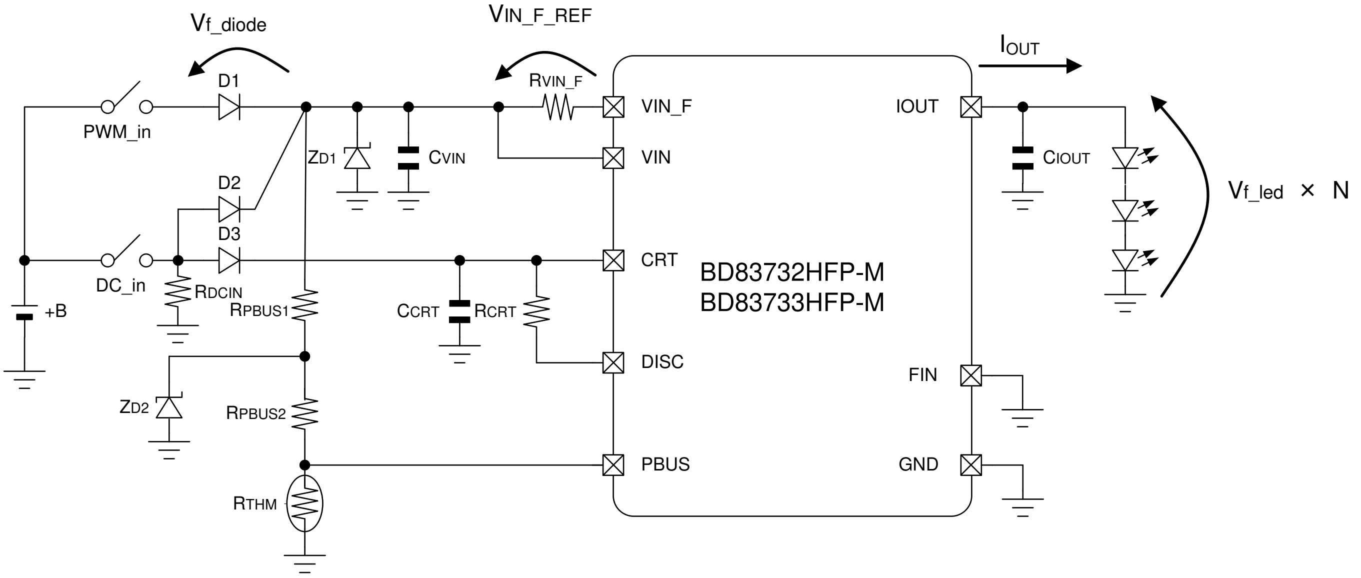


Figure 33. Application Circuit Diagram for Thermal Description

Thermal design should meet the following equation:

