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Comparison of xenon flash and high current LEDs for photo flash in camera phones

The quality of camera phones is continually improving – more megapixels, better lenses, improved image-processing software, anti hand-shake features. The one area that has been lagging behind is the power and energy of the flash for taking pictures in low light. It is often in low light environments where people want to take photos to record the occasion, such as in restaurants, bars or nightclubs. Many cell phones have compromised by providing a low-current LED photo light or flash, which provides insufficient light energy for an acceptable photo in low light, as shown in Fig 1.

Fig 1: Photo taken in very low ambient light using a low current LED and 1W flash power. The girl is 2m from the camera. Note the colour reference chart beside the girl and how the colours are barely apparent.

Now, two solutions are emerging to provide a good photo flash in low ambient light:

– high current LEDs supported by a supercapacitor
– and xenon

This article will explore the limitations of existing LED flash implementations without a supercapacitor, and go on to compare LED flash with supercapacitor and xenon flash solutions. The comparison will be across multiple dimensions:

– light power and energy
– shutter requirements
– ease of circuit implementation
– safety
– size

Light Power vs Light Energy

The light power of a flash determines how bright it appears. Naturally, this is what draws most people's attention. However, what is important to a pixel in a camera sensor is the total amount of light it receives while it is capturing data. This is the light energy. For a flash pulse, this is the area under the curve of light power over time. If the light power is constant during the flash pulse, as is the case for LED flash, then the light energy is light power (lux) x the flash pulse duration (secs), and the unit is lux.sec.

- Xenon flash has fantastic light power, up to several hundred thousand lux, but a very short pulse duration, typically 50 – 100μsec.
- An LED Flash, with the support of a supercapacitor, can now generate upwards of several 100 lux with a flash pulse of up to ~100msecs.

This means the xenon needs to have 1000 to 2000 times the power of the LED Flash to deliver the same light energy. A major restriction on the light energy delivered by a xenon pulse is the size of the electrolytic 330V storage capacitor.

In this article we show the results of light power over time for:

- Three xenon camera phones, with varying size storage capacitors, the largest of which has an external xenon flash accessory
- Existing low-power LED flash
- A supercapacitor-based high-current LED Flash solution.

Integration of the area under the curves gives light energy available to fill pixels in the camera sensor and enables the relative merits of the two solutions to be objectively compared.

Limitations of LED Flash currently used in camera phones

The standard Flash driver is a boost converter in current control mode. There are many demands on cell phone batteries, so designers are loath to allow more than 800 - 1000mA to be drawn from the battery for LED Flash. Assume the battery voltage is 3.6V, the LED Forward voltage = 4.2V and the boost converter efficiency is 85%. Then, for 800mA battery current, the LED current = 0.8 x 3.6/4.2 x 0.85 = 580mA and LED Power = 2.4W. At this current, a typical high-current LED will only provide 7 – 8 lux at 2m distance from the scene[1]. If the camera sensor frame rate is 7.5 frames/sec, then the light energy per pixel = 7.5lux x 0.133s = 1 lux.sec. Figs 8 & 9 show that the light energy for a Nokia 73 with an image exposure time of 90msecs using a low current LED at 1W is only 1.7 lux.secs at 1m from the subject and 0.4 lux.secs at 2m. Most LED Flash phones today drive LED Flash @ 1W – 2W and provide < 4 lux.secs at 1m and < 1 lux.secs at 2m distance from the subject. Examples are the Nokia 6680, N70 and N73 which all drive their LED at 1W, and the SonyEricsson K750 which drives a pair of LEDs at ~2W total.

A good picture ideally requires 10 – 15 lux.secs of light energy. Until the advent of supercapacitors, a xenon flash tube was the only practical means of generating reasonable light energy, but this poses some problems for camera phones.

Xenon Flash

In a xenon flash, an electrolytic capacitor is pre-charged to 330V. This is then discharged across a tube filled with xenon gas to produce an intensely bright flash (up to several hundred 1000 lux at 1m) of very short duration (typically < 100μsec). A trigger circuit operating in the range of 4000 – 8000V is required to precipitate the gas discharge. The high energy stored at 330V is a safety concern, special care is required to prevent the high voltage trigger circuit from arcing to other circuits, and the electrolytic capacitor is bulky and difficult to fit in thin form factor camera phones.

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[1] Luxeon Flash PWF1 High Uniformity Option

Supercapacitor-based LED Flash

Using a supercapacitor to support LED Flash allows the battery to supply only the charge current to the supercapacitor while the supercapacitor provides all the LED current during the flash pulse. Supercapacitor-based LED flash drivers were recently detailed in Power Management Design Line, http://www.powermanagementdesignline.com/showArticle.jhtml?printableArticle=true&articleId=188100789 . Fig 2 shows a block diagram of a typical flash driver using a supercapacitor.

