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AS3685A/AS3685B

Ultra Small High Efficiency 1000mA Charge Pump for White LED Flash

General Description

The AS3685 is low noise high efficiency capacitive charge pump with 1:1, 1:1.5 and 1:2 operating modes in a small 3x3mm DFN10 or a tiny 2x1.5mm WL-CSP (Wafer Level Chip Scale Package) package. It can drive one flash LED at up to 1000mA current. It supports flash/torch and indicator mode for the flash LED.

Additionally the AS3685 limits the flash time automatically to protect the flash LED.

Ordering Information and Content Guide appear at end of datasheet.

Key Benefits & Features

The benefits and features of AS3685A/AS3685B, Ultra Small High Efficiency 1000mA Charge Pump for White LED Flash are listed below:

Figure 1:
Added Value Of Using AS3685A/AS3685B

Benefits	Features
• System safety	• High efficiency capactive charge pump with 1:1, 1:1.5 and 1:2 modes therefore maximum input current is exactly controlled. • Overtemperature protection • Automatic 800ms flash timeout to protect the flash LED
• Drive LED at high brightness for better pictures	• Up to 1000mA LED Current

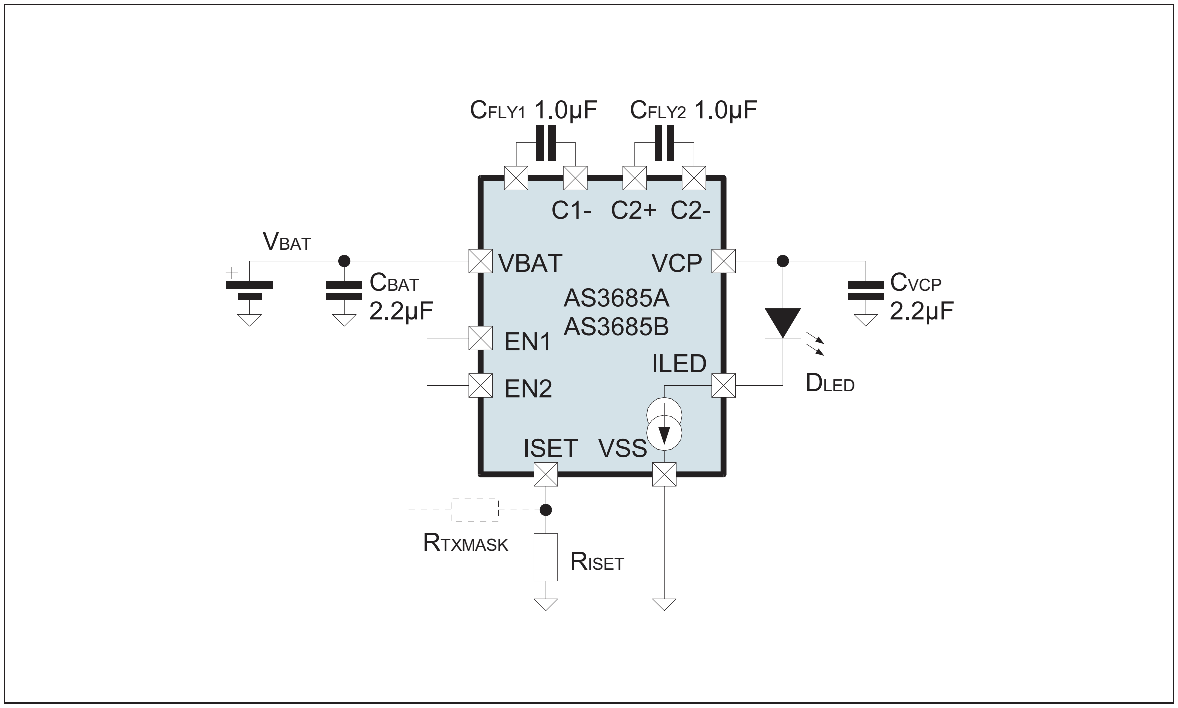
• Flexible selection of interface type	• Two device variants:
	  • AS3685A: Direct control to select three currents
	  • AS3685B: Single pin interface or two pin interface with strobe input; 17 different currents can be selected

• Flexible package options	• DFN10 (3x3mm) 10 pins + exposed pad • WL-CSP (2x1.5mm) 3x4 balls 0.5mm pitch

Applications

The AS3685A/AS3685B, Ultra Small High Efficiency 1000mA Charge Pump for White LED Flash is ideal for Flash / Torch for Mobile Phones, Digital Cameras and PDAs.

Figure 2:
Application Diagram of AS3685A/AS3685B



Pin Assignment

DFN10 (3x3mm)

Figure 3:
Pin Diagram DFN10 (3x3mm)

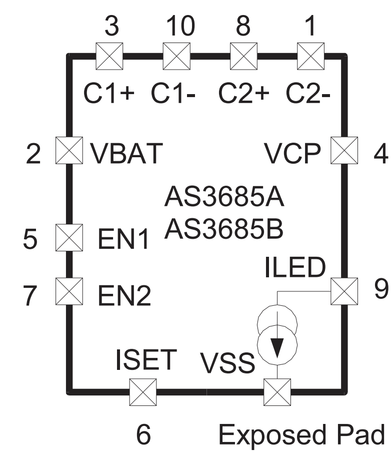


Figure 4:
Pin Description DFN10 (3x3mm)

Pin Number	Pin Name	Type	Description
1	C2-	AI/O	Flying Capacitor 2 connection – connect 1µF ceramic capacitor C_{FLY2} between C2- and C2+
2	VBAT	S	Battery Supply Voltage
3	C1+	AI/O	Flying Capacitor 1 connection – connect 1µF ceramic capacitor C_{FLY1} between C1- and C1+
4	VCP	AI/O	Charge Pump Output voltage – connect flash LED anode to this pin and add C_{VCP} capacitor with 2.2µF to VSS
5	EN1	DI	Digital Control Signal EN1
6	ISET	AI/O	Current Generator input pin – connect current set resistor R_{ISET} between this pin and VSS (and optional R_{TXMASK})
7	EN2	DI	Digital Control Signal EN2

Pin Number	Pin Name	Type	Description
8	C2+	AI/O	Flying Capacitor 2 connection – connect 1µF ceramic capacitor C_{FLY2} between C2- and C2+
9	ILED	AI/O	Current Source input pin – connect flash LED cathode to this pin
10	C1-	AI/O	Flying capacitor 1 connection – connect 1µF ceramic capacitor C_{FLY1} between C1- and C1+
Exposed Pad	VSS	S	Ground Connection – a proper thermal connection with several vias to the ground plane is recommended

Note(s):

1. Pin Type Descriptions:
   AI/O: Analog Pin
   DI: Digital Input
   S: Supply Pin

WL-CSP (2x1.5mm)

Figure 5:
WL-CSP (2x1.5mm) Pin Diagram

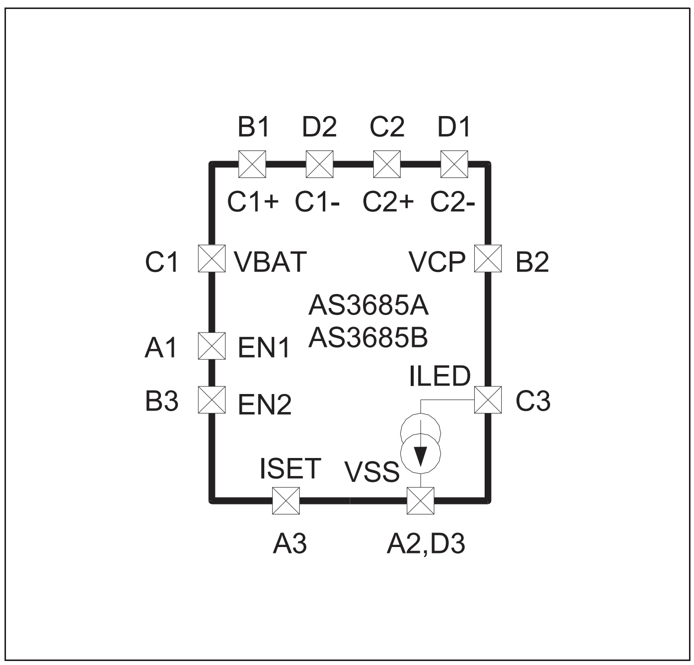


Figure 6:
Pin Description WL-CSP (2x1.5mm)

