

Design Consideration with AP3615

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1. Introduction

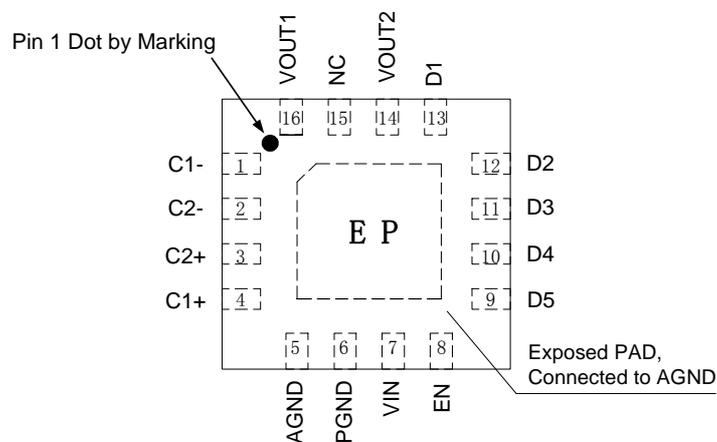
The AP3615 is a step-up DC/DC converter based on 1x/1.5x charge pump for white LED backlight applications. The AP3615 integrates 5 channels current sink and automatic mode selection charge pump. High efficiency is achieved by utilizing a 1x/1.5x fractional charge pump in combination with low dropout current sink.

The AP3615 supports up to 5 white LEDs and regulates a constant current for brightness control. The LED current can be changed from 1.25mA to 20mA by applying a pulse signal to the EN pin. There are totally 16 steps for current control. Additionally,

1MHz high switching frequency enables the use of small external flying capacitors.

The supply voltage range of AP3615 is from 2.8V to 5.5V which make them ideally suitable for applications powered by Li-ion battery. Internal soft-start circuitry prevents excessive inrush current during start-up and mode transition.

The AP3615 is available in a tiny package of QFN-3x3-16. Its operating temperature range is from -40°C to 85°C. The pin configuration and the representative block diagram of the AP3615 are respectively shown in Figure 1 and Figure 2:



Note: Pin 14 should be connected with Pin 16 on PCB Board.

Figure 1. Pin Configuration of AP3615 (Top View)

