

## Design Consideration with AP3606/AP3607

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### 1. Introduction

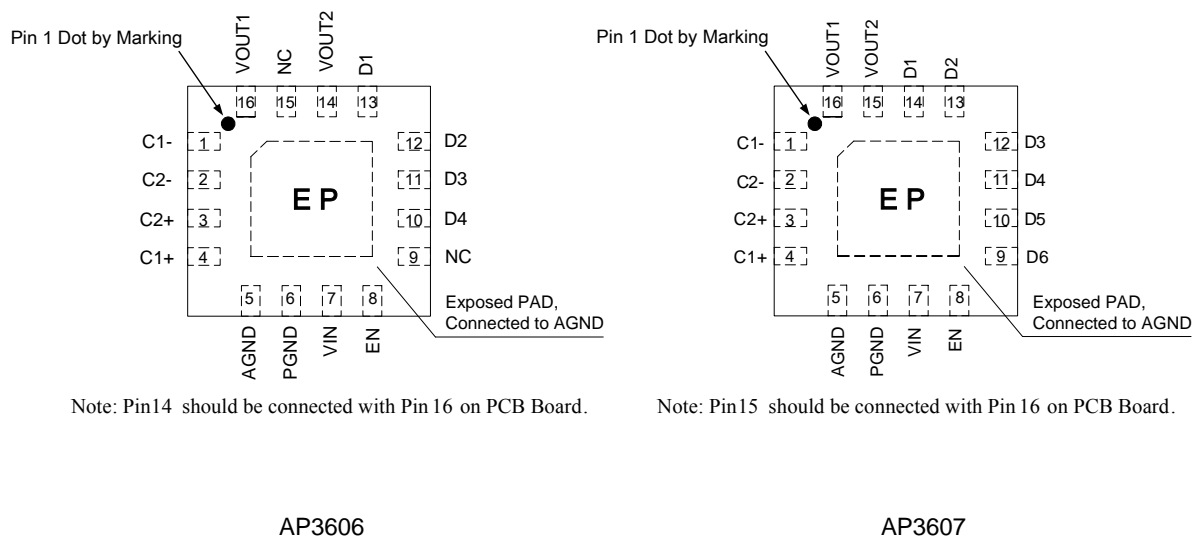
The AP3606 and AP3607 are step-up DC/DC converters based on 1x/1.5x charge pump for white LED backlight application. The AP3606(AP3607) integrates 4(6) channels current sink and automatic mode selection charge pump. High efficiency is achieved by utilizing a 1x/1.5x fractional charge pump in combination with low dropout current sink.

The AP3606(AP3607) supports up to 4(6) 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 ranges of AP3606 and AP3607 are from 2.7V to 5.5V which make them ideally suit for applications powered by Li-ion battery. Internal soft-start circuitry prevents excessive inrush current during start-up and mode transition.

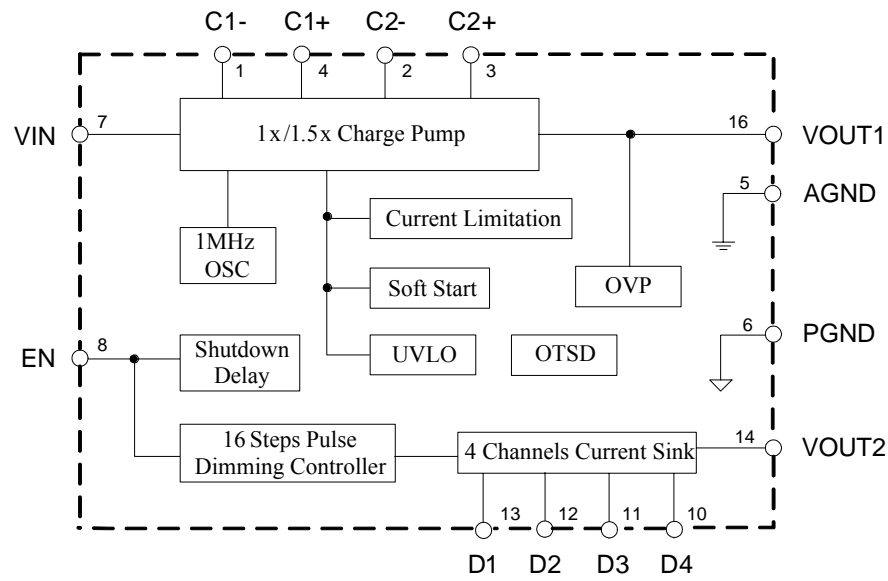
The AP3606 and AP3607 are available in a tiny package of QFN-3 × 3-16. Its operating temperature range is from -40°C to 85°C. The pin configuration and the representative block diagrams of the AP3606 and AP3607 are respectively shown in Figure 1 and Figure 2:



