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AS3649

2500mA High Current LED Flash Driver

1 General Description

The AS3649 is an inductive high efficient DCDC step up converter with two current sources. The DCDC step up converter operates at a fixed frequency of 4MHz and includes soft startup to allow easy integration into noise sensitive RF systems. The two current sources can operate in flash / torch or video light modes.

The AS3649 includes flash timeout, overvoltage, overtemperature, undervoltage and LED short/open circuit protection functions. A TXMASK/TORCH function reduces the flash current in case of parallel operation to the RF power amplifier and avoids a system shutdown. Alternatively this pin can be used to directly operate the torch light directly. If the TXMask function is not used, it can be used as a hardware torch input (programmable).

A hardware NTC pin can be used to measure the LED temperature with the ADC and to automatically reduce the LED current if a temperature threshold is exceeded.

The AS3649 is controlled by an I²C interface and has a hardware reset pin ON. Setting ON=0 resets the AS3649. Interface input voltage levels are 1.8V compliant.

The AS3649 is available in a space-saving WL-CSP package measuring only 2.06x2.02x0.6mm and operates over the -30ºC to +85ºC temperature range.

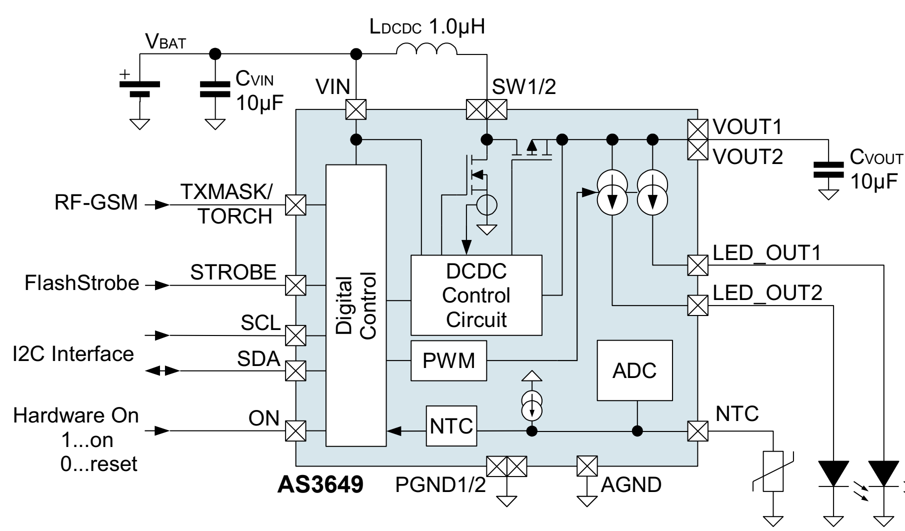
2 Key Features

- High efficiency 4MHz fixed frequency DCDC Boost converter with soft start allows small coils
  - Stable even in coil current limit
- LED current adjustable up to 2x1000mA(2x1250mA with current boost) or 2000mA and automatic load balancing for two LEDs
- Automatic current adjustment for low battery voltage
- PWM operation for lower output current for reliable light output of the LED; can run at 31.5kHz to avoid audible noise
- Protection functions:
  Automatic Flash Timeout timer to protect the LED(s)
  Overvoltage and undervoltage Protection
  Overtemperature Protection
  LED short/open circuit protection
- ADC to measure LED temperature
- NTC to automatically reduce the flash current if the LED temperature is too high (programmable level)
- I²C Interface with hardware reset pin
- Available in tiny WL-CSP Package, 16 balls 0.5mm pitch, 2.06x2.02x0.6mm package size

3 Applications

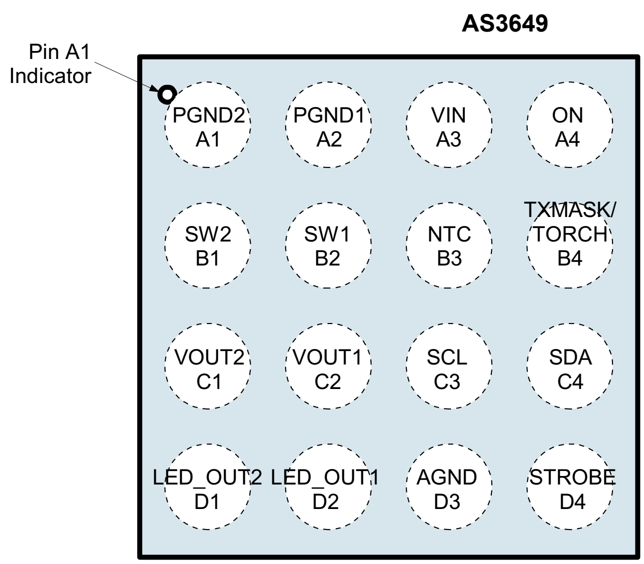
Flash/Torch for mobile phones

Figure 1. Typical Operating Circuit



4 Pin Assignments

Figure 2. Pin Assignments (Top View)



4.1 Pin Description

Table 1. Pin Description for AS3649

Pin Number[1]	Pin Name	Description
A1	PGND2	Power ground; make a short connection between all GND balls
A2	PGND1	Power ground; make a short connection between all GND balls
A3	VIN	Positive supply voltage input - connect to supply and make a short connection to input capacitor C_{VIN} and to coil L_{DCDC}
A4	ON	Hardware reset input; an active low signal resets the registers of AS3649 and enters shutdown (and I^2C lines SDA and SCL are in high-Z), active high allows to operate the device
B1	SW2	DCDC converter switching node - make a short connection to SW1 / coil L_{DCDC}
B2	SW1	DCDC converter switching node - make a short connection to SW2 / coil L_{DCDC}
B3	NTC	LED temperature sensor input (NTC) for LED overtemperature protection
B4	TXMASK/TORCH	Function 1: Connect to RF power amplifier enable signal - reduces currents during flash to avoid a system shutdown due to parallel operation of the RF PA and the flash driver Function 2: Operate torch current level without using the I^2C interface to operate the torch without need to start a camera processor (if the I^2C is connected to the camera processor
C1	VOUT2	DCDC converter output capacitor - make a short connection to C_{VOUT} / VOUT1
C2	VOUT1	DCDC converter output capacitor - make a short connection to C_{VOUT} / VOUT2

Table 1. Pin Description for AS3649

Pin Number[1]	Pin Name	Description
C3	SCL	serial clock input for I^2C interface
C4	SDA	serial data input/output for I^2C interface (needs external pullup resistor)
D1	LED_OUT2	Flash LED current source
D2	LED_OUT1	Flash LED current source
D3	AGND	Analog ground; make a short connection between all GND balls
D4	STROBE	Digital input with pulldown to control strobe time for flash function

1. Final pinout subject to change - now only used to count number of pins

5 Absolute Maximum Ratings

Stresses beyond those listed in Table 2 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 Electrical Characteristics on page 5 is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 2. Absolute Maximum Ratings

Parameter	Min	Max	Units	Comments
VIN to GND	-0.3	+7.0	V	
STROBE, TXMASK/TORCH, SCL, SDA, ON, NTC to GND	-0.3	VIN + 0.3	V	max. +7V
SW1/2, VOUT1/2, LED_OUT1/2 to GND	-0.3	+7.0	V	
VOUT1/2 to SW1/2	-0.3		V	**Note:** Diode between VOUT1/2 and SW1/2
voltage between AGND, PGND1/2 pins	0.0	0.0	V	short connection required
Input Pin Current without causing latchup	-100	+100 +I_{IN}	mA	Norm: EIA/JESD78
Continuous Power Dissipation (T_A = +70ºC)				
Continuous power dissipation		1470	mW	P_T at 70ºC[1]
Continuous power dissipation derating factor		20	mW/ºC	P_{DERATE}[2]
Electrostatic Discharge				
ESD HBM		±2000	V	Norm: JEDEC JESD22-A114F
ESD CDM		±500	V	Norm: JEDEC JESD 22-C101E
Temperature Ranges and Storage Conditions				
Junction to ambient thermal resistance		50[3]	ºC/W	For more information about thermal metrics, see application note AN01 Thermal Characteristics
Junction Temperature		+150	ºC	Internally limited (overtemperature protection), max. 20000s
Storage Temperature Range	-55	+125	ºC	
Humidity	5	85	%	Non condensing
Body Temperature during Soldering		+260	ºC	according to IPC/JEDEC J-STD-020
Moisture Sensitivity Level (MSL)	MSL 1			Represents a max. floor life time of unlimited

1. Depending on actual PCB layout and PCB used measured on demoboard; for peak power dissipation during flashing see document 'AS3649 Thermal Measurements'
2. P_{DERATE} derating factor changes the total continuous power dissipation (P_T) if the ambient temperature is not 70ºC. Therefore for e.g. T_{AMB}=85ºC calculate P_T at 85ºC = P_T - P_{DERATE} * (85ºC - 70ºC)
3. Measured on AS3649 demoboard.

6 Electrical Characteristics

V_{VIN} = +2.7V to +4.4V, T_{AMB} = -30ºC to +85ºC, unless otherwise specified. Typical values are at V_{VIN} = +3.7V, T_{AMB} = +25ºC, unless otherwise specified.

Table 3. Electrical Characteristics

Symbol	Parameter	Condition		Min	Typ	Max	Unit
General Operating Conditions							
V_{VIN}	Supply Voltage	Pin VIN		2.7	3.7	4.4	V
$V_{VINREDUCED\_FUNC}$	Supply Voltage	AS3649 functionally working, but not all parameters fulfilled		2.5		2.7	V
				4.4		5.5	
$I_{SHUTDOWN}$	Shutdown Current	TXMASK/TORCH=L, STROBE=L, ON=L, V_{VIN}<3.7V			1.0	2.0	µA
I_{STANBY}	Standby Current	Interface active, TXMASK/TORCH=L, STROBE=L V_{VIN}<3.7V			1.0	10	µA
T_{AMB}	Operating Temperature			-30	25	85	ºC
η[1]	Application Efficiency (DCDC and current source)	L_{COIL}=0.6µH@3A, L_{ESR}=60mΩ, LED_OUT1,2=2000mA, t_{FLASH}<300ms, VFLED=3.7V			83		%
t_{FLASH}	Flash Duration	V_{VIN}>3.3V, T_{AMB}<85ºC, I_{LED_OUT}<2000mA If T_{AMB} or I_{LED_OUT} is reduced or V_{VIN} is increased, longer flash times are allowed. For longer flash durations, see section Current Reduction by VIN Measurements in Flash Mode and Diagnostic Pulse on page 15				300	ms
DCDC Step Up Converter							
V_{VOUT}	DCDC Boost output Voltage (pin VOUT1/2)			2.8		5.5	V
R_{PMOS}	On-resistance	DCDC internal PMOS switch			45		mΩ
R_{NMOS}	On-resistance	DCDC internal NMOS switch			47		mΩ
f_{CLK}	Operating Frequency	All internal timings are derived from this oscillator		-7.5%	4.0	+7.5%	MHz
V_{VOUT5V}	DCDC Boost output Voltage (pin VOUT1/2)	Constant voltage mode operation const_v_mode (see page 30)=1			5.0		V
Current Sources							
V_{LED}	LED forward voltage	Two flash LEDs, I_{LED_OUT}<2x1000mA		2.8	3.32	4.0	V
		Single flash LED, I_{LED_OUT}<1800mA		2.8	3.32	4.4	V
I_{LED_OUT}	LED_OUT1/2 current combined	V_{VIN}>3.3V, coil_peak=11b, L_{COIL}=0.6µH@3.4A, L_{ESR}=60mΩ coil SPM3012T-1R0M, t_{FLASH}<300ms	dual flash LED, current_boost=0	0		2000	mA
			single flash LED	0		2000	mA
$I_{LED\_OUT\_BOOST}$	LED_OUT1/2 current combined	Dual flash LED, current_boost=1		0		2500[2]	mA
$I_{LED\_OUT\Delta}$	LED_OUT1/2 current source accuracy	Otherwise		-7		+7	%
		I_{LED_OUT}=500mA...800mA, 0ºC<T_J<100ºC		-5		+5	%
$I_{LED\_OUT\ RAMP}$	LED_OUT1/2 ramp time	Rampup initiated by I^2C command			730		µs
		Rampup started by STROBE			530		µs
		Full range Ramp-down			500		µs
$I_{LED\_OUT\ RIPPLE}$	LED_OUT current ripple	I_{LED_OUT} = 1000mA			40		mA_{PP}

