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AS3676_77 - Application Note 9 LED Series Configuration

Application Note - Confidential
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Abstract
This application note describes how to connect 9 LEDs in series configuration using one LED string of the HV current sinks available in AS3676 and AS2677.

For general description and key features of AS3676 and AS3677 please refer to the datasheets.

Table of Contents

1 AS3676: How-To connect 9 LEDs in series configuration

All current sinks in AS3676 have an integrated over voltage protection. CURR1, CURR2 and CURR6 are high-voltage compliant current sinks, used e.g., for series connection of white LEDs. *(For placement refer to Appendix 1: Application circuit AS3676)*

With the built in over voltage protection, described in AS3676 datasheet, chapter 8.2.2 Over voltage Protection in Current Feedback Mode, it's possible to set the over voltage protection to a certain voltage to protect the external components.

The voltage which the currents sinks in AS3676 can withstand is limited to 26V. For more information about the current sinks, voltage compliance, resolution etc. refer to AS3676 datasheet, Table 23 in Chapter 8.4.2 High Voltage Current Sinks CURR1, CURR2 and CURR6.

Whenever larger displays(1) or other applications with more then 6 white LEDs connected in series are used additional modification of the external circuit is needed.

(1) This Application note applies whenever more then 6 White LEDs are connected in series configuration. If the display support parallel configuration of the LEDs, for example 3 LEDs in series in 3 parallel rails, please refer to application note AN3677 – User Scenarios & Design Ideas

1.1 Over Voltage Protection set to 38V (9 LEDs Series Configuration)

Assuming a V_F of the White LEDs of 4V the Step-Up DC/DC Converter needs to achieve an output voltage of minimum 36V. To allow some margins due to variation of the V_F of the white LEDs the over voltage protection is set to 38V. Selecting R_2 resistor to 1,21MΩ will generate 38V as over voltage protection, explained below.

When driving white LEDs in series the Step-Up DC/DC converter in AS3676 is best configured using current feedback mode. In this mode the over voltage protection can be calculated and configured by Equation 1 below *(For detailed information refer to AS3676 datasheet chapter 8.2.2 Over voltage Protection in Current Feedback Mode)*

Equation 1: $$V_{PROTECT} = 1{,}25V + I_{DCDC\_FB} \times R_2$$

$$V_{PROTECT} = 1{,}25V + I_{DCDC\_FB} \times R_2 \Rightarrow 1{,}25V + +31\mu A \times 1{,}21\mathrm{M}\Omega = 38{,}76V$$

In current feedback mode resistor R_2 and C_7/C_8 is soldered and R_3 is omitted, see *Figure.1: AS3676, Current Feedback Mode*. An internal current sink is used to generate a voltage drop across the resistor R_2. If then the voltage on DCDC_FB is above 1.25V, the DCDC is momentarily disabled to avoid too high voltages on the output of the DCDC converter. *(For placement refer to Appendix 1: Application circuit AS3676)*