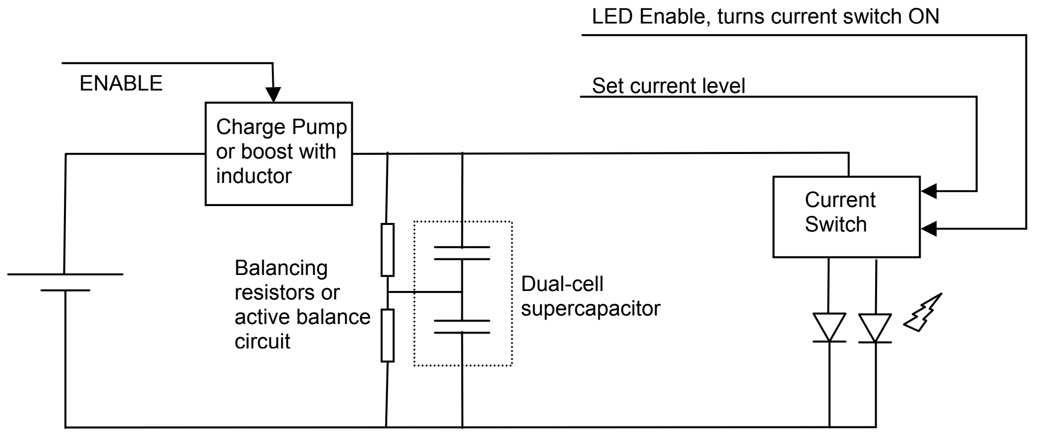

Fig 2: High Power LED Supercapacitor Solution Block Diagram

The current switch is shown on the high side, but can also be placed on the low side of the LEDs. The current level can be set to either fixed levels (say Torch and Flash), or the current level in flash mode can be set based on the ambient light to achieve optimum exposure for the picture. The supercapacitor has sufficiently high energy (high C) and sufficient power (low ESR) to supply the LED current for the flash pulse with little or no contribution from the battery. The battery charges the supercapacitor between flash photos. For example, if a 0.5F supercapacitor discharges 1V during the flash pulse, then it only requires 250mA charging current to recharge it in 2 secs to be ready for the next photo. Fig 3 shows flash current and battery current for a flash pulse driving 4 x Luxeon PWF1 LEDs at 1A each. Note that the battery current is limited to 300mA and the supercapacitor provides all the LED current during the flash pulse.

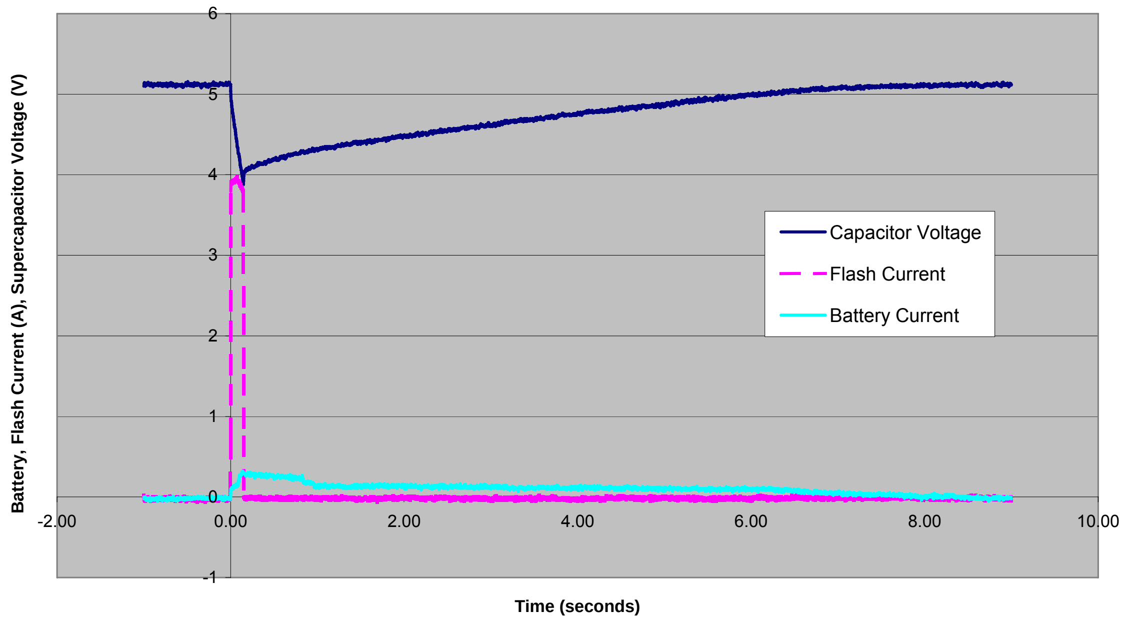

Fig 3: Supercapacitor provides 4A flash current while discharging from 5.2V to 4.0V. The battery only provides 300mA charge current to the supercapacitor.

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Comparison of light power and energy between xenon and LED flash

***Test setup**:*

We:

1. Used a calibrated photo detector to measure on axis illumination of various xenon and LED flash sources.
2. Captured light power over time at 1m and 2m distance from the source using a digital storage oscilloscope.
3. Then integrated the area under the power curves to measure the light energy at the detector as a function of time (or of the flash pulsewidth).

