WHITE PAPER

Flash for “Selfies”

An overview of illuminance requirements and why shorter flash pulses are the preferred solution for front flash

Introduction

Smartphones are ubiquitous in everybody’s daily lives, a trend that shows no sign of slowing. A key component of the smartphone is the camera, which has gained market share over Digital Still Cameras due to its convenience.

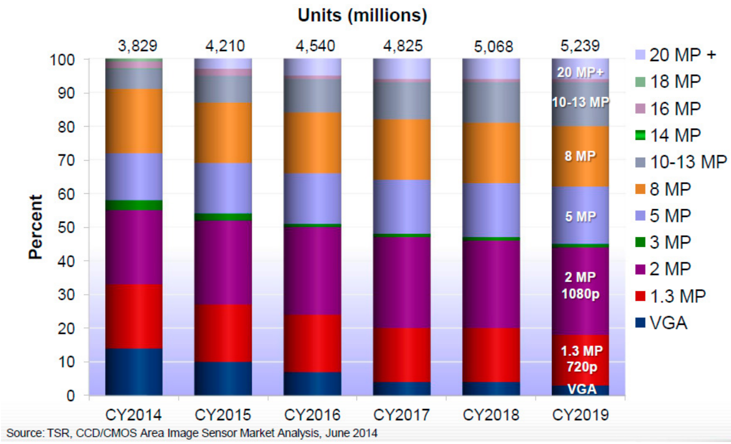

Figure 1. Expected market share of different image sensor resolution.

As the demand for smartphone cameras increases, sensor makers are continuously working to improve the resolution, as demonstrated by Figure 1. And while 20MPix capability gained in importance for the main camera of the smartphone, the resolution race has begun for the front camera. With the rise in popularity of “selfies” and the 5 to 8 Mpix resolution for the front camera (see Figure 2), it is not surprising that camera flash is starting to be more readily implemented for front cameras also. However, to make a successful front flash that captures an ideal “selfie,” there are certain illuminance requirements and shorter flash pulses that are recommended.

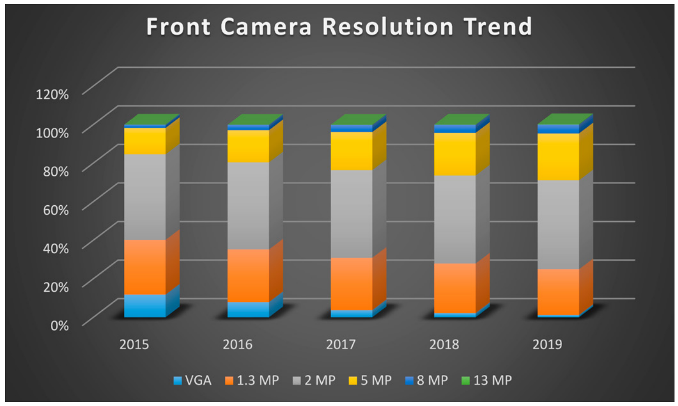

Figure 2. Expected market share of different sensor resolution in smartphone camera.

Illuminance Requirements

In low ambient lighting conditions, the camera flash needs to supply the illumination for the scene of the picture. The camera's lens makes an image of the scene with the light reflected by the different scene objects.

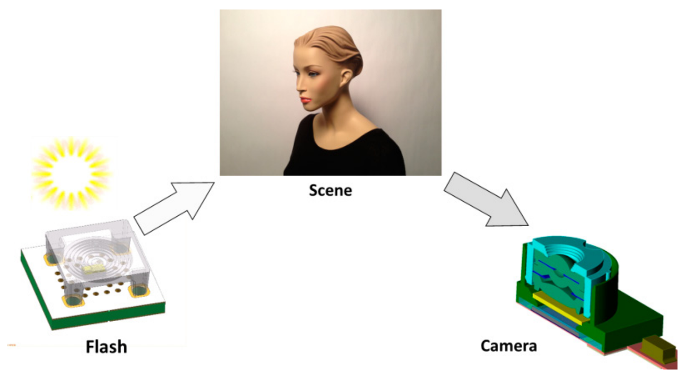

Figure 3. Light path flash to camera.

