Step-Up Converter for 4 Series White LEDs Driver

Features

- 2.5 V to 6V Input Voltage Range
- 400mA Internal Switch Current
- Up to 1MHz Switching Frequency
- 70µA Typical No Load Quiescent Current
- 0.1µA Typical Shutdown Current
- Internal Soft-Start
- Up to 87% Efficiency
- Operating Output Capacitor Down to 0.1µF
- Over Voltage Protection Included
- Lead Free and Green Devices Available (RoHS Compliant)

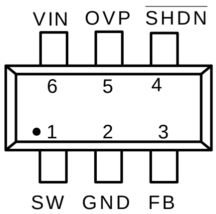
Applications

- Cellar Phones White LED Back Light
- PDAs, Handheld Computers
- Digital Still Cameras
- MP3 Players
- GPS Receivers

General Description

The APW7071 is a high frequency step-up DC/DC converter in a small 6-lead SOT-23 package specially designed to drive white LEDs with a constant current. The device can drive up to 4 LEDs in series from one Li-Ion cell. The APW7071 is ideal for LCD panels requiring low current and high efficiency as well as white LED applications for cellular phone back-lighting.

Pin Configuration



SOT-23-6 (Top View)

Ordering and Marking Information

APW7071□□-□□□ Assembly Material Handling Code Temperature Range Package Code	Package Code C : SOT-23-6 Operating Ambient Temperature Range I : -40 to 85°C Handling Code TR : Tape & Reel Assembly Material L : Lead Free Device G : Halogen and Lead Free Device
APW7071C : W71X	X - Date Code

Note: ANPEC lead-free products contain molding compounds/die attach materials and 100% matte tin plate termination finish; which are fully compliant with RoHS. ANPEC lead-free products meet or exceed the lead-free requirements of IPC/JEDEC J-STD-020C for MSL classification at lead-free peak reflow temperature. ANPEC defines "Green" to mean lead-free (RoHS compliant) and halogen free (Br or Cl does not exceed 900ppm by weight in homogeneous material and total of Br and Cl does not exceed 1500ppm by weight).

Absolute Maximum Ratings (Note 2)

Symbol	Parameter	Rating	Unit
V_{IN}	Input Supply Voltage	-0.3 ~ 7	V
	Voltage on Pins FB, $\overline{SHDN}$	-0.3 ~ V_{IN}+0.3	V
V_{OVP}	Voltage on Pin OVP	-0.3 ~ 20	V
V_{SW}	Switch Voltage on pin SW	-0.3 ~ 21	V
T_J	Junction Temperature Range	-40 ~ 150	°C
T_{STG}	Storage Temperature Range	-65 ~150	°C
T_{SDR}	Maximum Lead Soldering Temperature, 10 Seconds	260	°C

Note 2: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Thermal Characteristics

Symbol	Parameter	Typical Value	Unit
θ_{JA}	Junction-to-Ambient Resistance in Free Air (Note 3)	250	°C/W

Note 3: θ_{JA} is measured with the component mounted on a high effective thermal conductivity test board in free air.

Recommended Operating Conditions (Note 4)

Symbol	Parameter	Value			Unit
		Min.	Typ.	Max.	
V_{IN}	Input Supply Voltage	2.5	-	6.0	V
V_{SW}	Switch Voltage	-	-	20	V
V_{OUT}	Output Voltage	-	-	19	V
L	Inductor	2.2	-	10	µH
C_{IN}	Input Capacitor	4.7	-	-	µF
C_{OUT}	Output Capacitor	0.1	-	1	µF
T_A	Operating Ambient Temperature	-40	-	85	°C
T_J	Operating Junction Temperature	-40	-	125	°C

Note 4: Please refer to Typical Application Circuit

Electrical Characteristics

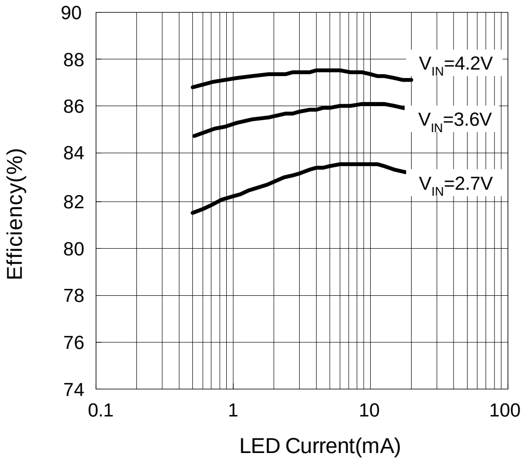
V_{IN}=3.3V, $\overline{SHDN}$=VIN, T_A= -40°C to +85°C, typical values are at T_A=+25°C (unless otherwise noted).