Table 3. Electrical Characteristics (Continued)

Symbol	Parameter	Condition		Min	Typ	Max	Unit
VILED_COMP	LED_OUT current source voltage compliance	Minimum voltage between pin VOUT1/2 and LED_OUT1/2 for operation of the current source with current_boost=0			230		mV
VILED_COMP_BOOST		VILED_COMP with current_boost=1			290		mV
LLED_CONNECTION	LED connection inductance	Represents a maximum connection length of 10cm (LED connection and ground return path)				100	nH
Protection and Fault Detection Functions (see page 12)							
VVOUTMAX	VVOUT overvoltage protection	DCDC Converter Overvoltage Protection		5.0	5.3	5.6	V
ILIMIT	Current Limit for coil LDCDC (Pin SW) measured at 25% PWM duty cycle[3] maximum 40000s lifetime operation in overcurrent limit		coil_peak=00b	2.25	2.5	2.75	A
			coil_peak=01b	2.61	2.9	3.19	
		Default value	coil_peak (see page 23)=10b	3.0	3.3	3.63	
			coil_peak=11b	3.3	3.7	4.1	
VLEDSHORT	Flash LED short circuit detection voltage	Voltage measured between pins LED_OUT1,2 and GND			1.2		V
TOVTEMP	Overtemperature Protection	Junction temperature			144		ºC
TOVTEMPHYST	Overtemperature Hysteresis				5		ºC
tFLASHTIMEOUT	Flash Timeout Timer	Can be adjusted with register flash_timeout (page 26)		4		1124	ms
		Accuracy		-7.5		+7.5	%
VUVLO	Undervoltage Lockout	Falling VVIN		2.25	2.4	2.5	V
		Rising VVIN		VUVLO +0.05	VUVLO +0.1	VUVLO +0.15	V
VIN_LOW_VOLTAGE	Battery Low Voltage Protection	Defined by vin_low_v - see Current Reduction by VIN Measurements in Flash Mode and Diagnostic Pulse on page 15		-2.5%	3.0-3.47	+2.5%	V
Protection and Fault Detection Functions - NTC							
INTC	NTC Current Source	Adjustable by ntc_current (page 25) in 40µA steps	Range	40		600	µA
			∆I - accuracy V(NTC) <= 1.7V	-7		+7	%[4]
				-5		+5	µA
VNTC_TH	Threshold for overtemperature	If ntc_on (page 25)=1 and the voltage on NTC drops below VNTC_TH, any flash/torch or pwm operation of LED_OUT is stopped			1.0		V
ADC							
Resolution					10		bits
Range	ADC input range; channel selected by adc_channel (page 27)		ADC Code	0		full scale	
		NTC		0.0		2.2	V
		VIN		0.0		5.5	V
		TJUNC (AS3649 junction temperature)		see Table 6			ºC
Accuracy	ADC measurement accuracy	NTC		-1.5		+1.5	% full scale
		TJUNC (-30ºC...150ºC)		-8		+8	ºC
		TJUNC (0ºC...85ºC)		-5		+5	ºC

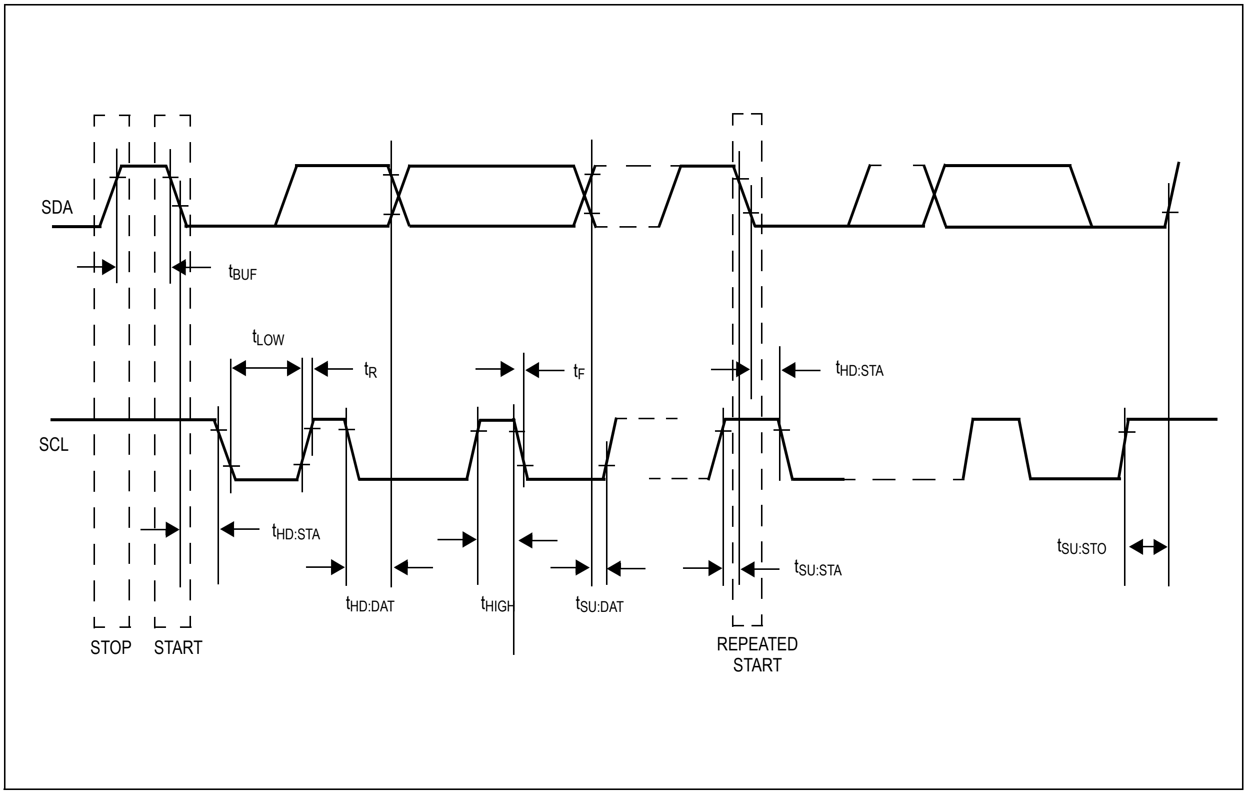
Table 3. Electrical Characteristics (Continued)

Symbol	Parameter	Condition	Min	Typ	Max	Unit
Digital Interface						
V_{IH}	High Level Input Voltage	Pins ON, SCL, SDA. and TXMASK/TORCH	1.26		V_{VIN}	V
V_{IL}	Low Level Input Voltage		0.0		0.54	V
$V_{IHFLASH}$	High Level Input Voltage	Pin STROBE.	0.84		V_{VIN}	V
$V_{ILFLASH}$	Low Level Input Voltage		0.0		0.54	V
V_{OL}	Low Level Output Voltage	Pin SDA, I_{OL}=3mA			0.3	V
I_{LEAK}	Leakage current	Pins ON, SCL, SDA	-1.0	0.0	+1.0	µA
I_{PD}	Pulldown current to GND[5]	Pins STROBE and TXMASK/TORCH		36		µA
$t_{DEBTORCH}$	TORCH debounce time		6.3	9	11.7	ms
$t_{DEBTXMASK}$	TXMASK debounce timer			1.5		µs
I^2C mode timings - see Figure 3 on page 8						
f_{SCLK}	SCL Clock Frequency		0		400	kHz
t_{BUF}	Bus Free Time Between a STOP and START Condition		1.3			µs
$t_{HD:STA}$	Hold Time (Repeated) START Condition[6]		0.6			µs
t_{LOW}	LOW Period of SCL Clock		1.3			µs
t_{HIGH}	HIGH Period of SCL Clock		0.6			µs
$t_{SU:STA}$	Setup Time for a Repeated START Condition		0.6			µs
$t_{HD:DAT}$	Data Hold Time[7]		0		0.9	µs
$t_{SU:DAT}$	Data Setup Time[8]		100			ns
t_R	Rise Time of Both SDA and SCL Signals		$20 + 0.1C_B$		300	ns
t_F	Fall Time of Both SDA and SCL Signals		$20 + 0.1C_B$		300	ns
$t_{SU:STO}$	Setup Time for STOP Condition		0.6			µs
C_B	Capacitive Load for Each Bus Line	C_B — total capacitance of one bus line in pF			400	pF
$C_{I/O}$	I/O Capacitance (SDA, SCL)				10	pF

1. To improve efficiency at low output currents, the active part of the internal switching transistor PMOS is reduced in size to 1/5 its original size. This reduces the current required to drive the PMOS transistor and therefore improves overall efficiency at low output currents.
2. The maximum current driving capability depends on supply voltage V_{VIN}, LED forward voltage and coil peak current limit.
3. Due to slope compensation of the current limit, I_{LIMIT} changes with duty cycle - see Figure 16 on page 11.
4. Accuracy defined in % of current setting and in absolute value (µA), accuracy values have to be added together
5. A pulldown current of 36µA is equal to a pulldown resistor of 42kΩ at 1.5V
6. After this period, the first clock pulse is generated
7. A device must internally provide a hold time of at least 300ns for the SDA signal (referred to the V_{IHMIN} of the SCL signal) to bridge the undefined region of the falling edge of SCL.
8. A fast-mode device can be used in a standard-mode system, but the requirement $t_{SU:DAT}$ = to 250ns must then be met. This is automatically the case if the device does not stretch the LOW period of the SCL signal. If such a device does stretch the LOW period of the SCL signal, it must output the next data bit to the SDA line t_R max + $t_{SU:DAT}$ = 1000 + 250 = 1250ns before the SCL line is released.

