SFH 7771
(Proximity Sensor + Ambient Light Sensor)
Application Note

1 Introduction

The SFH 7771 combines a digital ambient light sensor and a proximity sensor within an ultra-small package. Additionally the sensor provides an I^2C-bus interface and an interrupt pin to connect it to an e.g. microcontroller.

This application note describes the basic technical features and the components operation, allowing the user to achieve the full functionality and performance of the sensor. At the end a simple software code illustrates an example for the implementation of the SFH 7771 into a mobile phone environment.
Please note that this guide is only a brief introduction. For more detailed information and the latest products and updates please visit www.osram-os.com or contact your local sales office to get technical assistance during your design-in phase.

2 Applications

Typical application areas are mobile phones, PDAs, notebooks, cameras and other consumer products. Common tasks for the ambient light sensor are e.g. display brightness adjustments, whereas the proximity sensor is usually employed to detect objects and motions. This single component integrates several distinct functionalities and greatly simplifies the design-in process in consumer as well as industrial applications. Furthermore the SFH 7771 is capable of measuring the ambient light value outside a phone, even if the sensor is placed behind black cover glasses with different spectral transmission characteristics.

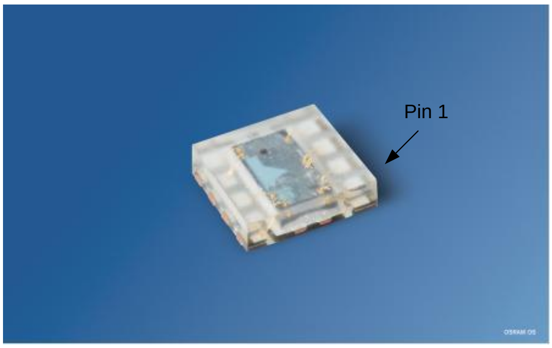


Fig. 1: Photography and orientation of the SFH 7771.

The ultra-low power consumption makes the SFH 7771 especially suited for mobile applications, where conservation of battery power is a critical point. The tiny footprint of 2.1 x 2.0 mm² saves valuable pcb-board real estate.

3 The SFH 7771

The SFH 7771 (see Fig. 1) consists of an ultra-low power ASIC which performs the signal processing and provides the I^2C-bus interface as well as an interrupt alert function. Additionally the ASIC contains two photodiodes: one for proximity and infra-red ambient light and another for visible ambient light sensing. The functional block diagram can be found in Fig. 2. The pinning of the device is stated in Tab. 1. The key features of the SFH 7771 include:

Proximity Sensor (PS)
- detection-range up to 300 mm
  (and beyond with external driver)
- optimized for 850 nm to 940 nm emitter
- ambient light suppression
- fast access to PS signal

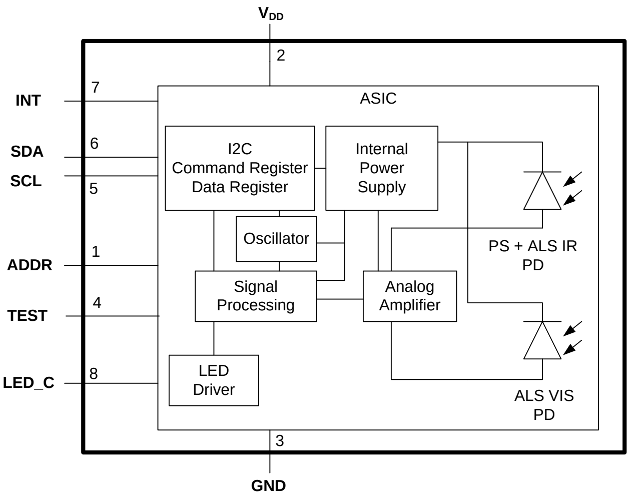


Fig. 2: SFH 7771 functional block diagram.

Pin No.	Pin Label	Description
1	ADDR	Address Pin
2	V_{DD}	Digital Supply Voltage
3	GND	Ground
4	TEST	must connect to GND
5	SCL	I^2C-Bus Clock Line
6	SDA	I^2C-Bus Data Line
7	INT	Interrupt Pin
8	LED_C	IR-LED Cathode

Tab. 1: Pin configuration of the SFH 7771

Ambient Light Sensor (ALS)
- 0.001 lx – 47 000 lx
- excellent linearity
- dual ALS concept: optimized to work behind dark cover glass
- lamp type detection

I^2C-Bus Interface
- configurable slave address: 0x38 or 0x39
- 100kHz / 400kHz I_2C bus speed
- programmable operation modes (*stand-by, free-running*)
- ultra low current consumption (< 1.5 µA) in *stand-by* mode
- configurable interrupt output with programmable threshold/hysteresis levels for PS and ALS
- persistence filter for interrupt

4 Ambient Light Sensor

The ambient light sensor is intended to provide ambient light measurement, e.g. to control and adjust the display brightness. To support this functionality the SFH 7771 provides a convenient user interface.

The ambient light sensor module consists of two photodiodes, labelled ALS_VIS (mainly sensitive in the visible range) and ALS_IR (sensitive in the infrared range) with different spectral characteristics (see Fig. 3).
The true illumination resp. lux can be calculated based on the information gathered by both diodes (see Eq. (1) on next page).

The two ambient light sensors deliver output values in the range from 0 to 65535 (16 bit). Low output values correspond to a low illumination of the sensor, while high values indicate high illumination. The range of the ambient light sensor sensitivity can be set by the user and covers more than 4 ½ decades in each setting. Two threshold levels for the ambient light sensor (ALS_VIS) can be set via the I^2C-bus, a lower and an upper threshold. In the case of exceeding this specified range, an interrupt signal can be generated, allowing e.g. the microcontroller to act accordingly (see Sec. 8.3 for the relevant registers and settings).

4.1 Spectral Sensitivity of the ALS

The spectral sensitivities of the ALS_VIS and ALS_IR sensor of the SFH 7771 (see Fig. 3) are designed to provide ample information about the light source and allows subsequently with a simple set of equations to calculate the true ALS value (illumination) based on this data. This is especially important as in mobile applications the SFH 7771 is often hidden behind a dark, IR-transmissive cover glass, which makes it difficult for a single channel ALS to calculate the (true) ALS value.

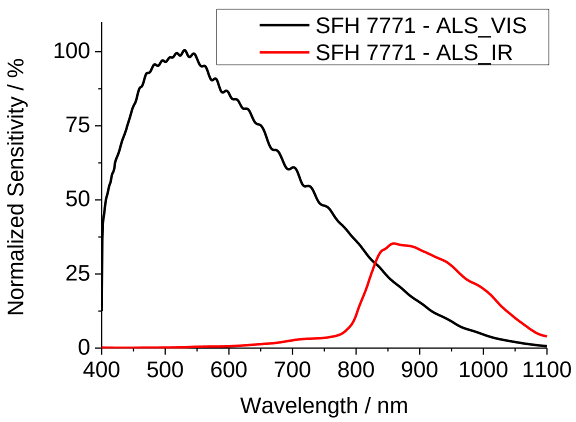


Fig. 3: Spectral sensitivity of the two photodiodes of the SFH 7771 (ALS_VIS and ALS_IR have equal gain setting). Please note the PS photodiode has the same spectral sensitivity as the ALS_IR photodiode.

Illumination Range	GAIN ALS_VIS	T_INT_ALS
0.70lx … 46659lx	1	100 ms
0.36lx … 23329lx	2	100 ms
0.011lx … 729lx	64	100 ms
0.0055lx … 364lx	128	100 ms
0.18lx …11664lx	1	400 ms
0.09lx … 5832lx	2	400 ms
0.0028lx …182lx	64	400 ms
0.0014lx … 91lx	128	400 ms

Tab. 2: ALS sensitivity vs. GAIN ALS_VIS resp. T_INT_ALS settings (e.g. white LED or fluorescent lamp).

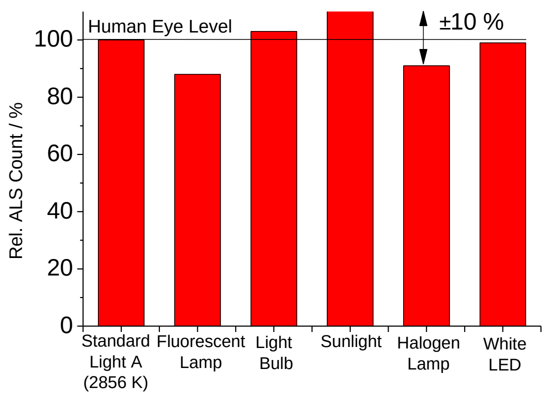


Fig. 4: Typ. ambient light sensor accuracy (calculated according to Eq. (1)) vs. different light sources.

