36V High Efficiency Boost Converter with I2C Controlled 6-CH LED Driver

General Description

The RT4527A is a high efficiency driver for white LEDs. It is suitable for single/two cell battery input to drive LED light bars which contains six strings in parallel and up to 10 WLEDs per string. The internal current sinks support a maximum of ±2% current mismatching for excellent brightness uniformity in each string of LEDs. To provide enough headroom for current sink operation, the boost controller monitors the minimum voltage of the feedback pins and regulates an optimized output voltage for power efficiency.

The RT4527A contains I2C interface for controlling the dimming mode, operating frequency and the LED current. The internal 250mΩ, 36V power switch with current-mode control provides over current protection.

The switching frequency of the RT4527A is also adjustable from 100kHz to 1.6MHz, which allows flexibility between efficiency and component size.

The RT4527A is available in the WQFN-20L 3.5 x 3.5 package.

Ordering Information

RT4527A□□

- Package Type
  QW : WQFN-20L 3.5x3.5 (W-Type)
- Lead Plating System
  G : Green (Halogen Free and Pb Free)

Note :

Richtek products are :

- RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- Suitable for use in SnPb or Pb-free soldering processes.

Features

- **Wide Operating Input Voltage : 2.7V to 24V**
- **High Output Voltage: Up to 36V**
- **Channel Current Programmable: 6mA to 25mA**
- **Channel Current Regulation with Accuracy ±3% and Matching ±2%**
- **Dimming Controls**
  - **Direct PWM up to 25kHz with Minimum 1% Duty**
  - **PWM to Analog up to 2kHz with 12-Bit Resolution, Up to 4kHz with 11-Bit Resolution, Up to 8kHz with 10-Bit Resolution**
  - **PWM to Mixed Up to 2kHz with 12-Bit Resolution, Up to 4kHz with 11-Bit Resolution**
  - **PWM to Mixed-26kHz up to 2kHz with 12-Bit Resolution, 4kHz with 11-Bit Resolution, Up to 8kHz with10-Bit Resolution**
- **I2C Programs LED Current, Switching Frequency, Dimming Mode**
- **Switching Frequency : 100kHz to 1.6 MHz**
- **Embedded Memory with MTP.**
- **Protections**
  - **LED Strings Open Protection**
  - **Current Limit Protection**
  - **Programmable Over Voltage Protection**
  - **Over Temperature Protection**
  - **Strings Short Detection**

Applications

- Tablet and Notebook LED Backlight

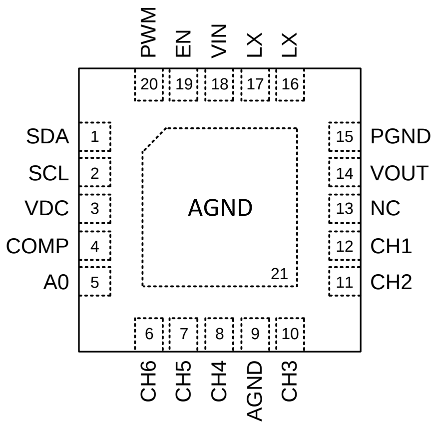
Marking Information

1N=YM
DNN

1N= : Product Code
YMDNN : Date Code

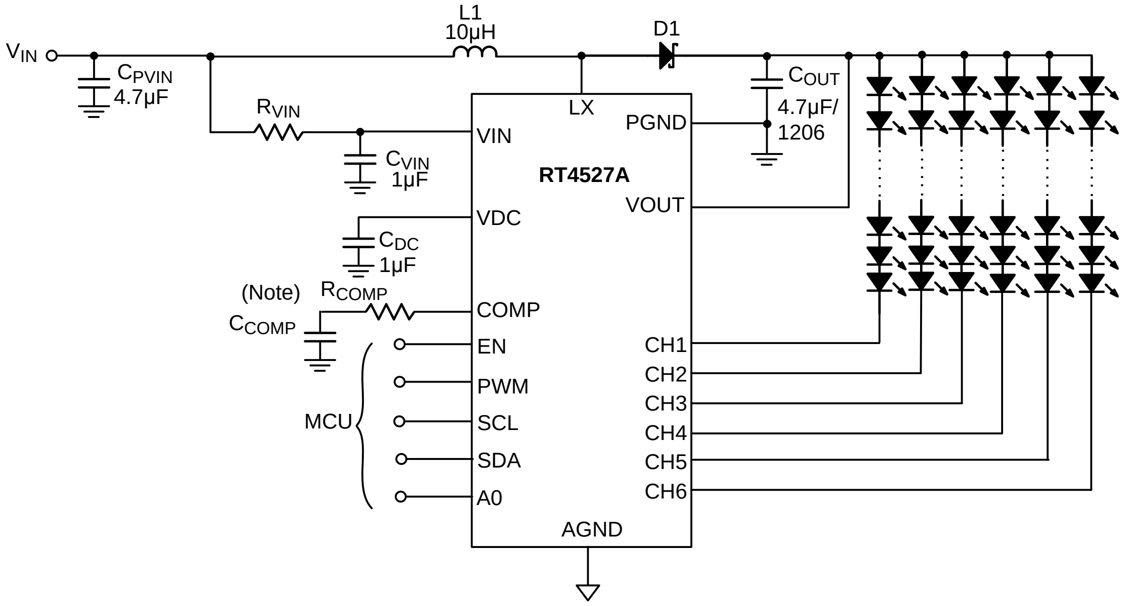
Pin Configuration

(TOP VIEW)



WQFN-20L 3.5x3.5

Typical Application Circuit

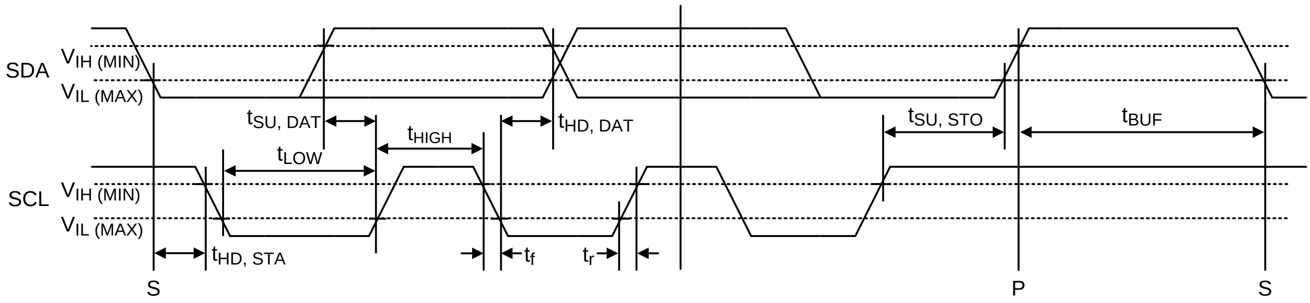


Note : RT4527A recommend to use differential compensation parameters for Low VIN application, For typical application, LED=6P11S, Boost Switching frequency = 1.225MHz, I_{LED} =2 4mA/CH, C_{OUT} = 4.7μF, L1 = 10μH, while the recommended value for compensation is as follows table:

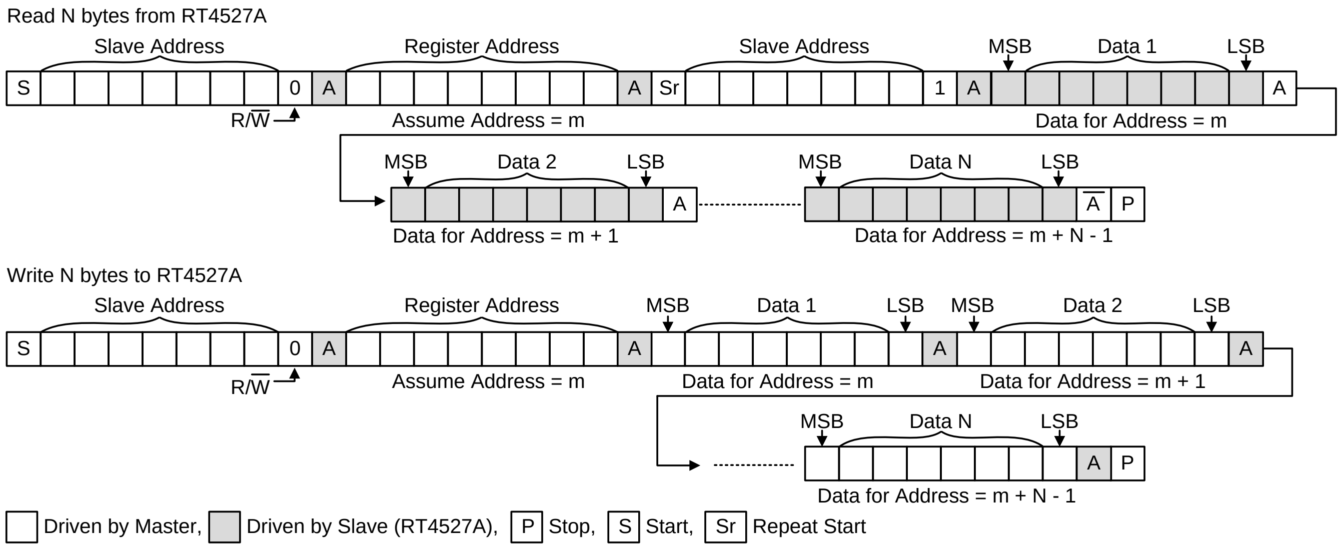
Case	V_{IN} Range (V)	R_{COMP} (kΩ)	C_{COMP} (nF)
Case1:PWM Mode	7~21V	20	1
Case2:DC Mode	5~21V	5.1	22