Fig 4 shows our test instrumentation being setup.

Fig 4: Dr Trevor Smith of CAP-XX setting up the light measurement equipment

***Light power over time**:*

Fig 5 shows the light power over time from various xenon sources at 1m and 2m respectively. The key points to note are:

The light power of the xenon flash is very intense, with the Sony Ericsson K800 delivering 205,000 lux peak power at 1m

- Light power measured at 2m is ≈¼ of the light power measured at 1m, which is as expected. For example, the light power for the SonyEricsson K800 at 2m is 53,000 lux compared to 205,000 lux at 1m
- The flash power and pulsewidth are traded off against the size of the electrolytic storage capacitor, described from largest to smallest size:
  - The SonyEricsson K750, which provides the xenon strobe as a large accessory that attaches to the phone when needed, uses a 60µF storage capacitor and at 2m distance generates nearly 100,000 lux with a pulsewidth (PW) of ~200µs,
  - The K800 has approximately half that capacitance (28µF) and only approximately half the light power at just over 50,000 lux with ~100µs PW,
  - The Gigabyte phone from Taiwan, uses a very small 15µF electrolytic and only generates 36,000 lux with a PW of ~50µs.

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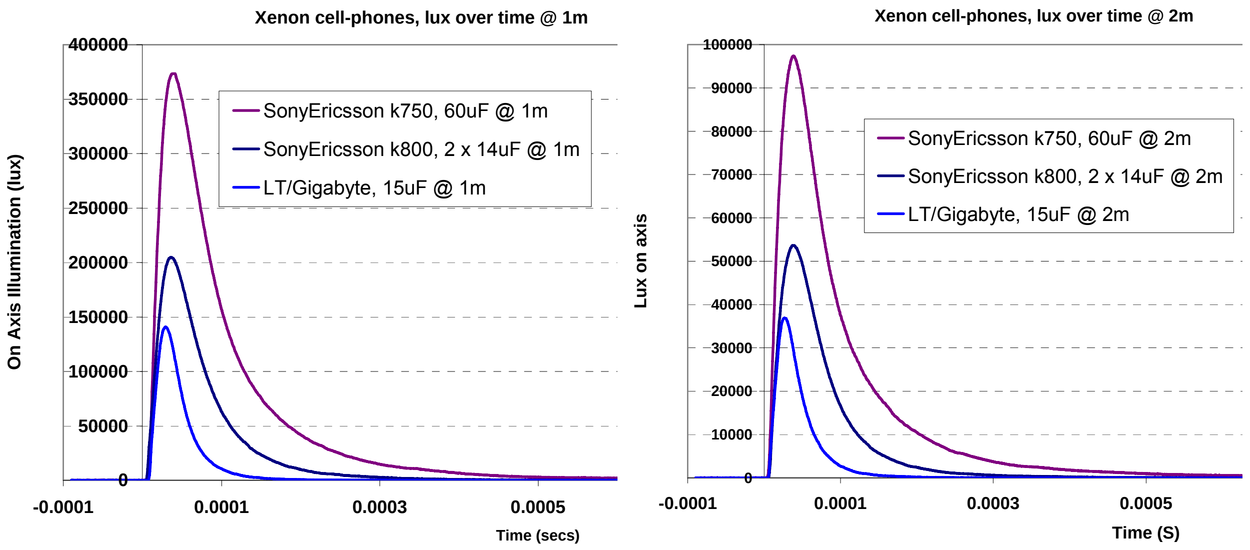

Fig 5: Light power over time for 3 different xenon sources

Fig 6 shows the light power over time for the latest high-power LEDs from the Luxeon Flash range. The graphs show 4 and 2 high-current LEDs with optic at 1m and 2m distance. The supercapacitor drives the LEDs at 1A each, i.e. 4A total for 4 LEDs.