6.1 Timing Diagrams

Figure 3. I²C mode Timing Diagram



7 Typical Operating Characteristics

VVIN = 3.7V, T_A = +25ºC (unless otherwise specified)

Figure 4. DCDC Efficiency vs. VVIN

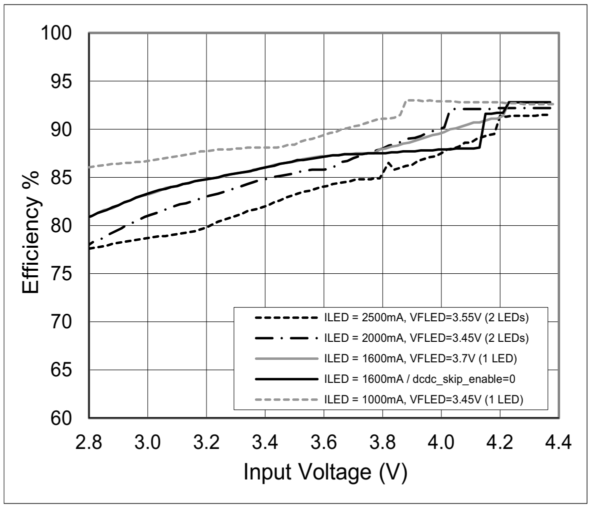


Figure 5. Application Efficiency (PLED/PVIN) vs. VVIN

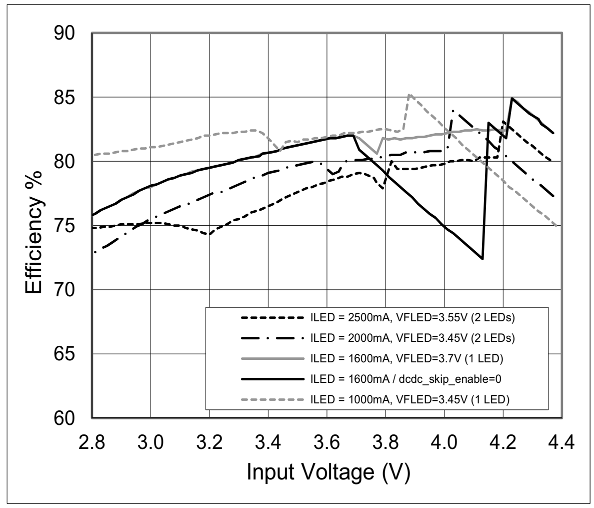


Figure 6. Battery Current vs. VVIN

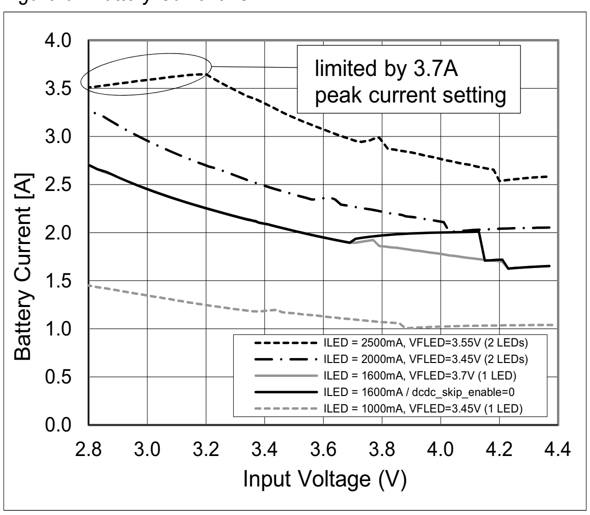


Figure 7. Efficiency at low currents (298mA/100mA)

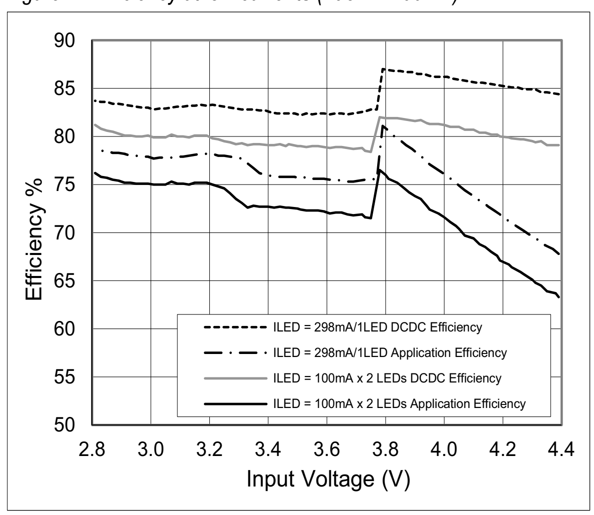


Figure 8. ILED Startup (ILED_OUT=1.0A)

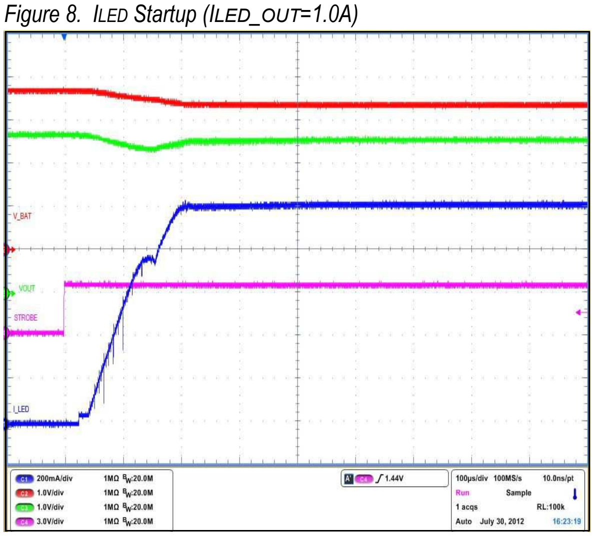


Figure 9. IVIN, ILED Startup (ILED_OUT=800mA)

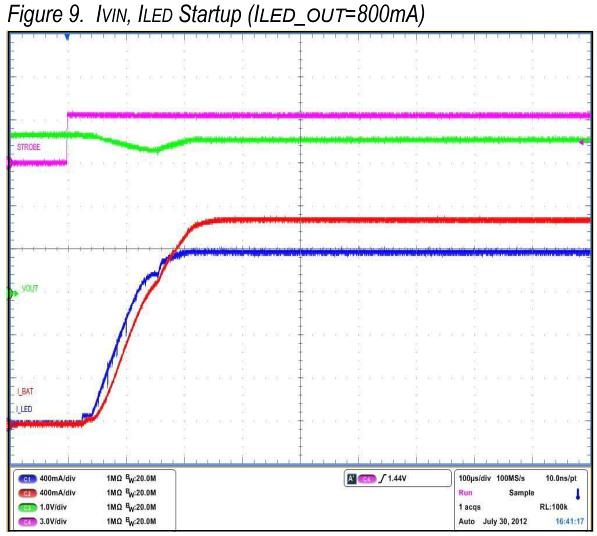


Figure 10. ILED vs. VVIN

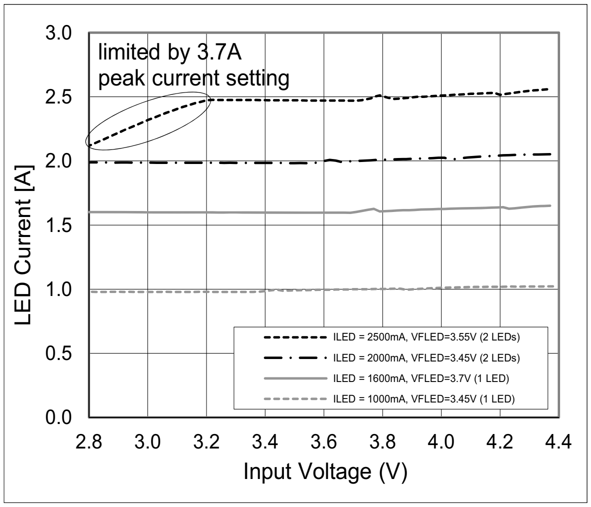


Figure 11. VOUT / ILED_OUT ripple, ILED_OUT = 2x1.0A

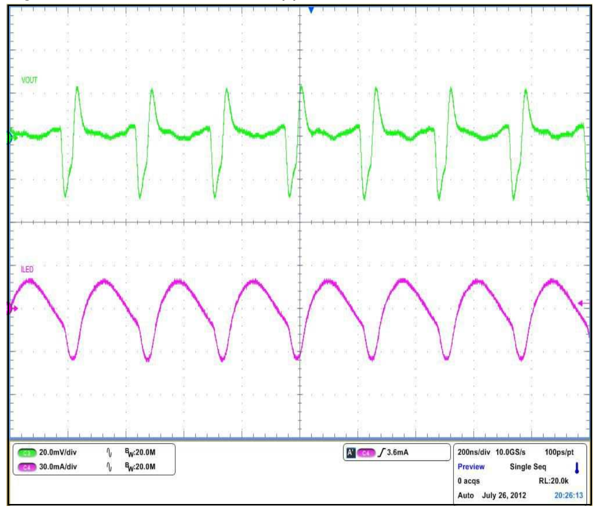


Figure 12. Diagnostic Pulse Operation

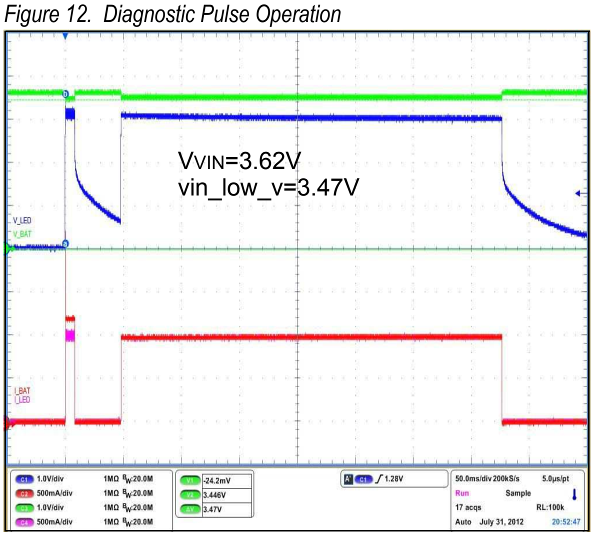


Figure 13. TxMask operation waveform (ILED, IVIN)