Imaging means that each pixel has a spatial correlation to a defined area of a scene. Each pixel thereby receives reflected light from that area in the scene, after passing through the lens and different filters. This light is absorbed by the sensor pixel and converted into electrons and transferred as 'charge packages' per exposure time for further (electronic) processing.

The pixels signal will thereby be proportional to the light dose per area—which is illuminance, multiplied by the integration or exposure time:

$$\text{Signal}_{\text{Sensor}} \propto \text{Illuminance}_{\text{Scene}} \cdot \text{Pixel area} \cdot \text{Exposure time}$$

To define the necessary light dose, the first decision to make is the targeted signal-to-noise ratio (SNR). Noise contributors include shot noise (proportional to $1/\sqrt{\text{number of photons}}$), electronic noise (amplifier), A/D noise (number of bit levels) and dark noise in the camera path.

Typically, the total SNR is determined by the level of shot noise. Shot noise can be improved by increasing the number of photons hitting each pixel. The following parameters are crucial:

- Pixel size (the number of photons collected is proportional to the pixel area)
- Sensor construction—the newer backside illumination (BSI) sensors use the complete available area by having the light sensitive area at the top of the sensor and the metallization layers below.
- The so-called F-number (F#) of the camera lens which is the lens focal distance f divided by the lens diameter. The signal will decrease inversely proportional with the square of F#, as the amount of light collected and illuminated spot size at sensor position will increase with the square of F#.
- Exposure time—increase of this will increase the SNR. The maximum exposure time, however, is limited by the maximum time the camera can be held still without image blur due to handshaking (without tripod). A general rule of thumb advises to keep the shutter speed [expressed in seconds] smaller than 1/focal length [in mm-1]. For phone cameras, this rule of thumb's maximum exposure time falls in the 30ms. The time can be prolonged (factor 2 and more) by image stabilization/ shake reduction technologies.
- Transmission of the complete camera lens system and filters in the camera's light path.

Performing the calculations of sensor signal to expect for F# of 2.4, integration time of 50ms and pixel size of 1.4um, an illuminance of 100lux (or 5lux.s) on scene produces an SNR on the picture of about 36dB—which is considered a good SNR. Note that with the increasing resolution race, the pixel size reduces further, regardless of resolution. To compensate the increasing light thirst of these smaller pixels (1.1um=1.6 more light needed compared to 1.4um), the F# goes down, too: numbers of 2.2 now 1.9 are on the market (with a F# of 1.9 we gain back a factor of 1.6 in light sensitivity compared to F#2.4). In case these factors do not go hand in hand, the illuminance of 100lux should proportionally increase.

In the case of a dim environment, the camera flash needs to supply the targeted illuminance for the requested time. The illuminance must be realized over the complete field of view (FOV) of the camera with only gradual decrease towards the borders of the scene (keeping the maximum illuminance for the center where the subject is in general located at). While the necessary illuminance for the camera is the same, independent of the distance of the camera to the scene (as the scene is imaged), the flux requirement will increase with the square of the distance between flash and scene in order to achieve the average illuminance of the scene. The maximum user distance will define how much flux is needed from the flash. For instance, for the front facing camera, the user distance will be about arm length, or about 0.5m. (For the rear camera, the user distance will be 1m or more. With a target distance of 1m, the rear camera flash will have to deliver already 4 times as much light.)

Due to the always decreasing thickness of smartphone builds, the FOV increases. For front cameras, FOV around 80° are common. For these larger FOV, the camera flash optics must make the beam slightly broader than a bare LED's Lambertian radiation pattern. The on-axis illuminance per LED flux will be at best close to 0.3lux/lm in typical smartphone geometries.

Therefore, to achieve a target of 100lux at a distance of 0.5m, the necessary flux out of the LED will be around 80lm.

Glare

A particular point of attention is glare sensation caused by the flash. As the person taking the picture needs to closely look back at the phone and screen to check the settings, the torch and flash light can cause discomfort in some cases.

