Charge pump for White LED

RN5T653

Development Specifications

Rev. 1.8

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Table of Contents

1. Outline

RN5T653 contains a constant frequency charge pump, which is optimized for White LED application. Output enable/disable, LEDs current and LDOs output voltage are individually controllable through single wire serial pulse I/F.

2. Feature

- White LED Charge Pump
  - ✓ Current capability: Up to 80mA
  - ✓ 1x/1.5x switchable charge pump mode
  - ✓ Power up four LEDs for backlight: Up to 20mA/LED
  - ✓ Luminance control through 16-logarithmic scale
  - ✓ Soft-start
- Power Supply Function
  - ✓ LDO (150mA) × 2 (ON/OFF through single wire serial pulse I/F)
  - ✓ Over current protection (All Regulators) and thermal shut-down
- Others
  - ✓ UVLO
  - ✓ Short-circuit protection
- Package
  - ✓ 20pin QFN package (Body size: 3.0 x 3.0mm, Pin pitch 0.4mm)
- Process
  - ✓ CMOS process

3. Ordering Information

RN5T653□ − □ : S, T, U, V.

	LDO1	LDO2	LED Luminance
RN5T653S	1.8V	2.8V	Type-A
RN5T653T	1.5V	2.8V	Type-A
RN5T653U	1.8V	2.8V	Type-B
RN5T653V	1.5V	2.8V	Type-B

LED Luminance

LED Luminance		Count Value
Type-A	Type-B	
OFF⇒ON(20.3mA)		0
19.8mA	19.8mA	1
18.8mA	18.8mA	2
17.8mA	17.8mA	3
16.8mA	16.8mA	4
16.0mA	15.5mA	5
12.8mA	13.0mA	6
10.3mA	10.0mA	7
9.0mA	9.0mA	8
8.0mA	6.8mA	9
6.3mA	5.0mA	10
5.0mA	3.3mA	11
4.5mA	2.0mA	12
4.0mA	1.0mA	13
3.3mA	0.5mA	14
0%		15