Symbol	Parameter	Test Conditions	APW7071			Unit
			Min.	Typ.	Max.	
SUPPLY VOLTAGE AND CURRENT						
V_{IN}	Input Voltage Range		2.5	-	6	V
I_Q	Operating Quiescent Current	I_{OUT}=0, not switching, V_{FB}=0.3V	-	70	90	μA
I_{Q_SD}	Shutdown Current	$\overline{SHDN}$=GND	-	0.1	1	μA
UVLO	Under-Voltage Lockout Threshold		-	2.2	2.4	V
	Under-Voltage Lockout Hysteresis		-	150	-	mV
ENABLE						
V_{IH}	$\overline{SHDN}$ High Level Input Voltage		1.3	-	-	V
V_{IL}	$\overline{SHDN}$ Low Level Input Voltage		-	-	0.4	V
I_i	$\overline{SHDN}$ Input Leakage Current	$\overline{SHDN}$=GND or VIN	-	0.1	1	μA
POWER SWITCH AND CURRENT LIMIT						
V_{SW}	Maximum Switching Voltage		-	-	20	V
t_{off}	Minimum Off-Time		300	400	550	ns
t_{on}	Maximum On-Time		4	6	7.5	μs
R_{dson}	MOSFET On-Resistance	V_{IN}=2.5V, I_{SW}=200mA	-	600	1000	mΩ
	MOSFET Leakage Current	V_{SW}=19V	-	0.1	1	μA
I_{LIM}	MOSFET Current Limit		350	400	500	mA
OUTPUT						
V_{OUT}	Adjustable Output Voltage Range		V_{IN}	-	19	V
I_{FB}	Feedback Input Bias Current	V_{FB}=1.3V	-	-	100	nA
V_{REF}	Feedback Trip Point Voltage	$2.5 \leqq V_{IN} \leqq 6.0V$	0.237	0.25	0.263	V
	OVP Threshold		16	17	18.5	V
	OVP Hysteresis		3	4	5	V
I_{OVP}	OVP Input Current	V_{OVP}=15V	-	5	10	μA
	OVP Leakage Current	$\overline{SHDN}$=GND, V_{OVP}=6V	-	0.1	1	μA

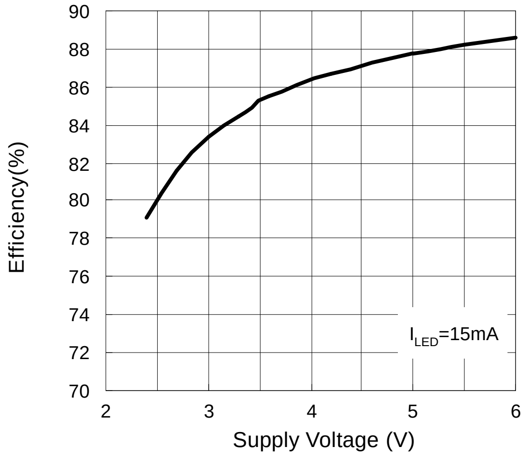
Typical Operating Characteristics

(Circuit of Figure 1, V_{IN} = 3.3V, I_{LED} = 20mA, L1 = 4.7µH, C_{IN} = 4.7µF, C_{OUT} = 0.1µF,4 LEDs, T_A = +25°C, unless otherwise noted.)

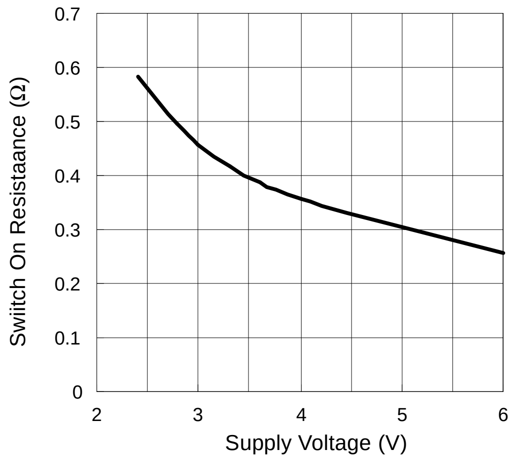
Efficiency vs. LED Current



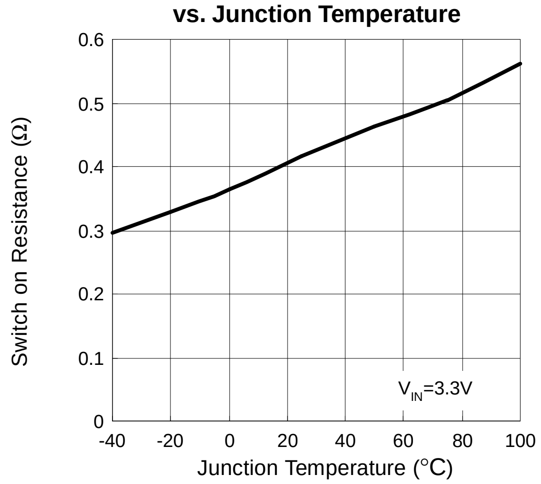
Efficiency vs. Supply Voltage



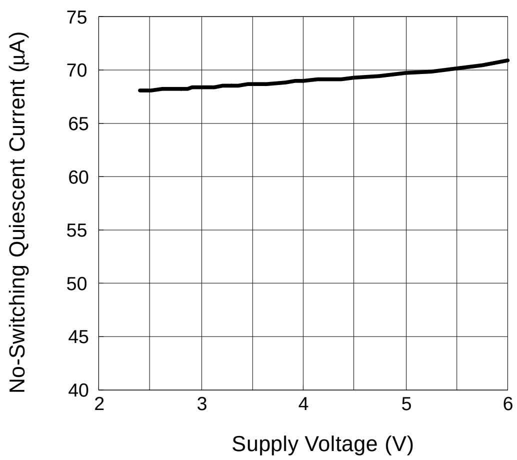
Switch on Resistance vs. Supply Voltage



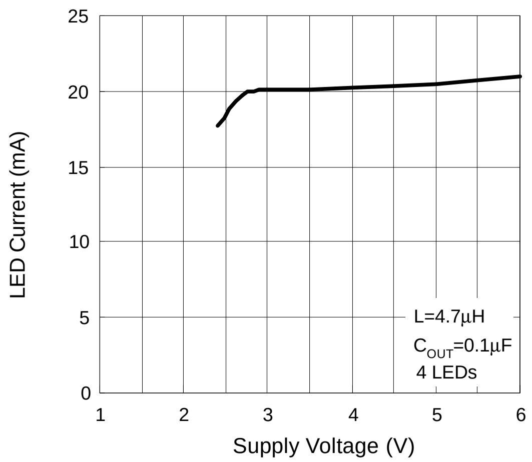
Switch on Resistance vs. Junction Temperature