The following Eqs. are recommended to be applied to calculate the true ALS lux-value out of the ALS_VIS and ALS_IR data. The Eqs. are valid for the illumination in front of the sensor (e.g. no cover glass or glasses with flat transmission characteristics from visible into the IR region). For applications with a (dark) cover glass please refer to Sec. 10.1.

```
IF (ALS_IR / ALS_VIS) < 0.25
    LUX = (0.712*ALS_VIS/GAIN_VIS
           -1.034*ALS_IR/GAIN_IR)
ELSE IF (ALS_IR / ALS_VIS) < 0.59
    LUX = (0.601 * ALS_VIS / GAIN_VIS
           - 0.551 * ALS_IR / GAIN_IR )
ELSE IF (ALS_IR / ALS_VIS) < 0.72
    LUX = (0.533 * ALS_VIS / GAIN_VIS
           - 0.434 * ALS_IR / GAIN_IR )
ELSE IF (ALS_IR / ALS_VIS) < 1.36
    LUX = (0.469 * ALS_VIS / GAIN_VIS
           - 0.343 * ALS_IR / GAIN_IR )
Else LUX = 0

LUX = LUX * 100 ms / T_INT_ALS
```

Eq. (1)

With **T_INT_ALS** representing the ALS integration time (t_{int_ALS}) according to register 0x41 setting and **GAIN_VIS = GAIN_IR** according to setting in reg. 0x42. If a cover glass is used an additional gain factor needs to be added to compensate for any Fresnel loss (attenuation) due to the glass.

Fig. 4 compares the calculated illumination (lux) values and relates them to the human eye sensitivity (V-lambda, V(λ)), assuming the same illuminance value. The values are normalized to the standard light source A (2856 K). The comparison to the perception of the human eye for different light sources unveils only a minor deviation.

4.2 Directivity of the ALS

The angular directivity of the SFH 7771 is presented in Fig. 5. The typical half-angle is around ± 60° with Lambertian (cosine) shape.

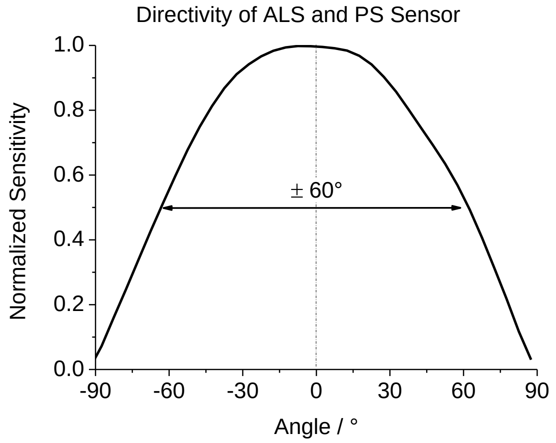


Fig. 5: Directional characteristics of the ambient light and proximity sensor.

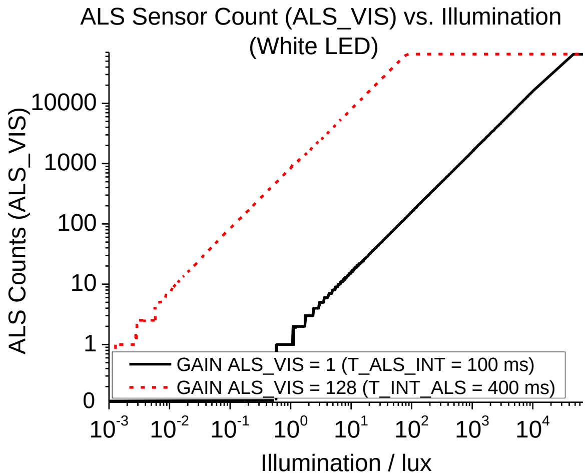


Fig. 6: Ambient light sensor count (ALS_VIS) vs. illumination (different gain and integration time settings). The curves represent maximum and minimum sensitivity settings.

This is an important point for considering the design of potential cover glass apertures (please refer to Sec. 10.9 for more details).

4.3 Sensitivity Range of the ALS

The sensitivity range of the ALS can be programmed by the user via the MODE_CONTROL (0x41) and ALS_PS_CONTROL register (0x42). The illumination range scales by the GAIN and ALS integration time (T_INT_ALS) settings. Fig. 6 presents the ALS_VIS signal vs. the

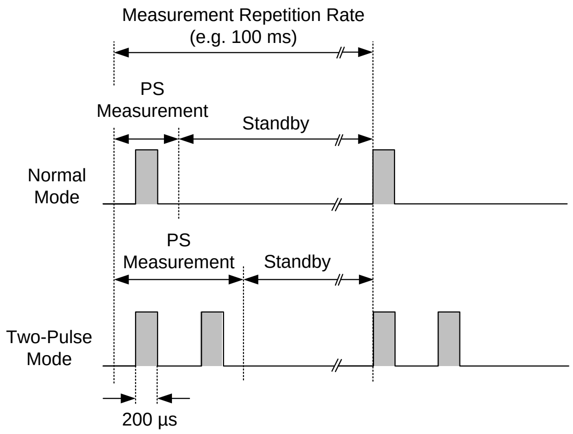


Fig. 7: LED drive current and timing during one proximity measurement cycle (two options are possible: normal and two-pulse mode).

illumination range. The graph represents the highest and lowest sensitivity range setting (valid for e.g. white LEDs or fluorescence lamps). Please refer to Tab. 2 for a listing of all the possible ALS ranges.

5 Proximity Sensor

The proximity sensor delivers output values within the range from 0 up to 4095 (12 bit, linear). Low output values correspond to low irradiance of the sensor, while high values indicate high irradiance. Threshold levels with or without a hysteresis for an interrupt alert can be set via the I^2C-bus (see Sec. 8.3 for the relevant registers and settings).
The integrated proximity measurement operates best in the range from 850 nm to 940 nm (see Fig. 3). The typ. sensitivity is 1.5 µW/cm²/count at 850 nm resp. 1.7 µW/cm²/count at 940 nm.

5.1 Functionality of the PS

The SFH 7771 uses a single 200 µs LED pulse. Fig. 7 illustrates the signal during a complete measurement cycle. After the measurement the proximity data are immediately available and interrupt registers are updated. Measurement repetition time in the free running mode can be selected to be 10ms, 50 ms, 100 ms or 400 ms (register

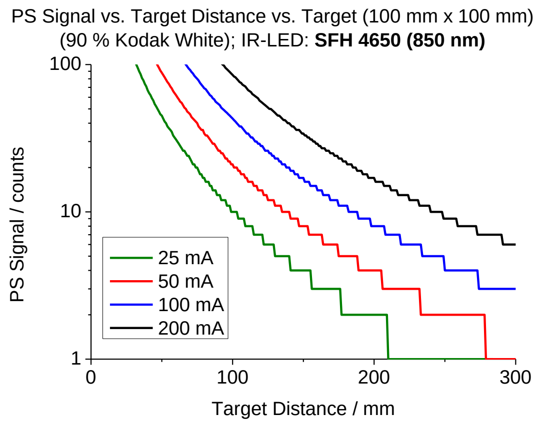


Fig. 8: Proximity sensor signal count vs. target distance and LED drive current (reflector: Kodak White, 90 %, 100 x 100 mm²). IR-LED: SFH 4650 (850 nm).

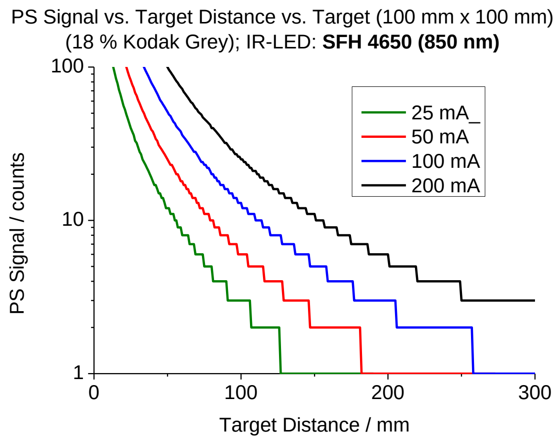


Fig. 9: Proximity sensor signal count vs. target distance and LED drive current (reflector: Kodak Grey, 18 %, 100 x 100 mm²). IR-LED: SFH 4650 (850 nm).

0x41). Two options are available: normal mode with a single IR-LED pulse and two-pulse mode with two consecutive pulses. In the latter case the persistence number increases twice as fast (see Sec. 5.5). PS data, PS related interrupt and persistence are updated after every pulse.

5.2 Proximity Count and Detection Range

The maximum detection range depends – among others – on target properties like size and reflectivity, on the IR-LED pulse current and the IR-LED type. To reach a maximum detection range the recommended value for the LED drive current is 200 mA. In general to reach a maximum detection distance a suitable IR-LED should be selected (Sec. 10.4 and 10.5 handle this topic in more detail).

