LW F65G for Flashlight Applications in Mobile Phones

Application Note

Abstract

This application note introduces the new LED OSLUX™ (LW F65G) with optimized characteristics for use as a flashlight, especially in mobile phone applications.
In addition to a short summary of the common advantages of LEDs and the requirements of flashlights, the most important parameters are described with reference to the flashlight operating mode. Furthermore, several assembly possibilities are shown including their thermal descriptions and some simulation results for the LW F65G in flash operating mode are provided.

Introduction

In today's information and communication society, everyday mobile telephones have become a necessity. Over the course of time, the mobile telephone has developed from a simple telephone to a mobile office or all around device with additional useful functionality.
In addition to the basic functions, the latest generation of phones offer even more features such as internet and multimedia functionality, or even an integrated flashlight, to name a few.
The advent of digital photography in the last few years, particularly the development of inexpensive image sensors and miniature camera modules, has opened up interesting new functionality for mobile telephones.
Not only are sensitive, high resolution image sensors important for achieving a pleasing picture quality, the available light also plays a significant role. Quite often, the amount of ambient light is not sufficient in everyday situations, requiring the use of an additional light source.

Flash light in mobile phones

In this case, LEDs offer a particularly optimal light source for mobile devices. Due to the rapid development in the area of semiconductor technology in recent years, LEDs possess a very high brightness and additional key features such as:

- high mechanical stability
- small dimensions
- low voltage required to create a flash, compared to that of flash tubes
- no charging time – the flash is immediately available
- longer lifetime than conventional flash tubes
- longer flash duration possible, up to continuous mode

Typical requirements for flash units for mobile phones

Table 1 summarizes the most important requirements for the use of LEDs as flash units in mobile phones.

Flash unit for use in mobile phones	
Minimal dimensions without optics	Height **<** 3 mm
Subject illuminance	> 30 lx
Flash duration	< 400 ms
Flash coverage	< 3 m
Flashlight lifetime	**> 30**,000 flashes
Viewing angle	50° - 75°
Illumination area	Rectangular
Color temperature	5500 K – 6500 K

Table 1: Flash unit for use in mobile phones

Due to the long integration time of typical CMOS image sensors (around 300 ms), an appropriate light source should ideally be capable of outputting a flash in the form of a square impulse (Figure 2).

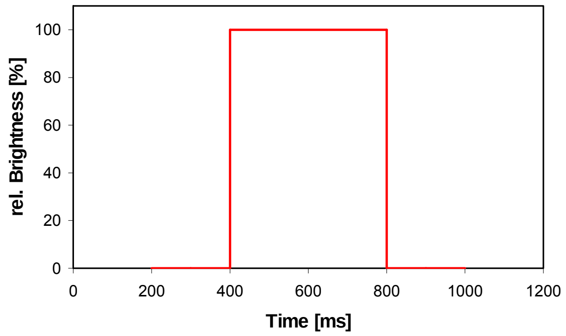

Figure 2: Ideal square impulse of a flash module

OSLUX™ - LW F65G

The LW F65G (Figure 3) was specially developed for flashlight applications with an emphasis on high brightness simultaneously combined with small dimensions (5 mm x 5.1 mm x 2.7 mm.

Figure 3: View of the LW F65G

In comparison to other LEDs which also can be used as a flashlight, the LW F65G features several decisive advantages like:

- Small package with integrated lens
- High efficiency due to newest top emitting chip technology with low forward voltage
- Good color homogeneity
- No secondary optics necessary
- Viewing field with rectangular illumination
- Several assembly possibilities

Construction of the LW F65G

Basically, the LED is constructed from a leadframe in contact with a semiconductor chip and a housing with an integrated lens (Figure 4).

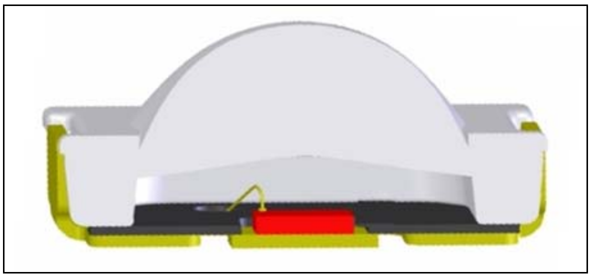

Figure 4: LW F65G, Vertical cut

The heart of the LED is a blue semiconductor chip based on the latest, highly efficient ThinGaN® thin film technology.
In addition to the high efficiency, the new ThinGaN® technology offers the advantage that the chip is almost a pure surface emitter.
For use in white LED applications, this means that the wavelength conversion for the creation of white light can be carried out directly at the chip level.
In this case, the converter material can be applied directly to the chip surface as a chip coating rather than in the casting as is the case for other white LEDs (volume conversion).
The advantage of the chip coating is that the converter can be applied to the chip surface as a homogeneous layer with a uniform concentration. As a result, the converted light is nearly constant across the entire chip surface.

As with most white LEDs, the color temperature of the LW F65G lies in the range of 5500 to 6500 K, with a color reproduction index (CRI) of 80.

The LED housing consists of a metal leadframe (Cu-Alloy) and a plastic lens (epoxy). The leadframe is designed to be connected by conventional soldering techniques or by spring contacts.

Generally, the optics consists of a molded plastic lens which is glued to the LED frame. Both package and lens are SMT Pb-free reflow solderable up to 260°C, according to J-STD-020B with preconditioning according to JEDEC level 4.
The design and construction of the LED yields a very low thermal resistance of R_{thJS} = 15K / W.

Optical performance

In order to determine whether an LED is suitable for use as a flashlight, various characteristic optical properties should be considered. These include

- the brightness of the LED
- the illuminance
- the radiation characteristics
- the brightness behavior with respect to flash duration

To determine whether an LED is appropriate as a flash source, one must look at the interaction of the individual values in comparison to other LEDs.

When characterizing LEDs, the brightness is usually stated as two values - luminous flux Φ_v (units of lm) and luminous intensity I_v (units of cd).
The luminous flux of an LED is defined as the total light output, independent of direction (Figure 6). Luminous intensity, however, reflects the amount of light within a specified solid angle in the direction of radiation (e.g. 0.01 sr = ±3.2°, see Figure 6).

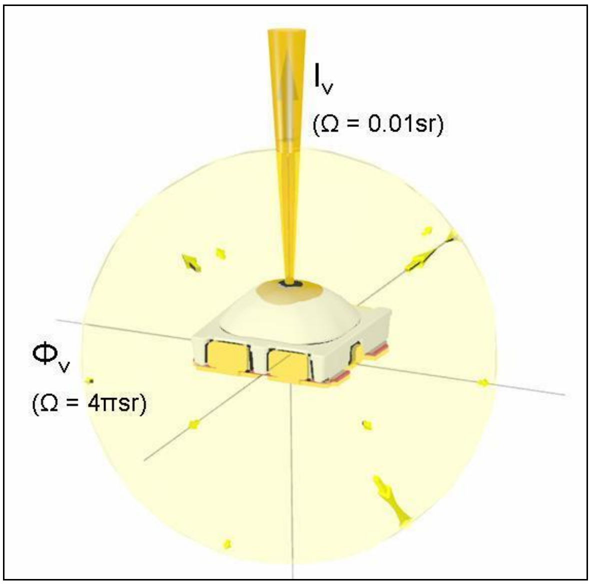

Figure 6: Definition of luminous flux and luminous intensity

Table 2 shows the optical specifications in relation to the forward current for the LW F65G®.

Due to the physical behavior of the semiconductor diode, the brightness of the LED does decrease linearly with the forward current applied.
This means that the forward current must increase by a multiple if the luminous flux at a specified value is to be doubled. This effect can also be observed in Table 2.