No-Switching Quiescent Current vs. Supply Voltage



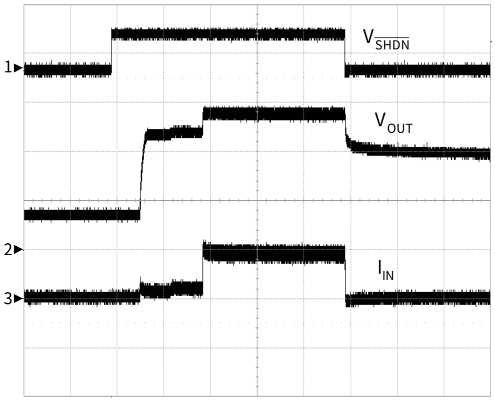
LED Current vs. Supply Voltage



Operating Waveforms

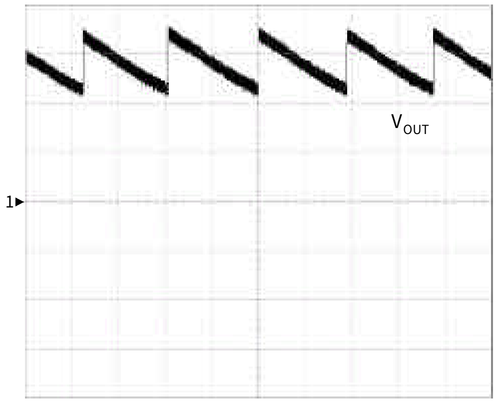
(Circuit of Figure 1, V_{IN} = 3.3V, I_{LED} = 20mA, L1 = 4.7µH, C_{IN} = 4.7µF, C_{OUT} = 0.1µF,4 LEDs, T_A = +25°C, unless otherwise noted.)

Start-up Waveform



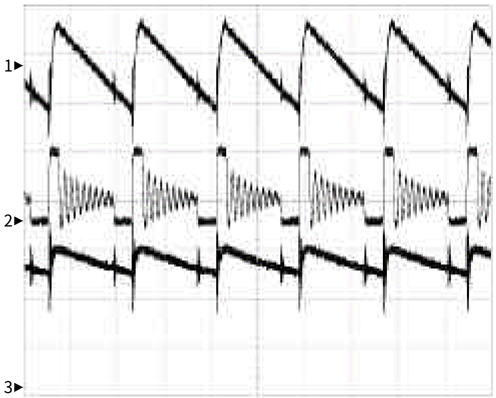
CH1: $V_{\overline{SHDN}}$, 2V/Div, DC
CH2: V_{OUT}, 5V/Div, DC
CH3: I_{IN}, 100mA/Div, DC
Time: 1ms/Div

OVP Waveform



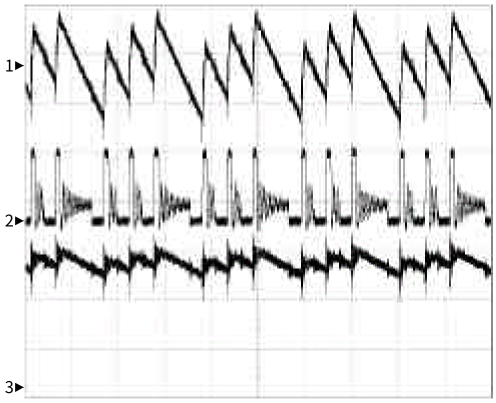
CH1: V_{OUT}, 5V/Div, DC
Time: 20ms/Div

PFM Operation



CH1: V_{OUT}, 200mV/Div, AC
CH2: V_{SW}, 10V/Div, DC
CH3: V_{FB}, 100mA/Div, DC
Time: 1µs/Div