Pin Number	Pin Name	Type	Description
A1	EN1	DI	Digital Control Signal EN1
A2	VSS	S	Ground Connection – a proper thermal connection to the ground plane is recommended
A3	ISET	AI/O	Current Generator input pin – connect current set resistor R_{ISET} between this pin and VSS (and optional R_{TXMASK})
B1	C1+	AI/O	Flying Capacitor 1 connection – connect 1µF ceramic capacitor C_{FLY1} between C1- and C1+
B2	VCP	AI/O	Charge Pump Output voltage – connect flash LED anode to this pin and add C_{VCP} capacitor with 2.2µF to VSS
B3	EN2	DI	Digital Control Signal EN2
C1	VBAT	S	Battery Supply Voltage
C2	C2+	AI/O	Flying Capacitor 2 connection – connect 1µF ceramic capacitor C_{FLY2} between C2- and C2+
C3	ILED	AI/O	Current Source input pin – connect flash LED cathode to this pin
D1	C2-	AI/O	Flying Capacitor 2 connection – connect 1µF ceramic capacitor C_{FLY2} between C2- and C2+
D2	C1-	AI/O	Flying capacitor 1 connection – connect 1µF ceramic capacitor C_{FLY1} between C1- and C1+
D3	VSS	S	Ground Connection – a proper thermal connection to the ground plane is recommended

Note(s):

1. Pin Type Descriptions WL-CSP (2x1.5mm):
   AI/O: Analog Pin
   DI: Digital Input
   S: Supply Pin

Absolute Maximum Ratings

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

Figure 7:
Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Units	Comments
V_{BATMAX}	Maximum Supply Voltage	-0.3	7.0	V	
I_{IN}	Input Pin Current without causing latchup	-25	+25	mA	At 25°C, according to JEDEC 17
T_{STRG}	Storage Temperature Range	-55	125	°C	
RH_{NC}	Relative Humidity (non-condensing)	5	85	%	
ESD_{HBM}	Electrostatic Discharge (Human Body Model)	±1000		V	MIL 883 E Method 3015
PT	Total Continuous Power Dissipation		1.14	W	DFN10 (3x3mm), T_{AMB} = 70°C (1)
			1.02	W	WL-CSP (2x1.5mm), T_{AMB} = 70°C (1)
P_{DERATE}	PT Derating Factor (2)		16.3	mW/°C	DFN10 (3x3mm)
			14.7	mW/°C	WL-CSP (2x1.5mm)
T_{JUNC}	Junction Temperature		150	°C	
T_{BODY}	Body Temperature during Soldering		260	°C	According to IPC/JEDEC J-STD-020C
MSL	Moisture sensitivity level	1			WLCSP package; Represents a max. floor life time of unlimited hours
		3			DFN package; Represents a max. floor life time of 168 hours

Note(s):

1. Depending on actual PCB layout and PCB used; for peak power dissipation during flashing see document 'AS3685 Thermal Measurements'.
   For 1A flash current see application notes 'AN3685_1Aflash' and 'AN3685_1Aflash_thermal_1v0'.
2. The PT derating factor changes the total continuous power dissipation, if the ambient temperature is different to 70°C. Therefore for e.g. 85°C calculate $PT_{85°C} = PT - P_{DERATE} * (85°C \text{ to } 70°C)$.

Electrical Characteristics

All limits are guaranteed. The parameters with minimum and maximum values are guaranteed with production tests or SQC (Statistical Quality Control) methods.

Figure 8:
Operating Conditions

Symbol	Parameter	Min	Typ	Max	Units	Note
VBAT	Battery Supply Voltage	3.0	3.6	5.5	V	Supply voltage range
VBATFUNC	Battery Supply Voltage (functionally working)	2.6			V	AS3685 functionally working, but not all parameters fulfilled
I_{BAT}	Operating Current			0.4	A	Depending on load current and charge pump mode
				2.0	A	Limited lifetime, max 20,000s
T_{AMB}	Ambient Temperature	-30	25	85	°C	
I_{OFF}	Off Mode Current		1.0	4.0	µA	EN1 = 0, EN2 = 0; VBAT ≤ 4.2V
$I_{OPERATING}$	Power Consumption (without load)		0.85		mA	1:1 Mode
			6.6		mA	1:1.5 Mode
			8.1		mA	1:2 Mode

Figure 9:
Charge Pump Characteristics

Symbol	Parameter	Min	Typ	Max	Units	Note
V_{CPOUT}	V(VCP) Output Voltage (without load – do not short to VSS)			V_{BAT} x CP-mode	V	CP-mode is 1, 1.5 or 2 (automatically selected)
	Output Limitation		5.4	5.6		Internally limited
R_{CP}	Charge Pump Effective Resistance		0.28	0.53	Ω	1:1 Mode V_{BAT} = 3.6V, I_{CPOUT} = 200mA
			1.37	2.00	Ω	1:1.5 Mode V_{BAT} = 3.3V, I_{CPOUT} = 500mA, $T_{JUNCTION}$ ≤ 85°C
			1.95	2.44	Ω	1:2 Mode V_{BAT} = 3.0V, I_{CPOUT}=700mA, $T_{JUNCTION}$ ≤ 85°C
Eta	Efficiency	75		93	%	Vin=3.0V-4.5V, Iout=100mA (charge pump alone)
V_{RIPPLE}	Output Ripple Voltage		100		mVpp	Vin=3.0-4.5V, Iout=350mA,

Symbol	Parameter	Min	Typ	Max	Units	Note
fclk	Operating Frequency	-20%	1.0	+20%	MHz	
$t_{UP\_DEB\_LONG}$	Initial Mode Switching Debounce Time		256		µs	Mode switching up-debounce time after enabling of the charge pump or after mode switching between 1:1 to 1:1.5
t_{UP_DEB}	Mode Switching Debounce Time		16		µs	Mode switching up-debounce time in normal operation

Figure 10:
Current Source (Sink) Characteristics

Symbol	Parameter	Min	Typ	Max	Units	Note
I_{LED}	Output Current Range		700	1000	mA	700mA: R_{ISET} = 14.2kΩ 1000mA: R_{ISET} = 10kΩ
$I_{ACCURACY}$	Current Setting Accuracy	-10%	500	+10%	mA	Measured with R_{ISET} = 19.9kΩ and maximum flash current
V_{ISET}	Current Generator Set Point Voltage (pin ISET)		1.3		V	$I_{ISET} = V_{ISET} / R_{ISET}$ if the resulting bias current is higher than 200µA (typ.), the current source is disabled
I_{ISET}	Current Generator Operating Range	10.0		130	µA	
$I_{FLASH2ISET}$	Flash Current to Bias Current Ratio		7650		A/A	AS3685A, EN1=1, EN2=1 or AS3685B at full flash current (700mA with R_{ISET} = 14.2kΩ)
$I_{TORCH2ISET}$	Torch Current to Bias Current Ratio		1639		A/A	AS3685A, EN1=0, EN2=1 (150mA with R_{ISET} = 14.2kΩ)
V_{SWITCH}	Mode Switching Threshold on V(ILED) between 1:1 → 1:1.5 and 1:1.5 → 1:2		400		mV	AS3685A, EN1=1, EN2=1 or AS3685B with I_{LED}>350mA (with R_{ISET} = 14.2kΩ)
		150	200	250	mV	All lower currents