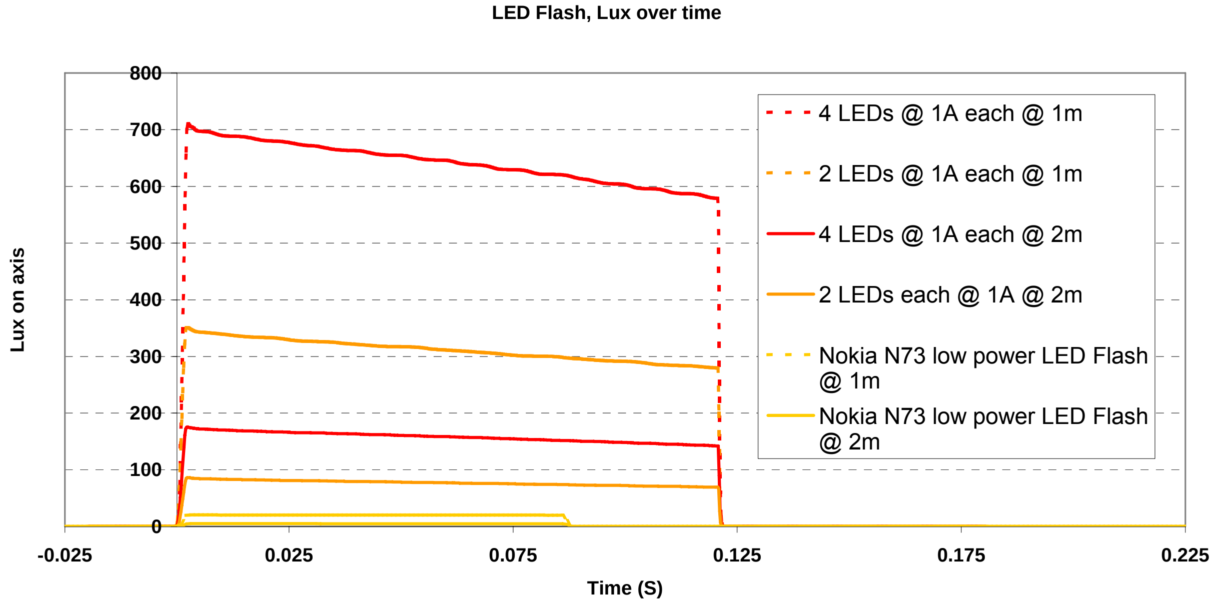

Fig 6: Light power over time for LED Flash

The key points from Fig 6 are:

- As per the xenon power graphs, the power measured at 2m distance for all cases is ~¼ the power measured at 1m.
- LEDs can deliver approximately constant light power for long flash pulses, allowing their use with a CMOS sensor rolling shutter with no mechanical shutter added to the camera-phone. The LED light power decreases slightly during the flash pulse

due to heating. Starting with a slightly lower LED current and ramping up the current during the pulse can compensate for this.

- Standard LED Flash, in this case the Nokia N73, barely registers on this scale. The 1W electrical power only delivers 16 lux at 1m, compared to ~300 lux for 2 high-power LEDs @ 1m.

Key parameter is light energy:
Figs 5 and 6 compared light power over time. However, as previously explained, the key parameter is light energy, not light power.

Fig 7 shows how light is captured by a CMOS sensor with a rolling shutter. A frame is made of N lines each with M pixels. Each pixel of a line is reset, and then sometime later each pixel is read. The voltage read from each pixel is proportional to the light energy that has accumulated in the pixel in the time between the pixel was reset and the pixel was read. That light energy is the light power integrated over that time, shown in Figs 8 and 9. When all pixels in the N lines have accumulated light energy for the same period of time, a frame has been captured. As shown in Fig 7 this occurs in a period of twice the frame interval. If the frame rate is 15 frames/sec, then the image is captured in 2 x 1/15 = 2 x 66.7ms = 133ms. Each line has captured light energy (integrated light power) for 66.7ms. An LED Flash can provide constant illumination for the image capture period and can be used with a rolling shutter. It is possible to control the LED current (and hence light intensity) based on the ambient light measured. This will provide correct light exposure for the image. Alternatively, the line exposure time can be reduced. The frame rate will remain the same, but each line may only collect data for say 20msecs instead of ~66ms.

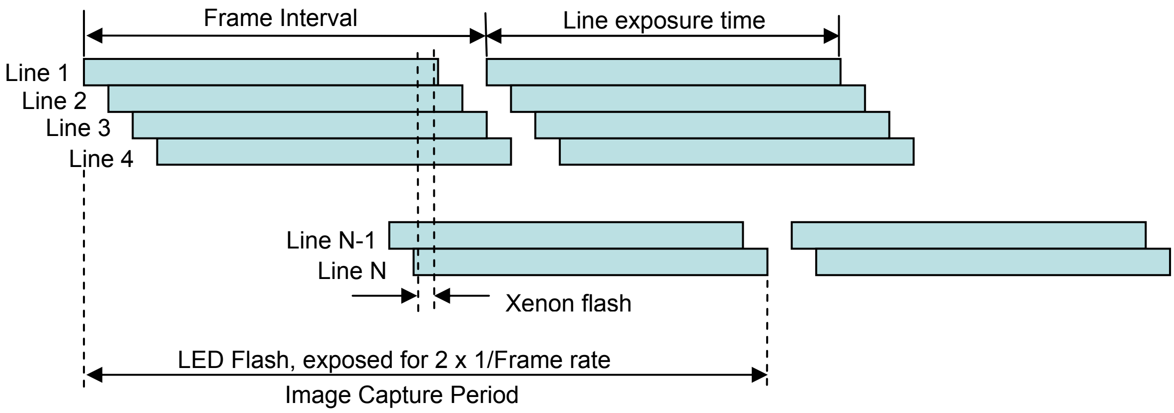

Fig 7: Light capture in a CMOS sensor

A xenon flash only lasts a fraction of a millisecond. Therefore it must be timed to strobe on the few millisecond period when all N lines are capturing light. The xenon circuit usually includes a photo detector that shuts the xenon down when sufficient light has been gathered to prevent over exposure. However, ambient light is still captured by each line in the period outside the xenon flash pulse. For Line 1 this period will be for just less than 66.7ms before the xenon strobe and for Line N for a few ms less than 66.7ms after the strobe. To prevent this ambient light from overexposing the image, a mechanical shutter is necessary.