Pulse Burst Operation

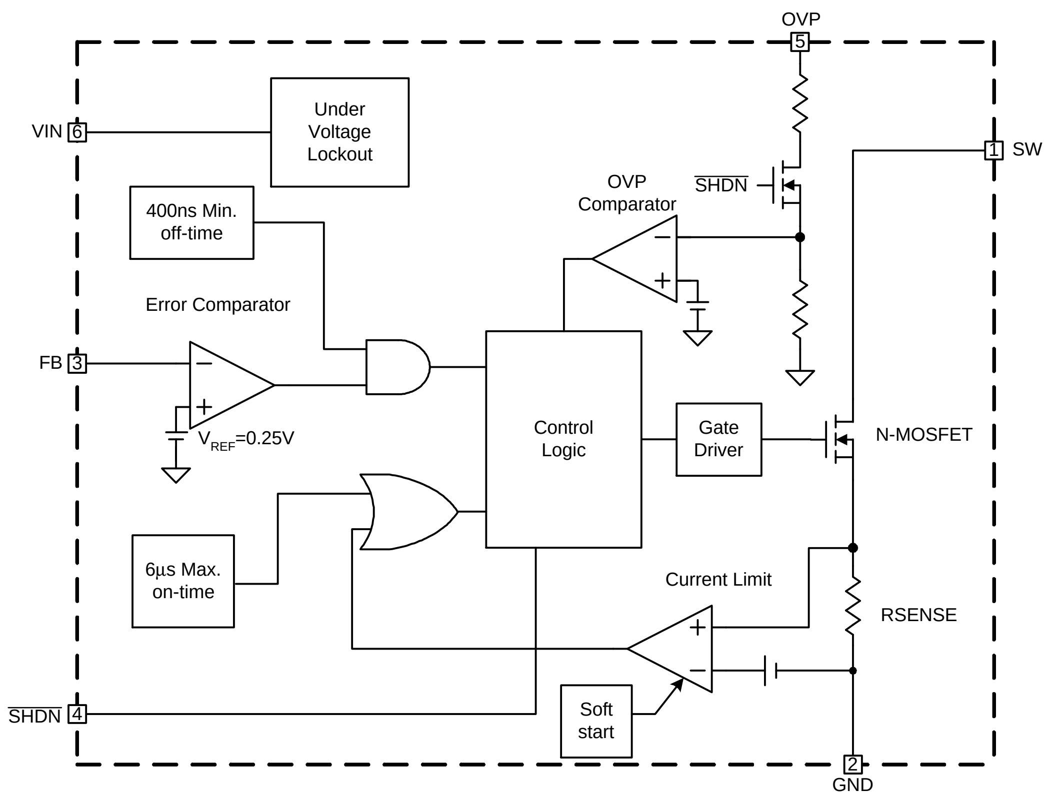


CH1: V_{OUT}, 200mV/Div, AC
CH2: V_{SW}, 10V/Div, DC
CH3: V_{FB}, 100mA/Div, DC
Time: 2µs/Div

Pin Description

NO	NAME	FUNCTION
1	SW	Switch Pin. Connect this pin to inductor/diode here.
2	GND	Ground Pin.
3	FB	Feedback Pin. Reference voltage is 0.25V. Connect this pin to cathode of lowest LED and resistor (R_{FB}). Calculate resistor value according to $R_{FB} = 0.25V/I_{LED}$
4	$\overline{SHDN}$	Shutdown Pin. Pulling this pin to ground forces the device into shutdown mode reducing the supply current to less than 1μA. This pin should not be left floating.
5	OVP	Over voltage protection sense pin. Connect this pin to output capacitor. Left it unconnected to disable OVP function.
6	VIN	Supply voltage Pin.

Block Diagram



Typical Application Circuits

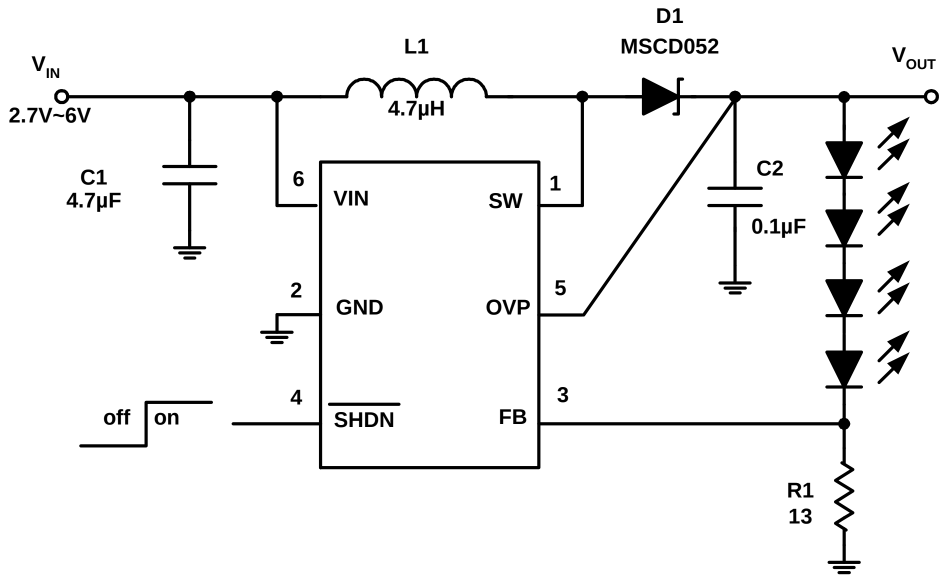


Figure.1 Typical 4 LEDs application

Using one or more output capacitors with larger capacitance like 1µF can reduce the LED ripple current as well as improve line regulation.

Function Description

Operation

The APW7071 operates in a pulse frequency modulation (PFM) scheme with constant peak current control. The operation can be understood by referring to the Block Diagram. The converter keeps monitoring the output voltage through the resistor-divider connected with FB, GND, and V_{OUT}. When the feedback voltage on FB falls below the reference voltage (typical 0.25V), the internal switch turns on and the inductor current ramps up. The switch turns off if the inductor current reaches the internal peak current limit (400mA typical). The second criterion that turns off the switch is the maximum on-time control. As the switch is off, the external Schottky diode forwards bias, so that the current is delivered to the output. The switch remains off for a minimum of 400ns (typical), and it wouldn't be turned on again until the feedback voltage drops below the reference voltage. This regulation scheme allows a wider selection range for the inductor and output capacitor.

