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LED Drivers for LCD Backlights

White LED Driver for large LCD Panels (DCDC Converter type)



BD9428

● **General Description**

BD9428 is a high efficiency driver for white LEDs and designed for large LCDs. This IC is built-in a boost DCDC converters that employ an array of LEDs as the light source. BD9428 has some protect function against fault conditions, such as the over-voltage protection (OVP), the over current limit protection of DCDC (OCP), the short circuit protection (SCP), the open detection of LED string. Therefore BD9428 is available for the fail-safe design over a wide range output voltage.

● **Key Specifications**

- Operating power supply voltage range: 9.0V to 35.0V
- LED minimum current 30mA
- LED maximum current: 250mA
- Oscillator frequency: 150kHz (RT=100kΩ)
- Operating Current: 4.5mA (Typ.)
- Operating temperature range: -40°C to +85°C

● **Applications**

TV, Computer Display, Notebook, LCD Backlighting

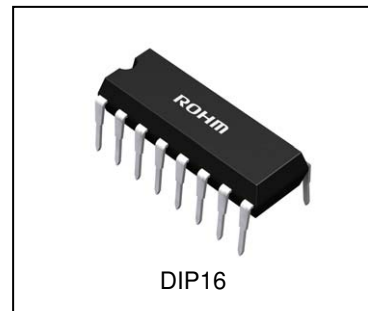
● **Features**

- 4ch LED constant current driver and DC/DC converter
- Maximum LED Current: 250mA
- LED Feedback Voltage: 0.40V (@ILED=100mA), so lower heat. Adjustable Feed Back Voltage by following LED Current setting.
- ±2% LED current accuracy (when each LED is set to 100mA)
- LED pin rating 80V
- Individual detection and individual LED OFF for both open and short circuits
- Built-in ISET pin short-circuit protection circuit
- Set Soft-Start time by external capacitor (SSFB pin).
- FET's Gate (N pin) is driven by 10V swing
- Built-in Vout overvoltage protection (OVP) / Short circuit protection (SCP)
- DIP16 package

● **Package**

DIP16

W(Typ.) x D(Typ.) x H(Max.)
19.40mm x 6.50mm x 7.95mm



● **Typical Application Circuit (4 light with PWM)**

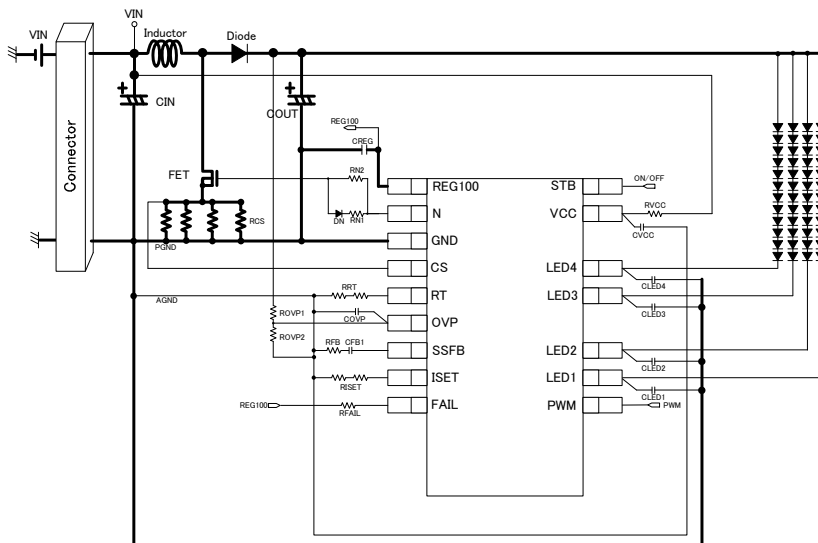


Figure 1. Typical Application Circuit

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

● Absolute maximum ratings (Ta=25°C)

Parameter	Symbol	Rating	Unit
Power supply voltage	VCC	36	V
STB, OVP, PWM, FAIL terminal voltage	STB, OVP, PWM, FAIL	36	V
LED1 to 4 terminal voltage	LED1 to 4	80	V
CS, ISET, SSFB, RT terminal voltage	CS, N, ISET, SSFB, RT	7	V
REG100, N terminal voltage	REG100, N	13	V
Power dissipation	Pd	1.25 *1	W
Operating temperature range	Topr	-40~+85	°C
Storage temperature range	Tstg	-55~+150	°C
Junction temperature	Tjmax	150	°C

*1 Ta = 25°C or more, diminished at -10mW/°C

● Operating Ratings (Ta = 25°C)

Parameter	Symbol	Limits	Unit
VCC supply voltage	VCC	9.0 to 35.0	V
Min. output current of LED1 to 4	ILED_MIN	30	mA *1
Max. output current of LED1 to 4	ILED_MAX	250	mA *1,2
DC/DC oscillation frequency	fsw	100 to 800	kHz
Min. on-duty time for PWM light modulation 1 (under soft-start)	PWM_MIN 1	30	us
Min. on-duty time for PWM light modulation 2 (after soft-start)	PWM_MIN 2	5	us

*1 The amount of current per channel.

*2 If LED makes significant variations in its reference voltage, the driver will increase power dissipation, resulting in a rise in package temperature. To avoid this problem, design the board with thorough consideration given to heat radiation measures.

● Pin Configurations

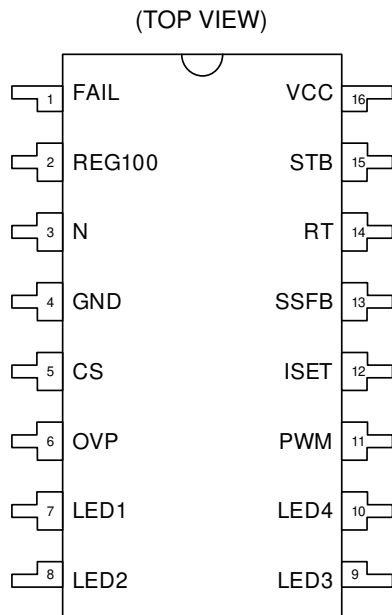


Figure 2. Pin Configuration

● Marking Diagram and Physical Dimension

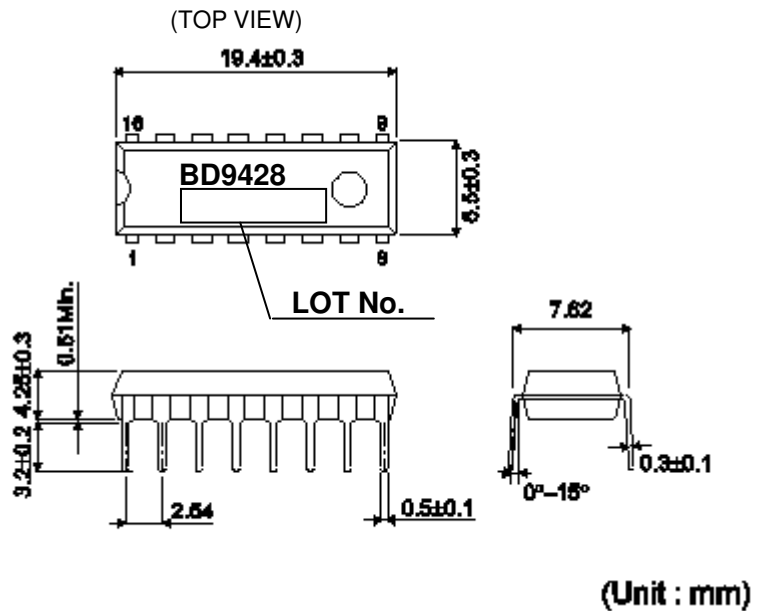


Figure 3. Marking Diagram and Physical Dimension

●Electrical Characteristics (Unless otherwise noted, Ta = 25°C, VCC=24V)

Parameter	Symbol	Limit			Unit	Condition
		Min.	Typ.	Max.		
[Whole Device]						
Circuit current while in operation	ICC	-	4.5	9	mA	VSTB=3V, VPWM=3V, RRT=100kΩ
Circuit current while in standby	ISTB	-	40	80	μA	STB=0V
[REG100 Block]						
REG100 Output Voltage	REG100	9.9	10	10.1	V	Io=0mA
REG100 Maximum Output Current	IREG100	15	-	-	mA	
[UVLO Block]						
UVLO release voltage	VUVLO_VCC	6.5	7.5	8.5	V	VCC=SWEEP UP
UVLO hysteresis voltage	VUHYS_VCC	150	300	600	mV	VCC=SWEEP DOWN
REG100 UVLO detect voltage	VUVLO_REG	5.4	6	6.6	V	VCC=SWEEP DOWN
REG100 UVLO hysteresis voltage	VUHYS_REG	250	500	750	mV	VCC=SWEEP UP
[DC/DC Block]						
Error amp. Reference voltage	VLED	0.36	0.40	0.44	V	ILED=100mA
Oscillation frequency	fsw	142.5	150.0	157.5	kHz	RRT=100kΩ
Max. duty cycle per output of N pin	DMAX	90	95	99	%	RRT=100kΩ
On resistance on N pin source side	RONH	-	5	10	Ω	ION=-10mA
On resistance on N pin sink side	RONL	-	3	6	Ω	ION=10mA
Soft start source current	ISSSO	-10.4	-8	-5.6	μA	VSSFB=2V
SSFB sink current	IFBSI	80	100	120	μA	VLED=2V, VSSFB=1V
SSFB source current	IFBSO	-115	-100	-85	μA	VLED=0V, VSSFB=1V
SSFB sink current (Slave Mode)	IFBSI_SL	-5	0	5	μA	VLED=2V, VSSFB=1V, VCS=5V
SSFB source current (Slave Mode)	IFBSO_SL	-190	-160	-130	μA	VLED=0V, VSSFB=1V, VCS=5V
Over current detection voltage	VCS	0.40	0.45	0.50	V	VCS=SWEEP UP
[DC/DC Protection Block]						
Overvoltage protection detection voltage	VOVP	2.7	3.0	3.3	V	VOVP=SWEEP UP
Overvoltage protection detection hysteresis voltage	VOVP_HYS	50	100	200	mV	VOVP=SWEEP DOWN
Short circuit protection detection voltage	VSCP	0.04	0.10	0.25	V	VOVP=SWEEP DOWN
[LED Driver Block]						
LED pin current accuracy	dILED	-2	-	2	%	ILED=100mA
LED pin Leakage Current	ILLED	-2.5	-	2.5	μA	VLED=80V
LED open detection voltage	VOPEN	0.05	0.20	0.285	V	VLED=SWEEP DOWN
LED short detection voltage	VSHORT	8.5	9	9.5	V	VLED=SWEEP UP