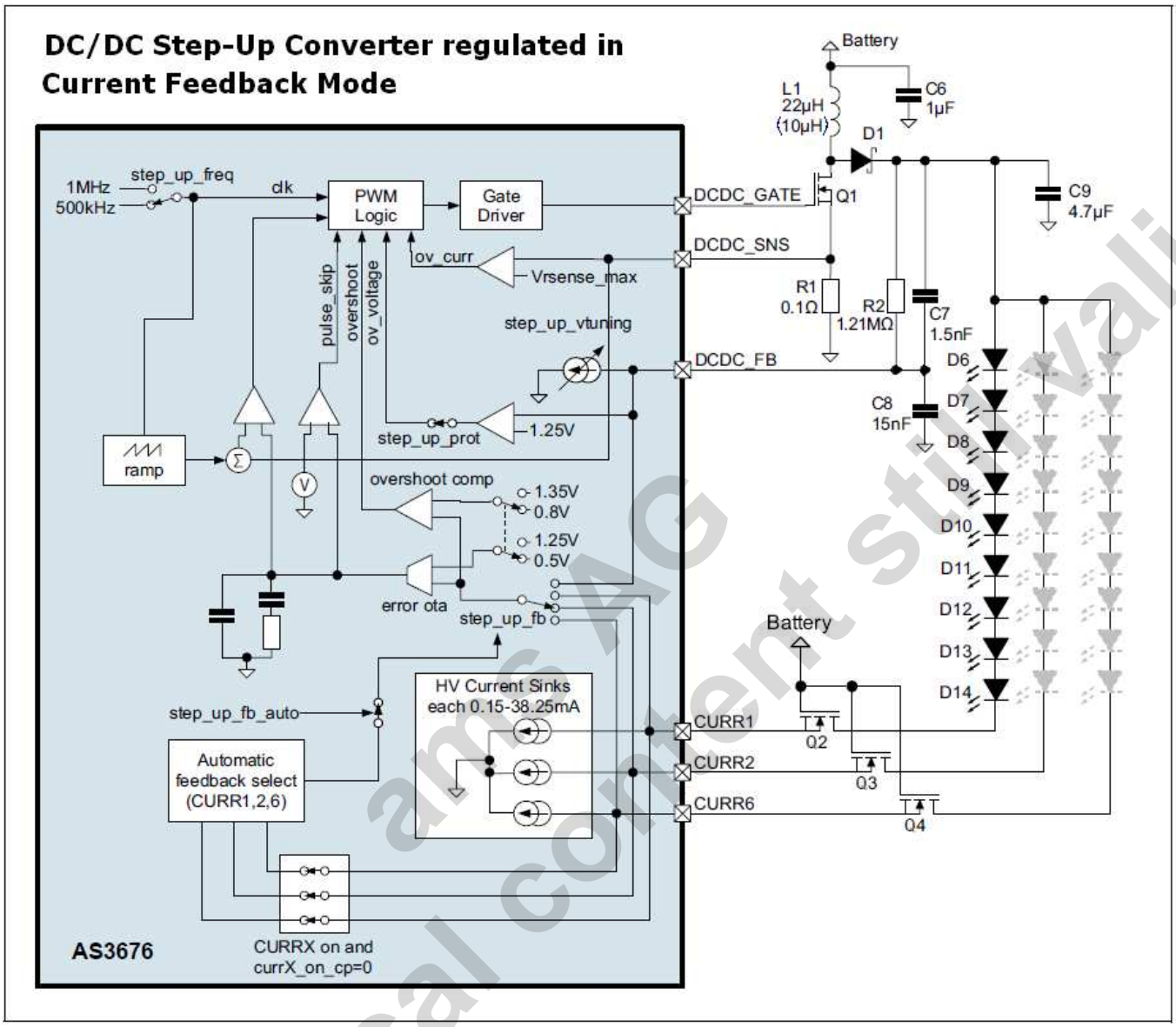


Figure.1: *AS3676, Current Feedback Mode*

1.2 DC/DC Step-Up Converter switching frequency and coil selection (9 LEDs Series Configuration)

To maximize the efficiency it's recommended to use a higher value of the inductor (15-22uH) and to change the switching frequency of DC/DC Step-Up converter in AS3676 to 500kHz. This is done by setting the first bit to "1" in the DCDC control1 register, bit name "step_up_frequ" For detailed information refer to Table 11 in AS3676 datasheet.

Lowering the switching frequency to 500kHz will increase the maximum duty cycle of the DC/DC Step-Up converter to 95% (90% at 1MHz). A higher duty cycle increases the DCDC switch on time which increases the energy stored in the inductor to support the amount of energy required by the load.

The duty Cycle, together with the inductor value, input voltage, switching frequency and the output current are important parameters for improving the efficiency of the DC/DC Step-Up converter.

Important to highlight is that due to the high rated voltage of the external components (50V), the dimensional structure of the component will get big. In some cases even to big, depending on application, referring to the inductor size which with an I_{SAT} rating of 700mA and 15-22µH as inductor value, needed for best efficiency performance, gives a inductor size of around 4.0 x 4.0 alternative 5.0 x 5.0 mm with a height of above 2.0mm in some cases. Using a 10µH coil will work.

Chapter 3 highlights different setup based upon theoretical calculations for 9 LED configuration connected to one current sink. For comparison both 10µH and 22µH is used.