Timing Diagram

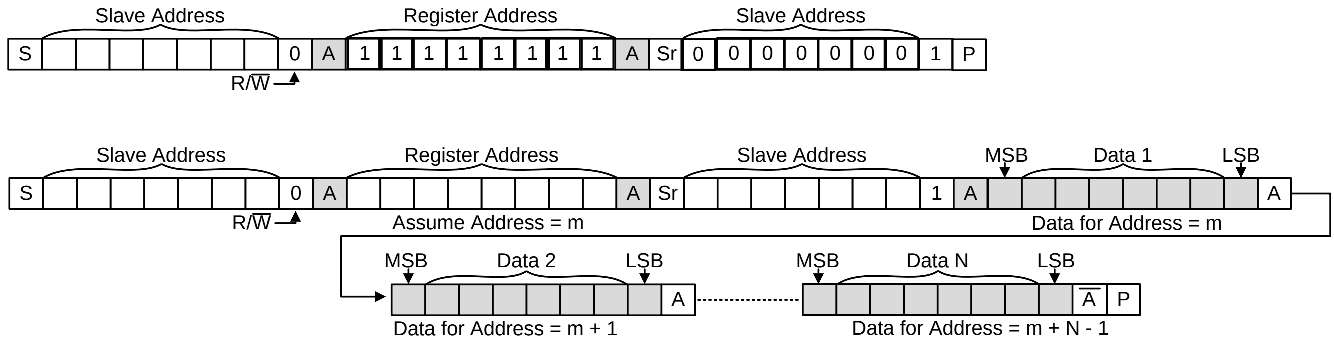
I^2C Interface



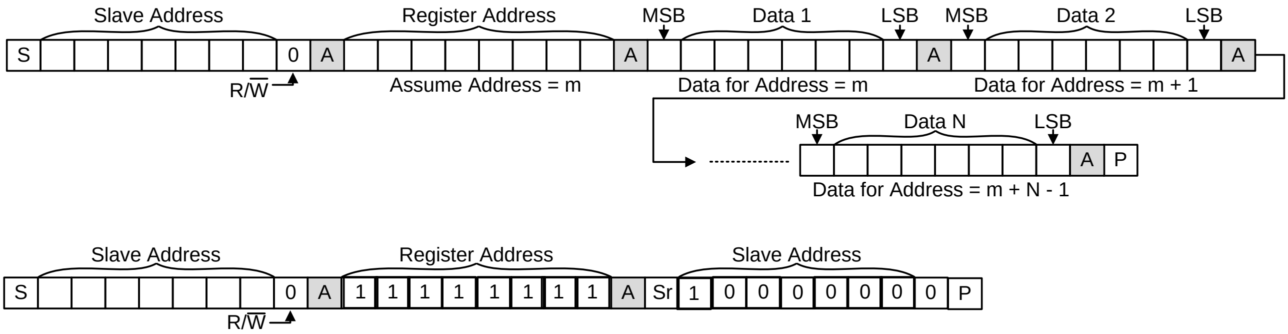
RT4527A I^2C slave address = 7'b0110_110(A_0 = 0) and 7'b0110_111(A_0 = 1). I^2C interface support fast mode (bit rate up to 400kb/s). The write or read bit stream ($N \geq 1$) is shown below



Read N bytes from RT4527A(from EEPROM)

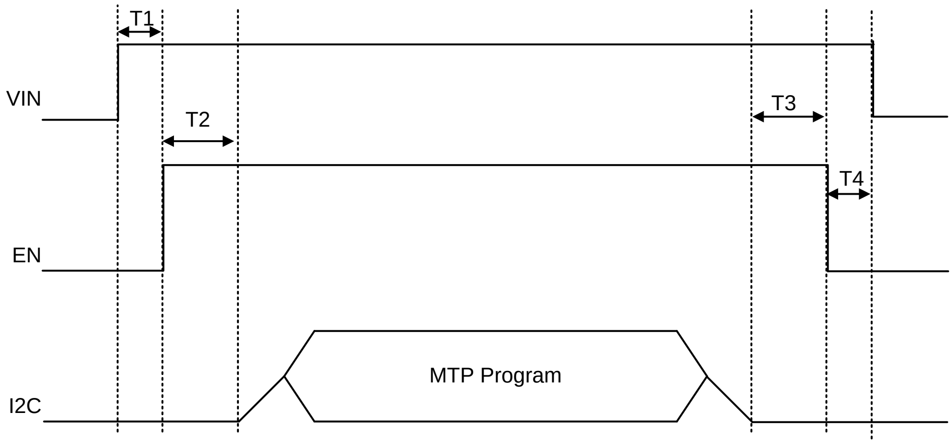


Write N bytes to RT4527A (to EEPROM)



Driven by Master, Driven by Slave (RT4527A), P Stop, S Start, Sr Repeat Start

MTP Program Sequence



Write :

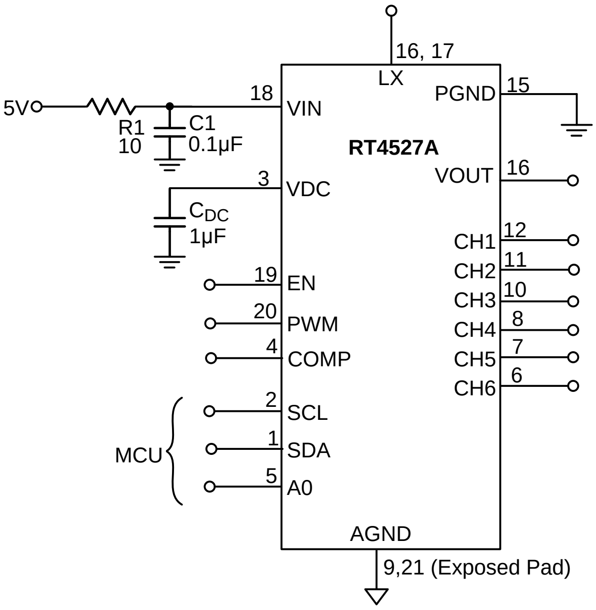
T1 = 30ms, T2 = 50ms, T3 = 500ms, T4 = 100ms

Read

T1 = 30ms, T2 = 50ms, T3 = 10ms, T4 = 100ms

f_{SCL} = 400kHz

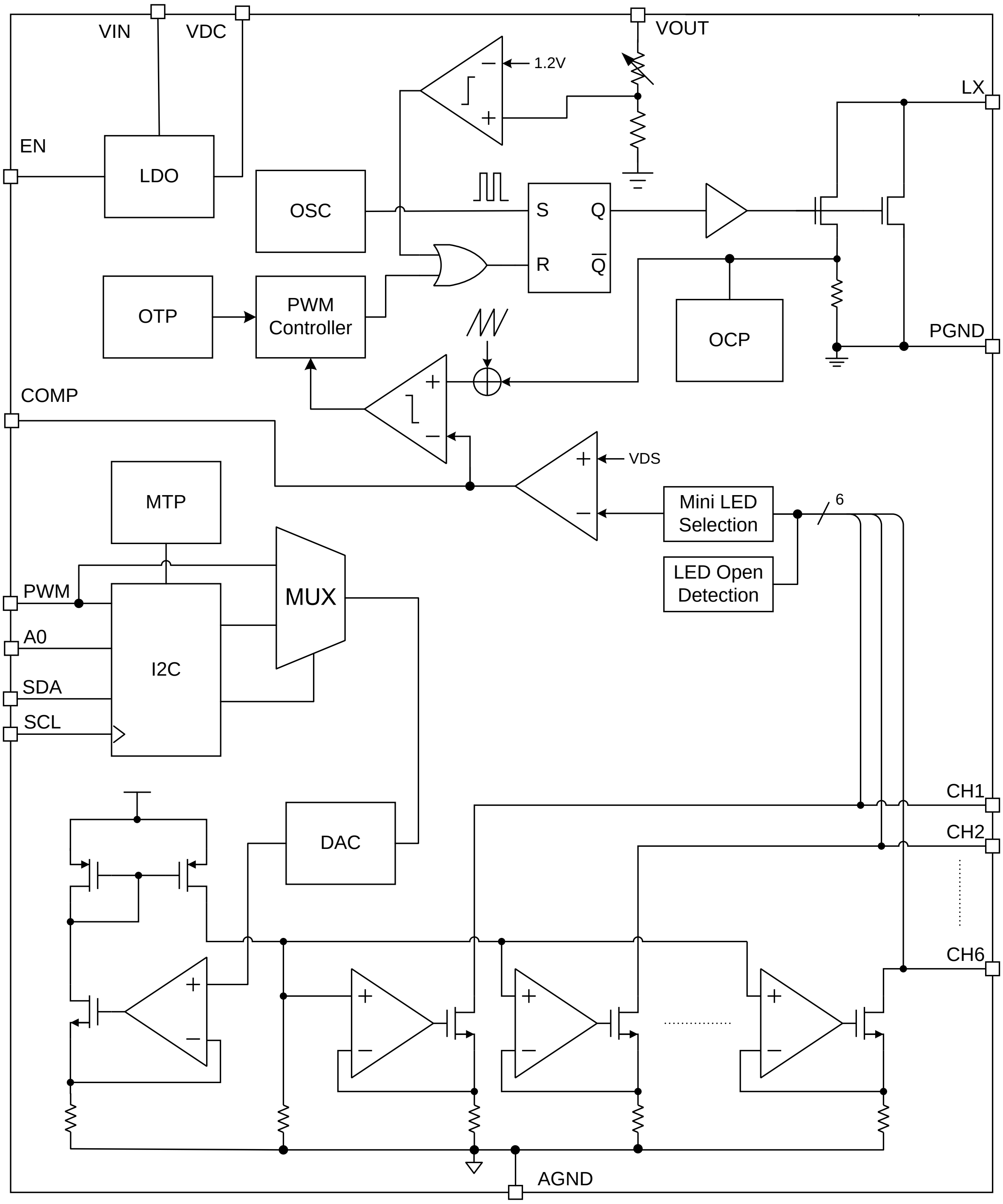
MTP Program Application Circuit for Single Chip



Functional Pin Description

Pin No.	Pin Name	Pin Function
1	SDA	Data signal pin of I^2C interface.
2	SCL	Clock signal pin of I^2C interface.
3	VDC	Output of internal regulator.
4	COMP	Boost external compensator pin.
5	A0	Device Address Select (7bits), A0 = 0 (Low)→(0x6Ch), A0 = 1 (High) → (0x6Eh).
6	CH6	Current sink for LED6.
7	CH5	Current sink for LED5.
8	CH4	Current sink for LED4.
10	CH3	Current sink for LED3.
11	CH2	Current sink for LED2.
12	CH1	Current sink for LED1.
13	NC	No internal connection.
14	VOUT	Output of boost converter.
15	PGND	Power ground.
16, 17	LX	Switch node of boost converter.
18	VIN	Power supply input.
19	EN	Enable control input (active high).
20	PWM	PWM dimming control input.
9, 21 (Exposed pad)	AGND	Analog ground. The exposed pad must be soldered to a large PCB and connect to AGND for maximum power dissipation.

Functional Block Diagram



Operation

Enable Control

When VIN is higher than the UVLO voltage and the EN pin input voltage is higher than rising threshold, the VDC will be regulated around 3.3V if VIN is higher than 3.3V.

Switching Frequency

The LED driver switching frequency is adjusted by the I2C. The switching frequency is from 100kHz to 1.6MHz.

PWM Controller

This controller includes some logic circuit to control LX N-MOSFET on/off. This block controls the minimum on-time and max duty of LX. The RT4527A PWM controller is a current mode Boost converter integrated with a 250mΩ, 40V power switch and can cover a wide VIN range from 2.7V to 24V and contains I2C interface. The part integrates under voltage lockout, build-in soft start, analog and digital dimming control; moreover, it provides the over voltage, over temperature and current limiting protection feature.