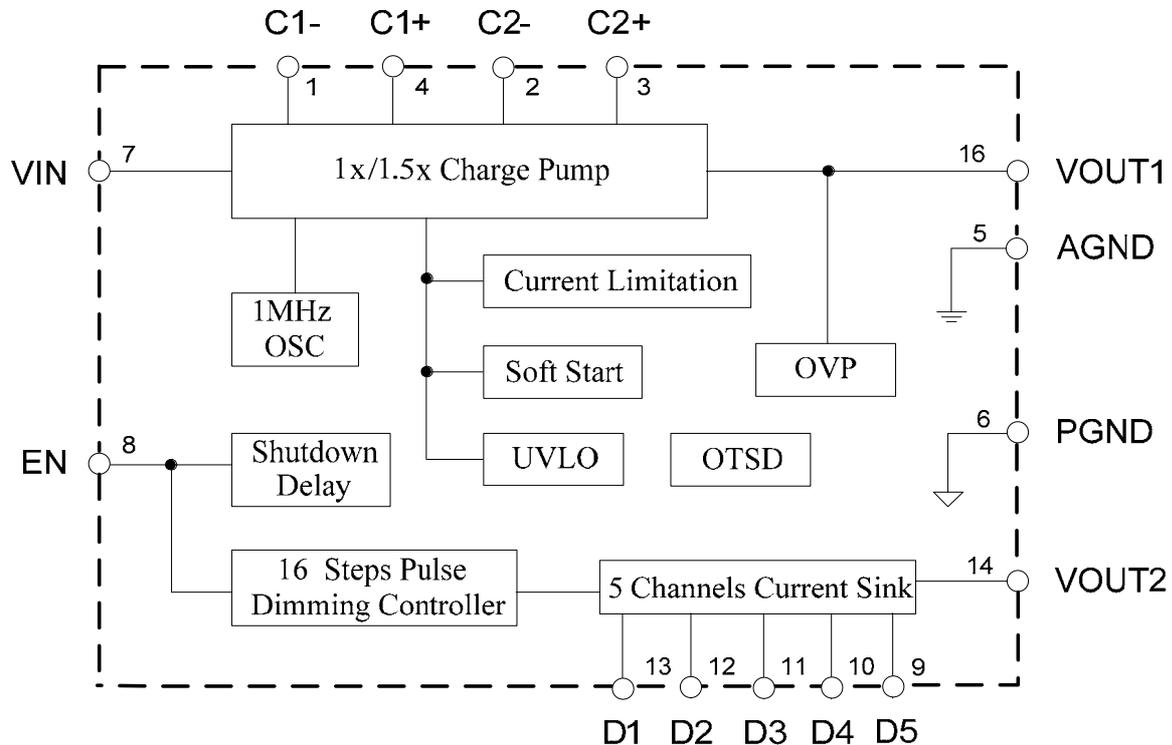


Figure 2. Functional Block Diagram of AP3615

1.1 Soft Start

The AP3615 has an internal soft start circuit to limit the inrush current during startup and charge pump mode transition. It prevents possible drop of the input voltage if a high impedance power source is connected to the input of the AP3615.

In mobile phone applications, the AP3615 is powered by Li-ion battery. The soft start function prevents excessive output current from leaving the battery, which can cause excessive voltage drop. It is of benefit to other circuits powered by Li-ion battery directly.

1.2 Enable and Dimming Control

The AP3615 has an EN pin to enable/disable the IC or control the brightness of white LEDs. When a logic high signal is added to the EN pin, the AP3615 starts up and operates normally. When a logic low

signal is added to the EN pin and remains more than 1ms, the IC will shut down. The shutdown current is very small. It can minimize the power dissipation and extend the battery life.

If adding a pulse signal to the EN pin, the AP3615 will operate in dimming mode. The LED current can be changed from 1.25mA to 20mA, in 16 steps totally. The detailed operation of brightness dimming please refer to 4.3.

1.3 Current Matching

Current matching is most important for WLED backlights. The AP3615 current sink block implements the current matching function. It can achieve less than $\pm 3\%$ current matching between 5 channels.

As we know, WLED is current control device whose

forward voltage has a wide distribution. If the LED lot number is different, the distribution is much wider. A highlight feature of AP3615 is that its current matching precision is independent on LED forward voltage. It can guarantee $\pm 3\%$ current matching precision for all types of WLEDs.

1.4 White LED Connection

The AP3615 supports up to 5 white LEDs that are connected from VIN to D1, D2, D3, D4 and D5 channels respectively. If a certain channel is not used, it should be connected to VIN directly. It should not be left floating.

1.5 Mode Selection

The AP3615 can automatically switch between 1x mode and 1.5x mode for optimizing the efficiency. An internal current sensing circuit monitors WLED current to keep it constant when the battery voltage fluctuates. The AP3615 switches to 1.5x mode whenever the dropout condition is detected from any of the 5 current sinks and returns to 1x mode whenever the dropout condition releases.

1.6 Under Voltage Lockout

The AP3615 provides an under voltage lockout (UVLO) circuit to prevent it from undefined status when startup. The UVLO circuit shuts down the device when V_{IN} drops below a typical threshold of 2.2V. The UVLO circuit has 250mV hysteresis, which means the device starts up again when V_{IN} rises to 2.45V or above. The UVLO hysteresis can prevent AP3615 from unstable state when startup.

1.7 Over Voltage Protection

The AP3615 has an internal over voltage protection circuit. When the white LEDs are disconnected from the circuit or fail to open, the voltage between input and output will be clamped at 5.5V.

1.8 Over Temperature Protection

The AP3615 is also equipped with a thermal protection and shutdown circuit that continuously monitors the IC junction temperature. When some abnormal operations occur, the internal junction temperature rises. If the thermal protection circuit senses the junction temperature exceeding approximately 160°C , it will disable AP3615 and protect the device from damaged. The thermal protection and shutdown circuit has 20°C of system hysteresis

2. Components Selection

2.1 Capacitor Selection

Careful selection of the four external capacitors C_{IN} , C_{OUT} and C_{FLY} (C1 and C2) is very important because they will affect charge pump capability, output voltage ripple, input voltage ripple and power efficiency. Polarized capacitor such as tantalum or aluminum is not recommended for using with the AP3615. For the two flying capacitors C1 and C2, it is important to use low ESR capacitors to avoid unnecessary efficiency losses. To reduce the input and output ripple effectively, low ESR capacitors on VIN and VOUT are recommended. To get the optimum performance, low ESR ceramic capacitor will be the best option for C_{IN} , C_{OUT} and C_{FLY} . The recommended value for each capacitor is $1\mu\text{F}$ typical.

