AP2071AEN

High Current (8A) white LEDs driver for Flash with I^2C

1. General Description

The AP2071AEN is a white LED driver IC for camera flash, using EDLC (Electronic Double Layer Capacitor) in portable equipment. The AP2071AEN integrates a current mode synchronous boost DC-DC converter and four maximum 2A current sources (maximum 8.0A total). The internal boost DC-DC converter integrates a switching FET and synchronous rectifier, and supporting small size multilayer inductor with 2MHz switching frequency. An integrated EDLC voltage control circuit and a charge current control circuit makes the AP2071AEN most suitable for EDLC charge systems. The AP2071AEN also includes eight protections that are an under voltage lock out, EDLC cell short/open protection, thermal detection, LED open/short detection, LED thermal protection, output-ground short protection, inductor current limitation and flashing time limitation to avoid significant system problems. Flash current, torch current, charge current, inductor limit current, flash on-time and EDLC full charge voltage are programmable through I^2C interface. The AP2071AEN is housed in a small size package (24-pin QFN, 4.0mm x 4.0mm) to utilize less board space.

2. Features

- Power Supply Voltage(VIN): 2.5V~5.5V
- LED Current: max 8.0A, total (max 2.0A/ch)
- High Efficiency:
  - 90% @ VIN pin=3.7V, VOUT pin=4.5V, total LED current= 240mA, Torch mode, with recommended external parts
- Switching Frequency: 2.0 MHz
- Mode:
  - Charge (charge to EDLC)
  - Flash
  - Torch
  - Bypass torch (Boost circuit off, only drive LEDs with fixed current source)
  - Discharge
- I^2C Function:
  - Flash/Torch LED current setting (Each channel can be set independently)
  - Flashing ON-time setting
  - Charge current setting
  - Current Limit value setting
  - Full charge voltage setting (EDLC)
  - Discharge finishing voltage setting (EDLC)
  - NTC voltage detection voltage setting
- Protection Function:
  - UVLO (Under Voltage Lock Out) protection
  - EDLC cell short/open protection
  - Thermal protection
  - LED Open/Short protection
  - LED thermal protection
  - Output-GND protection
  - Inductor current limitation protection
  - Flashing time limitation protection
- Ta: -30 to 85°C
- Package: 24-pinUQFN (4.0 x 4.0mm, 0.5mm pitch)

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4. Block Diagram

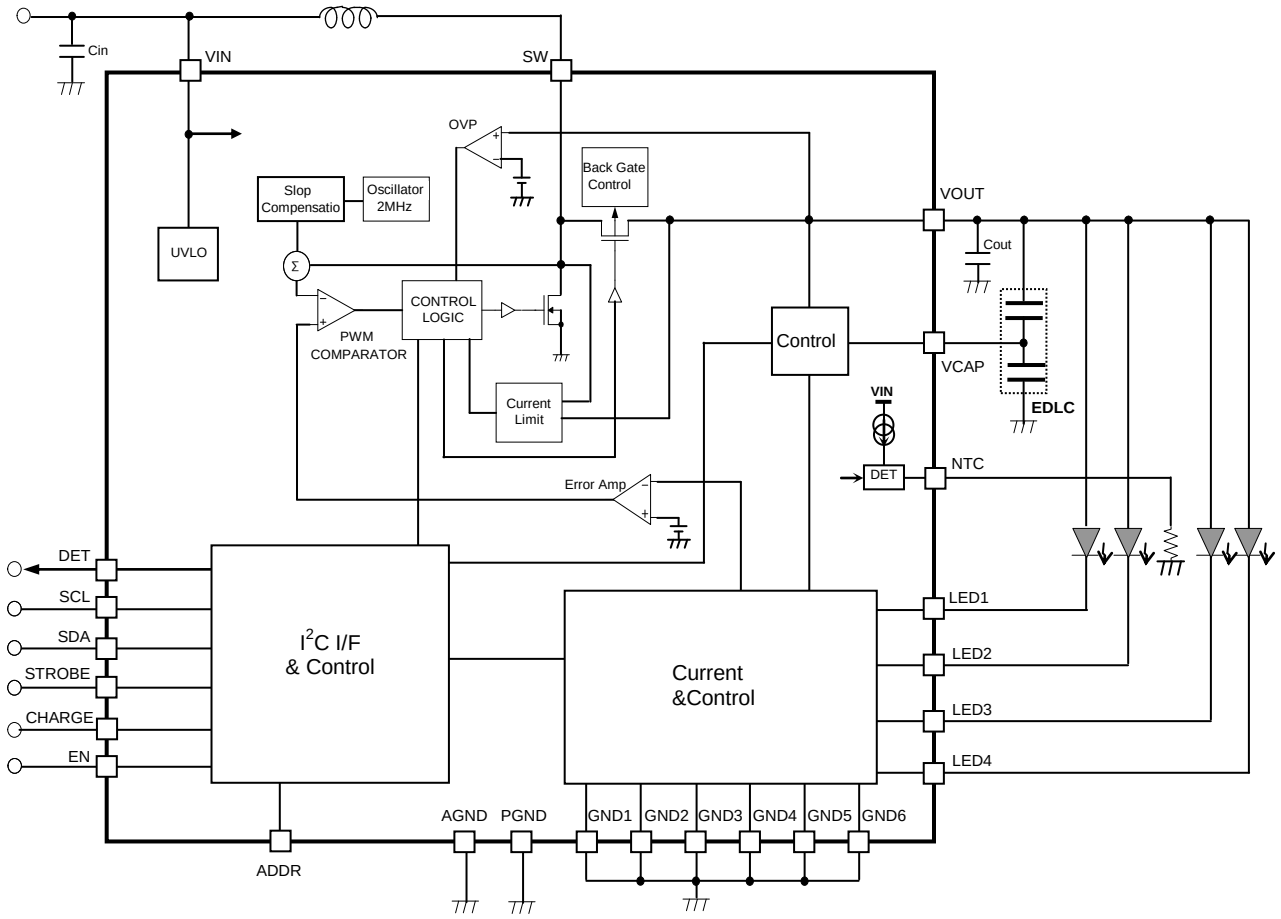


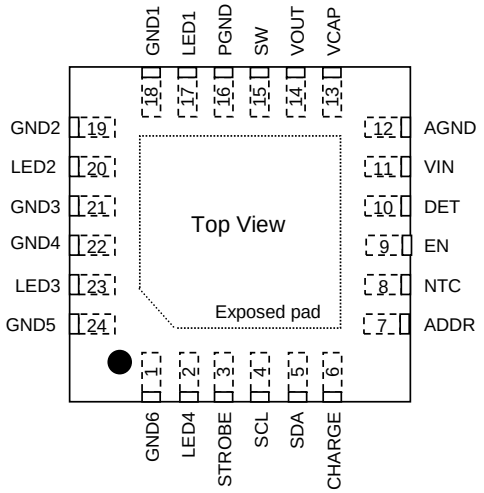
Figure 1. AP2071AEN Block Diagram

5. Pin Configurations and Functions

■ Ordering Guide

AP2071AEN –30 to 85°C 24-pin QFN

■ Pin Configurations



■ PIN Functions

No.	Pin Name	I/O	Function
1,18,19, 21,22,24	GND1-6	-	Ground for current sources
2	LED4	I	Connect to Flash/Torch LED pin4 (This pin must be open when not used)
3	STROBE	I	Flashing control input pin
4	SCL	I	I^2C clock input pin
5	SDA	I/O	I^2C data input pin
6	CHARGE	I	EDLC charge pin 0: charge stop (DC-DC convert is stopped too) 1: charge (Connect this pin to GND when not used)
7	ADDR	I	Chip address LSB bit Low: "0"; High: chip address= "1"
8	NTC	I/O	Connect to NTC resistor (Connect this pin to GND when not used)
9	EN	I	Enable pin
10	DET	O	EDLC full charge voltage detection pin (Open drain)
11	VIN	I	Connect to battery
12	AGND	-	Ground for Analog circuit
13	VCAP	O	EDLC voltage protection pin
14	VOUT	O	Voltage output pin
15	SW	I	Connect to coil
16	PGND	-	Ground for DC-DC
17	LED1	I	Connect to Flash/Torch LED pin1 (This pin must be open when not used)
20	LED2	I	Connect to Flash/Torch LED pin2 (This pin must be open when not used)
23	LED3	I	Connect to Flash/Torch LED pin3 (This pin must be open when not used)

6. Absolute Maximum Ratings

(AGND=PGND=GND1~6=0V; (Note 1))

Parameter	Symbol	min	max	Unit
VIN, SW, VOUT, LED1, LED2, LED3, LED4, NTC and VCAP pins	V_{IN1}	−0.3	6.5	V
DET, EN, STROBE, CHARGE, SCL, SDA and ADDR pins (Note 2)	V_{IN2}	−0.3	VIN + 0.3	V
Junction Temperature	T_J	-	125	°C
Storage Temperature	T_{STG}	−55	150	°C
Maximum Power Dissipation (Note 3)	P_D		2.5	W

Note 1. All voltage is respect to ground. All ground should be connecting to same ground.

Note 2. The maximum value is a lower value either 6.5V or VIN+0.3V.

Note 3. Measured by recommended foot pattern; Size: 50 x 40mm x 1.0mm, 2 layered board (metal densities of top layer: 80%, metal densities of bottom layer: 80%). This value is reduced by 25mW/°C when the temperature is more than 25°C (Ta≥25°). The thermal resistance is 40°C/W
The value is internal dissipation of the AP2071AEN that does not include power dissipation of external parts.
"Exposed PAD" must be connected to ground.

Note: Since the actual thermal resistance is much dependent on the board layout and the thermal design, make sure that the junction temperature of the IC will not exceed 125°C by the system design.

WARNING: Operation at or beyond these limits may result in permanent damage to the device.
Normal operation is guaranteed at these extremes.

7. Recommended Operating Conditions

(AGND=PGND=GND1~6=0V; (Note 1))

Parameter	Symbol	min	typ	max	Unit
Input Voltage (VIN)	Vbatt	2.5	3.7	5.5	V
SCL, SDA, STROBE, CHARGE, EN, ADDR pins	V_{INPUT}	1.2		VIN	V
Operation Temperature	Ta	-30	25	85	°C

8. Electrical Characteristics

(AGND=PGND=GND1~6=0V ;(Note 1), VIN=3.7V, Ta=25°C, Recommend Parts, unless otherwise specified)