OCP & OTP

When LX N-MOSFET peak current is higher than 2.5A (typically), the LX N-MOSFET is turned off immediately and resumed again at next clock pulse. When the junction temperature is higher than 150°C (typically), the LX N-MOSFET will be turned off until the temperature is lower than the 130°C (typically).

Minimum LED Selection

This block detects all LEDx voltage and select a minimum voltage to EA (Error Amplifier). This function can guarantee the lowest of the LED pin voltage is around 500Mv (typically) and VOUT can be Boost to the highest forward voltage of LED strings.

LED Open Detection

If the voltage at LEDx pin is lower than 100mV, this channel is defined as open channel and the Minimum LED Selection function will discard it to regulate other used channels in proper voltage.

LED Strings short Detection

If CHx pin voltages exceeds the threshold of approximately 5.6V during normal operation, the channels will be turned off and it can reset by EN or UVLO.

Absolute Maximum Ratings (Note 1)

- Supply Input Voltage ---------- –0.3V to 26.5V
- VIN,EN,PWM to AGND ---------- –0.3V to 26.5V
- LX, VOUT, CH1, CH2, CH3, CH4, CH5, CH6 to AGND ---------- –0.3V to 40V
- SDA, SCL, VDC, A0 to AGND ---------- –0.3V to 6V
- Power Dissipation, P_D @ T_A = 25°C
- WQFN-20L 3.5x3.5 ---------- 2.77W
- Package Thermal Resistance (Note 2)

  WQFN-20L 3.5x3.5, θ_{JA} ---------- 36°C/W

  WQFN-20L 3.5x3.5, θ_{JC} ---------- 5.3°C/W
- Lead Temperature (Soldering, 10 sec.) ---------- 260°C
- Junction Temperature ---------- 150°C
- Storage Temperature Range ---------- –65°C to 150°C
- ESD Susceptibility (Note 3)

  HBM (Human Body Model) ---------- 3kV

Recommended Operating Conditions (Note 4)

- Supply Input Voltage ---------- 2.7V to 24V
- Ambient Temperature Range ---------- –40°C to 85°C
- Junction Temperature Range ---------- –40°C to 125°C

Electrical Characteristics

(V_{IN} = 4.2V, C_{VIN} = 1μF, T_A = 25°C, unless otherwise specified)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Input Power Supply						
Input Supply Voltage	V_{IN}		2.7	4.2	24	V
Quiescent Current	I_Q	EN = H, LX switching 300kHz	--	2.8	--	mA
		EN = H, LX no switching, PWM = 0%	--	2.2	--	mA
Shutdown Current	I_{SHDN}	V_{IN} = 4.2V, EN = L	--	--	10	μA
Under Voltage Lockout Threshold	V_{UVLO}		--	2.3	--	V
Under Voltage Lockout Hysteresis	ΔV_{UVLO}		--	200	--	mV
Interface Characteristic						
EN, PWM, SCL, SDA, A0 Input Voltage	V_{IH}		1.2	--	--	V
	V_{IL}		--	--	0.6	
Internal Pull Low Resistor for EN, PWM	R_{PULL_LOW}		--	1	--	MΩ
Internal Pull Low Current for SCL, SDA	I_{IH_2}		--	0.01	1	μA

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
Output Low Level for SDA	V_{OL_SDA}	External pull high current = 3mA	--	0.3	0.5	V
Output Leakage Current for SDA	V_{LK_DIO}	SDA pin voltage = 3.3V	--	--	1	μA
I2C Interface Timing						
Maximum I2C Clock Frequency	f_{SCL_MAX}		1	400	--	KHz
Hold Time for START and Repeated START Condition	t_{HO_I2C}		0.6	--	--	μs
SCL Clock Low Time	t_{LO_SCL}		1.3	--	--	μs
SCL Clock High Time	t_{HI_SCL}		600	--	--	ns
Setup Time for a Repeated START Condition	t_{SU_RSTART}		600	--	--	ns
SDA Data Hold Time	t_{HO_SDA}		50	--	--	ns
SDA Data Setup Time	t_{SU_SDA}		100	--	--	ns
Rise Time of SDA, SCL	$t_{RT\_SCL,SDA}$		--	--	300	ns
Fall Time of SDA, SCL	$t_{FT\_SCL,SDA}$		--	--	300	ns
Setup Time for STOP Condition	t_{SU_STOP}		600	--	--	ns
I2C Bus Free Time Between a STOP and a START	t_{FREE_BUS}		1.3	--	--	μs
Capacitive Load for I2C Bus	C_b		--	--	400	pF
Boost Converter						
Switching Frequency Accuracy	f_{SW_ACC}	Boost operates at PWM mode, f_{SW} = 300KHz	–15	--	15	%
Switching Frequency Setting Range	f_{SW_RG}	Boost operates at PWM mode	0.1	--	1.6	MHz
Maximum Duty Cycle	D_{MAX}	f_{SW} = 300KHz	90	95	--	%
Boost Switch RDSON	$R_{DS(ON)}$	V_{IN} = 4.2V	--	250	--	mΩ
Switching Current Limitation	I_{OCP}		2	2.5	3	A
Boost Minimum ON Time	t_{MON}		--	100	--	ns
VOUT Over Voltage Limit	V_{OVP}	Register address = "02h", 5 bits step = 1V, default = 36V, C_{OUT} = 4.7μF	--	36	--	V
LED Current						
Leakage Current of CHx	I_{LK_CSX}	V_{CHx} = 36V, I_{CHx} = 0mA	--	--	2	μA
Minimum CHx Regulation Voltage	V_{CS_MIN}	I_{CHx} = 20mA	0.35	0.5	--	V
Maximum LED Current Setting	I_{CS_MAX}	LED 100% setting	6	--	25	mA
Minimum LED Current Setting	I_{CS_MIN}	Setting by dimming	100	--	--	μA

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
LED Current Accuracy	I_{CS_ACC}	PWM duty = 100%, I_{CHx} = 20mA , PWM Freq = 1kHz	–3	--	3	%
		PWM duty = 15%, I_{CHx} = 20mA , PWM Freq = 1kHz	–3	--	3	%
		PWM duty = 5%, I_{CHx} = 20mA , PWM Freq = 1kHz	–5	--	5	%
		PWM duty = 1%, I_{CHx} = 20mA , PWM Freq = 1kHz	–15	--	15	%
LED Current Matching	I_{CS_MAT}	PWM duty = 100%, I_{CHx} = 20mA , PWM Freq = 1kHz	–2	--	2	%
		PWM duty = 15%, I_{CHx} = 20mA , PWM Freq = 1kHz	–2	--	2	%
		PWM duty = 5%, I_{CHx} = 20mA , PWM Freq = 1kHz	–5	--	5	%
		PWM duty = 1%, I_{CHx} = 20mA , PWM Freq = 1kHz	–10	--	10	%
DC Dimming Resolution	S_{res_2k}	PWM Freq < 2kHz	--	4096	--	Steps
	S_{res_4k}	PWM Freq = 2 to 4kHz	--	2048	--	Steps
	S_{res_8k}	PWM Freq = 4 to 8kHz	--	1024	--	Steps
	S_{res_25k}	PWM Freq = 8 to 25kHz	--	512	--	Steps
PWM Minimum On Time	t_{PWM_MIN}	PWM Dimming Freq = 25kHz	--	400	--	ns
Protection						
OTP Threshold	T_{OTP}		--	150	--	°C
OTP Hysteresis	T_{OTPHYS}		--	20	--	°C
Light bar open threshold	V_{CS_OPEN}		--	0.1	--	V
Light bar short threshold	V_{VLED_SHORT}		--	5.6	--	V
MTP						
Data Write Time	TWR	Timing of write one page into MTP(16 byte)	--	60	--	ms

Note 1. Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

Note 2. θ_{JA} is measured under natural convection (still air) at T_A = 25°C with the component mounted on a high effective-thermal-conductivity four-layer test board on a JEDEC 51-7 thermal measurement standard. θ_{JC} is measured at the exposed pad of the package.

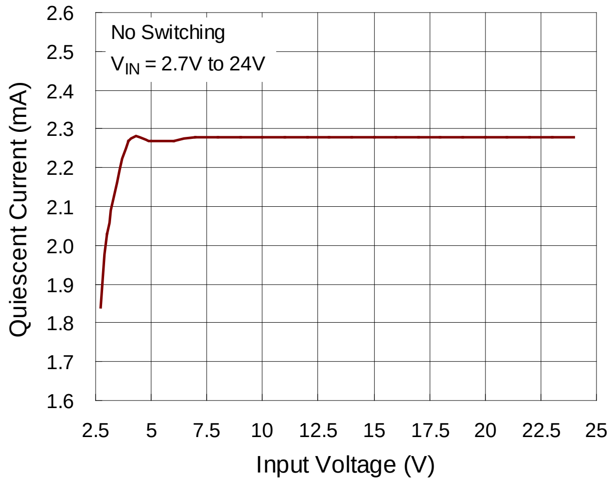
Note 3. Devices are ESD sensitive. Handling precaution is recommended.

Note 4. The device is not guaranteed to function outside its operating conditions.

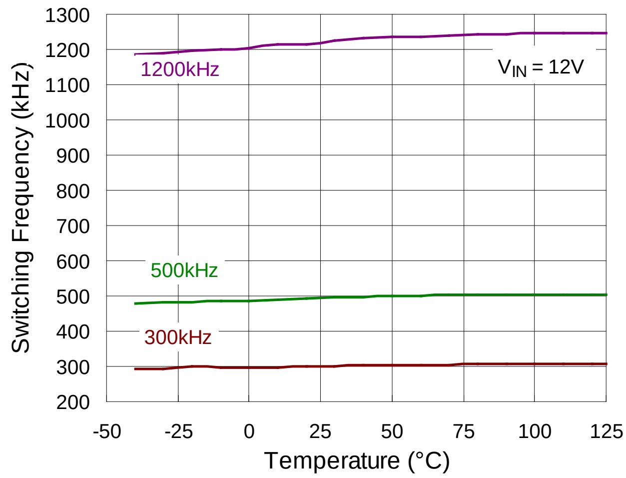
Note 5. VIN voltage have to rise 2.8V level, I2C can write to MTP.