	**LW F65G**				
I_f	**350 mA**	**500 mA**	**700 mA**	**1 A**	**1.5 A**
Φ_v (typ.)	48.5lm	60lm	73lm	81lm	92.5lm
I_v (typ.)	26cd	33cd	40cd	45cd	52cd
E_v at 1 m	34.5lx	42.5lx	52lx	58lx	66lx
E_v at 1.5 m	15 lx	19 lx	23 lx	25.5lx	29.5lx
E_v at 2 m	8.5 lx	11 lx	12.5 lx	14.5lx	16.5lx
E_v at 3 m	3.8 lx	4.7 lx	5.8 lx	6.5 lx	7.3 lx

Table 2: Characteristics of the LW F65G

The two characteristic values Φ_v and I_v are only conditionally suitable for the characterization of flash LEDs.
With regard to the application, the photometric value for luminous flux density E_v (units of lx = lm / m²) is most often used. Illuminance describes the luminous flux for a specific area at a specific distance (Figure 7).

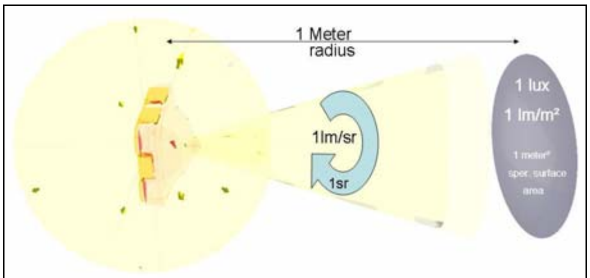

Figure 7: Definition of Illuminance E_v

When comparing illuminance values from various LEDs, the distance at which the values were obtained must be taken into account, since illuminance is indirectly proportional to the square of the distance.

$$E_v(r) = \frac{I_v}{r^2}$$

(photometric distance law)

This means for example, that when the distance is doubled, the illuminance decreases by a factor of four (see Figure 10).
Furthermore, it should be noted that the measured illuminance only represents the brightness at the center of the LED or illumination field. Outside the center, illuminance level falls off more or less sharply, depending on the radiation characteristics of the particular LED.
In order to achieve a uniform illumination and thus positively influence the image quality, the entire image area should be nearly homogeneously illuminated.
Figure 8 shows the distribution diagram for the luminous flux density of the LW F65G at a distance of 1 m, with respect to the relevant target field.

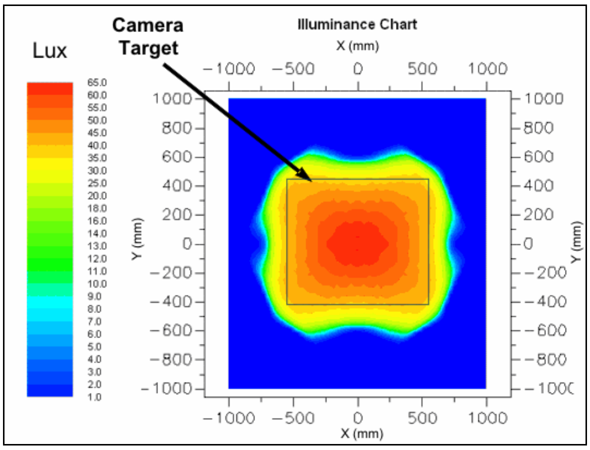

Figure 8: Rectangular illumination pattern of the LW F65G at a distance of 1 m

The nearly homogeneous illumination of the target area was achieved by means of a specially designed lens which was adapted to the requirements of camera modules for mobile telephones.
The typically accepted viewing field of the camera is rectangular with viewing angles of 60° by 47°. With two optical surfaces, the lens provides a uniform rectangular illumination pattern with a viewing angle of 60°/47° (Figure 9). This leads to a corresponding target area of 115 cm x 87 cm at a distance of 1 m.

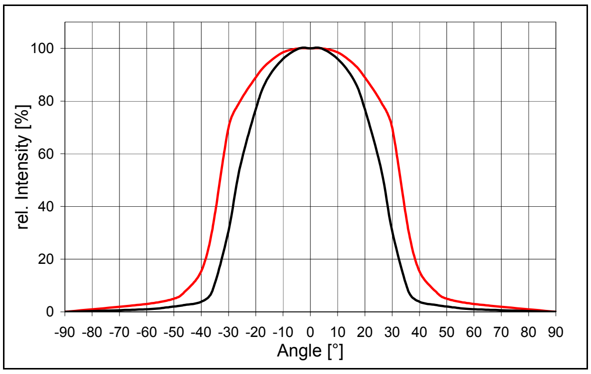

Figure 9: Radiation pattern of the LW F65G

The inner and outer surfaces of the lens cup direct most of the light to the target viewing field of the camera, adjusted to the picture format.
Compared to other flash LEDs with a typical circular Lambertian or beam radiation pattern, the LW F65G exhibits a very uniform brightness distribution over the target viewing field, with a minor decrease in the outer border areas.

In Figure 8, the camera target field represented by the rectangular area in the picture corresponds to a camera viewing angle of 60°/47°.
In this area, the decrease in brightness between center and edge is only 40%. Beyond that target area the brightness decreases strongly. However, no light is required in this region since it cannot be captured by the camera.
The well adapted lens of the LW F65G enables light to be concentrated in the target area. Thus, when taking photos, the subject is illuminated in a laminar and uniform fashion rather than in a central area. Dark picture contours and/or dark backgrounds are a thing of the past.

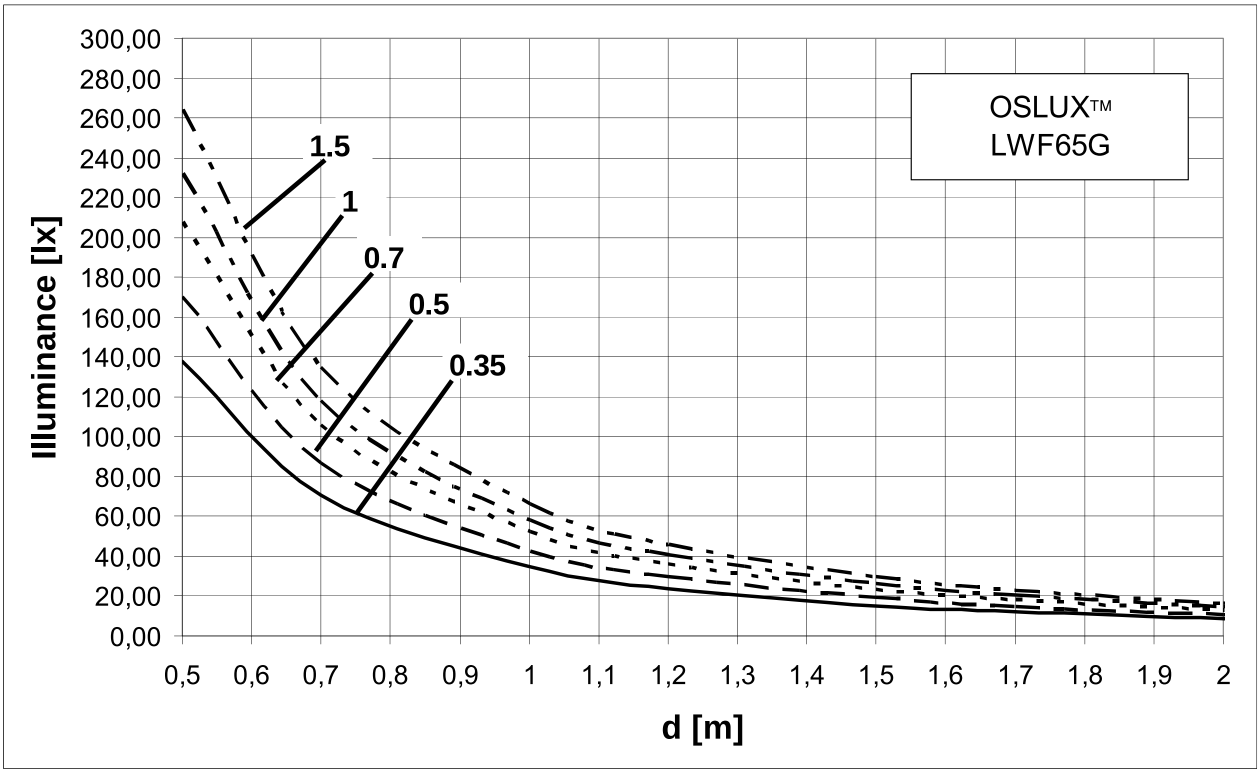

Figure 10: Illuminance of LW F65G for different distances with typ. brightness of 48lm @ 350mA