Figs. 8 to 10 present the proximity values vs. target distance for a 100 x 100 mm^2 Kodak White (90 %), Kodak Grey (18 %) and Opteka Black (~ 4 %) target (no cover glass) vs. different LED currents in combination with a 850 nm MIDLED SFH 4650 emitter (see Tab. 9 for details). As indicated, the typ. maximum detection range for the SFH 7771 is in the range of up to 300 mm (by using 200 mA LED current with a SFH 4650 (850 nm) and Kodak White as

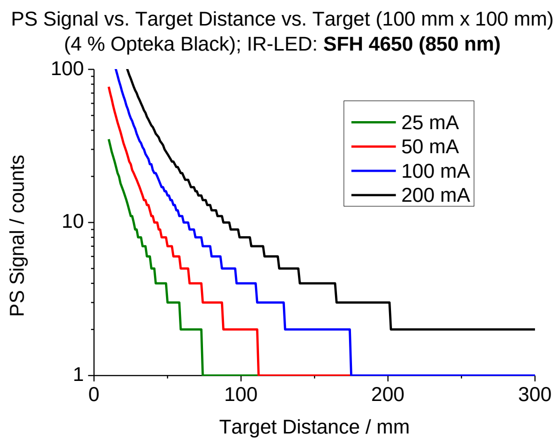


Fig. 10: Proximity sensor signal count vs. target distance and LED drive current (reflector: Opteka Black, ca. 4 %, 100 x 100 mm²). IR-LED: SFH 4650 (850 nm).

target with a threshold level around 7 counts). As a general rule it is recommended for a robust design to set the threshold level at least up to around 7 counts above any offset level (the typ. internal offset level of the SFH 7771 is below 1 count).

5.3 Directivity and Spectral Responsivity of the PS Diode

The directivity and the spectral sensitivity of the PS sensor is the same as for the ambient light sensor ALS_IR photodiode (see Fig. 3 and 5, refer to ALS_IR = PS). The spectral response of the PS sensor covers the important IR wavelength range from 820 nm to 960 nm, giving the user the freedom to choose the best IR-LED for the particular application. For more information on the typical behaviour of the SFH 7771 in combination with different IR-LEDs please refer to Sec. 10.4 and 10.5.

5.5 PS Persistence Feature

The SFH 7771 features a persistence option. This helps to suppress any potential flickering of the interrupt signal in case an object / signal jitters between the two thresholds (hysteresis), i.e. this functionality smoothens out the transition between interrupt on and off.
The implemented persistence function can be activated in reg. (0x43). Only if n-consecutive measurements fulfil the threshold condition the interrupt is initiated and the interrupt pin is set e.g. low (n can be set to be between 1 and 15). Please note that the two-pulse operation mode (accessible via MODE_CONTROL register (0x41)) in combination with persistence allows two times faster update of the interrupt functionality instead of normal (single pulse) mode operation.

6. Power Consumption

The following equations give an idea on the total power consumption of the SFH 7771 during standard operation at 2.5 V.

By operating the PS in the free-running mode, the current consumption in normal operation mode (single PS pulse mode) can be approximated by the following Eq. (depending on the LED current I_{LED} and the measurement repetition time t_{rep_PS} according to setting in register 0x41):

$$I_{AVG\_PS} \approx 200\mu s \cdot \frac{(I_{LED} + 6.5\,mA)}{t_{rep\_PS}} + 50\mu A \qquad \text{Eq. (2)}$$

The current consumption during operation of the ALS depends on the ALS integration time t_{int_ALS} as well as the ALS repetition time t_{rep_ALS} and can be approximated by:

$$I_{AVG\_ALS} \approx 60\,\mu A + 130\,\mu A \cdot \frac{t_{int\_ALS}}{t_{rep\_ALS}} \qquad \text{Eq. (3)}$$

Example for total PS current consumption (I_{LED} = 100 mA and t_{rep_PS} = 100 ms):
⇨ I_{AVG_PS} ≈ 263 µA (incl. IR-LED current)

Example for total ALS current consumption (T_{int_ALS} = 100 ms and t_{rep_ALS} = 400 ms):
⇨ I_{AVG_ALS} ≈ 92 µA

This compares to a stand-by current consumption of less than 1.5 µA (typ. 0.8 µA).

7 Operating Modes

The SFH 7771 can be operated in different modes:

free-running (ALS and / or PS running alone or simultaneously): The sensor continuously measures and writes the results into the relevant registers, ready to be read via the I²C-bus interface. Optionally the interrupt alert function with the user-defined threshold levels (PS and/or ALS) will be executed if such an event takes place.
stand-by: The initial state after power-up. The SFH 7771 is in low power mode (I_{DD} < 1.5 µA), no operations are carried out, but the device is ready to respond to I²C-bus commands.
additionally, there is the off-state:
off: The SFH 7771 is inactive, supply current is typ. below 0.8 µA. The SDA, SCL and INT pins are in Z-state (high impedance). All register entries are reset to the default values.

The initial start-up time is 2 ms. The typ. voltage V_{DD} to switch the SFH 7771 into the off-state is < 2.0 V. To power the SFH 7771 into the stand-by mode typ. 2.0 V are required.

ADDR pin Voltage Level	I2C Bus Address of SFH 7771
GND	0x38
V_{DD}	0x39

Tab. 3: The I^2C-bus address options of the SFH 7771.

Mode	Bit Rate
Standard mode (Sm)	≤ 100 kbit/s
Fast mode (Fm)	≤ 400 kbit/s

Tab. 4: The I^2C-bus protocol speed mode compatibility of the SFH 7771.

8 I^2C – Bus Communication

The ***I^2C-bus address*** of the SFH 7771 is either ***0x38 or 0x39***, depending on the voltage level of the ADDR pin (see Tab. 3 for details).

8.1 I²C - Bus Environment

The SFH 7771 is a digital ambient light and proximity sensor. The communication is performed via a 2-wire I²C bus interface, so the device can be integrated into a typical multi-master / multi-slave I²C bus environment. A typical I²C bus network consists of a master and different I²C bus slave devices. For a more detailed discussion on the topic of I^2C-bus please refer to [2].
The built-in I^2C-bus interface is compatible with all common I^2C-bus modes (see Tab. 4). The logic voltage (V_{IO}) of the SFH 7771 ranges from 1.65 V – 3.6 V (according to I^2C-bus specification [2]).

8.2 I²C - Bus Communication

By embedding the SFH 7771 in an I²C-bus network and after applying V_{DD} = 2.5 V, the communication can start as follows (Fig. 11 illustrates this I²C-bus conversation):
1. Activation of the ALS and PS:
The default mode of the sensor is STAND-BY and the SFH 7771 needs to be activated by the master (e.g. microcontroller).

Each I²C bus communication begins with a start command “S” of the Master (SDA line is changing from “1” to “0” during SCL line stays “1”) followed by the address of the slave (SFH 7771 address is set to be 0x38 by connecting the ADDR pin to GND). After the 7bit slave address the read (1) or write (0) R/W bit of the master will follow. The R/W bit controls the communication direction between the master and the addressed slave. The slave is responding to a proper communication with an acknowledge command. Acknowledge “A” (or not acknowledge “NA”) is performed from the receiver by pulling the SDA line down (or leave in “1” state).
For the activation of the sensor the master needs to write an activation command (e.g. 0x09 to activate ALS and the PS with T_int_ALS = 100 ms and repetition time of 400 ms and 100 ms for the PS) into the corresponding mode_control register (0x41). Each command needs to be acknowledged by the slave. After activation the master ends the communication with a STOP command “P” (SDA line is changing from LOW to HIGH during SCL line stays HIGH). Additionally the ALS gain is set to 64 and PS current to 200 mA by writing 0x2B into the ALS_PS_Control register (0x42).

2. Sensor in Operation:
After activation, the sensor will change from STAND-BY to FREE-RUNNING mode. After a delay of e.g. 100 ms (depending on T_INT_ALS setting) the first measurement values are available and can be read via the I²C-bus.

