High-Performance LED Flash for Camera Phones
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The internet is the most popular media for social networking and the sharing of pictures and videos. Media-centric phones are gaining market share over voice-centric phones, causing a migration to larger size and higher resolution color displays. The backlighting of these displays demand higher power from portable battery sources. Beyond the display, the mobile handset is becoming a high quality digital still camera requiring special lighting functions for video-recording and photography in low light environments and consuming more battery peak power and energy.

Light-emitting-diode (LED) technology is widely used to provide illumination for the pixels in small format liquid crystal displays (LCDs) in battery-powered applications. White light, emitted by the LEDs, is transmitted through a polarizer to the LCD where the light can be blocked or attenuated and sent on to RGB color filters to create colored light.

The very same LED technology can be used to illuminate a scene when taking a picture with a camera phone in dim light conditions. Figure 1 shows a system-level view of a camera flash using National Semiconductor’s LM3554, which consists of a boost DC/DC converter, and two current regulators capable of driving one or two high-current white LEDs. How much light is needed? How much current will the flash unit consume? Answering these questions can guide the designer in the selection of the appropriate LED flash unit.

![Figure 1: Camera Flash System with LM3554.](image)

Shutter Operation for CMOS Image Sensors

Although high-resolution digital still cameras are available today, their technology is not easily applicable to handsets. The camera function cannot increase cost, size and power consumption at the expense of talk time. The most important function of
the mobile phone is to make a call and speak to somebody. CMOS image sensors, which are manufactured with a standard CMOS process, enable mobile imaging applications by integrating image sensing and digital signal processing on the same chip as to achieve reductions in system size and cost. In addition, CMOS sensors comply with the severe power consumption restrictions in mobile phones. CMOS image sensors are made up of a two-dimension array of pixels, which are covered by color filters and consist of one photodiode and few transistors each. An image, which is comprised of many tiny colored dots, is captured by converting light from an object into voltages at the photosensitive area, namely the photodiodes. The photocurrent through each diode is integrated in order to produce output voltage levels that depend on the amount of light, $I$, that falls on the pixel, in terms of both intensity $E_v$, measured in lux, and exposure time $t$, measured in seconds, given by:

$$I = E_v \times t$$

In digital still cameras, the exposure time is controlled by the duration of the opening of the mechanical shutter. Most CMOS image sensors allow the elimination of the mechanical shutter, which adds to cost and makes the phone thicker, by incorporating an on-chip electronic rolling shutter. Figure 2 shows how an image is captured by a CMOS image sensor with a rolling shutter. A frame is made up of N rows, each with M pixels. Each row of pixels is sequentially read out and reset starting from the top of the image. When capturing an image, the voltage of each pixel is ignored during the first frame and then read and processed during the second frame. Each pixel in the array integrates incident light for the duration of a frame. When all $N \times M$ pixels have been exposed for the same period of time, a full image has been captured, which occurs in two frame intervals. This shutter mechanism is called Full Frame Integration. However, in some cases it is desirable to reduce the time in which the pixels in the array are allowed to integrate incident light without changing the frame rate. This is known as Partial Frame Integration and can be achieved by resetting pixels in a given row ahead of the row being selected for readout. An LED flash unit can provide constant illumination for the image capture period and therefore can be used with a rolling shutter, whereas a xenon flash needs a mechanical shutter to prevent ambient light from overexposing the image. The xenon flash lasts only a fraction of a millisecond, but ambient light is still integrated by each line in the period outside of the flash pulse. For example, if the frame rate is 30 fps, then the LED flash is required to illuminate the scene for $2 \times 1/30\text{sec} = 66\text{ms}$. The operation of a flash LED driver with a CMOS imager operating in rolling shutter mode can be summarized as follows:

1. The flash LED is turned on;
2. The reset process sweeps through the image row by row;
3. The pixels are sequentially read out row by row;
4. The flash LED is turned off.
The main constraints that the designer has to face are light output and peak current consumption. There are severe peak current restrictions on batteries in mobile phones, such as a flash unit that draws too much current causing the phone to shut down. On the other hand, as camera resolution doubles or triples, the pixel size is reduced to accommodate the larger number of pixels. As pixel size drops, more light is needed. For a given input power budget, there are three main ways to increase the brightness of a flash event to help the designer reach the illumination target. LED selection, LED current drive, and LED configuration all play a huge role in optimizing the light output of a given flash LED driver.

The first step in the LED flash unit design consists in quantifying the amount of light required by the application. The guide number (GN) of a camera flash measures its ability to properly illuminate a scene at a specific sensor speed, measured in ISO. The GN is found by multiplying the flash-to-subject distance by the f-stop required for a correct exposure at that distance:

$$GN = d \times N$$

where \(d\) is the flash-to-subject distance in meters and \(N\) is the aperture, expressed as an f-number. Although any distance could be used, one meter is the commonly used value. A higher guide number will produce a more powerful camera flash. The fundamental equation for correct exposure at a distance of one meter yields:

$$GN = 1 \times N = \sqrt{\frac{E_v \times t \times S}{C}}$$
where \( t \) is the exposure time in seconds, \( E_v \) is the illuminance on the scene in lux, \( S \) is the sensitivity of the image sensor in ISO and \( C \) is an arbitrary constant chosen by the manufacturer of an exposure meter to reflect its view of what represents the “correct exposure”. Let us consider, for example, a camera system with the following specifications:

\[
t = 66\text{ms} \\
S = 100 \\
C = 200 \\
N = 2.8
\]

The illumination target for the scene is given by:

\[
E_v = \frac{N^2 \times C}{S \times t} \approx 240\text{lx}
\]