Shutdown

Driving $\overline{SHDN}$ to ground places the APW7071 in shutdown. When in shutdown, the internal power MOSFET turns off, all internal circuitry shuts down and the quiescent supply current of VIN reduces to <0.1µA (typical).

Soft-Start

The APW7071 limits this inrush current by increasing the current limit at start-up.

Under Voltage Lockout

Transients cause system damage or failure when powering on or undergoing instantaneous glitches in the supply voltage. Then, the undervoltage lockout circuit turns the main switch off to prevent malfunction at low input voltage.

Over Voltage Protection

In driving LED applications, the feedback voltage on FB pin falls down if one of the LEDs, in series, is failed. Meanwhile, the converter unceasingly boosts the output voltage like a open-loop operation. Therefore, an over-voltage protection (OVP), monitoring the output voltage via OVP pin, is integrated into the chip to prevent the SW and the output voltages from exceeding their maximum voltage ratings. When the voltage on the OVP pin rises above the OVP threshold (17V typical), the converter stops switching and prevents the output voltage from rising. The converter can work again when the OVP voltage falls below the OVP voltage threshold.

Application Information

Setting the LEDs Current

In figure 1, the converter regulates the voltage on FB pin, connected with the cathod of the lowest LED and the current-sense resistor R1, at 0.25V(typical). Therefore, the current (I_{LED}), flowing via the LEDs and the R1, is calculated by the following equation:

$$I_{LED} = \frac{0.25V}{R1}$$

Brightness Control

The brightness of the LEDs is controlled by adjusting the LED current. There are three following recommended methods to adjust the brightness of the LEDs :

a. Using an adjustable DC voltage applied to the R3 is shown in figure. 2.

In figure 2, an additional network (R2 and R3) is connected between the FB, the junction of the LED cathode and R1. An adjustable DC voltage (V_{ADJ}), connected with R3, injects a constant current (I1, $I1=(V_{ADJ}-0.25V)/R3$) into the FB node when the FB voltage is regulated at 0.25V. Therefore, the voltage across R1 is reduced by the offset voltage (I1xR2), reducing the LED current and brightness. The LED current is calculated by the following equation:

$$I_{LED} = \frac{0.25V - \frac{R2}{R3} \times (V_{ADJ} - 0.25)}{R1}$$

With the V_{ADJ} from 0V to 3.3V, the LED current can be controlled from 0mA to 20mA.

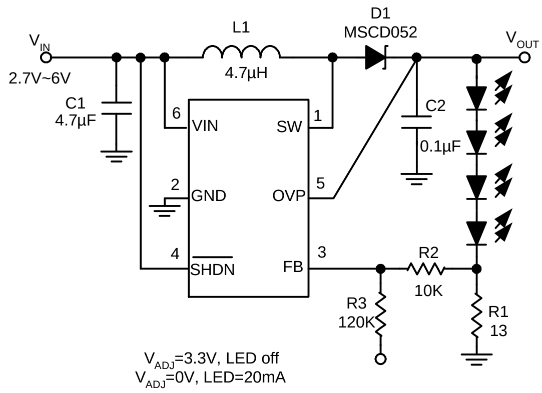


Figure. 2 Brightness Control by an adjustable DC voltage

b. Using a PWM signal to apply to $\overline{\text{SHDN}}$

An external PWM signal applied to $\overline{\text{SHDN}}$ pin cyclically turns on or off the converter. The average current through the LEDs will increase proportionally to the duty cycle of the PWM signal. Due to the soft-start duration, the PWM signal with frequency from 100Hz to 300Hz is recommended.

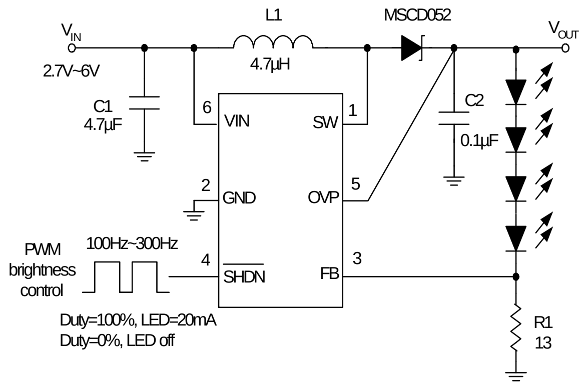


Figure. 3 Brightness Control by applying a PWM signal to $\overline{\text{SHDN}}$

c. Using a filtered PWM signal

In figure. 4, the brightness control can be achieved by applying a PWM signal to an RC filter (R4 and C3) to generate a filtered PWM signal instead of the V_{ADJ}. The PWM signal with frequency above 5kHz is recommended.

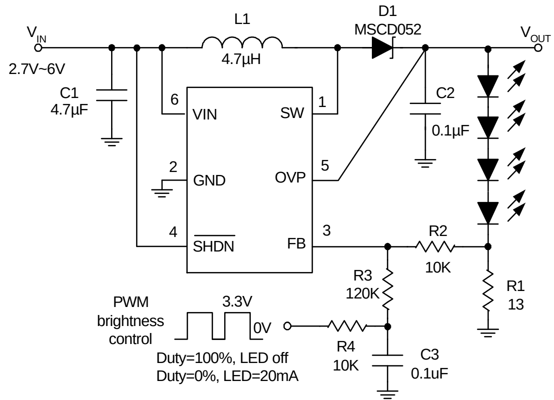


Figure. 4 Brightness Control by a filtered PWM signal

Inductor Selection

The inductor together with the load current (I_{OUT}), internal peak current (I_{PK}), input (V_{IN}) and output voltage (V_{OUT}) of the application determines the switching frequency of the

Application Information (Cont.)