Ceramic Capacitors have features of very low ESR, low cost, small PCB footprint, and are non-polarized. All the above are of benefit to the charge pump. The main materials of ceramic capacitor include NPO (COG), X7R, X5R, Y5U, Z5U and Y5V. MLCC X7R and X5R dielectrics are much more desirable because of their capacitance, precision, operating temperature range, temperature stability and cost (compare with NPO ceramic capacitor). Table 1 gives the key features of X7R and X5R ceramic capacitors.

Table 1. Key Features of X7R and X5R Ceramic Capacitors

Ceramic Capacitor	Operating Temperature Range ($^{\circ}\text{C}$)	Precision	Capacitance	Temperature Stability
X7R	-55 to 125	$\pm 15\%$	150pF to 4.7 μF	-5% to 5%
X5R	-55 to 85	$\pm 15\%$	0.47 μF to 10 μF	-15% to 5%

2.2 White LED Selection

The AP3615 is specifically intended for driving white LEDs with forward voltage from 0V to 4.0V. Since the D1 to D5 current sinks are independent of the voltage, the LED brightness will be matched regardless of the specific LED forward voltage (V_F) levels.

In a word, the AP3615 can drive most white LEDs for backlighting with good current matching.

3. Typical application

The AP3615 is designed especially for white LED driver with current matching. Figure 3 and Figure 4 show the typical application circuits. In these applications, the LED current can be changed from 1.25mA to 20mA by applying a pulse signal to the EN pin. There are totally 16 steps of current can be set by users.

If the LED is not used, the LED pin should be connected to VIN directly. Figure 3 and Figure 4 show the connection in 4 WLEDs and 5 WLEDs applications.

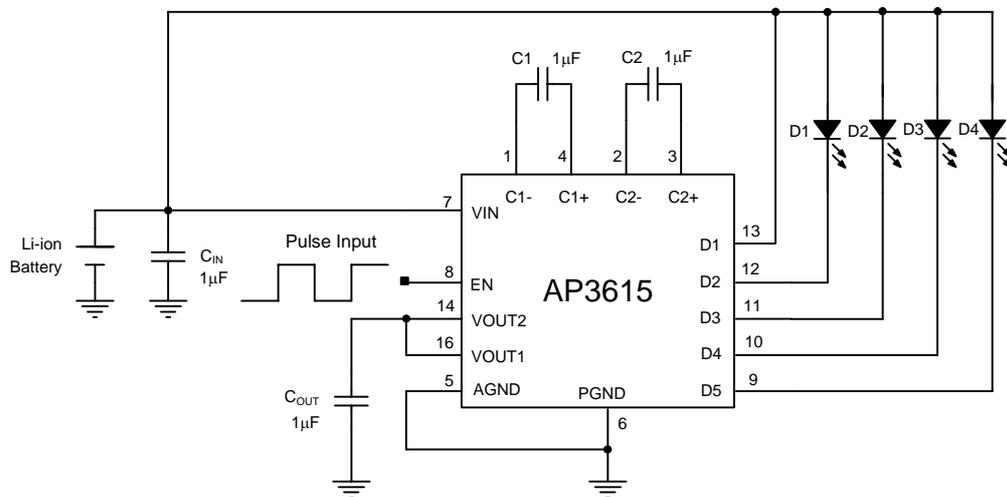


Figure 3. Typical Application of AP3615 (4 WLEDs)