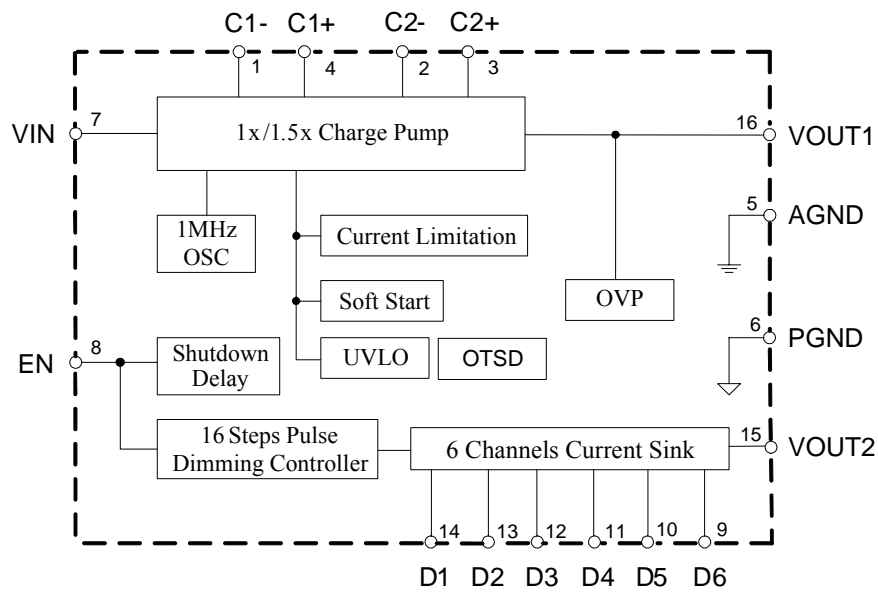
Note: Pin14 should be connected with Pin 16 on PCB Board.

Note: Pin15 should be connected with Pin 16 on PCB Board.

Figure 1. Pin Configuration of AP3606/AP3607 (Top View)



AP3606



AP3607

Figure 2. Functional Block Diagram of AP3606/AP3607

### 1.1 Soft Start

The AP3606(AP3607) 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 AP3606(AP3607).

In mobile phone applications, the AP3606(AP3607) 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 AP3606(AP3607) 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 AP3606(AP3607) 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 AP3606(AP3607) 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 AP3606(AP3607) current sink block implements the current matching function. It can achieve less than  $\pm 3\%$  current matching between 4 channels for AP3606 and 6 channels for AP3607.

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 AP3606(AP3607) 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 AP3606 supports up to 4 white LEDs that are connected from VIN to D1, D2, D3 and D4 channels respectively. The AP3607 supports up to 6 white LEDs which are connected from VIN to D1, D2, D3, D4, D5 and D6 channels respectively. If a certain

channel is not used, it should be connected to VIN directly. It should not be floating.

### 1.5 Mode Selection

The AP3606(AP3607) 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 AP3606(AP3607) switches to 1.5x mode whenever the dropout condition is detected from any of the 4(6) current sinks and returns to 1x mode whenever the dropout condition releases.