1.3 External Component Selection AS3676

Table 1: External Components AS3676

Description	Name	Min	Value Typ.	Max	Tol (Min)	Rating (Max)	Notes	Package (Min)([1])
Coil	L1		10µH ([2])		±20%		Taiyo Yuden (NR3012T100M) 10µH/700mA	
Output Capacitor	C9		4,7µF		±20%	50V	Step-Up DCDC Output muRata (GRM319R61H475KA12)	1206
Filter Capacitor	C8		15nF		±20%	6,3V	Ceramic, X5R (Step Up DCDC Feedback, 15nF for over voltage protection)	0402
Filter Capacitor	C7		1,5nF		±10%	50V	Ceramic, X7R (Step Up DCDC Feedback, 1,5nF for over voltage protection) muRata (GRM155R71H152KA01)	0402
DCDC NMOS	Q1	FDMA3N109				30V ([3])	Integrated NMOS and Shottky Diode	MicroFET 2x2 mm
DCDC DIODE	D1	Integrated in FDMA3N109						
Cascode NMOS	Q2-Q4	FDMC8462				40V	N-Channel Power Trench® MOSFET	Power 33 3x3 mm
LED	D6-D14						Application Specific	

1. In 1/100 inch (unless otherwise specified)
2. See Chapter 1.3.1 External Component Comments
3. See Chapter 1.3.1 External Component Comments

1.3.1 External Component Comments

DCDC NMOS Q1:
The FDMA3N103 device has 30V maximum voltage rating. When AS3676 is configured for driving 9 LEDs in series connection, depending on the V_F and I_F of the LEDs, 30V can be enough. The bulk resistance effect of the LED will increase the forward voltage for a given current and particularly at higher current levels. Limiting the I_F (Allowed maximum backlight current) the V_F of the LEDs will be lower and within the 30V rating.

Output Capacitor C9:
To select a suitable output CAP is application dependent. The most important parameter is the DC bias characteristics of the Cap, and depending on the LED configuration the output voltage from the Step-Up DCDC Converter will change. At maximum output voltage from the DCDC the Cap value should be in the area 0.7 – 1.0µF to ensure a stability of the Step-Up DCDC Converter.

The output capacitor in the external component selection table fulfills the 9 LED series requirements.

Coil L1:
To maximize the efficiency the Coil L1 can be changed into a higher inductance value as discussed in Chapter 1.2. Needed I_{SAT} of the coil is 700mA to support full range of current sinks (0-20mA).

15µH – VLS4012T-150MR57 - 15uH, this coil has a rated DC Current with typ. 0.78A but this is of course independent of inductance saturation and temperature rise.
Size 4.0 x 4.0 x 1.2 mm

22µH – VLS4012T-220MR57 - 22uH, this coil has a rated DC Current with typ. 0.7A but this is of course independent of inductance saturation and temperature rise.
Size 4.0 x 4.0 x 1.2 mm

Cascode NMOS Q2-Q4:
The FDMC8462 ensures over voltage protection for 9 LEDs in series connection, the maximum rated V_{DS} Voltage is 40V and hence more then enough for even worse case scenarios of the LED V_F. This NMOS will protect the current sinks in AS3676 even when up to 10-12 LEDs are connected in Series.

*Note: As can be seen in **Table 3:** Efficiency Table different LED configurations, the output voltage of the Step-Up DCDC Converter does not exceed 30V when 9 LEDs in Series connection is used. By setting the over voltage protection to 30V enables usage of standard external components used as reference in the AS3676 and AS3677 datasheets.*

2 AS3677: How-To connect 9 LEDs in series configuration

As in AS3676, all current sinks in AS3677 have an integrated over voltage protection. CURR1, CURR2 and CURR6 are high-voltage compliant current sinks limited to 26V. *(For placement refer to Appendix 1: Application circuit AS3677)*

One difference between AS3676 and AS3677 is that the DCDC Low side NMOS switch is integrated. To protect the DCDC switch (SW Pin) it's necessary to add one additional cascode NMOS. *See component Q1 in Figure.2: AS3677, 9 LED Series configuration*