Typical Operating Characteristics

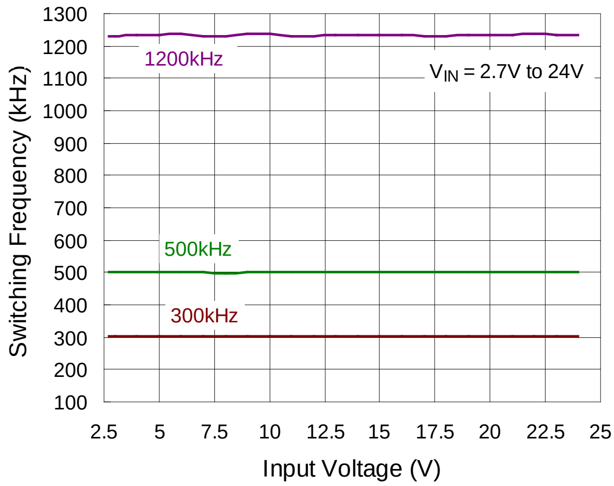
Quiescent Current vs. Input Voltage



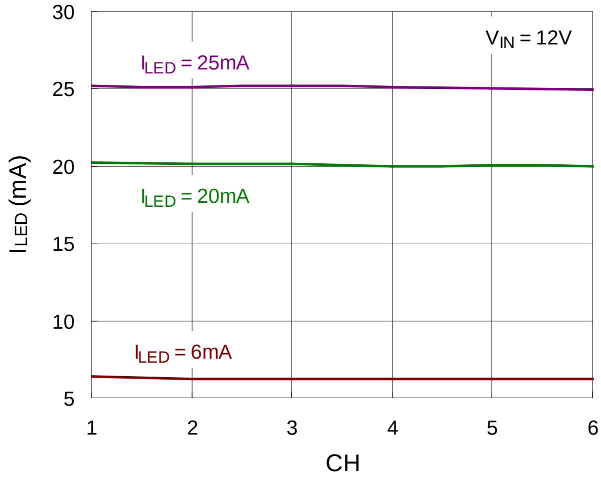
Switching Frequency vs. Temperature



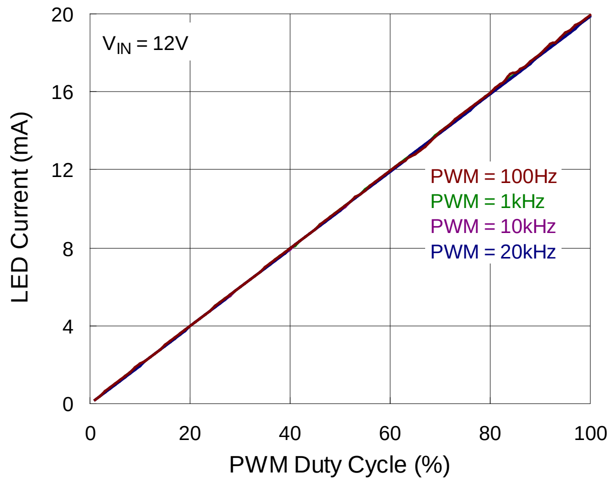
Switching Frequency vs. Input Voltage



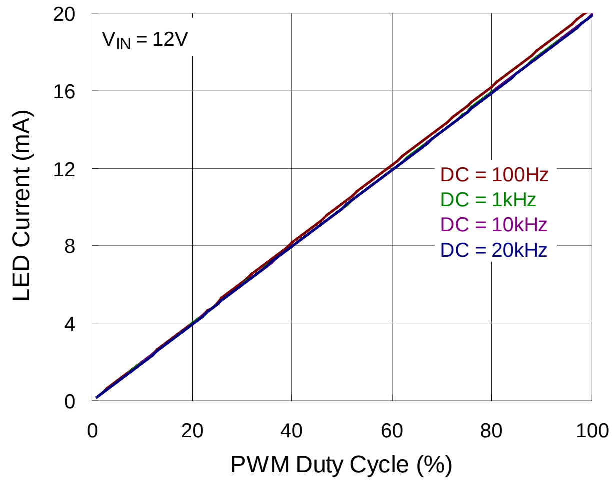
Channel Output Current vs. Channel

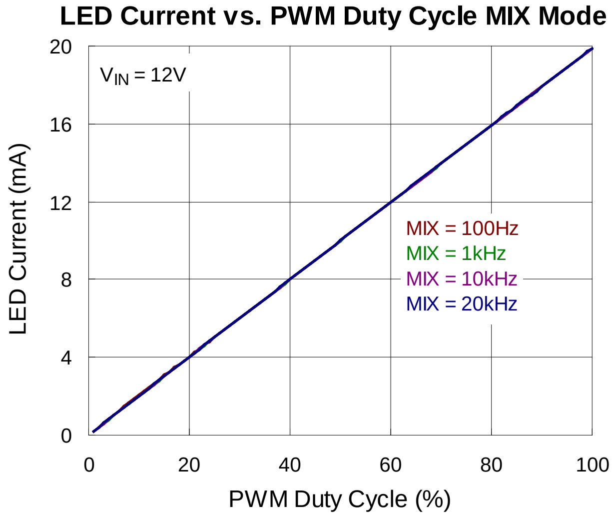


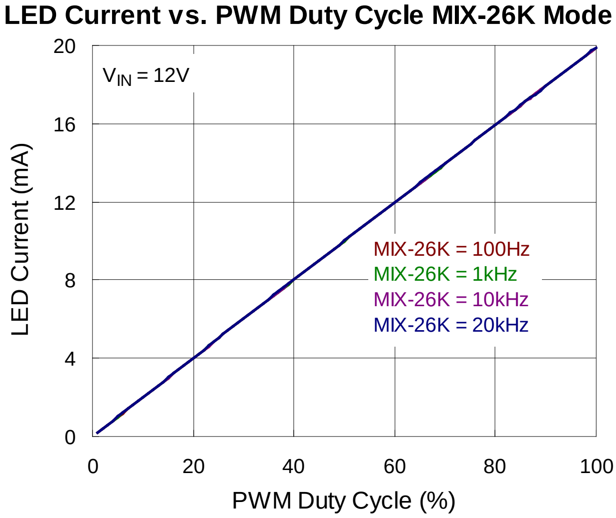
LED Current vs. PWM Duty Cycle PWM Mode

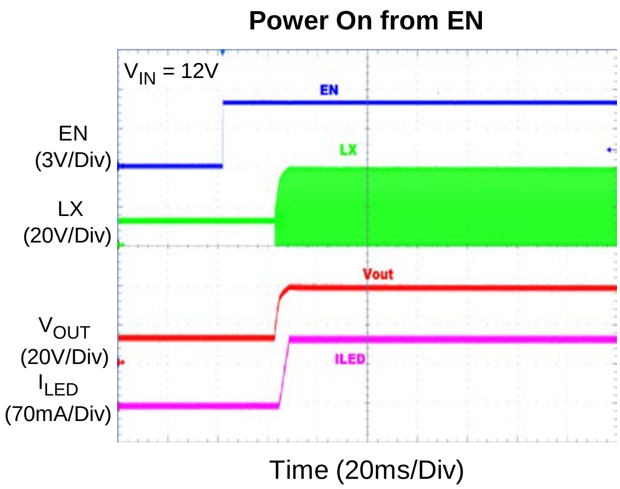


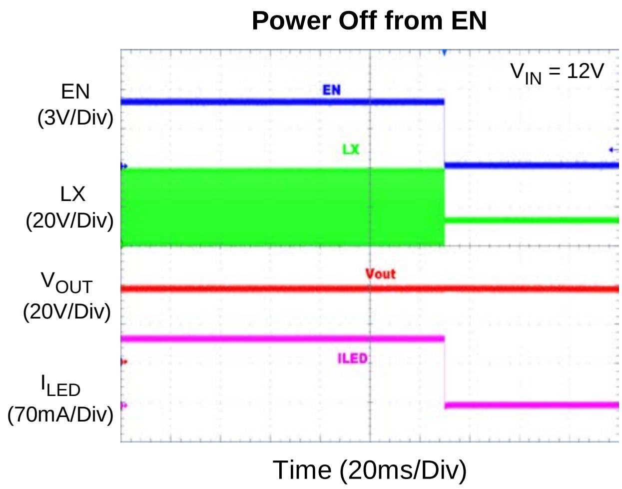
LED Current vs. PWM Duty Cycle DC Mode




LED Current vs. PWM Duty Cycle MIX Mode
V_{IN} = 12V
MIX = 100Hz
MIX = 1kHz
MIX = 10kHz
MIX = 20kHz
LED Current (mA)
PWM Duty Cycle (%)
0
4
8
12
16
20
0
20
40
60
80
100


LED Current vs. PWM Duty Cycle MIX-26K Mode
V_{IN} = 12V
MIX-26K = 100Hz
MIX-26K = 1kHz
MIX-26K = 10kHz
MIX-26K = 20kHz
LED Current (mA)
PWM Duty Cycle (%)
0
4
8
12
16
20
0
20
40
60
80
100


Power On from EN
V_{IN} = 12V
EN (3V/Div)
LX (20V/Div)
V_{OUT} (20V/Div)
I_{LED} (70mA/Div)
EN
LX
Vout
ILED
Time (20ms/Div)


Power Off from EN
V_{IN} = 12V
EN (3V/Div)
LX (20V/Div)
V_{OUT} (20V/Div)
I_{LED} (70mA/Div)
EN
LX
Vout
ILED
Time (20ms/Div)

Application Information

Register Map

Note : Blank part in table is restricted register.

<table>
<tr><td colspan="10">Slave Address : b0110110/b0110111</td></tr>
<tr><th>Register Address</th><th>bit7</th><th>bit6</th><th>bit5</th><th>bit4</th><th>bit3</th><th>bit2</th><th>bit1</th><th>bit0</th><th>Default Value</th></tr>
<tr><td>0x00</td><td colspan="6">Reserved[7:2]</td><td colspan="2">Dimming Mode Selection</td><td>01h</td></tr>
<tr><td>0x01</td><td colspan="8">ILED Current Setting</td><td>8Dh</td></tr>
<tr><td>0x02</td><td>Boost Compensation</td><td colspan="5">Over Voltage Protection Selection</td><td colspan="2">VIN UVLO Selection</td><td>E8h</td></tr>
<tr><td>0x03</td><td colspan="2">Reserved[7:6]</td><td>PFM Function Enable</td><td>Reserved</td><td colspan="4">Boost Switching Frequency</td><td>24h</td></tr>
<tr><td>0x04</td><td colspan="6">Lowest Switching Frequency for PFM</td><td colspan="2">LX Edge Rate Control</td><td>F3h</td></tr>
<tr><td>0x05</td><td colspan="8">Reserved[7:0]</td><td>00h</td></tr>
<tr><td>0x06</td><td colspan="2">Reserved[7:6]</td><td colspan="2">Internal Setting</td><td colspan="2">Reserved[3:2]</td><td colspan="2">LED Driver Headroom</td><td>22h</td></tr>
<tr><td>0x07</td><td colspan="3">Reserved[7:5]</td><td>LED Short Protection</td><td colspan="2">Reserved[3:2]</td><td colspan="2">LED OVP Level</td><td>00h</td></tr>
<tr><td>0x08</td><td>Reserved</td><td>Fading Time Duty Change Threshold</td><td colspan="3">Fading Time_SEL2</td><td colspan="3">Fading Time_SEL1</td><td>00h</td></tr>
<tr><td>0x10</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0x11</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0x12</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0x13</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0x14</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0x15</td><td colspan="9">Reserved[7:0]</td></tr>
<tr><td>0xFF</td><td>MTP Programming</td><td colspan="6">Reserved[6:1]</td><td>MTP Read</td><td>00h</td></tr>
</table>

Note 6. Writing 0 when writing Reserved bit.