Brightness behavior within the flash duration

An important optical characteristic of the LW F65G is the brightness behavior within the operating mode (flash duration).
Figure 11 shows the brightness of the LED versus time. When power is applied to the LED, the forward voltage reaches a maximum followed by a rapid drop. Initially, the LED is dark and begins operation at room temperature. Due to the current, the brightness decreases as the LED becomes warmer. The slight decline starts when the LED warms up and the heat is transferred within the PCB. The graph becomes saturated when thermal equilibrium is achieved between the PCB and the surrounding environment.

The higher the LED current is, the sharper is the decrease in brightness. The time required to reach thermal equilibrium is dependent on the PCB material used.
Nevertheless, the drop of brightness during the entire flash is less than 10%, resulting in a nearly constant light level. The slight decrease can be compensated by the driving circuitry.

Because brightness decreases slightly over time, it is important to specify at what time the LED is measured when comparing different flash LEDs. OSRAM-OS LEDs are measured as follows: After waiting around 10 ms for the current to stabilize, the brightness is measured for a short time period, typically 20 ms.

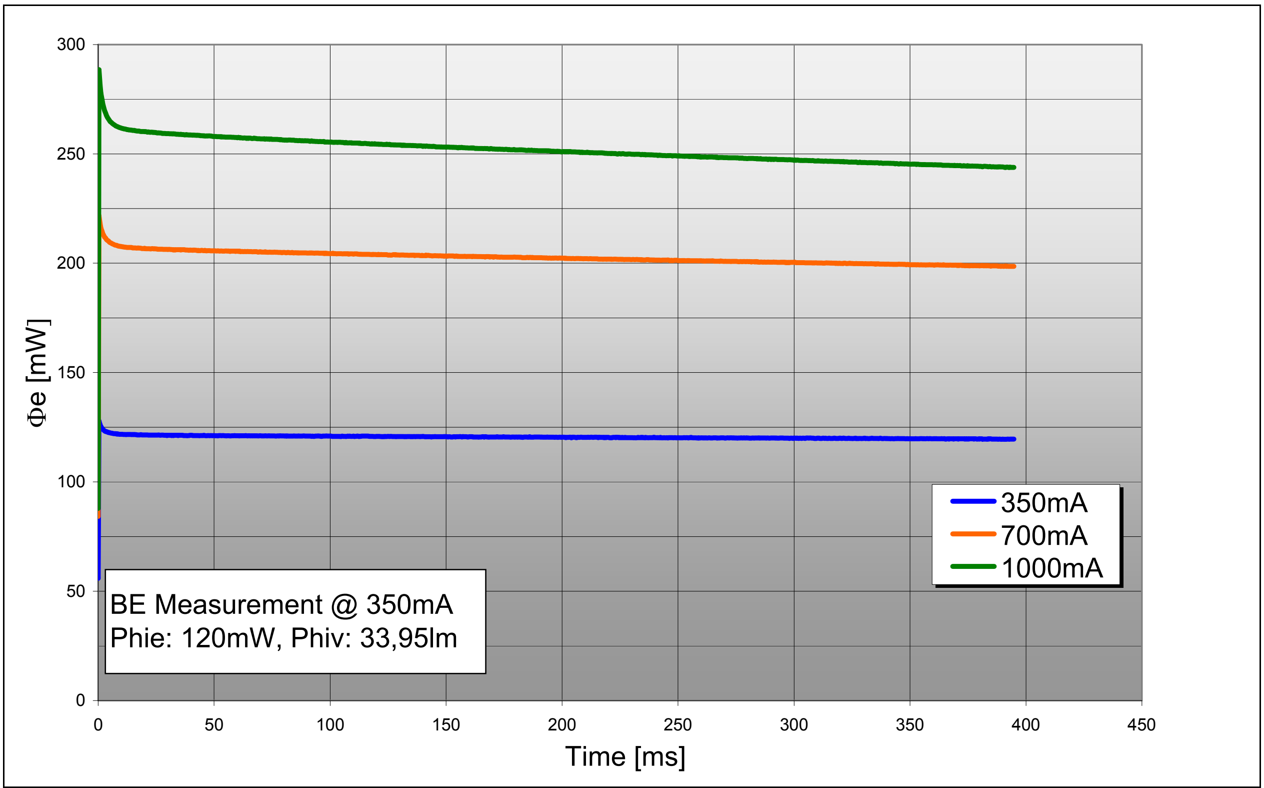

Figure 11: Brightness behavior within the flash duration

Assembly possibilities

The LW F65G provides a flexible mechanical design which permits the following three assembly methods:

- Assembly on PCB
- Bottom spring contacts
- Side spring contacts

Usually, the opening for the flash LED in the mobile phone cover is enclosed with a clear window. The window material should exhibit a good optical transmittance value. The size of the window needs to be large enough to allow all emitted light from the LED to exit through the window and is dependent on the distance between the LED and cover.

Besides mounting on a PCB, the LED can also be snapped in the cover. This can be realized in two ways: with bottom spring contacts and with side spring contacts. In this case the LED can function as cover, but it is recommended to close the opening in the cover by a clear window, to protect the LED against dust or mechanical damage.

1. Assembly on PCB
The LED can either be mounted on the main PCB or on a separate PCB. This assembly method provides good heat transfer due to the direct thermal connection to the PCB. Because of differences in PCB materials regarding heat transfer, the use of a material with a low thermal resistance is recommended.

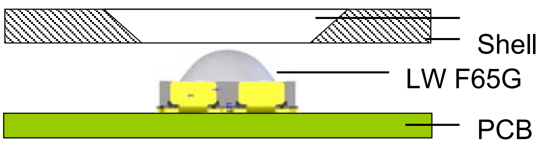

Figure 15: LED assembly on PCB

2. Assembly with bottom spring contacts
Using bottom spring contacts, the LED can be fixed by pushing it into the shell. Figure 16 shows that the phone cover can directly contact the flat outer ring of the lens.

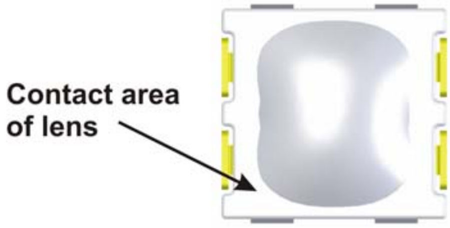

Figure 16: Allowed contact area of lens for mounting with spring contacts

A flattened cover should be used in order not to shadow the LED light, as is shown in Figure 17.

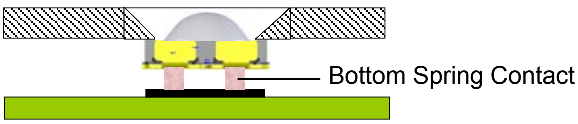

Figure 17: LED assembly with bottom spring contacts

3. Assembly with side spring contacts
The LW F65G is also suitable for assembly with side spring contacts (Figure 18). Some applications may require electrical contact from the side. The LW F65G has electrical contacts at the side of the package for this purpose. The electrical contacts are connected thermally, thus thermal heat conduction is also provided. The LED can be integrated in the phone cover as well, as is described in method 2.