4. Pin Configuration

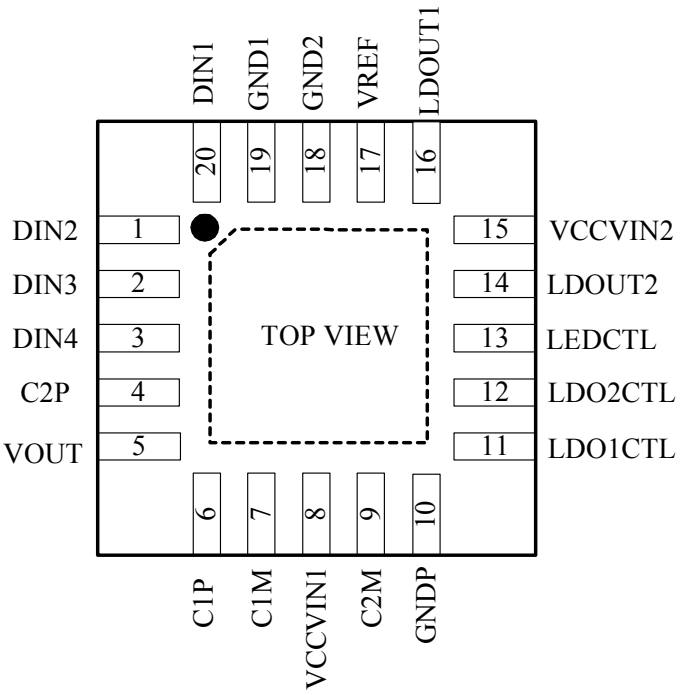


Fig 4-1 Pin Configuration

5. Typical Application Circuit

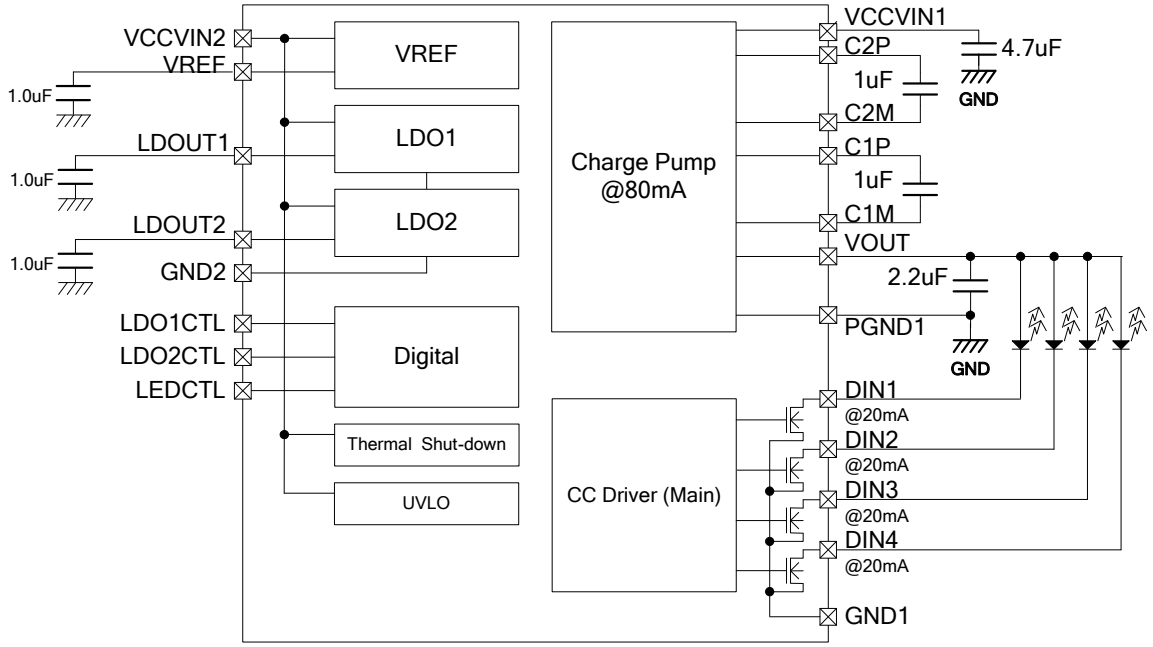


Fig 5-1 Typical Application Circuit

6. Pin Description

No.	Name	I/O	Description	Notes
1	DIN2	O	LED driver current control output	
2	DIN3	O	LED driver current control output	
3	DIN4	O	LED driver current control output	
4	C2P	-	Charge pump boost capacitor connection	
5	VOUT	O	LED driver voltage output	
6	C1P	-	Charge pump boost capacitor connection	
7	C1M	-	Charge pump boost capacitor connection	
8	VCCVIN1	PWR	Power supply for charge pump. VCCVIN1 is high impedance during shut-down.	
9	C2M	-	Charge pump boost capacitor connection	
10	GNDP	GND	Power Ground 1	
11	LDO1CTL	I	Input of LDO1 for ON/OFF.	
12	LDO2CTL	I	Input of LDO2 for ON/OFF.	
13	LEDCTL	I	Input of LED for ON/OFF and current setting.	
14	LDOUT2	O	Output of LDO2	
15	VCCVIN2	PWR	Power supply for LDO, UVLO, VREF and TSHUT.	
16	LDOUT1	O	Output of LDO1.	
17	VREF	O	Output of voltage reference. Please do not connect anything.	No load
18	GND2	GND	Ground2	
19	GND1	GND	Ground1	
20	DIN1	O	LED driver current control output	

Table 6-1 Pin Description

7. Functional Blocks

7.1 Regulators

RN5T653 has 2 Low Drop Output regulators, LDO1 and LDO2. (See Table 6-1)

On/Off operation of each LDO are controllable with LDO1/2CTL pin through single wire serial pulse I/F.

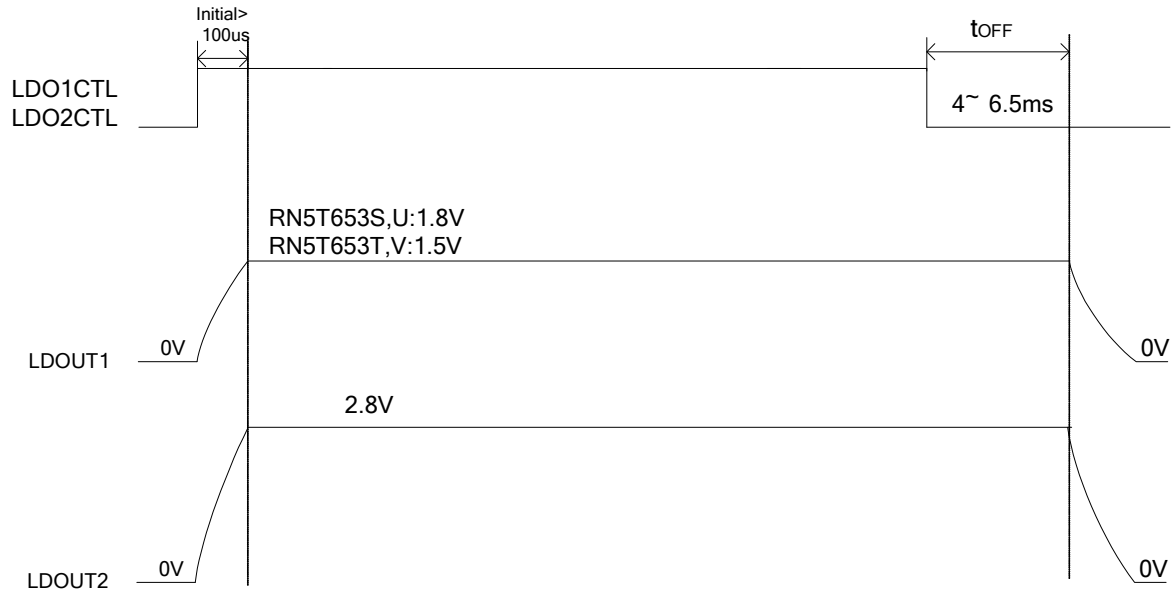


Fig 7-1 LDO Output Voltage Control

For the type of the bypass capacitor, it must be a ceramic type, not tantalum type, since the optimization design is based on the ceramic type for the phase compensation.

・t_{OFF} : 4~6.5 ms or more “L” of LDO1/2CTL pin turns off LDO1/2.

