Driving High Power LED Camera Flash

Whilst camera phones continue to improve with greater resolution, better lenses, improved image-processing software, anti hand-shake features and so on, the ability to save power and energy when carrying out flash photography is lagging way behind. Many cell phones have compromised by providing a low-current LED photo light or flash, but this provides insufficient light energy for an acceptable photo in low light conditions. To become a usable flash technology, the light source must be capable of adequate illumination within a target range of around 50lux at 1m distance. This can be achieved by state-of-the art high power, high brightness white LED technology, driven by up to 1500mA per chip. This article discusses LED camera flash challenges including high-power LED driver architecture, battery current and voltage drop considerations. **Christophe Vaucourt, Portable Power Systems Engineer, Texas Instruments, Freising, Germany**

In order to help fulfill the increasing market demand for camera phones, and the consequent need for more miniaturisation and versatility, smaller form factor and shorter time to market, a new family of easy to design in high-power LED flashlight drivers has been introduced (TPS61050/2/4). These devices feature a solution size of less than 25mm² and are capable of supplying up to 5W power to the LED (see Figure 1).

In portable applications with a single-cell lithium-ion (Li-ion) battery, the sum of the voltage drop across the white LED and the headroom voltage across the current regulator can be lower or higher than the battery voltage. This means that the LED driver topology should handle buck and boost operating modes. The easiest way to implement down conversion is by the means of a linear low-side current regulator. The advantages of this method are low-cost and high efficiency as the LED forward voltage is typically slightly lower than the nominal battery voltage.

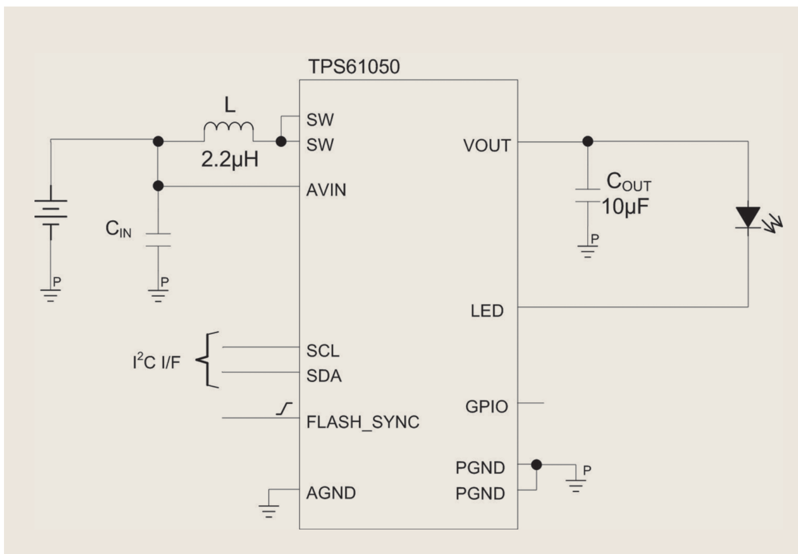

Figure 1: TPS61050 application overview

LED camera flash driver topology

Regardless of the vendor, type, size and power, all LEDs work best when driven at a constant current. Light output, measured in lumens, is proportional to current, and hence LED manufacturers specify the device characteristics (such as Illuminance, colour, temperature) at a specified forward current (I_F). High-power LEDs tend to exhibit a steep I-V curve, therefore driving an LED with a constant voltage can lead to significant and hard to predict forward current variations.

The TPS6105x family employs a 2MHz constant-frequency, current-mode PWM converter to generate the output voltage required to drive high-power LEDs. The device integrates a power stage based on an NMOS switch and a synchronous NMOS rectifier. The device also implements a linear low-side current regulator to control the LED current when the battery voltage is higher than the diode forward voltage.

Low-side sensing has been adopted for simplicity reasons and silicon area utilisation. The current sensing circuit is based on an active current mirror designed to operate in the saturation region. Depending on the voltage drop across the current sink, the device will automatically transition between linear down-mode and inductive boost mode featuring minimum sense voltage of typically 250mV.