3. PS value: reading data (MSB and LSB)
The two byte PS value is accessible via the output registers (0x44 (LSB) and 0x45 (MSB)). After reading the two 8-bit words, the communication can be ended by the master with a not acknowledge “NA” and the stop command “P”. The two byte PS output readings of the SFH 7771 can then be converted to a final decimal PS value via Eq. (4):

1.1 Activate ALS (T_int_ALS = 100 ms, T_rep_ALS = 400 ms) and PS (T_rep_PS = 100 ms)

S	SFH7771 Address (0x38)	W	A	Mode_Control Register (0x41)	A	Activate ALS + PS Mode (0x09)	A	P

1.2 Set Proximity LED Current to 200 mA and ALS Gain to 64

*	S	SFH7771 Address (0x38)	W	A	ALS_PS_Control Register (0x42)	A	ALS Gain + LED Current Mode (0x2B)	A	P

2. Sensor in Operation

3.1 Read Out PS Data (LSB)

S	SFH7771 Address (0x38)	W	A	PS Data Register (0x44)	A	P
S	SFH7771 Address (0x38)	R	A	PS Data (LSB)	NA	P

3.2 Read Out PS Data (MSB)

S	SFH7771 Address (0x38)	W	A	PS Data Register (0x45)	A	P
S	SFH7771 Address (0x38)	R	A	PS Data (MSB)	NA	P

4.1 Read Out ALS_VIS Data (LSB)

S	SFH7771 Address (0x38)	W	A	ALS Data Register (0x46)	A	P
S	SFH7771 Address (0x38)	R	A	ALS Data (LSB)	NA	P

4.2 Read Out ALS_VIS Data (MSB)

S	SFH7771 Address (0x38)	W	A	ALS Data Register (0x47)	A	P
S	SFH7771 Address (0x38)	R	A	ALS Data (MSB)	NA	P

4.3 Read Out ALS_IR Data (LSB)

S	SFH7771 Address (0x38)	W	A	ALS Data Register (0x48)	A	P
S	SFH7771 Address (0x38)	R	A	ALS Data (LSB)	NA	P

4.4 Read Out ALS_IR Data (MSB)

S	SFH7771 Address (0x38)	W	A	ALS Data Register (0x49)	A	P
S	SFH7771 Address (0x38)	R	A	ALS Data (MSB)	NA	P

Communication from Master to SFH 7771

Communication from SFH 7771 to Master

W: Master Writes
R: Master Reads
A: Acknowledge
NA: Not Acknowledge
S: Start Condition
P: Stop Condition
* this line is optional

Fig. 11: I²C-bus communication for the example described below.

$$DATA_{16bit,decimal} = DATA_{LSB} + 256 \cdot DATA_{MSB} \quad \text{Eq. (4)}$$

4. ALS value: reading data (MSB and LSB)

The sensor's two 16bit ALS measurement values are composed of 2 bytes each (LSB & MSB). The bytes are accessible via the

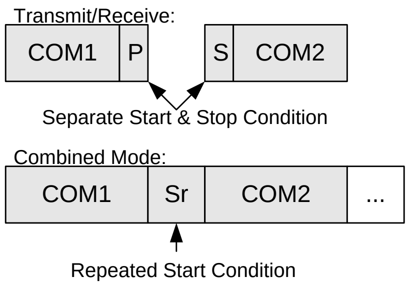


Fig. 12: Combined mode structure.

two output registers (0x46 to 0x49). After addressing the LSB (least significant byte) resp. the MSB (most significant byte) output register, the communication direction has got to be changed from the slave to the master by repeating the address and the R/W byte with a changed R/W bit. After reading LSB and MSB, the communication is ended by the master with a not acknowledge "NA" and the stop condition "P". The conversion of the two byte output data into 16bit values can easily be done by again using Eq. (4).
Finally the true lux value can be obtained from the two ALS data (ALS_VIS, ALS_IR) by using the simple instructions according to Eq. (1).

After finishing the measurement, the SFH 7771 mode may be changed to STAND-BY via the mode_control register.

Combined mode
To ensure interference free communication the I²C-bus combined mode should be used. Instead of performing two independent read or write commands (COM 1 & COM 2) the commands can be combined by a repeated start condition "Sr" (Fig. 12 illustrates the combined mode structure).
The start and repeated start commands ("Sr") are the same: the SDA line is changing from "1" to "0" during SCL line "1". The "Sr" condition is placed behind "A" or "NA". The combined mode is not limited to 2 read/write commands, so the addressing of the sensor and reading/writing of multiple register values can be performed within one block.

Block read/write mode
The Block read/write mode of the SFH 7771 can be used to read all output registers in cyclic manner.

After addressing and reading an output register (e.g. LSB) in normal mode, the master is not placing the stop condition, but sends an acknowledge and continues to read the output registers. The SFH 7771 will automatically increase the register address and the content of the next sensor output register can be read following the register addresses:
0x40→0x41→…→0x51→0x52→0x40→...
For register addresses and content see Sec. 8.3 and Tab. 5.
The block read mode can be ended by placing a not acknowledge (NA) with the subsequent stop condition from the master.

8.3 Registers

The SFH 7771 has 19 different registers (see Tab. 5).
The following pages will describe the registers and their structure resp. content.

I²C Addr	Type	Name	Description
0x40	R/W	SYSTEM_CONTROL	System Control
0x41	R/W	MODE_CONTROL	ALS and PS General Control
0x42	R/W	ALS_PS_CONTROL	ALS Gain and PS Current Control
0x43	R/W	PERSISTENCE	PS Interrupt Persistence Control
0x44	R	PS_DATA_LSB	LSB data for PS
0x45	R	PS_DATA_MSB	MSB data for PS
0x46	R	ALS_VIS_DATA_LSB	LSB data for ALS_VIS - diode
0x47	R	ALS_VIS_DATA_MSB	MSB data for ALS_VIS - diode
0x48	R	ALS_IR_DATA_LSB	LSB data for ALS_IR - diode
0x49	R	ALS_IR_DATA_MSB	MSB data for ALS_IR - diode
0x4A	R/W	INTERRUPT_CONTROL	Interrupt Control
0x4B	R/W	PS_TH_LSB	PS interrupt up threshold level, LSB
0x4C	R/W	PS_TH_MSB	PS interrupt up threshold level, MSB
0x4D	R/W	PS_TL_LSB	PS interrupt low threshold level, LSB
0x4E	R/W	PS_TL_MSB	PS interrupt low threshold level, MSB
0x4F	R/W	ALS_VIS_TH_LSB	ALS_VIS interrupt up threshold level, LSB
0x50	R/W	ALS_VIS_TH_MSB	ALS_VIS interrupt up threshold level, MSB
0x51	R/W	ALS_VIS_TL_LSB	ALS_VIS interrupt low threshold level, LSB
0x52	R/W	ALS_VIS_TL_MSB	ALS_VIS interrupt low threshold level, MSB

Tab. 5: SFH 7771 control and data registers.

SYSTEM_CONTROL: The SYSTEM_CONTROL register is used to control the software (SW) reset and the interrupt function (INT). Manufacturer ID and Part ID can be read.

RW-Register 0x40										
Bit	7		6		5	4	3	2	1	0
	SW reset		INT reset		Manufacturer ID (read only)			Part ID (read only)		
default	**0**	**Initial rest is not started**	**0**	**INT pin status is not initialized**	**001**			**001**		
	1	Initial reset started	1	INT pin become inactive (high impedance)						

MODE_CONTROL: Mode CONTROL for PS operating modes and time settings. Normal ALS measurement time is 100 ms. High sensitive ALS mode is with a true measurement time of 400 ms (=t_{int_ALS}). The 50 ms ALS integration time setting (1100) might lead to susceptibility to flicker and requires additinal functionality in the software. This setting is not recommended by OSRAM OS.

RW-Register 0x41							
Bit	7 6 5	4		3	2	1	0
	Reserved (read only)	PS Mode		Measurement Repetition Rate			
					ALS	PS	
default		**0**	**normal**	**0000**	**standby**	**standby**	
		1	two-pulse mode	0001	standby	10 ms	
				0010	standby	40 ms	
				0011	standby	100 ms	
				0100	standby	400 ms	
				0101	100 ms (=t_{int_ALS})	standby	
				0110	100 ms (=t_{int_ALS})	100 ms	
				0111	100 ms (=t_{int_ALS})	400 ms	
				1000	400 ms (t_{int_ALS}= 100ms)	standby	
				1001	400 ms (t_{int_ALS}= 100ms)	100 ms	
				1010	400 ms (=t_{int_ALS})	standby	
				1011	400 ms (=t_{int_ALS})	400 ms	
				1100	50 ms (=t_{int_ALS}) *)	50 ms	
				else	forbidden		

*) to apply the 50 ms setting the following software handling of the ALS data is necessary before lux calculation can be performed (as bit # (15) indicates data overflow in 50 ms mode). Note that the max. count in 50 ms is 0x7FFF (15 bit long instead of 16):

```
If (ALS_VIS & 0x8000) == 0x8000   // bitwise AND to identify the overflow flag in bit 15 of ALS_VIS
        {ALS_VIS = 0x7FFF;}
If (ALS_IR & 0x8000) == 0x8000    // bitwise AND to identify the overflow flag in bit 15 of ALS_IR
        {ALS_IR = 0x7FFF;}
```

ALS_PS_CONTROL: Control to set the PS output, the ALS Gain and the LED current.