Parameter	Symbol	min	typ	max	Unit	Conditions
Power-down Current	I_{PD}		0.5	2.0	μA	EN= "L" VOUT=0V
Quiescent Current in VIN pin	I_Q		1.0	1.5	mA	I_{LEDn}= 0mA VOUT= 5.0V
VOUT Detection Voltage Accuracy1	A_{VOUT1}	-1.6		1.6	%	VSET[2:0]= "101", "110"
VOUT Detection Voltage Accuracy2	A_{VOUT2}	-3.0		3.0	%	VSET[2:0]= "101", "110" VIN=2.5~5.5V Ta= -30~85°C
VOUT Detection Voltage Accuracy3	A_{VOUT3}	-3.5		3.5	%	VSET[2:0]= "001", "010", "011", "100", "101", "111" VIN=2.5~5.5V Ta= -30~85°C
LED pins Voltage1 (Flash mode)	V_{LED1}		0.30	0.45	V	I_{LEDn} = 2A/ch
LED pins Voltage2 (Torch mode)	V_{LED2}		0.50	0.60	V	I_{LEDn} = 0.24A/4ch
LED Current Accuracy1 (flash)	A_{LEDC1}	-10		10	%	I_{LEDn} = 1.6~2A/ch V_{LEDn}= 0.5V
LED Current Accuracy2 (flash)	A_{LEDC2}	-12		12	%	I_{LEDn} = 1.6~2A/ch V_{LEDn} = 0.6~2.2V VIN= 2.5~5.5V Ta= -30~85°C
LED Current Accuracy3 (flash)	A_{LEDC3}	-18		18	%	$I_{LEDn} \leqq$1.4A/ch V_{LEDn} = 0.6~2.2V VIN= 2.5~5.5V Ta= -30~85°C
LED Current Accuracy4 (torch)	A_{LEDC4}	-15		15	%	V_{LEDn} = 0.4~0.7V
LED Current Accuracy5 (torch)	A_{LEDC5}	-20		20	%	V_{LEDn} = 0.4~0.7V VIN= 2.5~5.5V Ta= -30~85°C
Charger Current Accuracy	A_{CHAR}	-10		10	%	VOUT>1.0V
Maximum Limit Current	I_{MAXL}	1200	1500	1800	mA	VOUT=4.5V
Efficiency (Note 4) (Torch mode)	Effi		90		%	I_{LEDn} = 0.24A VOUT=4.5V
Under Voltage Lock Out	$V_{IN,LOW}$	2.2	2.3	2.4	V	
Boost Frequency1	F_{BOOST1}	1.5	2.0	2.2	MHz	
Boost Frequency2	F_{BOOST2}	1.4	2.0	2.3	MHz	VIN= 2.5~5.5V Ta= -30~85°C
Flash Timer Accuracy	A_{Timer}	-15		30	%	VIN= 2.5~5.5V Ta= -30~85°C
NTC Detection Voltage Accuracy	Vdet	-6		6	%	
NTC Current	Vcurr	33	35	37	μA	
VCAP pin Maximum Output Current (source)	$I_{MAXVCAPS}$	100	200	300	mA	VOUT= 5.0V VCAP= 2.3V
VCAP pin Maximum Output Current (sink)	$I_{MAXVCAPS}$	100	200	300	mA	VOUT= 5.0V VCAP= 2.7V
Thermal Protection Temperature	Treg	120	140		°C	
Discharge Impedance	R_{DISC}	51	68	85	Ω	

Note 4. Efficiency= $VOUT \times I_{LED} / (VIN \times I_{IN}) \times 100$

■ Input Logic Characteristics

(Ta= -30 ~ 85°C; VIN=2.6 ~ 5.5V), SCL, SDA, STROBE, CHARGE, EN, ADDR pins.

Parameter	Symbol	min	typ	max	Unit
High-Level Input Voltage	VIH	1.2	-	VIN	V
Low-Level Input Voltage	VIL	-	-	0.4	V
High-Level Output Voltage (SDA pin, Iout= -80μA)	VOH	1.4	-	-	V
Low-Level Output Voltage (SDA pin, Iout= 3mA)	VOL	-	-	0.4	V
Input Leakage Current (SCL, SDA, DET pins)	Iin1	-2	-	+2	μA
Pull-down Resistance (STROBE, CHARGE, EN pins)	R_{IN}	200	400	700	kΩ
Control Interface Timing:					
SCL Clock Frequency	FSCL	-	-	400	kHz
Bus Free Time Between Transmissions	tBUF	1.3	-	-	μs
Start Condition Hold Time (prior to first clock pulse)	tHD:STA	0.6	-	-	μs
Clock Low Time	tLOW	1.3	-	-	μs
Clock High Time	tHIGH	0.6	-	-	μs
Setup Time for Repeated Start Condition	tSU:STA	0.6	-	-	μs
SDA Hold Time from SCL Falling (Note 5)	tHD:DAT	0		-	μs
SDA Setup Time from SCL Rising	tSU:DAT	0.1	-	-	μs
Rise Time of Both SDA and SCL Lines	tR	-	-	0.3	μs
Fall Time of Both SDA and SCL Lines	tF	-	-	0.3	μs
Setup Time for Stop Condition	tSU:STO	0.6	-	-	μs
Capacitive load on bus	Cb	-		400	pF
Pulse Width of Spike Noise Suppressed by Input Filter	tSP	0	-	50	ns
Power-down & Reset Timing					
EN Pulse Width (Note 6)	tPD	300	-	-	ns

Note 5. Data must be held long enough to bridge the 300ns transition time of SCL.
Note 6. The AP2071AEN can be reset by holding the EN pin= "L" upon power-up.

■ Timing Diagram

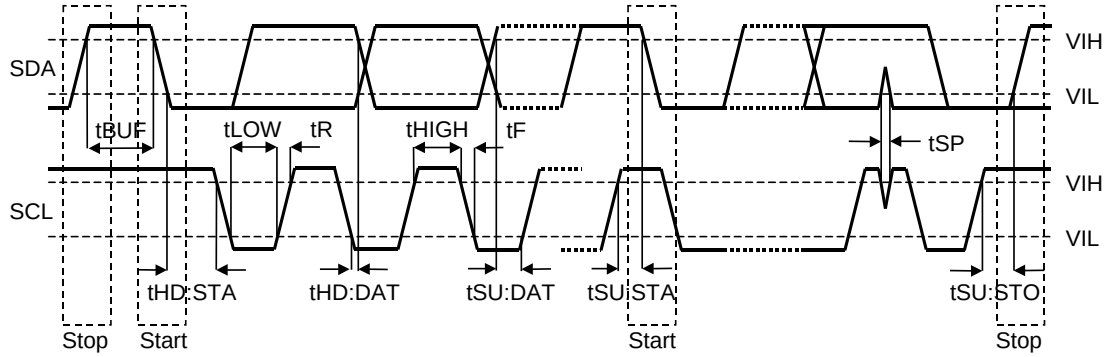


Figure 2. I²C Bus Mode Timing

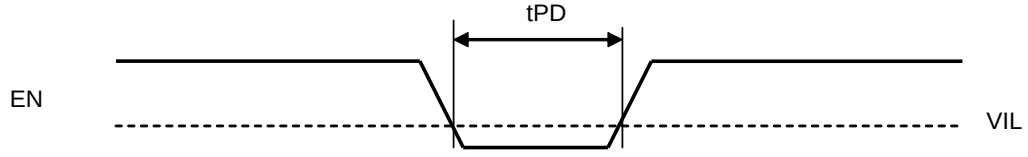


Figure 3. Enable & Reset Timing

9. Functional Descriptions

The AP2071AEN integrates a boost DC-DC converter which integrates a switching FET and a synchronous rectifier, supporting small size multilayer inductor with 2MHz switching frequency. The AP2071AEN has four current sources to control the LED current which connected to LED1, LED2, LED3, LED4 pins. The AP2071AEN supports five operation modes (Charge, Flash, Torch, Bypass torch and Discharge).

Mode	Function	Register Setting	Explanation
Mode 1	Charger Mode	CHAR bit= "1" FLASH bit= "0" TORCH bit= "0" DISCH[1:0]= "00"	Charge EDLC.
Mode 2	Flash Mode	FLASH bit= "1" TORCH bit= "0" DISCH[1:0]= "00"	Drive LED with flashing setting current.
Mode 3	Torch Mode	CHAR bit= "1" FLASH bit= "0" TORCH bit= "1" DISCH[1:0]= "00"	Drive LED with torching setting current and the DC-DC boost circuit operating.
Mode 4	Bypass Torch Mode	CHAR bit= "1" FLASH bit= "0" TORCH bit= "1" DISCH[1:0]= "00" VSET[2:0]= "000"	Drive LED with torching setting current and the DC-DC boost circuit not operating.
Mode 5	Discharger Mode	DISCH[1:0]= "01" or "10"	Discharge EDLC until the setting voltage through 68Ω which connected to GND.

■ Charging Sequence

The AP2071AEN is changed to charge mode by setting the CHARGE pin to “H” or CHAR bit to “1” if EN pin= “H”. In this mode, an external EDLC will be charged with the default setting. Register settings are available during this charging period. When VOUT pin reach setting voltage, DET pin (external pull-down) will change from “H” to “L”.

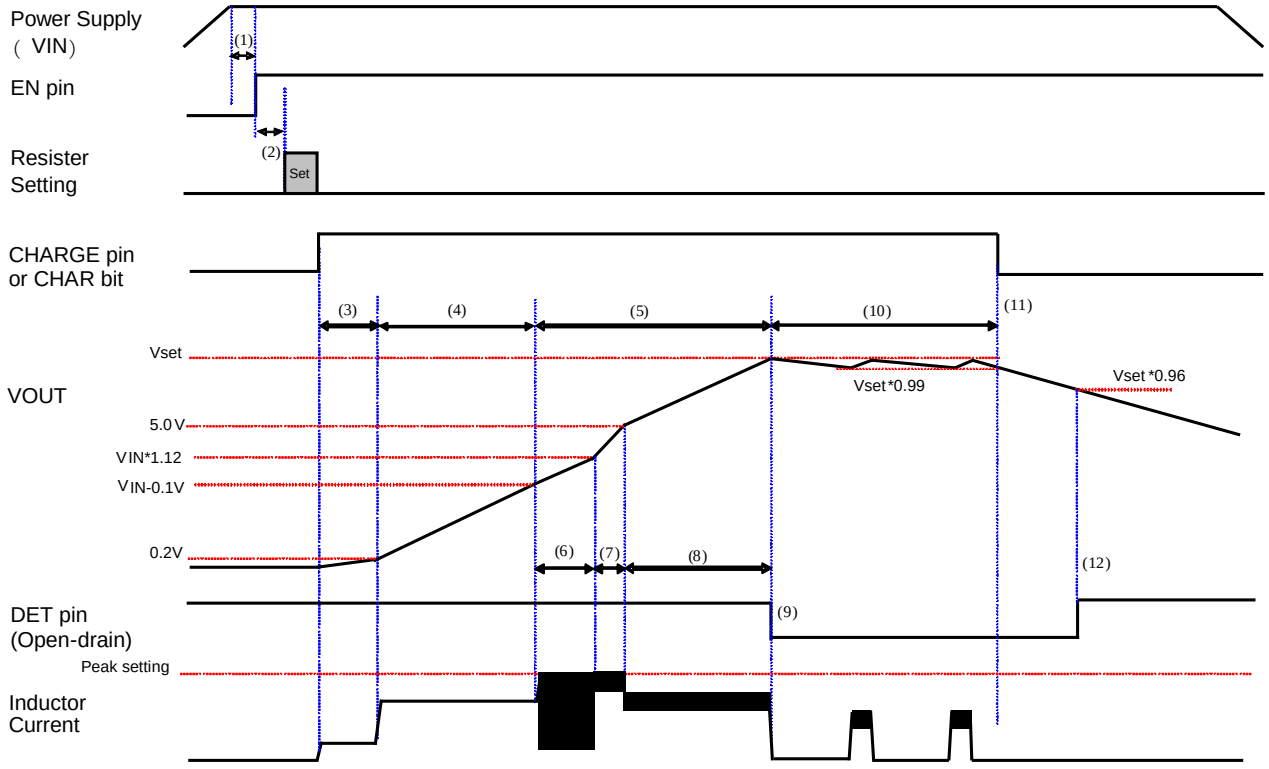


Figure 4. Recommend sequence in case of charge mode

(1) The power must be supplied when the EN pin = “L”. After the power is supplied (VIN≥2.5V), the EN pin can be set from “L” to “H”. In this case, the EN pin should be held to “L” longer than 300ns to reset the AP2071AEN.
(2) Set registers 1ms after the EN pin is set from “L” to “H”.
(3) When the CHARGE pin is set to “H” or CHAR bit is set to “1”, the EDLC will be charged with 200mA until the VOUT pin = 0.2V.
(4) When the VOUT reaches 0.2V, EDLC will be charged with setting current which set by CHAR[1:0] bits.
(5) When the VOUT reaches (VIN-0.1V), internal DC-DC will start operating, and the EDLC will be charged with a maximum inductor peak current which is set by CLIMIT[2:0] bits.
(6) When the VOUT is in the range of (VIN-0.1V) ~ (VIN*120%), the EDLC is changed by PFM control.
(7) When the VOUT is more than 120% of VIN (VOUT > VIN*120%), the EDLC is charged by PWM control.
(8) When the VOUT reaches 5.0V, the EDLC is charged with the setting maximum inductor peak current by LIMIT2-0 bits except the cases shown below.
When LIMITSEL= “0”, the inductor peak current is limit to 500mA.
When LIMITSEL= “1”, the inductor peak current is limit to 1000mA.
(9) When the VOUT reaches the setting voltage (VSET[2:0] bits), the DET pin will changed from “H” to “L”.
(10) When the VOUT reaches the setting voltage (VSET[2:0] bits), the charging circuit will be powered down. In this period, an EDLC is discharged by 100μA by internal circuits, and it is charged again when the VOUT drops to 99% of the setting voltage.
(11) When the CHARGE pin is set to “L” and CHAR bit is set to “0”, charge circuit and DC-DC circuit are powered down. Even if the VOUT drops to the value lower than 99% of the setting voltage,
(12) When the VOUT reaches 96% of the setting voltage (VSET[2:0] bits), the DET pin will change from “L” to “H”.