### 1.6 Under Voltage Lockout

The AP3606(AP3607) 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 AP3606(AP3607) from unstable state when startup.

### 1.7 Over Voltage Protection

The AP3606(AP3607) 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 AP3606(AP3607) 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 AP3606(AP3607) 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 AP3606(AP3607). 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<sub>IN</sub>, C<sub>OUT</sub> and C<sub>FLY</sub>. The recommended value for each capacitor is 1 $\mu$ 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 ( )	Precision	Capacitance	Temperature Stability
X7R	-55 to 125	$\pm 15\%$	150pF to 4.7 $\mu$ F	-5% to 5%
X5R	-55 to 85	$\pm 15\%$	0.47 $\mu$ F to 10 $\mu$ F	-15% to 5%

## 2.2 White LED Selection

The AP3606(AP3607) is specifically intended for driving white LEDs with forward voltage from 0V to 4.0V. Since the D1 to D6 current sinks are independent of the voltage, the LED brightness will be matched regardless of the specific LED forward voltage (V<sub>F</sub>) levels.

The AP3606(AP3607) is designed especially for white LED driver with current matching. Figure 3, 4, 5 and 6 shows 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.

In a word, the AP3606(AP3607) can drive most white LEDs for backlighting with good current matching.

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

## 3. Typical application

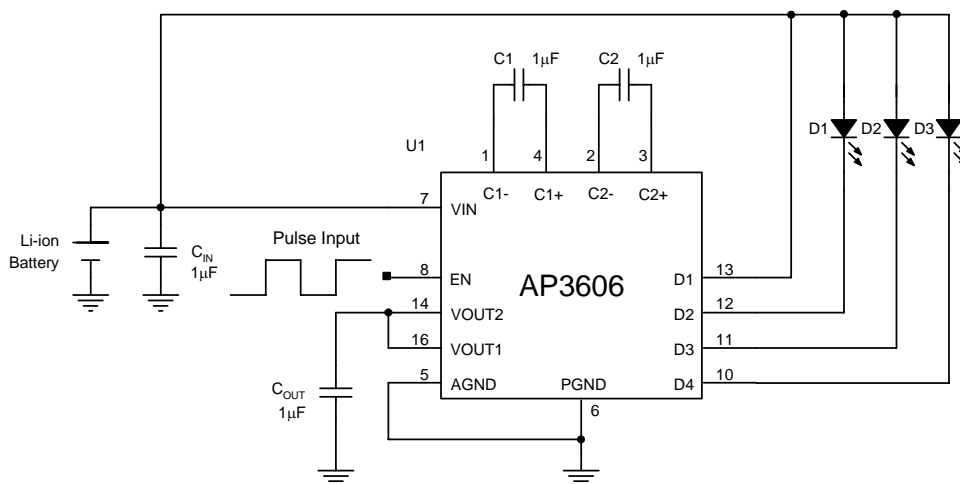


Figure 3. Typical Application of AP3606 (3 WLEDs)

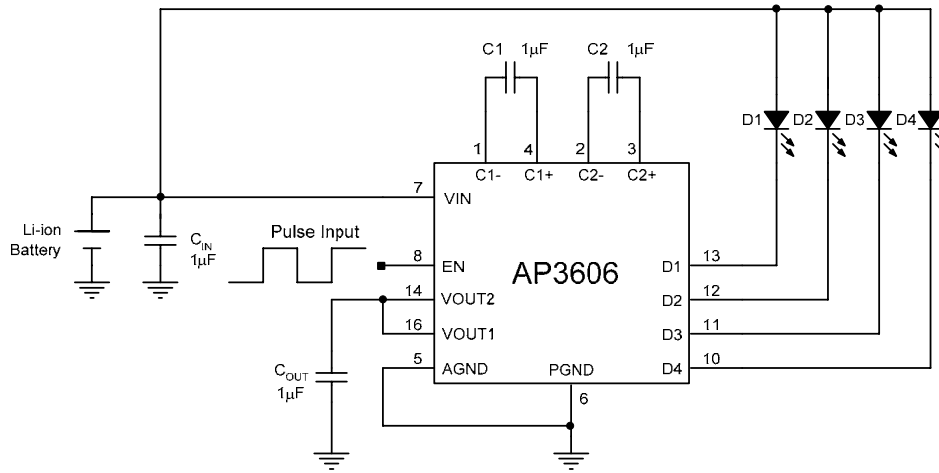


Figure 4. Typical Application of AP3606 (4 WLEDs)