Figure 11:
Digital Interface Characteristics

Symbol	Parameter	Min	Typ	Max	Units	Note
V_{IH}	High Level Input Voltage	1.5		VBAT	V	For Pins EN1 and EN2 Do not leave EN1 and EN2 floating (47kΩ pulldowns can be used)
V_{IL}	Low Level Input Voltage	0.0		0.5	V	
$I_{LEAKAGE}$	Input Pin Leakage Current	-10		10	µA	
$t_{PULSEWIDTH}$	Pulsewidth for Signals on EN1 and EN2 (high or low pulses)	1.0		unlimited	µs	

Figure 12:
Protection Functions

Symbol	Parameter	Min	Typ	Max	Units	Note
T_{OVTEMP}	Overtemperature Protection		140		°C	If the junction temperature exceeds T_{OVTEMP}, the current sink will be disabled and the charge pump switched back into 1:1 mode until the temperature drops below T_{OVTEMP} - $T_{OVTEMPHYST}$
$T_{OVTEMPHYST}$	Overtemperature Protection Hysteresis		5		°C	
$t_{FLASHTIMEOUT}$	Flash Timeout Time	-20%	800	+20%	ms	AS3685A, EN1=1, EN2=1 or AS3685B flash modes

Typical Operating Characteristics

Figure 13:
Efficiency vs. Battery Voltage (with Lumiled PWF1)

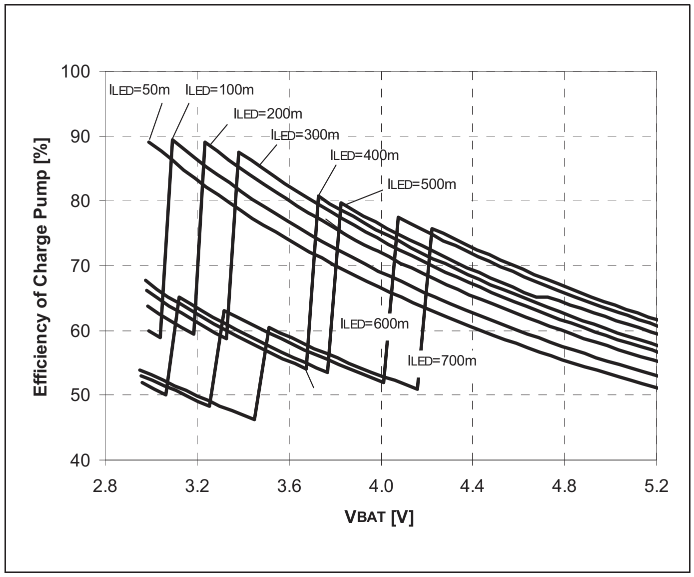


Figure 14:
Battery Current vs. Battery Voltage (with Lumiled PWF1)

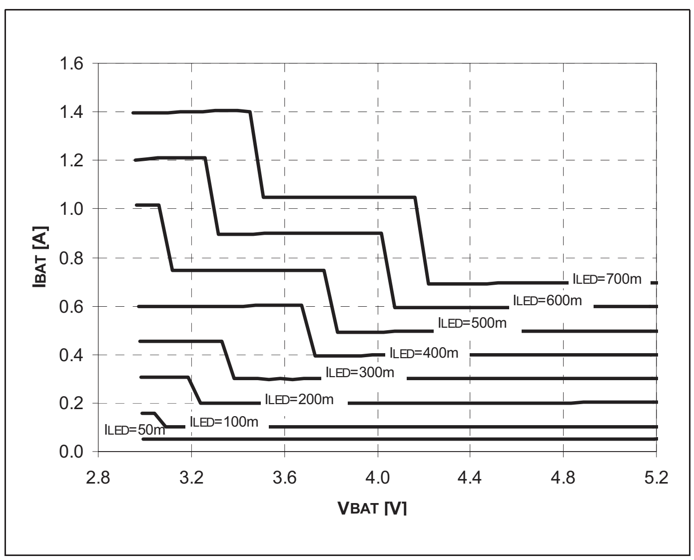


Figure 15:
LED Current I(ILED) vs. Battery Voltage (with Lumiled PWF1)

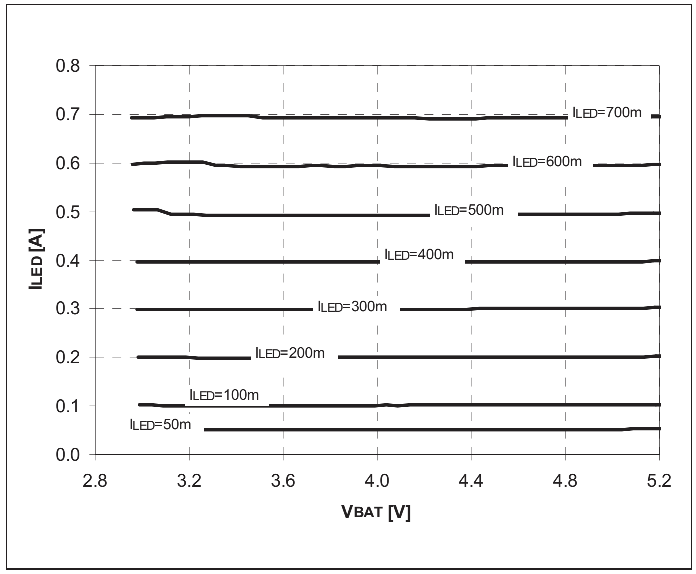


Figure 16:
Linearity of Current Sink

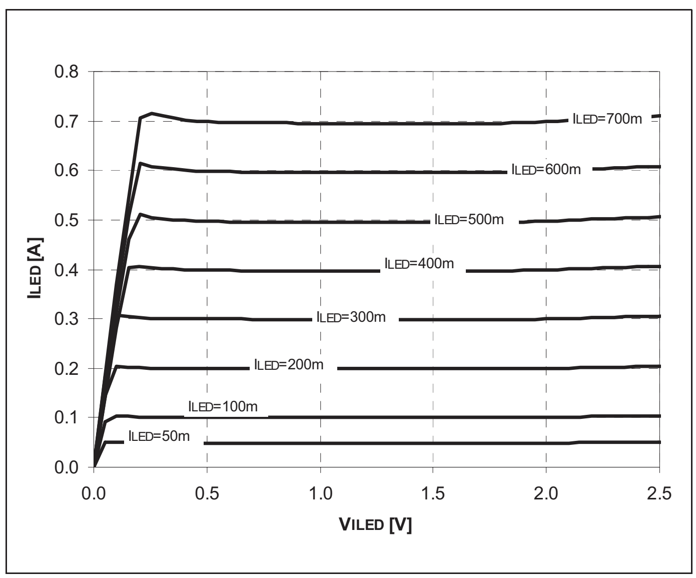


Figure 17:
I(ILED) vs. R(ISET) (Flash and Torch Mode of AS3685A)