●Electrical Characteristics (Unless otherwise noted, Ta = 25°C, VCC=24V)

Parameter	Symbol	Limit			Unit	Condition
		Min.	Typ.	Max.		
[STB Block]						
STB pin high-level voltage	STBH	2	-	35	V	V _{STB} =SWEEP UP
STB pin low-level voltage	STBL	-0.3	-	0.8	V	V _{STB} =SWEEP DOWN
STB pin pull-down resistance	RSTB	500	1000	1500	kΩ	V _{STB} =3V
[PWM Block]						
PWM pin high-level voltage	PWMH	2	-	35	V	V _{PWM} =SWEEP UP
PWM pin low-level voltage	PWML	-0.3	-	0.8	V	V _{PWM} = SWEEP DOWN
PWM pin pull-down resistance	RPWM	180	300	420	kΩ	V _{PWM} =3V
[Failure Indication Block (Open Drain)]						
FAIL pin on resistance	RFAIL	250	500	1000	Ω	V _{FAIL} =1V
FAIL pin leakage current	ILFAIL	-2	0	2	μA	V _{FAIL} =5V

● Pin Descriptions

Pin No	Pin Name	In/Out	Function	Rating [V]
1	FAIL	Out	Error detection output pin.	-0.3 ~ 36
2	REG100	Out	Power supply for N pin	-0.3 ~ 13
3	N	Out	DC/DC switching output pin	-0.3 ~ 13
4	GND	-	Ground pin	-
5	CS	In	DC/DC output current detection and OCP detection pin	-0.3 ~ 7
6	OVP	In	Overvoltage protection detection pin	-0.3 ~ 36
7	LED1	Out	Output pin 1 for LED (If unused, connect LED1 to GND)	-0.3 ~ 80
8	LED2	Out	Output pin 2 for LED (If unused, connect LED2 to GND)	-0.3 ~ 80
9	LED3	Out	Output pin 3 for LED (If unused, connect LED3 to GND)	-0.3 ~ 80
10	LED4	Out	Output pin 4 for LED (If unused, connect LED4 to GND)	-0.3 ~ 80
11	PWM	In	External PWM light modulation signal input pin for LED1-4	-0.3 ~ 36
12	ISET	Out	LED current setting resistor connection pin	-0.3 ~ 7
13	SSFB	In/Out	Soft start setting, Loop compensation setting pin	-0.3 ~ 7
14	RT	Out	DC/DC drive frequency setting resistor connection pin.	-0.3 ~ 7
15	STB	In	Enable pin	-0.3 ~ 36
16	VCC	In	Power supply pin	-0.3 ~ 36