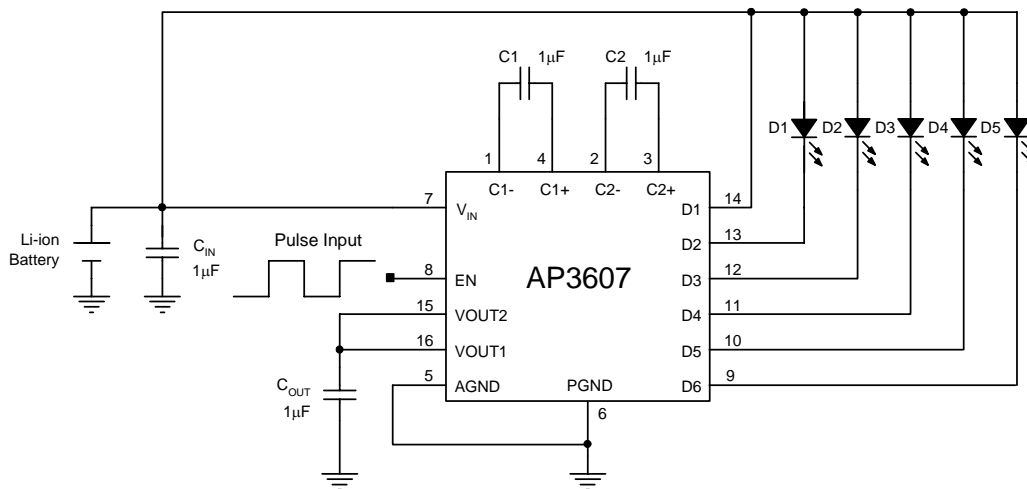


Figure 5. Typical Application of AP3607 (5 WLEDs)

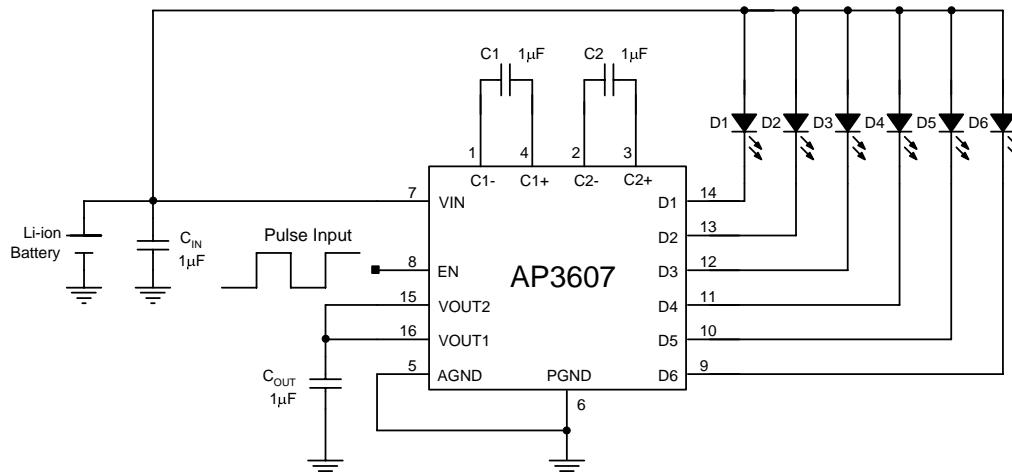


Figure 6. Typical Application of AP3607 (6 WLEDs)

## 4. Application Hints

### 4.1 Output Ripple

Low ESR ceramic capacitor for C<sub>OUT</sub> and C<sub>FLY</sub> and high switching frequency of AP3606(AP3607) minimize the output voltage ripple.

