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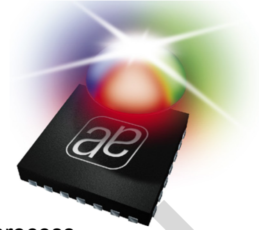
AS3676

Flexible Lighting Management (CP, DCDC, 13 Current Sinks, ADC, LED Test, LDO, DLS and Ambient Light sensing)



1 General Description

The AS3676 is a highly-integrated CMOS Power and Lighting Management Unit for mobile telephones, and other 1-cell Li+ or 3-cell NiMH powered devices.

The AS3676 incorporates one Step Up DC/DC Converter for white backlight LEDs, one high-power Charge Pump, one Analog-to-Digital Converter, 13 current sinks, LED in-circuit function test, a two wire serial interface, and control logic all onto a single device. It supports **ambient light sensor** processing and a Dynamic Luminance Scaling (**DLS**) input. Output voltages and output currents are fully programmable.

The AS3676 is part of the austriamicrosystems AS3675, AS3687/87XM and AS3689 lighting management unit family. It is software compatible to AS3687/87XM and AS3689 and pin and software compatible to AS3675.

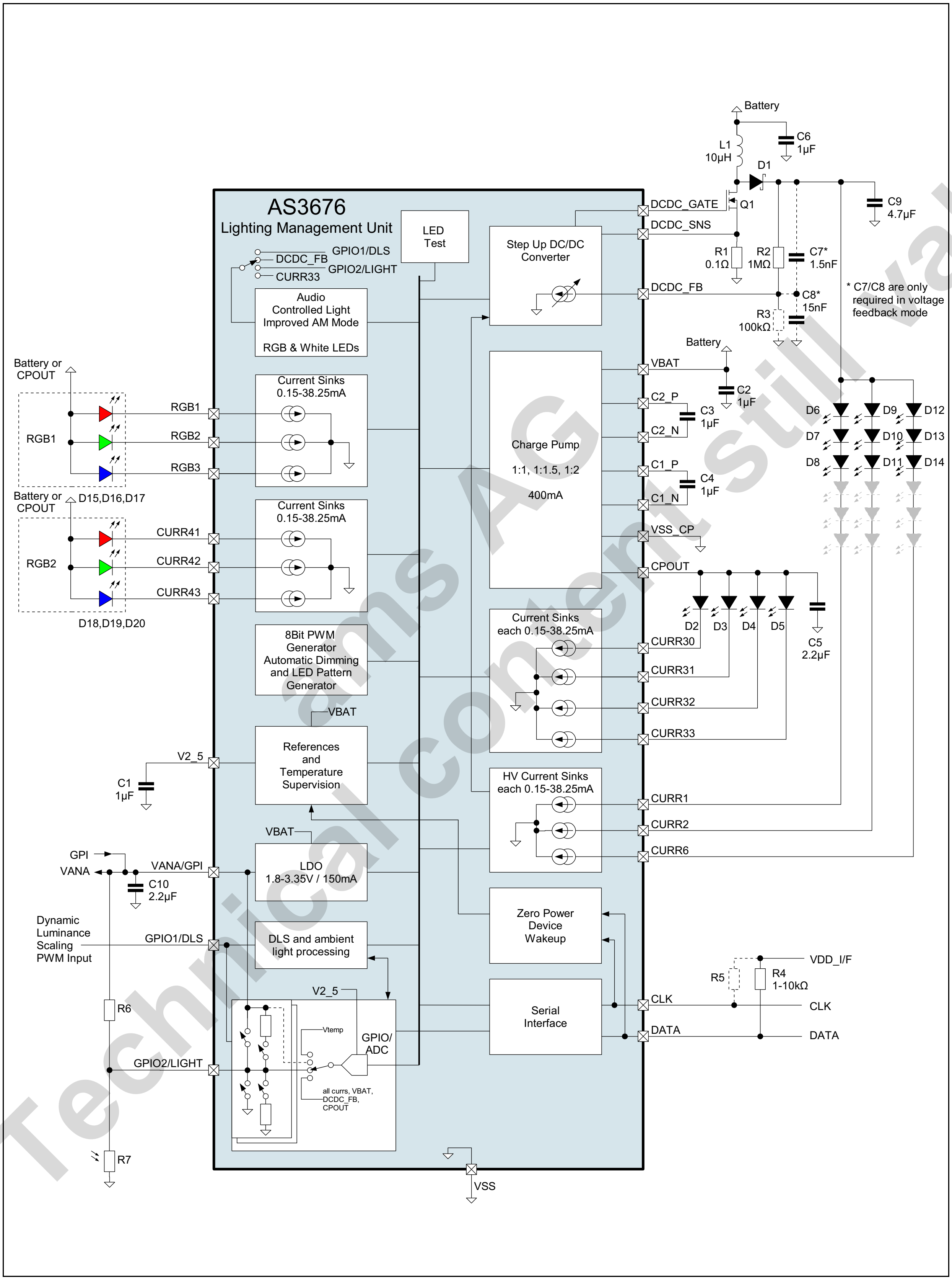
2 Key Features

- High-Efficiency Step Up DC/DC Converter
  - Up to 26V/50mA for White LEDs
  - Programmable Output Voltage with External Resistors and Serial Interface
  - Over voltage Protection
- High-Efficiency High-Power Charge Pump
  - 1:1, 1:1.5, and 1:2 Mode
  - Automatic Up Switching (can be disabled and 1:2 mode can be blocked)
  - Output Current up to 400mA/500mA pulsed
  - Efficiency up to 95%
  - Very Low effective Resistance (2.5Ω typ. in 1:1.5)
  - Only 4 External Capacitors Required: 2 x 1µF Flying Capacitors, 2 x 2.2µF Input/Output Capacitors
  - Supports LCD White Backlight LEDs, or RGB LEDs
- 13 Current Sinks
  - All 13 current sinks fully Programmable (8-bit) from: 0.15mA to 38.5mA (up to 75.6mA for CURR30...CURR33)
  - Three current sinks are High Voltage capable (CURR1, CURR2, CURR6)
  - Programmable Hardware Control (Strobe, and Preview or PWM)
  - Selectively Enable/Disable Current Sinks
  - Dynamic Luminance Scaling (DLS) support to improve backlight operating time (can adjust any current source)
  - Light Sensor input with internal hardware processing to control backlight according to ambient light using 3 groups - any current source can select one of the groups or no light sensor control
- Internal PWM Generation
  - 8 Bit resolution
  - Autonomous Logarithmic up/down dimming
- Led Pattern Generator
  - Autonomous driving for Fun RGB LEDs
  - Support indicator LEDs
- 10-bit Successive Approximation ADC
  - 27µs Conversion Time
  - Selectable Inputs: VANA/GPI, GPIO1/DLS, GPIO2/LIGHT, all current sources, VBAT, CPOUT, DCDC_FB
  - Internal Temp. Measurement
  - Light Sensor input with Java support (JSR-256): read ADC processed value
- Support for automatic LED testing (open and shorted LEDs can be identified)
- Strobe Timeout protection
  - Up to 1600ms
  - Three different timing modes
- Two General Purpose Inputs/Output
  - GPIO1/DLS, GPIO2/LIGHT
  - Digital Input, Digital Output using VANA/GPI supply and Tristate
  - GPIOs Programmable Pull-Up/Down
- Programmable LDO
  - 1.8 to 3.35V, 150mA
  - Programmable via Serial Interface
- Standby LDO always on
  - Regulated 2.5V max. output 10mA
  - 3µA Quiescent Current
- Audio can be used to drive RGB LED(s)
  - Color and Brightness depends on audio amplitude
- Wide Battery Supply Range: 3.0 to 5.5V
- Two Wire Serial Interface Control
- Over current and Thermal Protection
- WL-CSP30 3x2.5mm, 0.5mm pitch Package

3 Applications

Power- and lighting-management for mobile telephones and other 1-cell Li+ or 3-cell NiMH powered devices.