7.1.1 Linear Regulators Table (Ordering Table)

RN5T653S, U	LDO1	LDO2
Output Voltage	1.8	2.8
Initial State	OFF	OFF
ON/OFF Control	Single wire serial pulse I/F	

RN5T653T, V	LDO1	LDO2
Output Voltage	1.5	2.8
Initial State	OFF	OFF
ON/OFF Control	Single wire serial pulse I/F	

Table 7-1 Linear Regulators Table

7.2 LDO1/2 Electrical Characteristics

Unless otherwise specified, VCCVIN=3.6V, Ta=25℃, Cout=1.0uF

Symbol	Parameter	Condition		Min	Typ	Max	Units
VOUT	Output Voltage	50uA＜IOUT＜150mA VOUT+0.5V≦V_{BATT}(VCCVIN)≦4.5V		-2%		+2%	V
IOUT	Output Current	-				150	mA
ILIM	Current Limit	VOUT=0V		200	250	350	mA
VDRP	Drop-out Voltage	IOUT=150mA,T_a =85℃,VOUT≧2.8V			200		mV
$\frac{\Delta VOUT}{\Delta VCCVIN}$	Line Regulation	VOUT+0.5V≦V_{BATT}(VCCVIN)≦4.5V IOUT=150mA			2.4	14	mV
$\frac{\Delta VOUT}{\Delta IOUT}$	Load Regulation	50uA＜IOUT＜150mA			25	30	mV
$\frac{\Delta VOUT}{\Delta T_a}$	Output Voltage Temperature Coefficient	-40℃≦T_a≦85℃			±100		ppm/℃
RR	Ripple Rejection	f=10Hz-10kHz, C_{out}=1.0uF IOUT=75mA			60		dB
EN	Output Noise (RMS)	BW=100Hz-100kHz, C_{out}=1.0uF IOUT=75mA			35		uVrms
BC	Bypass Capacitor	0uA＜IOUT＜150mA			1.0		uF
ISS	Supply Current	Normal (IOUT=0mA)		30	50	70	uA
		OFF				1	
POUT	Output Voltage	IOUT=150mA	RN5T653S, U	-2%	1.8 *1 2.8 *2	+2%	V
			RN5T653T, V		1.5 *1 2.8 *2		

Note*: For optimized phase compensation, the bypass capacitor must be a ceramic type.
Note*1: LDOUT1 Output Voltage.
Note*2: LDOUT2 Output Voltage.

Table 7-2 LDO1/2 Electrical Characteristics

7.3 Charge Pump

RN5T653 drives up to 4 white LEDs with regulated constant current. Utilizing 1x/1.5x charge pump modes achieves high-efficiency. On/off of LED is individually controllable through single wire serial pulse I/F. Also, the luminance of LED is individually controllable through single wire serial pulse I/F.

The capacitor is highly recommended to be ceramics.

7.3.1 Block Diagram

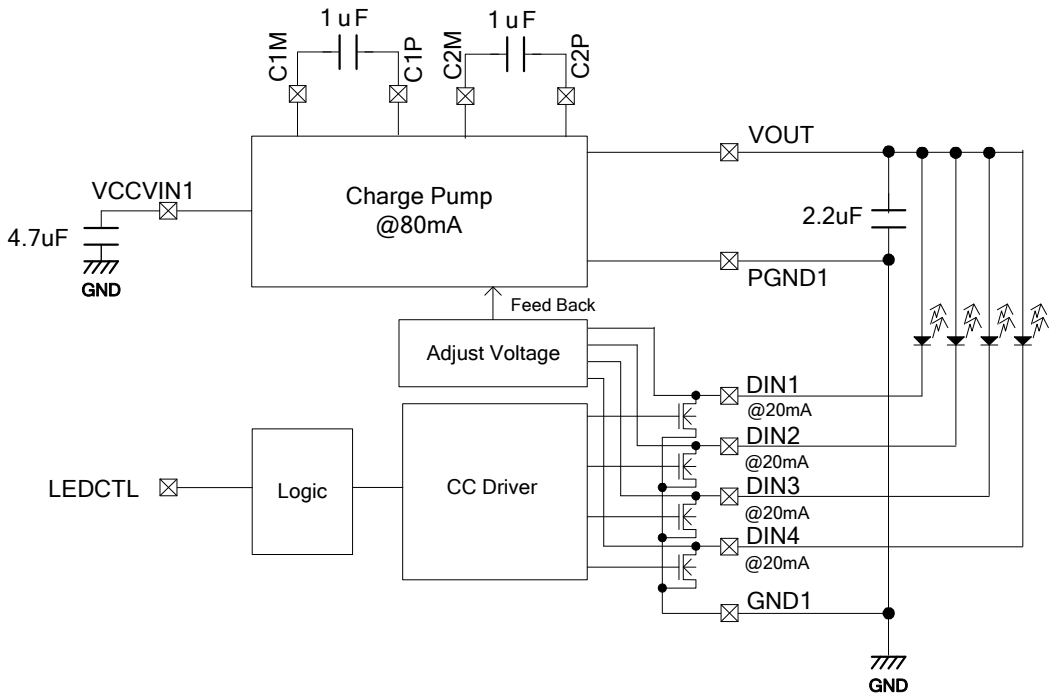


Fig 7-2 Charge Pump Circuit Diagram

7.3.2 Backlight LED

For maximized power efficiency, the charge pump operates 1x mode and 1.5x mode, where the operation mode is determined by comparing the forward voltage of each LED with the input voltage.

Initial and 1x mode

When any LED channel is enabled and VCCVIN1 voltage is greater than the charge pump output (VOUT), the charge pump initially starts in 1x mode and VOUT is pulled up to VCCVIN1. During start-up, built-in Soft-start circuitry will prevent excessive inrush current.

In 1x mode, the following relation is the condition to stay in 1x mode.

$$VOUT - Vf > 220mV \quad (1)$$

VOUT: Charge pump output

Vf: White LED forward voltage

220mV: Mode transition threshold voltage when LED output current is set at 20mA.