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

$$V_{\text{RIPPLE}} = \frac{I_D \times \frac{1}{f} \times \frac{1}{2}}{C_{\text{OUT}}} + 2 \times I_D \times \text{ESR}_{\text{COUT}} \quad (1)$$

I<sub>D</sub> ---equal to the sum of LED current

f --- operating frequency, 1MHz

C<sub>OUT</sub> --- output capacitor

ESR<sub>COUT</sub> --- 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 AP3606

(AP3607) can be calculated through formula 2 and formula 3.

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

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

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<sub>F</sub>=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<sub>IN</sub>.

### 4.3 Dimming Control

The AP3606(AP3607) implements a pulse dimming mechanism to control the brightness of white LEDs.

When AP3606(AP3607) is powered on, the WLED is in full brightness. Its current is about 20mA. The dimming control can be achieved by applying a pulse to EN pin. When the low level duration time of pulse is between  $T_{LOmin}$  and  $T_{LOmax}$ , and the high-level duration time is larger than  $T_{HImin}$ , the LED current will decrease 1/16. If the low level duration time is larger than  $T_{SHDNmax}$ , the IC will be turned off. When

AP3606/AP3607 is powered on, the WLED is in full brightness. And it will keep maximum current until the pulse is detected. After 15 pulses the WLED current decreases to 1/16 of full brightness. It will increase to full brightness if a pulse is added to EN pin then. Please refer to Figure 7 and Figure 8 for detailed information and example.