R/W-Register 0x42								
Bit	7	6	5	4	3	2	1	0
	Reserved (read only)	PS Output	ALS Gain for ALS VIS and ALS IR				LED Current	

Field	Bits	Default	Description	
Reserved	7	**0**	**0**	**Write 0**
PS Output	6	**0**	**0**	**Proximity output**
			1	Infrared DC level output
ALS Gain	5:2	**0000**	**0000**	**ALS VIS: x 1 ALS IR: x 1**
			0100	ALS VIS: x 2 ALS IR: x 1
			0101	ALS VIS: x 2 ALS IR: x 2
			1010	ALS VIS: x 64 ALS IR: x 64
			1110	ALS VIS: x 128 ALS IR: x 64
			1111	ALS VIS: x 128 ALS IR: x 128
			else	forbidden
LED Current	1:0	**11**	**11**	**200 mA**
			00	25 mA
			01	50 mA
			10	100 mA

PERSISTANCE: Settings of persistence interrupt function and interrupt status.

RW-Register 0x43								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	Reserved (read only)				**Persistence**			
default	**0000**				**0001**	**Interrupt status updated after each measurement**		
					0000	Interrupt becomes active after each measurement		
					0001	Interrupt status updated after each measurement		
					0010	Interrupt status is updated if two consecutive threshold judgement are the same		
					0011 or higher	Interrupt status is updated if threshold judgement are the same over n-consecutive times (n is set in bits (0:3))		

PS_DATA_LSB: LSB of the PS output.

R-Register 0x44								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data							
default	**0000 0000**							

PS_DATA_MSB: MSB of the PS output.

R-Register 0x45								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data							
default	**0000 0000**							

ALS_VIS_DATA_LSB: LSB of the ALS VIS output.

R-Register 0x46								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data							
default	**0000 0000**							

ALS_VIS_DATA_MSB: MSB of the ALS VIS output.

R-Register 0x47								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data							
default	**0000 0000**							

ALS_IR_DATA_LSB: LSB of the ALS IR output.

R-Register 0x48								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data							
default	**0000 0000**							

ALS_IR_DATA_MSB: MSB of the ALS IR output.

R-Register 0x49								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data							
default	**0000 0000**							

INTERRUPT_CONTROL: Setting of the interrupt functions.

R/W-Register 0x4A								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	PS INT Status (read only)	**ALS INT Status (read only)**	**INT Mode**		**INT assert**	**INT latch**	**INT trigger**	

Field	**Bits**	**Default**	**Description**	
PS INT status	7	**0**	**0**	**PS interrupt signal inactive**
			1	PS interrupt signal active
ALS INT status	6	**0**	**0**	**ALS VIS interrupt signal inactive**
			1	ALS VIS interrupt signal active
INT mode	5:4	**00**	**00**	**PS_TH is only active**
			01	PS_TH & PS TL are active (Hysteresis)
			10	PS_TH & PS TL are active as outside detection
			11	forbidden
INT assert	3	**0**	**0**	**INT "L" is stable if newer measurement results is also interrupt active**
			0	INT "L" is de-assert and re-assert if newer measurement results is also interrupt active
INT latch	2	**0**	**0**	**INT is latched until INT register is read or initialized**
			1	INT is updated after each measurement
Interrupt mode	1:0	**00**	**00**	**INT pin is inactive**
			00	Triggered by PS only
			10	Triggered by ALS VIS only
			11	Triggered by PS or ALS only

Note: Bits 6 & 7 (interrupt inactive / active) are reset as soon as register 0x4A is read. This is also valid for the INT-pin (becomes inactive as soon as register 0x4A is read).

PS_TH_LSB: LSB for the PS threshold „HIGH".

RW-Register 0x4B								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data (upper threshold)							
default	**1111 1111**							

PS_TH_MSB: MSB for the PS threshold „HIGH".

RW-Register 0x4C								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data (upper threshold)							
default	**1111 1111**							

PS_TL_LSB: LSB for the PS threshold „LOW".

RW-Register 0x4D								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data (lower threshold)							
default	**0000 0000**							

PS_TL_MSB: MSB for the PS threshold „LOW".

RW-Register 0x4E								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data (lower threshold)							
default	**0000 0000**							

ALS_VIS_TH_LSB: LSB for the ALS_VIS threshold „HIGH".

RW-Register 0x4F								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data (upper threshold)							
default	**1111 1111**							

ALS_VIS_TH_MSB: MSB for the ALS_VIS threshold „HIGH".

RW-Register 0x50								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data (upper threshold)							
default	**1111 1111**							

ALS_VIS_TL_LSB: LSB for the ALS_VIS threshold „LOW“.

RW-Register 0x51								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	LSB data (lower threshold)							
default	**0000 0000**							

ALS_VIS_TL_MSB: MSB for the ALS_VIS threshold „LOW“.

RW-Register 0x52								
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
	MSB data lower threshold)							
default	**0000 0000**							

9 Interrupt Alert

The SFH 7771 provides an interrupt pin which can be configured completely by the user (access via register 0x4A). E.g. the interrupt function can be configured to operate in latched or normal mode. In normal mode the interrupt event/signal is updated after every measurement, whereas in the latched mode it is guaranteed that even single peaks are detected (e.g. the interrupt is held as long as the microcontroller reads out the interrupt register). Other options include the selection of the interrupt trigger source (PS or/and ALS) as well as the option of having PS hysteresis (e.g. in combination with a persistence function) and/or an ALS_VIS event window (upper and lower ALS VIS threshold). For the exact interrupt event definition please refer to Tab. 6. This is especially valuable as it allows the SFH 7771 to operate as stand alone device in the *free-running mode,* independent from the main microcontroller. This functionality relieves the microcontroller from active involvement in the PS / ALS monitoring resp. measurement cycle and reduces significantly the I^2C-bus traffic, thus reducing the overall power consumption of the system. Only if the user-defined thresholds are violated, the interrupt signal will inform

Interrupt Event Definition		
proximity sensor	Without Hysteresis:	
	ON:	PS data > PS_TH (threshold high)
	OFF:	PS data < PS_TH (threshold high)
	With Hysteresis:	
	ON:	PS data > PS_TH (threshold high)
	OFF:	PS data < PS_TL (threshold low)
ambient light sensor	Interval:	
	ON:	ALS_VIS > ALS_VIS_TH (threshold high) *or* ALS_VIS < ALS_VIS_TL (threshold low)
	OFF:	ALS_VIS_TL < ALS_VIS < ALS_VIS_TH

Tab. 6: Interrupt event definition. Note that the on/off definition of the PS can be inverted by user setting within register (0x4A) to allow switching from inside target to outside target detection.

the microcontroller and the predefined actions can be executed (e.g. after optional read-out of the interrupt and PS / ALS data registers to get the actual data - if desired).

Note: Interrupt pin level and bits 6 & 7 of register 0x4A (Interrupt register) are reset as soon as interrupt register 0x4A is read.

10 Design-in Guidelines

By implementing the SFH 7771 behind a (dark) cover glass, a few issues need to be taken into account:

- ALS: ambient light calculation
- PS: maximum detection distance
- PS: IR-LED selection
- PS: crosstalk due to cover glass
- ALS & PS: aperture design

The following Sections deal with these issues and give the designer valuable guidelines to achieve the maximum performance of the sensor.

10.1 Implementing the Illumination (Lux) Calculation: General Procedure

The design of the sensor allows computing from the two ALS data sets (ALS_VIS and ALS_IR) the “true” ALS value in front of a (“dark”) cover glass.

In general the calculation of the lux value is based on a set of equations which are typically derived by measurements and some mathematics. This set of equations looks like:

```
IF (ALS_IR / ALS_VIS) < r_0
    LUX = (a_0 * ALS_VIS / GAIN_VIS
          - b_0 * ALS_IR / GAIN_IR)

 ELSE IF (ALS_IR / ALS_VIS) < r_1
    LUX = (a_1 * ALS_VIS / GAIN_VIS
          - b_1 * ALS_IR / GAIN_IR )

 ELSE IF (ALS_IR / ALS_VIS) < r_2
    LUX = (a_2 * ALS_VIS / GAIN_VIS
          - b_2 * ALS_IR / GAIN_IR )

 ELSE IF (ALS_IR / ALS_VIS) < r_3
    LUX = (a_3 * ALS_VIS / GAIN_VIS
          - b_3 * ALS_IR / GAIN_IR )

Else LUX = 0

LUX = LUX * 100 ms / T_INT_ALS
```

Eq. (5)

The first case (indicated by ***ALS_IR / ALS_VIS < r_0***) covers e.g. LED, fluorescence and sunlight based lighting situations. The second case (***< r_1***) handles incandescent and halogen lamps, whereas cases three (***< r_2***) and four (***< r_3***) cover dimmed halogen and incandescence lamps, characterized by increased IR content.