Figs 8 and 9 show light energy for xenon and LEDs at 1m and 2m distance from the detector respectively. The charts have a logarithmic timescale so that the very short xenon pulses and longer LED flash pulses can be displayed on the same graph. They are the integral of the light power charts shown in Figs 5 and 6 and reflect the light a CMOS sensor would capture.

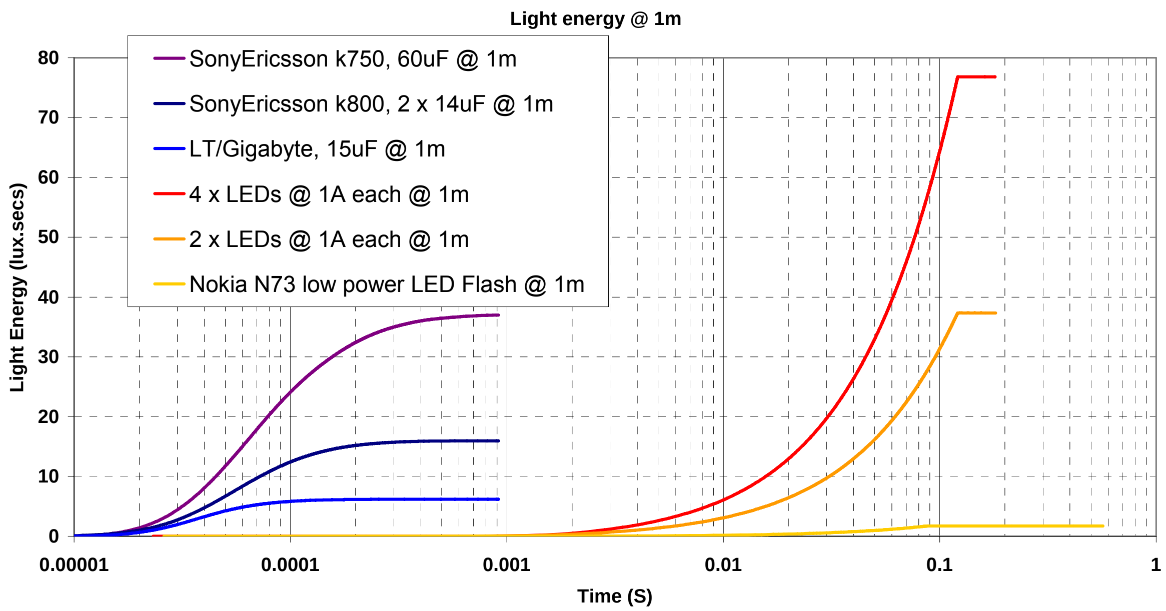

Fig 8: Light energy @ 1m for xenon and LED Flash

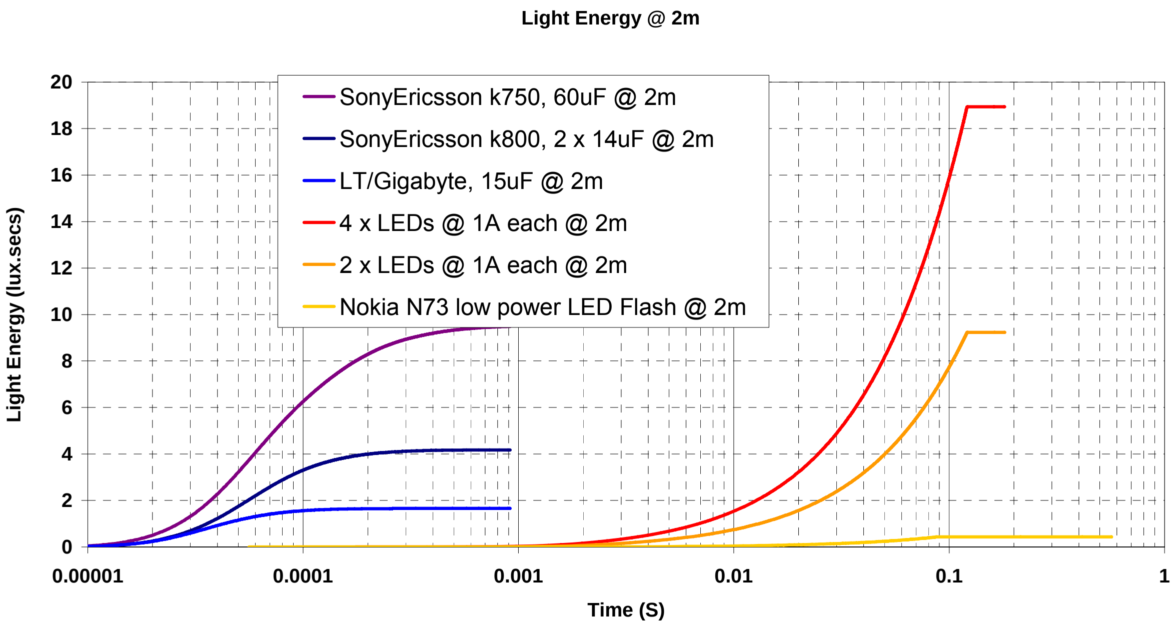

Fig 9: Light energy @ 2m for xenon and LED Flash

The light energy for a xenon flash can be read from the final value shown on the charts at 900µsecs. All this light energy will be captured by the CMOS sensor within the period labelled “Xenon flash” in Fig 7. The light energy for LEDs for a given exposure time of a line in a CMOS sensor can be read from the charts, e.g. at 1m distance, the 2 LEDs case has 10 lux.secs for 30ms exposure, 22 lux.secs for 67ms exposure and 32 lux.secs after 100ms exposure. Table 1 below tabulates light energy and power for various cases.

Table 1:

Source	**Storage Capacitor**	**Distance (m)**	**Peak Light Power (lux)**	**Exposure Time (msecs)**	**Light Energy (lux.secs)**
Xenon, SonyEricsson K750	60µF	1	370,000	<1	37.0
Xenon, SonyEricsson K800	2 x 14µF	1	203,000	<1	16.0
Xenon, Gigabyte cell phone	15µF	1	139,000	<1	6.2
4 x LEDs @ 1A each	0.55F	1	708	17	10.8
				33	21.9
				67	43.7
2 x LEDs @ 1A each	0.55F	1	349	17	5.3
				33	10.9
				67	21.4
Nokia N73 LED Flash	NA	1	20.0	90	1.71
Xenon, SonyEricsson K750	60µF	2	97,000	<1	9.5
Xenon, SonyEricsson K800	2 x 14µF	2	53,000	<1	4.2
Xenon, Gigabyte cell phone	15µF	2	36,000	<1	1.7
4 x LEDs @ 1A each	0.55F	2	175	17	2.7
				33	5.4
				67	10.8
2 x LEDs @ 1A each	0.55F	2	86	17	1.3
				33	2.7
				67	5.3
Nokia N73 LED Flash	NA	2	5.0	90	0.43

Points to note from table 1 are:

- 4 LEDs with a line exposure time of 67ms (CMOS sensor frame rate of 15/sec) deliver 18% more light energy than the SonyEricsson K750 with a xenon attachment that included a 60µF electrolytic capacitor.
- 2 LEDs with a rolling shutter and a line exposure time of 67ms (CMOS sensor frame rate of 15/sec) deliver 34% more light energy than the SonyEricsson K800 xenon flash with a 28µF storage capacitance.
- 1 LED driven at 1A with a rolling shutter running at 15 frames/sec would deliver 75% more light energy than the small Gigabyte xenon flash with a 15µF storage capacitance.