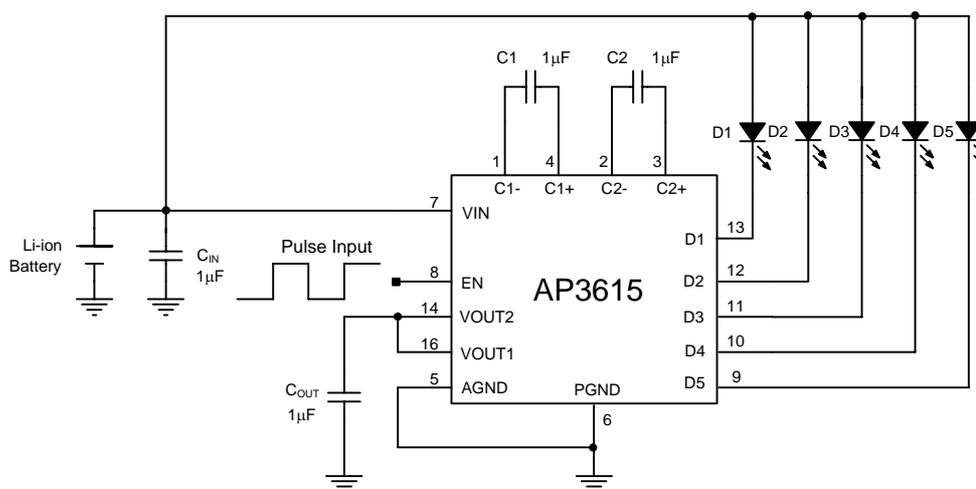


Figure 4. Typical Application of AP3615 (5 WLEDs)

4. Application Hints

4.1 Output Ripple

Low ESR ceramic capacitor for C_{OUT} and C_{FLY} and high switching frequency of AP3615 minimize the output voltage ripple.

Formula 1 can be used to calculate the output voltage ripple.

$$V_{RIPPLE} = \frac{I_D \times \frac{1}{f} \times \frac{1}{2}}{C_{OUT}} + 2 \times I_D \times ESR_{C_{OUT}} \quad (1)$$

I_D --- equal to the sum of LED current

f --- operating frequency, 1MHz

C_{OUT} --- output capacitor

$ESR_{C_{OUT}}$ --- the equivalent serial resistor of output capacitor

The current sink is powered by charge pump. Because of its high bandwidth, the output voltage ripple is filtered by the current sink. So, there is little current ripple in the current sink. It is of benefit to the LED.

4.2 Power Efficiency

The power conversion efficiency of the AP3615 can

be calculated through formula 2 and formula 3.

$$\eta_{LED} = \frac{V_D \times I_D}{V_{IN} \times I_{IN}} \approx \frac{V_D \times I_D}{V_{IN} \times 1.5I_D} = \frac{V_D}{1.5V_{IN}} \quad (1.5x \text{ mode}) \quad (2)$$

$$\eta_{LED} = \frac{V_D \times I_D}{V_{IN} \times I_{IN}} \approx \frac{V_D \times I_D}{V_{IN} \times I_D} = \frac{V_D}{V_{IN}} \quad (1x \text{ mode}) \quad (3)$$

With a fully charged battery, the charge pump operates in 1x mode. The efficiency will increase along with the decrease of battery voltage. When the battery voltage drops to about 3.5V ($V_F=3.2V$), the efficiency will reach the top point which is about 91%. As the discharge of battery ceaselessly run out, leading to the current sinks no longer have enough voltage overhead to maintain a constant current regulation, the charge pump will switch into 1.5x mode. The conversion efficiency is lowest at this crossover. As the battery discharges further, the efficiency again increases and reaches a second maximum at about 2.7V V_{IN} .

4.3 Dimming Control

The AP3615 implements a pulse dimming mechanism to control the brightness of white LEDs.