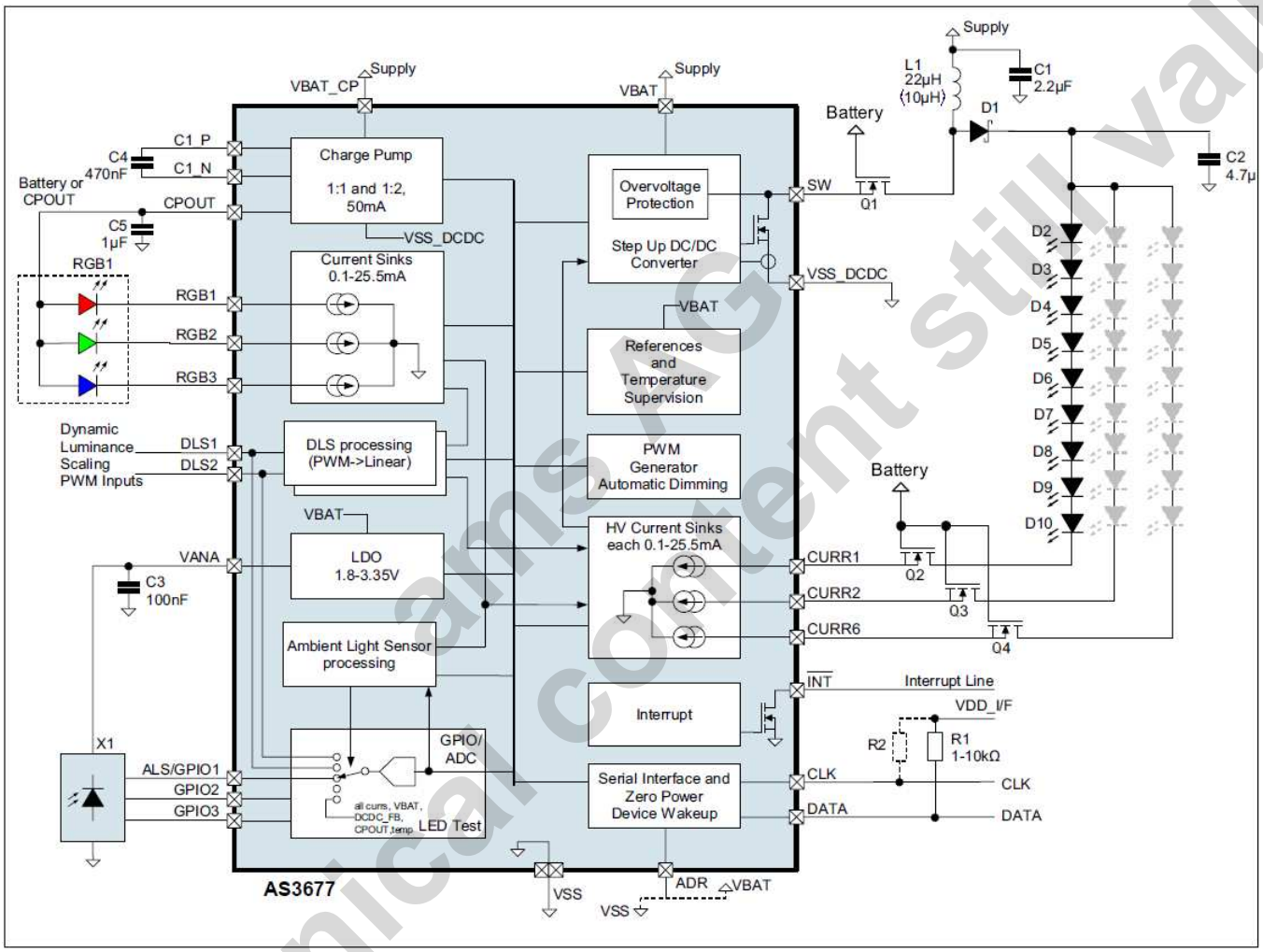


Figure.2: *AS3677, 9 LED Series configuration*

2.1 Over Voltage Protection (9 LEDs Series Configuration)

Important to highlight is when AS3677 is designed for output voltages above 26V and the cascode NMOS is protecting the internal DCDC switch, the Over Voltage Protection will not function anymore.

The voltage drop over the NMOS will protect the SW pin, which, hence always will be smaller than the output voltage of DC/DC Step-Up converter. If a potential overshoot occurs due to sudden shortage or breakdown of one or several LEDs, the protecting NMOS and other components connected to the DC/DC Step-Up Converter output could break due to over voltage.