● Pin ESD Type

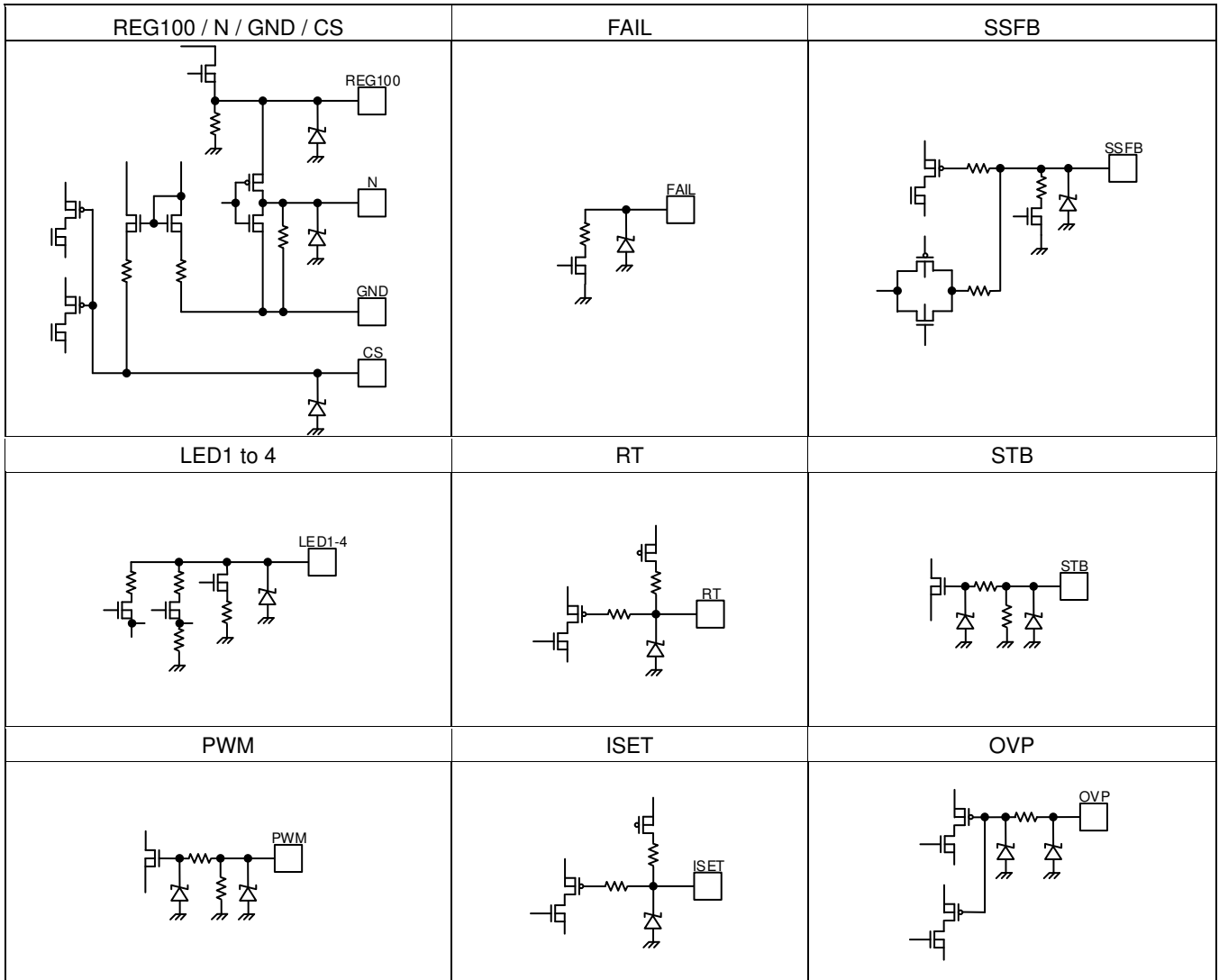


Figure 4. Pin ESD Type

●Block Diagram

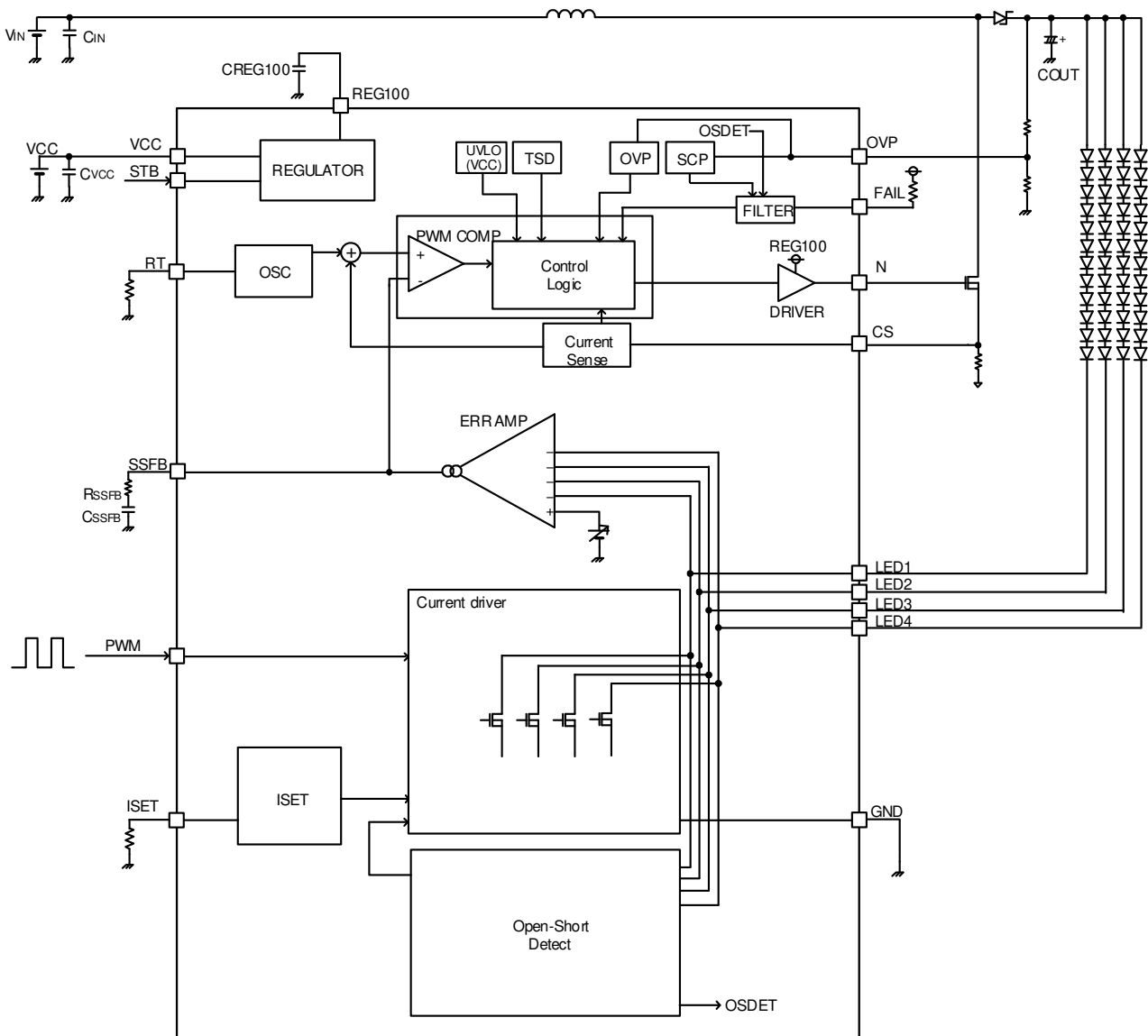


Figure 5. Block Diagram

● Typical Performance Curves

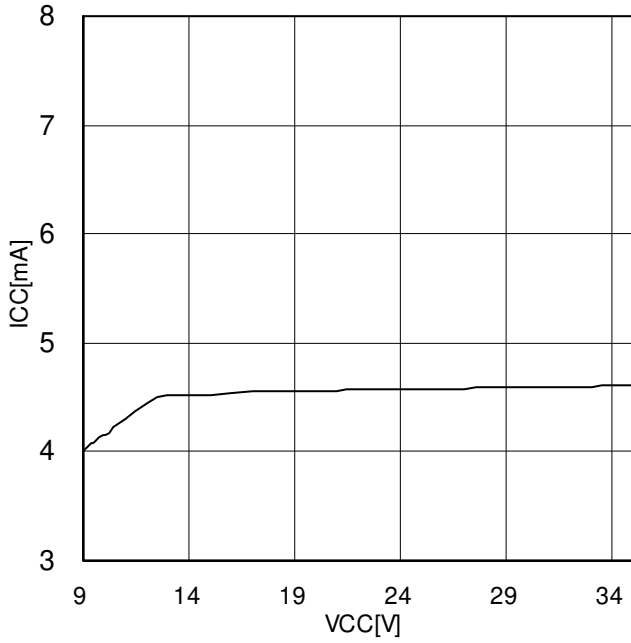


Figure 6. Operating Current (ICC) [mA] vs. VCC [V]

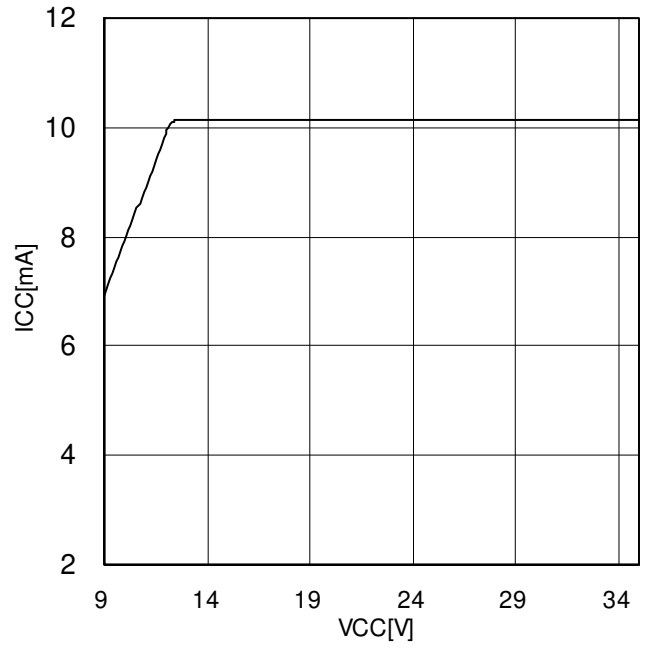


Figure 7. REG100 Voltage [V] vs. VCC [V]

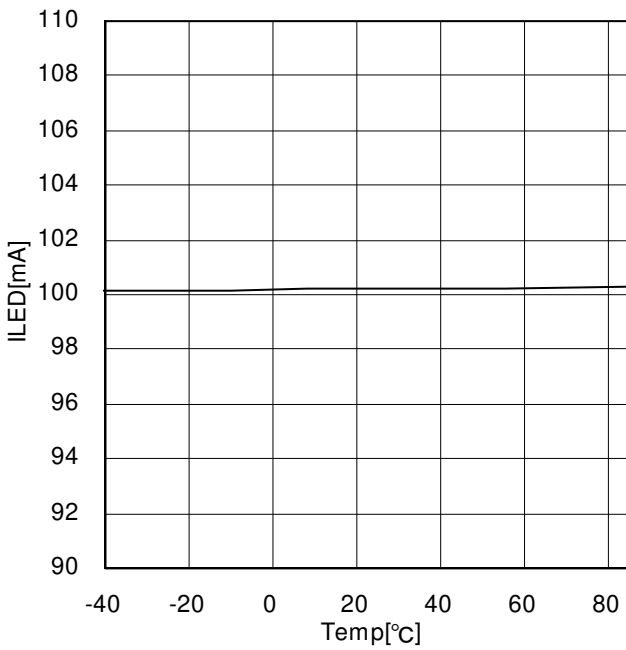


Figure 8. LED Current (ILED) [mA] vs. Temp [°C]

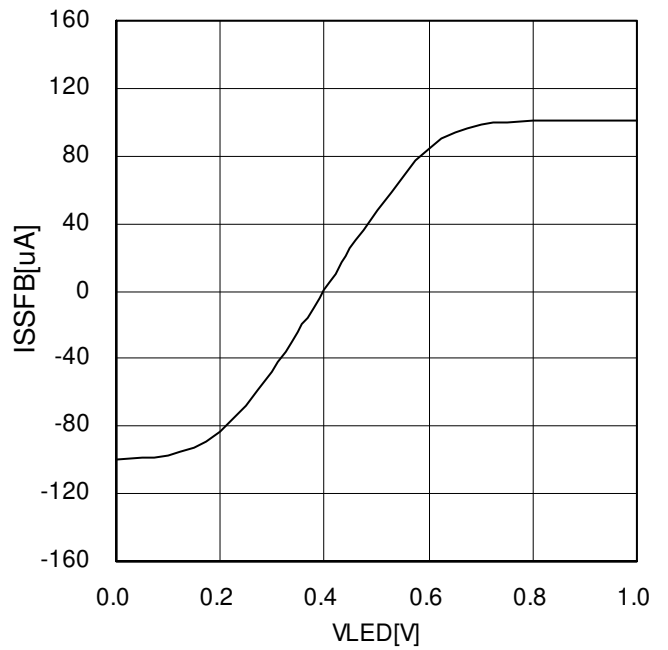


Figure 9. SSFB sink / source current (ISSFB) [uA] vs. VLED [V]

● Pin Functions

OVCC

The VCC pin is used to supply power for the IC in the range of 9 to 35V.

If the VCC pin voltage reaches 7.5V (Typ.) or more, the IC will initiate operation. If it reaches 7.2V (Typ.) or less, the IC will be shut down.

OREG100

The REG100 pin is used in the DC/DC converter driver block to output 10V power. The maximum operating current is 15mA. Using the REG100 pin at a current higher than 15mA can affect the N pin output pulse, causing the IC to malfunction and leading to heat generation of the IC itself. To avoid this problem, it is recommended to make load setting to the minimum level. The characteristic of VCC line regulation at REG100 is shown as Figure 7. (page.8). VCC must be used in more than 12V (I_o=0mA), 14V (I_o=15mA) for stable 10V output, respectively.

Please place the ceramic capacitor connected to REG100 pin (2.2uF~10uF) closest to REG100-GND pin.

OCS

The CS pin has the following two functions:

1. DC/DC current mode current feedback function

Current flowing through the inductor is converted into voltage by the current sensing resistor RCS connected to the CS pin and this voltage is compared with voltage set with the error amplifier to control the DC/DC output voltage.

2. Inductor current limit function

The CS pin also incorporates the over current protection (OCP) function. If the CS pin voltage reaches 0.45V (Typ.) or more, switching operation will be forcedly stopped.