The advantage of this architecture is very high efficiency over all LED currents and battery voltage conditions, because the input voltage can be boosted to the sum of the LED forward voltage and current-sink headroom voltage.

The challenge of current sensing is to make it accurate and efficient, two goals which are in direct conflict. The lower the headroom voltage across the current sensing/regulation circuit, the more power saved, but this comes at the expense of noise sensitivity.

As the LED flashlight functionality may not be used that often in camera phone applications, the idea was conceived to use the inductive power stage for an additional

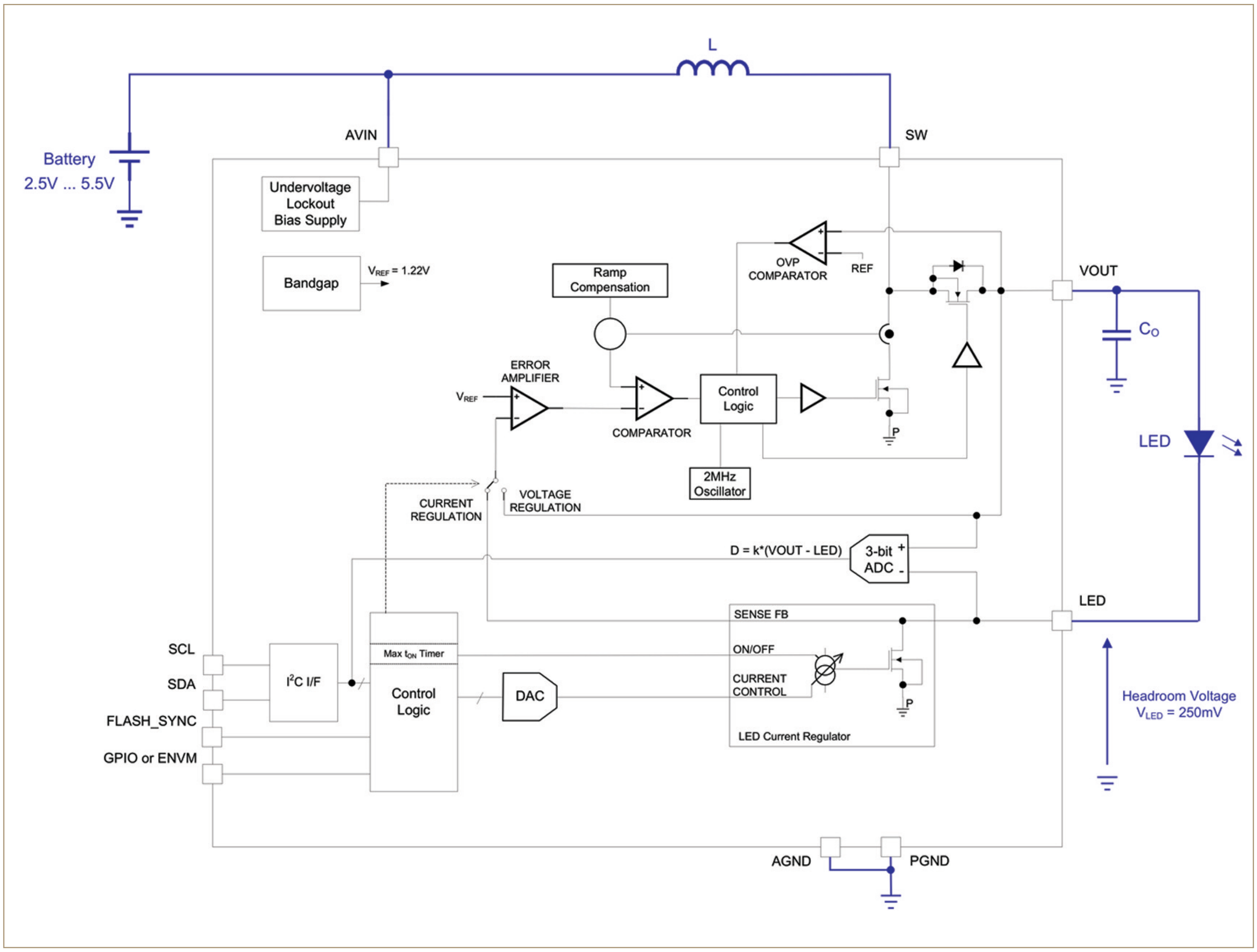

Figure 2: TPS61050 functional block diagram

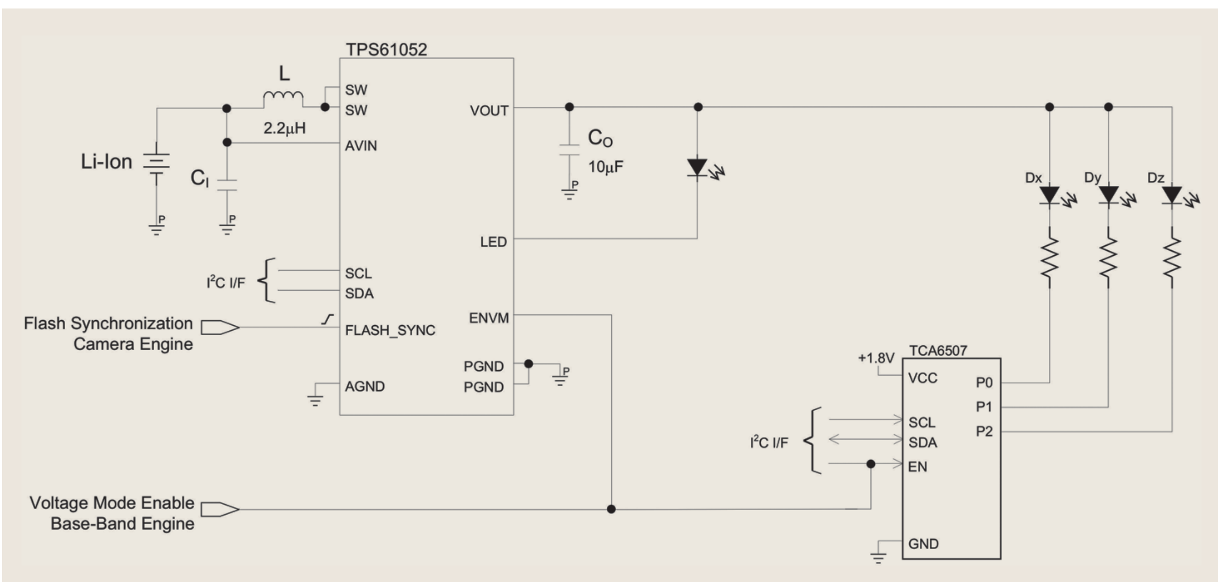

Figure 3: White LED flashlight driver and auxiliary lighting zone power supply

role. The TPS6105x device not only operates as a regulated current source, but also as a standard voltage-boost regulator.

The voltage-mode operation can be activated either by a software command or by means of a hardware signal (ENVM).

This additional operating mode can be useful to synchronise the converter properly when supplying other high-power devices in the system, such as LED drivers, hands-free audio power amplifiers, or any other components requiring a supply voltage higher than the battery voltage.

To support either LED current regulation or output voltage regulation, the TPS6105x device implements a new multi-purpose regulation scheme (see Figures 2 and 3) providing seamless on-the-fly transition between the two control loops.

LED power, battery current and voltage drop

The output power relation to be used in the efficiency calculation is $P_{LED} = V_F \times I_F$. The LED drive efficiency, i.e. the ratio of electrical LED power over battery power, is equal to:

$$\eta = \frac{V_F \times I_F}{V_{IN} \times I_{IN}}$$

conversely

$$I_{BAT} = \frac{1}{\eta} \times \frac{V_F}{V_{IN}} \times I_F$$

Figure 4 shows efficiency versus input current curves. For a given LED current, the forward voltage can vary with process and temperature. This means that the conversion efficiency from electrical battery power to light output can vary, while still maintaining constant brightness, since the latter depends solely on the current.