Figure 1. AS3676 Block Diagram



Contents

4 Pinout

Table 1. Pin Description for AS3676

Pin Number	Pin Name	Type	Description
A1	GPIO1/DLS	AIO	Digital Luminance Scaling PWM input and General Purpose Input Output 1
A2	VANA/GPI	AIO	LDO Output/General Purpose Input
A3	C2_N	AIO	Charge Pump flying capacitor; connect a ceramic capacitor of 500nF to this pin.
A4	C1_P	AIO	Charge Pump flying capacitor; connect a ceramic capacitor of 500nF to this pin.
A5	CPOUT	AO	Output voltage of the Charge Pump; connect a ceramic capacitor of 1µF (±20%).
A6	DATA	DIO	Serial interface data input/output.
B1	GPIO2/LIGHT	AIO	Ambient Light Sensor input and General Purpose Input Output 2
B2	VSS_CP	GND	Ground Pad for Charge Pump
B3	C1_N	AIO	Charge Pump flying capacitor; connect a ceramic capacitor of 500nF to this pin.
B4	C2_P	AIO	Charge Pump flying capacitor; connect a ceramic capacitor of 500nF to this pin.
B5	DCDC_GATE	AO	DCDC gate driver.
B6	CLK	DI	Clock input for serial interface.
C1	CURR41	AI	Analog current sink input
C2	RGB3	AI	Analog current sink input
C3	VSS	GND	Ground pad
C4	VBAT	S	Supply pad. Connect to battery.
C5	CURR30	AI	Analog current sink input, intended for activity icon LED
C6	DCDC_SNS	AI	Sense input of shunt resistor for Step Up DC/DC Converter.
D1	CURR43	AI	Analog current sink input
D2	RGB1	AI	Analog current sink input
D3	CURR33	AI	Analog current sink input, intended for activity icon LED
D4	CURR31	AI	Analog current sink input, intended for activity icon LED
D5	CURR2	AI_HV	Analog current sink input (intended for Keyboard backlight)
D6	DCDC_FB	AI	DCDC feedback. Connect to resistor string.
E1	CURR42	AI	Analog current sink input
E2	RGB2	AI	Analog current sink input
E3	CURR32	AI	Analog current sink input, intended for activity icon LED
E4	CURR6	AI_HV	Analog current sink input (intended for Keyboard backlight)
E5	CURR1	AI_HV	Analog current sink input (intended for Keyboard backlight)
E6	V2_5	AO3	Output voltage of the Low-Power LDO; always connect a ceramic capacitor of 1µF (±20%) or 2.2µF (+100%/-50%).

4.1 Pin Definitions

Table 2. Pin Type Definitions

Type	Description
DI	Digital Input
DO	Digital Output
DIO	Digital Input/Output
AIO	Analog Pad
AI	Analog Input
AI_HV	High-Voltage (26V) Pin
AO3	Analog Output (3.3V)
S	Supply Pad
GND	Ground Pad

5 Absolute Maximum Ratings

Stresses beyond those listed in Table 3 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 Table 4, "Operating Conditions," on page 6 is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 3. Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Units	Comments
V_{IN_HV}	26V Pins	-0.3	26	V	Applicable for high-voltage current sink pins CURR1, CURR2, CURR6
V_{IN_MV}	5V Pins	-0.3	7.0	V	Applicable for 5V pins VBAT, CURR30-33, CURR41-43, RGB1-3, C1_N, C2_N, C1_P, C2_P, CPOUT, DCDC_FB, DCDC_GATE, CLK, DATA;
V_{IN_LV}	3.3V Pins	-0.3	5.0	V	Applicable for 3.3V pins V2_5; DCDC_SNS, GPIO1/ DLS, GPIO2/LIGHT, VANA/ GPI
	Input Pin Current	-25	+25	mA	At 25ºC, Norm: JEDEC 17
T_{strg}	Storage Temperature Range	-55	125	ºC	
I_{IN}	Humidity	5	85	%	Non-condensing
V_{ESD}	Electrostatic Discharge	-2000	2000	V	Norm: MIL 883 E Method 3015
Pt	Total Power Dissipation		0.75	W	TA = 70 ºC, Tjunc_max = 125ºC
T_{BODY}	Peak Body Temperature		260	ºC	T = 20 to 40s, in accordance with IPC/JEDEC J-STD 020.
MSL	Moisture Sensitivity Level	MSL 1			Represents a max. floor life time of unlimited

6 Electrical Characteristics

Table 4. Operating Conditions

Symbol	Parameter	Condition	Min	Typ	Max	Unit
General Operating Conditions						
V_{HV}	High Voltage	Applicable for high-voltage current sink pins CURR1, CURR2 and CURR6.	0.0		26.0	V
V_{BAT}	Battery Voltage	Pin VBAT	3.0	3.6	5.5	V
V_{PERI}	Periphery Supply Voltage	For serial interface pins.	1.5		5.5	V
V_{2_5}	Voltage on Pin V2_5	Internally generated	2.4	2.5	2.6	V
T_{AMB}	Operating Temperature Range		-30	25	85	ºC
I_{ACTIVE}	Battery current	Normal Operating current (see Operating Modes on page 80)		110		µA
$I_{STANDBY}$	Standby Mode Current	Current consumption in standby mode. Only 2.5V regulator on, interface active		8	13	µA
$I_{SHUTDOWN}$	Shutdown Mode Current	interface inactive (CLKand DATA set to 0V)		0.1	3	µA

7 Typical Operating Characteristics

Figure 2. DCDC Step Up Converter: Efficiency of +15V, Step Up to 15V vs. Load Current at VBAT=*3.8V*

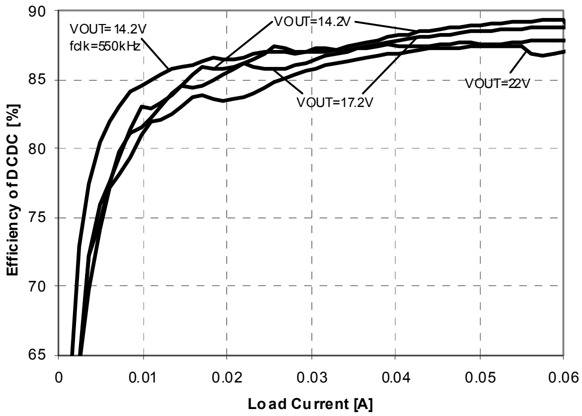


Figure 3. Charge Pump: Efficiency vs. VBAT

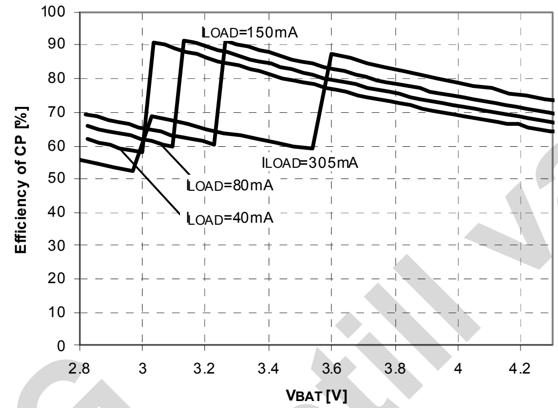


Figure 4. Charge Pump: Battery Current vs. VBAT

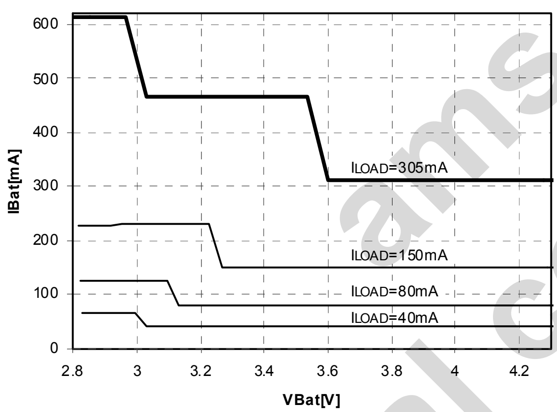


Figure 5. Current Sink CURR1 vs. V(CURRx)

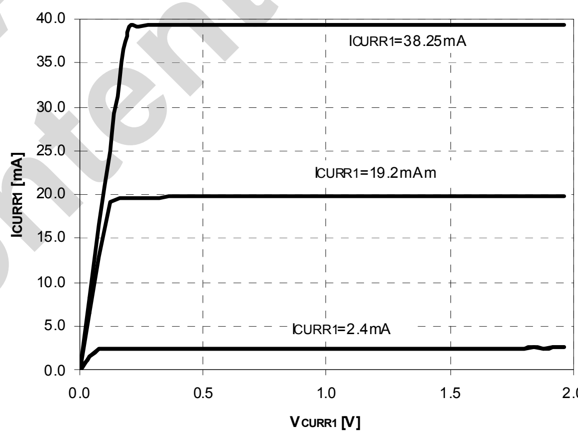


Figure 6.