ON

The N pin is used to output power to the external NMOS gate driver for the DC/DC converter in the amplitude range of approx. 0 to REG100. ON resistances is 5Ω (Typ.) in source (H side), 3Ω (Typ.) in sink (L side).

Frequency setting can be made with a resistor connected to the RT pin. For details of frequency setting, refer to the description of the RT pin.

OGND

Ground of the IC.

OLED1 – LED4

The LED1 to 4 pins are used to output constant current to LED drivers. Current value setting can be made by connecting a resistor to the ISET pin.

For the current value setting procedure, refer to the description of "ISET pin".

If any of the LED pins is put in an erroneous state (e.g. short circuit mode, open circuit mode, or ground short circuit mode), the relevant protection function will be activated.

This IC is detected automatically that it is an unused channel by assuming the LED terminal to be connected to GND before start up.

OPWM

The PWM pin is used to turn ON and OFF LED drivers. Light can be modulated by changing the duty cycle through the direct input of a PWM light modulation signal

The high and low voltage levels of PWM pin is as listed in the table below:

State	PWM Voltage
LED ON	PWM= 2.0V to 35V
LED OFF	PWM= -0.3V to 0.8V

OISET

The ISET pin is an output current setting resistor. Output current I_{LED} varies in inverse proportion to resistance.

The relation between output current I_{LED} and the resistance of ISET pin connection resistor R_{ISET} is given by the following equation:

$$I_{LED} [mA] = \frac{7500}{R_{ISET} [k\Omega]}$$

Output current setting should be made in the range of 30 to 250mA.

When it reaches under V_{ISET} × 0.90V(typ), the LED current is off to prevent from passing a large current to the LED pin when the R_{ISET} is shorted and the ISET pin is shorted to the GND. And as the ISET pin returns to a normal state, the LED current returns.

It prepares automatically to suitable LED feedback voltage that can output LED current set by ISET pin. In short LED feedback voltage is dropped when the LED current is small and the IC heating is held automatically. In case of a large current is needed, raise the LED pin feedback voltage. And it adjusts automatically to LED pin voltage that can be flow large LED current. The calculation is as below.

$$V_{LED} = 3.0 \times I_{LED} [A] [V]$$

The LED feedback voltage (VLED) is clamped to 0.40V (Typ.) when the LED current (ILED) is less than 133.3mA.

OSSF

The SSFB pin is used to make setting of soft start time and duty for soft start, and DC/DC current mode control error amplifier. It performs constant current charge of 8 uA to the external capacitor connected to SSFB terminal, which enables soft-start of DC/DC converter.

The SSFB pin detects the voltages of LED pins (1 to 4) and controls inductor current so that the pin voltage of the LED located in the row with the highest Vf will come to 0.40V (ILED=100mA). As a result, the pin voltages of other LEDs become higher by Vf variation. After completion of soft start, the SSFB pin is put into the high-impedance state with the PWM signal being in the low state, thus maintaining the SSFB voltage.

Since the LED protection function (OPEN/SHORT detection) works when it turns to the LED feedback mode.

ORT

The RT pin is used to connect a DC/DC frequency setting resistor. DC/DC drive frequency is determined by connecting the RT resistor.

ODrive frequency vs. RT resistance (Ideal)

$$R_{RT} = \frac{15000}{f_{sw} [kHz]} [k\Omega]$$

When RT is 100kΩ, Fsw is 150kHz(Typ.). However, drive frequency setting should be made in the range of 100 kHz to 800 kHz.

OVP

The OVP pin is an input pin for over-voltage protection and short circuit protection of DC/DC output voltage. If over-voltage is detected, the OVP pin will stop the DC/DC converter conducting step-up operation. When the short circuit protection (SCP) function is activated, the DC/DC converter will stop operation, and then the timer will start counting. When the timer completes counting the preset period of time, the LED drivers are stopped.

The OVP pin is of the high impedance type and involves no pull-down resistor, resulting in unstable potential in the open-circuited state. To avoid this problem, be sure to make input voltage setting with the use of a resistive divider or otherwise.

OSTB

The STB pin is used to make setting of turning ON and OFF the IC and allowed for use to reset the IC from shutdown.

Note: The IC state is switched (i.e., the IC is switched between ON and OFF state) according to voltages input in the STB pin. Avoid using the STB pin between two states (0.8 to 2.0V).

OFAIL

This FAIL pin is used to output FAIL signal (open drain). If any error is detected, NMOS will be put into the open-circuited state.

If no LED pin is used, LED pin processing will be conducted in the open-circuited state, LED_OPEN protection will be detected to output the OPEN signal from the FAIL pin.

STATE	FAIL Signal Output
Normal operation	GND Level
Error detection (after timer is latched)	OPEN

● Startup operation and soft start capacitance setting

The following section describes the sequence for the startup of this IC.

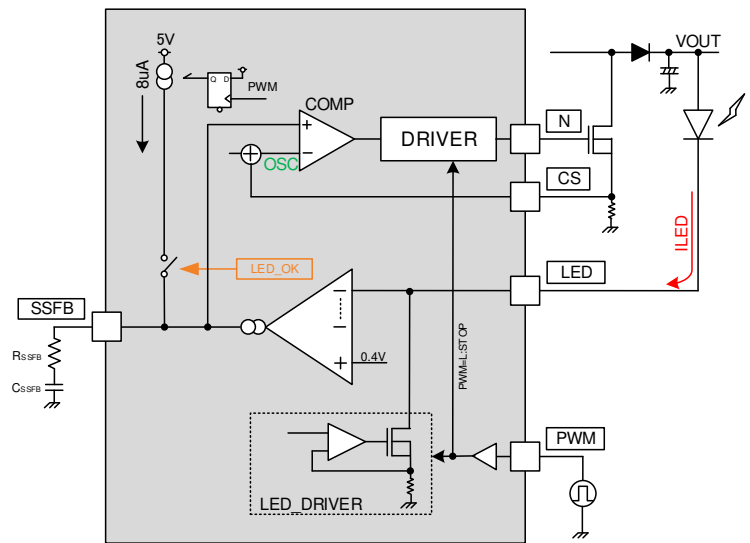
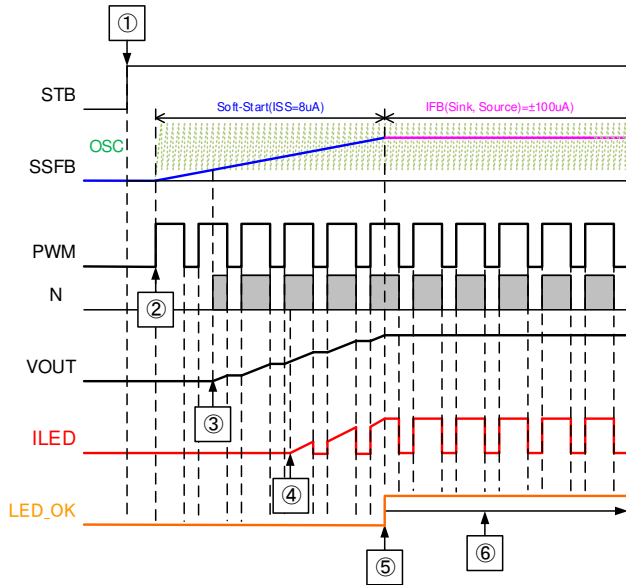


Figure 10. Timing Chart at startup

○ Description of startup sequence

- (1) Set the STB and PWM pin to "ON".
 - (2) Set all systems to "ON", SSFB charge will be initiated.
 - (3) Since the SSFB pin reach the lower limit of the internal sawtooth wave of the IC, the DC/DC converter operates to start VOUT voltage rising.
 - (4) The Vout voltage continues rising to reach a voltage at which LED current starts flowing.
 - (5) When the LED current reaches the set amount of current, the startup operation is completed.
 - (6) After that, conduct normal operation following the feedback operation sequence with the LED pins.
- If the SSFB pin sink/source current is $\pm 100\mu\text{A}$, the LED protection function will be activated.

○ SSFB capacitance setting procedure

As aforementioned, this IC stops DC/DC converter when the PWM pin is set to Low level and conducts step-up operation only in the section in which the PWM pin is maintained at High level. Consequently, setting the PWM duty cycle to the minimum will extend the startup time. The startup time also varies with application settings of output capacitance, LED current, output voltage, and others.

Startup time at minimum duty cycle can be approximated according to the following method:

Make measurement of VOUT startup time with a 100% duty cycle, first. Take this value as "Trise100".

The startup time "Trise_min" for the relevant application with the minimum duty cycle is given by the following equation.

$$T_{rise_min} = \frac{T_{rise_100}[\text{Sec}]}{\text{Min_Duty}[\text{ratio}]} \quad [\text{Sec}]$$

However, since this calculation method is just for approximation, use it only as a guide.

Make setting of time during which the SSFB pin voltage reaches the feedback voltage longer than this startup time.

Assuming that the SSFB pin voltage is VSSFB, the time is given by the following equation:

$$T_{ss} = \frac{C_{SSFB}[\text{F}] \times V_{SSFB}[\text{V}]}{8[\mu\text{A}]} \quad [\text{sec}]$$

As a result, it is recommended to make SSFB capacitance setting so that "TSSFB" will be greater than "Trise_min"

●LED current setting

Setting of LED output current "ILED" can be made by connecting a resistor R_{ISET} to the ISET pin.