- The standard low-current LED Flash, using the Nokia N73 camera phone with a 90ms flash pulse as the example, generates much less light energy than the other solutions, i.e. 8% of the light energy produced by 2 high-current LEDs with a 67ms flash pulse and 11% of the light energy generated by the SonyEricsson K800.

- 2 LEDs with a line exposure time of only 17ms deliver 85% of the light energy delivered by a xenon flash with a 15µF storage capacitor – i.e. enough light for a photo of comparable quality. Some CMOS sensors have a frame extension capability, where the line exposure time is extended and the following frame is dropped. The period labelled as "Xenon flash" in Fig 7 can then be expanded, enabling an image capture time of 17ms. This is short enough (1/60th of a second) to eliminate photo blurring due to handshake by the photographer. Like xenon, this solution would also require a mechanical shutter.
- Similarly, 4 LEDs with a line exposure time of 17ms deliver 75% more light energy than the 15µF xenon flash, and 67% of the light energy from the SonyEricsson K800 phone with 28µF storage capacitance, enabling high quality photos to be taken with a short exposure time and mechanical shutter

Note that while an image capture time in the order of 67ms – 133ms for a rolling shutter is relatively long and may suffer if the photographer's hand moves, there is now image-processing software that removes much of the blurring due to hand movement. A xenon strobe, with its very short exposure time, will always be superior for capturing fast moving action shots in low light. However, most photos taken with camera phones in low light are of friends posing at parties, a nightclub etc. where movement is not an issue and image-processing software can correct for a photographer's hand movement.

Fig 10 shows a photo taken under the same conditions as Fig 1. Fig 10 used a Nokia 6680 modified by CAP-XX with a supercapacitor to drive 4 x PWF1 LEDs. Note how the girl's face is now filled in rather than shadowed and colour chart now shows good colour rendition.

Fig 10: Photo taken in the same conditions as Fig 1 using the same camera phone modified with a supercapacitor to drive 4 x PWF1 LEDs at 0.9A each for a total flash power of 15W. The girl is no longer shadowed and the colours in the colour reference chart beside her are clear compared with Fig 1, which was taken using low power LED flash.