Efficiency is, therefore, not an adequate figure of merit to evaluate power consumption. What must be considered is battery current versus LED brightness, i.e. LED current. Input power is the true measure of how much energy is drained out of the battery for a given LED illuminance.

When a heavy load is applied to the battery, the open-circuit battery voltage is distorted by the voltage drop that is due to the internal impedance of the battery pack. The impedance of batteries is largely dominated by a number of parameters. Brand new Li-ion cells show an impedance in the approximate range of 50~70mΩ. The impedance is cell-dependent and can be expected to vary by 15% per production batch. The battery voltage keeps changing after application/ removal of the pulsed load (Relaxation

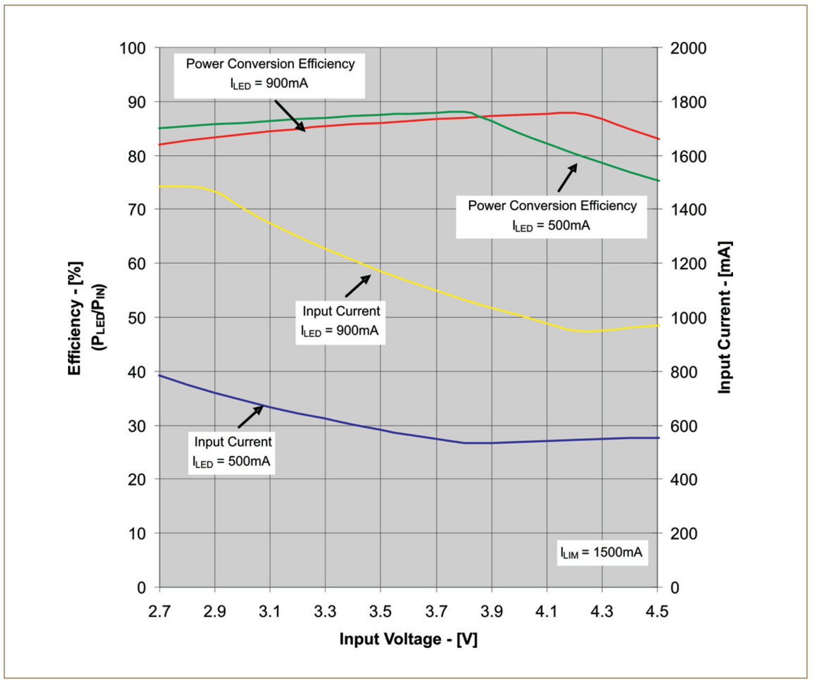

Figure 4: Efficiency versus input current curves

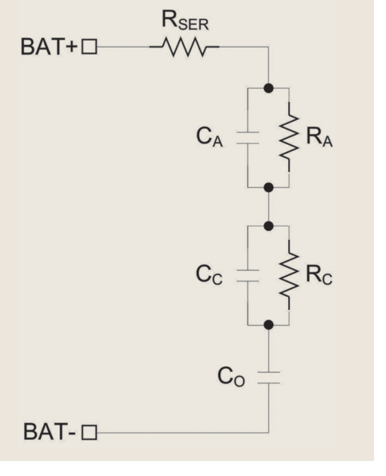

Figure 5: Battery equivalent circuit