Figure 7. Current Sink CURR3x vs. VBAT

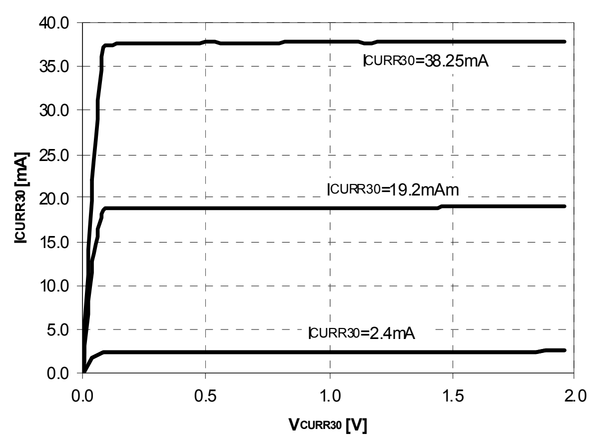
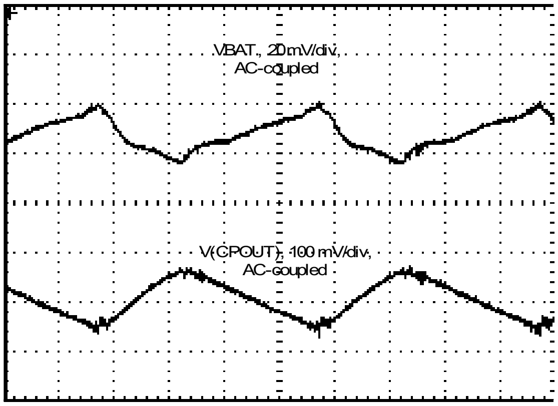
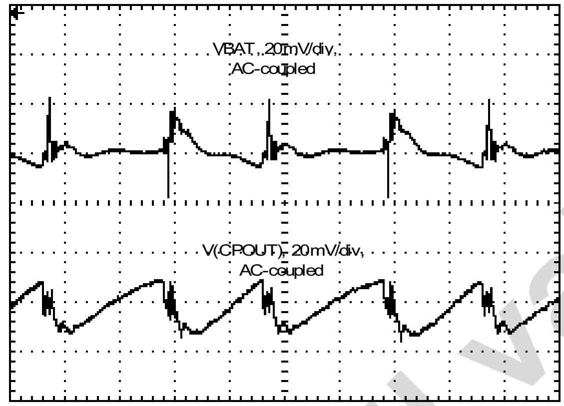


Figure 8. Charge Pump Input and Output Ripple 1:1.5 Mode, 100mA load



250ns/div
Measured with battery (3.8V) on demoboard

Figure 9. Charge Pump Input and Output Ripple 1:2 Mode, 100mA load



250ns/div
Measured with battery (3.0V) on demoboard

VBAT = 3.6V, T_A = +25ºC (unless otherwise specified).

8 Detailed Description

8.1 Analog LDO

The LDO is a general purpose LDO and the output pin connected to VANA/GPI. The design is optimized to deliver the best compromise between quiescent current and regulator performance for battery powered devices.

Stability is guaranteed with ceramic output capacitors of 1µF ±20% (X5R) or 2.2µF +100/-50%(Z5U). The low ESR of these capacitors ensures low output impedance at high frequencies. The low impedance of the power transistor enables the device to deliver up to 150mA even at nearly discharged batteries without any decrease in performance.

The LDO is off by default after start-up.

Figure 10. Analog LDO Block Diagram

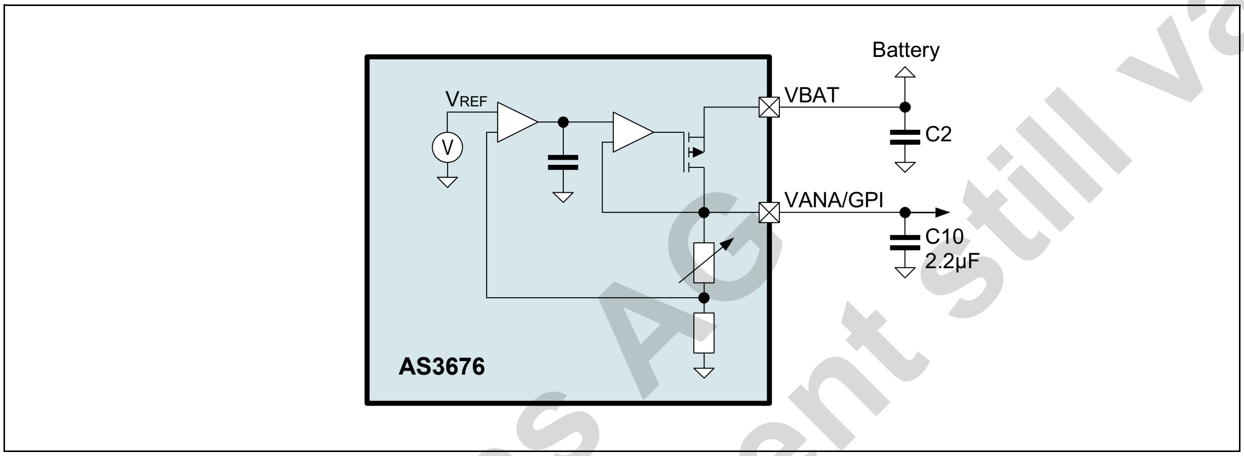


Table 5. Electrical Characteristics

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{BAT}	Supply Voltage Range		3.0		5.5	V
R_{ON}	On Resistance	@150mA, full operating temperature range			1.0	Ω
$V_{DROPOUT}$	Dropout Voltage	@150mA			150	mV
		@50mA			50	mV
I_{ON}	Supply Current	Without load		50		µA
		With 150mA load		150		
I_{OFF}	Shutdown Current	Without load			100	nA
t_{start}	Start-up Time				200	µs
V_{out_tol}	Output Voltage Tolerance		-3		+3	%
V_{OUT}	Output Voltage	V_{BAT} = 3.0V and I_{OUT}=150mA	1.8		2.85	V
		Full Programmable Range; V_{BAT} > V_{OUT}+ 150mV and I_{OUT}<=150mA	1.8		3.35	V
I_{LIMIT}[1]	LDO Current Limit	Pin VANA/GPI. LDO acts as current source if the output current exceeds I_{LIMIT}.	300	450[2]		mA

1. Not production tested – guaranteed by design and laboratory verification
2. During startup of the LDO the current limit is half the value of I_{LIMIT}

8.1.1 LDO Registers

Table 6. Reg. control Register

Addr: 00		Reg. control			
		This register enables/disables the LDOs, Charge Pumps, Charge Pump LEDs, current sinks, the Step Up DC/DC Converter, and low-power mode.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	ldo_on	0	R/W	0	Analog LDO is switched off
				1	Analog LDO is switched on

Table 7. LDO Voltage Register

Addr: 07h		LDO Voltage			
		This register sets the output voltage (VANA/GPI) for the LDO.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
4:0	ldo_voltage	00000b	R/W	Controls LDO voltage selection.	
				00000b	1.8V
				...	LSB=50mV
				11111b	3.35V

8.2 Step Up DC/DC Converter

The Step Up DC/DC Converter is a high-efficiency current mode PWM regulator, providing output voltage up to e.g. 25V/50mA[1]. A constant switching-frequency results in a low noise on the supply and output voltages.