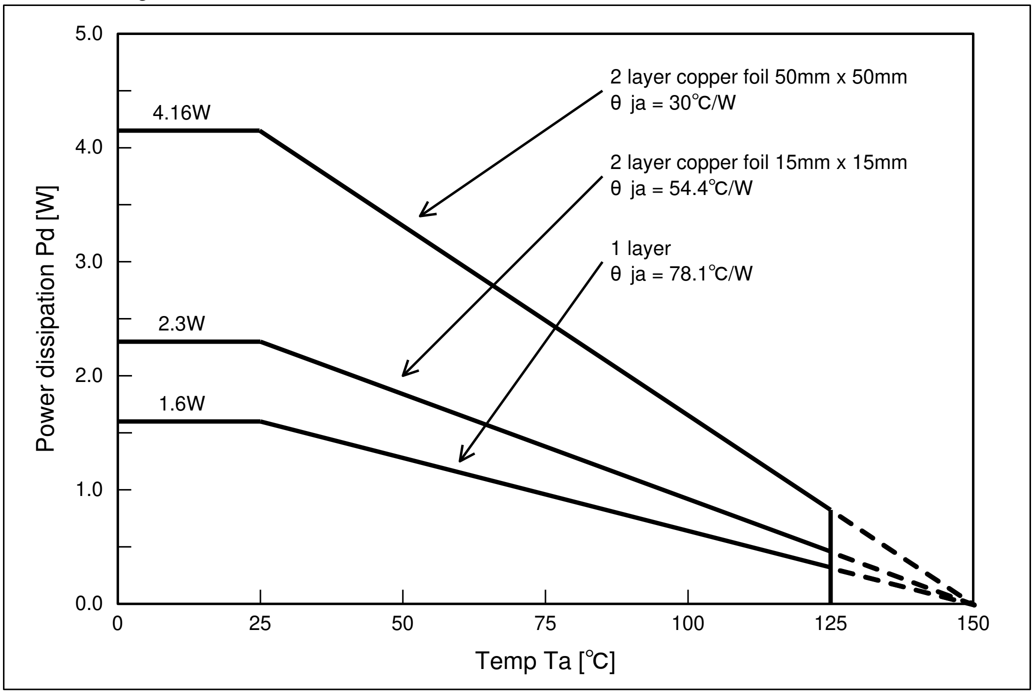
$Pd > Pc$

$Pd = (1/\theta ja) \times (Tjmax - Ta)$ or $(1/\theta jc) \times (Tjmax - Tc)$

$Pc = (+B - V_{f\_diode} - V_{IN\_F\_REF} - V_{f\_led} \times N) \times I_{OUT} + I_{VIN} \times V_{IN}$

where:
Pd is the Power Dissipation
Pc is the Power Consumption
+B is the Battery Voltage
V_{f_diode} is the Reverse Connection Preventing Diode Vf
$V_{IN\_F\_REF}$ is the VIN_F Terminal Voltage (V_{IN}-V_{IN_F})
V_{f_led} is the LED Vf
N is the Number of LED Levels
I_{OUT} is the Output Current
I_{VIN} is the Circuit Current
V_{IN} is the Power Supply Voltage
θja is the Thermal Resistance between Tj and Ta
θjc is the Thermal Resistance between Tj and Tc
Tjmax is the Max Joint Temperature (150°C)
Ta is the Ambient Temperature
Tc is the Case Surface Temperature

HRP7 Package



(Caution1) When mounted with 70.0mm X 70.0mm X 1.6mm glass epoxy substrate.
(Caution2) Above copper foil area indicates backside copper foil area.
(Caution3) Value changes according to number of substrate layers and copper foil area. Note that this value is a measured value, not a guaranteed value.

Figure 34. Thermal Dissipation Curve

Thermal Design for Small Number of LEDs

If there are few LED lamps, it is suggested to insert resistance between IOUT terminal and LED to reduce heat generation in the IC and dissipate heat.
(This does not apply where amperage is low.)
In that case, the range of current accuracy will be as shown in the following equation:

$$+B \geq V_{f\_diode} + V_{f\_led} \times N + V_{IN\_F\_REF} + V_{DR\_IOUT} + I_{OUT} \times R1$$

V_{f_diode} is the Reverse Connection Preventing Diode Vf
V_{f_led} is the LED Vf
N is the Number of LED Levels
$V_{IN\_F\_REF}$ is the VIN_F Terminal Voltage (V_{IN} - V_{IN_F})
V_{DR_IOUT} is the IOUT Terminal Drop Voltage
I_{OUT} is the Output Current
R1 is the Thermal Dissipation Resistance

Thermal design should meet the following equation when inserting thermal dissipation resistance:

$$Pd = (1/\theta ja) \times (Tjmax - Ta) \text{ or } (1/\theta jc) \times (Tjmax - Tc)$$
$$Pc = (+B - V_{f\_diode} - V_{IN\_F\_REF} - V_{f\_led} \times N - I_{OUT} \times R1) \times I_{OUT} + I_{VIN} \times V_{IN}$$

Pd is the Power Dissipation
Pc is the Power Consumption
+B is the Battery Voltage
V_{f_diode} is the Reverse Connection Preventing Diode Vf
$V_{IN\_F\_REF}$ is the VIN_F Terminal Voltage (V_{IN} - V_{IN_F})
V_{f_led} is the LED Vf
N is the Number of LED Levels
I_{OUT} is the Output Current
R1 is the Thermal Dissipation Resistance
I_{VIN} is the Circuit Current
V_{IN} is the Power Supply Voltage
θja is the Thermal Resistance between Tj and Ta
θjc is the Thermal Resistance between Tj and Tc
Tjmax is the Max Joint Temperature (150°C)
Ta is the Ambient Temperature
Tc is the Case Surface Temperature