The way to obtain the parameters of the equations is governed by four steps:

1) measurement under different lighting conditions
2) harmonization of results and plotting
3) grouping and linear approximation
4) derive set of final equations for illumination calculation

In the following pages this procedure is described in more detail:

1) Based on a setup according to Fig. 13 the illumination value $E_{v\_Measured}$ (in lux) in front of the cover is recorded in parallel to the readings of ALS_VIS resp. ALS_IR (with appropriate settings of ALS gain to avoid saturation resp. too low counts). This needs to be performed with various different light sources

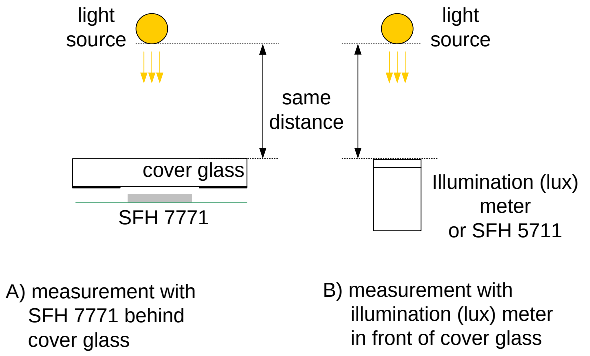


Fig. 13: Measurement setup for deriving the required equations to calculate the illumination (lux) value out of ALS_VIS, ALS_IR.

2) The next step comprises a harmonization of the results. A recommended approach is to normalize all measurements to e.g. 100 ms, unity gain (Gain ALS_VIS = Gain ALS_IR = 1) and to identical illumination value E_{v_norm} (e.g. 1 lux).
In essence it means to normalize the measured ALS_VIS and ALS_IR data by using:

$$ALS\_VIS = \frac{ALS_{VIS\_MEASURED}}{E_{v\_Measured}(in\ lux)} \cdot \frac{100\,ms}{T_{INT\_ALS} \cdot GAIN_{VIS}}$$

Eq. (6)

$$ALS\_IR = \frac{ALS_{IR\_MEASURED}}{E_{v\_Measured}(in\ lux)} \cdot \frac{100\,ms}{T_{INT\_ALS} \cdot GAIN_{IR}}$$

Eq. (7)

The obtained data points from Eqs. (6) and (7) are now plotted into a diagram (ALS_IR vs. ALS_VIS) like in Fig. 14.

3) The next step is to group the data points together like seen in Fig. 14 and derive the linear approximation equation for each group. Recommended grouping / linearization should combine light sources with similar properties, e.g. combine white LEDs and fluorescence lamps. Next group could be halogen and traditional incandescent lamps. The final group(s) could be dimmed incandescent light sources as their IR/VIS ratio is the highest.

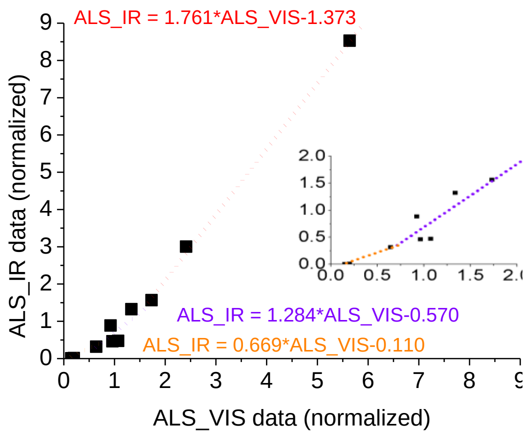


Fig. 14: Graph representing the normalized ALS data points (according to Eq. (6) and (7)). The linear approximation is done here with e.g. three linear segments and corresponds to a cover glass according to Fig. 15. Inset: Zoomed area at low ALS data.

The mathematical syntax is as follows for the linear approximation (resulting in N+1 equations):

Group 0:
$ALS_{IR} = c_0 \cdot ALS_{VIS} - d_0$
Group 1:
$ALS_{IR} = c_1 \cdot ALS_{VIS} - d_1$
…
Group N:
$ALS_{IR} = c_N \cdot ALS_{VIS} - d_N$

Eq. (8)

4) Now the linearization Eqs. (8) are compared with the original illumination (lux) Eqs. to derive the constant values:

Group 0:
$LUX = a_0 \cdot ALS\_VIS - b_0 \cdot ALS\_IR$
Group 1:
$LUX = a_1 \cdot ALS\_VIS - b_1 \cdot ALS\_IR$
….
Group N:
$LUX = a_N \cdot ALS\_VIS - b_N \cdot ALS\_IR$ Eq. (9)

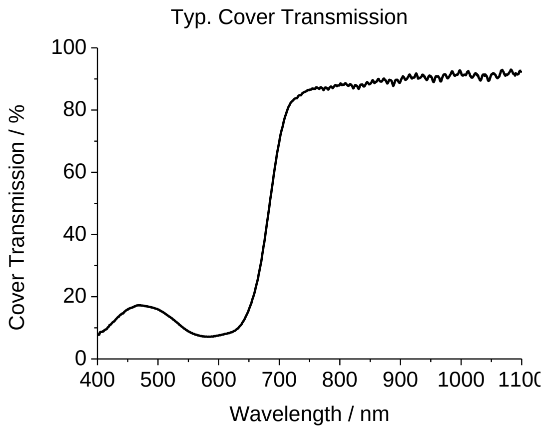


Fig. 15: Typ. cover glass transmission characteristics.

The two sets of equations (8 and 9) can be solved to determine the constant values a_N resp. b_N. The result is as follows with E_{v_norm} as the normalized illumination in lux (i.e. E_{v_norm} = 1 lx; according to step 3).

$$a_i = E_{v\_norm} \cdot c_i / d_i \qquad \text{Eq. (10)}$$

$$b_i = E_{v\_norm} / d_i \qquad \text{Eq. (11)}$$

The constant values (a, b) in Eqs. (9) are now determined. The last step is to define the threshold level r_N at which point one equation is replaced by the next one:

$$r_0 = \frac{ALS\_IR}{ALS\_VIS} = \frac{(a_0 - a_1)}{(b_0 - b_1)}$$

$$r_1 = \frac{ALS\_IR}{ALS\_VIS} = \frac{(a_1 - a_2)}{(b_1 - b_2)}$$

$$\ldots$$

$$r_N = \frac{ALS\_IR}{ALS\_VIS} = \frac{(a_N - 0)}{(b_N - 0)}$$

Eq. (12)

The final instruction set for implementation now need to take again into account any different settings (gain and ALS integration time) under which the sensor is operated and look like:

```
IF (ALS_IR / ALS_VIS) < r_0
    LUX = (a_0 * ALS_VIS / GAIN_VIS
          - b_0 * ALS_IR / GAIN_IR)

 ELSE IF (ALS_IR / ALS_VIS) < r_1
    LUX = (a_1 * ALS_VIS / GAIN_VIS
          - b_1 * ALS_IR / GAIN_IR )

 ELSE IF (ALS_IR / ALS_VIS) < r_2
    LUX = (a_2 * ALS_VIS / GAIN_VIS
          - b_2 * ALS_IR / GAIN_IR )

 ELSE IF (ALS_IR / ALS_VIS) < r_3
    LUX = (a_3 * ALS_VIS / GAIN_VIS
          - b_3 * ALS_IR / GAIN_IR )

Else LUX = 0

LUX = LUX * 100 m / T_INT_ALS
```

Eq. (13)

Note 1: the above threshold condition via r_N is valid for having equal gain setting between GAIN_VIS and GAIN_IR in the application. If gain is set unequal, the threshold levels r_N need to be divided by a factor of two.

Note 2: To achieve the necessary accuracy during this procedure it is mandatory not to change the number of decimal places or in other words not to change the accuracy of the numbers.

10.2 Implementing the Illumination (Lux) Calculation: Example

Next is a ***practical example*** with a cover glass featuring transmission characteristics according to Fig. 15.