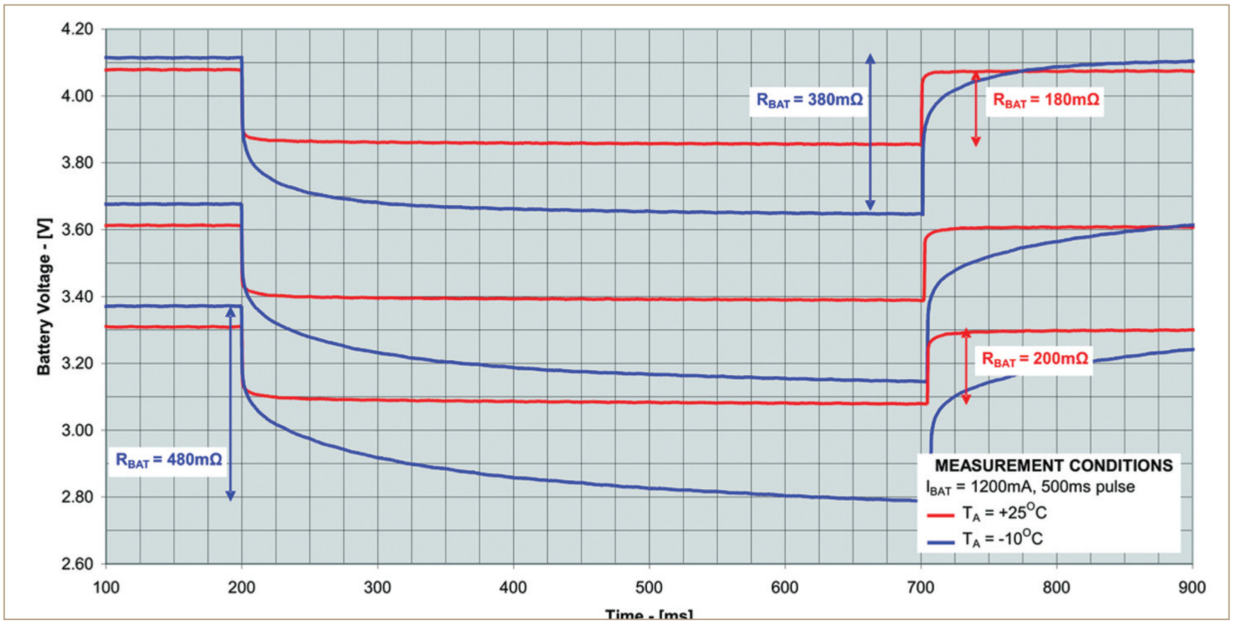

Figure 6: 900mAh, Li-Ion battery transient response versus SOC and temperature

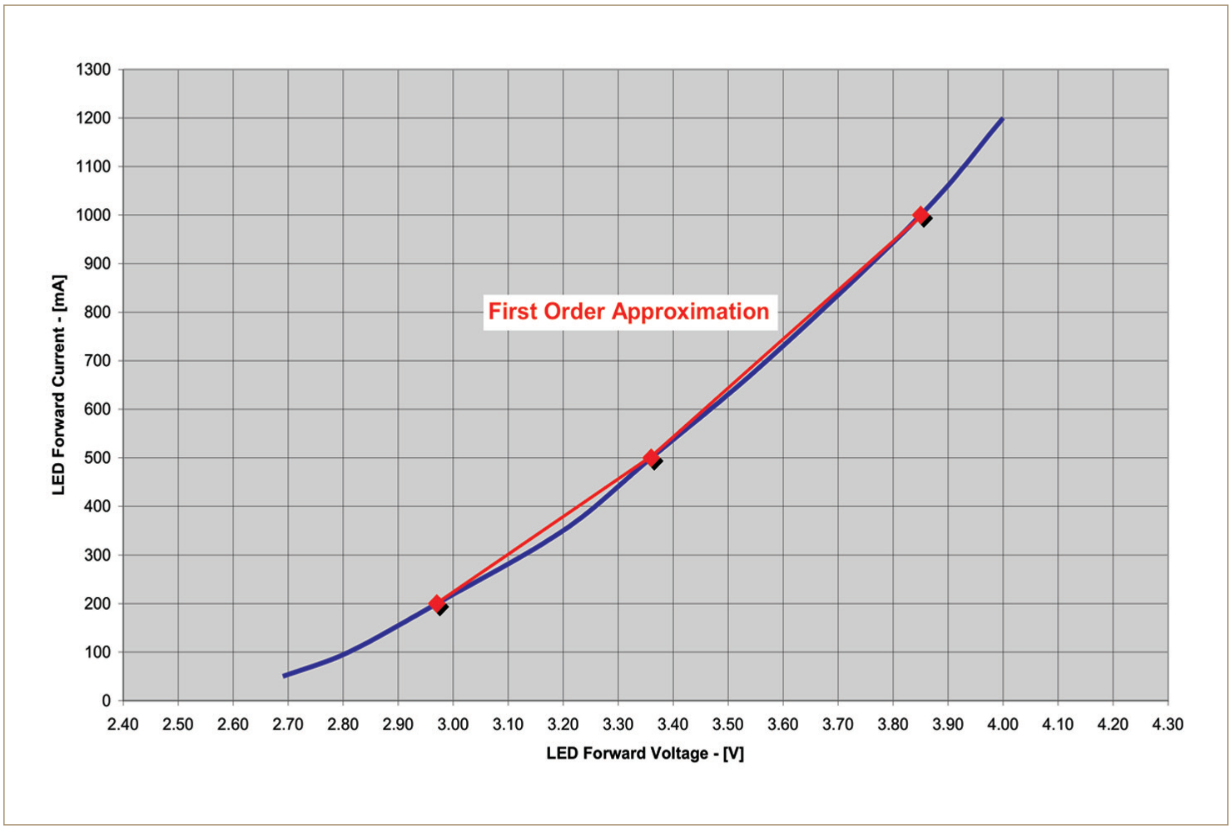

Figure 7: LED forward voltage approximation

Effect). The cell impedance exhibits a strong dependence to temperature and can increase by 50% every 10°C temperature drop. The internal resistance depends on state of charge (SoC) and increases at the end of discharge. Li-ion battery packs feature back-to-back protection MOSFETs that are in series with the cells. Their resistance is in the approximate range of 50~70mΩ. The battery pack is typically to hooked-up to the system via a couple of spring connectors, 25mΩ DC resistance each.

From an electrical point of view, batteries are often represented either as simply a voltage source, or as voltage source connected in series with a resistor representing internal resistance of the battery. To represent battery transient behaviour correctly, we should use an equivalent circuit rather than simple resistance.

When a battery is charged or discharged, its open circuit voltage changes, therefore it can be electrically represented as a capacitor with variable capacitance (C_O).

In Figure 5, R_A and R_C are summary diffusion, conduction and charge transfer resistances for cathode and anode correspondingly. C_A and C_C are surface capacitances. R_{SER} is serial resistance that includes electrolyte, current collectors and wires resistances. Each stage is associated with its own time constants, which causes complex electrical behaviour.

As seen in Figure 6, the battery voltage response to the current step is delayed, but after some time it approaches the behaviour of a capacitor with a serial resistor. After termination of current, the battery voltage does not immediately return to a no current state, but slowly increases until eventually it reaches the level of