The position of the flash and time can have an effect on glare impression:

1. Use indirect flash light: As in the photographer's studio, a flash light pointing to studio walls and the ceiling to create an "ambient" lighting rather than a direct flash illumination. For the front facing camera, the situation around the subject is not as controlled as in the studio, not to mention that ceilings and walls may not be present.
2. Use shorter flash pulses: In a paper from Ronald Gibbons and Christopher Edwards, "A Review of Disability and Discomfort Glare Research and Future Direction," the effects of glare in traffic situations was summarized. The article cites Lehnert and his investigation that a shorter flash light as generated by a vehicle bounce can result in lower glare sensation than longer duration of the same illuminance. The equation given is:

$$W = 10.6 - 1.7 \cdot log_{10}\left(\frac{E_{max}}{0.0318}\right) \cdot log_{10}\left(\frac{t_{pulse}}{0.0064}\right)$$

where:

W is the mean value on deBoer's scale;

E_{max} is maximum level of illumination in the observer's eye [lux] and

t_{pulse} is the duration of the light pulse[s].

The deBoer scale is a qualitative scale as shown in the following table:

Table 1. DeBoer scale.

DEBOER AND SCHREUDER SCALE (W)	
1	Unbearable
3	Disturbing
5	Just admissible
7	Satisfactory
9	Unnoticeable

A light dose is the product of illuminance and pulse length. To achieve the same given light dose of 5lux.s, there is a trade-off between the values of illuminance and time: when choosing a lower illuminance, the time must be longer and when going for a higher illuminance, the time can be shorter.

Figure 4 shows how this choice impacts the glare sensation: the shorter pulses result in a higher (=less glary) deBoer rating. This will still give pictures with the same SNR as long as the LED flash allows high current pulses for high maximum illuminance values during the short flash pulse.

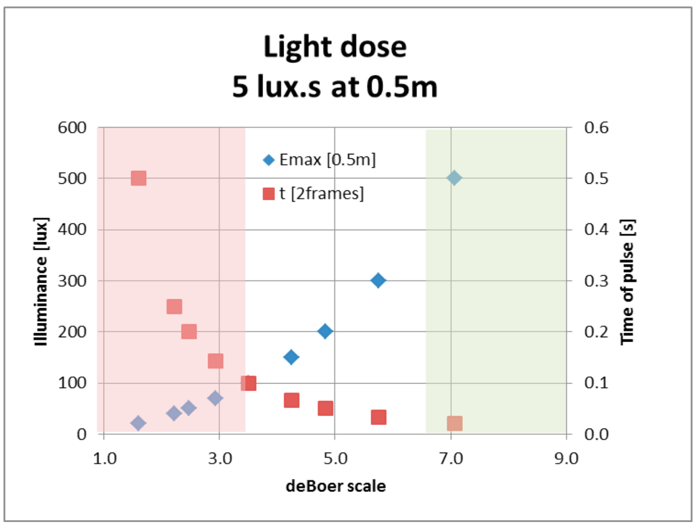

Figure 4. Illuminance and pulse length for constant light dose vs. deBoer scale.

One more thing is taken into account in Figure 4. The current complementary metal-oxide-semiconductor CMOS sensor has a so-called rolling shutter—the sensor is read out line for line, one after the other. While one line is read out, the others are open and collect light, either for the current frame or the one before (a frame is the time for a complete picture (all lines of the sensor) to be exposed and read out). After each frame read-out, there is a short pause where all lines of the sensor are exposed, called frame blanking (in the case of maximum integration time as in dim environment). Because the individual lines of the sensor are read out sequentially, all pixels within the same line are exposed at the same moment in time; pixels from one line compared to another, however, are exposed at different moments. The further away the lines with respect to another on the sensor, the more the moment of exposure are shifted in time with respect to each other.

Thus, the consequence for flash timing is this—the long flash pulse must be applied over 2 frames to make sure all lines receive the same light dose, while the short flash pulse must be applied within the frame blanking period. This means that using the frame blanking for flash allows already an improvement in the deBoer scale of about 1, as the full pulse is used for exposure instead of only ½ the pulse. Also, the maximum frame rate gives a lower limit to the pulse length of the camera flash (30fps ~ 33ms), while frame blanking does not know this limit. Moreover, there is no restriction to the pulse shape, as all pixels integrate at the same time. Last, by reducing the exposure time, motion blur in pictures with moving objects is reduced.