2.2 External Component Selection AS3677

Table 2: External Components AS3677

Description	Name	Min	Value Typ.	Max	Tol (Min)	Rating (Max)	Notes	Package (Min)([1])
Coil	L1		10µH ([2])		±20%		Taiyo Yuden (NR3012T100M) 10µH/700mA	
Output Capacitor	C2		4,7µF		±20%	50V	Step-Up DCDC Output muRata (GRM319R61H475KA12)	1206
DCDC DIODE	D1	NSR0340V2T1, NSR0240V2T1					Shottky Barrier Diode	SOD-523
Cascode NMOS	Q1-Q4	FDMC8462				40V	N-Channel Power Trench® MOSFET	Power 33 3x3 mm
LED	D2-D10						Application Specific	

1. In 1/100 inch (unless otherwise specified)
2. See Chapter 1.3.1 External Component Comments

3 Design Considerations

The intention with this section is to highlight other possibilities. Connecting LEDs I parallel using AS3676 and AS3677 to avoid external components with a voltage rating of 50V etc. and /or to give an indication of the efficiency at a certain configuration.

In general, the below indications off efficiency applies to both AS3676 and AS3677. Some results have been measured in laboratory with the evaluation board for AS3676 and AS3677 as setup of the system, others use a theoretical calculation tool where losses of parasitic etc. are considered.

3.1 AS3676 9-LED configurations; Measurements, 1x10 LEDs, 1x9 LEDs, 4+5 LEDs

In Table 3 below shows efficiency measurements with different combination of the LEDs. The Total Efficiency is the Step-Up DCDC Converter efficiency while the Systems Efficiency also takes the power consumed by the current sinks into account.

External components used for the measurements in Table 3:
C9: KEMET - C1210C475K5RACTU - Capacitor, 1210, 4.7UF, 50V, X7R
Q1: FAIRCHILD SEMICONDUCTOR - FDFMA3N109 - MOSFET, N, MLP6
Inductor(s): TAIYO_YUDEN - NR3012T100M - 10uH/700mA
TDK-EPC: VLS4012T-220MR57 - 22uH, Size 4,0 x 4,0 x 1,2 mm
TDK-EPC: VLS4012T-150MR57 - 15uH, Size 4,0 x 4,0 x 1,2 mm

Table 3: Efficiency Table different LED configurations

Setup	Ue (V)	Ua (V)	Iin (mA)	Iout (mA)	Vcurr1	Vcurr2	Pin (mW)	Pout (mW)	Pcurr (mW)	Total Efficiency	System Efficiency
1x9 LEDs 10uH	3,679	28,562	196,47	20,09	0,5	0	722,8	573,8	10,0	79,4%	78,0%
	3,05	28,535	241,41	20,09	0,5	0	736,3	573,3	10,0	77,9%	76,5%
1x9LEDs 15uH	3,6774	28,546	189,9	20,09	0,5	0	698,3	573,5	5,0	82,1%	81,4%
	3,051	28,546	227,5	20,09	0,5	0	694,1	573,5	5,0	82,6%	81,9%
1x9LEDs 22uH	3,6776	28,55	187,9	20,95	0,5	0	691,0	598,1	5,2	86,6%	85,8%
	3,0511	28,55	244,2	20,12	0,5	0	745,1	574,4	5,0	77,1%	76,4%
4+5 LEDs	3,675	16,09	205,94	40,31	0,5	3,3	756,8	648,6	76,6	85,7%	75,6%
	3,05	16,08	252,14	40,31	0,5	3,3	769,0	648,2	76,6	84,3%	74,3%

3.2 AS3676 9-LED configurations; Simulation, 3x3 LEDs

One of many ways to get around the larger voltage rating of the external components is to use 3 LED strings with 3 serial LEDs per channel, as shown in **Figure.3:** 9 *LEDs, 3x3, configuration*, below. The benefit except for lower rating or the external components is also efficiency due to less Step-Up voltage is needed.