○R_{ISET} vs. ILED current relation equation

$$R_{ISET} = \frac{7500}{I_{LED} [mA]} \quad [k\Omega]$$

However, LED current setting should be made in the range of 30mA to 150mA.

[Setting example]

To set ILED current to 100mA, R_{ISET} resistance is given by the following equation:

$$R_{ISET} = \frac{7500}{I_{LED} [mA]} = \frac{7500}{100 [mA]} = 75 \quad [k\Omega]$$

●DC/DC converter drive frequency setting

DC/DC converter drive frequency is determined by making R_T resistance setting.

○Drive frequency vs. R_T resistance (ideal) relation equation

$$R_{RT} = \frac{15000}{f_{sw} [kHz]} \quad [k\Omega]$$

where f_{sw} = DC/DC converter oscillation frequency [kHz]

This equation has become an ideal equation without any correction item included.

For accurate frequency settings, thorough verification should be performed on practical sets.

[Setting example]

To set DC/DC drive frequency "f_{sw}" to 200 kHz, R_{RT} is given by the following equation:

$$R_{RT} = \frac{15000}{f_{sw} [kHz]} = \frac{15000}{200 [kHz]} = 75 \quad [k\Omega]$$

●OVP/SCP Settings

OVP pin is DC/DC output voltage's over voltage protection and short circuit protection input pin.

OVP pin is a high impedance pin with no pull down resistor. Thus, at OPEN state please set the voltage input settings using voltage dividing resistor and such.

Respective OVP pin protection conditions are as below

Protection Name	Detection Pin	Detection Condition	Cancellation Condition	Timer Operations	Protection Type
OVP	OVP	OVP>3.0V	OVP<2.9V	No	DCDC stops during detection
SCP	OVP	OVP<0.1V	OVP>0.1V	Yes	All latch

○OVP Detection Setting

VOUT abnormally increase, voltage detected by OVP, $VOVP_{DET}$, R1,R2 settings are as follows

$$R1 = R2[k\Omega] \times \frac{(VOVP_{DET}[V] - 3.0[V])}{3.0[V]} \quad [k\Omega]$$

○OVP Cancellation Setting

R1,R2 set from above equation, OVP cancellation voltage $VOVP_{CAN}$ equals to

$$VOVP_{CAN} = 2.9V \times \frac{(R1[k\Omega] + R2[k\Omega])}{R2[k\Omega]} \quad [V]$$

○SCP Detection Setting

When R1,R2 are set using values obtained above, SCP voltage setting is $VSCP_{DET}$ is as follows

$$VSCP_{DET} = 0.1V \times \frac{(R1[k\Omega] + R2[k\Omega])}{R2[k\Omega]} \quad [V]$$

【Setting Example】

VOUT at normal operation 56V, OVP detection voltage $VOVP_{DET}=68V$, $R2=10k$, R1 is as follows

$$R1 = R2[k\Omega] \times \frac{(VOVP_{DET}[V] - 3.0[V])}{3.0[V]} = 10[k\Omega] \times \frac{(68[V] - 3[V])}{3[V]} = 216.7 \quad [k\Omega]$$

When R1, R2 are set at these values, OVP cancellation voltage, $VOVP_{CAN}$

$$VOVP_{CAN} = 2.9[V] \times \frac{(R1[k\Omega] + R2[k\Omega])}{R2[k\Omega]} = 2.9[V] \times \frac{10[k\Omega] + 216.7[k\Omega]}{10[k\Omega]} [V] = 65.7 \quad [V]$$

In addition, at this R1, R2, SCP detection voltage

$$VSCP_{DET} = 0.1[V] \times \frac{(R1[k\Omega] + R2[k\Omega])}{R2[k\Omega]} = 0.1[V] \times \frac{10[k\Omega] + 216.7[k\Omega]}{10[k\Omega]} [V] = 2.27 \quad [V]$$

To select DC/DC components, give consideration to IC variations as well as individual component variations, and then conduct thorough verification on practical systems.

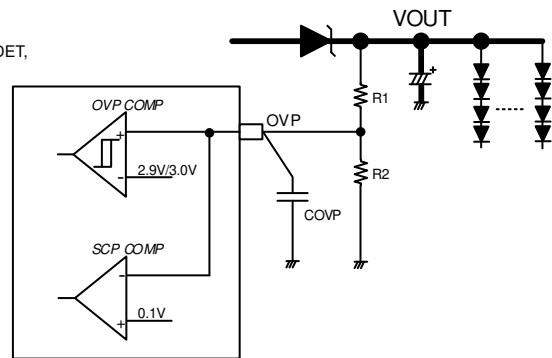


Figure 11. OVP/SCP Block Diagrams

● Timer Latch Time Setting

This IC has a built-in timer latch counter. Timer latch time is set by counting the clock frequency which is set at the RT pin.

● Timer Latch Time

When various abnormal conditions happen, counting starts from the timing, latch occurs after below time has passed. Furthermore, even if PWM=L, if abnormal condition continues, timer count will not reset.

$$LATCH_{TIME} = 2^{12} \times \frac{R_{RT}}{1.5 \times 10^{10}} = 4096 \times \frac{R_{RT} [k\Omega]}{1.5 \times 10^7} [s]$$

Here, $LATCH_{TIME}$ = time until latch condition occurs
 R_{RT} = Resistor value connected to RT pin

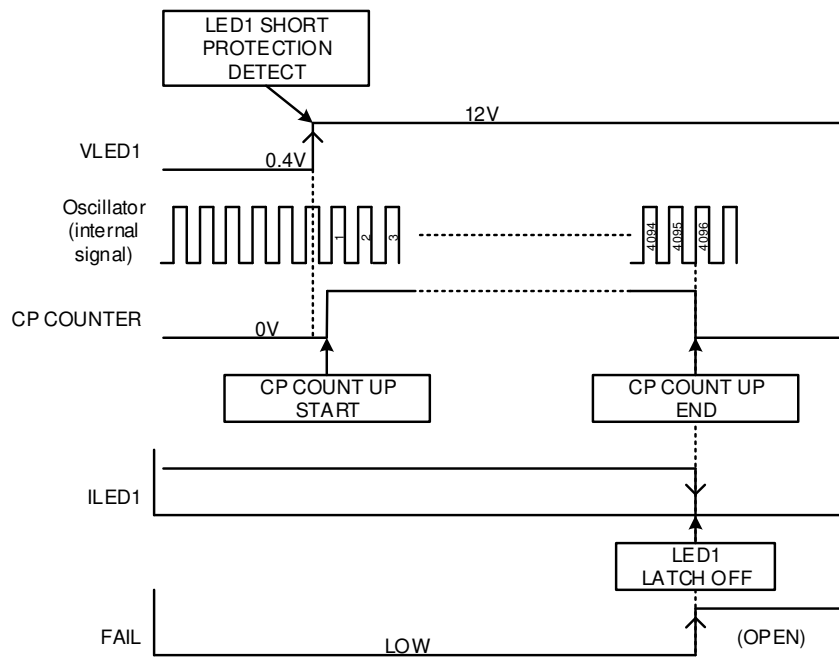


Figure 12. Example of LED Short protection Timing Chart

【Setting Example】

Timer latch time when $R_T=75k\Omega$

$$LATCH_{TIME} = 4096 \times \frac{R_{RT} [k\Omega]}{1.5 \times 10^7} = 4096 \times \frac{75 [k\Omega]}{1.5 \times 10^7} = 0.02 [s]$$

● - OCP Settings/DCDC Components' Current Capacity Selection Method

One of the function of CS pin - when its pin voltage > 0.45 it stops the DCDC. Thus, RCS resistor value need to be checked after the peak current flow through the inductor is calculated. Furthermore, DCDC external components' current capacity needs to be greater than peak current flowing through this inductor.

(Inductor peak current Ipeak calculation method)

Firstly, ripple voltage which occurs at the CS pin is decided depending on the DCDC application conditions.

The conditions when made as below;

Output voltage = VOUT[V]

LED total current = IOUT[A]

DCDC input voltage = VIN[V]

DCDC efficiency = η[%]

Total required average input current IIN:

$$I_{IN} = \frac{V_{OUT}[V] \times I_{OUT}[A]}{V_{IN}[V] \times \eta[\%]} \quad [A]$$

Inductor ripple current IL[A] which occurs at inductor L[H] during DCDC drive operation with switching frequency = fsw[Hz] is as follows

$$\Delta IL = \frac{(V_{OUT}[V] - V_{IN}[V]) \times V_{IN}[V]}{L[H] \times V_{OUT}[V] \times f_{sw}[Hz]} \quad [A]$$

Therefore, IL's peak current Ipeak can be calculated using below equation

$$I_{peak} = I_{IN}[A] + \frac{\Delta IL[A]}{2} \quad [A] \dots (1)$$

(Resistor RCS connected to CS pin selection method)

This Ipeak flows in RCS and generates voltage. (refer to time chart diagram on the right). This voltage value, VCSpeak can be calculated as below

$$V_{CS_{peak}} = R_{cs} \times I_{peak} \quad [V]$$

This VCSpeak when reach 0.45V, will stop the DCDC output. Thus when selecting RCS value, below condition needs to be met.

$$R_{cs}[\Omega] \times I_{peak}[A] < 0.45[V]$$

(DCDC Components' Current Capacity Selection Method)

When OCP reach detection voltage CS=0.45V, Iocp current

$$I_{OCP} = \frac{0.45[V]}{R_{cs}[\Omega]} \quad [A] \dots (2)$$

Ipeak current (1), Iocp current (2), and components' MAX current capacity needs to satisfy the following

$$I_{peak} < I_{OCP} < \text{Rated current of components}$$

Above condition needs to be satisfied when selecting DCDC application parts eg. FET, inductor, diode etc. Furthermore, continuous mode is recommended for normal DCDC applications. Inductor's ripple current MIN limit value, Imin becoming

$$I_{min} = I_{IN}[A] - \frac{\Delta IL[A]}{2} [A] > 0$$

Is a condition to be met. If this is not met, it is called discontinuous mode.