■ Flashing Sequence

The LED current is supplied from an external EDLC via the VOUT pin to the LEDs which are connected to the LED1-4 pins. LED current can be set in the range from 200mA to 2200mA (2000mA guaranteed) by register settings for each channel independently. Set the STROBE pin= "H" or FLASH bit= "1", the AP2071AEN can drive LEDs with flashing current when VOUT pin >2V.

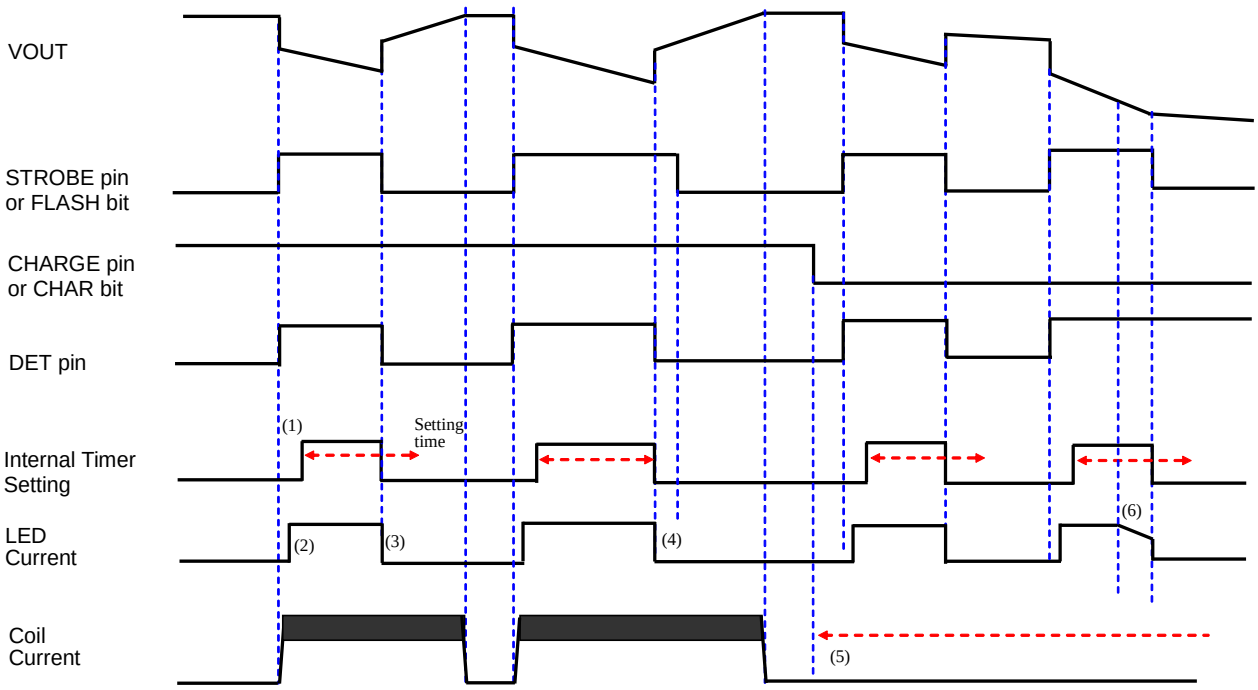


Figure 5. Flash Mode Sequence

(1) The internal safety timer starts in 120µs after the STORBE pin is changed to "H" from "L" or FLASH bit is changed to "1" from "0".
(2) The LED current reaches setting value in 80µs after the STORBE pin is changed to "H" from "L" or FLASH bit is changed to "1" from "0".
(3) The LED current becomes 0mA when changing the STORBE pin to "L" from "H" if the setting time of internal timer (TIME[3:0]) is longer than "H" period of the STOBE pin.
(4) The LED current becomes 0mA when the timer is finished if the setting time of internal timer (TIME[3:0]) is shorter than "H" period of the STOBE pin.
(5) When the CHARGE pin= "L" and CHAR bit= "0", the charging circuit and the DC-DC circuit are powered down. In this case, the consumption current will be 100µA at the VOUT pin.
(When driving LEDs in flash mode (CHARGE pin= "H" or CHAR bit= "1"), the LEDs are also supplied by battery, so the lighting time can be extended.)
(6) LED current will be decreased when VOUT< V_F of LEDs + LED1~4 voltages 0.3V (typ).
Driving LEDs with a setting current, the conditions shown below should be satisfied.

$$VOUT > V_F + \frac{I_{FLASH} \times T_{FLASH}}{\text{Capacity}} + I_{FLASH} \times ESR + V_{LED}(V)$$

V_F: LED V_F which is connected to LED1~4 pins.
Capacity: EDLC capacity value
ESR: EDLC impedance+ wire impedance
I_{FLASH}: Flashing current (4ch total value)
T_{FLASH}: Flashing time
V_{LED}: LED pins voltage 0.3V (typ)

■ Torching Sequence

A battery can drive LEDs which is connected to the LED1~4 pins through the VOUT pin. The LED current (torching current) can be set in the range from 10mA to 140mA by a register setting. The AP2071AEN will be in torch mode by setting TORCH bit to "1" after setting the EN pin to "H" if the CHARGE pin is "H" or CHAR bit is "1". LEDs can be driven when the VOUT voltage reaches the voltage which is set by VSET[2:0] bits.

The stable VOUT voltage is determined by input voltage (VIN), VOUT setting voltage (VSET) and LED V_F.

Formula (1): In the case of VSET > V_F + 0.5V > VIN*1.07
VOUT = V_F + 0.5V
Formula (2): In the case of VSET > VIN*1.07 > V_F + 0.5V
VOUT = VIN *1.07
Formula (3): In the case of V_F > VSET → LED cannot be driven.

Set appropriate VOUT voltage for LEDs in consideration of V_F value of LED.

(1) Torching sequence (Formula (1): In the case of VSET > V_F +0.5V > VIN*1.07)

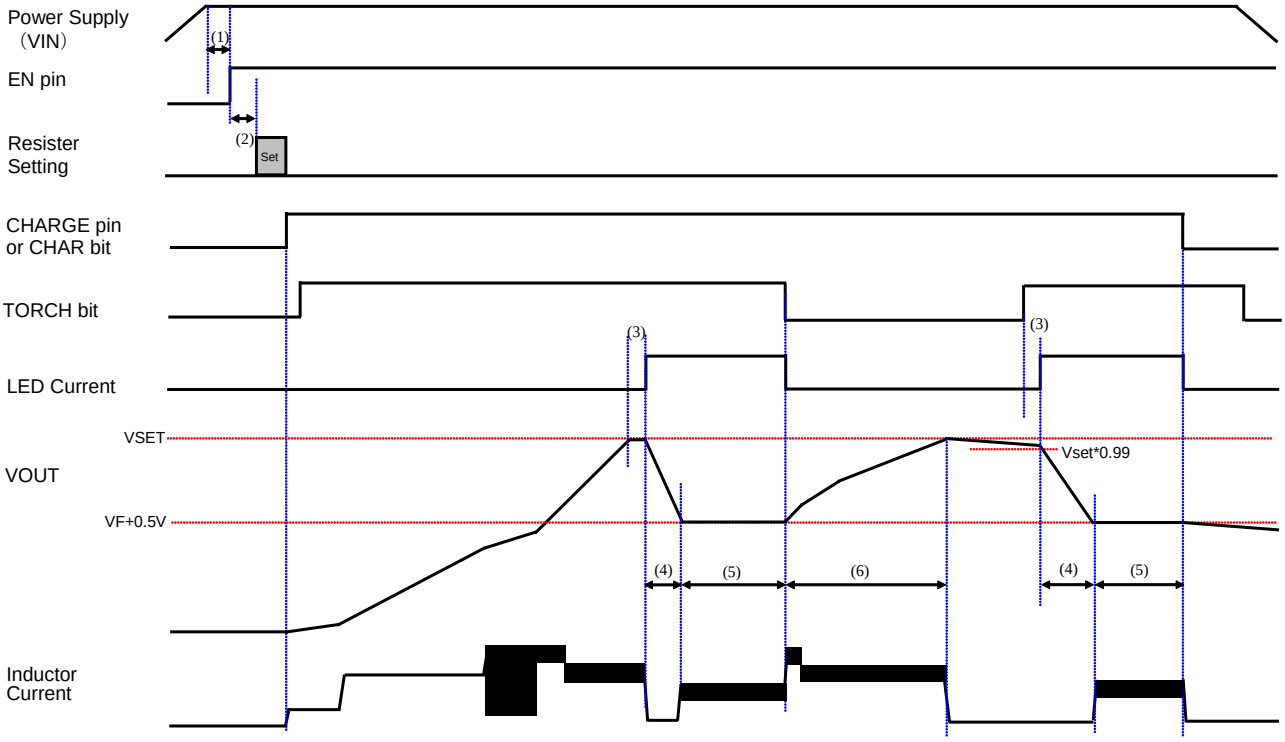


Figure 6. Torch Mode Sequence (Formula (1))

(1) The power must be supplied when the EN pin = “L”. After the power is supplied (VIN≥2.5V), the EN pin can be set from “L” to “H”. In this case, the EN pin should be held to “L” longer than 300ns to reset the AP2071AEN.
(2) Set registers 1ms after the EN pin is set from “L” to “H”.
(3) LEDs can be driven if the output voltage (VOUT) reaches VSET voltage.
LED current reaches the setting current within 80us.
(4) The internal DC-DC boosting circuit is not in operation VOUT > V_F+0.5V.
(5) The internal DC-DC boosting circuit starts operation when VOUT = V_F+0.5V.
(6) The LED current becomes 0mA when the CHARGE pin is “L” and CHAR bit= “0”, or setting TORCH bit to “0”.
CHARGE pin= “H” or CHAR bit= “1”: The AP2071AEN starts charging to an external EDLC.
CHARGE pin= “L” and CHAR bit= “0”: The AP2071AEN does not charge to an external EDLC.