1x or 1.5x transition

When VCCVIN1 falls and DIN_ pin voltage drops lower than the mode transition threshold voltage 220mV for 100us, the charge pump circuit switches to 1.5x mode to boost voltage.

In 1x mode, the following relation is the transition condition to change to 1.5x mode.

$$VOUT - Vf \leqq 220mV \quad (2)$$

Every 1sec, the charge pump circuit resets to 1x mode and stays in 1x mode for approximately 100us to judge whether it changes to 1.5x mode or stay in 1x mode.

Mode transition

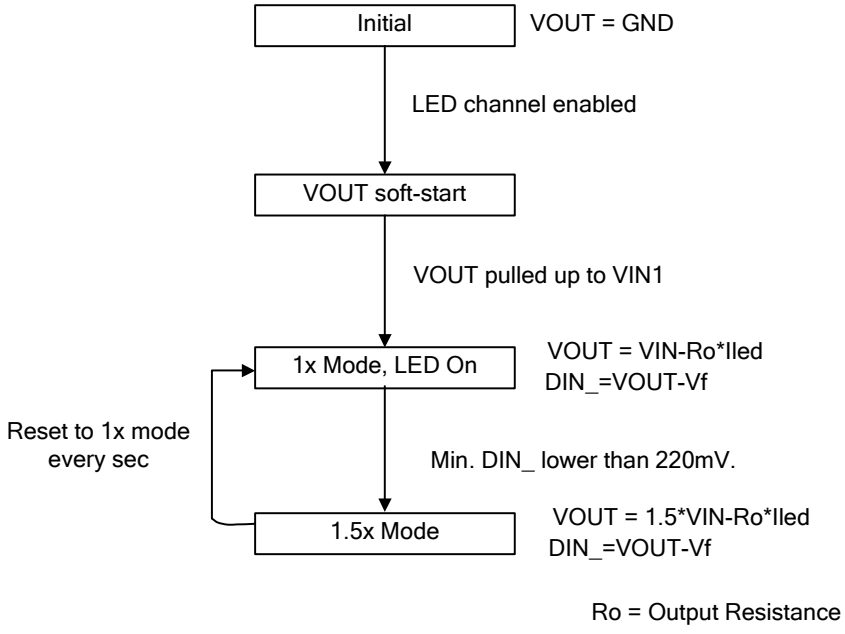


Fig 7-3 Mode Transition Diagram

7.3.3 Protection Circuit

When any DIN_ pin is floating or grounded, VOUT voltage is limited below protection voltage by gating on/off charge pump. In case that any LED fails as an open circuit, VOUT voltage is also limited. Besides, when VOUT is smaller than approximately 1.2V, Charge pump will stop.

7.3.4 Unused DIN_ pin

Please ground unused DIN_ pin to avoid over-voltage protection status.

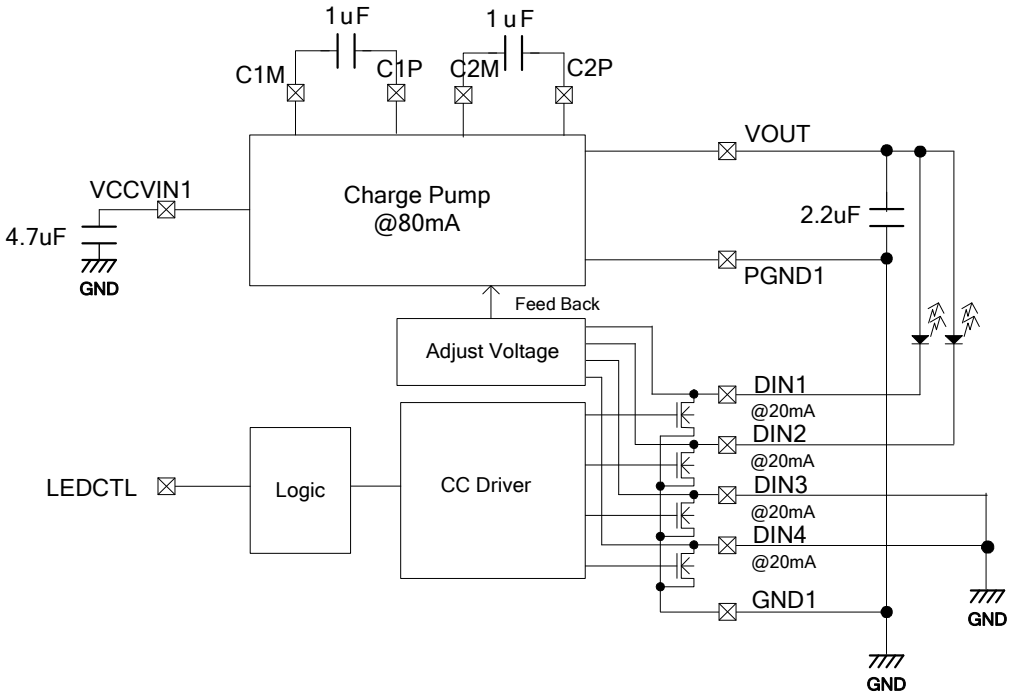


Fig 7-4 Unused DIN_ pin

7.3.5 Soft-start

RN5T653 includes Soft-start circuitry to prevent excessive inrush current during turn on. (The internal resistance gradually increases just after LEDs enabled.)

When the charge pump turns on, the capacitors are charged directly from input voltage.

Soft-start time is less than 300 us, and it is decided by the amount of the external capacitors.

7.3.6 Luminance Control

RN5T653 charge pump drives 4 LEDs with regulated constant current for uniformed intensity. LEDCTL input is used to enable, disable and adjust the current for each with a 16-logarithmic scale.