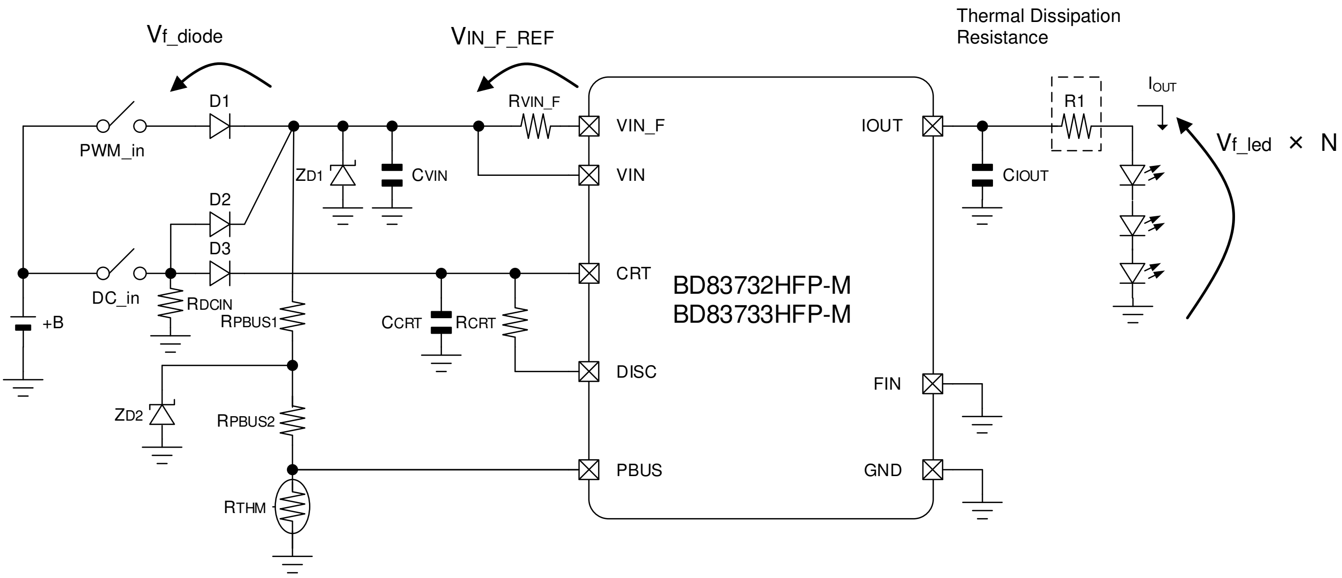
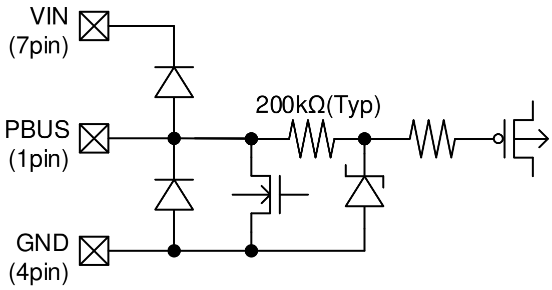
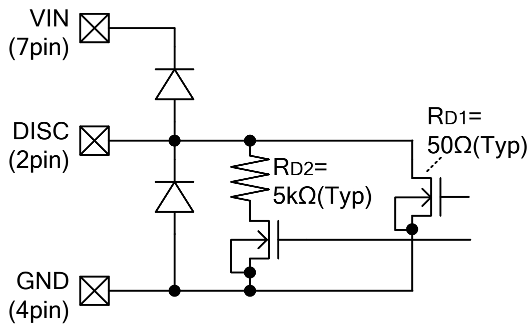
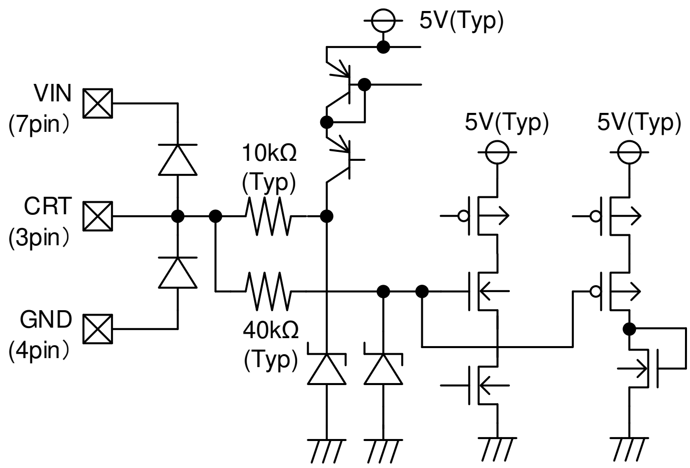
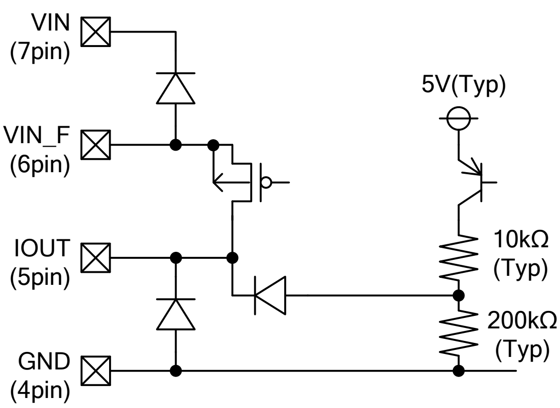