Figure 11. Step Up DCDC Converter Block Diagram Option: Current Feedback with Over voltage protection

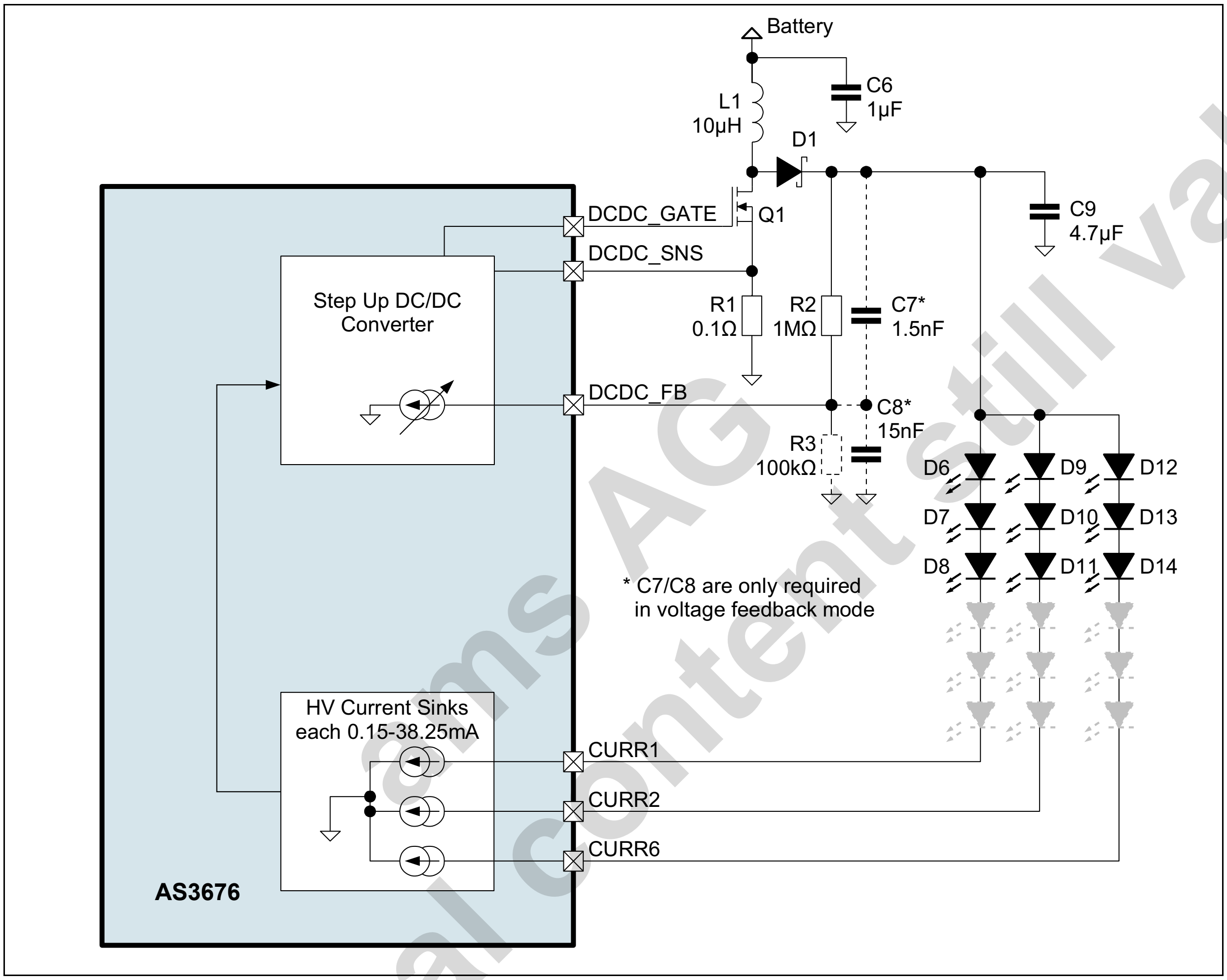


Table 8. Step Up DC/DC Converter Parameters

Symbol	Parameter	Condition	Min	Typ	Max	Unit
I_{VDD}	Quiescent Current	Pulse skipping mode.		140		µA
V_{FB1}	Feedback Voltage for External Resistor Divider	For constant voltage control. *step_up_res* = 1	1.20	1.25	1.30	V
V_{FB2}	Feedback Voltage for Current Sink Regulation	on CURR1, CURR2 or CURR6 in regulation. *step_up_res* = 0	0.4	0.5	0.6	V

1. The AS3676 internal driver structure allows output voltage higher than 25V. The Over voltage Protection in Current Feedback Mode (see page 13) or Voltage Feedback (see page 14) should be set to fit to the external components used (maximum voltage rating of Q1, C9 and D1).

Table 8. Step Up DC/DC Converter Parameters

Symbol	Parameter	Condition	Min	Typ	Max	Unit
I_{DCDC_FB}	Additional Tuning Current at Pin DCDC_FB and over voltage protection	Adjustable by software using Register DCDC control1 1µA step size (0-31µA) $V_{PROTECT}$ = 1.25V + I_{DCDC_FB} * R_2	0		31	µA
	Accuracy of Feedback Current at full scale		-6		6	%
V_{rsense_max}	Current Limit Voltage at R_1	e.g., 1.32A for 0.1Ω sense resistor R_1.	92	132	170	mV
		For fixed startup time of 500us	50	66	86	
		If step_up_lowcur= 1	60	86	114	
R_{SW}	Switch Resistance	ON-resistance of external switching transistor.			1	Ω
I_{LOAD}	Load Current	At 26V output voltage	0		50	mA
f_{IN}	Switching Frequency	Internally trimmed	0.9	1	1.1	MHz
C_{OUT}	Output Capacitor	Ceramic, ±20%. Use nominal 4.7µF capacitors to obtain at least 0.7µF under all conditions (voltage dependence of capacitors)	0.7	4.7		µF
L	Inductor	Use inductors with small $C_{parasitic}$ (<100pF) to get high efficiency.	7	10	13	µH
t_{MIN_ON}	Minimum on Time		90	140	190	ns
MDC	Maximum Duty Cycle		90			%
Vripple	Voltage ripple >20kHz	Cout=4.7µF,Iout=0..45mA, VBAT=3.0...4.2V			160	mV
	Voltage ripple <20kHz				40	mV
Efficiency	Efficiency	Iout=20mA,Vout=17V,VBAT=3.8V		85		%

To ensure soft startup of the dcdc converter, the over current limits are reduced for a fixed time after enabling the dcdc converter. The total startup time for an output voltage of e.g. 26V is less than 2ms. If C7 and C8 are mounted and the bit step_up_prot is set, the total startup time can exceed 2ms.

Note: If the DCDC converter is only used in current feedback mode (CURR1, CURR2 or CURR6 - and not used for a constant voltage source), the capacitors C7 and C8 can be removed.

8.2.1 Feedback Selection

Register DCDC control1 and DCDC control2 selects the type of feedback for the Step Up DC/DC Converter.

The feedback for the DC/DC converter can be selected either by current sinks (CURR1, CURR2, CURR6) or by a voltage feedback at pin DCDC_FB. If the register bit step_up_fb_auto is set, the feedback path is automatically selected between CURR1, CURR2 and CURR6 (the lowest voltage of these current sinks is used).

Setting step_up_fb enables feedback on the pins CURR1, CURR2 or CURR6. The Step Up DC/DC Converter is regulated such that the required current at the feedback path can be supported. (Bit step_up_res should be set to 0 in this configuration)

Note: Always choose the path with the highest voltage drop as feedback to guarantee adequate supply for the other (unregulated) paths or enable the register bit step_up_fb_auto.