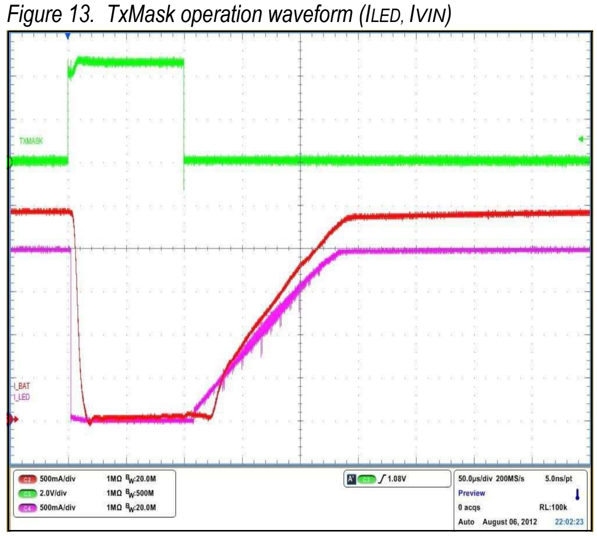


Figure 14. Timeout Timer

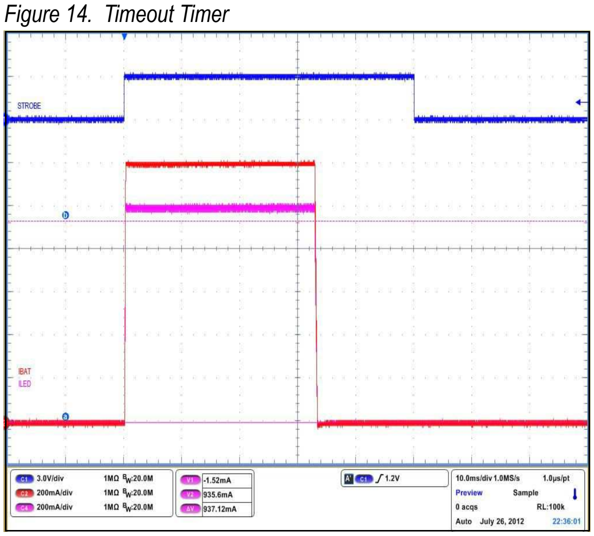
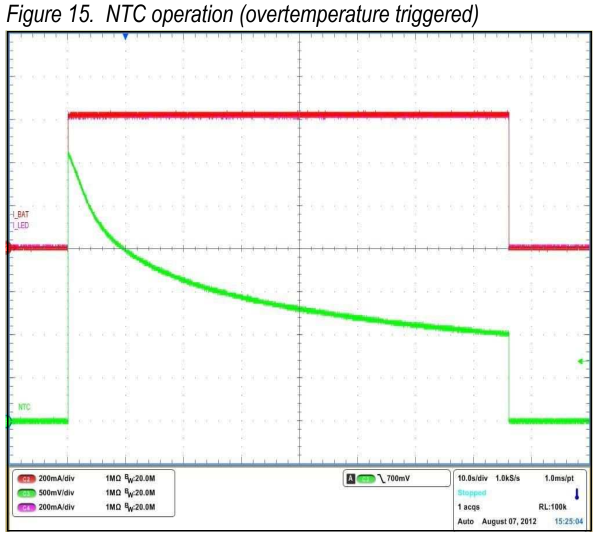


Figure 15. NTC operation (overtemperature triggered)



8 Detailed Description

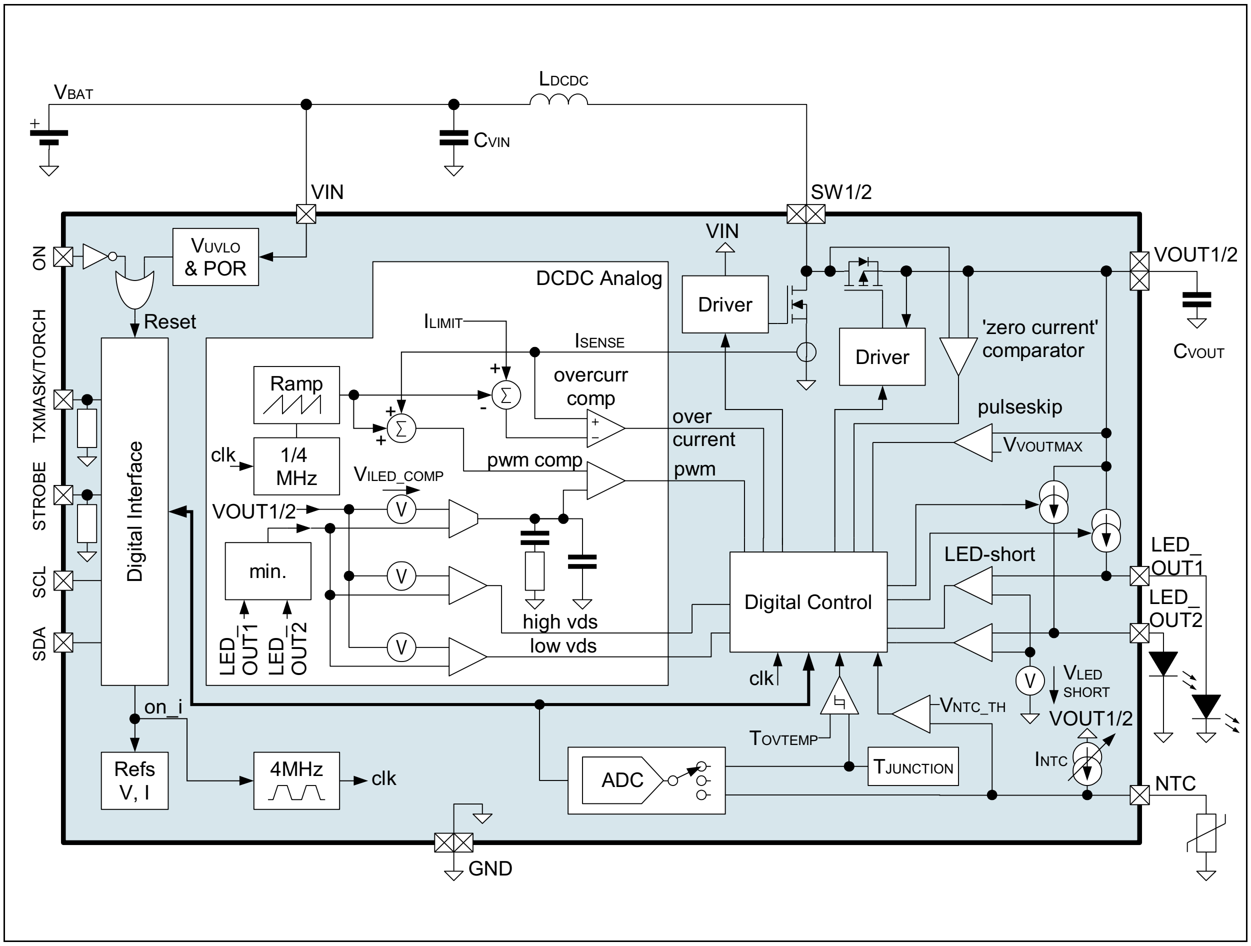
The AS3649 is a high performance DCDC step up converter with internal PMOS and NMOS switches. Its output is connected to one or two flash LEDs[1] with two internal current sources and hardware LED temperature protection using an external NTC. The device is controlled by the pins SDA and SCL in I^2C mode and includes a hardware reset input ON.

The actual operating mode like standby, torch light, indicator or flash mode, can then be chosen by the interface. If not in standby mode, the device automatically enters shutdown and resets all registers by setting pin ON=0.

The AS3649 includes a fixed frequency DCDC step-up with accurate startup control. Together with the current source (on LED_OUT1/2) it includes several protection and safety functions.

8.1 Internal Circuit Diagram

Figure 16. Internal Circuit Diagram



8.2 Softstart / Soft ramp down

During startup and ramp down the LED current is smoothly ramped up and ramped down. If the DCDC converter goes out of regulation (measured by monitoring the voltage across the current sources), the ramp up is temporarily stopped in order for the DCDC to return to regulation[2].

---

1. If two LEDs are connected, it is possible to operate each of the two LEDs individually as the LED current can be selected individually.
2. The actual value of the LED current setting can be readout by the register led_current_actual (see page 31) to allow the camera processor to adopt to the actual operating conditions.

8.3 4/1MHz Operating Mode Switching and Pulse Skipping

If freq_switch_on (see page 29)=1 and if led_current1>=40h or led_current2>=40h[3] and current_boost=0, the DCDC converter always operates in PWM mode (exception: PFM mode is allowed during startup) to reduce EMI in EMI sensitive systems. For high duty cycles close to 100% on-time (maximum duty cycle) of the PMOS, the DCDC converter can switch into a 1MHz operating mode and maximum duty cycle to improve efficiency for this load condition[4]. The DCDC converter returns back to its normal 4MHz operating frequency when load or supply conditions change. Due to this switching between two fixed frequencies the noise spectrum of the system is exactly defined and predictable. If improved efficiency is required, the fixed switching between 4MHz / 1MHz can be disabled by freq_switch_on (see page 29)=0. In this case pulseskip will be used.

The modes are selected according to Table 4:

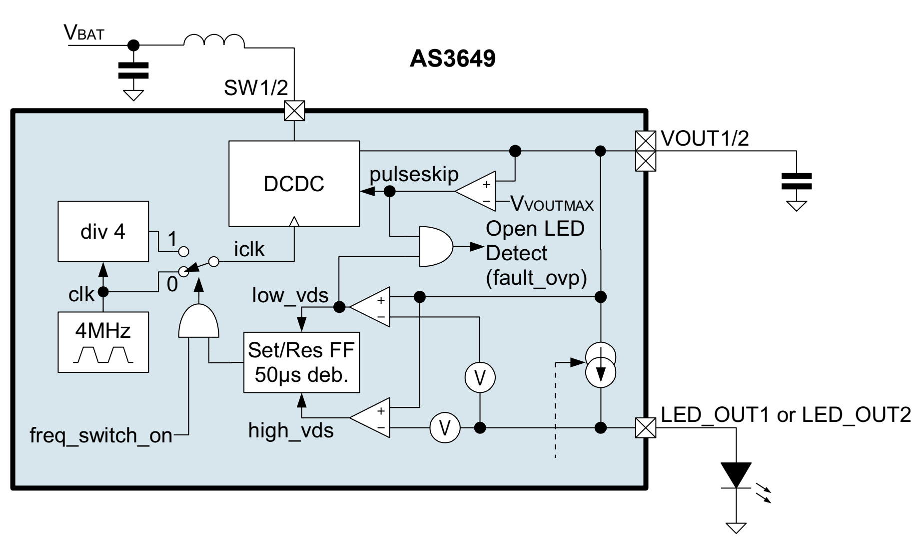
Table 4. 4/1MHz switching and pulseskip operating modes

freq_switch_on	dcdc_skip_enable	led_current1>=40h or led_current2>=40h	led_current1<40h and led_current2<40h
0	0	4MHz forced PWM operation (no 1MHz operation, no pulseskip)	
0	1	4MHz, pulse skipping allowed, no 1MHz operation	
1	0	4MHz/1Mhz forced PWM operation, pulseskip not allowed[1]	4MHz forced PWM operation (no 1MHz operation, no pulseskip)
1	1		4MHz, pulse skipping allowed, no 1MHz operation

1. If current_boost=1, freq_switch_on is set to '0'.

The internal circuit for switching between these two frequencies is shown in Figure 17 (for simplicity only a single current source is shown):

Figure 17. Internal circuit of 4MHz/1MHz selection



Note: If the voltage on VOUT1/2 exceeds VVOUTMAX, the DCDC will always skip pulses to limit the output voltage.

8.4 Protection and Fault Detection Functions

The protection functions protect the AS3649 and the LED(s) against physical damage. In most cases a Fault register bit is set, which can be readout by the I^2C interface. The fault bits are automatically cleared by a I^2C readout of the fault register. Additionally the DCDC is stopped and the current sources are disabled[5] by resetting mode_setting=00[6] and txmask_torch_mode=00.

3. Set register dcdc_skip_enable (see page 28)=1 if 4MHz forced operation shall be used below this LED current.
4. Efficiency compared to a 4MHz only DCDC converter forced to operate with minimum duty cycle.