(2) Torching sequence (Formula (2): In the case of VSET > VIN* 1.07 > V_F +0.5V)

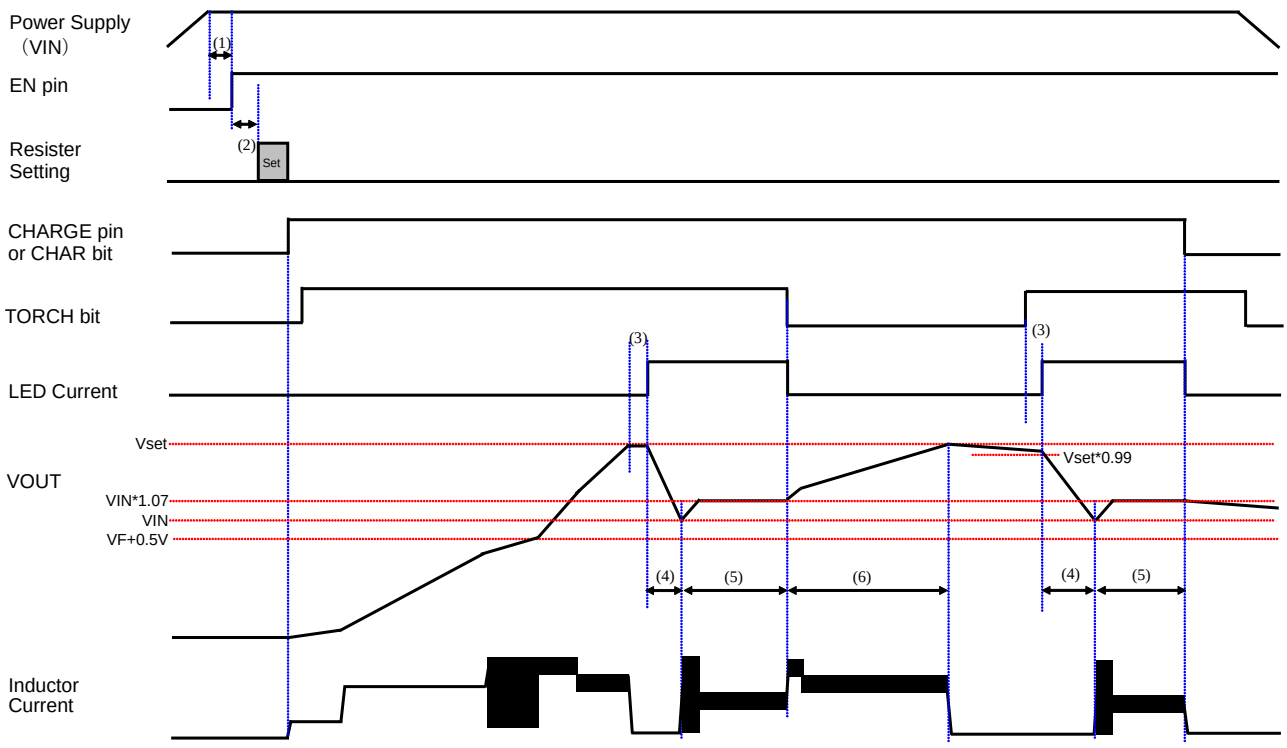


Figure 7. Torch Mode Sequence (Formula(2))

(1) The power must be supplied when the EN pin = “L”. After the power is supplied (VIN≥2.5V), the EN pin can be set from “L” to “H”. In this case, the EN pin should be held to “L” longer than 300ns to reset the AP2071AEN.
(2) Set registers 1ms after the EN pin is set from “L” to “H”.
(3) LEDs can be driven if the output voltage (VOUT) reaches VSET voltage.
LED current reaches the setting current within 80us.
(4) The internal DC-DC boosting circuit is not in operation while VOUT > VIN.
(5) The internal DC-DC boosting circuit starts operation when VOUT = VIN*1.07.
(6) The LED current becomes 0mA when the CHARGE pin is “L” and CHAR bit= “0”, or setting TORCH bit to “0”.
CHARGE pin= “H” or CHAR bit= “1”: The AP2071AEN starts charging to an external EDLC.
CHARGE pin= “L” and CHAR bit= “0”: The AP2071AEN does not charge to an external EDLC.

■ Bypass Torching Sequence

The DC-DC boost circuit can be powered off when bypass mode is set (VSET[2:0] bits= “000”), and LEDs are driven by only battery with PMOS and current source. LED current and operating condition are same as torch mode. The AP2071AEN cannot drive LEDs with a setting torch current if VIN < VOUT (the necessary voltage which is for driving LEDs with the setting current).
The condition which can drive LED with the setting current is,
(typ) VIN > V_F+0.5V + (inductor resistor + wire resistor + 0.27Ω (PMOS ON-RES)) * torching current.

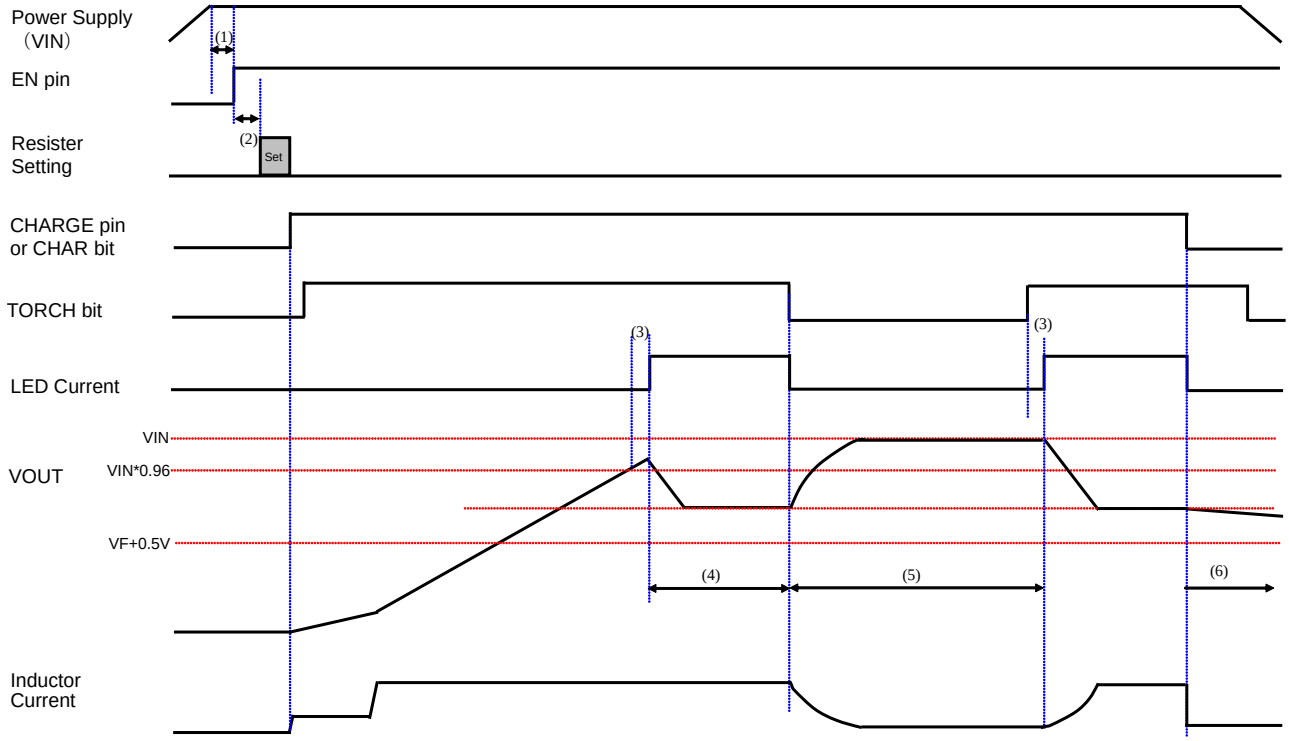


Figure 8. Bypass Torch Mode Sequence

(1) The power must be supplied when the EN pin = “L”. After the power is supplied (VIN≥2.5V), the EN pin can be set from “L” to “H”. In this case, the EN pin should be held to “L” longer than 300ns to reset the AP2071AEN.
(2) Set registers 1ms after the EN pin is set from “L” to “H”.
(3) LED can be driven if the output voltage (VOUT) reaches VSET*0.96 voltage.
LED current reaches the setting current within 80μs.
(4) A stable VOUT voltage in a range from V_F+0.5V and VIN (typical) is output.
VOUT(typ)=
V_F+0.5V+ (inductor resistance +wire resistance +0.27ohm (PMON ON-RES))*torching current
(5) Charge EDLC until VOUT=VIN.
(6) The LED current becomes 0mA when the CHARGE pin is “L” and CHAR bit= “0”, or setting TORCH bit to “0”.
CHARGE pin= “H” or CHAR bit= “1”: The AP2071AEN starts charging to an external EDLC.
CHARGE pin= “L” and CHAR bit= “0”: The AP2071AEN does not charge to an external EDLC.

■ Discharging Sequence

The AP2071AEN discharges an external EDLC by a 68Ω impedance by setting DISCH[1:0] bits = “01” or “10”. The EDLC can be discharged to 2.5V or GND selected by resister setting. Discharge mode has priority to any other operation modes (flash, torch and charge). When setting the AP2071AEN to discharge mode during charge or LED driving modes, the AP2071AEN exits charge or LED driving mode forcibly.

■ Protection Function

The AP2071AEN has protection functions shown below to avoid system failures and device damages.

Protection	Condition	Device Statement	Recovering Condition
Under Voltage Lock Out (UVLO)	VIN pin ≤ 2.3V	Charge, boost and current source circuits are powered down Address= "08H", UVLO bit= "0"→"1"	EN pin = "L" to "H"
EDLC protection 1 (cell-short)	In the case of VOUT pin > 2V and DISCH[1:0]= "11", VCAP pin >VOUT/2 + 30% or VCAP pin <VOUT/2 - 30%	Charge, boost and current source circuits are powered down. EDLC is discharged. Address= "08H", CAPERROR bit= "1" DISCHSTATUS bit= "1"	EN pin = "L" to "H"
EDLC protection 2 (VCAP pin open or short to GND)	VOUT pin =1.0V~1.5V and VCAP pin < 0.2V	Charge, boost and current source circuits are powered down. Discharge working Address= "08H", CAPERROR bit= "1" DISCHSTATUS bit= "1"	EN pin = "L" to "H"
EDLC protection 3 (VIN-GND short)	VIN pin =0V and VOUT pin >2.5V	Charge, boost and current source circuits are powered down. Discharge working	VIN pin ≥2.5V then EN pin = "L" to "H"
Over Thermal Protection (OTP)	Temperature >140°C	Charge, boost and current source circuits are powered down. Address= "08H", OTP bit= "1"	EN pin = "L" to "H"
LED open protection	In case of torch mode, VOUT pin > 1V LED pin < 0.2V	Charge, boost and current source circuits are powered down. Address= "08H", LEDERROR bit= "1"	EN pin = "L" to "H"
LED-GND short protection	In case of charge mode or torch mode, VOUT pin > 1V LED pin < 0.2V	Charge, boost and current source circuits are powered down. Address= "08H", LEDERROR bit= "1"	EN pin = "L" to "H"
LED thermal protection (Note 7) (refer to next page)	In case of LED1 or LED2 or LED3 or LED4= "1", NTC pin < setting voltage	Charge, boost and current source circuits are powered down. Address= "08H", LEDTHRM bit= "1"	EN pin = "L" to "H"
VOUT pin-LED pin short	Except to charge mode, LED pin >VOUT pin * 0.8	Charge, boost and current source circuits are powered down. Address= "08H", LEDERROR bit= "1"	EN pin = "L" to "H"
Current Limit (OCL) (coil current limited)	Coil current > current set by LIMIT[1:0]	Coil current is maintained by limitation current	
VOUT-GND short protection	In case of VOUT pin < 0.2V	Charging current= 200mA Address= "08H", VOUTDOWN bit= "1"	

Note 7. The parasitic capacitance of the NTC pin must be below 50pF.
* When set EN = "Low" to "High", all register will be reset.