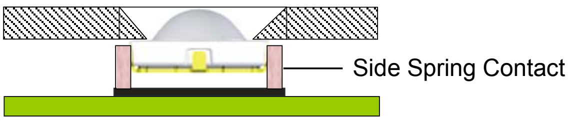

Figure 18: LED assembly with side spring contacts

Electrical characteristics

In addition to the optimized optical behavior, the new ThinGaN technology also provides improved electrical characteristics when compared to standard chip technologies.
This results in a significantly reduced forward voltage and higher allowable current levels. Table 3 shows the electrical characteristics of the LWF65G.

	OSLUX™ - LW F65G				
I_f	**350 mA**	**500 mA**	**700 mA**	**1A**	**1.5 A**
U_f (typ.)	3.2 V	3.4 V	3.6 V	3.8 V	4.3 V
U_f (max.)	3.8 V	4 V	4.2 V	4.5 V	4.9 V
Pulse duration [T_a=25°C]	DC	DC	500 ms	300ms	50 ms

Table 3: Electrical Characteristics of the LW F65G

To provide more details regarding the progression of the forward voltage, the plots of minimum, typical and maximum forward voltages versus forward current are shown in Figure 12.
Due to the semiconductor behavior of LEDs, the forward voltage is dependent on changes in temperature arising from the forward current.
During the flash operation, the LED becomes warmer and the forward voltage decreases (Figure 13). In the diagram, the forward voltage was measured for a flash duration of 400 ms.
The highest voltage occurs at the beginning, since the LED is at room temperature when power is applied. After that, the temperature of the LED rises sharply, leading to a decrease in forward voltage.
Afterwards, the heat is continuously transferred to the PCB and the voltage decrease at a reduced rate. At 400 ms, thermal equilibrium between LED and environment has not yet been reached and the voltage continues to decrease.
As can be observed in the diagram, the higher the forward current, the warmer the LED becomes and the greater the decrease in forward voltage during the flash duration.

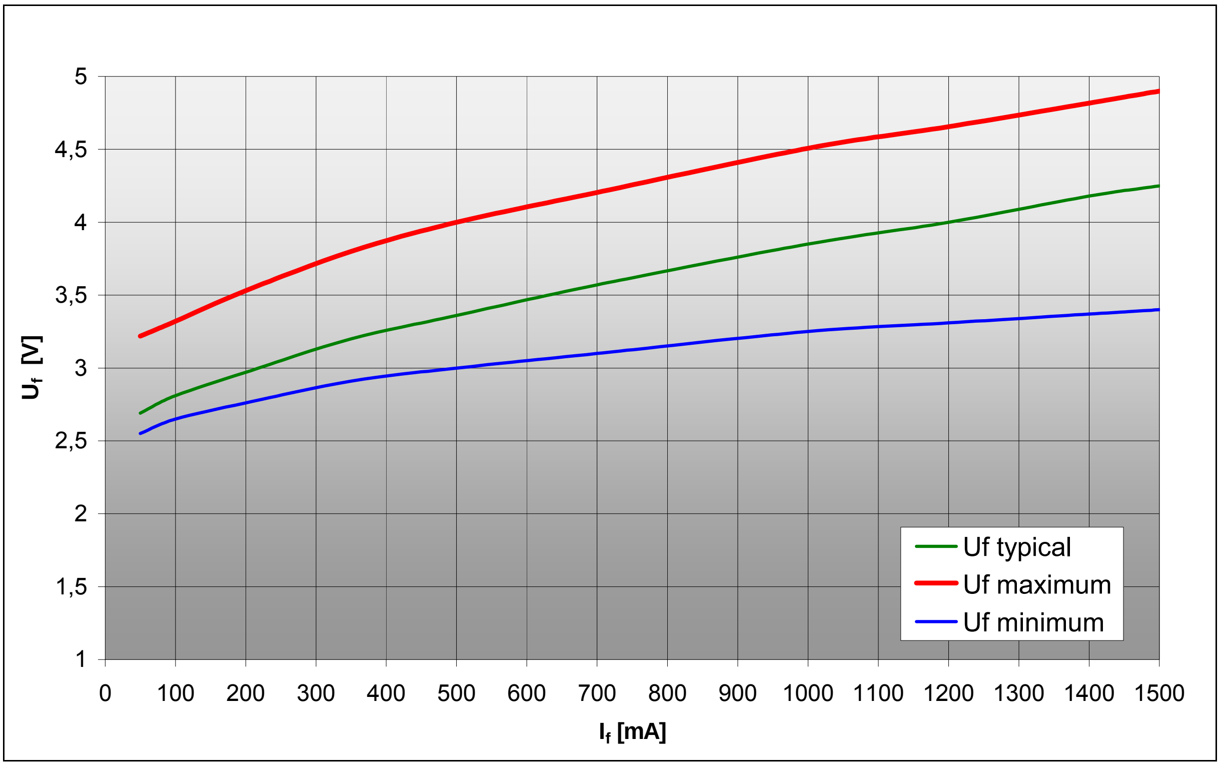

Figure 12: Forward voltage versus forward current of the LW F65G

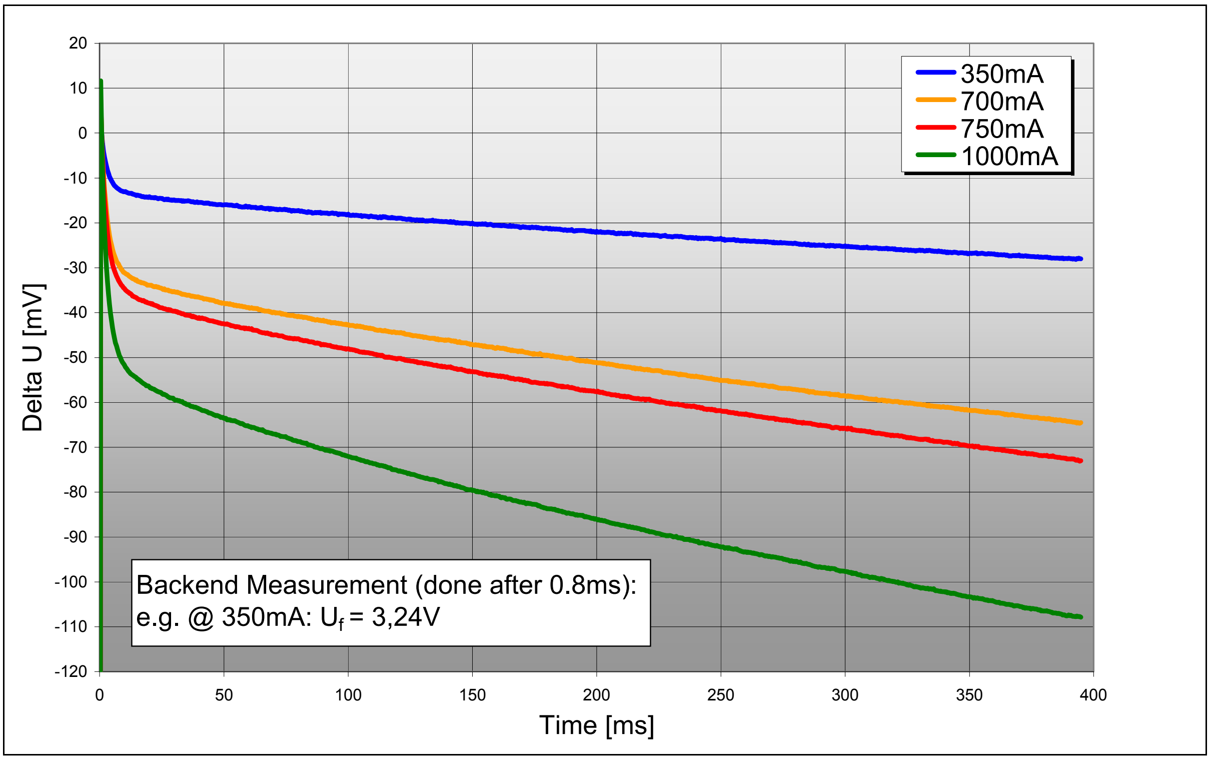

Figure 13: Behavior of forward voltage during flash duration

The forward voltage is not only dependent on the current, but also on the ambient temperature. Figure 14 shows the voltage versus ambient temperature for different forward currents. For each forward current, the maximum and minimum voltage curves according to Figure 12 are shown. For mobile phone applications, an operating temperature range of -20°C to 55°C is required, resulting in a maximum voltage decrease of about 0.4V within in this range for a given starting value.