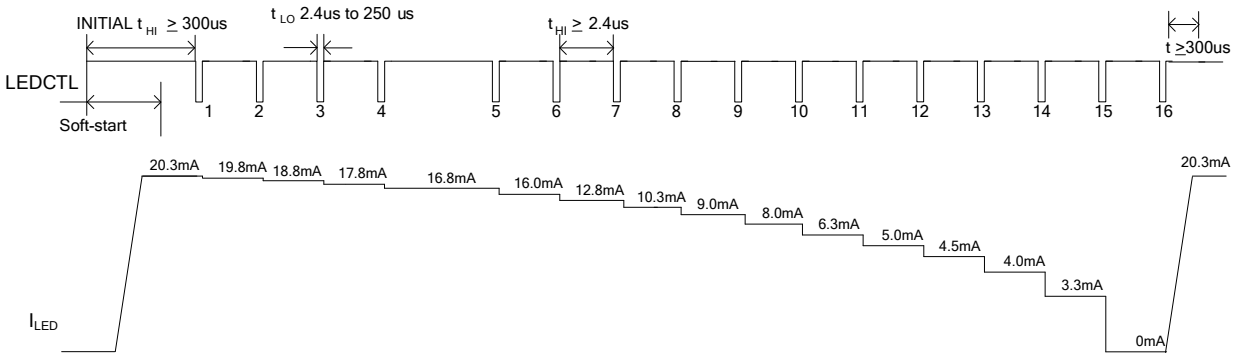


Fig 7-5 Luminance Control Diagram

・t_{HI} : Pulling LEDCTL pin to "H" for 300 us or more enables LED. The minimum "H" time of LEDCTL pin is 2.4 us.

・t_{OFF} : 4~6.5 ms or more "L" of LEDCTL pin turns off LED.

Luminance		Count value
653S, T	653U, V	
OFF⇒ON(20.3mA)		0
19.8mA	19.8mA	1
18.8mA	18.8mA	2
17.8mA	17.8mA	3
16.8mA	16.8mA	4
16.0mA	15.5mA	5
12.8mA	13.0mA	6
10.3mA	10.0mA	7
9.0mA	9.0mA	8
8.0mA	6.8mA	9
6.3mA	5.0mA	10
5.0mA	3.3mA	11
4.5mA	2.0mA	12
4.0mA	1.0mA	13
3.3mA	0.5mA	14
0mA		15

Table 7-3 LED Luminance Control

7.3.7 PWM Adjustment with Time Control

When LEDCTL goes high, LEDs are enabled at the maximum luminance. After subsequent low going pulse reduces LED current in logarithmical scale.

7.3.7.1 Disable LED

LED can be powered off by driving LEDCTL pin low longer than tOFF.

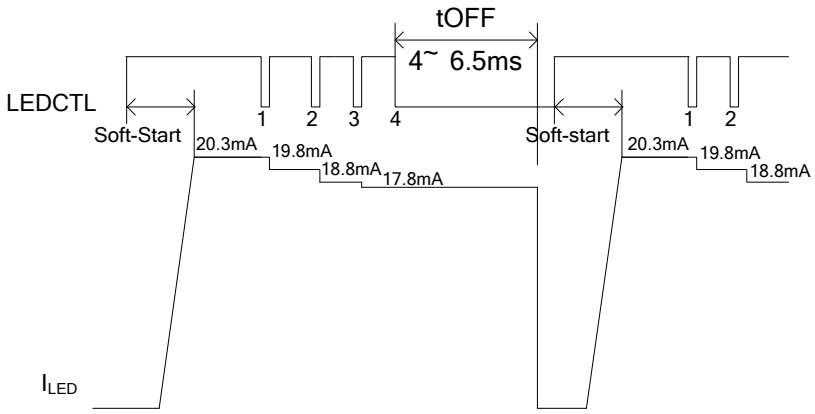


Fig 7-6 Disable LED

7.3.7.2 Initialization of LED

The luminance can be adjusted to the initial value by driving LEDCTL pin "H" longer than tRESET but not over tOFF. (LED remains power-on.)

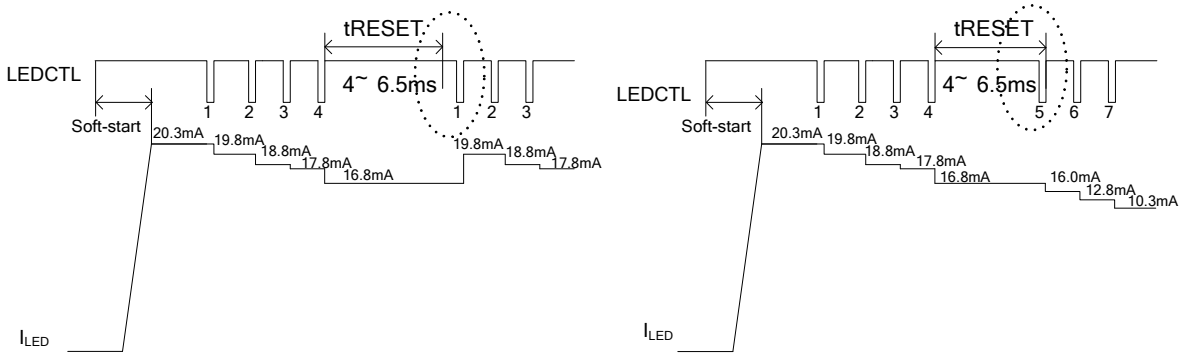


Fig 7-7 Initialization of LED

* Timer description

・tRESET timer starts at the falling edge of the input clock from LEDCTL, and is cleared at the rising edge of the input clock from LEDCTL.