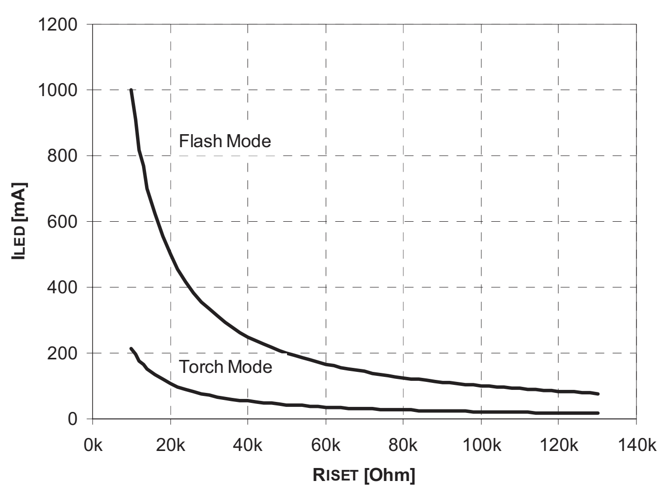


Figure 18:
Startup of AS3685A -- I_{LED} Current

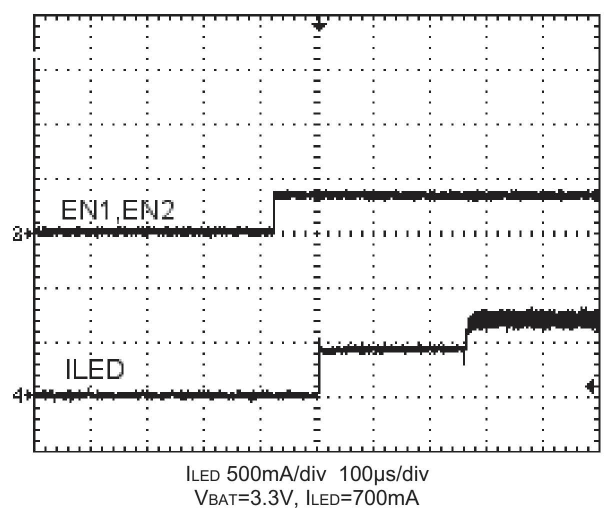


Figure 19:
Startup of AS3685A -- I_{BAT} Current

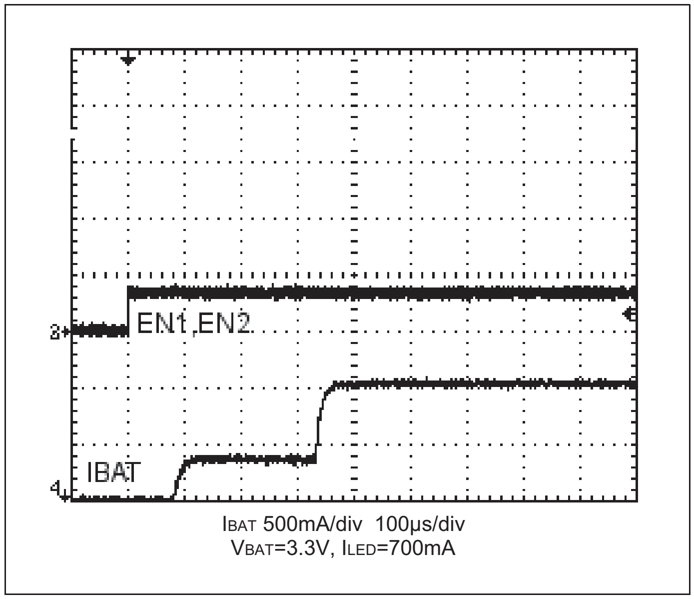


Figure 20:
Shutdown of AS3685A -- I_{BAT} Current

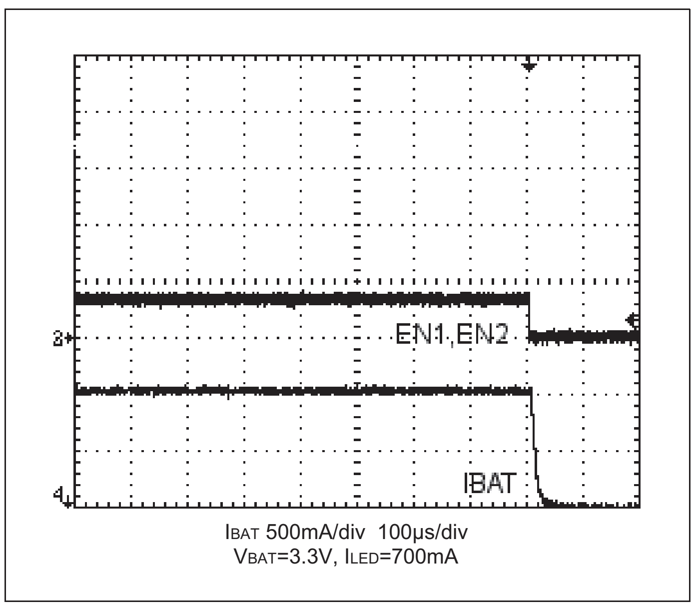
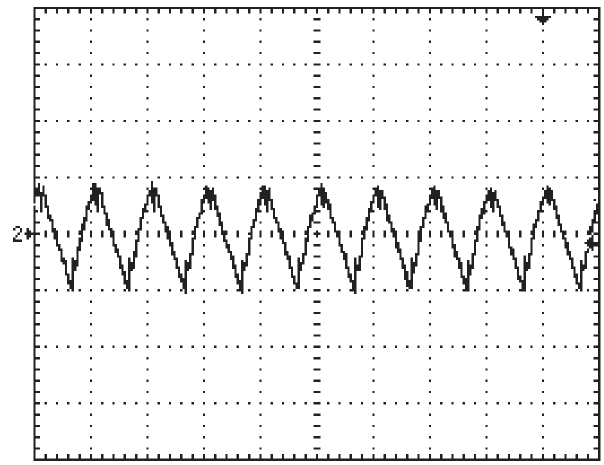
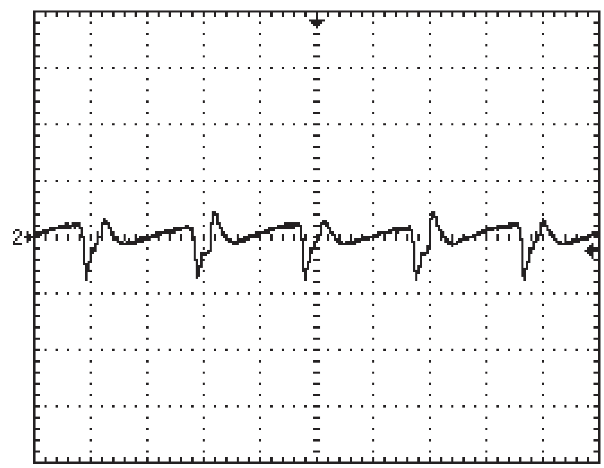


Figure 21:
Typical Operating Waveforms 1:1.5 Mode



VCP ac-coupled, 100mV/div 1µs/div
V_{BAT}=3.3V, I_{LED}=500mA

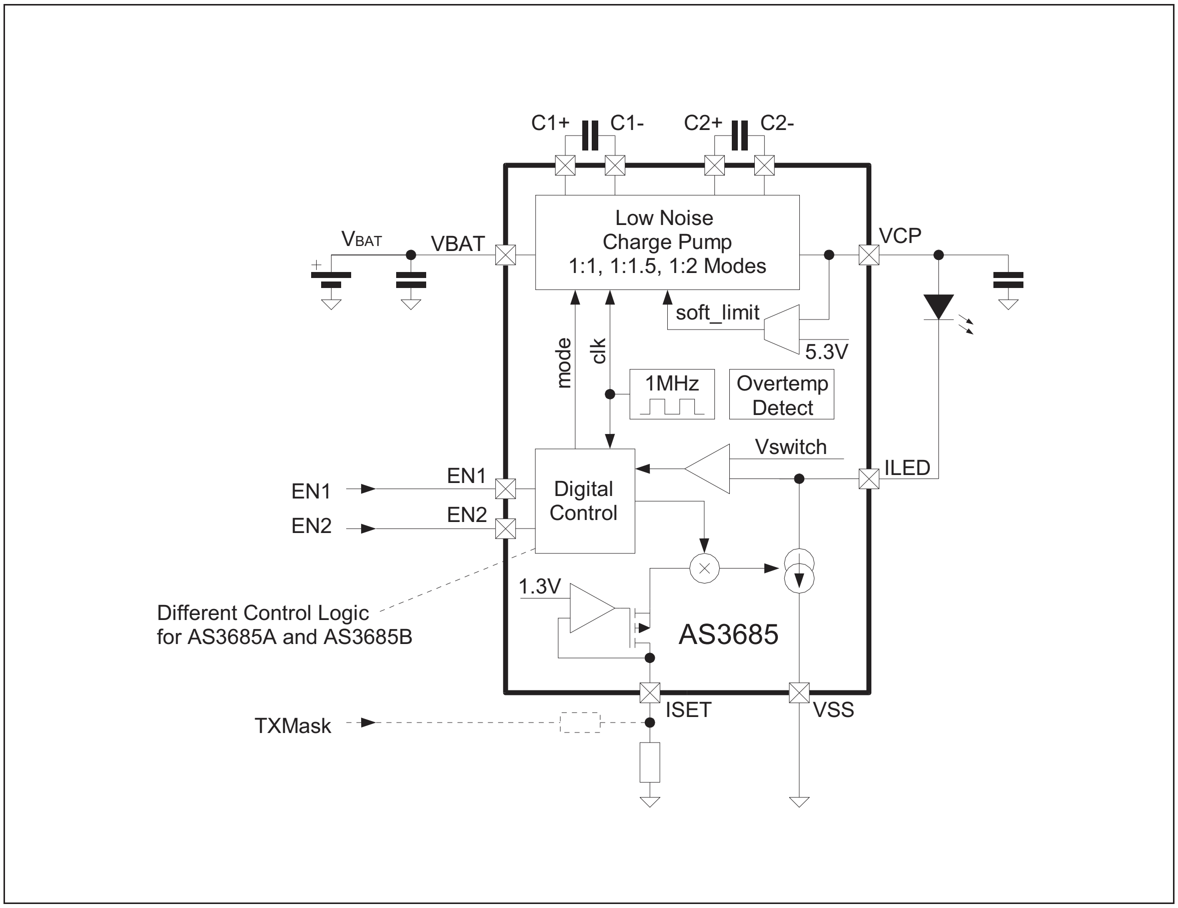
Figure 22:
Typical Operating Waveforms 1:2 Mode