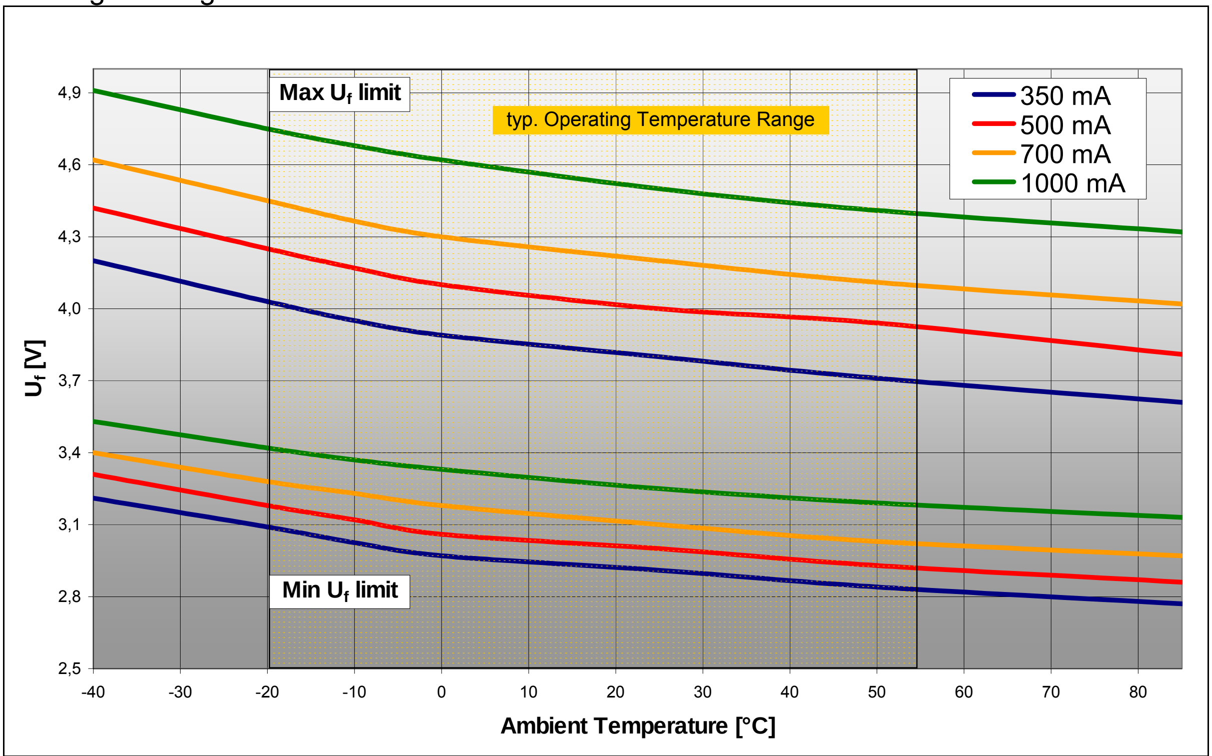

Figure 14: Behavior of forward voltage during flash duration

For flash operation, the LED can be driven up to a maximum pulse current of 1.5 A. Table 4 gives the maximum allowable flash duration dependent on the forward current, for the following conditions:

- LW F65G mounted on a 1.15 mm thick FR4 PCB (main board) with 8 layers
- Ambient temperature of T_a = 35°C

I_f	Pulse Duration [T_a=35°C]	Pulse interval
500 mA	DC	-
700 mA	> 1 s	3 s
1 A	300 ms	3 s
1.5 A	50 ms	3 s

Table 4: Maximum allowable pulse duration for the LW F65G on FR4 PCB

Thermal characteristics

An important feature of the LW F65G is that the chip is directly mounted on the Cu-Alloy leadframe.
Thus, the heat generated by the chip is transferred through the leadframe and can subsequently flow through the PCB to the environment. This setup leads to a low thermal resistance for the LED of
R_{thJS}= 15 K/W.
Furthermore, due to the optimized low thermal resistance, the LW F65G can be driven with currents up to 1.5 A in pulse mode in special cases.
In order to achieve optimal performance, thermal management should be considered.

The assembly methods presented here were further examined with respect to their thermal properties and were thermally simulated in various modes of operation.

With regards to mounting on circuit boards, three approaches were considered:

1. LED mounted on FR4 main PCB
2. LED mounted on Flex PCB
3. LED mounted on Flex on Al PCB

This resulted in specification of the following boundary conditions for the thermal simulation:

- Ambient Temperature: T_{amb} = 35°C
- Heat transfer coefficient of mobile phone cover: $\alpha = 8\ Wm^{-2}K^{-1}$

Figure 19, 20 and 21 show three different PCB materials on which the LW F65G is mounted. The material characteristics of the PCBs are given below.

1. FR4 PCB

- LED on FR4 main board
- PCB with 8 layers
- PCB thickness 1.15 mm

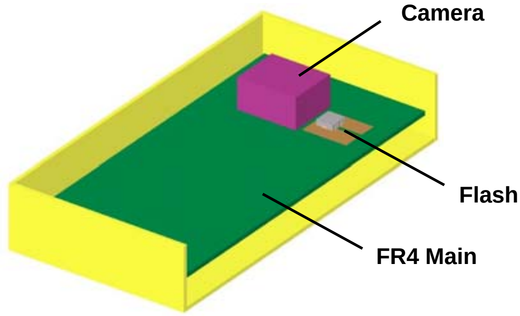

Figure 19: LED on FR4 main PCB

2. Flex PCB

- LED on separate Flex PCB
- Flex PCB with 1 layer
- Layer with 35 µm Cu, 30 µm PEN

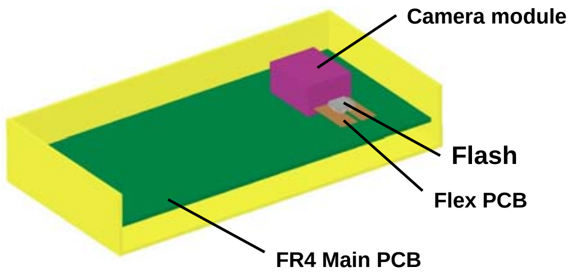

Figure 20: LED on separate Flex PCB

3. Flex on Aluminum

- LED on Flex PCB on Al
- PCB with 1 mm Al and 50 µm adhesive
- PCB thickness 1.15 mm

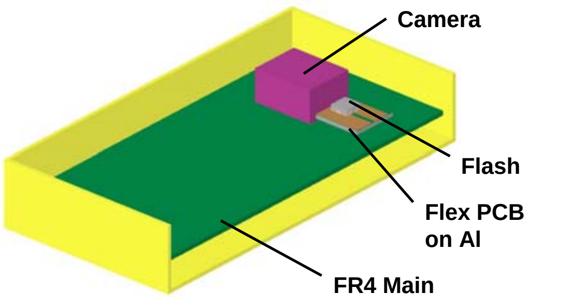

Figure 21: LED on separate Flex on Al PCB

The thermal simulation was done for 5 flash cycles with a flash pulse condition of

- t_P = 300 ms
- T_{total} = 3 s
- D = 0.1
- I_f = 1 A

The results of the thermal simulation are shown in Figure 22.
The simulation shows that there is only a minor difference in the thermal behavior of the two materials Flex on Aluminum and FR4 Main PCB.