8.4.1 Overvoltage Protection

In case of no or a broken LED(s) at the pin LED_OUT1/2 and an enabled DCDC converter, the voltage on VOUT1/2 rises until it reaches $V_{VOUTMAX}$ (overvoltage condition) and the voltage across the current source is below low_vds[7]., the DCDC converter is stopped, the current sources are disabled and the bit fault_ovp (see page 29)[8] is set[9]. In a dual LED configuration for the AS3649, if a single open LED is detected, this LED is disabled, fault_ovp is set and the device continuous operation with the other LED.

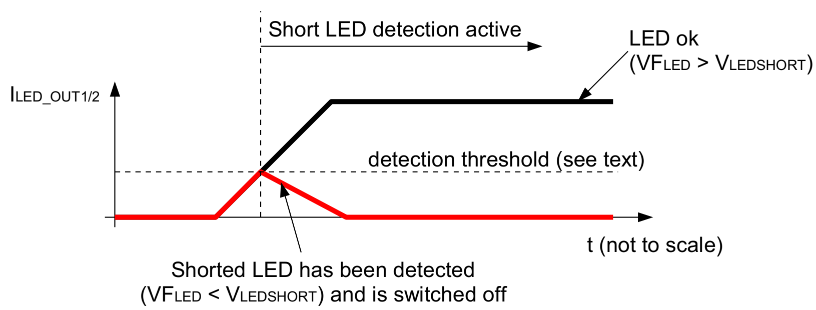
Note: In PWM operating mode (mode_setting=01b), open LED detection is disabled (and fault_ovp is not set). The output voltage will nevertheless be kept below $V_{VOUTMAX}$.

8.4.2 Short Circuit Protection

After the startup of the DCDC converter, the voltage on LED_OUT1/2 is continuously monitored and compared against $V_{LEDSHORT}$ if the LED current is above 27.5mA (current_boost=0), 34.3mA (current_boost=1)[10],[11](see Figure 18). If the voltage on the LED (VF_{LED} = LED_OUT1/2) stays below $V_{LEDSHORT}$, the DCDC is stopped (as a shorted LED is assumed), the current sources are disabled and the bit fault_led_short (see page 29) is set. In a dual LED configuration for the AS3649, if a single shorted LED is detected, this LED is disabled, fault_led_short is set and the device continuous operation with the other LED.

Note: In PWM operating mode (mode_setting=01b), short circuit protection is disabled.

Figure 18. Short LED Detection



8.4.3 Overtemperature Protection

The junction temperature of the AS3649 is continuously monitored. If the temperature exceeds T_{OVTEMP}, the DCDC is stopped, the current sources are disabled (instantaneous) and the bit fault_overtemp (see page 29) is set (but the operating mode mode_setting is not changed). The driver is automatically re-enabled[12] once the junction temperature drops below T_{OVTEMP}-$T_{OVTEMPHYST}$.

8.4.4 TXMASK event occurred

If during flash, TXMASK current reduction is enabled (see TXMASK on page 15, configured by txmask_torch_mode=01) and a TXMASK event happened (pin TXMASK/TORCH=1), the fault register bit fault_txmask (see page 28) is set.

5. Applies for all faults except TXMASK event occurred
6. Except for TXMASK event occurred and Overtemperature Protection
7. If overvoltage is reached, but none of the low_vds comparator(s) triggers, VOUT1/2 is still regulated below $V_{VOUTMAX}$.
8. In indicator or low current PWM mode (mode_setting (see page 26)=01) the register fault_ovp is not set under an overvoltage conditions. The output voltage is nevertheless kept below $V_{VOUTMAX}$.
9. In constant voltage mode (5V generation, register bit const_v_mode=1) this fault is disabled.
10. To avoid errors in short LED detection for LEDs with a high leakage current
11. The LED short circuit protection is disabled in indicator mode (or low current mode using PWM) (mode_setting on page 26=01b)
12. In constant voltage mode (const_v_mode=1) the DCDC will not be automatically re-enabled.

8.4.5 Flash Timeout

If the flash is started a timeout timer is started in parallel. If the flash duration defined by the STROBE input (strobe_on=1 and strobe_type=1, see Figure 25 on page 18) exceeds $t_{FLASHTIMEOUT}$ (adjustable by register flash_timeout (see page 26)), the DCDC is stopped and the flash current sources (on pin LED_OUT1/2) are disabled (ramping down) and fault_timeout is set.

If the flash duration is defined by the timeout timer itself (strobe_on = 0, see Figure 23 on page 17), the register fault_timeout is set after the flash has been finished.

8.4.6 Supply Undervoltage Protection

If the voltage on the pin VIN (=battery voltage) is or falls below V_{UVLO}, the AS3649 is kept in shutdown state and all registers are set to their default state.

8.4.7 NTC - Flash LED Overtemperature Protection

The ntc_on (see page 25)=1, the flash LED is protected by the AS3649 using an internal comparator connected to NTC and an current source controlled by ntc_current (see page 25) (V_{NTC_TH}, I_{NTC} as shown in Figure 16, "Internal Circuit Diagram," on page 11); once it is triggered, the DCDC is stopped, the current sources are disabled (instantaneous) and the bit fault_ntc (see page 28) is set.

As the external NTC cannot measure the LED temperature in real time during a high current flash pulse (the duration from heating up of the LED until the NTC recognizes a too hot LED is usually too long), it is advisable to measure the LED temperature before the flash pulse (with the ADC (see page 19) and ntc_current (see page 25)) and judge how much current can be driven through the LED (to be estimated depending on LED heat sink and is usually specified by the LED manufacturer).

8.5 Operating Mode and Currents

The output currents and operating mode currents are selected according to the following table:

Table 5. Operating Mode and Current Settings

AS3649 Configuration					Operating Mode and Currents	
ON, SCL, SDA	**TXMASK/TORCH**	**STROBE**	**mode_setting (see page 26)**	**Condition**	**Mode**	**LED_OUT1/2 Output current**
ON=0	X	X	X	X	Shutdown All registers are reset to their default values	0
ON=1; I^2C commands are accepted on pins SCL and SDA	X	X	00	txmask_torch_mode (see page 23) not 10	standby	0
	0	X		txmask_torch_mode =10		
	1	X		txmask_torch_mode =10	external torch mode	LED current is defined by the 6LSB[1] bits of led_current1 and led_current2
	X	X	01		indicator mode or low current pwm mode[2]	LED current is defined by the 6LSB bits (bits 5...0) of led_current1 and led_current2 pwm modulated defined by register inct_pwm (31.5kHz: 1/16...4/16) or 7.9kHz: 1/64...3/64)
	X	X	10		torch light mode	LED current is defined by the 6LSB[2] bits (5...0) of led_current1 and led_current2
	X	X	11	strobe_on (see page 28) = 0	flash mode; flash duration defined by flash_timeout (see page 26)	LED current is defined by led_current1 and led_current2 - the current can be reduced during flash, see Flash Current Reductions below
	X	0->1		strobe_on = 1 and strobe_type (see page 28) = 0		
	X	1		strobe_on = 1 and strobe_type = 1	flash mode; flash duration defined by STROBE input; timeout defined by flash_timeout	

1. The MSB bit of this register not used to protect the LED; therefore the maximum torch light current = 1/4 * the maximum flash current
2. The low current mode is a general purpose PWM mode to drive less current through the LED in average, but keep the actual pulsed current in a range where the light output from the LED is still specified. As only the 6 LSBs of led_current1 and led_current2 is used the maximum current is limited to 1/4 of the maximum flash current.

Always keep led_current1 >= led_current2.

8.5.1 Flash Current Reductions

TXMASK.

Usually the flash current is defined by the register led_current1 and led_current2. If the TXMASK/TORCH input is used and (configured by txmask_torch_mode=01), the flash current is reduced to flash_txmask_current if TXMASK/TORCH=1.

Current Reduction by VIN Measurements in Flash Mode and Diagnostic Pulse.

Due to the high load of the flash driver and the ESR of the battery (especially critical at low temperatures), the voltage on the battery drops. If the voltage drops below the reset threshold, the system would reset. To prevent this condition the AS3649 monitors the battery voltage and keeps it above vin_low_v as follows:

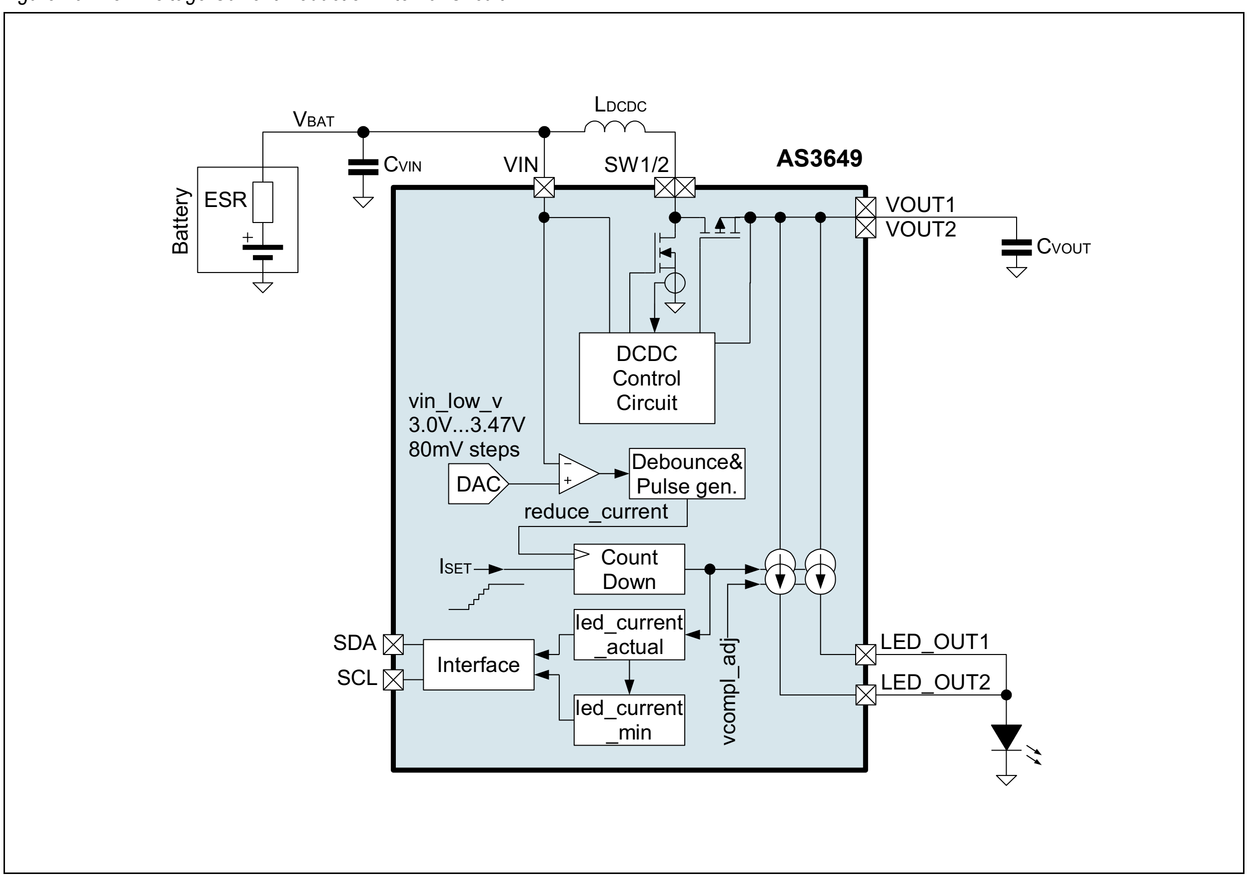
If the voltage on VIN before the flash is below vin_low_v, the DCDC is not started at all. Otherwise during flash, if the voltage on VIN drops below the threshold defined by vin_low_v, the flash current is reduced (or ramping of the current is stopped during flash current startup) and status_uvlo is set. The timing for the reduction of the current is 2µs/LSB current change.