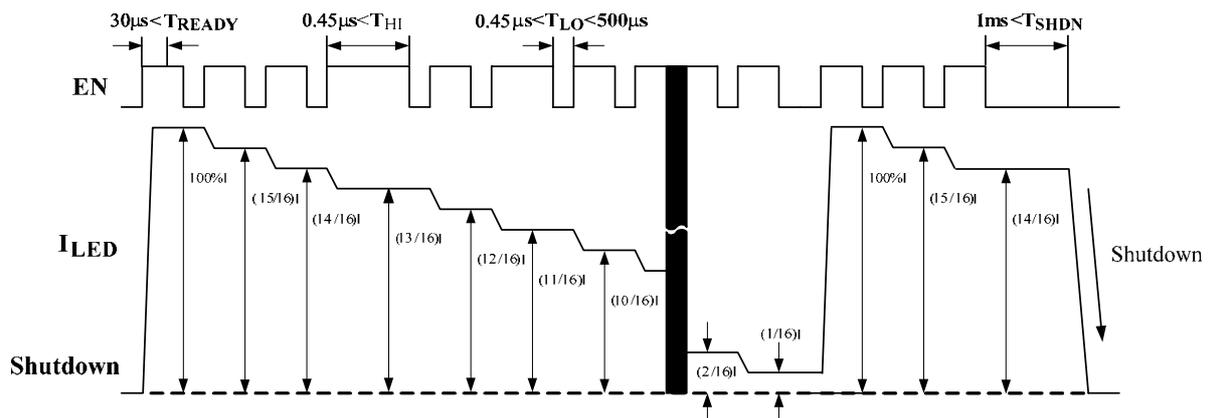


Figure 5. Dimming Control by Pulse Signal

The WLED comes to full brightness with about 20mA current on each channel when the AP3615 is powered on. The dimming control can be achieved by applying a pulse to EN pin. When the low level duration time of the pulse is between T_{LOmin} and T_{LOmax} , and the high-level duration time is larger than T_{HImin} , the I_{LED} will decrease 1/16. After 15 such

pulses applied, the WLED brightness will be reduced to 1/16 of its full brightness. And, at that time if one more such pulse applied to EN pin, the WLED will return back to its full brightness. And this repeats. If the low level duration time is larger than $T_{SHDNmax}$, the IC will be turned off, apply one pulse to EN pin to turn on it if necessary.

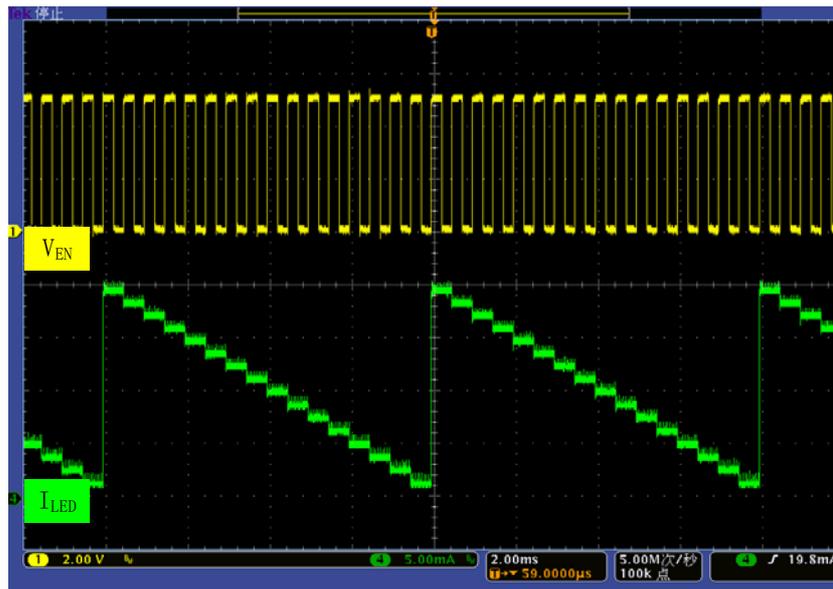


Figure 6. WLED Current vs. Dimming Signal

4.4 PCB Layout Consideration

Due to high switching frequency and large transient current produced by AP3615, careful PCB layout is necessary. For best performance, all external capacitors should be located as close as possible to the device. A true ground plan and short connection is highly recommended.

In detail, C_{OUT} has the first priority to be located closely to VOUT and GND pin which is advantageous to reduce noise coupling from charge pump to LEDs and reduce the output ripple. C_{FLY} has the second priority and C_{IN} has the third priority.

Furthermore, the traces from pins to flying capacitors should be short and wide to reduce parasitic resistance. V_{IN} traces should be wide to minimize inductance and handle the large current. The exposed pad, PGND and AGND should be connected to a strong ground plane for heat sinking and noise

prevention. These rules are adopted to minimize the LED current ripple, improve the drive capability and efficiency, and minimize the input voltage ripple to prolong the battery life. Figure 7 gives a PCB layout example of the AP3615. In this example, the package type of AP3615 is QFN-3×3-16 and the type of C_{IN} , C_{OUT} and C_{FLY} is 0805.

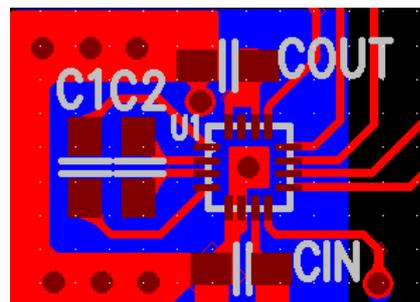


Figure 7. AP3615 PCB Layout Example