8.2.2 Over voltage Protection in Current Feedback Mode

The over voltage protection in current feedback mode (step_up_fb = 01, 10 or 11 or step_up_fb_auto = 1) works as follows: Only resistor R2 and C7/C8[2] is soldered and R3 is omitted. An internal current source (sink) is used to generate a voltage drop across the resistor R2. If then the voltage on DCDC_FB is above 1.25V and step_up_prot=1, the DCDC is momentarily disabled to avoid too high voltages on the output of the DCDC converter. When the voltage on DCDC_FB drops below 1.25V, the DCDC automatically resumes operation.

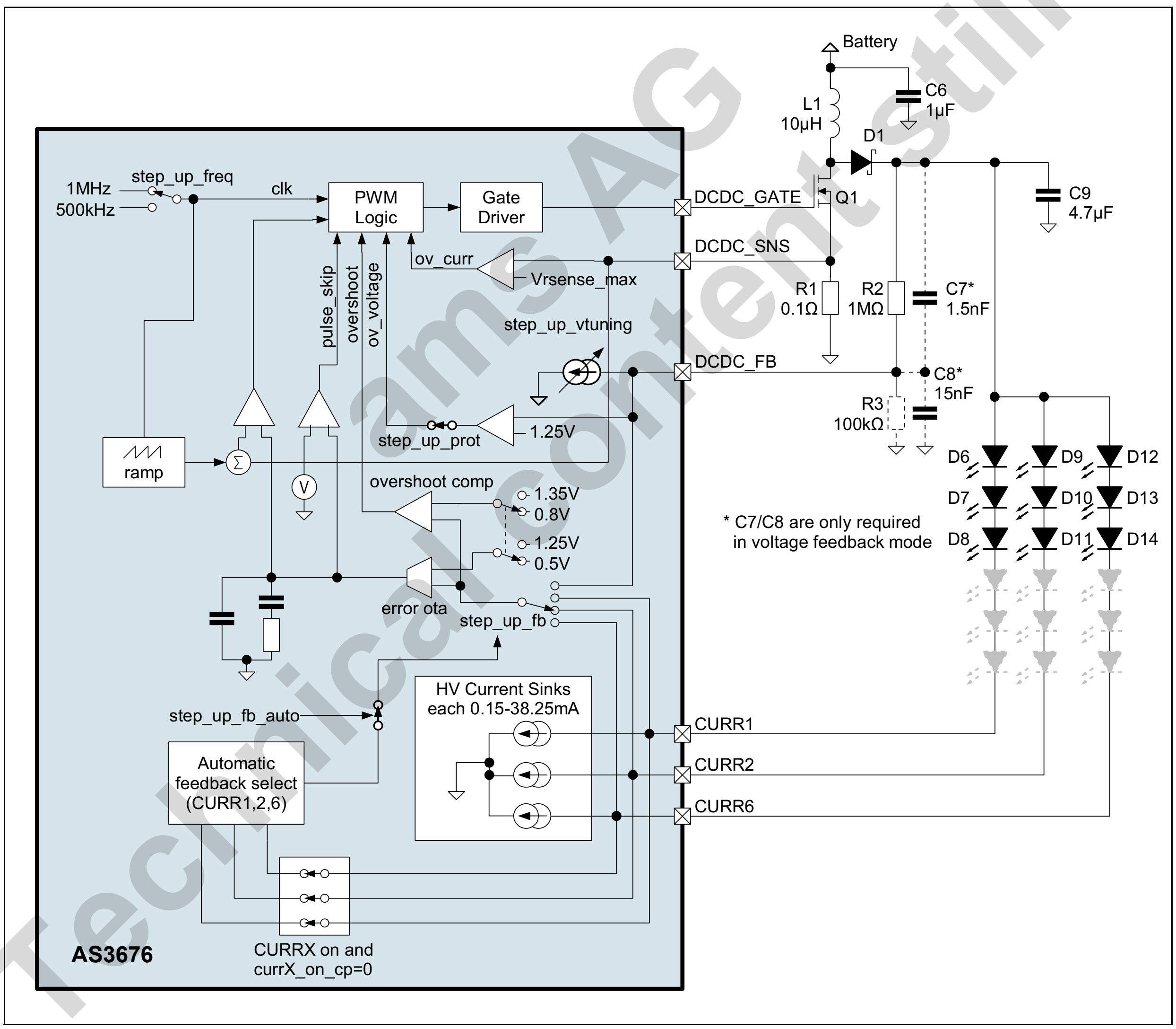
The protection voltage can be calculated according to the following formula:

$$V_{PROTECT} = 1.25V + I_{DCDC\_FB} * R_2 \quad \text{(EQ 1)}$$

Note: The voltage on the pin DCDC_FB is limited by an internal protection diode to VBAT + one diode forward voltage (typ. 0.6V).

If the over voltage protection is not used in current feedback mode, connect DCDC_FB to ground.

Figure 12. Step Up DC/DC Converter Detail Diagram; Option: Regulated Output Current, Feedback is automatically selected between CURR1, CURR2, CURR6 (step_up_fb_auto=1); over voltage protection is enabled (step_up_prot=1); 1MHz clock frequency (step_up_frequ=0)



2. If the DCDC converter is only used in current feedback mode (CURR1, CURR2 or CURR6 - and not used for a constant voltage source), the capacitors C7 and C8 can be removed.

8.2.3 Voltage Feedback

Setting bit step_up_fb (see page 15) = 00 enables voltage feedback at pin DCDC_FB. Capacitors C7 and C8 have to be soldered in this operating mode.

The output voltage is regulated to a constant value, given by (Bit step_up_res should be set to 1 in this configuration)

$$U_{Step\ up\_out} = (R_2+R_3)/R_3 * 1.25 + I_{DCDC\_FB} * R_2 \qquad (EQ\ 2)$$

If R3 is not used, the output voltage is by (Bit step_up_res should be set to 0 in this configuration)

$$U_{Step\ up\_out} = 1.25 + I_{DCDC\_FB} * R_2 \qquad (EQ\ 3)$$

Where:

$U_{Step\ up\_out}$ = Step Up DC/DC Converter output voltage

R_2 = Feedback resistor R2

R_3 = Feedback resistor R3

I_{DCDC_FB} = Tuning current at ball DCDC_FB; 0 to 31µA

Table 9. Voltage Feedback Example Values

I_{DCDC_FB}	$U_{Step\ up\_out}$	$U_{Step\ up\_out}$
µA	**R2 = 1MΩ, R3 not used**	**R2 = 500kΩ, R3 = 50kΩ**
0	-	13.75
1	-	14.25
2	-	14.75
3	-	15.25
4	-	15.75
5	6.25	16.25
6	7.25	16.75
7	8.25	17.25
8	9.25	17.75
9	10.25	18.25
10	11.25	18.75
11	12.25	19.25
12	13.25	19.75
13	14.25	20.25
14	15.25	20.75
15	16.25	21.25
…	…	…
30	31.25	28.75
31	32.25	29.25

Note: The voltage on CURR1, CURR2 and CURR6 must not exceed 26V (see page 25)

8.2.4 PCB Layout Hints

To ensure good EMC performance of the DCDC converter, keep its external power components C6, R1, L1, Q1, D1 and C9 close together. Connect the ground of C6, R1 and C9 locally together and connect this with a short path to AS3676 VSS. This ensures that local high-frequency currents will not flow to the battery.

8.2.5 Unused DCDC converter

If the DCDC converter is not used, connect DCDC_SNS to GND. DCDC_FB[3] and DCDC_GATE can be left open.