Inductor Selection (Cont.)

converter. The switching frequency is calculated as:

$$F_{SW} = \frac{2 \cdot I_{OUT} \cdot (V_{OUT} - V_{IN} + V_F)}{L \cdot I_{PK}^2}$$

where

V_F is the foward voltage of the Schottky diode.

A smaller inductor gets higher switching frequency but lower efficiency. To operate under discontinuous conduction mode, the inductor can be selected as below:

$$L \leq \frac{T_{OFF,MIN} \cdot (V_{OUT} + V_F - V_{IN})}{I_{PK}}$$

For the white LED applications, the inductor values between 2.2 μH and 10 μH are recommended.
The inductor also affects the maximum output power. The maximum output current is calculated as:

$$I_{OUT,MAX} = \frac{V_{IN}}{V_{OUT}} \cdot I_{IN,AVG} \cdot \eta = \frac{V_{IN}}{V_{OUT}} \cdot \frac{1}{2} \cdot I_{PK} \cdot \frac{T_{ON} + T_{OFF}}{T_S} \cdot \eta$$

where

$$T_{ON} = \frac{L \cdot I_{PK}}{V_{IN}}$$

$$T_{OFF} = \frac{L \cdot I_{PK}}{V_{OUT} - V_{IN} + V_F}$$

$$T_S = T_{ON} + T_{OFF,MIN} = T_{ON} + 0.4\mu s \text{ (typical)}$$

It can be understood by the following figure.

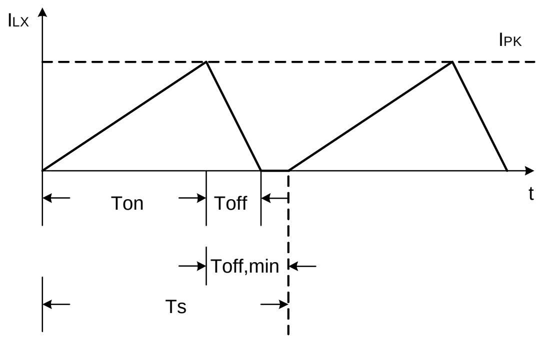


Figure.5 Discontinuous Conduction Mode Operation Waveform

The efficiency can be estimated by the section of "Typical Operating Characteristics".

Recommended inductors

Part No.	Value (mH)	Vendor
LQH31CN2R2M03L	2.2	Murata
LQH32CN4R7M23L	4.7	Murata
SH30184R7YSB	4.7	ABC
LQH32CN100K53L	10	Murata
SH3018100YSB	10	ABC

Output capacitor selection

For better output voltage filtering, a low ESR output capacitor like ceramic capacitors is recommended. The selection of the output capacitance directly influences the output voltage ripple of the converter. The output voltage ripple is calculated as:

$$\Delta V_{OUT} = \frac{1}{C} \cdot \frac{L \cdot I_{PK}}{V_{OUT} - V_{IN} + V_F} \cdot \left(\frac{1}{2} I_{PK} - I_{OUT}\right)$$

In white LED applications, the output ripple is proportional to the LED current. A proper output capacitor from 0.1μF to 1μF is recommended to limit the maximum current ripple of the LED current.

Recommended output capacitor

Part No.	Value	Vender
GRM188R61E105KA12	1.0μF/X5R/0603/25V	Murata
Any	0.22μF	Any
Any	0.1μF	Any

Input capacitor selection

For good input voltage filtering, low ESR ceramic capacitors are recommended. A 4.7μF ceramic input capacitor is sufficient for most applications. For better-input voltage filtering the capacitor value can be increased.

Recommended input capacitor

Part No.	Value	Vender
GRM188R60J475KE19D	4.7μF/X5R/0603/6.3V	Murata
GRM219R60J106KE19D	10μF/X5R/0805/6.3V	Murata

Diode selection

To achieve high efficiency, a Schottky diode must be used. The current rating of the diode must meet the peak current rating of the converter.

Application Information (Cont.)

Diode selection (Cont.)