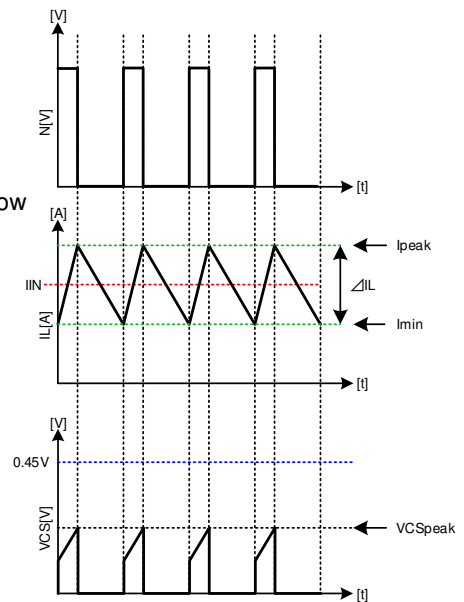
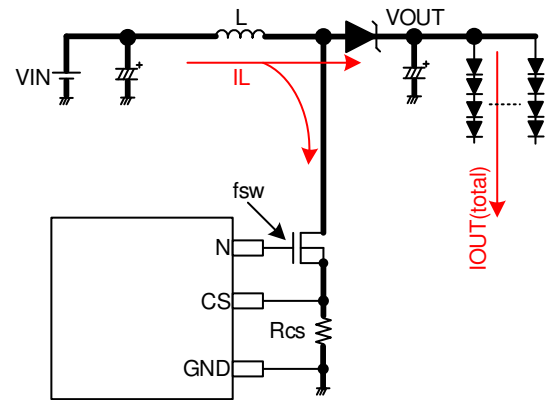


Figure 13. DC/DC Converter Application Circuit (a) and Inductor Current Waveform

【Setting Example】Output voltage=V_{OUT}[V]=56VLED total current=I_{OUT}[A]=100mA × 4ch=0.40ADCDC input voltage=V_{IN}[V]=14V

DCDC efficiency=η [%]=90%

Total required average input current I_{IN}:

$$I_{IN}[A] = \frac{V_{OUT}[V] \times I_{OUT}[A]}{V_{IN}[V] \times \eta[\%]} = \frac{56[V] \times 0.40[A]}{14[V] \times 90[\%]} = 1.78 [A]$$

When, DCDC switching frequency =f_{sw}[Hz]=200kHz

Inductor L[H]=33uH,

Inductor ripple current ΔIL[A]:

$$\Delta IL = \frac{(V_{OUT}[V] - V_{IN}[V]) \times V_{IN}[V]}{L[H] \times V_{OUT}[V] \times f_{sw}[Hz]} = \frac{(56[V] - 14[V]) \times 14[V]}{33 \times 10^{-6}[H] \times 56[V] \times 200 \times 10^3[Hz]} = 1.59 [A]$$

Thus, IL peak current I_{peak} becomes

$$I_{peak} = I_{IN}[A] + \frac{\Delta IL[A]}{2} [A] = 1.78[A] + \frac{1.59[A]}{2} = 2.58 [A] \quad \dots \text{Peak current calculation result}$$

RCS resistor value when set at 0.1Ω

$$V_{CS\ peak} = R_{CS} \times I_{peak} = 0.10[\Omega] \times 2.58[A] = 0.258 [V] < 0.45V \quad \dots \text{RCS resistor consideration}$$

and satisfy the condition.

In addition, OCP detection current I_{OCP} at this time is

$$I_{OCP} = \frac{0.45[V]}{0.1[\Omega]} = 4.5 [A]$$

If parts used (FET, INDUCTOR, DIODE etc)'s current capacity < 5A,

$$I_{peak} < I_{OCP} < \text{Rated current of components} = 2.58[A] < 4.5[A] < 5[A]$$

Thus, there is no problem of parts selection as the above condition is satisfied.

…DCDC current capacity consideration

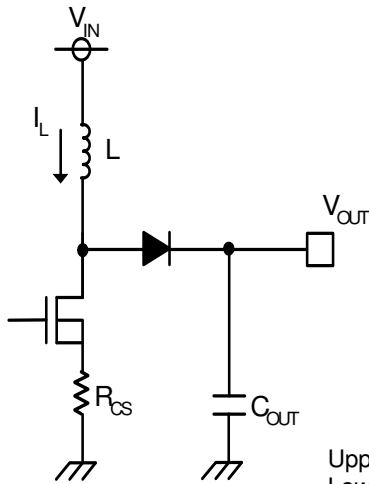
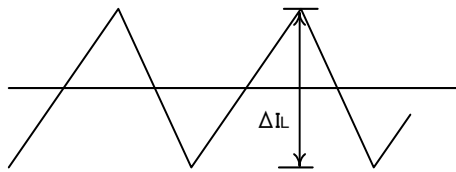
In addition, IL ripple current minimum limit I_{min} is

$$I_{min} = I_{IN}[A] - \frac{\Delta IL[A]}{2} [A] = 1.78[A] - 0.795[A] = 0.985[A] > 0$$

Thus, will not become discontinuous mode.

To select DC/DC components, give consideration to IC variations as well as individual component variations, and then conduct thorough verification on practical systems.

● Selection of inductor L



The value of inductor has significant influence on the input ripple current. As shown by Equation (1), the larger the inductor and the higher the switching frequency, the inductor ripple current ΔIL becomes increasingly lower.

$$\Delta IL = \frac{(V_{OUT} - V_{IN}) \times V_{IN}}{L \times V_{OUT} \times f_{SW}} [A] \quad \dots \dots (1)$$

Expressing efficiency as shown by Equation (2), peak input current is given as Equation (3).

$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}} \quad \dots \dots (2)$$

$$I_{LMAX} = I_{IN} + \frac{\Delta IL}{2} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times \eta} + \frac{\Delta IL}{2} \quad \dots \dots (3)$$

where, L: Reactance value [H],
 VOUT: DC/DC output voltage [V],
 VIN: Input voltage [V],
 IOUT: Output load current (total output current) [A],
 IIN: Input current [A], and
 FSW: Oscillation frequency [Hz]

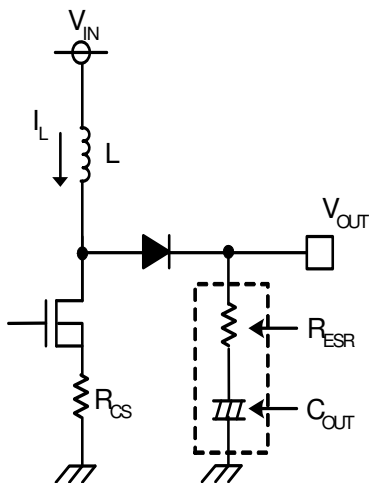
Upper: Figure 14. Inductor Current Waveform
 Lower: Figure 15. DC/DC Converter Application Circuit (b)

Note: If a current in excess of the rated current of the inductor applies to the coil, the inductor will cause magnetic saturation, resulting in efficiency degradation.

Select an inductor with an adequate margin so that peak current will not exceed the rated current of the inductor.

Note: To reduce power dissipation from and increase efficiency of inductor, select an inductor with low resistance component (DCR or ACR).

● Selection of output capacitor COUT



Select a capacitor on the output side taking into account the stability region of output voltage and equivalent series resistance necessary to smooth ripple voltage. Note that higher output ripple voltage may result in a drop in LED pin voltage, making it impossible to supply set LED current. The output ripple voltage ΔVOUT is given by Equation (4).

$$\Delta V_{OUT} = I_{LMAX} \times R_{ESR} + \frac{1}{C_{OUT}} \times \frac{I_{OUT}}{\eta} \times \frac{1}{f_{SW}} [V] \quad \dots \dots (4)$$

where RESR = Equivalent series resistance of COUT.

Note: Select capacitor ratings with an adequate margin for output voltage.

Note: To use an electrolytic capacitor, an adequate margin should be provided for permissible current. Particularly to apply PWM light modulation to LED, note that a current higher than the set LED current transiently flows.

Figure 16. DC/DC Converter Application Circuit (c)

● Selection of switching MOSFET transistors

There will be no problem for switching MOSFET transistors having absolute maximum rating higher than rated current of the inductor L and VF higher than “COUT breakdown voltage + Rectifier diode”. However, to achieve high-speed switching, select transistors with small gate capacity (injected charge amount).

Note: Rated current larger than overcurrent protection setting current is recommended.

Note: Selecting transistors with low on resistance can obtain high efficiency.

● Selection of rectifier diodes

Select Schottky barrier diodes having current capability higher than the rated current of the inductor L and inverse breakdown voltage higher than COUT breakdown voltage, particularly having low forward voltage VF.