8.2.6 Step up Registers

Table 10. Reg. control Register

Addr: 00		Reg. control				
		This register enables/disables the Charge Pump and the Step Up DC/DC Converter.				
Bit	**Bit Name**	**Default**	**Access**	**Description**		
3	step_up_on	0	R/W	Enable the step up converter		
				0b	Disable the Step Up DC/DC Converter	
				1b	Enable the Step Up DC/DC Converter	

Table 11. DCDC control1 Register

Addr: 21h		DCDC control1			
		This register controls the Step Up DC/DC Converter.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	step_up_frequ	0	R/W	Defines the clock frequency of the Step Up DC/DC Converter.	
				0	1MHz
				1	500kHz
2:1	step_up_fb	00	R/W	Controls the feedback source if step_up_fb_auto = 0	
				00	DCDC_FB enabled (external resistor divider). Set step_up_fb=00 (DCDC_FB)
				01	CURR1 feedback enabled (feedback via LEDs)
				10	CURR2 feedback enabled (feedback via LEDs)
				11	CURR6 feedback enabled (feedback via LEDs)
7:3	step_up_vtuning	00000	R/W	Defines the tuning current at pin DCDC_FB.	
				00000	0 µA
				00001	1 µA
				00010	2 µA
				....	
				10000	15 µA
				.....	
				11111	31 µA

3. DCDC_FB can be used as a general purpose ADC input (see Analog-to-Digital Converter on page 65)

Table 12. DCDC control2 Register

Addr: 22h		DCDC control2			
		This register controls the Step Up DC/DC Converter and low-voltage current sinks CURR3x.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	step_up_res	0	R/W	Gain selection for Step Up DC/DC Converter	
				0	Select 0 if Step Up DC/DC Converter is used with current feedback (CURR1, CURR2, CURR6) or if DCDC_FB is used with current feedback only – R2, C7, C8 connected, R3 not used
				1	Select 1 if DCDC_FB is used with external resistor divider using 2 resistors: R2 and R3
1	skip_fast	0	R/W	Step Up DC/DC Converter output voltage at low loads, when pulse skipping is active	
				0	Accurate output voltage, more ripple
				1	Elevated output voltage, less ripple
2	step_up_prot	1	R/W	Step Up DC/DC Converter protection	
				0	No over voltage protection
				1	Over voltage protection on pin DCDC_FB enabled voltage limitation =1.25V on DCDC_FB
3	step_up_lowcur	0	R/W	Step Up DC/DC Converter coil current limit	
				0	Normal current limit
				1	Current limit reduced by approx. 33%
7	step_up_fb_auto	0	R/W	0	step_up_fb selects the feedback of the DCDC converter
				1	If step_up_fb is not DCDC_FB (00), then feedback is automatically chosen within the current sinks CURR1, CURR2 and CURR6. Only those are used for this selection, which are enabled (currX_mode must not be 00) and not connected to the charge pump (currX_on_cp must be 0).

8.3 Charge Pump

The Charge Pump uses two external flying capacitors C3, C4 to generate output voltages higher than the battery voltage. There are three different operating modes of the charge pump itself:

- 1:1 Bypass Mode
  - Battery input and output are connected by a low-impedance switch
  - battery current = output current.
- 1:1.5 Mode
  - The output voltage is up to 1.5 times the battery voltage (without load), but is limited to VCPOUTmax all the time
  - battery current = 1.5 times output current.
- 1:2 Mode
  - The output voltage is up to 2 times the battery voltage (without load), but is limited to VCPOUTmax all the time
  - battery current = 2 times output current

As the battery voltage decreases, the Charge Pump must be switched from 1:1 mode to 1:1.5 mode and eventually in 1:2 mode in order to provide enough supply for the current sinks. Depending on the actual current the mode with best overall efficiency can be automatically or manually selected:

Examples:

- Battery voltage = 3.7V, LED dropout voltage = 3.5V. The 1:1 mode will be selected and there is 200mV drop on the current sink and on the Charge Pump switch. Efficiency 95%.
- Battery voltage = 3.5V, LED dropout voltage = 3.5V. The 1:1.5 mode will be selected and there is 1.5V drop on the current sink and 250mV on the Charge Pump. Efficiency 66%.

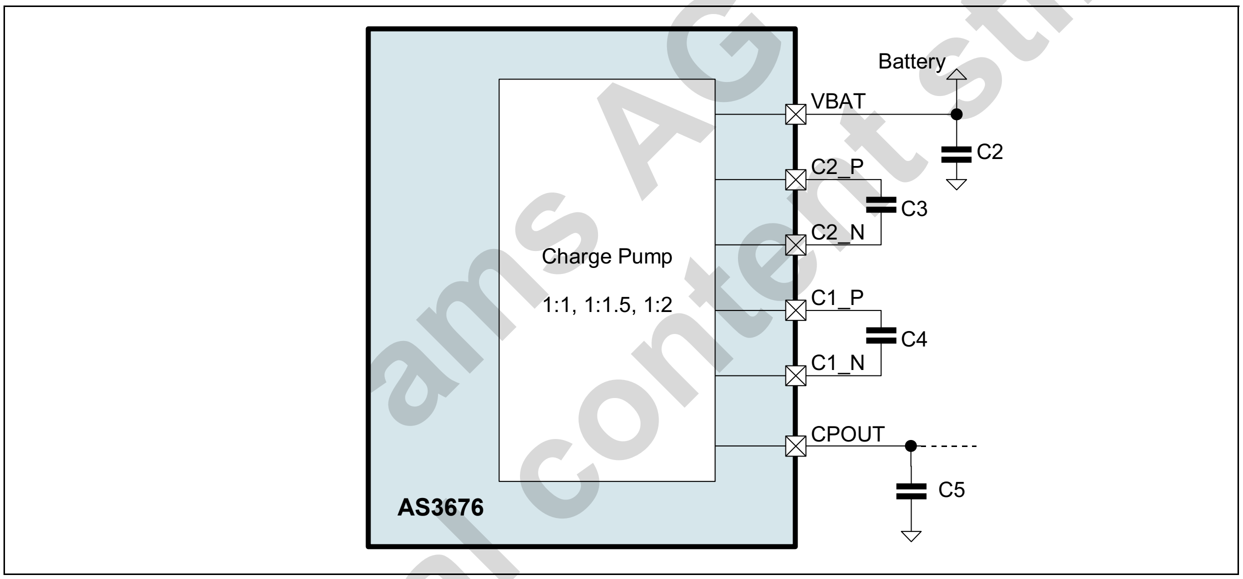
The efficiency is dependent on the LED forward voltage given by:

$$Eff=(V\_LED*Iout)/(Uin*Iin) \quad \text{(EQ 4)}$$

The charge pump mode switching can be done manually or automatically with the following possible software settings:

- Automatic up all modes allowed (1:1, 1:1.5, 1:2)
  - Start with 1:1 mode
  - Switch up automatically 1:1 to 1:1.5 to 1:2
- Automatic up, but only 1:1 and 1:1.5 allowed
  - Start with 1:1 mode
  - Switch up automatically only from 1:1 to 1:1.5 mode; 1:2 mode is not used
- Manual
  - Set modes 1:1, 1:1.5, 1:2 by software

Figure 13. Charge Pump Pin Connections



The Charge Pump requires the external components listed in the following table:

Table 13. Charge Pump External Components

Symbol	Parameter	Condition	Min	Typ	Max	Unit
C_2	External Decoupling Capacitor	Ceramic low-ESR capacitor between pins VBAT and VSS.		1.0		µF
C_3, C_4	External Flying Capacitor (2x)	Ceramic low-ESR capacitor between pins C1_P and C1_N, between pins C2_P and C2_N and between VBAT and VSS		1.0		µF
C_5	External Storage Capacitor	Ceramic low-ESR capacitor between pins CPOUT and VSS, pins CPOUT and VSS. Use nominal 2.2µF capacitors (size 0603)		2.2		µF

Note: The connections of the external capacitors C2, C3, C4 and C5 should be kept as short as possible.

The maximum voltage on the flying capacitors C3 and C4 is VBAT.