VCP ac-coupled, 50mV/div 250ns/div
V_{BAT}=3.3V, I_{LED}=500mA

Detailed Description

Figure 23:
Internal Circuit Diagram of AS3685A/AS3685B



Low Noise Charge Pump

The AS3685 charge pump uses two external flying capacitors to generate output voltages higher than the battery voltage. The charge pump can operate in three different modes:

- 1:1 Bypass Mode or Off Mode
  - Battery input and output are connected by a low-impedance switch
  - Battery current = output current
- 1:1.5 Mode
  - The output voltage is 1.5 times the battery voltage (without load)
  - Battery current = 1.5 times output current
- 1:2 Mode
  - The output voltage is 2 times the battery voltage (without load)
  - Battery current = 2 times output current

The flying capacitors are switched at the fixed frequency fclk.

Mode Switching

The AS3685 monitors the voltage at the current sink V(ILED) and if this voltage falls below V_{SWITCH}, for a time longer than the debounce time, the charge pump automatically switches into a higher mode. The debounce time is set to $t_{UP\_DEB\_LONG}$ at enabling of the charge pump or immediately after a 1:1 to 1:1.5 mode change. Afterwards the debounce time is reduced to t_{UP_DEB}. (This allows the LED current to settle properly on startup or after a mode change).

The charge pump enters always 1:1 mode in off mode or in case of overtemperature. It is possible to avoid the 1:2 mode (factory programmable) to limit the battery current to 1.5 times the output (=LED) current.

Soft Start

The soft start mechanism reduces the inrush current. Battery current is smoothed when switching the charge pump on and also at each switching condition. This precaution reduces electromagnetic radiation significantly.

Current Source (Sink)

The AS3685 operates in three different modes:

- Indicator Mode: A small (average) current is used to obtain an indication function with the flash LED (e.g. indication for camera operation).
- Torch Mode: A moderate current of e.g. 150mA allows the use of the flash LED as a torch or video light.
- Flash Mode: A high current of e.g. 700mA (up to 1000mA) is set for a high brightness flash. Only in this mode, the flash timeout timer limits the total flash time.
- Pulsed Indicator Mode (only AS3685A): The control device sends a short sequence to the AS3685A and the AS3685A enables the flash LED for a defined fixed duration (torch current setting). This duration is controlled by the AS3685A and the control device does not need to start an internal timer function.

The current through the LED and the operating mode is controlled by the two digital pins EN1 and EN2. There are two versions of the AS3685 available: AS3685A and AS3685B. The only difference between these versions is the digital interface as shown below:

AS3685A Current Setting

For the AS3685A, the operating mode and the current through the LED is defined by the following table:

Figure 24:
AS3685A Current Settings

EN1	EN2	Mode	I_{LED} for R_{ISET} = 14.2kΩ	I_{LED} for R_{ISET} = 10kΩ	Percent of Full Scale	I_{LED}/I_{ISET}
0	0	Off	0mA	0mA	0%	0 (Off)
1	0	Indicator	4.7mA average (=150mA with 1/32 duty cycle [1])	6.7mA average (=214mA with 1/32 duty cycle [1])	0.67% (=21.4% / 32)	52.2 (=$I_{TORCH2ISET}$/32)
0	1	Torch	150mA	214mA	21.4%	1639 (=$I_{TORCH2ISET}$)
1	1	Flash	700mA	1000mA	100%	7650 (=$I_{FLASH2ISET}$)

Note(s):

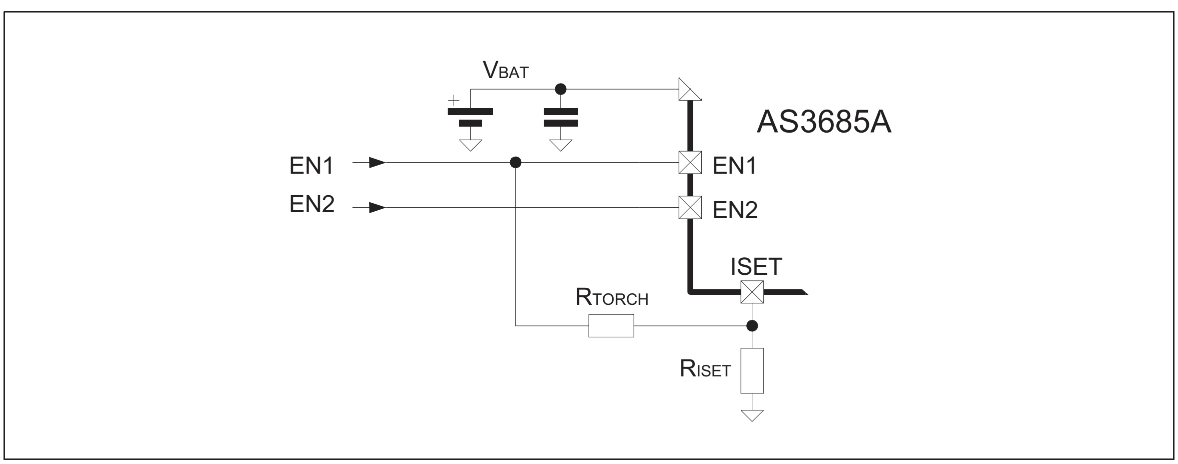
1. The on-time for indicator mode is 1µs, off time 31µs (32µs = 32.25kHz).