During the flash pulse the actual used current can be readout by the register led_current_actual.

After the flash pulse the minimum current can be readout by the register led_current_min - this allows to adjust the camera sensitivity (gain or iso-settings) for the subsequent flash pulse (e.g. when using a pre-flash and a main flash pulse).

The internal circuit for low voltage current reductions are shown in Figure 19:

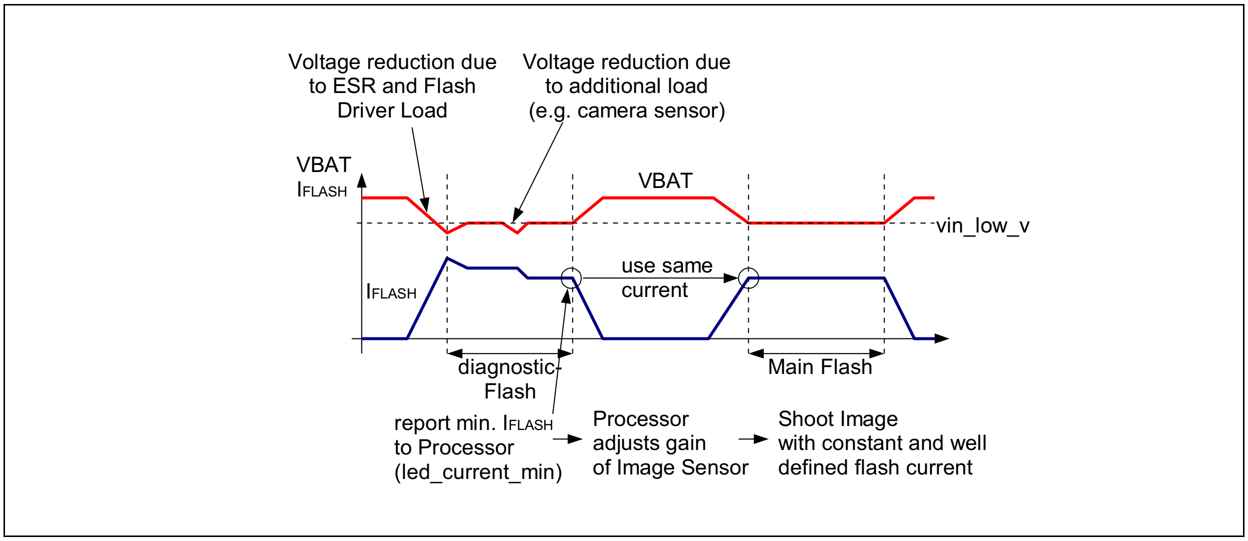
Figure 19. Low Voltage Current Reduction Internal Circuit



A mobile phone camera flash system can trigger a diagnostic flash and a main-flash:

The diagnostic flash is initiated by the processor. After this diagnostic flash, the determined maximum flash current can be read back through the I^2C interface from register led_current_min (see page 30) and used for the setting for the main flash. Therefore the current in the main-flash is constant and additionally the camera system can use this current for picture quality adjustments - the waveforms for this concept are shown in Figure 20:

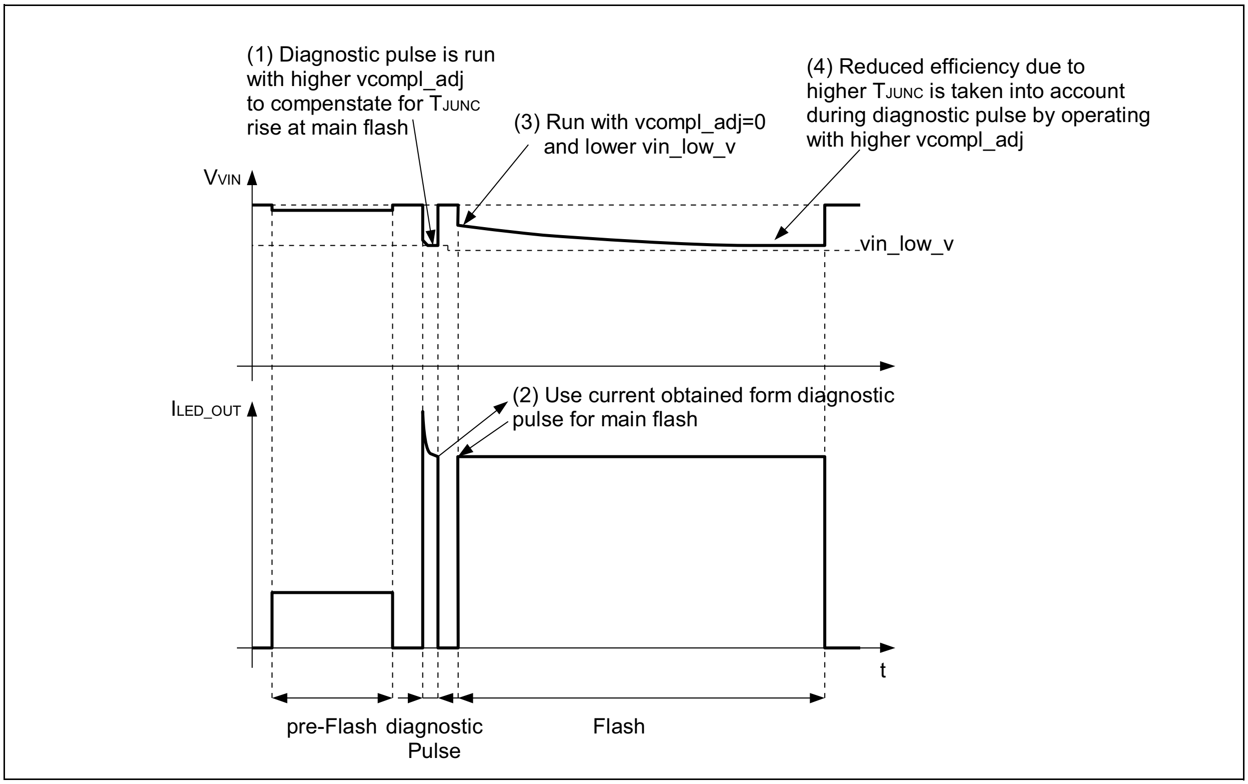
Figure 20. Low Voltage Current Reduction Waveform with Diagnostic-Flash and Main-Flash Phase



Short Diagnostic Pulse.

If the diagnostic flash should be short (e.g. 4ms) it is recommended to operate this diagnostic flash at a different vcompl_adj (see page 27) and higher vin_low_v (see page 24) settings compared to the main flash as shown in Figure 21:

Figure 21. Low Voltage Current Reduction Waveform with Short Diagnostic-Flash and Main-Flash Phase



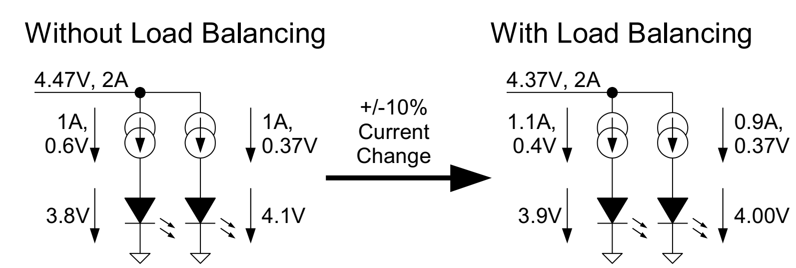
The AS3649 efficiency reduction during main flash can be compensated during a short diagnostic flash by adjusting vcompl_adj as shown in Figure 21. Reducing vin_low_v during main flash additionally takes into account a longer time constant of the battery for high loads and allows a very short diagnostic pulse (only 4ms).

Using the ams AG linux software driver it is possible to calculate the maximum flash duration for a given operating condition (additionally using TJUNCTION measured through the AS3649 ADC).

8.5.2 Load Balancing

To improve the efficiency of the AS3649 for LEDs with unmatched forward voltage and reduce the internal power dissipation of the AS3649, set the bit load_balance_on=1. This bit can change the currents through the LEDs by up to +/-15% to match the forward voltage of the LED better as shown in Figure 22:

Figure 22. Load Balancing



8.6 Flash Strobe Timings

The flash timing are defined as follows:

1. Flash duration defined by register flash_timeout and flash is started immediately when this mode is selected by the I^{2}C command (see Figure 23):
   set strobe_on = 0, start the flash by setting mode_setting = 11b
2. Flash duration defined by register flash_timeout and flash started with a rising edge on pin STROBE (see Figure 24):
   set strobe_on = 1 and strobe_type = 0
3. Flash start and timing defined by the pin STROBE; the flash duration is limited by the timeout timer defined by flash_timeout (see Figure 25 and Figure 26):
   set strobe_on = 1 and strobe_type = 1

Figure 23. AS3649 Flash Duration Defined by flash_timeout Without Using STROBE Input

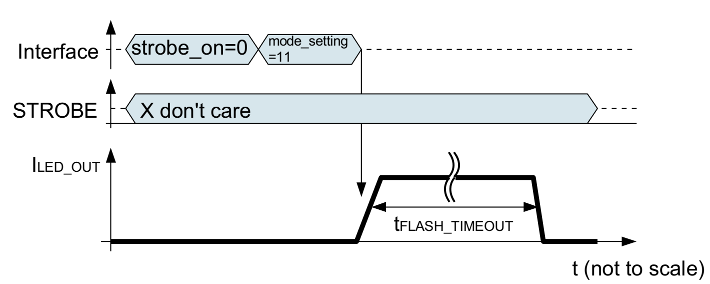


Figure 24. AS3649 Flash Duration Defined by flash_timeout, Starting Flash with STROBE Rising Edge

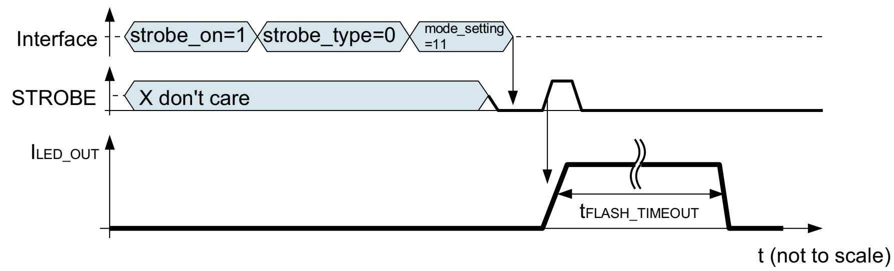


Figure 25. AS3649 Flash Duration and Start Defined by STROBE, Limited by flash_timeout; Timer Not Expired