Table 14. Charge Pump Characteristics

Symbol	Parameter	Condition	Min	Typ	Max	Unit
ICPOUT	Output Current Continuous	Depending on PCB layout	0.0		400	mA
	Output Current Pulsed	max. 200ms V_{CPOUT}= VBAT * CP_{MODE} – I_{LOAD} * R_{CP}	0.0		500	mA
VCPOUTmax	Output Voltage	Internally limited, Including output ripple			5.6	V
η	Efficiency	Including current sink loss; ICPOUT < 100mA.	60		90	%
ICP1_1.5	Power Consumption without Load fclk = 1 MHz	1:1.5 Mode		3.4		mA
ICP1_2		1:2 Mode		3.8		
Rcp1_1	Effective Charge Pump Output Resistance (Open Loop, fclk = 1MHz)	1:1 Mode; VBAT ≥ 3.5V		0.57		Ω
Rcp1_1.5		1:1.5 Mode; VBAT ≥ 3.3V		2.65		
Rcp1_2		1:1.2 Mode; VBAT ≥ 3.1V		3.25		
fclk Accuracy	Accuracy of Clock Frequency		-10		10	%
currhv_switch	CURR1, 2, 6 minimum voltage	If the voltage drops below this threshold, the charge pump will use the next available mode (1:1 -> 1:1.5 or 1:1.5 -> 1:2)			0.45	V
currlv_switch	CURR30-33, RGB1-3, CURR41-3, minimum voltage				0.2	V
	CURR30-33 0-75.6mA range for strobe if curr3x_strobe_high=1				0.4	V
t_{deb}	CP automatic up-switching debounce time	cp_start_debounce=0		240		µsec
		After switching on CP (cp_on set to 1), if cp_start_debounce=1		2000		µsec

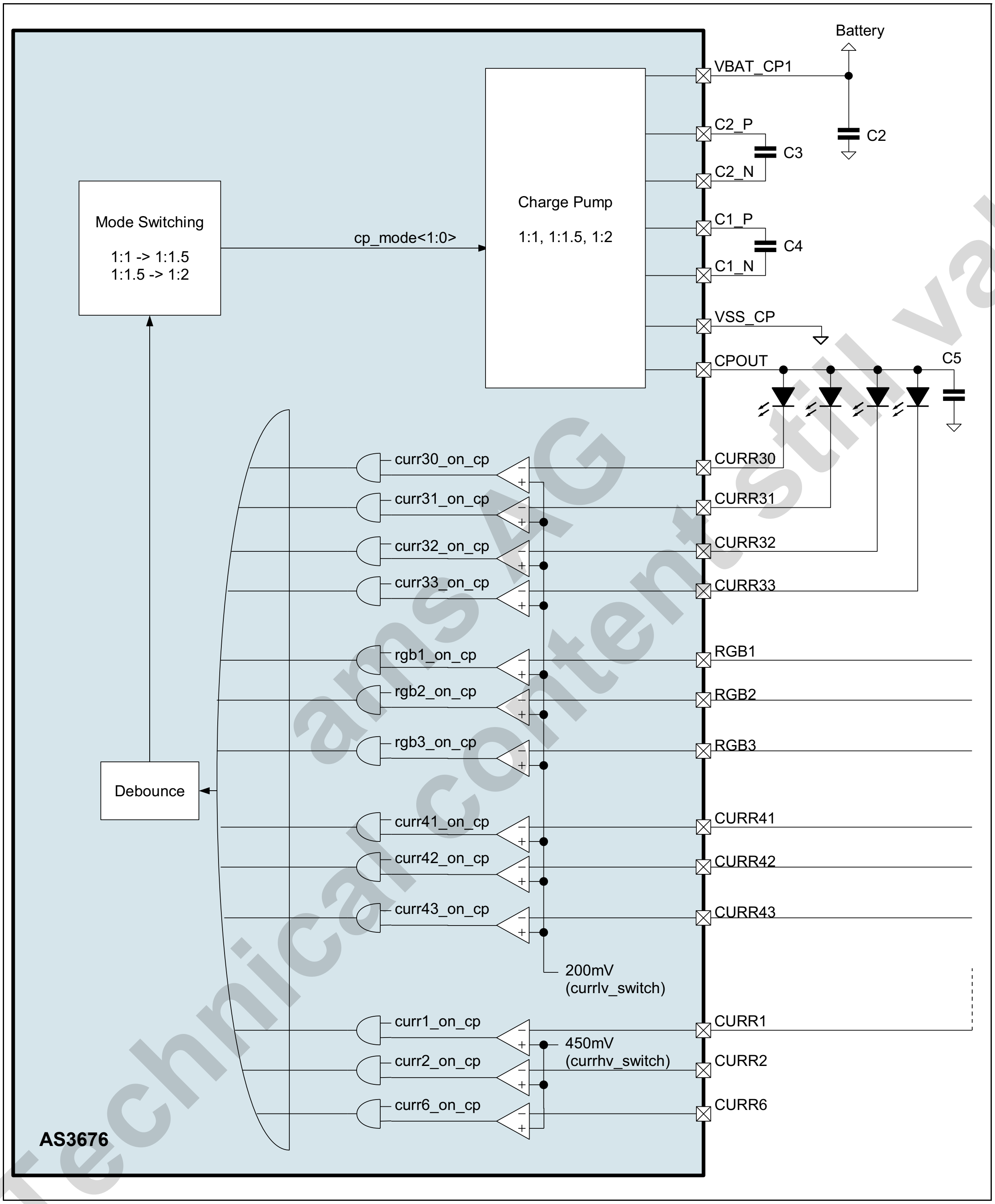
8.3.1 Charge Pump Mode Switching

If automatic mode switching is enabled (cp_mode_switching (see page 20) = 00 or cp_mode_switching = 01) the charge pump monitors the current sinks, which are connected via a led to the output CPOUT. To identify these current sources (sinks), the registers CP mode Switch1 and CP mode Switch2 (register bits curr30_on_cp (see page 21) … curr33_on_cp, rgb1_on_cp … rgb3_on_cp, curr1_on_cp, curr2_on_cp, curr41_on_cp … curr43_on_cp and curr6_on_cp) should be setup before starting the charge pump (cp_on (see page 20) = 1). If any of the voltage on these current sources drops below the threshold (currlv_switch, currhv_switch), the next higher mode is selected after the debounce time.

To avoid switching into 1:2 mode (battery current = 2 times output current), set cp_mode_switching = 01.

If the currX_on_cp=0 and the according current sink is connected to the charge pump, the current sink will be functional, but there is no up switching of the charge pump, if the voltage compliance is too low for the current sink to supply the specified current.

Figure 14. Automatic Mode Switching



8.3.2 Soft Start

An implemented 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.

8.3.3 Unused Charge Pump

If the charge pump is not used, capacitors C3, C4 and C5 can be removed. The pins C1_P, C1_N, C2_P, C2_N and CPOUT should be left open and keep register cp_on and cp_auto_on at 0 (default value).

8.3.4 Charge Pump Registers

Table 15. Reg. control Register

Addr: 00h		Reg. control			
		This register controls the Charge Pump.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
2	cp_on	0	R/W	0	Set Charge Pump into 1:1 mode (off state) unless cp_auto_on is set
				1	Enable manual or automatic mode switching

Table 16. CP control Register

Addr: 23h		CP control			
		This register enables/disables the Charge Pump and the Step Up DC/DC Converter.			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	cp_clk	0	R/W	Clock frequency selection.	
				0	1 MHz
				1	500 kHz
2:1	cp_mode	00b	R/W	Charge Pump mode (in manual mode sets this mode, in automatic mode reports the actual mode used)[1]	
				00	1:1 mode
				01	1:1.5 mode
				10	1:2 mode
				11	NA
4:3	cp_mode_switching	00b	R/W	Set the mode switching algorithm	
				00	Automatic Mode switching; 1:1, 1:1.5 and 1:2 allowed
				01	Automatic Mode switching; only 1:1 and 1:1.5 allowed
				10	Manual Mode switching; register cp_mode defines the actual charge pump mode used
				11	Reserved
5	cp_start_debounce	0	R/W	0	Mode switching debounce timer is always 240µs
				1	Upon startup (cp_on set to 1) the mode switching debounce time is first started with 2ms then reduced to 240µs
6	cp_auto_on	0	R/W	0	Charge Pump is switched on/off with cp_on
				1	Charge Pump is automatically switched on if a current sink, which is connected to the charge pump (defined by registers CP Mode Switch 1 & 2) is switched on