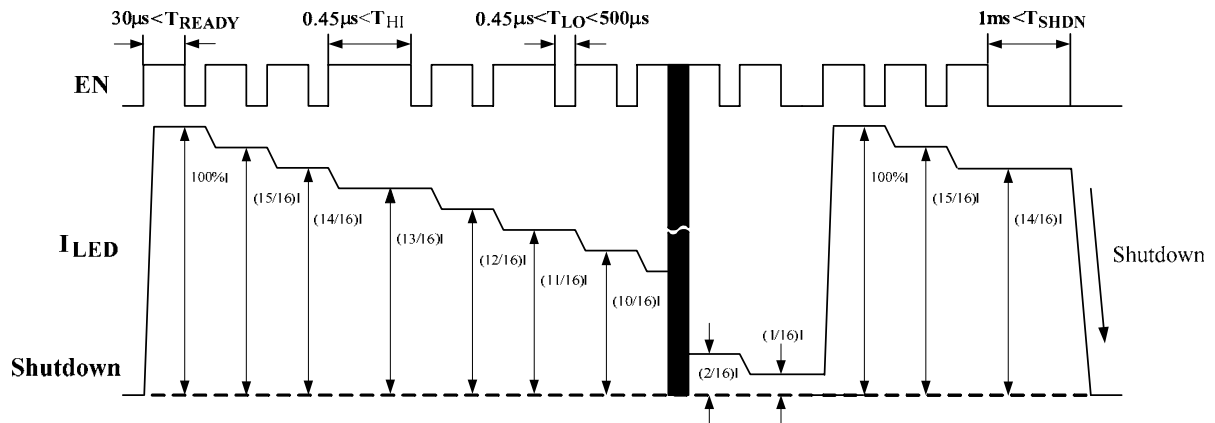


Figure 7. Dimming Control by Pulse Signal

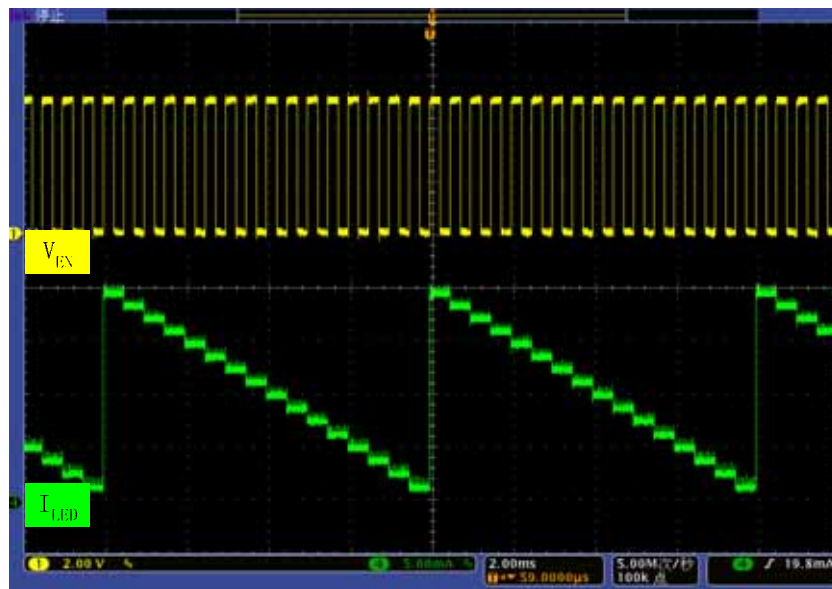


Figure 8. WLED Current vs. Dimming Signal (AP3607)

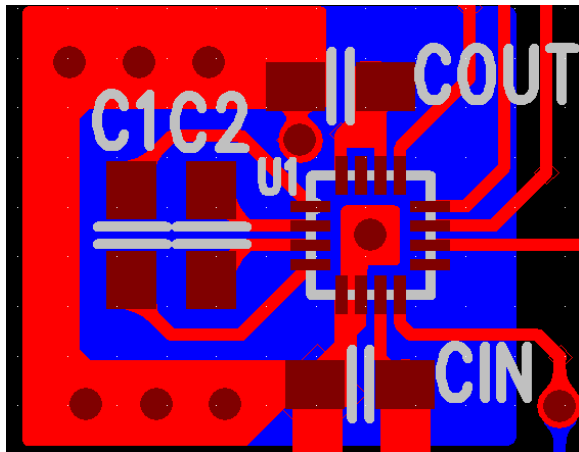
#### 4.4 PCB Layout Consideration

Due to high switching frequency and large transient currents produced by AP3606(AP3607), careful PCB layout is necessary. For best performance, all external capacitors should be located as close as possible to the device. A true ground plane and short connection is highly recommended.

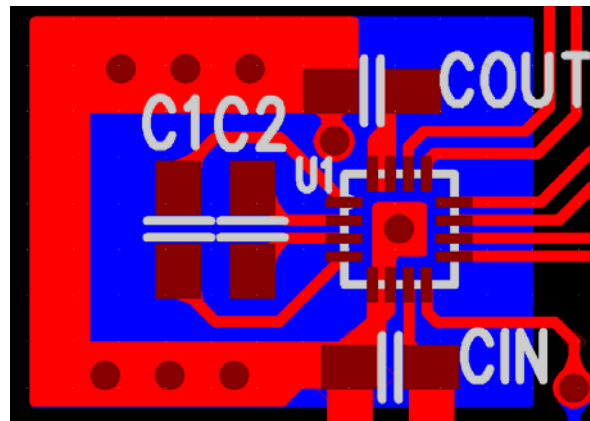
In detail,  $C_{OUT}$  has the first priority to be located closely to  $V_{OUT}$  and GND pin which is advantageous to reduce noise coupling from charge pump to LEDs and reduce the output ripple.  $C_{FLY}$  has the second priority and  $C_{IN}$  has the third priority.

Furthermore, the traces from pins to flying capacitor 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 9 gives an layout example of the AP3606(AP3607). In this example, the package of AP3606(AP3607) is QFN-3x3-16 and the package of  $C_{IN}$ ,  $C_{OUT}$  and  $C_{FLY}$  is 0805.