Figure 35. Example of How to Connect Thermal Dissipation Resistance

I/O equivalence circuits

<table>
<tr><th>Number</th><th>Terminal Name</th><th>Equivalence Circuit</th></tr>
<tr><td>1</td><td>PBUS</td><td>
</td></tr>
<tr><td>2</td><td>DISC</td><td>
</td></tr>
<tr><td>3</td><td>CRT</td><td>
</td></tr>
<tr><td>4</td><td>GND</td><td>-</td></tr>
<tr><td>5</td><td>IOUT</td><td rowspan="2">
</td></tr>
<tr><td>6</td><td>VIN_F</td></tr>
<tr><td>7</td><td>VIN</td><td>-</td></tr>
</table>

Operational Notes

1. **Reverse Connection of Power Supply**
   Connecting the power supply in reverse polarity can damage the IC. Take precautions against reverse polarity when connecting the power supply, such as mounting an external diode between the power supply and the IC's power supply terminals.

2. **Power Supply Lines**
   Design the PCB layout pattern to provide low impedance supply lines. Separate the ground and supply lines of the digital and analog blocks to prevent noise in the ground and supply lines of the digital block from affecting the analog block. Furthermore, connect a capacitor to ground at all power supply pins. Consider the effect of temperature and aging on the capacitance value when using electrolytic capacitors.

3. **Ground Voltage**
   Ensure that no pins are at a voltage below that of the ground pin at any time, even during transient condition.

4. **Ground Wiring Pattern**
   When using both small-signal and large-current ground traces, the two ground traces should be routed separately but connected to a single ground at the reference point of the application board to avoid fluctuations in the small-signal ground caused by large currents. Also ensure that the ground traces of external components do not cause variations on the ground voltage. The ground lines must be as short and thick as possible to reduce line impedance.

5. **Thermal Consideration**
   Should by any chance the power dissipation rating be exceeded the rise in temperature of the chip may result in deterioration of the properties of the chip. The absolute maximum rating of the Pd stated in this specification is when the IC is mounted on a 70mm x 70mm x 1.6mm glass epoxy board. In case of exceeding this absolute maximum rating, increase the board size and copper area to prevent exceeding the Pd rating.

6. **Recommended Operating Conditions**
   These conditions represent a range within which the expected characteristics of the IC can be approximately obtained. The electrical characteristics are guaranteed under the conditions of each parameter.

7. **Rush Current**
   When power is first supplied to the IC, it is possible that the internal logic may be unstable and inrush current may flow instantaneously due to the internal powering sequence and delays, especially if the IC has more than one power supply. Therefore, give special consideration to power coupling capacitance, power wiring, width of ground wiring, and routing of connections.

8. **Operation Under Strong Electromagnetic Field**
   Operating the IC in the presence of a strong electromagnetic field may cause the IC to malfunction.

9. **Testing on Application Boards**
   When testing the IC on an application board, connecting a capacitor directly to a low-impedance output pin may subject the IC to stress. Always discharge capacitors completely after each process or step. The IC's power supply should always be turned off completely before connecting or removing it from the test setup during the inspection process. To prevent damage from static discharge, ground the IC during assembly and use similar precautions during transport and storage.

10. **Inter-pin Short and Mounting Errors**
    Ensure that the direction and position are correct when mounting the IC on the PCB. Incorrect mounting may result in damaging the IC. Avoid nearby pins being shorted to each other especially to ground, power supply and output pin. Inter-pin shorts could be due to many reasons such as metal particles, water droplets (in very humid environment) and unintentional solder bridge deposited in between pins during assembly to name a few.