Note 7. Address: 0x06h Internal Setting bit5 writing 1 and bit4 writing 0.

The RT4527A is a general purpose 6-CH LED driver and is capable of delivering a maximum 25mA LED current. The IC is a current mode Boost converter integrated with a 2.5A power switch and can cover a wide VIN range from 2.7V to 24V and contains I2C interface for controlling the dimming mode, operating frequency and the LED current. The Internal 250mΩ, 40V power switch with current-mode control provides over current protection. The switching frequency of the RT4527A is adjustable from 100kHz to 1.6MHz, which allows flexibility between efficiency and component size. The part integrates under voltage lockout, build-in soft start, analog and digital dimming control; moreover, it provides the over voltage, over temperature and current limiting protection feature.

Programmable functions includes :

- PWMO frequencies
- LED constant current
- Boost switching frequency
- Slope for brightness changes
- Output Current Resolution

Brightness Control by PWM Pin

The RT4527A provide four dimming modes for controlling the LED brightness. The four dimming modes include PWM mode, DC mode, Mix mode and Mix-26K mode, and the dimming mode could be set by register 00h. The RT4527A can support PWM to Analog, PWM to Mix and PWM to Mix-26kHz dimming up to 4kHz with 11-bit resolution.

Table 2. Dimming Control Mode Selection

Address	Bit	Name	Default Value	Description	R/W
00h	[1:0]	Dimming Mode Selection	DC Mode (B01)	B00: PWM Mode B01: DC Mode B10: MIX Mode B11:MIX-26K Mode	R/W

LED Current Setting

The LED current of each channel could be set by I2C command; it is shown in the Table 3.

Table 3. LED Current Setting

Address	Bit	Name	Default Value	Description	R/W
01h	[7:0]	LED Current Setting	20mA (0x8Dh)	Control the max current. 0x01h to 0xBFh : 6mA~25mA (Table)	R/W

The one step of LED current is approximately 0.1mA.

LED_Curr <7:0>	I_{LED} (mA)	LED_Curr <7:0>	I_{LED} (mA)	LED_Curr <7:0>	I_{LED} (mA)	LED_Curr <7:0>	I_{LED} (mA)	LED_Curr <7:0>	I_{LED} (mA)	LED_Curr <7:0>	I_{LED} (mA)
BF	25	9E	21.7	7D	18.4	5C	15.1	3B	11.8	1A	8.5
BE	24.9	9D	21.6	7C	18.3	5B	15	3A	11.7	19	8.4
BD	24.8	9C	21.5	7B	18.2	5A	14.9	39	11.6	18	8.3
BC	24.7	9B	21.4	7A	18.1	59	14.8	38	11.5	17	8.2
BB	24.6	9A	21.3	79	18	58	14.7	37	11.4	16	8.1
BA	24.5	99	21.2	78	17.9	57	14.6	36	11.3	15	8
B9	24.4	98	21.1	77	17.8	56	14.5	35	11.2	14	7.9
B8	24.3	97	21	76	17.7	55	14.4	34	11.1	13	7.8
B7	24.2	96	20.9	75	17.6	54	14.3	33	11	12	7.7
B6	24.1	95	20.8	74	17.5	53	14.2	32	10.9	11	7.6
B5	24	94	20.7	73	17.4	52	14.1	31	10.8	10	7.5
B4	23.9	93	20.6	72	17.3	51	14	30	10.7	0F	7.4
B3	23.8	92	20.5	71	17.2	50	13.9	2F	10.6	0E	7.3
B2	23.7	91	20.4	70	17.1	4F	13.8	2E	10.5	0D	7.2
B1	23.6	90	20.3	6F	17	4E	13.7	2D	10.4	0C	7.1
B0	23.5	8F	20.2	6E	16.9	4D	13.6	2C	10.3	0B	7
AF	23.4	8E	20.1	6D	16.8	4C	13.5	2B	10.2	0A	6.9
AE	23.3	8D	20	6C	16.7	4B	13.4	2A	10.1	09	6.8
AD	23.2	8C	19.9	6B	16.6	4A	13.3	29	10	08	6.7
AC	23.1	8B	19.8	6A	16.5	49	13.2	28	9.9	07	6.6
AB	23	8A	19.7	69	16.4	48	13.1	27	9.8	06	6.5
AA	22.9	89	19.6	68	16.3	47	13	26	9.7	05	6.4
A9	22.8	88	19.5	67	16.2	46	12.9	25	9.6	04	6.3
A8	22.7	87	19.4	66	16.1	45	12.8	24	9.5	03	6.2
A7	22.6	86	19.3	65	16	44	12.7	23	9.4	02	6.1
A6	22.5	85	19.2	64	15.9	43	12.6	22	9.3	01	6
A5	22.4	84	19.1	63	15.8	42	12.5	21	9.2	00	0
A4	22.3	83	19	62	15.7	41	12.4	20	9.1		
A3	22.2	82	18.9	61	15.6	40	12.3	1F	9		
A2	22.1	81	18.8	60	15.5	3F	12.2	1E	8.9		
A1	22	80	18.7	5F	15.4	3E	12.1	1D	8.8		
A0	21.9	7F	18.6	5E	15.3	3D	12	1C	8.7		
9F	21.8	7E	18.5	5D	15.2	3C	11.9	1B	8.6		

VIN UVLO Selection

The VIN UVLO selection could be set by the I2C, it is shown in the Table 4. When the VIN UVLO Selection command is below B00, the VIN UVLO voltage will be kept at 2.3V. The maximum VIN UVLO voltage selection is 3.8V.

OVP Level Selection

The RT4527A integrates over voltage protection. The over voltage protection could be set by the I2C, the voltage of over voltage protection (VOVP) could be selected as the Table 4.

Table 4. VIN UVLO Selection & OTP Selection & Boost Compensation

Address	Bit	Name	Default Value	Description	R/W
02h	[1:0]	VIN UVLO Selection	2.3V (B00)	VIN UVLO Selection B00: 2.3V B01: 2.7V B10: 3.2V B11: 3.8V	R/W
	[6:2]	Over Voltage Protection Selection	36V (0x1Ah)	Boost Output Over Voltage Protection 0x00h to 0x1Eh : 10V to 40V (Table)	R/W
	[7:7]	Boost Compensation	Internal(B01)	Boost Compensation B00: External B01: Internal	R/W

Over Voltage Protection Selection [6:2]	Boost Output Over Voltage (V)
0x00h	10
0x01h	11
0x02h	12
0x03h	13
0x04h	14
0x05h	15
0x06h	16
0x07h	17
0x08h	18
0x09h	19
0x0Ah	20
0x0Bh	21
0x0Ch	22
0x0Dh	23
0x0Eh	24
0x0Fh	25
0x10h	26
0x11h	27
0x12h	28
0x13h	29
0x14h	30
0x15h	31

Over Voltage Protection Selection [6:2]	Boost Output Over Voltage (V)
0x16h	32
0x17h	33
0x18h	34
0x19h	35
0x1Ah	36
0x1Bh	37
0x1Ch	38
0x1Dh	39
0x1Eh	40

Boost Switching Frequency Setting

The LED driver switching frequency is adjusted by the I2C, the switching frequency setting range and resolutions are shown in the Table 5.

PFM Function Enable

The PFM function could be set by I2C command; it is shown in the Table 5.

Table 5. Switching Frequency Setting

Address	Bit	Name	Default Value	Description	R/W
03h	[3:0]	Boost Switching Frequency	300kHz (0x04h)	0x00h: 100kHz 0x04h: 300kHz 0x0Fh: 1600kHz (Table)	R/W
	[5:5]	PFM Function Enable	B1	B0:off B1:on	R/W

Boost Switching Frequency [3:0]	Frequency (kHz)
0x00h	100
0x01h	150
0x02h	200
0x03h	250
0x04h	300
0x05h	400
0x06h	500
0x07h	600
0x08h	700
0x09h	800
0x0Ah	900
0x0Bh	1000
0x0Ch	1225
0x0Dh	1335
0x0Eh	1450
0x0Fh	1600

LX Slew Rate Control

The LED driver LX Slew Rate is adjusted by the I2C, the slew rate level and resolutions are shown in the Table 6.

Lowest Switching Frequency for PFM

The lowest switching frequency for PFM is adjusted by the I2C, the lowest switching frequency for PFM setting formula shown in the Table 6.

Table 6. LX Slew Rate and Lowest Switching Frequency of PFM Control

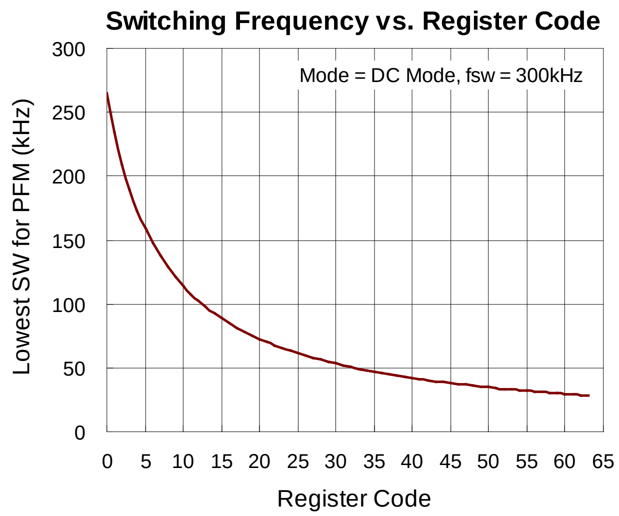
Address	Bit	Name	Default Value	Description	R/W
04h	[1:0]	LX Edge Rate Control	200% (B11)	B00: 25% B01: 50% B10: 100% B11: 200%	R/W
	[7:2]	Lowest Switching Frequency for PFM	0x3Ch	Lowest switching frequency setting Formula : 16000/{16000/FSW}+(8*DAC)+7}	R/W

Note : FSW = Boost Switching Frequency setting by address 0x03h[3:0]

DAC = Lowest Switching Frequency for PFM setting by address 0x04h[7:2]

The PFM function enable can be control by address 03h[5:5]. If the bit equals to 0, it means the boost switching frequency just depends on the switching frequency setting. Otherwise, if the bit equals to 1, the boost switching frequency will be decreased, when the boost on time is lower

than the minimum on time.



LED Driver Headroom

The LED driver headroom could be set by the I2C, it is shown in the Table 7.