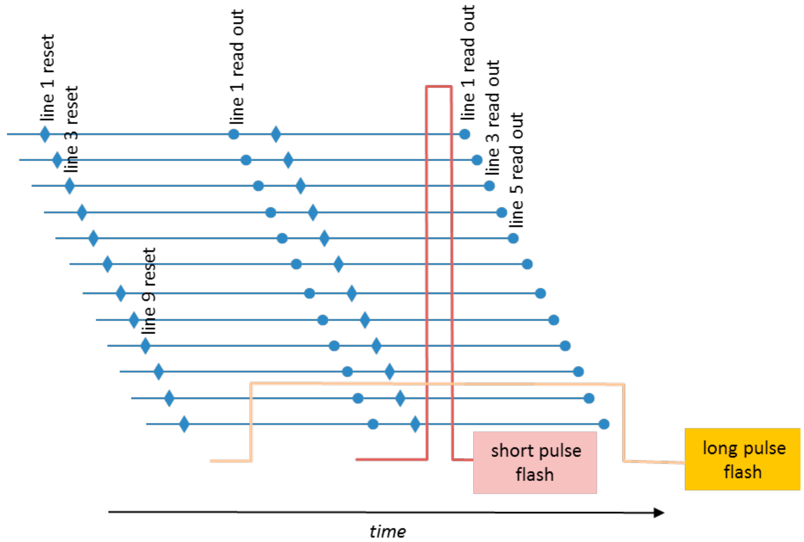

Figure 5. Rolling shutter time sequence with integration times and readout.

For a side by side comparison, starting again from the target light dose of about 5 lux.s

Table 2. Side by side comparison of long vs. short flash pulse.

PARAMETER	LONG PULSE	SHORT PULSE	UNITS
Distance	0.5	0.5	m
Exposure Time	0.067 [1]	0.015	s
Illuminance at Distance	70	315	lux
Realized Dose	4.8	4.7	lux.s
Pulse Time [2]	0.25	0.015	s
W (deBoer glaring index)	1.53	8.09	
Pulse Shape	Constant amplitude	Free	
Motion Freeze	None	Factor ≥5 improved	

Notes for Table 2:
1. 67ms for 15fps; handshake 30ms with stabilization.
2. Measured pulse width of smart phone about 4x exposure time.

Demonstrator

To test the effect of the length of flash pulse, we have built a demonstrator:

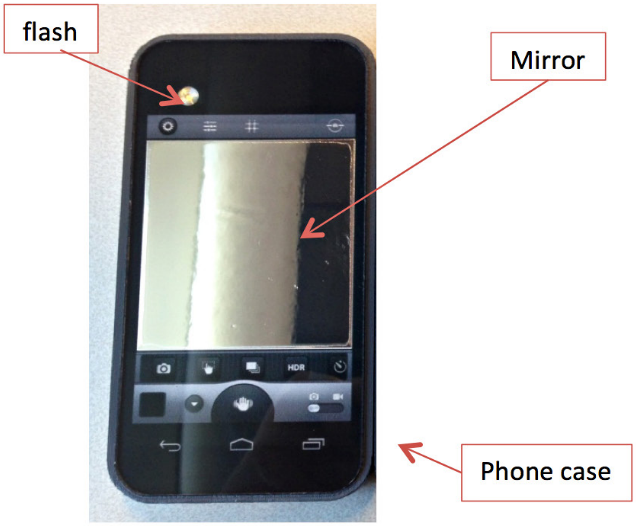

Figure 6. Camera flash for selfie demonstrator.

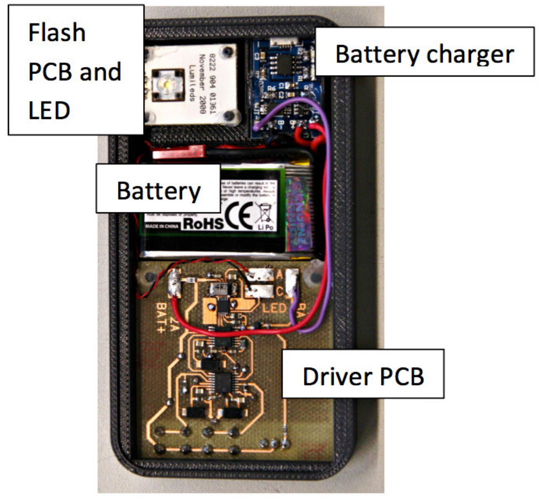

Figure 7. camera flash for selfie demonstrator (inside).

The driver has two modes, selectable with push buttons:

- A 250ms long low power pulse (175mA) and
- A 15ms short high power pulse (1A).