Recommended diode

Part No.	Reverse Voltage	Vender
MSCD052	20	Zowie

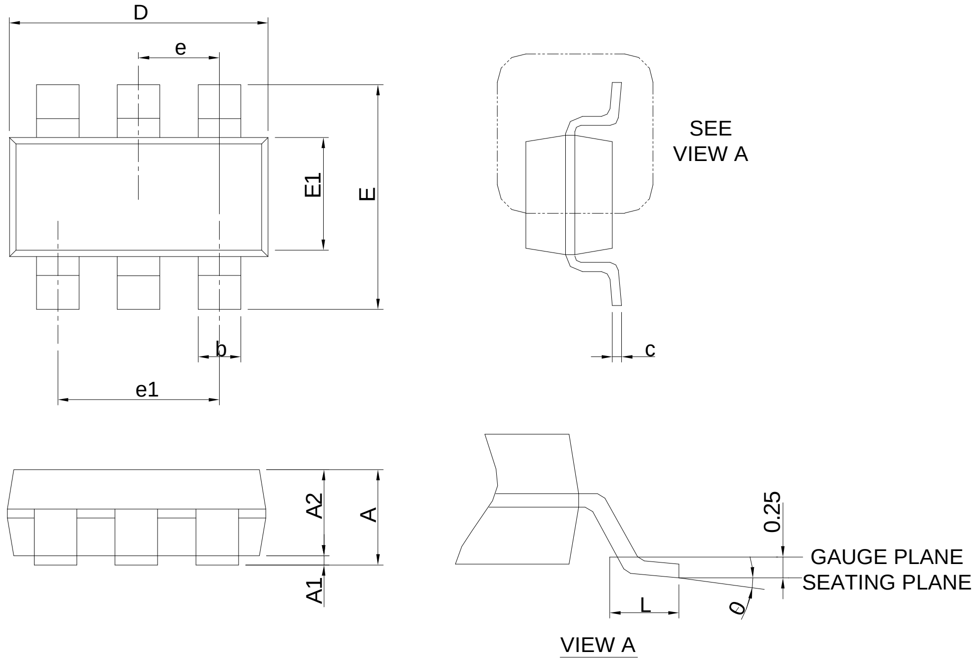
Layout consideration

For all switching power supplies especially with high peak currents and switching frequency, the layout is an important step in the design. If the layout is not carefully done, the regulator may show noise problems and duty cycle jitter.

1. The input capacitor must be placed close to the device, which can reduce copper trace resistance and effect input ripple of the IC .
2. The inductor and diode should be placed as close as possible to the switch pin to minimize the switching noise.
3. The feedback pin and feedback network should be far away from the inductor and shielded by a ground plane or trace to minimize the noise.

Package Information

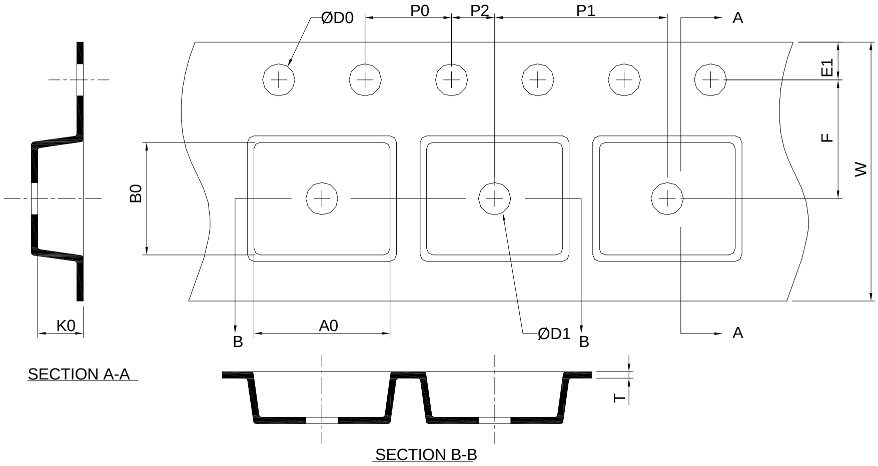
SOT-23-6

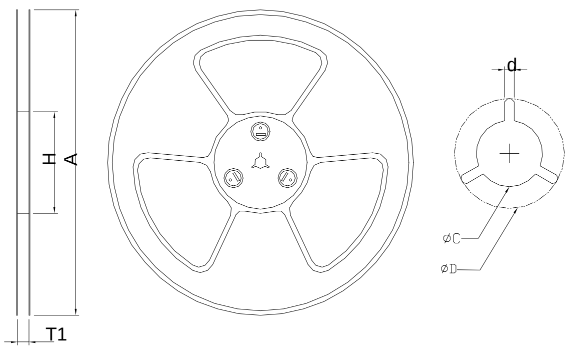


SYMBOL	SOT-23-6			
	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
A		1.45		0.057
A1	0.00	0.15	0.000	0.006
A2	0.90	1.30	0.035	0.051
b	0.30	0.50	0.012	0.020
c	0.08	0.22	0.003	0.009
D	2.70	3.10	0.106	0.122
E	2.60	3.00	0.102	0.118
E1	1.40	1.80	0.055	0.071
e	0.95 BSC		0.037 BSC	
e1	1.90 BSC		0.075 BSC	
L	0.30	0.60	0.012	0.024
θ	0°	8°	0°	8°

Note : 1. Follow JEDEC TO-178 AB.
2. Dimension D and E1 do not include mold flash, protrusions or gate burrs. Mold flash, protrusion or gate burrs shall not exceed 10 mil per side.