●Phase Compensation Setting Procedure

DC/DC converter application for current mode control includes one each of pole f_p (phase delay) by CR filter consisting of output capacitor and output resistor (i.e., LED current) and zero (phase lead) f_z by the output capacitor and capacitor ESR. Furthermore, the step-up DC/DC converter includes RHP zero “ f_{ZRHP} ” as the second zero. Since the RHP zero has phase delay (-90°) characteristics like the pole, the crossover frequency f_c should be set to not more than RHP zero

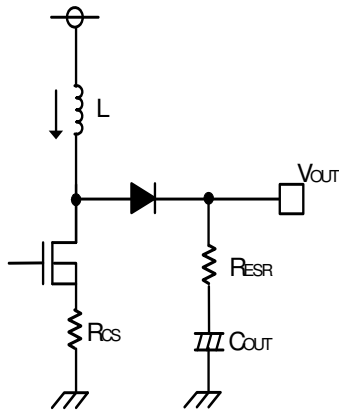


Figure 17. Output Block Diagram

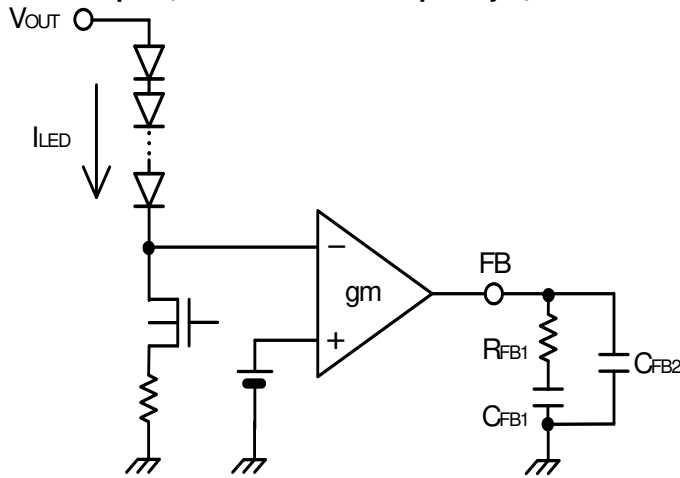


Figure 18. Error Amplifier Block Diagram

- i. Find pole f_p and RHP zero f_{ZRHP} of DC/DC converter.

$$f_p = \frac{I_{LED}}{2\pi \times V_{OUT} \times C_{OUT}} [Hz] \qquad f_{ZRHP} = \frac{V_{OUT} \times (1-D)^2}{2\pi \times L \times I_{LED}} [Hz]$$

Where I_{LED} = Total LED current [A], $D = \frac{V_{OUT} - V_{IN}}{V_{OUT}}$

- ii. Find phase compensation to be inserted in the error amplifier. (Set f_c to 1/5 of f_{ZRHP} .)

$$R_{FB1} = \frac{f_{RHZP} \times R_{CS} \times I_{LED}}{5 \times f_p \times gm \times V_{OUT} \times (1-D)} [\Omega] \qquad C_{FB1} = \frac{1}{2\pi \times R_{FB1} \times f_p} [F]$$

where $gm = 4.0 \times 10^{-4} [S]$

- iii. Find zero used to compensate ESR (R_{ESR}) of C_{OUT} (electrolytic capacitor).

$$C_{FB2} = \frac{R_{ESR} \times C_{OUT}}{R_{FB1}} [F]$$

Note: Even if a ceramic capacitor (R_{ESR} of the order of milliohms) for C_{OUT} , it is recommended to insert C_{FB2} for stable operation.

To improve transient response, it is necessary to increase R_{FB1} and reduce C_{FB1} . However, this improvement reduces a phase margin. To avoid this problem, conduct thorough verification, including variations in external components, on practical systems.

● Timing Chart

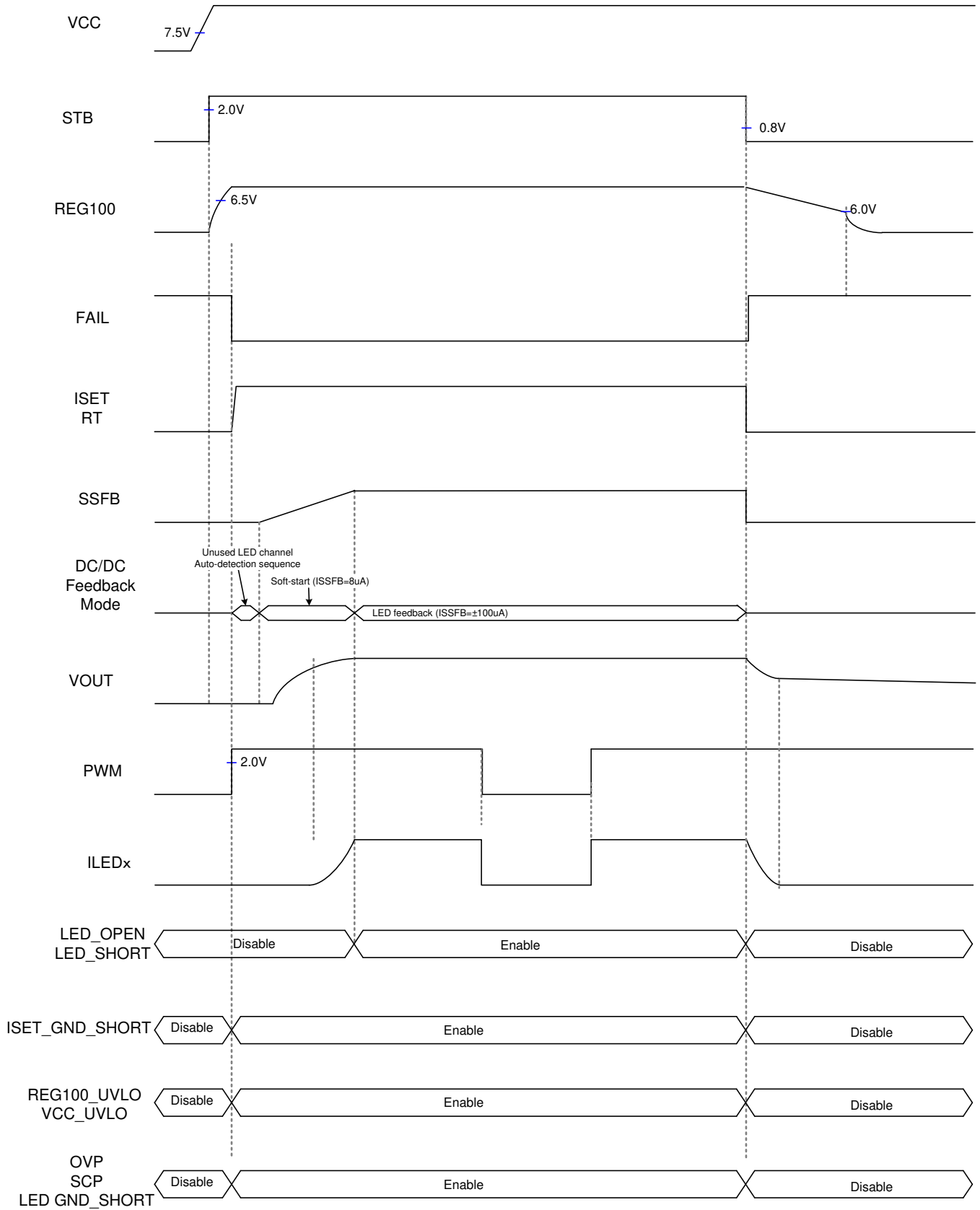


Figure 19. Timing Chart

●List of Protect Function (typ condition)

Protection Name	Detection Pin	Detection Conditions			Cancellation Conditions	Timer	Protection Type
		Detection pin	PWM	SS			
LED OPEN	LEDx	LEDx < 0.2V	H	After Soft-Start	LEDx > 0.2V	2 ¹² count	Latch (Only detected on)
LED SHORT	LEDx	LEDx > 9V	H	After Soft-Start	LEDx < 9V	2 ¹² count	Latch (Only detected on)
LED GNDSHORT	LEDx	LEDx < 0.2V and SSFB > 4.0V	H	-	LEDx > 0.2V or SSFB < 3.6V	(2 ¹² + 2 ⁷) count	Latch
ISET GND SHORT	ISET	Under ISET×90%	-	-	Above ISET×90%	Immediately Detect	Auto-Restart
REG100 UVLO	REG100	REG100<6V	-	-	REG100>6.5V	Immediately Detect	Auto-Restart
VCC UVLO	VCC	VCC<7.3V	-	-	VCC>7.5V	Immediately Detect	Auto-Restart
OVP	OVP	OVP>3.0V	-	-	OVP<2.9V	Immediately Detect	Auto-Restart
SCP	OVP	OVP<0.1V	-	-	OVP>0.1V	2 ¹² count	Latch
OCP	CS	OCP>0.45V	-	-	-	Immediately Detect	Pulse-by-Pulse

To clear the latch type, STB should be set to "L" once, and then to "H".