Comparison of solution size and energy density

The key advantage of LED Flash over xenon in camera phones is size. Fig 11 compares the electrolytic capacitor used in the SonyEricsson K800 and the supercapacitor used for the LED Flash. Note that the SonyEricsson K800 uses two of these electrolytic capacitors each measuring 7mm dia. x 18mm long. Similarly, the LED Flash solution uses two of these supercapacitors measuring 17mm x 39mm x 1.1mm side by side to keep the solution very thin.

Fig 11: Size comparison between cylindrical electrolytic storage capacitor used for xenon flash and thin prismatic supercapacitor used for LED Flash.

The electrolytic capacitors prevent the camera phone from having a thin form factor. Fig 12 shows the two electrolytics fitted in the K800 and the electrolytic and supercapacitor in profile next to the K800. Xenon solutions with smaller electrolytic storage capacitors, for example the 15µF used in the Gigabyte phone, compromise the light energy delivered. In this case, the Gigabyte delivers only just over ⅓ the light energy of the SonyEricsson K800 with 28µF storage capacitance and delivers just over 40% less light energy than 2 high power LEDs @ 1A LED current with a line exposure time of 33ms or 1 high power LED @ 1A LED current with a 67ms line exposure time.

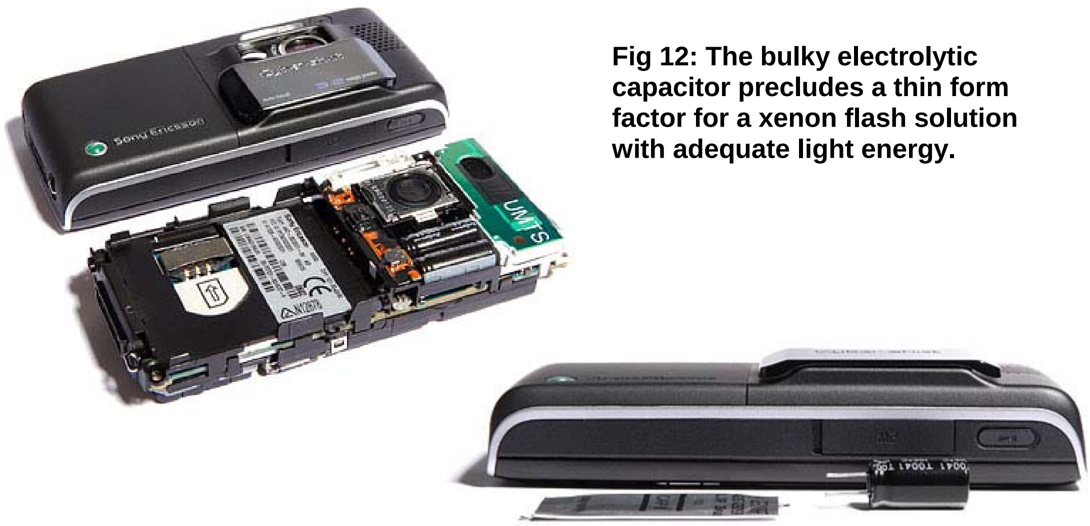

Fig 12: The bulky electrolytic capacitor precludes a thin form factor for a xenon flash solution with adequate light energy.

Table 2 compares the energy density between the electrolytic capacitors in the K800 and supercapacitors.

Table 2:

	Electrolytic Capacitor	Supercapacitor
Capacitance	2 x 14µF = 28µF	1.1F/2 = 0.55F
Energy storage	½ x 28µF x (330V^2 –100V^2) = 1.4J	½ x 0.55F x (5.5V^2 –4.5V^2) = 2.75J
Dimensions	(2) x 7mm dia. x 18mm long	(2) x 17mm x 28.5mm x 1.6mm
Volume	1.76cc (effective)[2]	1.55cc
Energy density	0.785J/cc	1.774J/cc

Comparing energy storage and voltage

For xenon flash, the storage capacitor is charged to 330V and discharges to ~100V at the end of the strobe. In LED flash, the supercapacitor is charged to 5.5V and discharges to

[2] The gap between a circle of dia 7mm and square with 7mm side is not usable volume, so the effective area is calculated as 7mm x 7mm x 18mm

~4.5V at the end of the flash pulse. The electrolytic capacitor has high energy storage by virtue of its high voltage, which poses some safety issues. The supercapacitor, on the other hand, has high energy storage due to its enormous capacitance and operates at low voltage with no safety issues.

The key messages from table 2 are that the supercapacitor stores approximately double the electrical energy of the electrolytic capacitor and has double the energy density, or energy stored per unit volume.

Comparison of other attributes between xenon and LED flash
Table 3 compares all attributes of xenon and LED flash.