Carrier Tape & Reel Dimensions





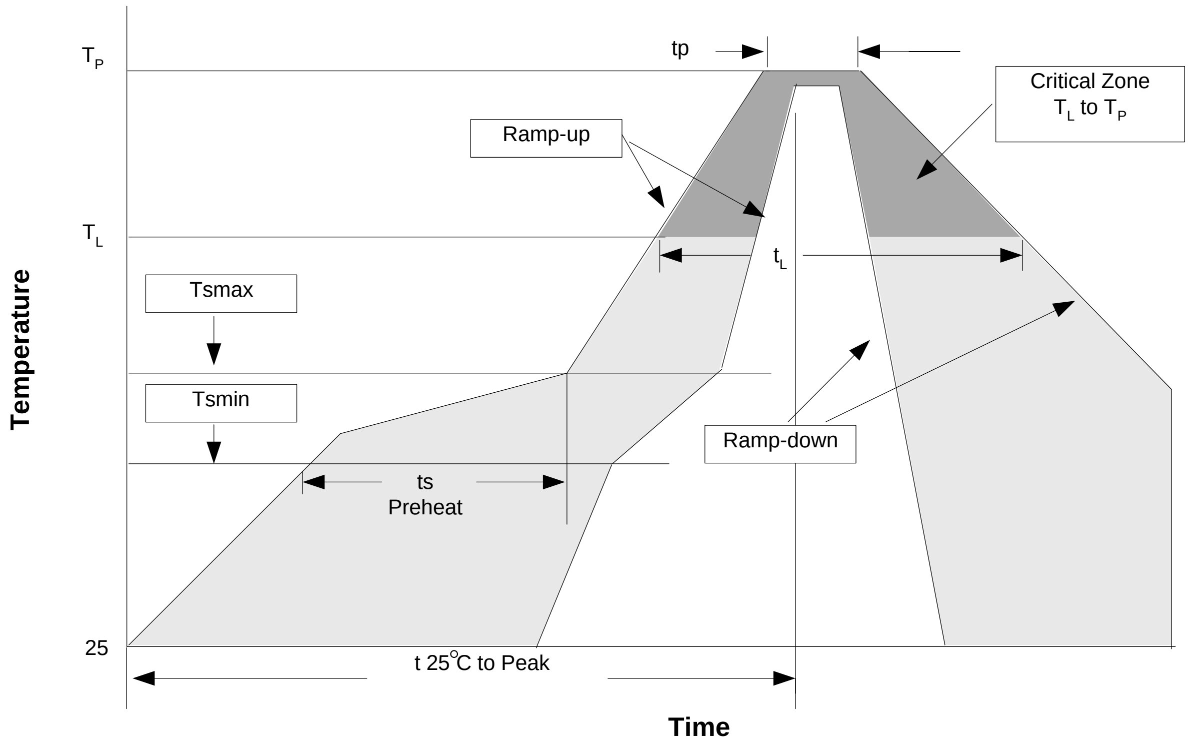
Application	A	H	T1	C	d	D	W	E1	F
SOT-23-6	178.0±2.00	50 MIN.	8.4+2.00 -0.00	13.0+0.50 -0.20	1.5 MIN.	20.2 MIN.	8.0±0.30	1.75±0.10	3.5±0.05
	P0	**P1**	**P2**	**D0**	**D1**	**T**	**A0**	**B0**	**K0**
	4.0±0.10	4.0±0.10	2.0±0.05	1.5+0.10 -0.00	1.0 MIN.	0.6+0.00 -0.40	3.20±0.20	3.10±0.20	1.50±0.20

(mm)

Cover Tape Dimensions

Package Type	Unit	Quantity
SOT-23-6	Tape & Reel	3000

Reflow Condition (IR/Convection or VPR Reflow)



Reliability Test Program

Test item	Method	Description
SOLDERABILITY	MIL-STD-883D-2003	245°C, 5 sec
HOLT	MIL-STD-883D-1005.7	1000 Hrs Bias @125°C
PCT	JESD-22-B, A102	168 Hrs, 100%RH, 121°C
TST	MIL-STD-883D-1011.9	-65°C~150°C, 200 Cycles
ESD	MIL-STD-883D-3015.7	VHBM > 2KV, VMM > 200V
Latch-Up	JESD 78	10ms, 1_{tr} > 100mA

Classification Reflow Profiles

Profile Feature	Sn-Pb Eutectic Assembly	Pb-Free Assembly
Average ramp-up rate (T_L to T_P)	3°C/second max.	3°C/second max.
Preheat - Temperature Min (Tsmin) - Temperature Max (Tsmax) - Time (min to max) (ts)	100°C 150°C 60-120 seconds	150°C 200°C 60-180 seconds
Time maintained above: - Temperature (T_L) - Time (t_L)	183°C 60-150 seconds	217°C 60-150 seconds
Peak/Classification Temperature (Tp)	See table 1	See table 2
Time within 5°C of actual Peak Temperature (tp)	10-30 seconds	20-40 seconds
Ramp-down Rate	6°C/second max.	6°C/second max.
Time 25°C to Peak Temperature	6 minutes max.	8 minutes max.

Notes: All temperatures refer to topside of the package. Measured on the body surface.

Classification Reflow Profiles (Cont.)

Table 1. SnPb Eutectic Process – Package Peak Reflow Temperatures

Package Thickness	Volume mm^3 <350	Volume mm^3 ^{3}350
<2.5 mm	240 +0/-5°C	225 +0/-5°C
≥2.5 mm	225 +0/-5°C	225 +0/-5°C

Table 2. Pb-free Process – Package Classification Reflow Temperatures

Package Thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
<1.6 mm	260 +0°C*	260 +0°C*	260 +0°C*
1.6 mm – 2.5 mm	260 +0°C*	250 +0°C*	245 +0°C*
≥2.5 mm	250 +0°C*	245 +0°C*	245 +0°C*

* Tolerance: The device manufacturer/supplier **shall** assure process compatibility up to and including the stated classification temperature (this means Peak reflow temperature +0°C. For example 260°C+0°C) at the rated MSL level.

Customer Service

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