The longer pulse time was chosen from pulse lengths measured in flash sequences in a dark environment on existing smartphones. According to the 10 people who were asked to test this out in a dim environment (as necessary for using the flash), the shorter pulse was always deemed less disturbing than the long flash pulse.

To verify the equivalence of the light dose of the two flash pulses, a smartphone was prepared with a photodiode covering the smartphone's camera flash. This diode can pick up the flash signal from the phone and be a trigger for the two cases of the 250ms long pulse (same as the flash sequence in smartphones) and the 15ms short pulse. The short flash pulse was delayed with respect to the frame flash trigger until it fires within the frame blanking.

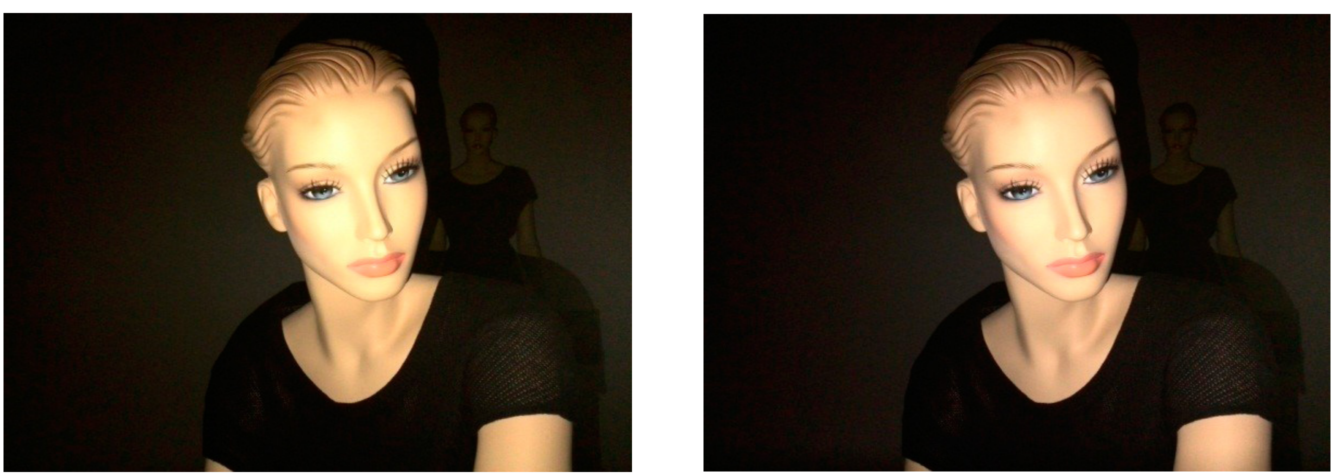

Figure 8: Pictures taken with long (250m, left) and with short (15ms, right) flash pulse.
Light dose about 5.5lux.s for left and 5lux.s for right picture.

For the implementation in a phone, the synchronization signal must come from the camera to precisely fit the moment of flashing with the frame-blanking period. As with any picture taken with flash, pulse amplitude and/or pulse length should be adjusted to optimize exposure level. The flash sequence could be 1) probably a very low level torch mode to tune auto focus, followed by a 2) pre-flash of similar energy as the main flash to determine best exposure with flash conditions to, finally, flash 3) the main, short flash within frame blanking.

Summary

Camera flash units are increasingly built into the front facing cameras of smartphones. For presently available sensors of 1.4 micron pixel size, a flash delivering 100lux illuminance (light dose 5lux.s) should produce a picture with a good signal-to-noise ratio of 36dB. With 0.5m distance between the camera and the subject (for the taking of a “selfie”), the necessary flux from the flash is about 80lm for the typical broad FOV of 80° to 85°.

To reduce glare when taking “selfies,” the pulse length should be reduced (≤25ms) to take advantage of the time-dependence of the glare sensation. Flash pulses this short should be timed in the frame blanking of a rolling shutter. The LED used for front facing flash needs to support high currents (order of 1A) to achieve the necessary light dose for a well-illuminated picture within the short flash pulse.

About Lumileds

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With a rich history of industry "firsts," Lumileds is uniquely positioned to deliver lighting advancements well into the future by maintaining an unwavering focus on quality, innovation and reliability.

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