The second step in the design consists in choosing the appropriate configuration for the LED flash unit. In order to make things clear let us select a flash LED with the following specifications:

\[
V_{LED} = 4.5V, I_{LED} = 1200mA \rightarrow E_v = 240\text{lx} \\
V_{LED} = 4V, I_{LED} = 500mA \rightarrow E_v = 150\text{lx}
\]

Now let's calculate the battery current in the case of the LM3554 driving a single LED, assuming 100% power conversion efficiency and \( V_{IN} = 3.6V \):

\[
I_{BAT} = \frac{I_{LED}}{1 - D} = \frac{1.2A}{0.8} = 1.5A
\]

where \( D \) is the duty cycle of the boost converter. The same light output can be achieved with the LM3554 driving two flash LEDs in parallel at 500mA each:

\[
E_v1 + E_v2 \approx 240\text{lx}
\]

This time the battery current is equal to:

\[
I_{BAT} = \frac{2 \times I_{LED}}{1 - D} = \frac{1A}{0.9} \approx 1.11A
\]

The battery current is reduced by 25% allowing the handset designer more flexibility in the power management scheme for the rest of the system.
Pushing Beyond the Limits

Battery technology today prohibits the peak current consumption generally to 1.5A. This poses a problem when trying to achieve a greater light output to illuminate shrinking pixel sizes as the market moves towards higher resolution cameras. Increasing the LED current beyond 1.2A will provide greater light output at the expense of the current pulled from the battery. For example, consider a camera system with the following specifications:

\[ t = 33ms \]
\[ S = 100 \]
\[ C = 200 \]
\[ N = 2.8 \]

The illumination target is again given by:

\[ Ev = \frac{N^2 \times C}{S \times t} \approx 475lx \]

Higher current LEDs will generally share the following characteristics:

\[ V_{LED} = 4.6V, I_{LED} = 2000mA \rightarrow Ev = 475lx \]

\[ I_{BAT} = \frac{2 \times I_{LED}}{1 - D} \approx \frac{4A}{0.78} \approx 5.13A \]

The 5.13A battery current is not possible in today’s mobile handset architecture due to the voltage droops that will cause the phone to shutdown. To solve this problem and achieve 475lx, a super capacitor is placed between the battery and the load as shown in figure 3. National Semiconductor’s LM3550 flash driver can optimally charge the super capacitor at acceptable battery currents less than 1A while providing >4A flash loads from the super capacitor device.

![Figure 3: Flash LED Driver System with Super Capacitor.](image-url)
Voltage droops and ESR are of a lesser concern on the battery, but need to be monitored on the super capacitor to optimize the flash current and duration. Figure 4 shows the typical voltage profile of the super capacitor during a flash using the LM3550.

![Super Cap Voltage vs. Time](image)

**Figure 4: Super Capacitor Voltage Profile**

When the flash is initiated, the voltage of the super capacitor immediately drops. This voltage drop is determined by multiplying the flash current by the ESR of the super capacitor, which is generally less than the ESR of a battery:

\[ V_{ESR} = I_{FLASH} \times R_{ESR} \]

The voltage droop of the super capacitor is calculated by the following equation, where \( I_{FLASH} \) is the flash current, \( t_{FLASH} \) is the flash duration, and \( C_{SC} \) is the capacitance value of the super capacitor:

\[ V_{DROOP} = \left( I_{FLASH} \times t_{FLASH} \right) \div C_{SC} \]

At \( t_{FINISH} \), the voltage jumps up at the same value, \( V_{ESR} \), it dropped down at \( t_{START} \) due to the lack of current. The flash current and duration can be adjusted based on the voltage
droop and ESR of the super capacitor to ensure enough headroom for the LED and an optimal flash solution.

Xenon flash technology exists today in very few high end camera phones. However, the thinner size of a super capacitor system proves to be more attractive than the bulky xenon camera module for the increasingly small form factor phones. Xenon flash can produce a high amount of light power (generally in thousands of lux) for a short period of time while super capacitor flash produces a lower amount of light power for a longer period of time. In terms of light output, or light energy (lux.sec), the two technologies are comparable in capturing high quality images. A growing demand of mobile video capture requires a separate LED for xenon flash modules to record in dim light conditions, where a super capacitor flash driver, like the LM3550, can use the same flash LEDs for video torch. Super capacitor LED flash drivers do not need a high voltage trigger to set off the flash nor do they need to store a substantial amount of energy in a large, 330V electrolytic capacitor which is held near the ear during phone conversation. These advantages provide a safer alternative to xenon technology.

Mobile phones are integrating more functionality causing additional strains on the battery while still demanding more battery life. Unlike xenon flash, super capacitors enable functionality beyond camera flash by creating a system rail that can be used for high power audio and RF systems among other applications. Super capacitors solutions create high current flash pulses, simplify design, and protect the battery from power surges.

**Illuminating Mobile Handsets**

LED technology will continue to drive illumination in mobile handsets and become more intelligent in the way power is consumed. The fundamental challenges of utilizing more power from a single cell lithium ion battery will remain the same. The selection of the appropriate LED flash unit becomes easier to navigate around the constraints of the system with clever techniques, including the LM3554’s dual LED architecture for efficient and optimized flash in traditional handset systems and the LM3550’s super capacitor enabled architecture for powerful flash in future handset designs. Whether it’s larger, higher resolution displays, brighter camera flash or general illumination, consumers will demand new features that will influence more functionality, aesthetics and usability. LED technology proves to be a viable solution to the challenges of implementing features, including camera flash, for next generation mobile handsets.