Where I_{ISET} is:

$$I_{ISET} = \frac{V_{ISET}}{R_{ISET}} = \frac{1.3V}{R_{ISET}} \quad \text{(EQ1)}$$

Application Hint: To obtain higher torch currents use the following circuit:

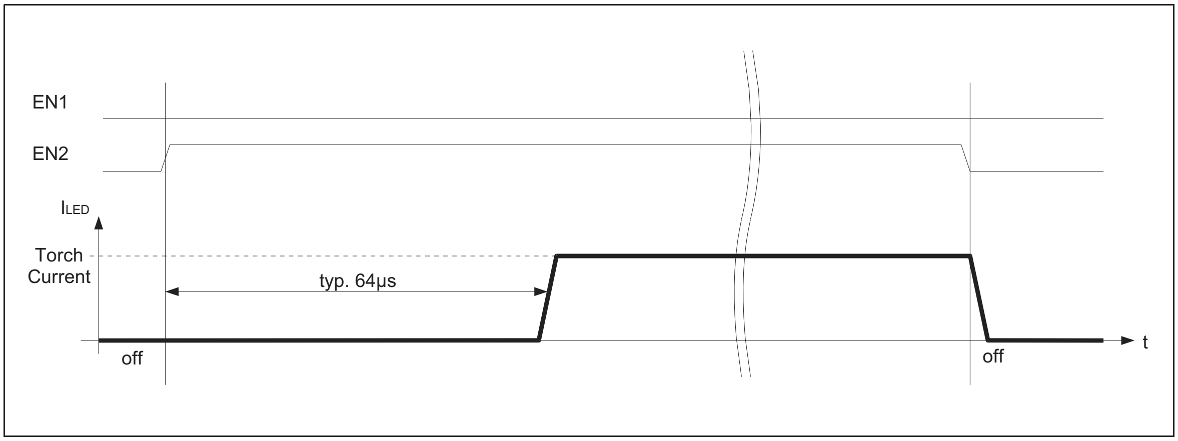
Figure 25:
AS3685A Increasing Torch Current



AS3685A Pulsed Indicator Mode

The torch mode is controlled by EN1=0 and EN2=1 as following figure shows:

Figure 26:
AS3685A Torch Mode



To allow an indication function using short pulses (with torch current settings), the pulsed indicator mode can be used. The control device sends a setup sequence (total time required: less than 128µs) to 'program' the AS3685A, and the AS3685A enables its current sink for the duration t_{TORCH} (the current used is exactly the torch current setting). Therefore the control does not need to setup a timer to accurately define the duration of the indicator pulse.

The duration t_{TORCH} can be setup from 1ms to 15ms depending on the number of pulses on EN2 as shown in the following figure and table:

Figure 27:
AS3685A Pulsed Indicator Mode

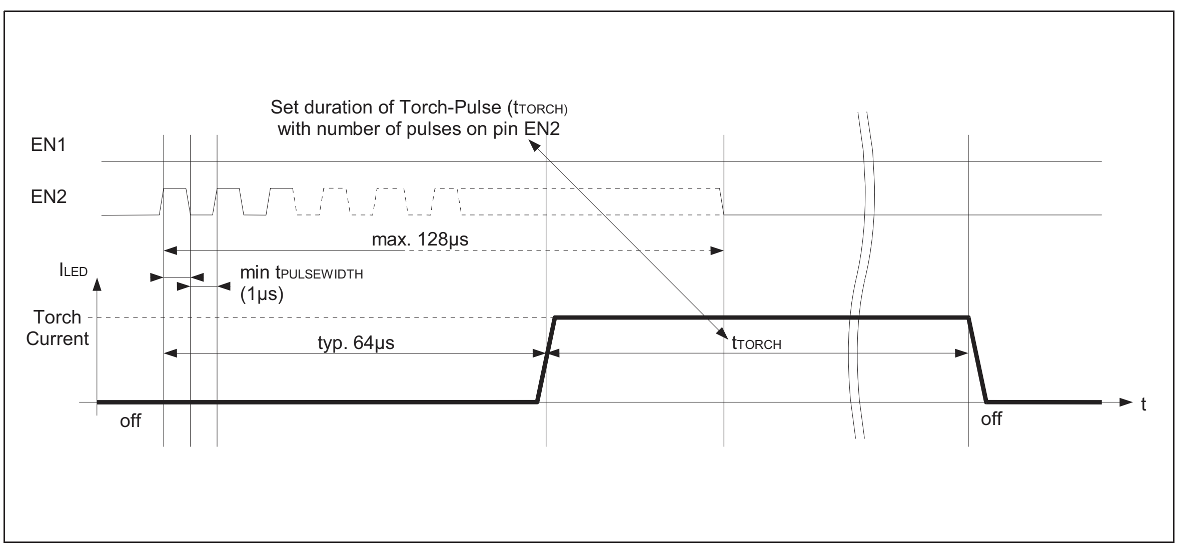


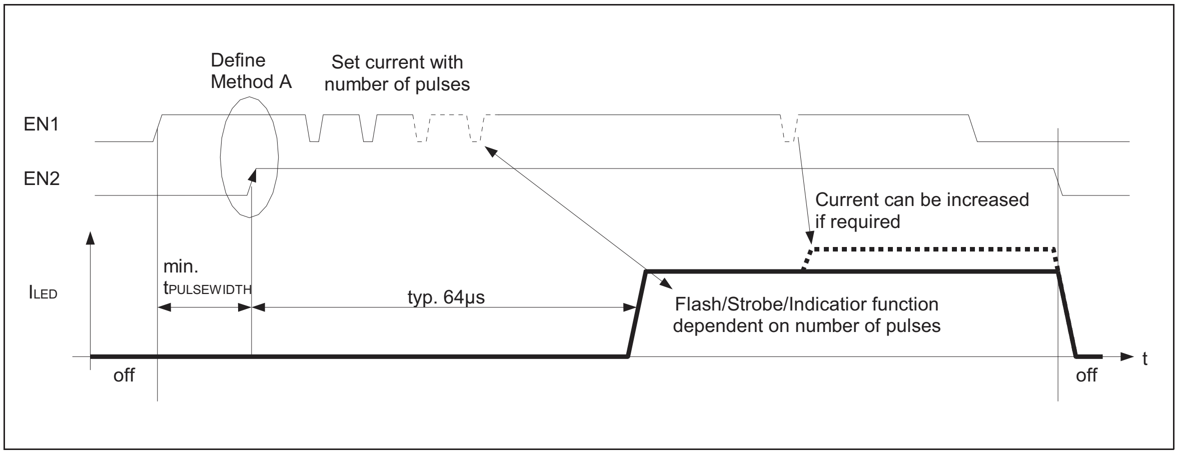
Figure 28:
AS3685A t_{TORCH} Timings

H-L Pulses on EN2	t_{TORCH}
1,2	0ms ignored (noise filter)
3	1ms
4	2ms
5	3ms
6	4ms
7	5ms
8	6ms
9	7ms
10	8ms
11	9ms
12	10ms
13	11ms
14	12ms
15	13ms
16	14ms
≥17	15ms

AS3685B Current Setting

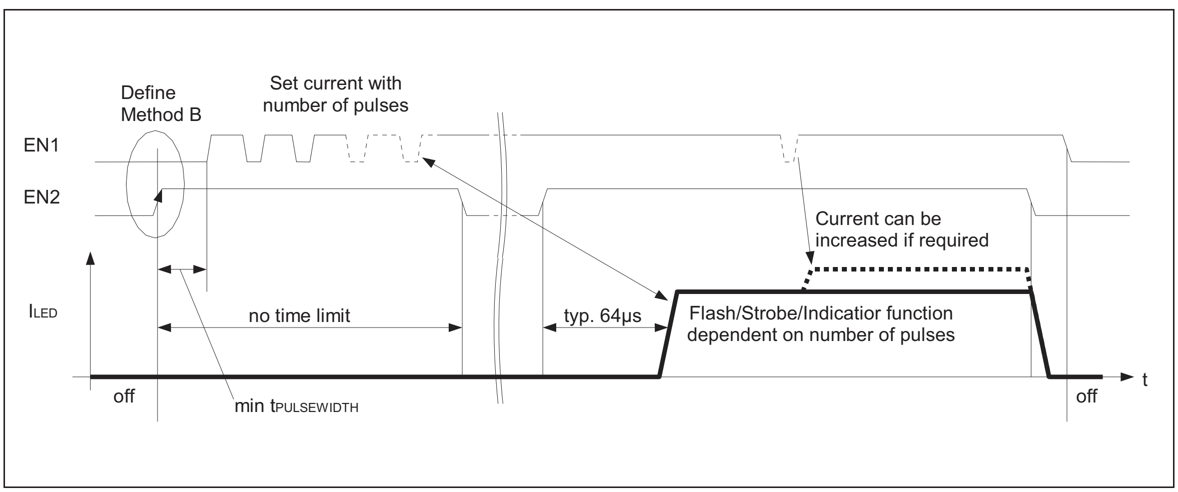
The current through the LED (I_{LED}) can be set in several steps using the following waveforms:

Figure 29:
AS3685B Current Setting Method A



For method A, the current is started after a certain time after the first rising edge of EN1. The AS3685B chooses method A, if EN1 is high at the first rising edge of EN2.