Table 3:

Xenon	LED Flash with Supercapacitor
Bulky: – Large electrolytic storage capacitor – Total volume of xenon solution in SonyEricsson ~3.8cc	Thin, < 2mm – Typically < 2cc
Drop test problems: – Xenon tube – Electrolytic – connection to flex PCB prone to fracture due to large mass of capacitors and flimsiness of PCB	No drop test problems: – No large mass – No fragile parts
Safety: 1.5J of energy stored at 330V can give a nasty shock, particularly near the ear.	Low voltage, no safety issues
High Voltage (HV) trigger circuit needed for xenon flash tube, > 4000V. Special measures and/or clearance is required to prevent arcing to other circuits.	No HV, no special steps to prevent arcing to other circuits.
Requires mechanical shutter: extra cost, size & current	Can use rolling shutter with no mechanical shutter
Hi voltage and current pulse for xenon strobe causes Electro Magnetic Interference (EMI)	High current delivered from supercap, EMI easier to manage
Still need a separate LED for video/torch mode	Same LEDs used for flash and video/torch
Long time to re-charge electrolytic capacitor between photos (~8s for SonyEricsson K800)	Short time to re-charge supercapacitor between photos (~2s)
Electrolytic capacitor cannot be used for any other peak power needs	Supercapacitor can be used to meet all peak power needs in the cell phone including: – Flash pulse – RF Transmission for GPRS – Audio – HDD for storing audio & video
Very high powered light delivered in < 200µsec: – No photo blur – Can take an action shot in low light	Light energy delivered over longer time: – Capable of high-quality still shots, but cannot take action shot in low light (but who tries to with a camera phone?) – Image stabilisation software corrects for hand movement

Supercapacitor can meet all peak power needs in the mobile phone
A key point in Table 3 is that the supercapacitor can meet all the mobile phone's peak power needs, not just LED Flash. Fig 13 shows a possible power architecture to achieve this.

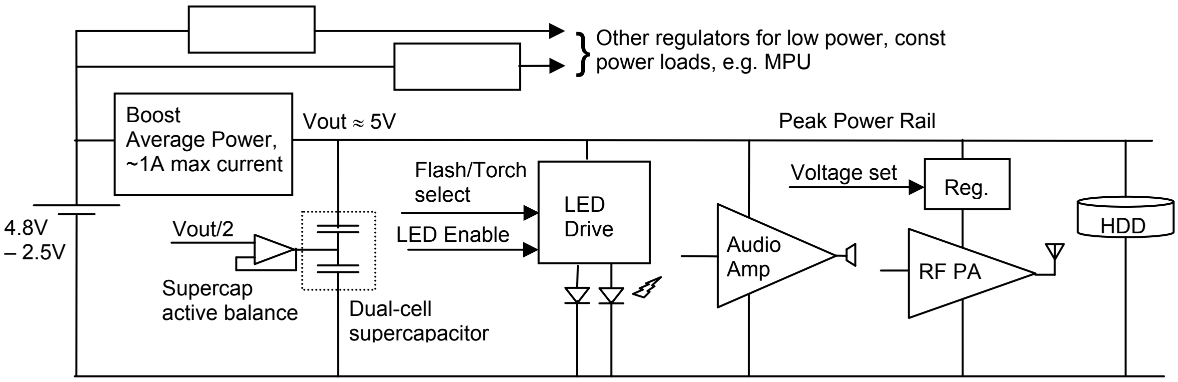

Fig 13: Possible power architecture for a mobile phone with a supercapacitor

The boost converter supplies average power to the supercapacitor. The supercapacitor can then supply peak power needs simultaneously to all the high power loads.

RF Amplifier
For example, the supercapacitor can supply the 2A peak current for 0.577ms to the RF PA to respond to a network poll during a 2A 133ms LED Flash pulse. The RF pulse would only discharge a 0.5F supercapacitor by 2.3mV. The supercapacitor also prevents excessive battery voltage droop during the RF pulse. This extends talk time and enables operation in sub 0°C temperatures outdoors.

Audio Amplifier
Similarly the supercapacitor could support the audio amp to drive high power audio (>5W) without requiring that the audio power supply be gated by the RF transmit pulse to ease the strain on the battery. The supercapacitor will "stiffen" the audio power rail to eliminate any noise from fluctuations in the audio amp power supply. Similarly, the supercapacitor will eliminate any noise reflected into the audio from power transients from the RF Amplifier, in particular any 217Hz buzz during from the GPRS frame frequency phone conversations.

Conclusions
This article has compared the performance and other key attributes of xenon and high power LED flash with a supercapacitor for use in mobile phones. With a rolling shutter the light energy generated by LED flash exceeds most xenon flashes. LED Flash is now approaching brightness levels so that frame extension can be used to capture an image in 1/60 sec. With supercapacitor-based LED Flash comparable to xenon in light energy, other attributes of the supercapacitor solution make this more attractive for use in mobile phones, most notably the thin form factor which enables a flash unit < 2mm thick. Finally, unlike the electrolytic storage capacitor for xenon, the supercapacitor can be used to meet all the peak power needs of the mobile phone including the RF Power Amp and the audio amplifiers to enable the phone to drive higher power high quality speakers.

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