・tOFF timer starts at the rising/falling edge of the input clock from LEDCTL and turns off when timer overflows.

7.3.7.3 Operation Flow

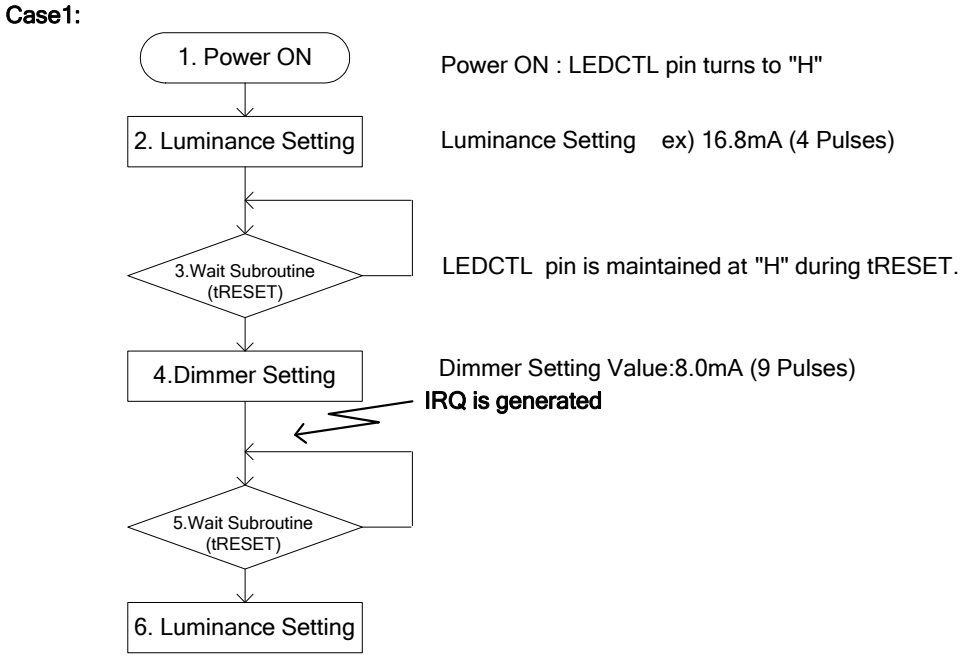


Fig 7-8 Operation Flow: Case1

* Wait Subroutine: Subroutine needs to be inserted to any status.

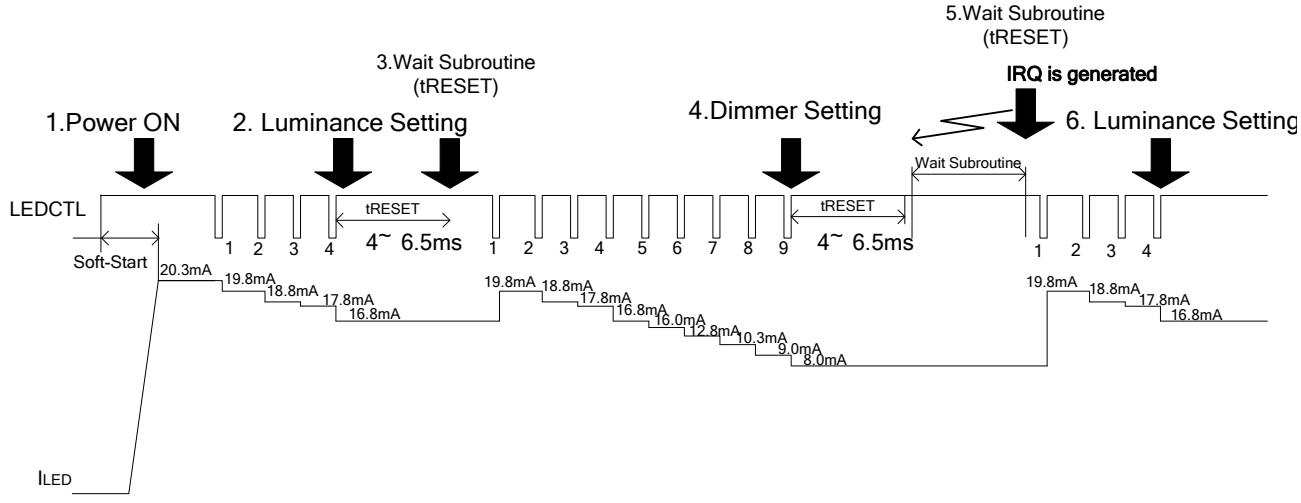
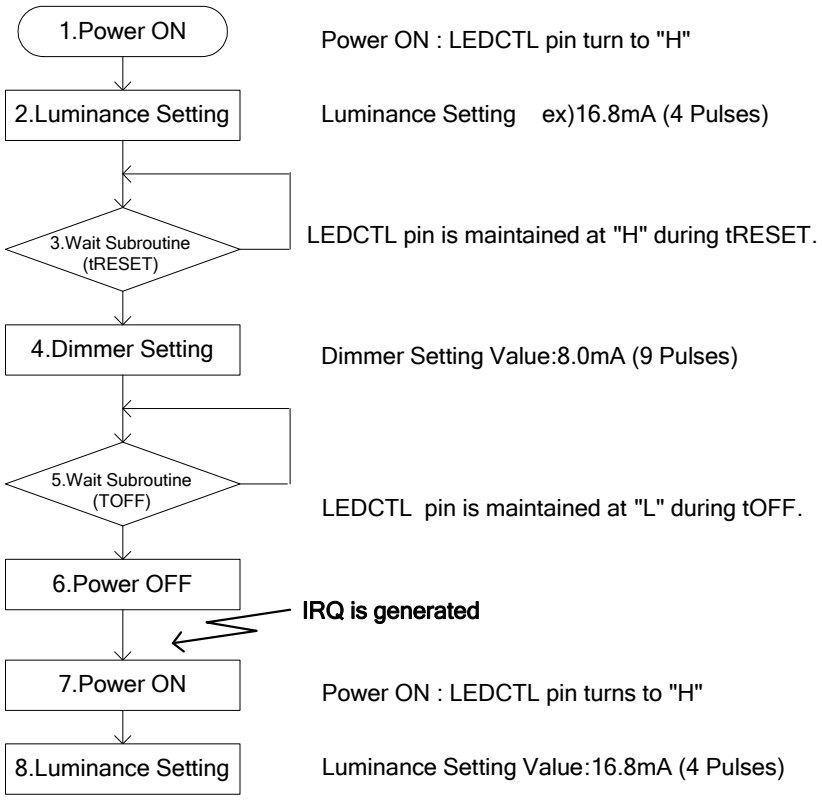