Figure 30:
AS3685B Current Setting Method B



For method B, the current is started after the second rising edge of EN2. The AS3685B chooses method B, if EN1 is low at the first rising edge of EN2.

Any high or low level duration for EN1 or EN2 should not be shorter than $t_{PULSEWIDTH}$.

The actual number of pulses on the pin EN1 (applies for methods A and B) define the mode and the current settings for the AS3685B:

Figure 31:
AS3685B Current Settings

H-L-H Pulses on EN1	Mode	I_{LED} (for R_{ISET} =14.2kΩ)	I_{LED} (for R_{ISET} = 10kΩ)	I_{LED}/I_{ISET}
EN1=EN2=0	Off	0mA	0%	0 (Off)
0	Indicator	4.7mA average (=150mA with 1/32 duty cycle[(1)])	6.7mA (=214mA with 1/32 duty cycle[(1)])	52.2 (=$I_{TORCH2ISET}$/32)
1				
2	Torch	41mA	60mA	448
3		85mA	120mA	929
4		129mA	180mA	1410
5		173mA	250mA	1891
6	Flash	217mA	310mA	2371
7	Flash	261mA	370mA	2852
8		305mA	440mA	3333
9		349mA	500mA	3814
10		393mA	560mA	4295
11		437mA	620mA	4776
12		481mA	690mA	5257
13		525mA	750mA	5737
14		569mA	810mA	6218
15		613mA	880mA	6699
16		657mA	940mA	7180
17		700mA	1000mA	7650 (=$I_{FLASH2ISET}$)

Note(s):
1. The on-time for indicator mode is 1µs, off time 31µs (32µs = 32.25kHz).

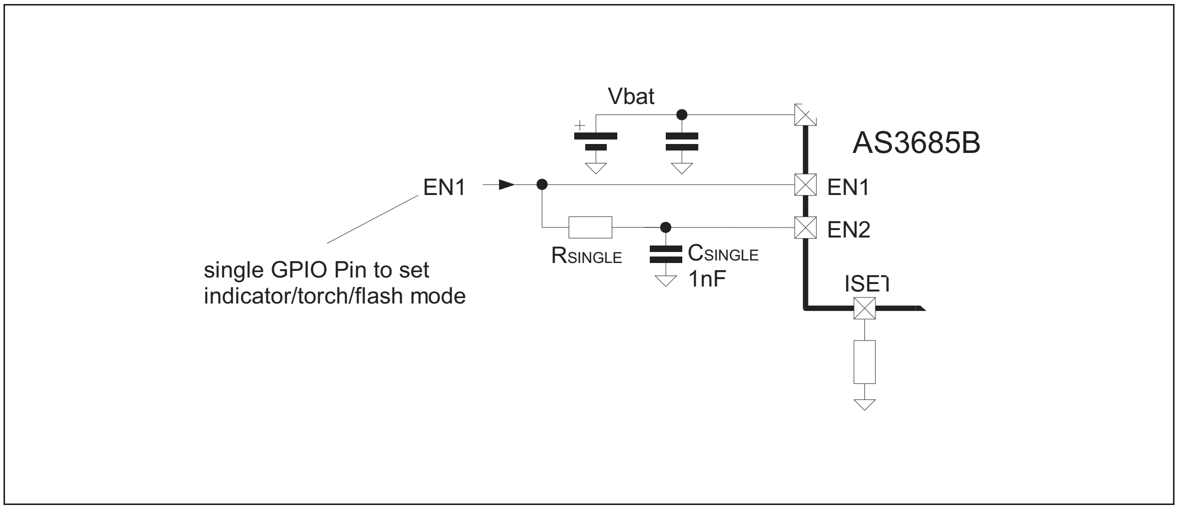
Where I_{ISET} is:

$$I_{ISET} = \frac{V_{ISET}}{R_{ISET}} = \frac{1.3V}{R_{ISET}} \quad \text{(EQ2)}$$

AS3685B Single Wire Interface

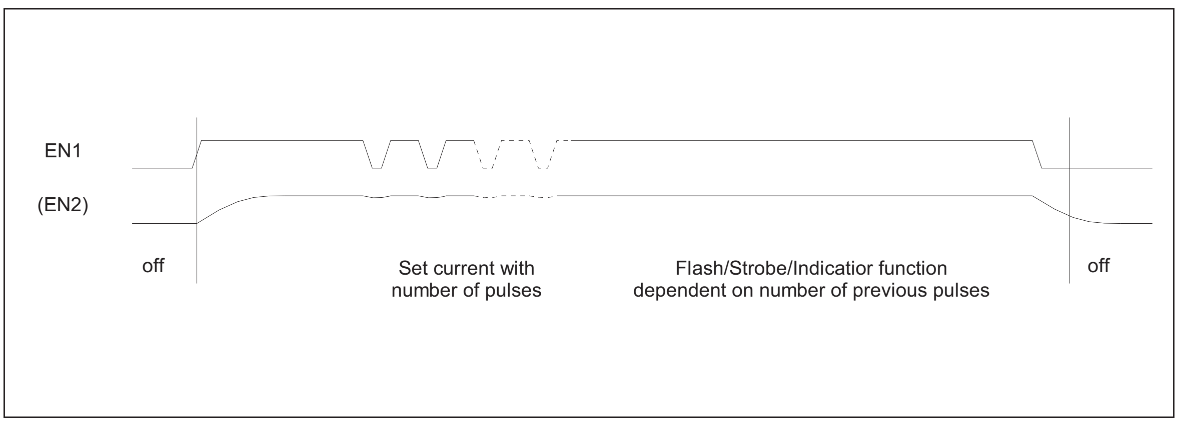
Using the following application schematic, a single GPIO pin can be used to control the mode and current of the AS3685B:

Figure 32:
AS3685B Single Wire Interface



An example driving waveform can be (this uses method A as shown above in section 'AS3685B Current Settings'):

Figure 33:
AS3685B Example Single Wire Interface Driving Waveform

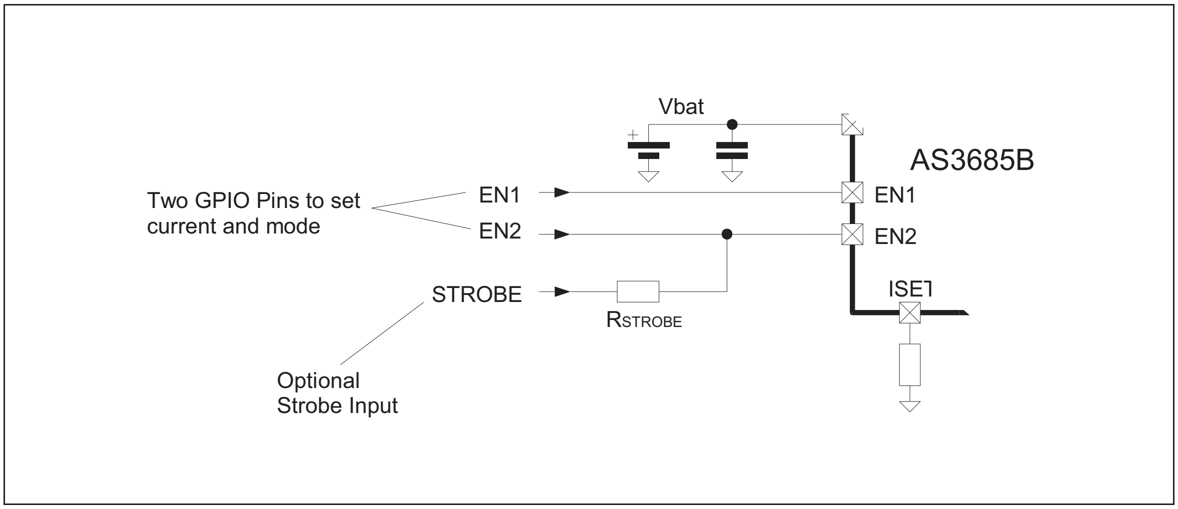


The low time of the pulses on EN1 for setting the current should be kept short. Then the (generated) signal on pin EN2 will stay at a high level during this time ensuring correct operation. R_{SINGLE} should be chosen to fit to the actual driving waveform on EN1.