Protect Function	Operation after protect function detects error			
	DC/DC	LED Driver	Soft Start	FAIL Pin
LED OPEN	Continues operation	Only detected LED stops operating after CP counting	Not discharged	Opens after CP counting
LED SHORT	Continues operation	Only detected LED stops operating after CP counting	Not discharged	Opens after CP counting
LED GNDSHORT	Stops operating after CP counting	Stops operating after CP counting	Discharged after CP counting	Opens after CP counting
ISET GND SHORT	Instantaneously stops operating	Instantaneously stops operating	Not discharged	Immediately opens
STB	Instantaneously stops operating	Stops operating (and when REG100 < (6)V)	Discharged	Immediately opens
REG100 UVLO	Instantaneously stops operating	Instantaneously stops operating	Discharged	Immediately opens
VCC UVLO	Instantaneously stops operating	Instantaneously stops operating	Discharged	Immediately opens
OVP	Instantaneously stops operating	Continues operation	Not discharged	Ground
SCP	Stops operating after CP counting	Stops operating after CP counting	Discharged after CP counting	Opens after CP counting
OCP	N pin limits duty cycle	Continues operation	Not discharged	Ground

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. Inrush 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. 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.

9. 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.

Operational Notes – continued

10. Unused Input Terminals

Input terminals of an IC are often connected to the gate of a MOS transistor. The gate has extremely high impedance and extremely low capacitance. If left unconnected, the electric field from the outside can easily charge it. The small charge acquired in this way is enough to produce a significant effect on the conduction through the transistor and cause unexpected operation of the IC. So unless otherwise specified, unused input terminals should be connected to the power supply or ground line.

11. Regarding the Input Pin of the IC

This monolithic IC contains P+ isolation and P substrate layers between adjacent elements in order to keep them isolated. P-N junctions are formed at the intersection of the P layers with the N layers of other elements, creating a parasitic diode or transistor. For example (refer to figure below):

When $GND > Pin A$ and $GND > Pin B$, the P-N junction operates as a parasitic diode.
When $GND > Pin B$, the P-N junction operates as a parasitic transistor.

Parasitic diodes inevitably occur in the structure of the IC. The operation of parasitic diodes can result in mutual interference among circuits, operational faults, or physical damage. Therefore, conditions that cause these diodes to operate, such as applying a voltage lower than the GND voltage to an input pin (and thus to the P substrate) should be avoided.

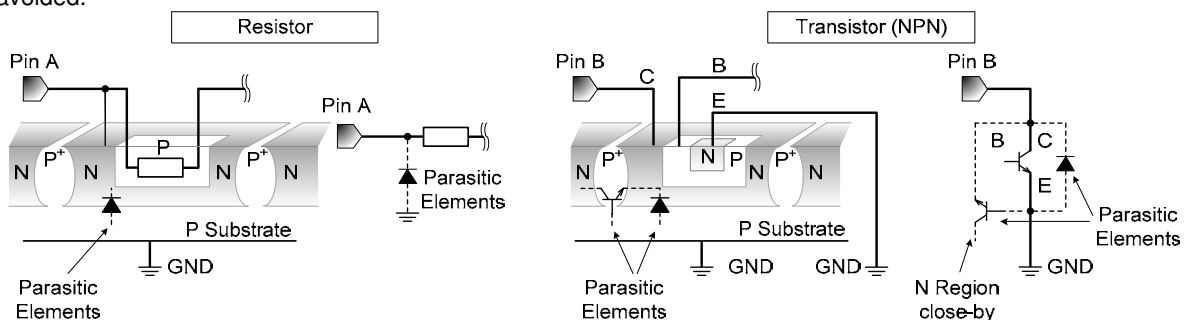


Figure 20. Example of monolithic IC structure

12. Ceramic Capacitor

When using a ceramic capacitor, determine the dielectric constant considering the change of capacitance with temperature and the decrease in nominal capacitance due to DC bias and others.

13. Area of Safe Operation (ASO)

Operate the IC such that the output voltage, output current, and power dissipation are all within the Area of Safe Operation (ASO).

14. Thermal Shutdown Circuit(TSD)

This IC has a built-in thermal shutdown circuit that prevents heat damage to the IC. Normal operation should always be within the IC's power dissipation rating. If however the rating is exceeded for a continued period, the junction temperature (T_j) will rise which will activate the TSD circuit that will turn OFF all output pins. When the T_j falls below the TSD threshold, the circuits are automatically restored to normal operation.

Note that the TSD circuit operates in a situation that exceeds the absolute maximum ratings and therefore, under no circumstances, should the TSD circuit be used in a set design or for any purpose other than protecting the IC from heat damage.

15. Over Current Protection Circuit (OCP)

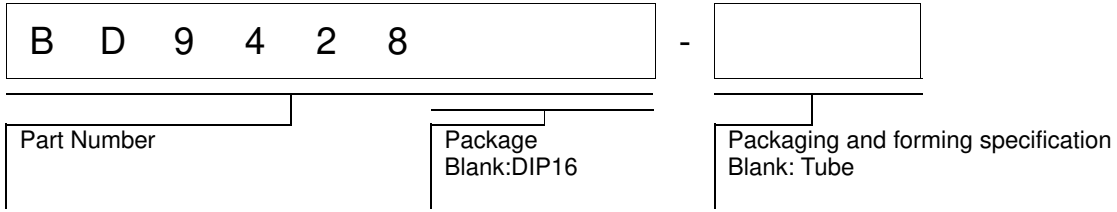
This IC incorporates an integrated overcurrent protection circuit that is activated when the load is shorted. This protection circuit is effective in preventing damage due to sudden and unexpected incidents. However, the IC should not be used in applications characterized by continuous operation or transitioning of the protection circuit.

Status of this document

The Japanese version of this document is formal specification. A customer may use this translation version only for a reference to help reading the formal version.

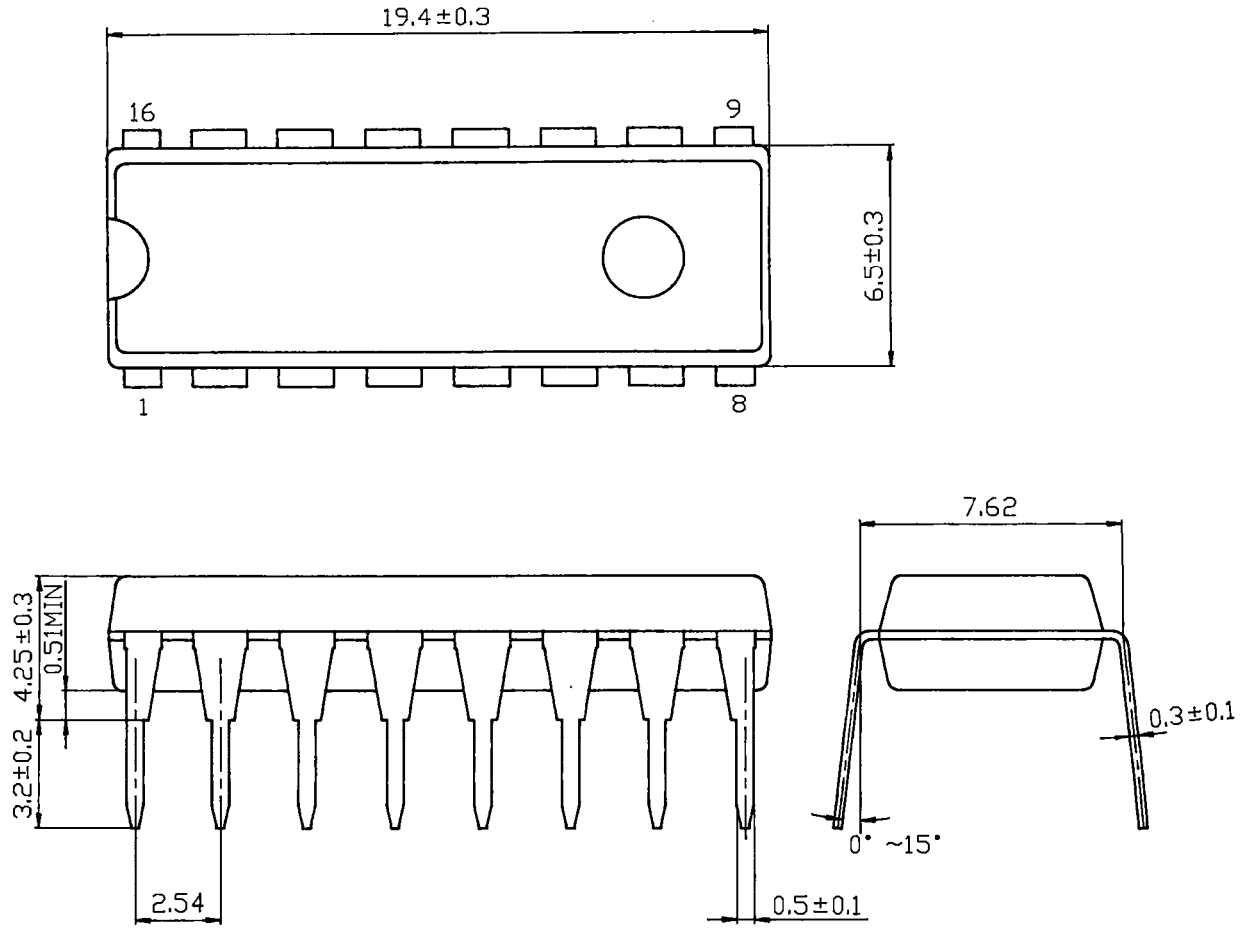
If there are any differences in translation version of this document formal version takes priority

●Ordering Information



●Physical Dimension, Tape and Reel Information

Package Name	DIP-16
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(UNIT : mm)

< Container Information >

Container	Tube
Quantity	1000pcs
Direction of feed	Direction of products is fixed in a container tube

Order quantity needs to be multiple of the minimum quantity.

● Revision History

Date	Revision	Changes
16.Oct.2013	001	New Release