Both materials function as good thermal conductors for the flash operation, as there is only a slight increase in the junction temperature of the chip.
The junction temperature of the LED mounted on a Flex PCB increases strongly during the flash operation. After 3 pulses, the maximum allowable junction temperature of 150°C is exceeded.
Therefore, it is recommended that the LW F65G should be mounted on the main PCB or on a Flex PCB on Al, especially at higher currents.

The two other mounting methods, side spring contact (Figure 23) and bottom spring contact, were examined with respect to their thermal properties for their use as a camera flash in addition to providing flashlight functionality.
For the bottom spring contact, heat transfer via a 1x1 mm² metal contact directly underneath the semiconductor was simulated; for the side spring contact, two side contacts were simulated.

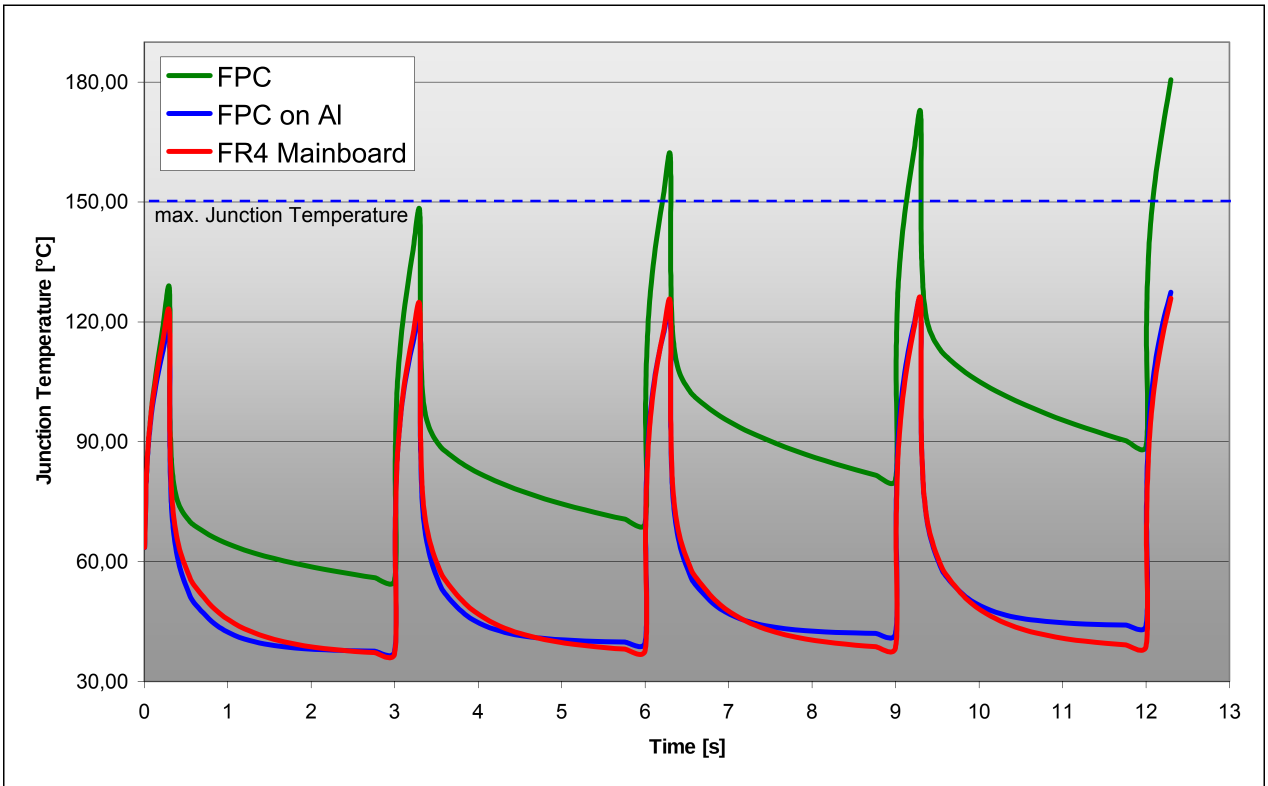

Figure 22: Comparison of different PCB materials for flash operation

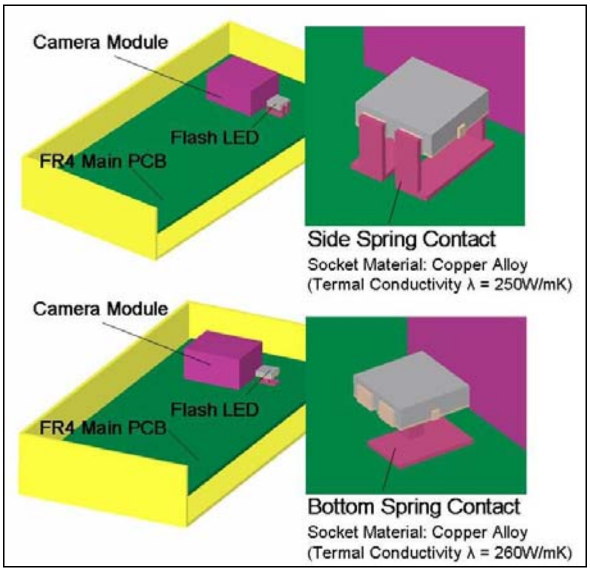

Figure 23: Side spring and bottom spring contact

In general, results showed that a connection by means of a bottom spring contact provided better thermal characteristics than that provided by side contacts (Figures 24 and 25). However, both contact methods are appropriate for currents up to 1.5 A, with the proper impulse duration.

The better thermal properties of the bottom spring contact can also be observed when the LW F65G functions as a flashlight (If = 250 mA , see Figure 26). The temperature offset from the maximum permissible junction temperature of 150°C is significantly greater.