■ LED Temperature Detection Function

The AP2071AEN can detect LED temperature with a NTC thermistor (Negative Temperature Coefficient Thermistor) which is connected to the NTC pin. The current which flows to the NTC thermistor is 35μA.

Protection	Conditions	Device Status	Recovering Condition
LED1~4 over temperature protection (Note 8)	NTC pin voltage < setting voltage (DET[2:0])	All circuits are powered down Address= "08H", LEDTHRM bit= "1"	Set LED1~4= "0" again or EN pin= "off"-> "ON" again

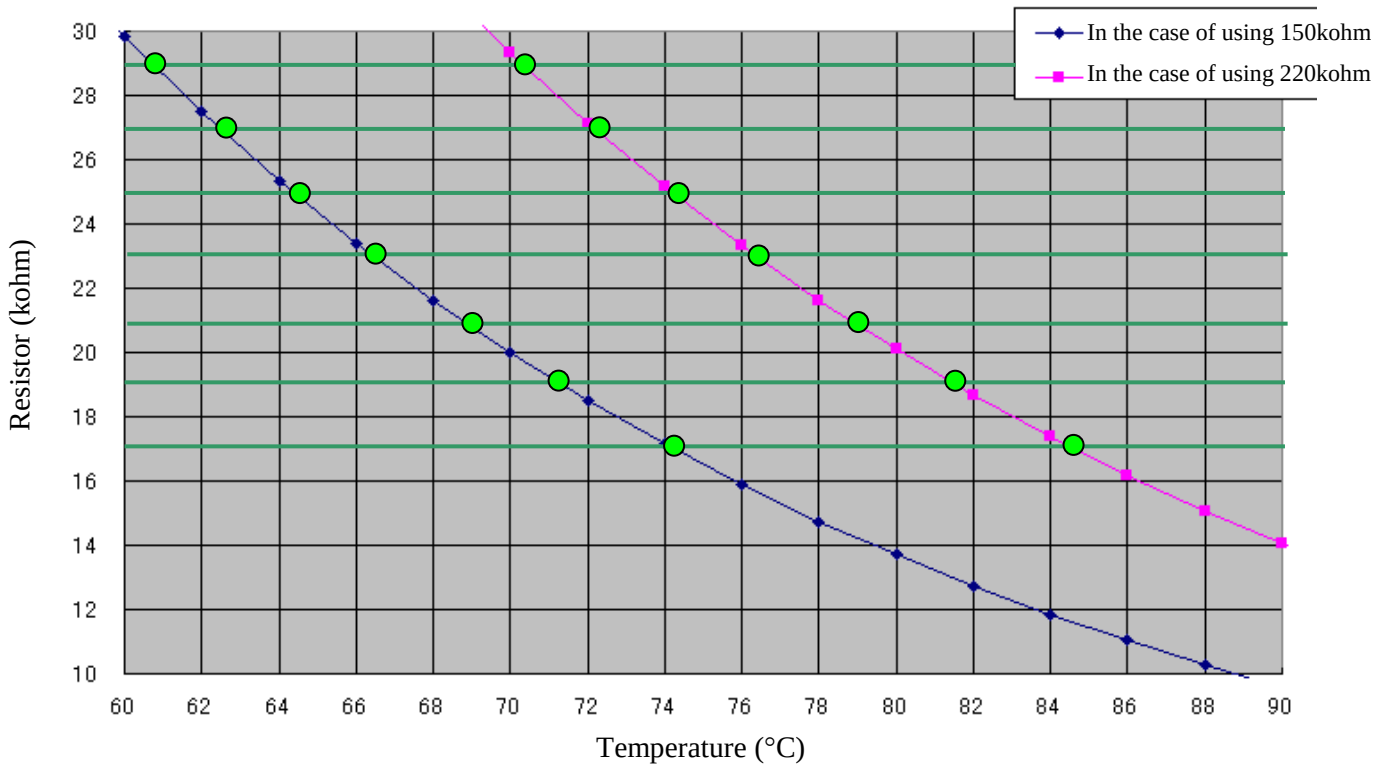
Note 8. The parasitic capacitor of NTC pin should be lower 50pF.

Example）

NTC thermistor: NCP15WM154 (150k @25°C、B constant=4582, 1005 size, Murata)
NCP15WM224 (220k @25°C, B constant=4582, 1005 size, Murata)

Formula: R=Ro*exp(B*(1/T-1/To))
(R: The value in the case of ambit temperature T(k)) (K: kelvin)
(Ro: The value in the case of ambit temperature To(k))

Detection Voltage (V) @typ (set by resistor)	0.60	0.67	0.74	0.81	0.88	0.95	1.02
Detection Resistor (kΩ)	17.1	19.1	21.1	23.1	25.1	27.1	29.1
Detection Temperature (°C) (in the case of using 150kohm)	74	71	69	66	64	62	61
Detection Temperature (°C) (in the case of using 220kohm)	84	82	79	76	74	72	70

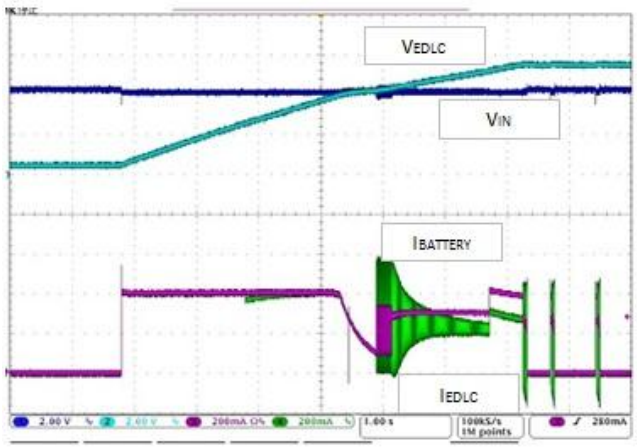


■ Typical Performance Characteristics

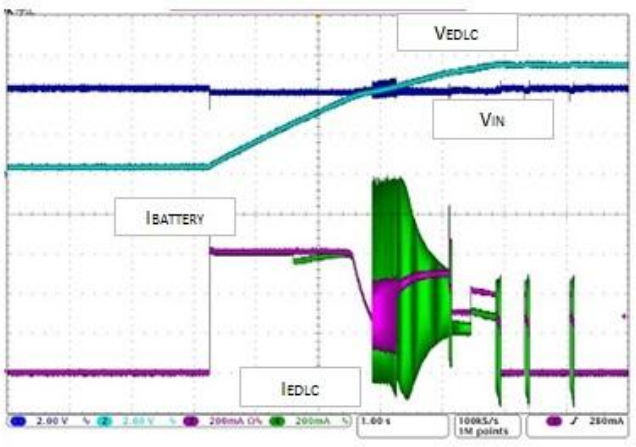
(VIN= 3.7V, Ta= 25 °C, with Recommend Parts, inductor: MLP2016H2R2M, Cin=Cout=10µF)

1) Charging Characteristics

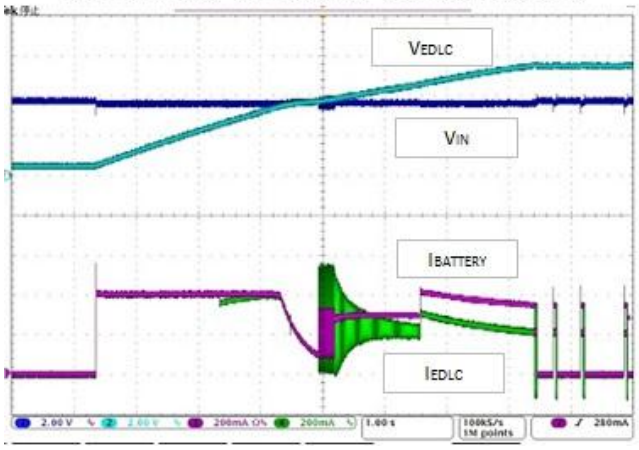
VIN=4.2V,VOUT=5.35V,Charge=400mA,Limit=500mA



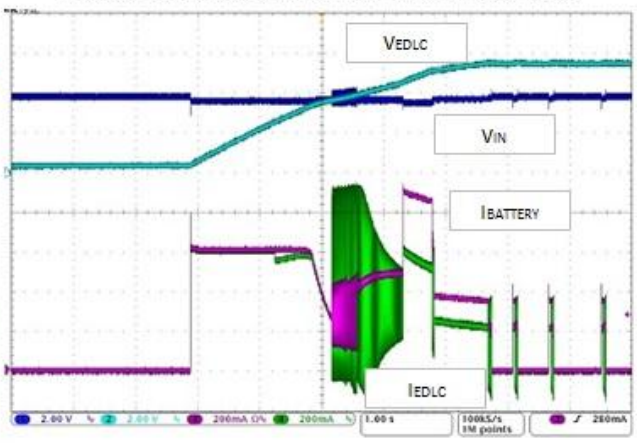
VIN=4.2V,VOUT=5.35V,Charge=600mA,Limit=1000mA



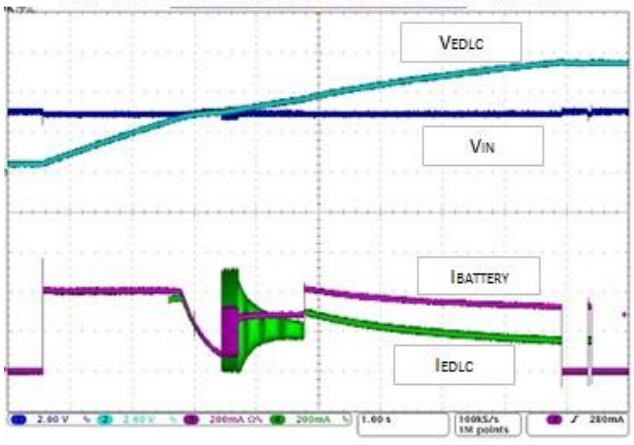
VIN=3.7V,VOUT=5.35V,Charge=400mA,Limit=500mA



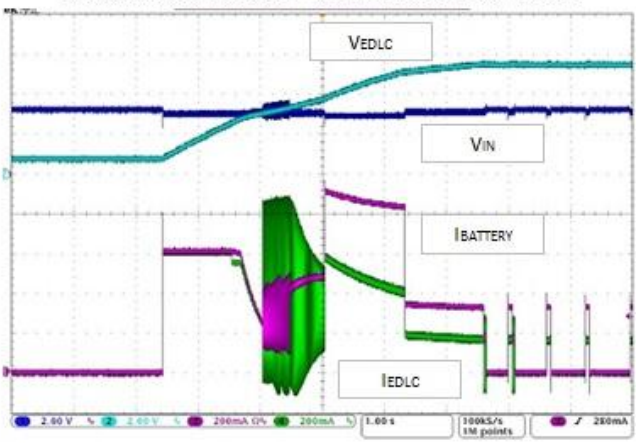
VIN=3.7V,VOUT=5.35V,Charge=600mA,Limit=1000mA