1. Direct switching from 1:1.5 mode into 1:2 in manual mode and vice versa is not allowed. Always switch over 1:1 mode.

Table 17. CP mode Switch1 Register

Addr: 24h		**CP mode Switch1**			
		Setup which current sinks are connected (via leds) to the charge pump; if set to '1' the correspond current source (sink) is used for automatic mode selection of the charge pump			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	curr30_on_cp	0	R/W	0	current Sink CURR30 is not connected to charge pump
				1	current sink CURR30 is connected to charge pump
1	curr31_on_cp	0	R/W	0	current Sink CURR31 is not connected to charge pump
				1	current sink CURR31 is connected to charge pump
2	curr32_on_cp	0	R/W	0	current Sink CURR32 is not connected to charge pump
				1	current sink CURR32 is connected to charge pump
3	curr33_on_cp	0	R/W	0	current Sink CURR33 is not connected to charge pump
				1	current sink CURR33 is connected to charge pump
4	rgb1_on_cp	0	R/W	0	current Sink RGB1 is not connected to charge pump
				1	current sink RGB1 is connected to charge pump
5	rgb2_on_cp	0	R/W	0	current Sink RGB2 is not connected to charge pump
				1	current sink RGB2 is connected to charge pump
6	rgb3_on_cp	0	R/W	0	current Sink RGB3 is not connected to charge pump
				1	current sink RGB3 is connected to charge pump

Table 18. CP mode Switch2 Register

Addr: 25h		**CP mode Switch2**			
		Setup which current sinks are connected (via LEDs) to the charge pump; if set to '1' the correspond current source (sink) is used for automatic mode selection of the charge pump			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	curr1_on_cp	0	R/W	0	current Sink CURR1is not connected to charge pump
				1	current sink CURR1 is connected to charge pump
1	curr2_on_cp	0	R/W	0	current Sink CURR2 is not connected to charge pump
				1	current sink CURR2 is connected to charge pump
2	curr41_on_cp	0	R/W	0	current Sink CURR41 is not connected to charge pump
				1	current sink CURR41 is connected to charge pump
3	curr42_on_cp	0	R/W	0	current Sink CURR42 is not connected to charge pump
				1	current sink CURR42 is connected to charge pump

Table 18. CP mode Switch2 Register (Continued)

Addr: 25h		CP mode Switch2			
		Setup which current sinks are connected (via LEDs) to the charge pump; if set to '1' the correspond current source (sink) is used for automatic mode selection of the charge pump			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
4	curr43_on_cp	0	R/W	0	current Sink CURR43 is not connected to charge pump
				1	current sink CURR43 is connected to charge pump
7	curr6_on_cp	0	R/W	0	current Sink CURR6 is not connected to charge pump
				1	current sink CURR6 is connected to charge pump

Table 19. Curr low voltage status1 Register

Addr: 2Ah		Curr low voltage status1			
		Indicates the low voltage status of the current sinks. If the currX_low_v bit is set, the voltage on the current sink is too low, to drive the selected output current			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	curr30_low_v	NA	R	0	voltage of current Sink CURR30 >currlv_switch
				1	voltage of current Sink CURR30 <currlv_switch
1	curr31_low_v	NA	R	0	voltage of current Sink CURR31 >currlv_switch
				1	voltage of current Sink CURR31 <currlv_switch
2	curr32_low_v	NA	R	0	voltage of current Sink CURR32 >currlv_switch
				1	voltage of current Sink CURR32 <currlv_switch
3	curr33_low_v	NA	R	0	voltage of current Sink CURR33 >currlv_switch
				1	voltage of current Sink CURR33 <currlv_switch
4	rgb1_low_v	NA	R	0	voltage of current Sink RGB1 >currlv_switch
				1	voltage of current Sink RGB1 <currlv_switch
5	rgb2_low_v	NA	R	0	voltage of current Sink RGB2 >currlv_switch
				1	voltage of current Sink RGB2 <currlv_switch
6	rgb3_low_v	NA	R	0	voltage of current Sink RGB3 >currlv_switch
				1	voltage of current Sink RGB31 <currlv_switch
7	curr6_low_v	NA	R	0	voltage of current Sink CURR6 >currlv_switch
				1	voltage of current Sink CURR6 <currlv_switch

Table 20. Curr low voltage status2 Register

Addr: 2Bh		Curr low voltage status2			
		Indicates the low voltage status of the current sinks. If the currX_low_v bit is set, the voltage on the current sink is too low, to drive the selected output current			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
0	curr1_low_v	NA	R	0	voltage of current Sink CURR1 >currhv_switch
				1	voltage of current Sink CURR1 <currhv_switch

Table 20. Curr low voltage status2 Register (Continued)

Addr: 2Bh		Curr low voltage status2			
		Indicates the low voltage status of the current sinks. If the currX_low_v bit is set, the voltage on the current sink is too low, to drive the selected output current			
Bit	**Bit Name**	**Default**	**Access**	**Description**	
1	curr2_low_v	NA	R	0	voltage of current Sink CURR2 >currhv_switch
				1	voltage of current Sink CURR2 <currhv_switch
2	curr41_low_v	NA	R	0	voltage of current Sink CURR41 >currlv_switch
				1	voltage of current Sink CURR41 <currlv_switch
3	curr42_low_v	NA	R	0	voltage of current Sink CURR42 >currlv_switch
				1	voltage of current Sink CURR42 <currlv_switch
4	curr43_low_v	NA	R	0	voltage of current Sink CURR43 >currlv_switch
				1	voltage of current Sink CURR43 <currlv_switch

8.4 Current Sinks

The AS3676 contains general purpose current sinks intended to control RGB LEDs, white LEDs (e.g. backlights) and can also be used for buzzers or vibrators. All current sinks have an integrated over voltage protection.

CURR1, CURR2 and CURR6 are also used as feedback for the Step Up DC/DC Converter (regulated to 0.5V in this configuration) see Feedback Selection on page 12.

- Current sinks CURR1, CURR2 and CURR6 are high-voltage compliant (26V) current sinks, used e.g., for series of white LEDs
- Current sinks CURR3*x* (CURR30, CURR31, CURR32 and CURR33) are parallel 5V current sinks, used for backlighting, indicator LEDs or RGB LEDs.
- Current sinks RGB1, RGB2, and RGB3 are general purpose current sinks e.g. for a fun LED.
- Current sinks CURR4x (CURR41, CURR42, and CURR43) are general purpose current sinks.

Table 21. Current Sink Function Overview

Current Sink	Max. Voltage (V)	Max. Current (mA)	Resolution		Software Current Control	Hardware On/Off Control	Can be assigned to Audio Controlled LED Channel
			(Bits)	(mA)			
CURR1	26.0	38.25	8	0.15	Separate	LED Pattern; Internal PWM; external PWM at GPIO1/DLS	ch1
CURR2							ch2
CURR6							ch3
CURR30	VBAT (5.5V)	38.25 (75.6mA for strobe if curr3x_strobe_high=1)	8	0.15	Combined in Strobe/ Preview or Separated	Flash LED Strobe (CURR1 or CURR30) & Preview (CURR2); Internal PWM; LED Pattern; external PWM at GPIO1/DLS	Completely individual assignment of the audio channels ch1,ch2 and ch3 to the outputs
CURR31							
CURR32							
CURR33							
RGB1		38.25	8	0.15	Separate	LED Pattern; Internal PWM; external PWM at GPIO1/DLS	ch1
RGB2							ch2
RGB3							ch3
CURR41		38.25	8	0.15	Separate	LED Pattern; Internal PWM; external PWM at GPIO1/DLS	ch1
CURR42							ch2
CURR43							ch3

8.4.1 Unused Current Sinks

Unused current sinks can be left open or used as a ADC input (see Analog-to-Digital Converter on page 65).