Table 7. LED Driver Headroom Setting

Address	Bit	Name	Default Value	Description	R/W
06h	[1:0]	LED Driver Headroom	B10	LED driver headroom B00: 400mV B01: 460mV B10: 500mV B11: 560mV	R/W

This block detects all CHx voltage and selects a minimum voltage to EA (Error Amplifier). When the LED driver headroom command is below B00, the LED driver headroom will be kept at 500mV and Vout can be boost to the highest forward voltage of LED strings. The Maximum LED driver headroom voltage is 560mV.

LED Protection

RT4527A has LED protection for LED OVP level. The LED protection could be set by the I2C, it is shown in the Table 8.

Table 8. LED Protection Setting

Address	Bit	Name	Default Value	Description	R/W
07h	[1:0]	LED OVP level	B00	LED OVP level B00: 2.1V B01: 2.52V B10: 2.8V B11: 3.5V	R/W
	[4:4]	LED Short Protection	B0	B0: off B1: on	R/W

LED OVP Level

The LED OVP level can be control by address 07h[1:0], there are four kind of LED OVP level that is from 2.1V to 3.5V.When the command is below B00, the LED OVP level that is the minimum CHx voltage up to the target level will be kept at 2.1V. This function can guarantee the highest of LED OVP level is 3.5V. When the minimum CHx voltage rises above the LED OVP level setting, the internal switch will be turned off. Once the minimum CHx voltage drops below the LED OVP level setting, the internal switch will be turned on again. The minimum CHx voltage can be clamped at the LED OVP level setting.

LED Short Protection

The LED short protection can be control by address 07h[4:4]. If the bit equals to 0, it means the function is turn off. Otherwise, if the bit equals to 1, the function is turn on. If CHx pin voltages exceeds the threshold of approximately 5.6V during normal operation, the channels will be turned off and it can reset by EN or UVLO.

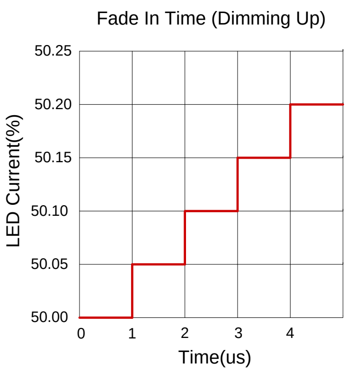
Fade IN / OUT Time Control

The fading time duty change threshold and fade in / out time control could be set by the I2C, it is shown in the Table 9.

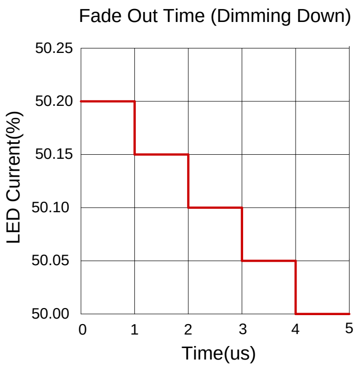
Table 9. Fade IN/OUT Time Setting

Address	Bit	Name	Default Value	Description	R/W
08h	[2:0]	Fading Time_SEL1 (Duty<Fading Time Duty Change Threshold)	1us(B000)	B000: 1us B001: 4us B010: 16us B011: 64us B100: 1024us B101: 4096us B110: 8192us B111: 16384us	R/W
	[5:3]	Fading Time_SEL2 (Duty>Fading Time Duty Change Threshold)	1us(B000)	B000: 1us B001: 4us B010: 16us B011: 64us B100: 512us B101: 1024us B110: 2048us B111: 4096us	R/W
	[6:6]	Fading Time Duty Change Threshold	12.5%(B0)	B0: 12.5% B1: 25%	R/W

Fade time duty change threshold can be control by address 08h[6:6], If the bit equals to 0, it means the PWM duty be smaller than 12.5% that the brightness time of per step can be control by address 08h[5:0], other the brightness time of per step will be kept at 1μs. Otherwise, if the bit equals to 1, the PWM duty be smaller than 25% that the brightness time of per step can be control by address 08h[5:0], other the brightness time of per step will be kept at 1μs. Fade in / out time can be control by address 08h[5:0]. There are eight brightness times that adjust range from 1μs to 16384μs. When the fade in/out command is below B000, the brightness time of per step will be kept at 1μs. This function can guarantee the highest of fade in/out time is 16384μs. The below Figure shows the fade in/out time at 11 bit resolution.



LED Current (Dimming Up) vs. Fade In Time



LED Current (Dimming Down) vs. Fade Out Time

MTP (Non-Volatile memory) Function

The RT4527A has MTP function for MTP Programming, MTP Read. The MTP function could be set by the I2C, it is shown in the Table 10. VIN must rise to 5V level, I2C can write to MTP

Table 10. LX Slew Rate Control

Address	Bit	Name	Default Value	Description	R/W
FFh	[0:0]	MTP Read	B0	MTP Read B0: I2C read data from DAC B1: I2C read data from MTP	R/W
FFh	[7:7]	MTP Programming	B0	MTP Programming B0: normal operation B1: start MTP programming sequence	R/W

The MTP register stores the RT4527A default settings. When power on, the contents of the MTP register are transferred to the I2C register. Writes and reads can be made directly to control the I2C register. MTP register are without any changes. If MTP default value must be changed, first to write all desired data to I2C register. Finally to write address FFh = 0xF0, it will write all I2C register data into MTP register.

LED Connection

The RT4527A equips 6-CH LED drivers and each channel supports up to 10 LEDs (Vf = 3V). The LED strings are connected from the output of the boost converter to pin LEDx (x = 1 to 6) respectively. If one of the current sink channels is not used, the LEDx pin should be connected to GND. If the un-used channel is not connected to GND, it will be considered that the LED string is opened; the channel will turn light when the LED string is recovering connected.

Open LED Protection

If the LEDx pin voltage is low to 0.1V, the LED driver will judge the channel to be open. The LEDx pin voltage will not be regulated and not latch, until the LEDx pin is recovery connected, the LEDx pin will normal work again. If all LEDx pin are open (floating), the output voltage will be clamped to the setting voltage of OVP (VOUT(OVP)).

Compensation

The regulator loop can be compensated by adjusting the external components connected to the COMP pin. The COMP pin is the output of the internal error amplifier. The compensation capacitor will adjust the integrator zero to maintain stability and the resistor value will adjust the frequency integrator gain for fast transient response. Typical value of the compensation components is CComp = 1nF and RComp = 20kΩ.

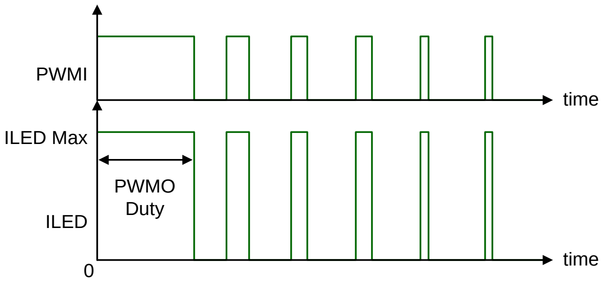
PWM, DC, Mix and Mix-26K Mode Brightness Dimming

The RT4527A dimming mode include PWM, DC, Mix and Mix-26K mode, and the dimming mode could be set by register 00h.

Table 11. Input PWM Dimming Frequency vs Duty(Mixed, Mixed-26k, PWM and DC Dimming Mode)

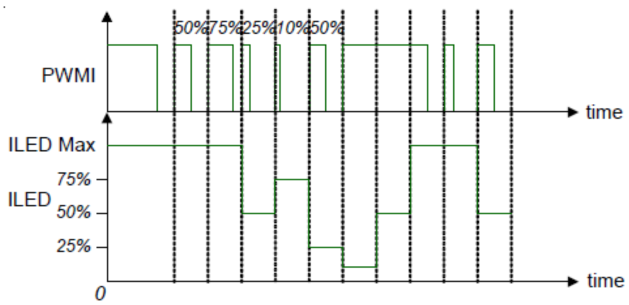
Dimming Frequency (Hz)	Duty(Min)	Duty(Max)
$100 < f_{PWM} \le 200$	0.50%	100%
$200 < f_{PWM} \le 500$	0.50%	100%
$500 < f_{PWM} \le 1k$	0.50%	100%
$1k < f_{PWM} \le 2k$	0.50%	100%
Note : The minimum duty in Table is based on the application circuit and does not consider the deviation of current linearity when f_{PWM} > 2kHz, I_{LED} may not achieve setting current in duty(min.) due to different VOUT/VIN ratio. For high accuracy for LED current, the I_{LED} current is recommended to set at default code.		

PWM Mode Dimming: address 00h [1:0] = 00h, the dimming mode operates in PWM mode. During the PWM dimming, the current source turn-on/off is synchronized with the PWM signal. The LED current frequency is equivalent to PWM input frequency.



PWM Dimming

DC Mode Dimming: address 00h [1:0] = 01h, the dimming mode operates in DC mode. The PWM and ILED will delay two period. First cycle delay is required for period, while the second cycle delay is for the duty rate calculation.

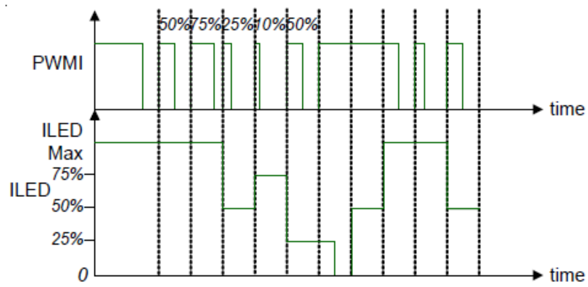


DC Dimming

Mix / Mix-26K Mode Dimming: address 00h [1:0] = 02 ~ 03h, the dimming mode operates in Mix / Mix-26K Mode. The PWM and ILED will delay two period. First cycle delay is required for period, while the second cycle delay is for the duty rate calculation.

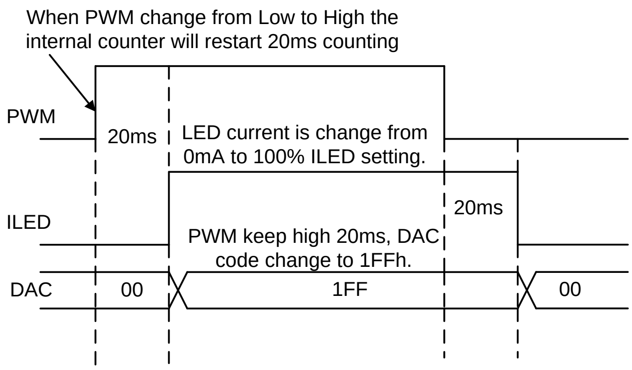
When 25% ≤ PWM duty ≤ 100%, the current source outputs are DC dimming, and the PWM duty cycle modulates the amplitude of the currents in 100% dimming.