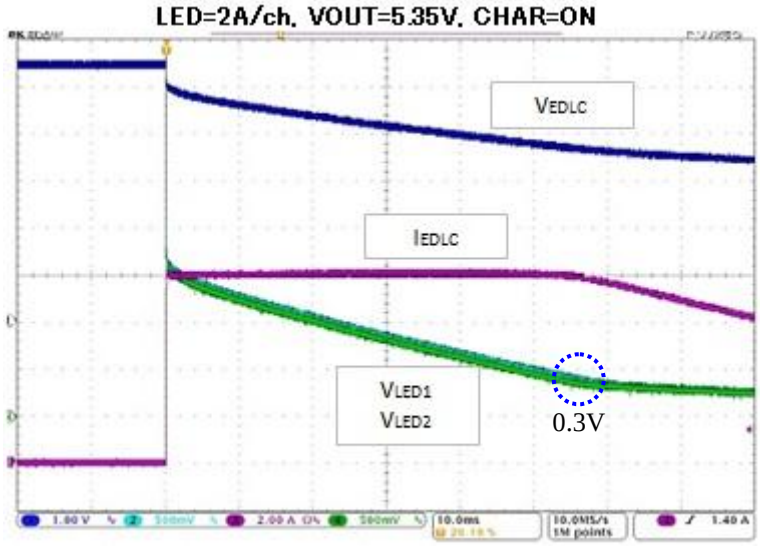
VIN=3.0V,VOUT=5.35V,Charge=400mA,Limit=500mA



VIN=3.0V,VOUT=5.35V,Charge=600mA,Limit=1000mA

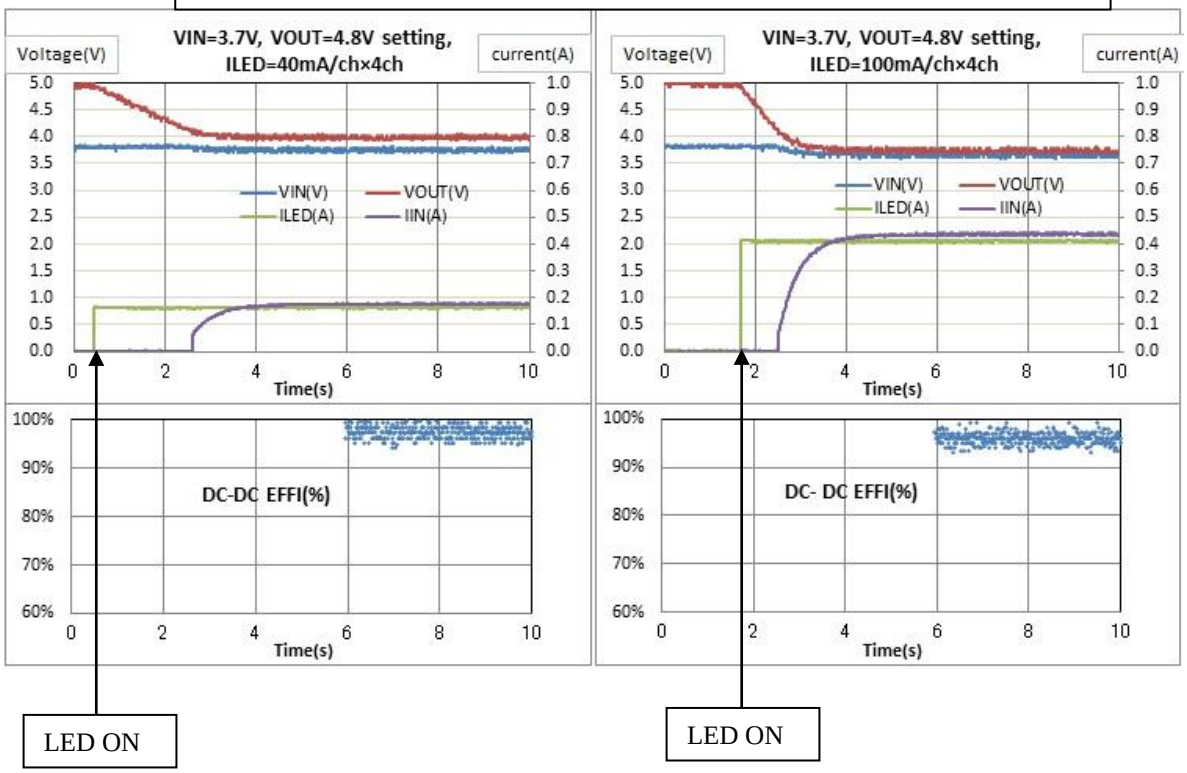


2) Flashing Characteristics (2A/ch ×4ch)



3) Torching Characteristics

When the EDLC voltage is high, firstly the AP2071 drives LED by EDLC.
When EDLC voltage becomes low, the AP2071 driver drive LED from battery.



Note) EFFI(%) = VOUT(V)×ILED(A) ×100 / (VIN(V)×IIN(A)

■ Serial Control Interface

The AP2071AEN supports a fast-mode I^2C-bus system (max: 400kHz). Pull-up resistors at the SCL and SDA pins should be connected to VIN or less.

1. WRITE Operations

Figure 9 shows the data transfer sequence for the I^2C-bus mode. All commands are preceded by a START condition. A HIGH to LOW transition on the SDA line while SCL is HIGH indicates a START condition (Figure 14). After the START condition, a slave address is sent. This address is 7 bits long followed by the eighth bit that is a data direction bit (R/W). The most significant six bits of the slave address are fixed as "011011" (Figure 10). The seventh bit is determined by ADDR pin. If the slave address matches that of the AP2071AEN, the AP2071AEN generates an acknowledge and the operation is executed. The master must generate the acknowledge-related clock pulse and release the SDA line (HIGH) during the acknowledge clock pulse (Figure 15). An R/W bit value of "1" indicates that the read operation is to be executed, and "0" indicates that the write operation is to be executed.

The second byte consists of the control register address of the AP2071AEN. The format is MSB first, and those most significant 4-bit are fixed to zero (Figure 11). The data after the second byte contains control data. The format is MSB first, 8bits (Figure 12). The AP2071AEN generates an acknowledge after each byte is received. A data transfer is always terminated by a STOP condition generated by the master. A LOW to HIGH transition on the SDA line while SCL is HIGH defines a STOP condition (Figure 14).

The AP2071AEN can perform more than one byte write operation per sequence. After receipt of the third byte the AP2071AEN generates an acknowledge and awaits the next data. The master can transmit more than one byte instead of terminating the write cycle after the first data byte is transferred. After receiving each data packet the internal 5-bit address counter is incremented by one, and the next data is automatically taken into the next address. If the address exceeds 0BH prior to generating the stop condition, the address counter will "roll over" to 00H and the previous data will be overwritten.

The data on the SDA line must remain stable during the HIGH period of the clock. The HIGH or LOW state of the data line can only change when the clock signal on the SCL line is LOW (Figure 16) except for the START and STOP conditions.

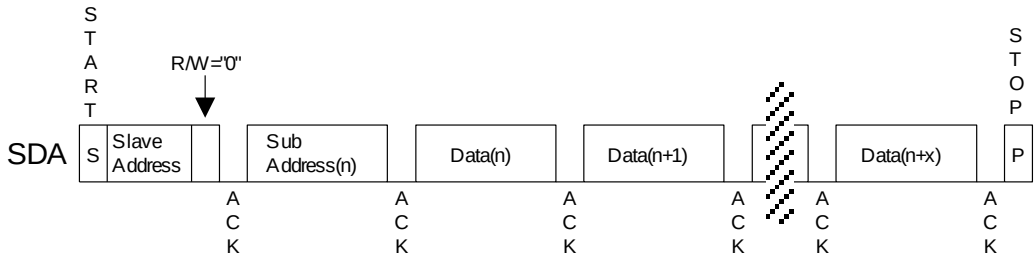


Figure 9. Data Transfer Sequence

0	1	1	0	1	1	ADDR	R/W

Figure 10. The First Byte (Do not change the ADDR pin in case of writing)

0	0	0	0	A3	A2	A1	A0

Figure 11. The Second Byte

D7	D6	D5	D4	D3	D2	D1	D0

Figure 12. Byte Structure After The Second Byte

2. READ Operations

Set the R/W bit = “1” for the READ operation of the AP2071AEN. The master can read the next address’s data by generating an acknowledge instead of terminating the write cycle after the receipt of the first data word. After receiving each data packet the internal 5-bit address counter is incremented, and the next data is automatically taken into the next address. If the address exceeds 08H prior to generating stop condition, the address counter will “roll over” to 00H and the previous data will be overwritten.

The AP2071AEN supports one basic read operation: Random Address Read.

2-1. Random Address Read

The random read operation allows the master to access any memory location at random. Prior to issuing the slave address with the R/W bit “1”, the master must first perform a “dummy” write operation. The master issues start request, a slave address (R/W bit = “0”) and then the register address to read. After the register address is acknowledged, the master immediately reissues the start request and the slave address with the R/W bit “1”. The AP2071AEN then generates an acknowledge, 1 byte of data and increments the internal address counter by 1. If the master does not generate an acknowledge to the data but generates a stop condition, the AP2071AEN ceases transmission.