AP3606



AP3607

Figure 9. AP3606/AP3607 PCB Layout Examples

#### 4.5 The Layout Compatibility of AP3606 and AP3607

There is a good layout compatibility between AP3606 and AP3607. It is convenient for user to use AP3606 or AP3607 as backlight drive in the same PCB board. In other word, the PCB board used for AP3606 also suits AP3607. Figure 10 illustrates how to apply AP3606 and AP3607 to the same PCB.

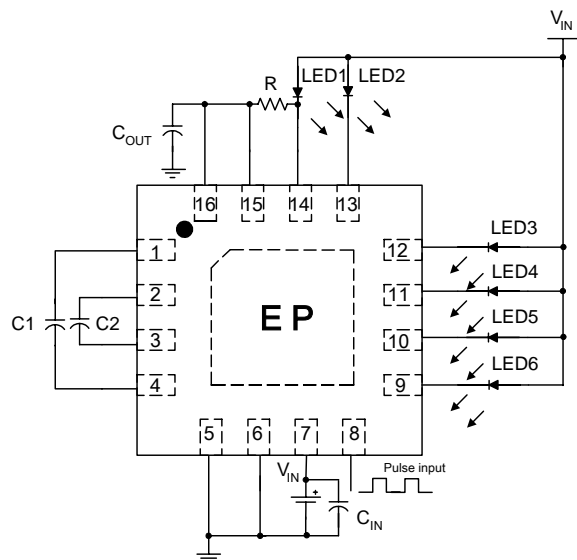


Figure 10.



If AP3606 is applied, please:

- 1) Remove LED1 & LED6
- 2) Set R to 0Ω

The recommended schematics please refer to Figure 11.

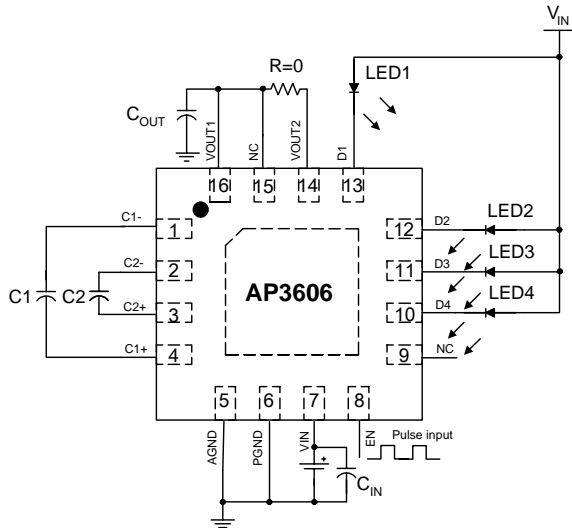


Figure 11.

In case AP3607 is used, please remove R as Figure 12 shows.

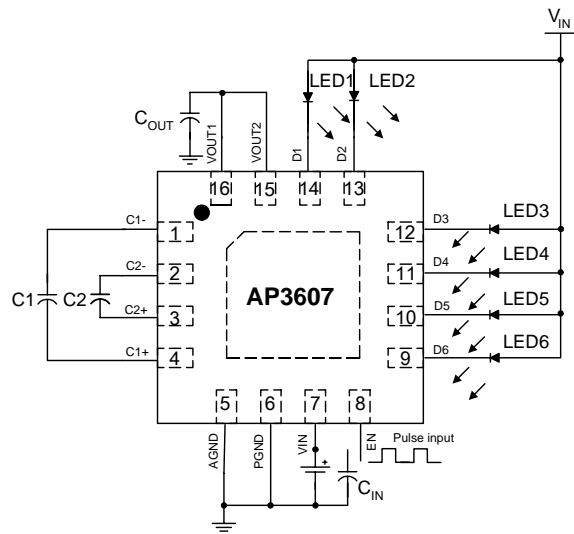


Figure 12.