PWM Duty < 25%, the DC dimming will translate to DC-PWM dimming to control the LED current. In this state, the LED current is fixed at 0.25 x ISET, and the dimming duty is 4 x PWM duties and Mix-26K dimming frequency are 24kHz to 27.5kHz.



Mixed Mode Dimming

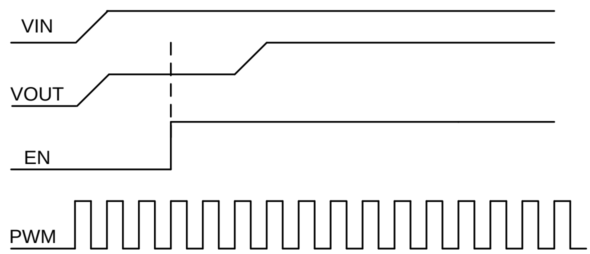
*During DC / Mix Mode dimming, when PWM Duty 100% and 0% ILED behavior show in Figure.



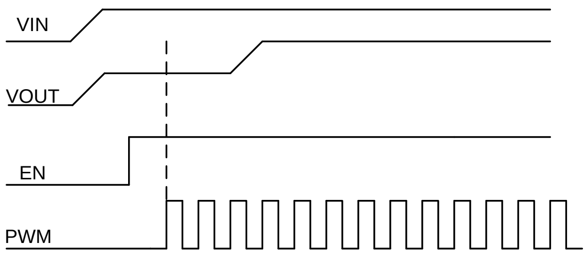
Duty 100% and Duty 0% ILED behavior.

Power Sequence

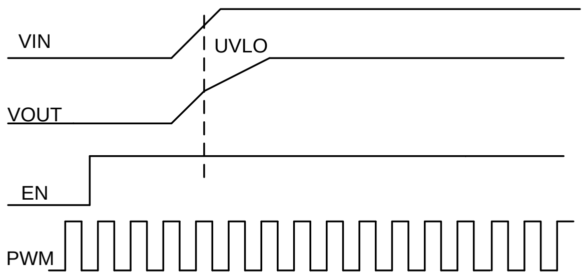
LED Driver is without power sequence concern for power on sequence free. Figure is different power sequences respectively. There is no concern in the above condition.



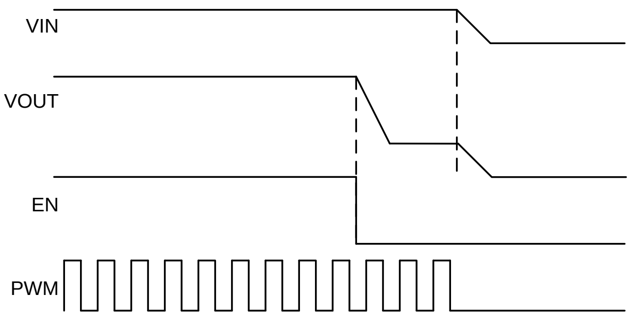
Power On Mode 1



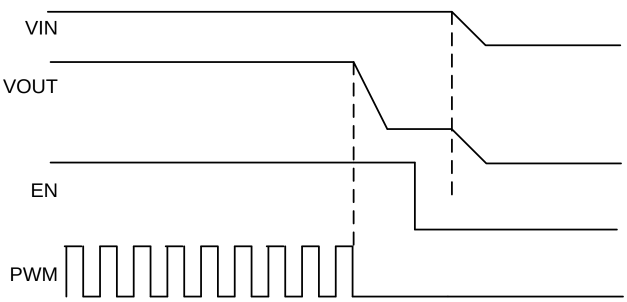
Power On Mode 2



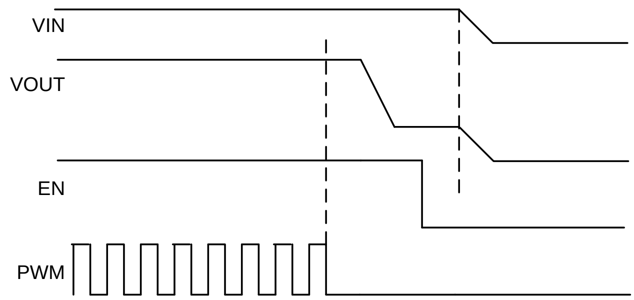
Power On Mode 3



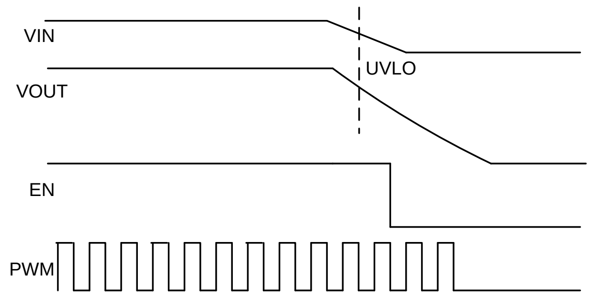
Power Off Mode 1



Power Off Mode 2 (PWM Mode)



Power Off Mode 2 (DC Mode)



Power Off Mode 3

LED Channel Short Protection

The RT4527A integrates LED Short Protection (SLP). If one of the LED1 to LED6 pin voltages exceeds a threshold of approximately 5.6V during normal operation, this short channel will be turn-off and latched.

Over Voltage Protection

The RT4527A integrates over voltage protection (OVP) function. The over voltage protection could be set by I2C. When OVP pin voltage is higher than 40V, the LX N- MOSFET is turned off immediately to protect the LX N- MOSFET.

Output Short to Ground Protection

The RT4527A integrates output to ground protection. When VOUT trigger output fault function IC will not switching.

Current-Limit Protection

The RT4527A can limit the peak current to achieve over current protection. The RT4527A senses the inductor current of on period that flows through the LX pin. The duty cycle depend on current signal and internal slope compensation compared with error signal. The internal switch will be turned off when the current signal is larger than the internal slope compensation. In the off period, the inductor current will be descended until the internal transistor is turned on by the oscillator.

Over Temperature Protection

The RT4527A has over temperature protection function to prevent the IC from overheating due to excessive power dissipation. The OTP function will shutdown the IC when junction temperature exceeds 150°C (typ.). When junction temperature is cool down to 130°C (TOTP_hys = 20°C), the LED driver will return to normal work.

Input Capacitor Selection

Low ESR ceramic capacitors are recommended for input capacitor applications. Low ESR will effectively reduce the input ripple voltage caused by the switching operation. Two 2.2μF low ESR ceramic capacitors are sufficient for most applications. Nevertheless, this value can be decreased for applications with lower output current requirement.

Another consideration is the voltage rating of the input capacitor, which must be greater than the maximum input voltage.

Boost Inductor Selection

The inductor value depends on the maximum input current. As a general rule the inductor ripple current is 20% to 40% of maximum input current. If 40% is selected as an example, the inductor ripple current can be calculated according to the following equation :

$$I_{IN(MAX)} = \frac{V_{OUT} \times I_{OUT(MAX)}}{\eta \times V_{IN}}$$

$$I_{RIPPLE} = 0.4 \times I_{IN(MAX)}$$

where η is the efficiency of the boost converter, $I_{IN(MAX)}$ is the maximum input current, and IRIPPLE is the inductor ripple current. The input peak current can be obtained by adding the maximum input current with half of the inductor ripple current as shown in the following equation :

$$I_{PEAK} = 1.2 \times I_{IN(MAX)}$$

Note that the saturated current of inductor must be greater than I_{PEAK}. The inductance can eventually be determined according to the following equation :

$$L = \frac{\eta \times (V_{IN})^2 \times (V_{OUT} - V_{IN})}{0.4 \times (V_{OUT})^2 \times I_{OUT(MAX)} \times f_{OSC}}$$

where f_{OSC} is the switching frequency. For better system performance, a shielded inductor is preferred to avoid EMI problems.

Boost Diode Selection

The Schottky diode is a good choice for any asynchronous boost converter due to the small forward voltage. However, when selecting a Schottky diode, important parameters such as power dissipation, reverse voltage rating, and pulsating peak current must all be taken into consideration. A suitable Schottky diode's reverse voltage rating must be greater than the maximum output voltage, and its average current rating must exceed the average output current.

Boost Output Capacitor Selection

Output ripple voltage is an important index for estimating the performance. This portion consists of two parts, one is the product of IIN and ESR of output capacitor, another part is formed by charging and discharging process of output capacitor. As shown in Figure 1, ΔVOUT1 can be evaluated based on the ideal energy equalization. According to the definition of Q, the Q value can be calculated as following equation :

$$Q = \frac{1}{2} \times \left[\left(I_{IN} - \frac{1}{2}\Delta I_L - I_{OUT} \right) + \left(I_{IN} - \frac{1}{2}\Delta I_L - I_{OUT} \right) \right] \times \frac{V_{IN}}{V_{OUT}} \times \frac{1}{f_{OSC}} = C_{OUT} \times \Delta V_{OUT1}$$

where f_{OSC} is the switching frequency and ΔI_L is the inductor ripple current. Move C_{OUT} to left side to estimate the value of ΔV_{OUT1} as following equation :

$$\Delta V_{OUT1} = \frac{D \times I_{OUT}}{\eta \times C_{OUT} \times f_{OSC}}$$

Where D is the duty cycle and η is the boost converter efficiency. Finally, taking ESR into account, the overall output ripple voltage can be determined by the following equation :

$$\Delta V_{OUT} = \Delta V_{ESR} = \frac{D \times I_{OUT}}{\eta \times C_{OUT} \times f_{OSC}}$$

Where $\Delta V_{ESR} = \Delta I_C \times R_{ESR} = I_{PEAK} \times R_{ESR}$

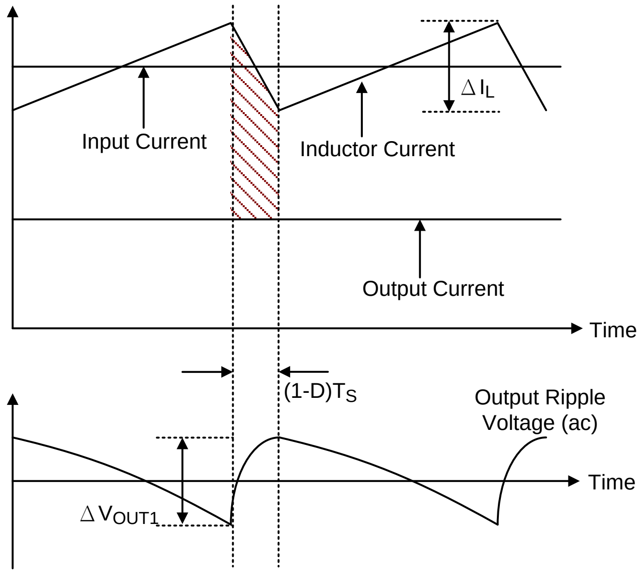


Figure 1. The Output Ripple Voltage Without the Contribution of ESR.