1) Measuring of the ALS data according to the setup in Fig. 13 (see Tab. 7).
2) Normalization according to Eqs. (6) and (7) and data point plotting (see Tab. 7 and Fig. 14).
3) In this case a three-segment linear approximation (see Fig. 14) has been chosen.
4) Deriving the final constants / equations - Eqs. (10) to (12) - like previously described:

	Fluorescence Lamp	White LED	Halogen Lamp	Incand. Lamp	Dimmed Incand. Lamp	Dimmed Halogen Lamp	Sunlight
Illumination in Front of Cover / lux	128	6750	245	185	118	26	100000
Gain Setting	128	2	64	2	2	128	1
ALS_VIS_measured	3250	2550	20900	640	1330	8030	64000
ALS_IR_measured	202	66	20800	580	2013	10000	32000
	↓	↓	↓ via Eqs. (6) and (7)	↓		↓	↓
ALS_VIS *)	0.198	0.189	1.333	1.730	0.959	2.413	0.640
ALS_IR *)	0.012	0.005	1.327	1.568	0.464	3.005	0.320

Tab. 7: Example of measured ALS data for various light sources and their normalized values (measured behind a cover with transmission characteristics according to Fig. 15).
**) normalized to 1 lux and gain = 1.*

Cover Glass Transmission (at IR)	Corresponding Detection Distance (Approximation)
100 % (no glass)	100 %
90 % (clear glass)	90 %
x %	x %

Tab. 8: Impact of one-way cover glass (IR-) transmission on PS detection range (assuming a sufficiently large reflector size).

```
IF (ALS_IR / ALS_VIS) < 0.522
    LUX = (6.082 * ALS_VIS / GAIN_VIS
          - 9.091 * ALS_IR / GAIN_IR)

 ELSE IF (ALS_IR / ALS_VIS) < 0.945
    LUX = (2.253 * ALS_VIS / GAIN_VIS
          - 1.754 * ALS_IR / GAIN_IR)

ELSE IF (ALS_IR / ALS_VIS) < 1.761
    LUX = (1.283 * ALS_VIS / GAIN_VIS
          - 0.728 * ALS_IR / GAIN_IR)

Else LUX = 0

LUX = LUX * 100 ms / T_INT_ALS
```

Eq. (14)

The typical accuracy of this implementation is around ± 20% for various light sources (behind the cover glass with transmission characteristics according to Fig. 15).

10.3 Proximity Sensor Detection Distance behind a Dark Cover Glass

Implementing the sensor behind a dark cover glass influences directly the detection range of the sensor.

It is important to mention that a reduced IR transmission (at 850 nm or 940 nm) through a dark cover glass also reduces the maximum detection distance (compared to the case that the sensor is operated without any cover).
As light from the sensor passes the cover glass twice (on the way to the target plus on its way back to the sensor) it reduces the proximity signal *PS* at sensor site by ~ T^2 with T as the one way cover transmission (e.g. T = 0.9 for 90 %). For most scenarios the relationship between proximity signal *PS* and detection distance d is: $PS \sim 1/d^2$ (see also Fig. 8 to 10). Combining both relations results in: $PS \sim T^2/d^2$. To achieve the same sensor signal level (i.e. counts) means that the max. detection distance is reduced by the same percentage as the cover glass' one way transmission. As a rule of thumb, an x % one way transmission loss reduces the detection range by around x % as well (compared to not using any cover glass at all). Please refer to Tab. 8 for an approximate relationship between detection distance (e.g. threshold) and cover glass IR transmission.

To compensate for, it is recommended to increase the LED current or/and lower the PS threshold level in the relevant register.

10.4 IR-LED Selection: IR-LED Type

The selection of an appropriate IR-LED depends strongly on the application profile. Key issues (among others) are: target detection range, target size, IR-LED radiant intensity and geometrical constraints (package size, height).
Tab. 9 presents estimations on the gain in detection distance one can achieve using different IR-LED types. Please note that this is only a rough overview. There are many more IR-LEDs available (refer to the www.osram-os.com for an update of the latest available IR-LEDs). Please see also Figs. 16 to 26 for reference. To achieve maximum performance it is mandatory to avoid any optical crosstalk between emitter and the SFH 7771 sensor (please refer to Sec. 10.7 for more details).

In any case, OSRAM recommends evaluating the impact of different LEDs as target size and target distance strongly impact the detection distance.

Note 1: The SFH 4059S contains a stacked emitter chip – which increases the intensity but also doubles the forward voltage.

Note 2: Narrow angle emitter might lead to a narrow detection area (see Fig. 16) compared to wide angle emitters.

10.5 IR-LED Selection: Wavelength (850 nm vs. 940 nm)

In general the SFH 7771 is around 15 % less sensitive at 940 nm compared to 850 nm (1.5 µW/cm² per count vs. 1.7 µW/cm² per count). Thus 850 nm leads in a first consideration to a slightly larger detection range (i.e. more efficient). In addition, IR-LEDs at 940 nm have typ. around 10 % less radiant power (mW) compared to their 850 nm counterparts. This leads to an overall system performance reduction of up to around 25 % at 940 nm vs. 850 nm resp. around 15 % in detection distance. (This is based on the proximity signal $PS \sim P_{IR\text{-}LED} / S$, with S as the detectors min. sensitivity (i.e. 1.5 µW/cm² vs. 1.7 µW/cm²). Usually the PS signals dependence on the target distance can be assumed to be $PS \sim 1/d^2$. Combined this relates to $PS \sim P_{IR\text{-}LED} / (S \cdot d^2)$ and leads to around 15 % less detection distance at 940 nm compared to 850 nm (see also Sec. 10.3)). But on the other side there are several reasons which might favour a 940 nm IR-LED.

One of them is the so called “red”-glow effect. In some applications this effect needs to be avoided due to aesthetic reasons. In this case a move to a 940 nm emitter might be justified. It provides a reduction of “red” glow roughly by a factor of 75. Anyway, the SFH 7771 features a very short LED-on time of only 200 µs per cycle to minimize this effect already at 850 nm.

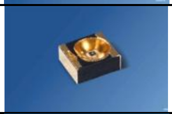
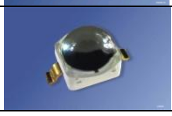
The second reason might be the implementation behind a dark cover glass. Nearly all dark, IR-transmitting inks (cover glasses) in use have higher transmittance at 940 nm compared to 850 nm (see also Fig. 15). This might actually more than compensate for the sensitivity loss (as long as radiant intensity is equal) as soon as the one way transmission ratio of the cover glass / ink justifies

$$\frac{Tx\,@\,950\,nm}{Tx\,@\,850\,nm} > 1.07 \qquad \text{Eq. (15)}$$

where Tx is the transmission of the ink.

A third issue might be crosstalk caused by Rayleigh-scattering inside the dark, IR-transmissive ink, which is typ. at least around a factor of two lower at 940 nm compared to 850 nm (scattering ~ λ^{-4}).

OSRAM Opto Semiconductors

LED	Package	Package Type	Gain in Detection Distance at same Forward Current (approx.)	Half-Angle / deg	Typ. Rad. Intensity / mW/sr	Component Height / mm
SFH 4650 SFH 4655 (850 nm)		MIDLED *(qualified for use in automotive)*	x 1.0	± 15	65 @ 100 mA	1.60
SFH 4451 (850 nm)		MiniMIDLED	x 1.0	± 17	60 @ 100 mA	0.90
SFH 4059 (850 nm)		ChipLED	x 1.0	± 10	100 @ 70 mA	1.85
SFH 4059S (850 nm)		ChipLED w. stacked emitter	x 1.3	± 15	130 @ 70 mA	1.85
SFH 4555 (850 nm)		Radial	x 1.2	± 5	550 @ 100 mA	7.9
SFH 4550 (850 nm)		Radial	x 1.4	± 3	900 @ 100 mA	9.0
SFH 4640 SFH 4645 (940 nm)		MIDLED *(qualified for use in automotive)*	x 0.9	± 15	60 @ 100 mA	1.60
SFH 4441 (940 nm)		MiniMIDLED	x 0.9	± 17	55 @ 100 mA	0.90
SFH 4045 (940 nm)		ChipLED	x 0.8	± 9	90 @ 70 mA	2.5
SFH 4545 (940 nm)		Radial	x 1.2	± 5	550 @ 100 mA	7.9
SFH 4783 (850 nm)		Power Emitter	x 1.2…1.5	± 12	2400 @ 1000 mA	5.7

Tab. 9: Table of selected 850 nm and 940 nm emitter devices. The relative gain in detection distance (in comparison to a SFH 4650) is a rough approximation and assumes driving the LEDs with identical current. The spacing between emitter and SFH 7771 is 13 mm (Note that the achievable gain depends also on target size, reflectivity, and distance as well as on the transmission of any cover glass. The above LEDs also have different radiation characteristics impacting the detection area).

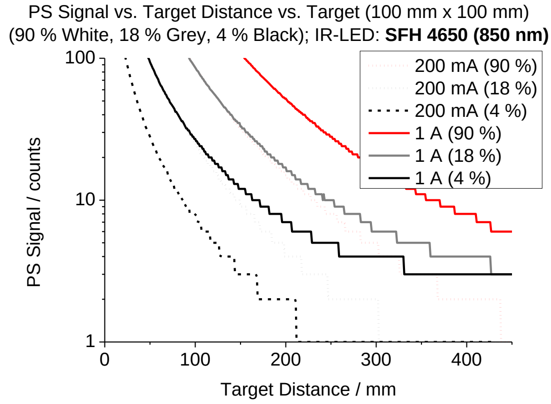


Fig. 16: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4650.