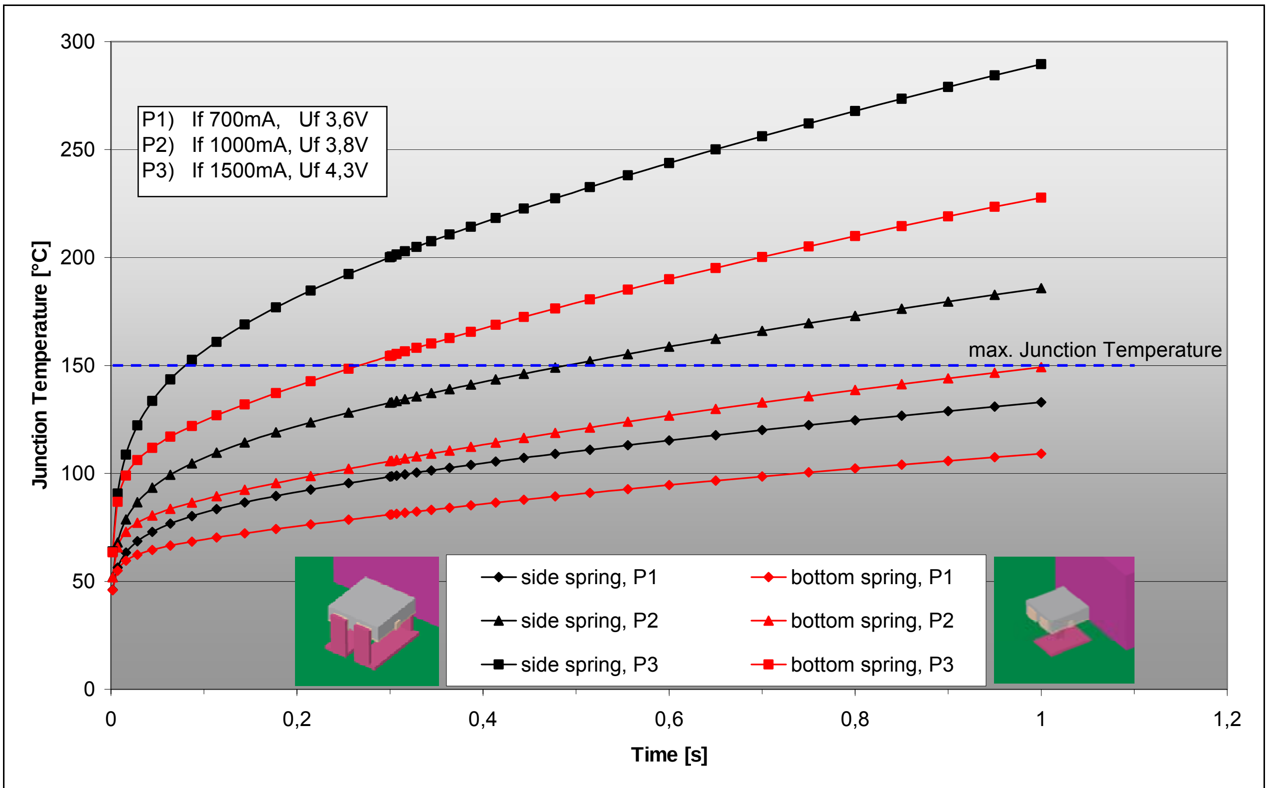

Figure 24: Comparison of bottom and side spring contact for flash operation

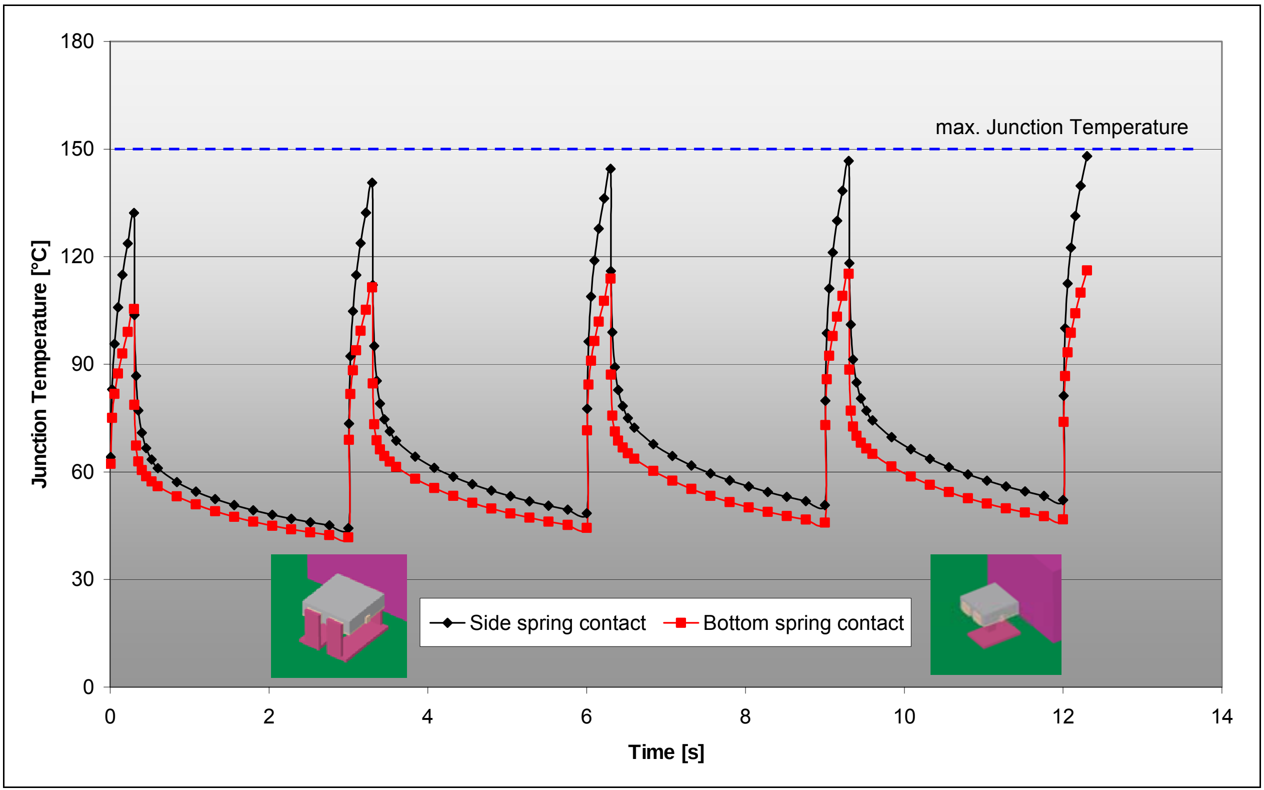

Figure 25: Comparison of bottom and side spring contact for flash operation (If 1000 mA)

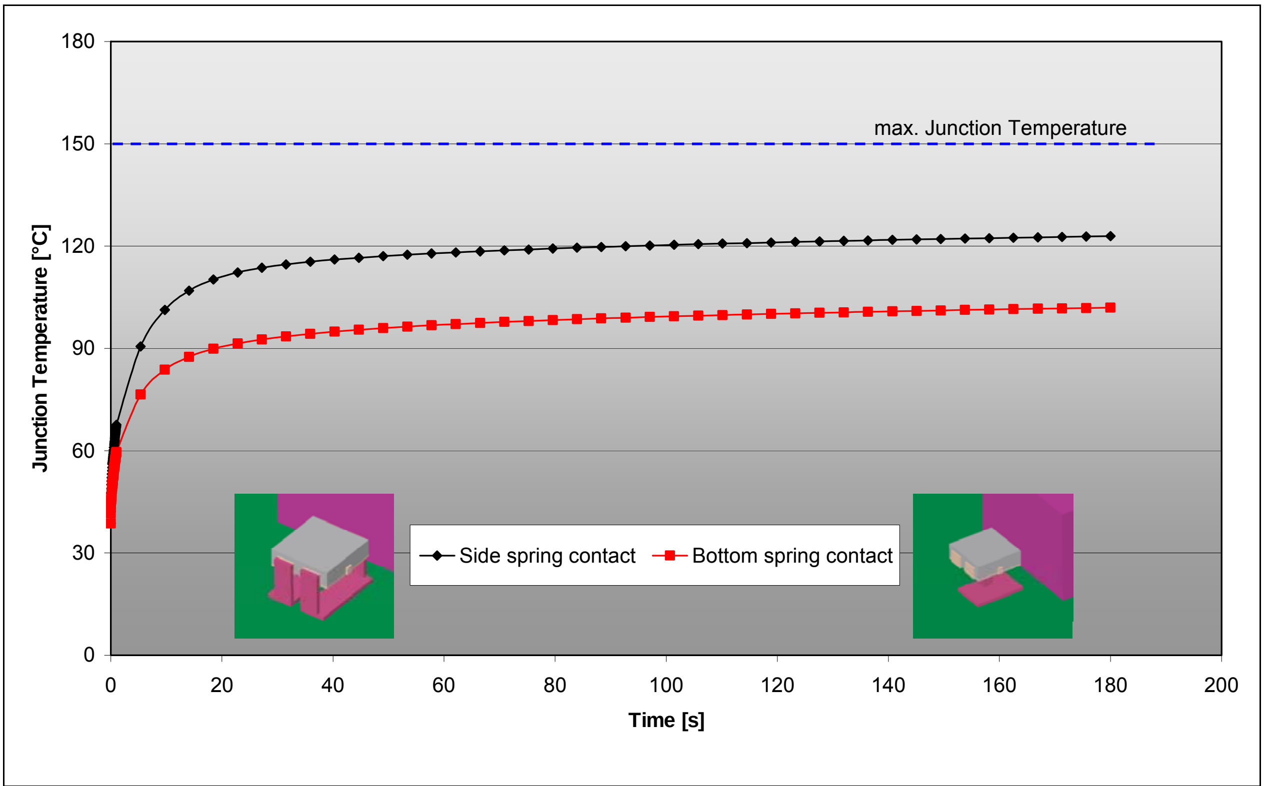

Figure 26: Comparison of bottom and side spring contact for flashlight operation (If 250 mA)

Electrical Switching Recommendations

With a low forward voltage (U_{fmax}= 4.5 V, @ 1000 mA) the LW F65G makes electrical control much easier compared to that required for other flash LEDs available on the market.