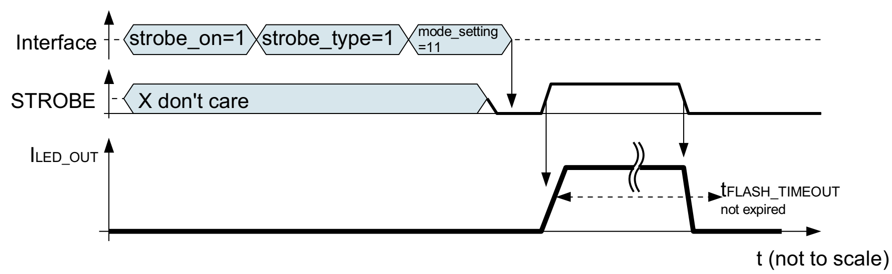
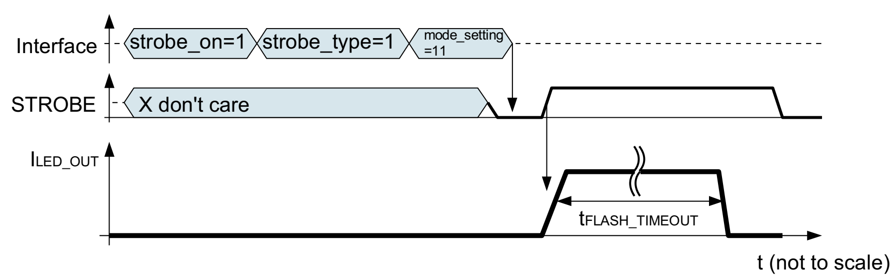


Figure 26. AS3649 Flash Duration and Start Defined by STROBE, Limited by flash_timeout; Timer Expired



8.7 ADC

The internal ADC is used to monitor LED temperature and DIE temperature. To operate the ADC, set the adc_channel (see page 27) and start the conversion by adc_convert. When adc_convert returns to '0' the result is available in register adc_result (see page 30) (Bits 9...7)and adc_result_lsbs (Bits 1...0).

The DIE junction temperature measurement returns the value according to Table 6:

Table 6. Junction Temperature Measurement ADC result

Junction Temperature - ºC	ADC Return Value (10bit)
-30	352
-20	343
-10	334
0	325
10	316
20	306
30	297
40	287
50	278
60	268
70	259
80	249
90	239
100	229
110	219
120	209
130	199
140	189
150	179

8.8 I^2C Serial Data Bus

The AS3649 supports the I^2C bus protocol. A device that sends data onto the bus is defined as a transmitter and a device receiving data as a receiver. The device that controls the message is called a master. The devices that are controlled by the master are referred to as slaves. A master device that generates the serial clock (SCL), controls the bus access, and generates the START and STOP conditions must control the bus. The AS3649 operates as a slave on the I^2C bus. Within the bus specifications a standard mode (100kHz maximum clock rate) and a fast mode (400kHz maximum clock rate) are defined. The AS3649 works in both modes. Connections to the bus are made through the open-drain I/O lines SDA and SCL.

The following bus protocol has been defined (Figure 27):

- Data transfer may be initiated only when the bus is not busy.
- During data transfer, the data line must remain stable whenever the clock line is HIGH. Changes in the data line while the clock line is HIGH are interpreted as control signals.

Accordingly, the following bus conditions have been defined:

Bus Not Busy. Both data and clock lines remain HIGH.

Start Data Transfer. A change in the state of the data line, from HIGH to LOW, while the clock is HIGH, defines a START condition.

Stop Data Transfer. A change in the state of the data line, from LOW to HIGH, while the clock line is HIGH, defines the STOP condition.

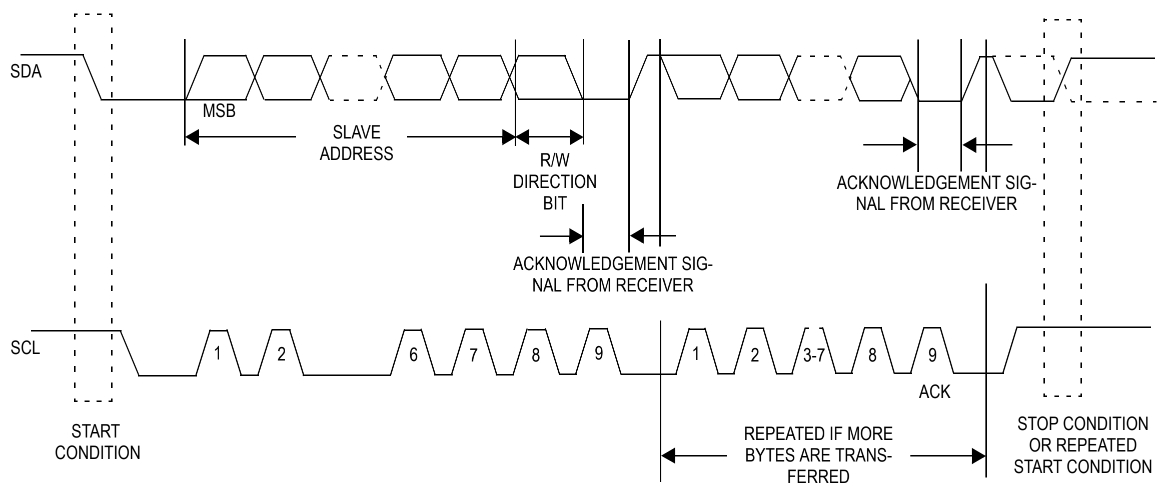
Data Valid. The state of the data line represents valid data when, after a START condition, the data line is stable for the duration of the HIGH period of the clock signal. The data on the line must be changed during the LOW period of the clock signal. There is one clock pulse per bit of data.

Each data transfer is initiated with a START condition and terminated with a STOP condition. The number of data bytes transferred between START and STOP conditions are not limited, and are determined by the master device. The information is transferred byte-wise and each receiver acknowledges with a ninth bit.

Acknowledge. Each receiving device, when addressed, is obliged to generate an acknowledge after the reception of each byte. The master device must generate an extra clock pulse that is associated with this acknowledge bit.

A device that acknowledges must pull down the SDA line during the acknowledge clock pulse in such a way that the SDA line is stable LOW during the HIGH period of the acknowledge-related clock pulse. Of course, setup and hold times must be taken into account. A master must signal an end of data to the slave by not generating an acknowledge bit on the last byte that has been clocked out of the slave. In this case, the slave must leave the data line HIGH to enable the master to generate the STOP condition.

Figure 27. Data Transfer on I^2C Serial Bus



Depending upon the state of the R/W bit, two types of data transfer are possible:

1. **Data transfer from a master transmitter to a slave receiver.** The first byte transmitted by the master is the slave address. Next follows a number of data bytes. The slave returns an acknowledge bit after each received byte. Data is transferred with the most significant bit (MSB) first.
2. **Data transfer from a slave transmitter to a master receiver.** The master transmits the first byte (the slave address). The slave then returns an acknowledge bit, followed by the slave transmitting a number of data bytes. The master returns an acknowledge bit after all received bytes other than the last byte. At the end of the last received byte, a “not acknowledge” is returned. The master device generates all of the serial clock pulses and the START and STOP conditions. A transfer is ended with a STOP condition or with a repeated START condition. Since a repeated START condition is also the beginning of the next serial transfer, the bus is not released. Data is transferred with the most significant bit (MSB) first.

The AS3649 can operate in the following two modes:

1. **Slave Receiver Mode (Write Mode):** Serial data and clock are received through SDA and SCL. After each byte is received an acknowledge bit is transmitted. START and STOP conditions are recognized as the beginning and end of a serial transfer. Address recognition is performed by hardware after reception of the slave address and direction bit (see Figure 28). The slave address byte is the first byte received after the master generates the START condition. The slave address byte contains the 7-bit AS3649 address, which is 0110000, followed by the direction bit (R/W), which, for a write, is 0.[13] After receiving and decoding the slave address byte the device outputs an acknowledge on the SDA line. After the AS3649 acknowledges the slave address + write bit, the master transmits a

register address to the AS3649. This sets the register pointer on the AS3649. The master may then transmit zero or more bytes of data, with the AS3649 acknowledging each byte received. The address pointer will increment after each data byte is transferred. The master generates a STOP condition to terminate the data write.

2. **Slave Transmitter Mode (Read Mode):** The first byte is received and handled as in the slave receiver mode. However, in this mode, the direction bit indicates that the transfer direction is reversed. Serial data is transmitted on SDA by the AS3649 while the serial clock is input on SCL. START and STOP conditions are recognized as the beginning and end of a serial transfer (Figure 29 and Figure 30). The slave address byte is the first byte received after the master generates a START condition. The slave address byte contains the 7-bit AS3649 address, which is 0110000, followed by the direction bit (R/W), which, for a read, is 1.[14] After receiving and decoding the slave address byte the device outputs an acknowledge on the SDA line. The AS3649 then begins to transmit data starting with the register address pointed to by the register pointer. If the register pointer is not written to before the initiation of a read mode the first address that is read is the last one stored in the register pointer. The AS3649 must receive a “not acknowledge” to end a read.