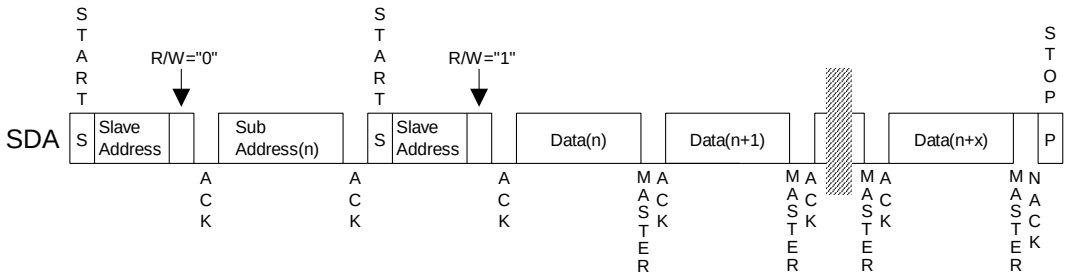


Figure 13. Random Address Read

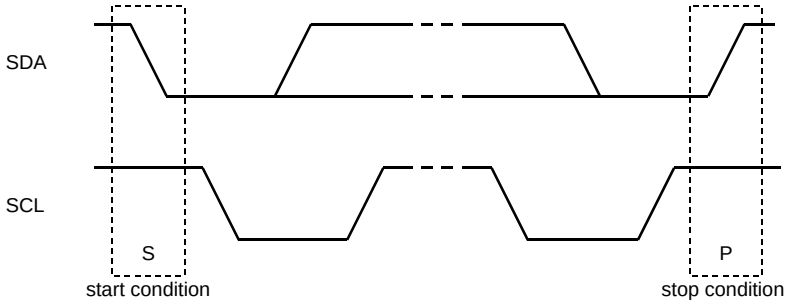


Figure 14. START and STOP Conditions

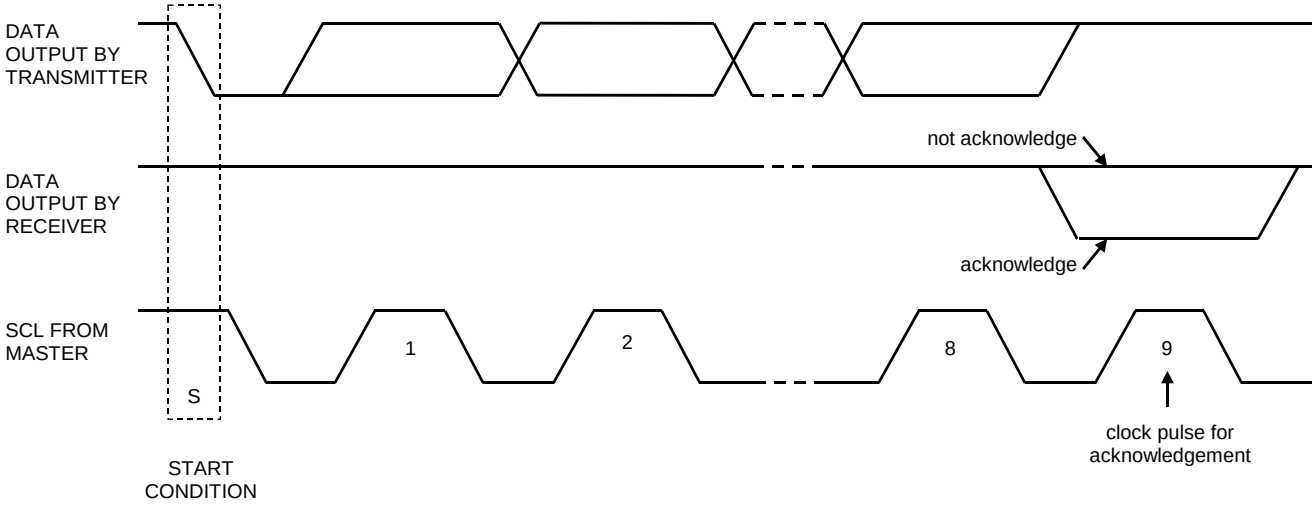


Figure 15. Acknowledge on the I^2C-Bus

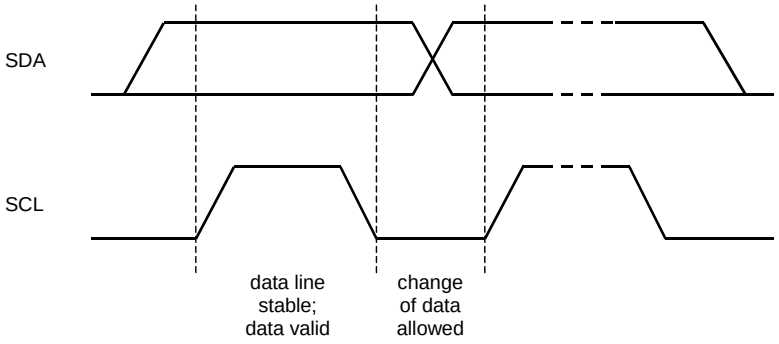


Figure 16. Bit Transfer on the I^2C-Bus

10. Register Map

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
00H	LED Setting1	LED1F4	LED1F3	LED1F2	LED1F1	LED1F0	LED1T2	LED1T1	LED1T0
01H	LED Setting2	LED2F4	LED2F3	LED2F2	LED2F1	LED2F0	LED2T2	LED2T1	LED2T0
02H	LED Setting3	LED3F4	LED3F3	LED3F2	LED3F1	LED3F0	LED3T2	LED3T1	LED3T0
03H	LED Setting4	LED4F4	LED4F3	LED4F2	LED4F1	LED4F0	LED4T2	LED4T1	LED4T0
04H	LED Setting5	LED4	LED3	LED2	LED1	TIME3	TIME 2	TIME 1	TIME 0
05H	Charge Setting	LIMIT2	LIMIT1	LIMIT0	CHAR1	CHAR0	VSET2	VSET 1	VSET 0
06H	Other Setting					LIMITSEL	NTC2	NTC1	NTC0
07H	Mode Control				DISCH1	DISCH0	CHAR	FLASH	TORCH
08H	Fault/Status			UVLO	VOUT DOWN	CAP ERROR	LED ERROR	LED THRM	OTP

Note) The access of Addr≥ “09H” is prohibited.

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
00H	LED Setting1	LED1F4	LED1F3	LED1F2	LED1F1	LED1F0	LED1T2	LED1T1	LED1T0
01H	LED Setting2	LED2F4	LED2F3	LED2F2	LED2F1	LED2F0	LED2T2	LED2T1	LED2T0
02H	LED Setting3	LED3F4	LED3F3	LED3F2	LED3F1	LED3F0	LED3T2	LED3T1	LED3T0
03H	LED Setting4	LED4F4	LED4F3	LED4F2	LED4F1	LED4F0	LED4T2	LED4T1	LED4T0
R/W		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default		0	1	1	1	1	1	0	0

LEDnT0, LEDnT1, LEDnT2: Torch current setting for LEDs that connect to LED1~4.
LEDnF0, LEDnF1, LEDnF2, LEDnF3, LEDnF4: Flash current setting for LEDs that connect to LED1~4.
(The current setting of each channel is independent.)

Table 1. Torch Mode LED Current Setting (unit: mA)

LEDnT2	LEDnT1	LEDnT0	Torch (1ch)	LEDnT2	LEDnT1	LEDnT0	Torch (1ch)
0	0	0	10	**1**	**0**	**0**	**80**
0	0	1	20	1	0	1	100
0	1	0	40	1	1	0	120
0	1	1	60	1	1	1	140

Table 2. Flash Mode LED Current Setting (unit: mA)

LEDnF4	LEDnF3	LEDnF2	LEDnF1	LEDnF0	Flash (1ch)	LEDnF4	LEDnF3	LEDnF2	LEDnF1	LEDFn0	Flash (1ch)
0	0	0	0	0	200	1	0	0	0	0	1825
0	0	0	0	1	400	1	0	0	0	1	1850
0	0	0	1	0	600	1	0	0	1	0	1875
0	0	0	1	1	800	1	0	0	1	1	1900
0	0	1	0	0	1000	1	0	1	0	0	1925
0	0	1	0	1	1200	1	0	1	0	1	1950
0	0	1	1	0	1400	1	0	1	1	0	1975
0	0	1	1	1	1600	1	0	1	1	1	2000
0	1	0	0	0	1625	1	1	0	0	0	2025
0	1	0	0	1	1650	1	1	0	0	1	2050
0	1	0	1	0	1675	1	1	0	1	0	2075
0	1	0	1	1	1700	1	1	0	1	1	2100
0	1	1	0	0	1725	1	1	1	0	0	2125
0	1	1	0	1	1750	1	1	1	0	1	2150
0	1	1	1	0	1775	1	1	1	1	0	2175
0	**1**	**1**	**1**	**1**	**1800**	1	1	1	1	1	2200

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
04H	LED Setting5	LED4	LED3	LED2	LED1	TIME3	TIME2	TIME1	TIME0
R/W		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default		0	0	0	0	1	1	0	1

TIME0, TIME1, TIME2, TIME3: On-time setting for LED1~4 in Flash mode

Table 3. LED On-time Setting

TIME3	TIME2	TIME1	TIME0	Time	TIME3	TIME2	TIME1	TIME0	Time
0	0	0	0	5ms	1	0	0	0	50ms
0	0	0	1	10ms	1	0	0	1	60ms
0	0	1	0	15ms	1	0	1	0	70ms
0	0	1	1	20ms	1	0	1	1	80ms
0	1	0	0	25ms	1	1	0	0	90ms
0	1	0	1	30ms	**1**	**1**	**0**	**1**	**100ms**
0	1	1	0	35ms	1	1	1	0	150ms
0	1	1	1	40ms	1	1	1	1	200ms

LED1, LED2, LED3, LED4: LED1~4 ON/OFF control. 0: ON; 1: OFF

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
05H	Charge Setting	LIMIT2	LIMIT1	LIMIT0	CHAR1	CHAR0	VSET2	VSET1	VSET0
R/W		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default		0	0	0	0	0	0	0	1

VSET0, VSET1, VSET2: VOUT pin voltage setting

The DET pin will change from "L" to "H" when VOUT = setting voltage (VSET [2:0]). If a flash is not lighten for a certain time after the voltage of an external EDLC (VOUT) reaches a setting value, the VOUT voltage is gradually reduced and the AP2701AEN will start charging EDLC when the VOUT voltage drops until 0.99V*VOUT.

Table 4. VOUT pin Voltage Setting

VSET2	VSET1	VSET0	VOUT
0	**0**	**0**	**VIN (Bypass Mode)**
0	0	1	4.40
0	1	0	4.80
0	1	1	5.00
1	0	0	5.25
1	0	1	5.35
1	1	0	5.45
1	1	1	4.07

* There is a possibility that VOUT exceeds the tolerate voltage of EDLC when setting the VOUT pin voltage to 5.45V (VSET [2:0]= "110").

CHAR1, CHAR0: Charge Current Setting for EDLC (VOUT=0.2V~ (VIN-0.1V))

The charge current will be 200mA when the VOUT voltage is less than 0.2V.

Table 5. Charge Current Setting

CHG1	CHG0	Current
0	**0**	**300mA**
0	1	400mA
1	0	500mA
1	1	600mA

LIMIT2, LIMIT1, LIMIT0: Inductor Limit Current Setting for during DC-DC Operation
*The setting of LIMIT2-0 = “110” or “111” is prohibited.

Table 6. Inductor Limit Current Setting

LIMITSEL	LIMIT2	LIMIT1	LIMIT0	Current (mA) VOUT≤5V	Current (mA) VOUT>5V
0	0	0	0	400	400
	0	**0**	**1**	**500**	**500**
	0	1	0	600	500
	0	1	1	800	500
	1	0	0	1000	500
	1	0	1	1500	500
	1	1	0	-	-
	1	1	1	-	-
1	0	0	0	400	400
	0	0	1	500	500
	0	1	0	600	600
	0	1	1	800	800
	1	0	0	1000	1000
	1	0	1	1500	1000
	1	1	0	-	-
	1	1	1	-	-

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
06H	Other Setting1					LIMITSEL	NTC2	NTC1	NTC0
R/W		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default		1	1	1	0	0	0	0	0

NTC0, NTC1, NTC2: NTC pin Detection Voltage Setting (The NTC pin supplies 35µA (typ.) current source.)
* Connect a thermistor resistance to the NTC pin. The AP2701AEN powers all circuit down when the voltage at the NTC pin drops under the setting value shown below as it is determined that LEDs are being heated. If this function is unnecessary, set DET[2:0] “000” to turn off the function. (The default setting is OFF.)