Fig 7-9 Operation Diagram: Case1

Case2:



Note*: Power ON/OFF means RN5T653 power ON/OFF, not the system's.

Fig 7-10 Operation Flow: Case2

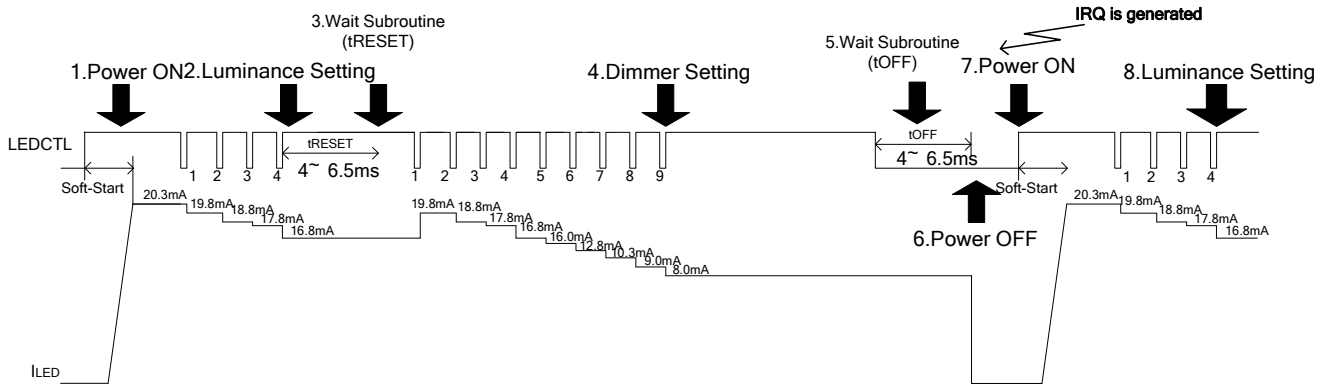


Fig 7-11 Operation Diagram: Case2

Case3:

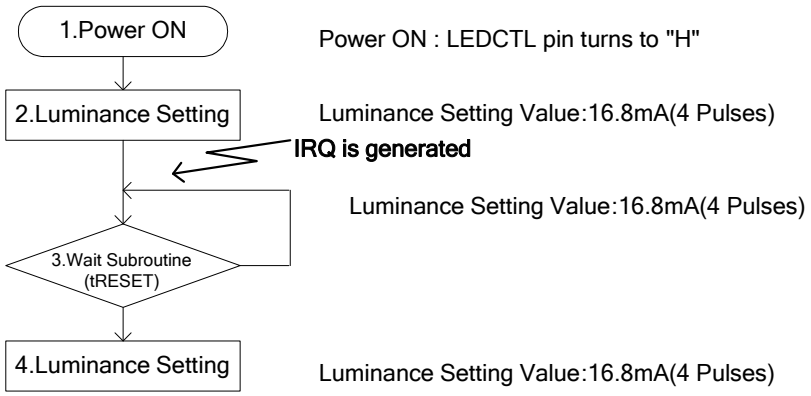


Fig 7-12 Operation Flow: Case3

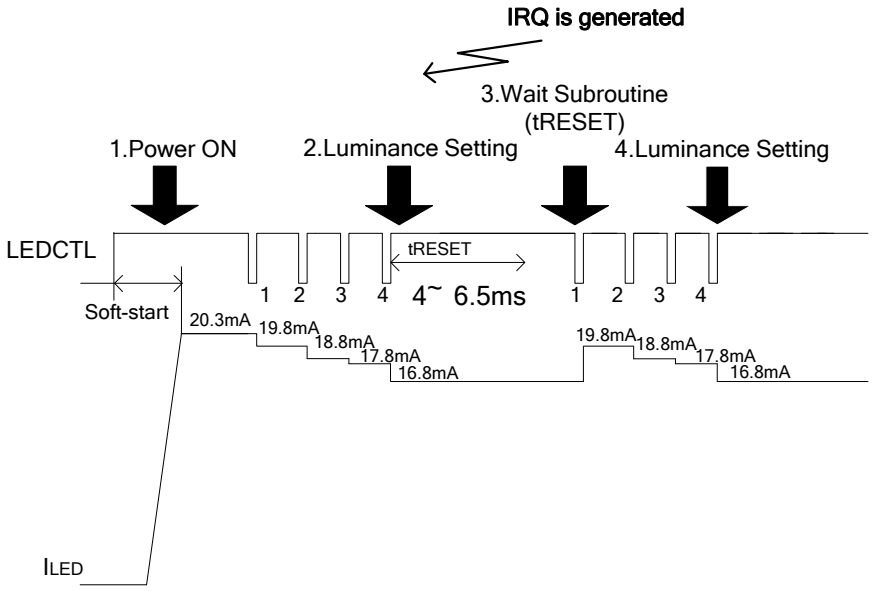


Fig 7-13 Operation Diagram: Case3

7.3.8 Charge Pump Electrical Characteristics

Operating Conditions (unless otherwise specified) VCCVIN=3.6V, Ta=25℃, C1=C2=1uF, Cout=2.2uF

Symbol	Parameter	Condition	Min	Typ	Max	Units
Charge Pump						
V_{IN}	Operating Voltage	VCCVIN voltage	2.7		4.5	V
I_{OUT}	Max. Output current	VCCVIN≧3.2V, VOUT voltage		80		mA
R_{ON}	Output resistance	1x mode, (VCCVIN-Vout)/Iout 1.5xmode, (1.5xVCCVIN-Vout)/Iout			1.5 6	Ω
V_{OVP}	Over voltage protection	VOUT Rising	4.65	4.8	4.95	V
F_{OSC}	Switching Frequency	-	1.18	1.25	1.40	MHz
T_{SOFT}	Soft-start time	-	30	180	300	us
Isc	Supply current	1x mode 1.5x mode			1 5	mA
Iss	Standby supply current	VCCVIN current			5	uA
I_{LIM}	Current limit	VOUT shorted	20	50	100	mA
V_{TH1}	1x to 1.5x transition threshold	-		220		mV
V_{TIM}	1x to 1.5x transition time	-		100		us
LED Driver						
Isink	Maximum Sink Current	Each DIN1-4		20		mA
A_{CC}	LED current accuracy	Setting DATA Max, DIN1-4=0.25V	-5		5	%
I_{MAT}	LED current matching	Vfdiff<0.4V	-2		2	%
V_{Drop}	Current Regulator Dropout	Setting DATA Max		220		mV
I_{LEAK}	DIN1-4 leakage in shut-down	-	-1	0.1	1	uA

Table 7-4 Charge Pump Electrical Characteristics

7.4 UVLO (Under Voltage Lock Out)

Operating Conditions (unless otherwise specified) VCCVIN = 3.6V, C_{REFO} = 1uF, T_a = 25℃

Symbol	Parameter	Condition	Min	Typ	Max	Units
$V_{Release}$	Under voltage lock out threshold	VCCVIN rising		2.25		V
V_{Detect}	Under voltage lock out threshold	VCCVIN falling	2.05	2.20	2.35	V
V_{HYS}	UVLO Hysteresis	-		50		mV

Table 7-5 UVLO Electrical Characteristics

7.5 Thermal Shut-down Circuit

Overheat state can be detected by comparing the output voltages from two temperature detection circuits, which have different temperature characteristics. If the overheat state is detected, RN5T653 will turn off to protect itself from overheating.

7.5.1 Thermal Shut-down Electrical Characteristics

Operating Conditions (unless otherwise specified) VCCVIN= 3.6V, C_{REFO} = 1uF, T_a = 25℃

Symbol	Parameter	Condition	Min	Typ	Max	Units
T_{DET}	Detected Temperature	-		140		℃
T_{RET}	Return Temperature	-		110		℃
I_{SS}	Supply Current	-		4		uA

Table 7-6 Thermal Shut-down Electrical Characteristics

8. Electrical Characteristics

8.1 Absolute Maximum Ratings

Symbol	Parameter	Condition	Rated value	Units
VCCVIN	Power Supply Voltage	Battery Voltage Input Pins	-0.3～6.0	V
Vin	Input Voltage Range	All Input Pins	-0.3～VCCVIN+0.3	V
PD	Package Allowable Dissipation	Mounted on Board, T_a =70℃	TBD	mW
T_{stg}	Storage Temperature	-	-55～+125	℃

Table 8-1 Absolute Maximum Ratings

8.2 Recommendation of Operation Conditions

Symbol	Parameter	Condition	Min	Typ	Max	Units
VCCVIN	Power Supply Voltage	Battery Voltage Input Pins	2.7	3.6	4.5	V
Ta	Temp. of Operation	-	-40		85	℃

Table 8-2 Recommendation of Operation Conditions

8.3 DC Characteristics

Operating Conditions (unless otherwise specified) VCCVIN= 3.6V, C_{REFO} = 1uF, T_a = 25℃

Symbol	Parameter	Condition	Min	Typ	Max	Units
Vih	“H” Input Voltage	-	1.6			
Vil	“L” Input Voltage	-			0.2	
I_{IL1}	Input Leakage Current 1	VCCVIN	-1	0.1	1	uA

Table 8-3 DC Characteristics

8.4 General Characteristics

Operating Conditions (unless otherwise specified) VCCVIN= 3.6V, CREFO = 1uF, Ta = 25℃

Symbol	Parameter	Condition	Min	Typ	Max	Units
Ishut	Shut-down Supply Current	Ta=25℃		1	3	uA

Table 8-4 General Characteristics

9. Package Information