Figure 28. Data Write - Slave Receiver Mode

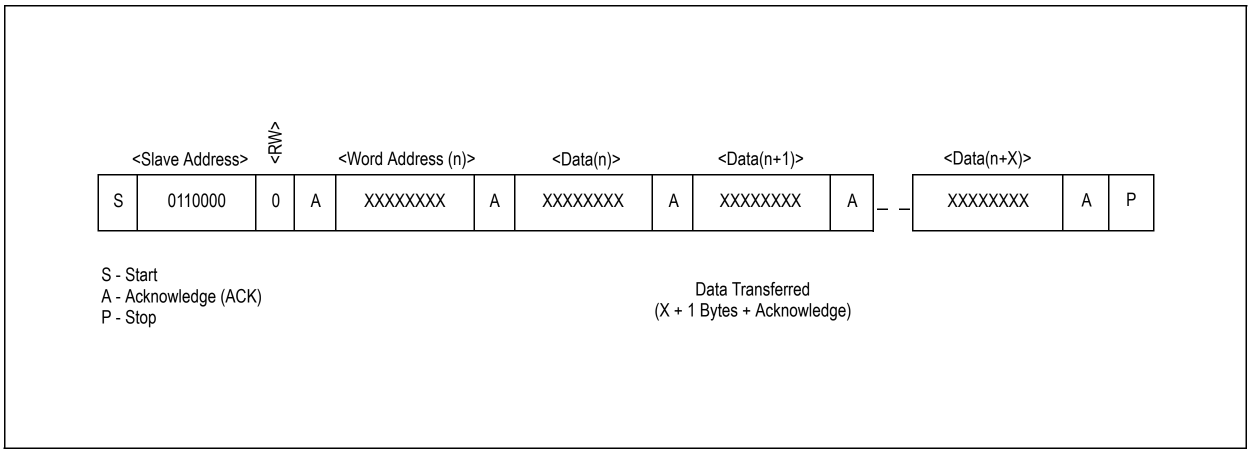
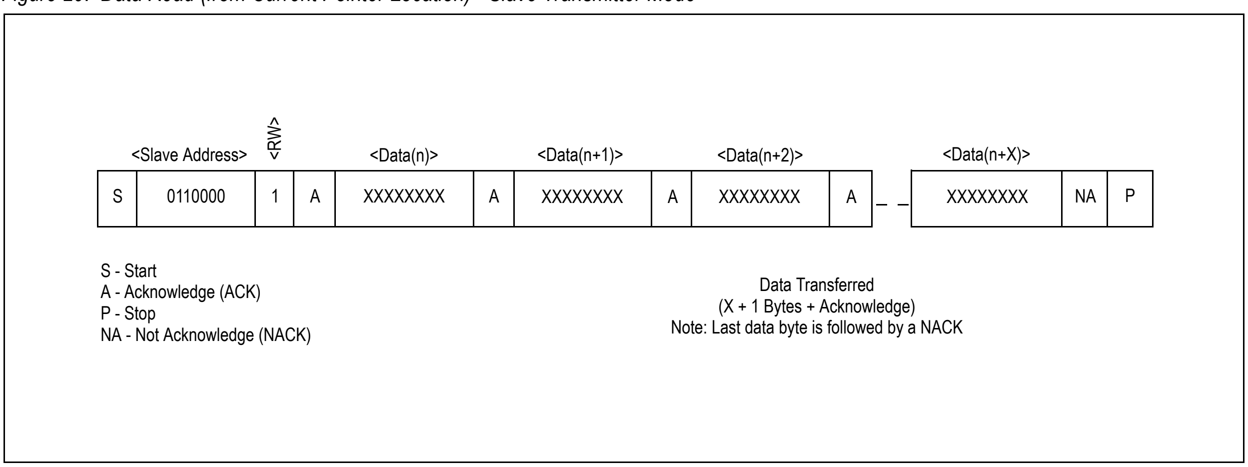
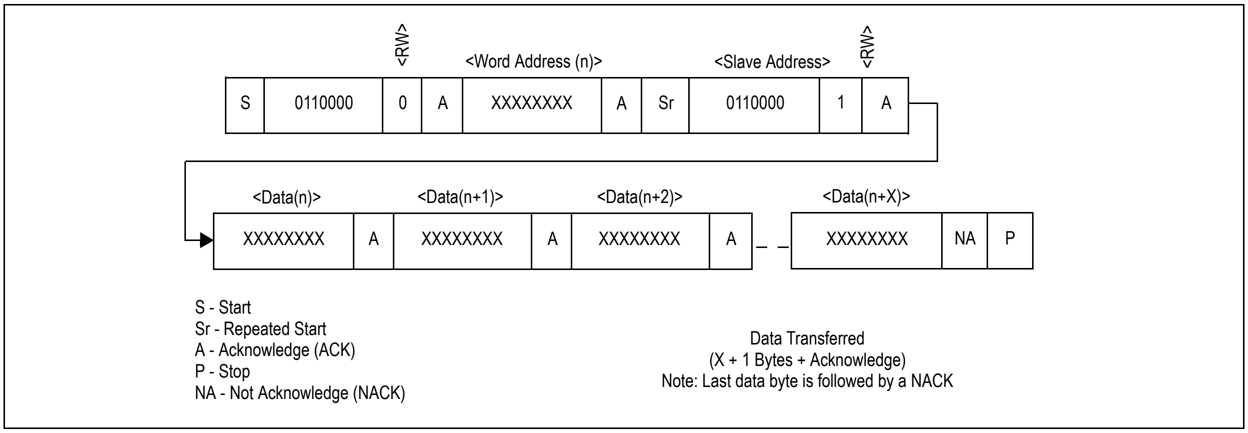


Figure 29. Data Read (from Current Pointer Location) - Slave Transmitter Mode



13. The address for writing to the AS3649 is 60h = 01100000b
14. The address for read mode from the AS3649 is 61h = 01100001b

Figure 30. Data Read (Write Pointer, Then Read) - Slave Receive and Transmit



8.9 Register Description

Table 7. ChipID Register

<table>
<tr><th colspan="2" rowspan="2">Addr: 0</th><th colspan="3">ChipID Register</th></tr>
<tr><th colspan="3">This register has a fixed ID</th></tr>
<tr><th>Bit</th><th>Bit Name</th><th>Default</th><th>Access</th><th>Description</th></tr>
<tr><td>2:0</td><td>version</td><td>Xh</td><td>R</td><td>AS3649 chip version number</td></tr>
<tr><td>7:3</td><td>fixed_id</td><td>11000b</td><td>R</td><td>This is a fixed identification (e.g. to verify the I^2C communication)</td></tr>
</table>

Table 8. Current Set LED1 Register

<table>
<tr><th colspan="2" rowspan="2">Addr: 1</th><th colspan="4">Current Set LED1 Register</th></tr>
<tr><th colspan="4">This register defines design versions</th></tr>
<tr><th>Bit</th><th>Bit Name</th><th>Default</th><th>Access</th><th colspan="2">Description</th></tr>
<tr><td rowspan="14">7:0</td><td rowspan="14">led_current1</td><td rowspan="14">9Ch</td><td rowspan="14">R/W</td><td colspan="2">Define the current on pin LED_OUT1;
torch mode uses bits 5:0 of this current setting (max. 1/4 of full current setting)
indicator or low current pwm mode uses only 5:0 of this current setting (max. 1/4 of full current setting)

Note: Always keep led_current1 >= led_current2</td></tr>
<tr><td>0h</td><td>0mA</td></tr>
<tr><td>1h</td><td>7.8mA</td></tr>
<tr><td>2h</td><td>11.7mA</td></tr>
<tr><td>...</td><td>...</td></tr>
<tr><td>3Fh</td><td>250mA (maximum current for torch light mode, indicator or low current pwm mode, mode_setting=01 or 10)</td></tr>
<tr><td>...</td><td>...</td></tr>
<tr><td>7Fh</td><td>500mA</td></tr>
<tr><td>...</td><td>...</td></tr>
<tr><td>9Ch</td><td>613.3mA - default setting</td></tr>
<tr><td>...</td><td>...</td></tr>
<tr><td>FEh</td><td>996mA (1245mA[1] if current_boost=1)</td></tr>
<tr><td>FFh</td><td>1000mA (1250mA[1] if current_boost=1)</td></tr>
</table>

1. Only use current_boost=1 for currents > 1000mA(code >= CCh)

Table 9. Current Set LED2 Register

Addr: 2		Current Set LED2 Register This register defines design versions			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
7:0	led_current2	9Ch	R/W	Define the current on pin LED_OUT2; torch mode uses bits 5:0 of this current setting (max. 1/4 of full current setting) indicator or low current pwm mode uses only 5:0 of this current setting (max. 1/4 of full current setting) **Note:** Always keep led_current1 >= led_current2	
				0h	0mA
				1h	7.8mA
				2h	11.7mA
				...	...
				3Fh	250mA (maximum current for torch light mode, indicator or low current pwm mode, mode_setting=01 or 10)
				...	...
				7Fh	500mA
				...	...
				9Ch	613.3mA - default setting
				...	...
				FEh	996mA (1245mA[1] if current_boost=1)
				FFh	1000mA (1250mA[1] if current_boost=1)

1. Only use current_boost=1 for currents > 1000mA(code >= CCh)

Table 10. TXMask Register

Addr: 3		TXMask Register This register defines the TXMask settings and coil peak current			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
1:0	txmask_torch_mode	00	R/W	Defines operating mode for input pin TXMASK/TORCH	
				00	pin has no effect
				01	txmask-mode; during flash if TXMASK/TORCH=1, the LED current is set to flash_txmask_current - (see TXMASK on page 15)
				10	external torch mode: if TXMASK/TORCH=1 and mode_setting=00, the AS3649is set into external torch mode (LED current is defined by the 6LSB[1] bits of led_current1 and led_current2)
				11	don't use
3:2	coil_peak	10	R/W	Defines the maximum coil current (parameter I_{LIMIT})	
				00	I_{LIMIT} = 2.5A
				01	I_{LIMIT} = 2.9A
				10	I_{LIMIT} = 3.3A
				11	I_{LIMIT} = 3.7A

Table 10. TXMask Register (Continued)

Addr: 3		TXMask Register			
		This register defines the TXMask settings and coil peak current			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
7:4	flash_txmask_current[2]	6h	R/W	Define the current on pin LED_OUT1 and LED_OUT2 (each current source) in flash mode if txmask_torch_mode=01 and TXMASK/TORCH=1	
				0h	0mA
				1h	31mA (39mA if current_boost=1)
				2h	63mA (78mA if current_boost=1)
				3h	94mA (118mA if current_boost=1)
				4h	125mA (157mA if current_boost=1)
				5h	157mA (196mA if current_boost=1)
				6h	188mA (235mA if current_boost=1) - default
				7h	220mA (275mA if current_boost=1)
				8h	251mA (314mA if current_boost=1)
				9h	282mA (353mA if current_boost=1)
				Ah	314mA (392mA if current_boost=1)
				Bh	345mA (431mA if current_boost=1)
				Ch	376mA (471mA if current_boost=1)
				Dh	408mA (510mA if current_boost=1)
				Eh	439mA (549mA if current_boost=1)
				Fh	471mA (588mA if current_boost=1)

1. The MSB bit of this register not used to protect the LED; therefore the maximum current = 1/4 the maximum flash current
2. If current_boost=1, the LED current is increased by 25%.

Table 11. Low Voltage / NTC Register

Addr: 4		Low Voltage / NTC Register			
		This register defines the operating mode with low battery voltages			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
2:0	vin_low_v	4h	R/W	Voltage level on VIN where current reduction triggers during operation (see Current Reduction by VIN Measurements in Flash Mode and Diagnostic Pulse on page 15) - only in flash mode; if VIN drops below this voltage during current ramp up, the current ramp up is stopped; during operation the current is decreased until the voltage on VIN rises above this threshold - status_uvlo is set	
				0h	function is disabled
				1h	3.0V
				2h	3.07V
				3h	3.14V
				4h	3.22V - default
				5h	3.3V
				6h	3.38V
				7h	3.47V

Table 11. Low Voltage / NTC Register (Continued)

Addr: 4		Low Voltage / NTC Register This register defines the operating mode with low battery voltages			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
3	ntc_on	0	R/W	Enable overtemperature protection on pin NTC (internal comparator comparing NTC to V_{NTC_TH})	
				0	disabled
				1	enabled
7:4	ntc_current	8h	R/W	Current through the NTC (I_{NTC}); it is enabled once the LED current source (LED_OUT1/2) is operating and ntc_on=1 or the ADC measures the LED temperature (see NTC - Flash LED Overtemperature Protection on page 14)	
				0h	off; can be used to use an external current to bias the NTC
				1h	40µA
				2h	80µA
				3h	120µA
				4h	160µA
				5h	200µA
				6h	240µA
				7h	280µA
				8h	320µA - default
				9h	360µA
				Ah	400µA
				Bh	440µA
				Ch	480µA
				Dh	520µA
				Eh	560µA
				Fh	600µA