Table 7. NTC Detection Voltage Setting

NTC2	NTC1	NTC0	NTC Pin Detection Voltage
0	**0**	**0**	**off**
0	0	1	0.60V
0	1	0	0.67V
0	1	1	0.74V
1	0	0	0.81V
1	0	1	0.88V
1	1	0	0.95V
1	1	1	1.02V

LIMITSEL: Peak Limit Setting of the Inductor when VOUT > 5V
Refer to Note 6

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
07H	Other Setting2				DISCH1	DISCH0	CHAR	FLASH	TORCH
R/W		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Default		0	0	0	1	1	0	0	0

TORCH: LED ON/OFF setting in the case of torch mode. 0: OFF; 1: ON
(CHAR bit should be set to "1")
FLASH: LED ON/OFF setting in the case of flash mode. 0: OFF; 1: ON
CHAR: Charge EDLC setting. 0: OFF 1: ON

DISCH1, DISCH0: Discharge EDLC(discharge through 68Ω which connected to GND)

Table 8. Discharge Setting

DISCH1	DISCH0	VOUT pin
0	0	No discharge EDLC Protection 1 invalid
0	1	GND
1	0	2.5V
1	**1**	**No discharge** **EDLC protection 1 valid**

Table 9. Mode Setting

DISCH1 bit	DISCH0 bit	CHAR bit	FLASH bit	TORCH bit	Recommend	Mode
0	**0**	**0**	**0**	**0**	**Y**	**Standby**
0	0	0	0	1	-	Standby
0	0	0	1	0	Y	Flash
0	0	0	1	1	-	Flash
0	0	1	0	0	Y	Charge
0	0	1	0	1	Y	Torch
0	0	1	1	0	Y	Flash
0	0	1	1	1	-	Flash
0	1	0	0	0	Y	Discharge
0	1	0	0	1		
0	1	0	1	0		
0	1	0	1	1		
0	1	1	0	0		
0	1	1	0	1		
0	1	1	1	0		
0	1	1	1	1		
1	0	0	0	0	Y	Discharge
1	0	0	0	1		
1	0	0	1	0		
1	0	0	1	1		
1	0	1	0	0		
1	0	1	0	1		
1	0	1	1	0		
1	0	1	1	1		
1	1	0	0	0	Y	Standby
1	1	0	0	1	-	Standby
1	1	0	1	0	Y	Flash
1	1	0	1	1	-	Flash
1	1	1	0	0	Y	Charge
1	1	1	0	1	Y	Torch
1	1	1	1	0	Y	Flash
1	1	1	1	1	-	Flash

DISCH1, DISCH0: EDLC Discharging Setting (Discharge to GND via a 68Ω internal resistor.)

Table 10. Discharging Setting

DISCH1	DISCH0	VOUT pin
0	0	Not discharge EDLC Protection 1 is invalid.
0	1	GND
1	0	2.5V
1	**1**	**Not discharge** **EDLC Protection 1 is valid.**

Addr	Register Name	D7	D6	D5	D4	D3	D2	D1	D0
08H	Fault/Status			UVLO	VOUT DOWN	CAP ERROR	LED ERROR	LED THRM	OTP
R/W		RD	RD	RD	RD	RD	RD	RD	RD
Default		0	0	0	0	0	0	0	0

OTP: Indicate Over Heat Protection Status
0: Not In Operation
1: Operation

LEDTHRM: Indicate Over Temperature Protection Status
0: Not In Operation
1: Operation

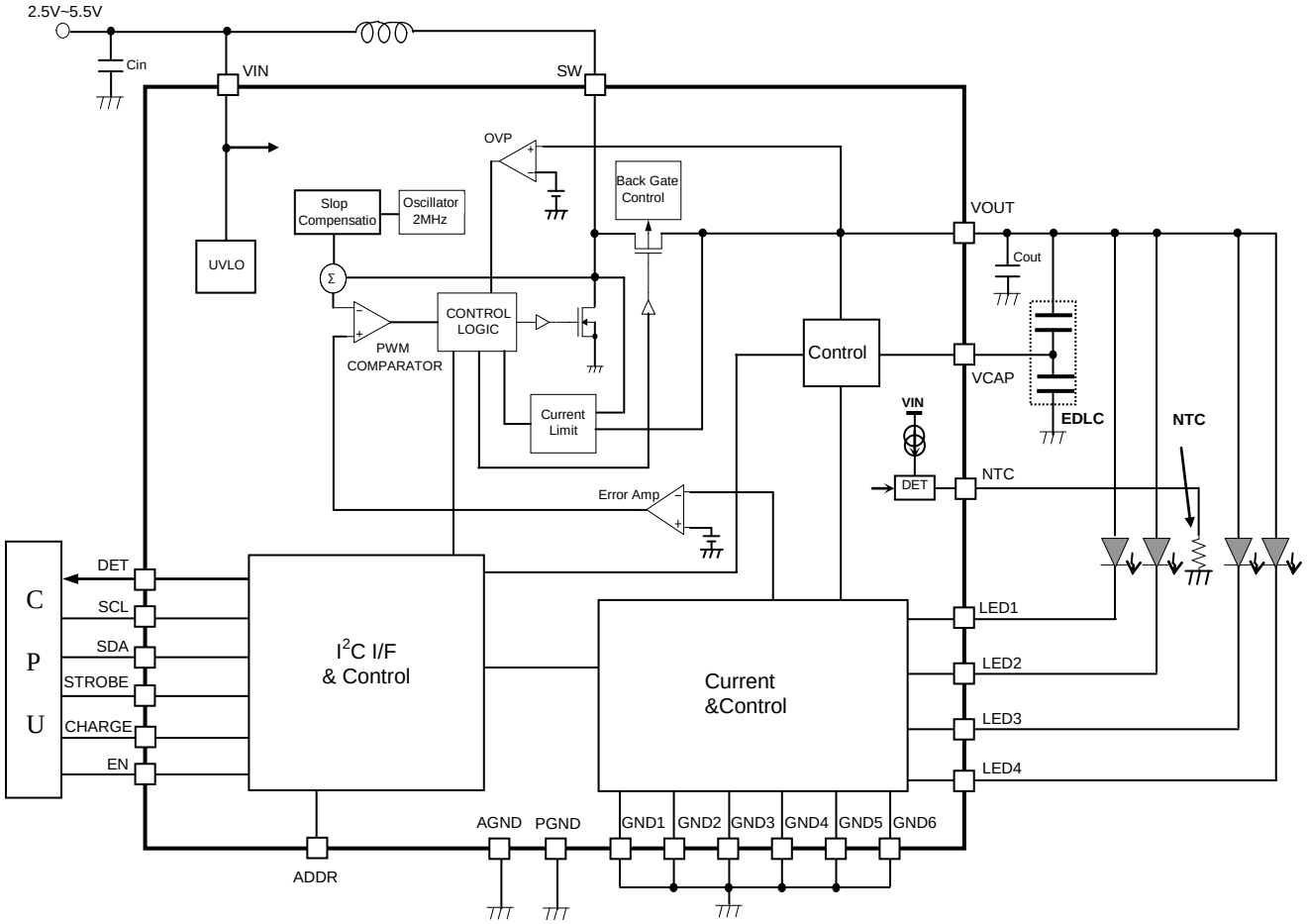
LEDERROR: LED Error Status for LRD1~4
0: Normal Operation
1: Error Status

CAPERROR: EDLC Error status
0: Normal Operation
1: Error Status

VOUTDOWN: VOUT Status
0: VOUT > 0.2V
1: VOUT ≤ 0.2V

UVLO: Indicate UVLO Protection Status
0: Not In Operation
1: Operation

11. Recommended External Circuits



■ Recommended Parts

Table 11. Recommend External Parts Example

Item	Symble	Value	Type(example)	Size	marker
Inductor	L	2.2µH	LQM2MPN2R2 MLP2016S2R2 MDT2012-CH2R2N	2.0×1.6 mm 2.0×1.6 mm 2.0×1.25 mm	Murata TDK TOKO
Condenser	Cin, Cout	10µF	C1608X5R1A106M C1608X5R1E106M	1.6×0.8 mm	TDK
			GRM188B31A106M GRM188R61E106M		Murata
		4.7µF	C1608JB0J475K C1608JB0J475M	1.6×0.8 mm	TDK
			GRM188B30J475K		Murata
NTC RES	R_{NTC}	150kΩ or 220kΩ or 470kΩ		-	
EDLC	-	350mF,470mF	-	-	Murata
		350mF,500mF	-	-	TDK
		1F	2.7DMA1M6.3x30	-	Rubycon

Note 9. All ground should be connected to the same ground plane.

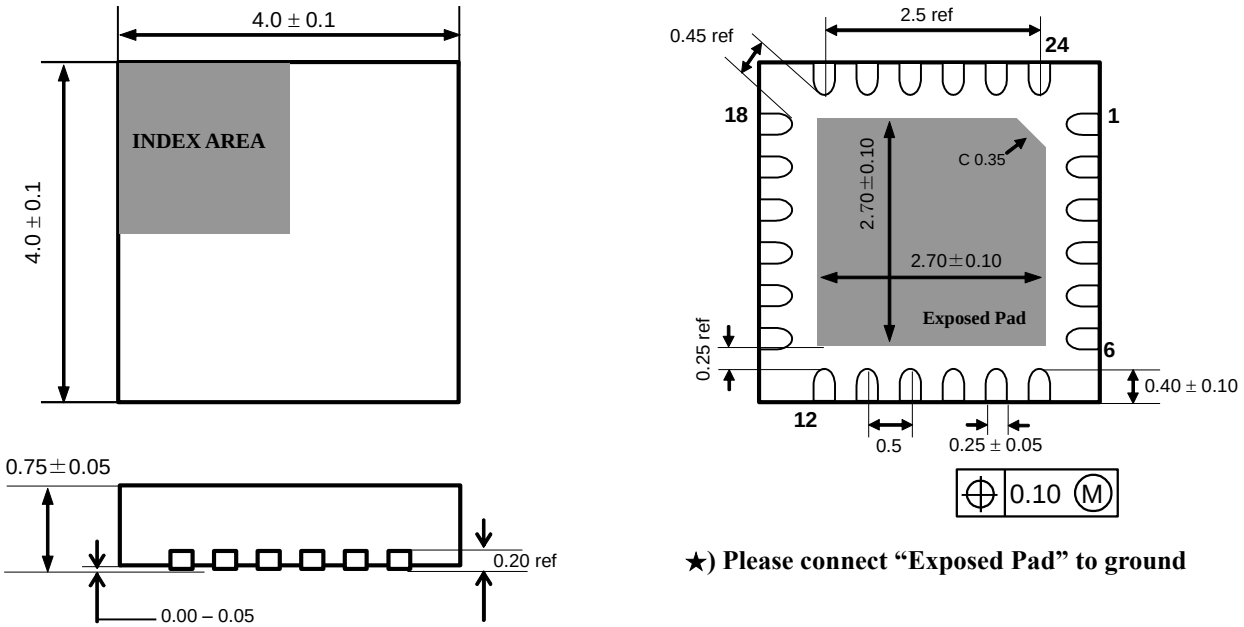
Note 10. The inductor should be placed as close as possible to the AP2071AEN.

Note 11. Capacitors should be placed as close as possible to the AP2071AEN. Low ESR (Equivalent Series Resistance) capacitors are recommended.

12. Package

■ Outline Dimensions

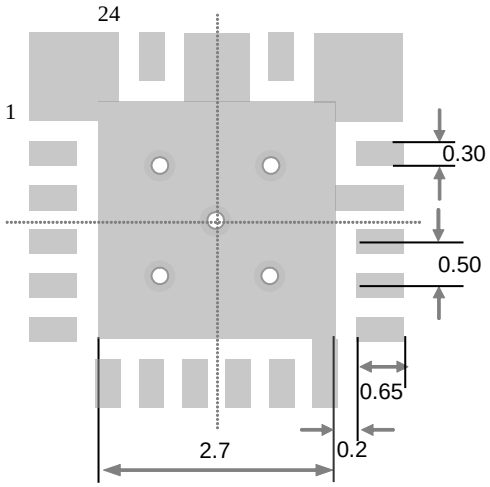
24pin HQFN（unit：mm）



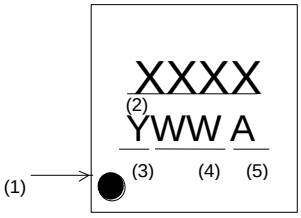
★) Please connect “Exposed Pad” to ground

■ PCB layout

（unit：mm）



■ Marking



(1) Show No1 pin
(2) Product name : “2071”
(3) Manufacture year (example: 2013? “3")
(4) Manufacture week
(5) Administration number

13. Revise History

Date (YY/MM/DD)	Revision	Page	Contents
14/03/07	00		First edition

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