Peak Current Calculation in DCM

In general backlight application and the loading is not much at low dimming duty. Therefore the boost converter usually operates in DCM. The peak current of through inductor (I_{L_peak}) can be calculated as following equation in DCM :

$$I_{L\text{-}peak} = \frac{V_{IN}}{L} D_{DCM} T_S$$

$$D_{DCM} = \sqrt{\frac{2LI_{OUT}(V_{OUT} - V_{IN}) \times fs}{V_{IN}^2}}$$

Where DDCM is the duty cycle of the switch turn-on in DCM.

Loop Compensation

The external compensation network of the RT4527A must be compensated by the designer to ensure the stability of the overall loop response. In power-supply design, a power supply is typically defined to be stable if the gain margin is greater than 10 dB and the phase margin is greater than 45°. The requirement for stability is typically forcing the loop to cross over with a -1 slope, or -20dB/Decade in the vicinity of the crossover frequency.

A relationship exists between the phase margin of a second-order closed-loop system and the quality coefficient Q of its transfer function. If the phase margin is too small, the peaking induces high output ringing, exactly as in an RLC circuit. On the contrary, if the phase margin becomes too large, it slows down the system: the overshoot goes away but to the detriment of response and recovery speed.

The stability exercise requires shaping the compensation circuit G(s) in order to provide adequate phase margin at the selected crossover point, together with a high gain in dc. Choose R_{COMP} to set high frequency integrator gain for fast transient response and C_{COMP} to set the integrator zero to maintain loop stability. For typical application, LED = 6P11S, Boost Switching frequency = 1.225MHz, I_{LED} = 24mA/CH, C_{OUT} = 4.7μF, L1 = 10μH, while the recommended value for compensation is as follows table:

Case	V_{IN} Range (V)	R_{COMP} (kΩ)	C_{COMP} (nF)
Case1:PWM Mode	7 to 21V	20	1
Case2:DC Mode	5 to 21V	5.1	22

Converter Bandwidth and stability always trade off at loop compensation, In DC Mode, LED current as a stable DC current and usually use Case2 to gain better stability performance.

In PWM Mode, LED Current as a pulse loading and Boost Converter need larger bandwidth to handle it for better transient ripple as Case1 but need to concern VIN range.

Moreover if system don't concern transient response, both DC and PWM Mode can be used in Case2.

Thermal Considerations

The junction temperature should never exceed the absolute maximum junction temperature $T_{J(MAX)}$, listed under Absolute Maximum Ratings, to avoid permanent damage to the device. The maximum allowable power dissipation depends on the thermal resistance of the IC package, the PCB layout, the rate of surrounding airflow, and the difference between the junction and ambient temperatures. The maximum power dissipation can be calculated using the following formula :

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

where $T_{J(MAX)}$ is the maximum junction temperature, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance.

For continuous operation, the maximum operating junction temperature indicated under Recommended Operating Conditions is 125°C. The junction-to-ambient thermal resistance, θ_{JA}, is highly package dependent. For a WQFN-20L 3.5 x 3.5 package, the thermal resistance, θ_{JA}, is 36°C/W on a standard JEDEC 51-7 high effective-thermal-conductivity four-layer test board. The maximum power dissipation at T_A = 25°C can be calculated as below :

$P_{D(MAX)}$ = (125°C − 25°C) / (36°C/W) = 2.77W for a WQFN-20L 3.5 x 3.5 package.

The maximum power dissipation depends on the operating ambient temperature for the fixed $T_{J(MAX)}$ and the thermal resistance, θ_{JA}. The derating curves in Figure 2 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

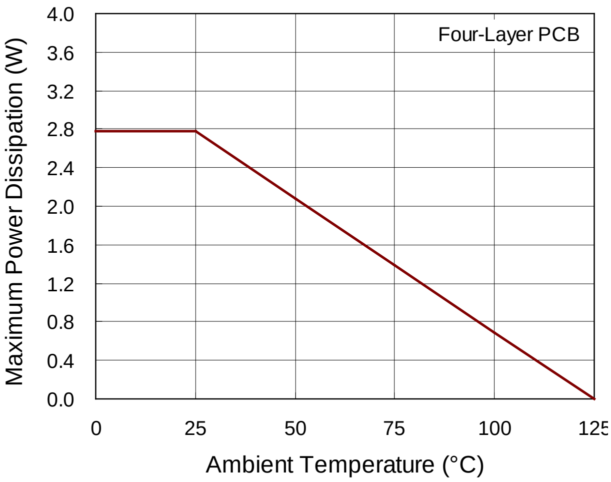


Figure 2. Derating Curve of Maximum Power Dissipation

Layout Guideline

PCB layout is very important to design power switching converter circuits. The following layout guide lines should be strictly followed for best performance of the RT4527A.

- The power components L1, D1, C_{IN} and C_{OUT} must be placed as close as possible to reduce the current loop. The PCB trace between power components must be short and wide as possible due to large current flow through these trace during operation.
- Place L1 and D1 as close to LX pins as possible. The trace should be short and wide as possible.
- Place the input capacitor C1 close to VIN pin.
- The exposed pad of the chip should be connected to ground plane for thermal consideration.

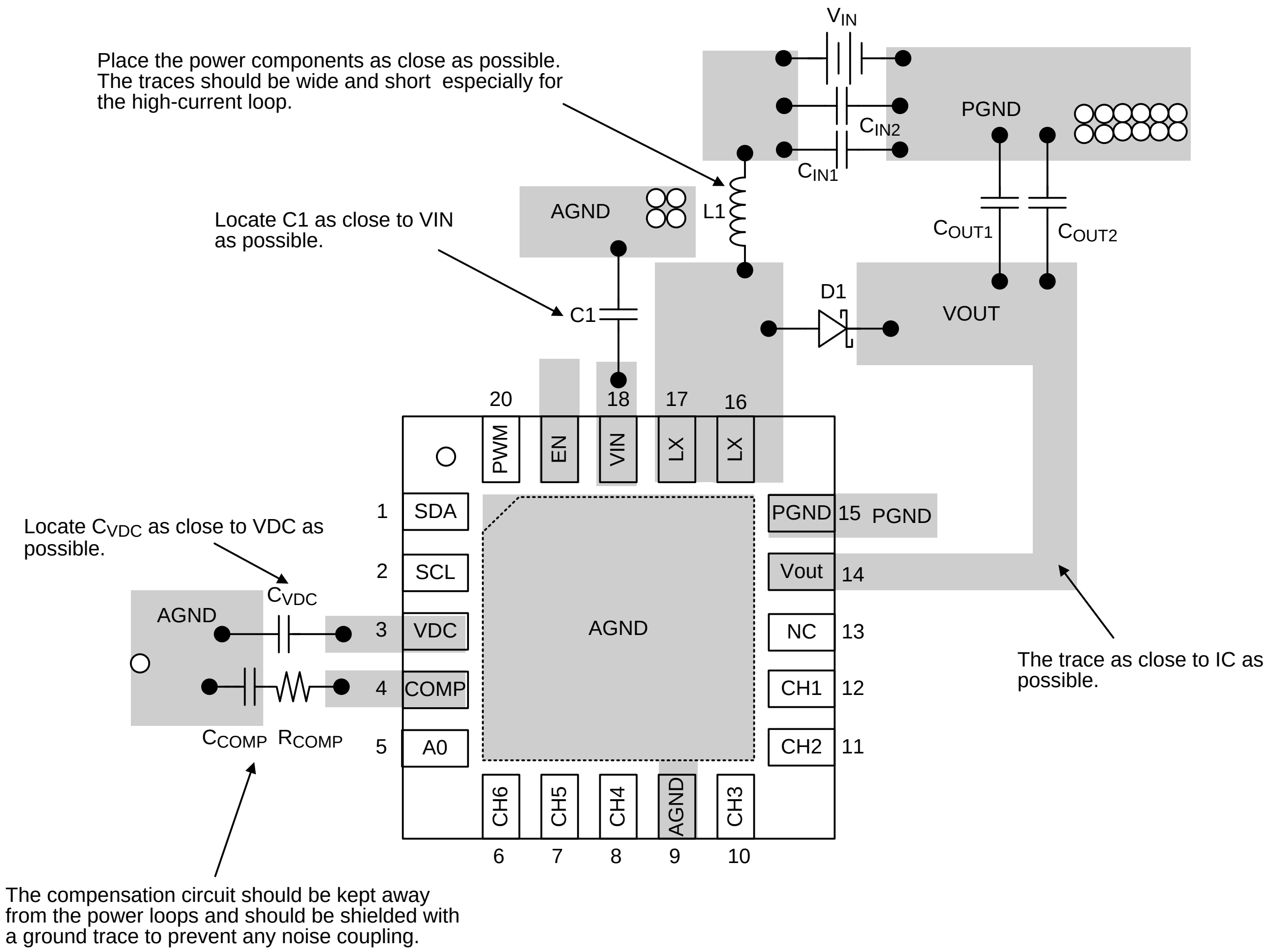
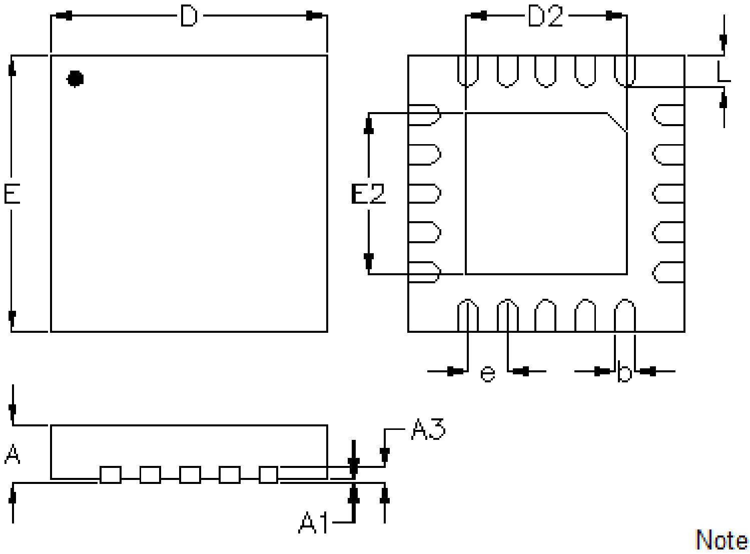
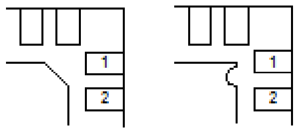


Figure 3. PCB Layout Guide

Outline Dimension





DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.200	0.300	0.008	0.012
D	3.400	3.600	0.134	0.142
D2	2.000	2.100	0.079	0.083
E	3.400	3.600	0.134	0.142
E2	2.000	2.100	0.079	0.083
e	0.500		0.020	
L	0.350	0.450	0.014	0.018

W-Type 20L QFN 3.5x3.5 Package

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