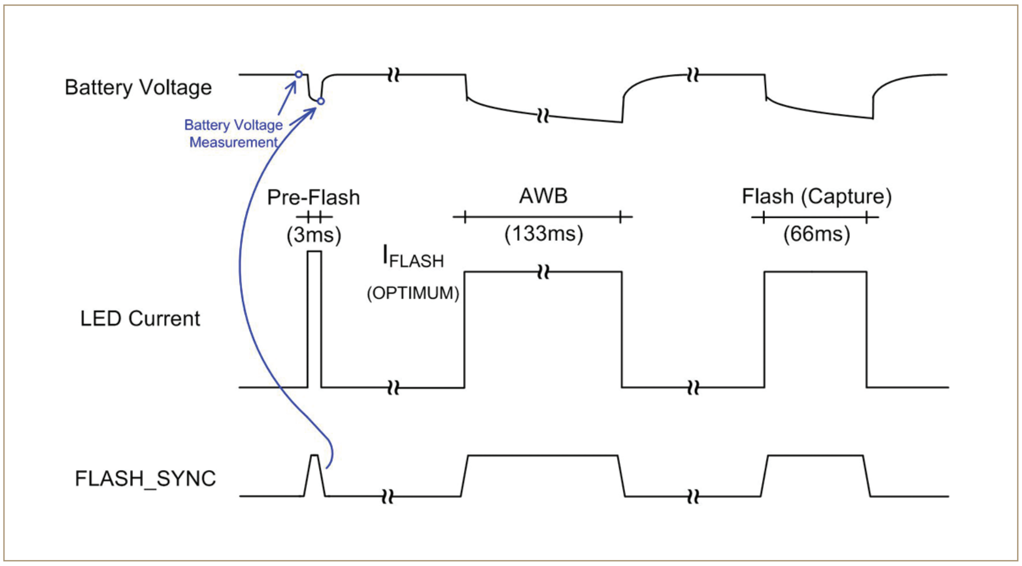

Figure 8: Image capture sequence with pulsed LED operation

equivalent capacitor voltage, which is the open circuit voltage.

Even when the battery holds insufficient capacity, the voltage drop across high internal impedance can cause the system to reach its cut-off voltage and the 'low battery' indicator to trigger. As a consequence, the mobile device is reset and/or stops working. This should be taken into account when calculating the camera engine cut-off voltage and the maximum LED flash current level.

In TDMA based systems like GSM/GPRS phones, the RF power amplifier (PA) also pulls high peak current from the battery. The TPS61050 device integrates a general purpose I/O pin (GPIO) that can be configured either as a standard logic input/output or as a flash masking input (Tx-MASK).

This blanking function turns the LED from flash to torch light, thereby reducing almost instantaneously the peak current loading from the battery. This system-level feature prohibits the phone from shutdown by avoiding two high-power loads (PA and flash LED) to be on at the same time.

LED flash current level optimisation

In cell phone applications, the camera engine is normally specified over an operating temperature range down to 0 or -10°C. In order to achieve a reliable system operation, the LED flash current would need to be rated according to the maximum tolerable battery voltage drop (i.e. highest battery impedance, lowest ambient temperature).

To optimise the LED flash current (i.e. light output) versus battery state-of-charge and temperature dynamically, we could consider the following self-adjustment procedure. This algorithm could be embedded into the auto-exposure, auto white-balance or red-eye reduction pre-flash algorithms.

A first order approximation of the LED forward voltage (V_F) can be achieved with the integrated 3bit A/D converter (see Figure 7). Simply perform three short flash strobes (a couple of tens of ms is enough) for three different flash currents (200mA, 500 and 1000mA). This data can help to estimate more precisely the actual LED electrical power versus flash current.

The battery voltage usually drops by a few hundred milli-volts during a high-power flash strobe. For short durations, this voltage drop should not be subject much to the battery intrinsic capacitance (i.e. relaxation effect) but more to its cell impedance (see Figure 8).

The camera and/or the base-band engines are usually capable of measuring the battery voltage before and at the end of a flash strobe. With this information, the system can compute the estimated battery impedance, defined as:

$$R_{BAT} \approx \frac{\Delta V_{BAT}}{I_{BAT}} ,$$

with

$$I_{BAT} = 1.15 \times I_F ,$$

linear down-mode operation ($V_F < V_{BAT}$)

$$I_{BAT} = \frac{1}{\eta} \times \frac{V_F}{V_{IN}} \times I_F \cong 1.25 \times \frac{V_F}{V_{IN}} \times I_F ,$$

boost-mode operation ($V_F > V_{BAT}$)

Based on the actual LED electrical characteristic, the mid-frequency battery impedance, state-of-charge and temperature information, the camera engine software can dynamically optimise the LED flash current to avoid the battery to collapse dangerously.