AS3685B Two Wire Interface with Strobe Input

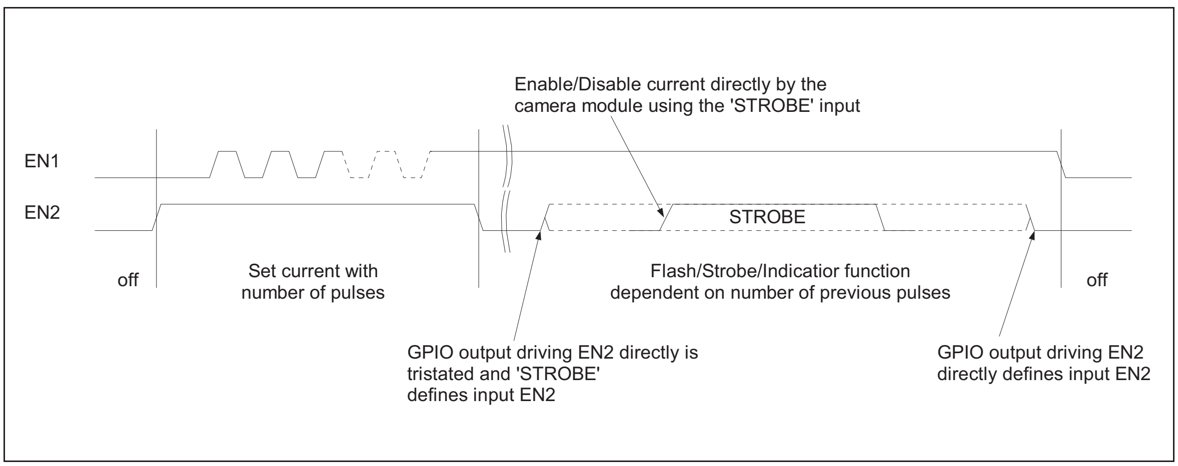
Using the following application schematic, the AS3685B current and mode can be set accurately and the camera can directly control the exact strobe time:

Figure 34:
AS3685B Two Wire Interface with Strobe Input



An example driving waveform can be (this uses method B as shown above in section AS3685B Current Setting):

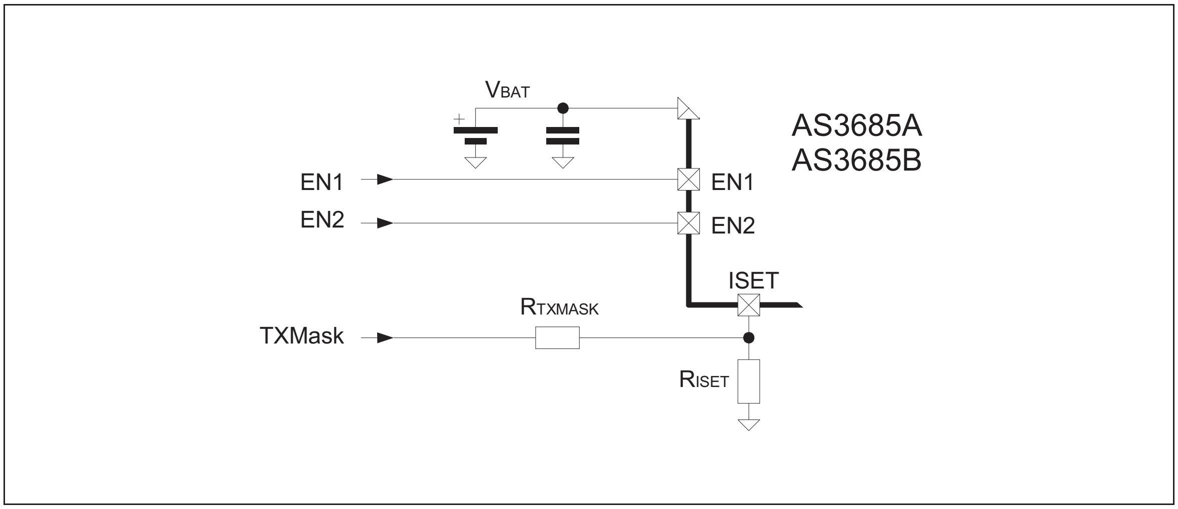
Figure 35:
AS3685B Example Two Wire Interface Driving Waveform



AS3685A and AS3685B TXMask Function

If the battery has to supply two high currents at the same time (e.g. the AS3685 flash and a RF-power amplifier) it is possible, that the total current causes a high voltage drop on the battery resulting in a shutdown of the complete system. In order to avoid this shutdown, the AS3685 (AS3685A or AS3685B) can reduce its current with the signal 'TXMask' using the following circuit:

Figure 36:
TXMask Function of the AS3685



The TXMask signal is connected to e.g. the (RF-) power amplifier enable pin (active high if the PA is enabled). This reduces the flash current if the power amplifier is enabled and avoids the unexpected shutdown of the system.

Note(s): The internal flash timeout timer ($t_{FLASHTIMEOUT}$) to limit the total flash duration, is not affected by the TXMask function (see also section Flash Timeout).

The I_{ISET} current (current into the pin ISET) for TXMask = 0 can be calculated with:

(EQ3)
$$I_{ISET,\ TXMASK\ =\ 0} = \frac{V_{ISET}}{R_{ISET}} + \frac{V_{ISET}}{R_{TXMASK}} = \frac{1.3V}{R_{ISET}} + \frac{1.3V}{R_{TXMASK}}$$

For TXMask = 1 the current I_{ISET} is reduced to:

(EQ4)
$$I_{ISET,\ TXMASK\ =\ 1} = \frac{V_{ISET}}{R_{ISET}} + \frac{V_{ISET} - V(TXMASK)}{R_{TXMASK}} = \frac{1.3V}{R_{ISET}} + \frac{1.3V - V(TXMASK)}{R_{TXMASK}}$$

V(TXMask) is the actual voltage for the high level ('1') for the signal TXMask

The maximum flash current I_{LEDMAX} for TXMask=0 or 1 can be calculated according to the following formula using the above obtained I_{ISET} values:

(EQ5)
$$I_{LEDMAX} = I_{FLASH2BIAS} I_{ISET} = 7650 \cdot I_{ISET}$$

Choose the values for R_{ISET} and R_{TXMASK} according to your application requirements.

Protection Functions

Overtemperature Protection

If the AS3685 junction temperature exceeds T_{OVTEMP} , the current sink will be disabled and the charge pump forced into 1:1 mode. If the junction temperature drops below T_{OVTEMP} – $T_{OVTEMPHYST}$, the device enables the current sink again and the charge pump resumes normal operation.

LED Shortcircuit Protection

If the LED is shorted (VCP to ILED), then depending on the set current and the resulting high power dissipation inside the AS3685, the overtemperature protection will trigger. This protects the AS3685 and the system against damage. If the AS3685 is in off-mode, then shorting of the diode will have no influence on the system.

Note(s): Do not short VCP to VSS if the supply is not current limited (e.g. by an internal protection inside the battery), as there is an internal diode between VBAT (anode) and VCP (cathode).

Flash Timeout

The flash duration of a single flash is limited automatically to $t_{FLASHTIMEOUT}$ (applies only for 'Flash' mode(s)). This protects the flash LED against thermal damage.