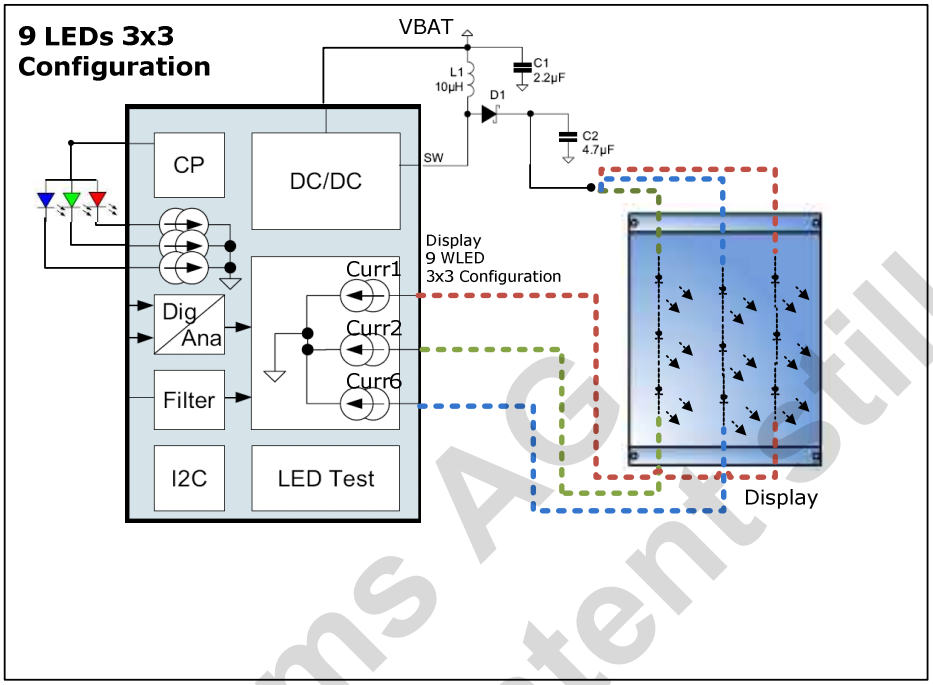


Figure.3: *9 LEDs, 3x3, configuration*

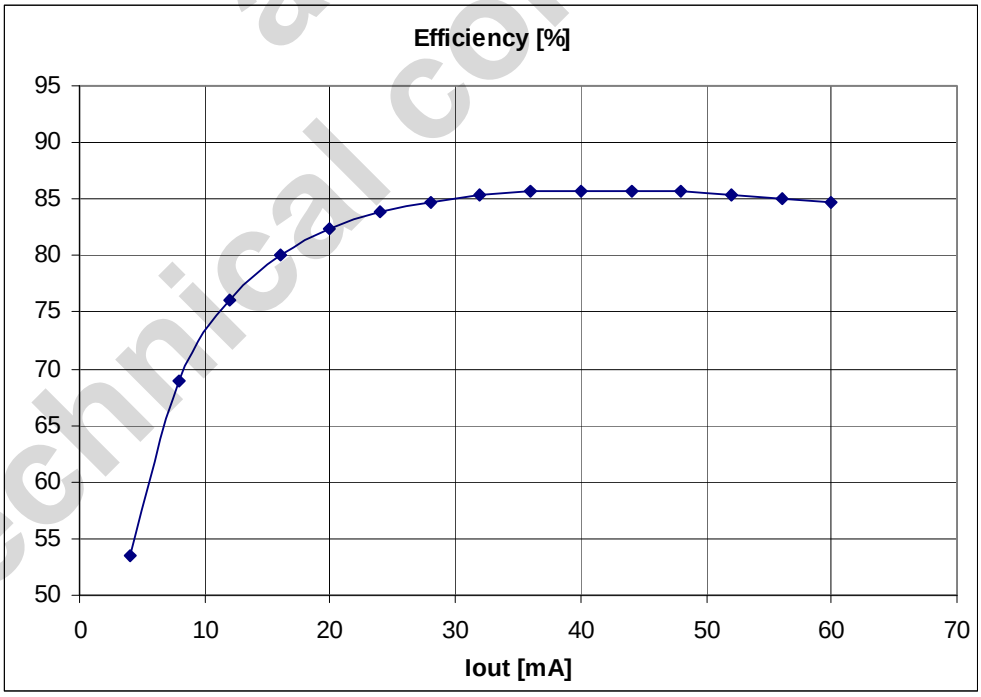
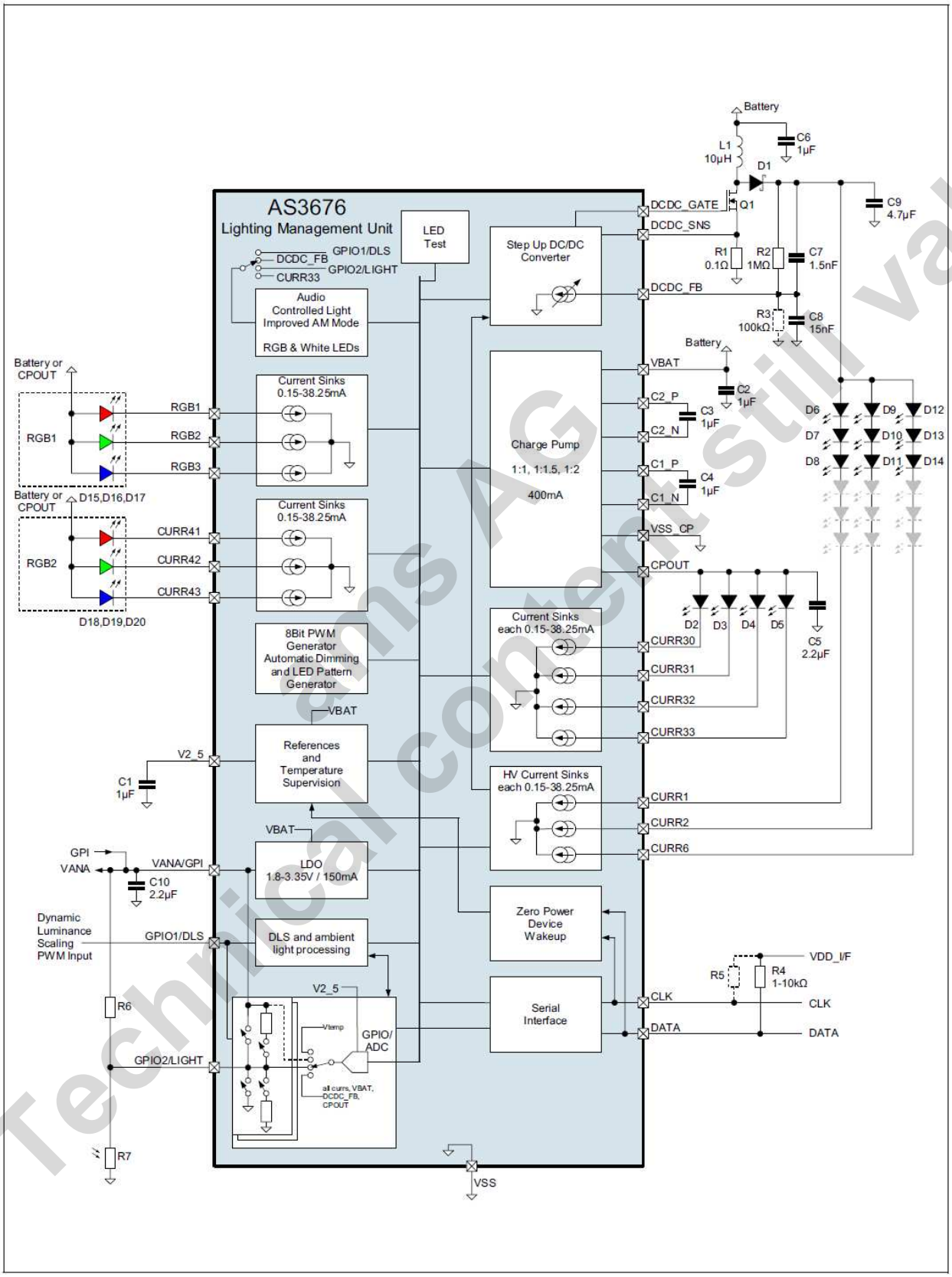


Figure.4: *Simulated Efficiency, 9 LEDs, 3x3, configuration*

4 Appendix 1: Application circuit – AS3676



5 Appendix 2: Application circuit – AS3677