In order to provide high current levels and flash switching, the use of a driver is highly recommended.
From the many possibilities for drive circuitry, two basic concepts for flash LEDs are presented here:

- inductive DC-DC converters
- charge pumps

Both concepts can provide currents up to 1A for the flash LED.

Inductive DC-DC converters (Figure 27) use coils and therefore might cause electromagnetic interference, which has to be properly addressed. Within their working range, DC-DC converters can convert the input voltage to any output voltage.

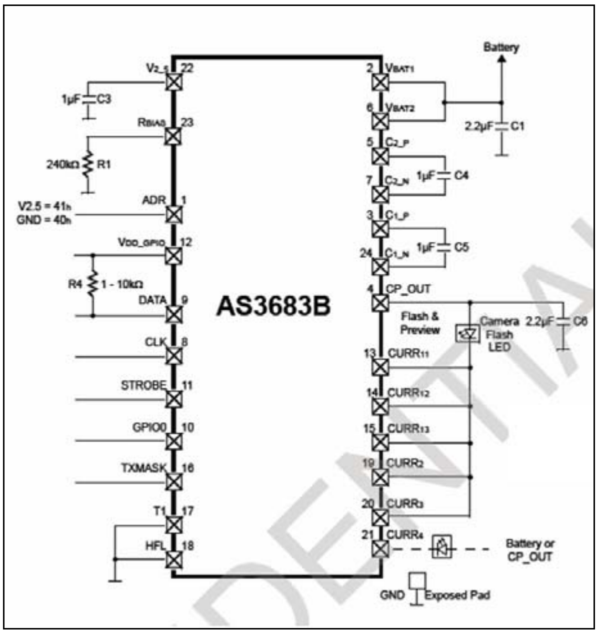

Figure 28: Example of a charge pump up to If = 1000 mA from Austria Microsystems

Charge pumps (Figure 28) use capacitors instead of coils. For this reason, charge pumps support automatic mode switching of input and output voltages, e.g. 1.5x or 2x mode. This means the output voltage can only be stepped up in multiples of the input voltage.

For a suitable LED driver for high current flash applications, please see the links in the appendix or contact OSRAM Opto Semiconductors.

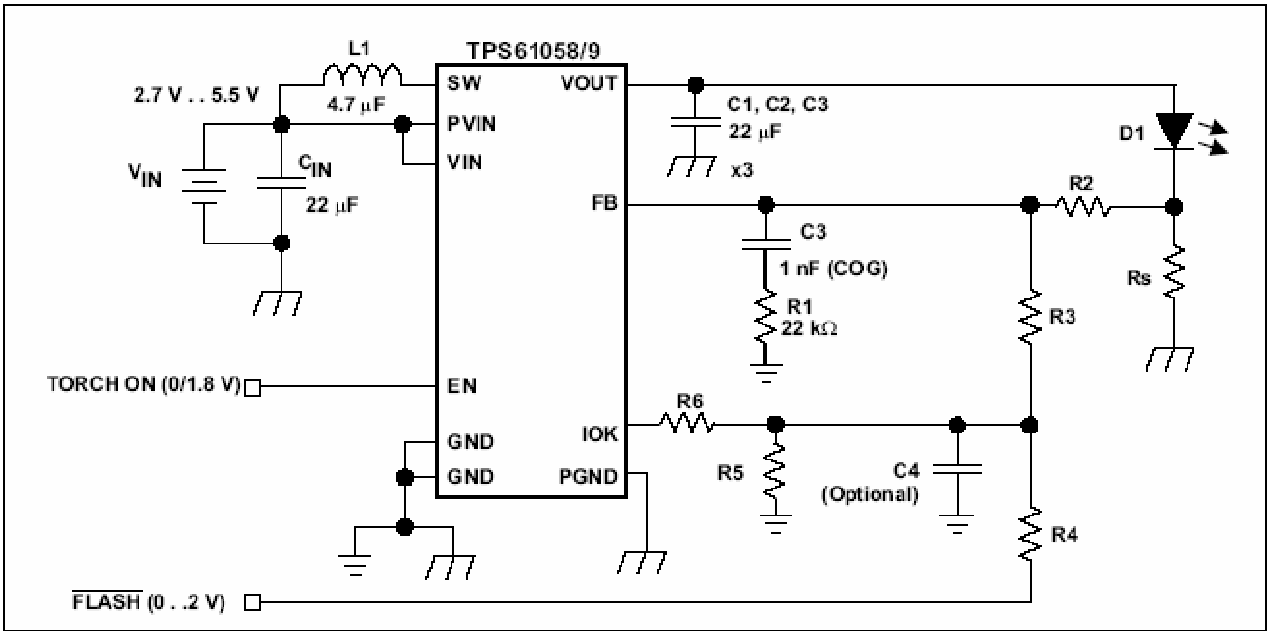

Figure 27: Example of a synchronous boost converter up to If = 700 mA from Texas Instruments

Conclusion

Without the necessary auxiliary optics, the OSLUX™ fulfills all requirements regarding characteristics and significantly exceeds other LEDs regarding brightness, uniform color and homogeneous illumination as well as optical system efficiency (60 lm/W).

Of all currently available LED types, the LW F65G is exceptionally well suited for use as a camera flash in mobile phone applications. Especially developed and optimized for this application, it fulfills all requirements regarding brightness (50 lx @ 1000 mA), color homogeneity and uniform illumination, adaptation to the display format ($\Delta_{center\text{-}edge}$ 30%, $\Delta_{center\text{-}corner}$ 40%) thereby exceeding other LEDs available on the market.
With its integrated lens, it exhibits the best optical performance as well as system efficiency.
For mobile phone cameras with an optical resolution of 1 Mpixel or greater, it represents the best choice.

Besides their use in flash units, the LED is also well suited as a flashlight for video cameras. The advantage in this case is that the flashes can be synchronized to the video frames; the flash only occurs during frame capture. Between frames, the flash is turned off. Compared to common video lamps for video cameras, this results in a lower energy usage.

For the best optical and electrical performance of the LED flashlight, typical properties of the semiconductor chips such as thermal behavior and their effects should be taken into account.

The further development of LEDs will lead to higher efficiency and additional light output. At the same time, the required forward current and the dimensions will be reduced.
As OSRAM-OS will continually develop improvements to the LED, please check the data sheets of the LED types for the latest performance data (www.osram-os.com).

Appendix

Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

www.ledlightforyou.com

Links for LED Flashlight Drivers

austriamicrosystems	www.austriamicrosystems.com
Linear Technologies	www.linear.com
ON Semiconductor	www.onsemi.com
Maxim	www.maxim.com
Monolithic Power	www.monolithicpower.com
National Semiconductor	www.national.com
STMicroelectronics	www.st.com
Supertex	www.supertex.com
Texas Instruments	www.ti.com

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About Osram Opto Semiconductors
Osram Opto Semiconductors GmbH, Regensburg, is a wholly owned subsidiary of Osram GmbH, one of the world's three largest lamp manufacturers, and offers its customers a range of solutions based on semiconductor technology for lighting, sensor and visualisation applications. The company operates facilities in Regensburg (Germany), San José (USA) and Penang (Malaysia). Further information is available at www.osram-os.com.