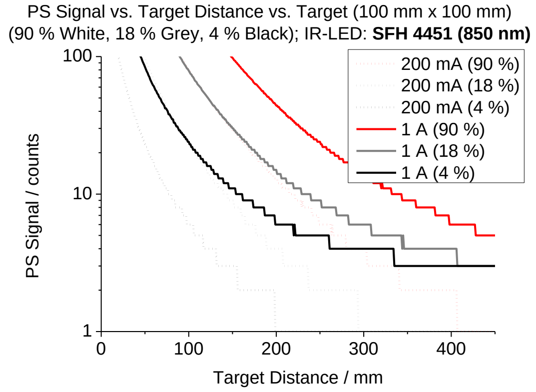


Fig. 17: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4451.

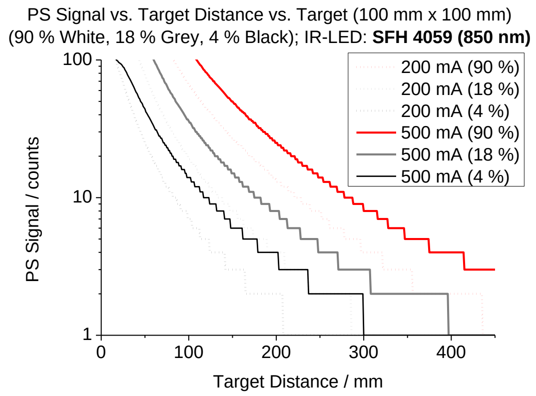


Fig. 18: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4059.

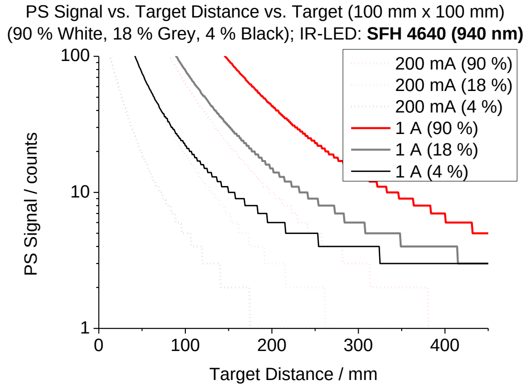


Fig. 19: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4640.

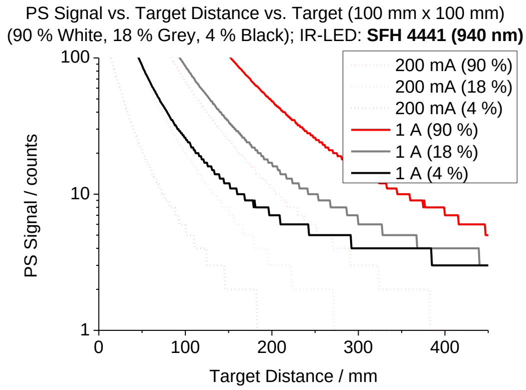


Fig. 20: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4441.

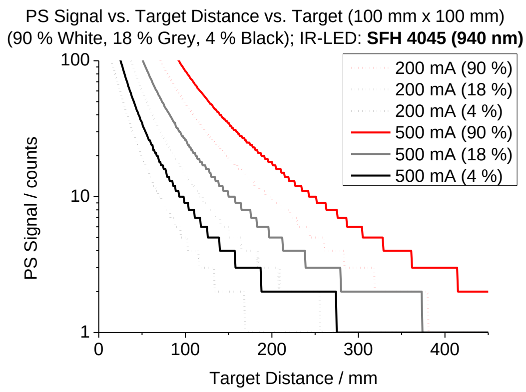


Fig. 21: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4045.

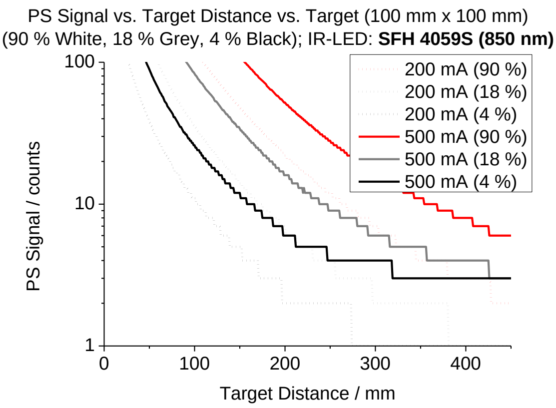


Fig. 22: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4059S.

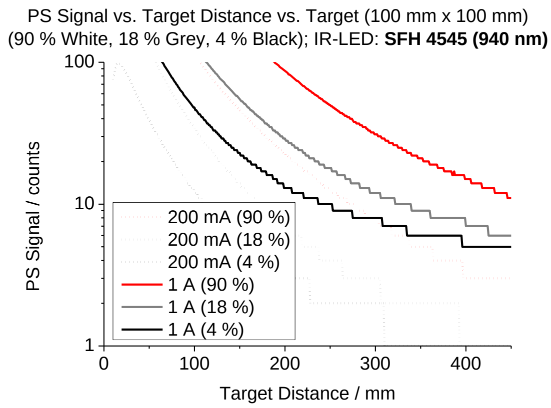


Fig. 25: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4545.

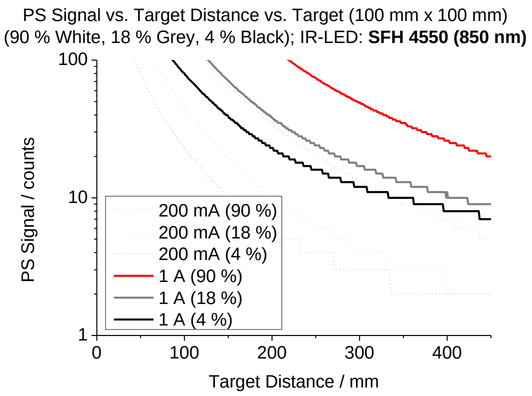


Fig. 23: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4550.

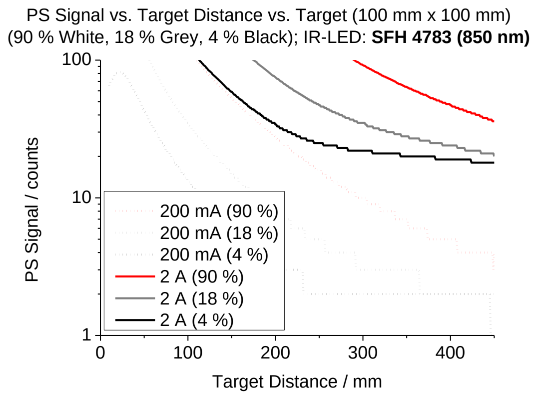


Fig. 26: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4783.

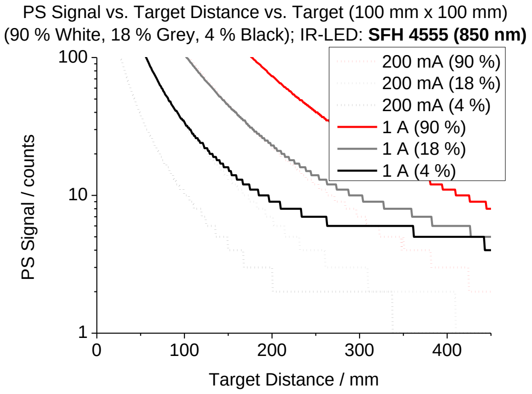


Fig. 24: Proximity sensor signal count vs. IR-LED drive current vs. target reflection for SFH 4555.

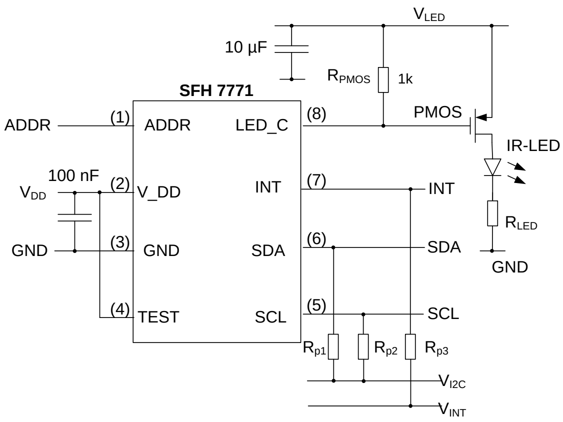


Fig. 27: Driving an IR-LED with an external circuit.

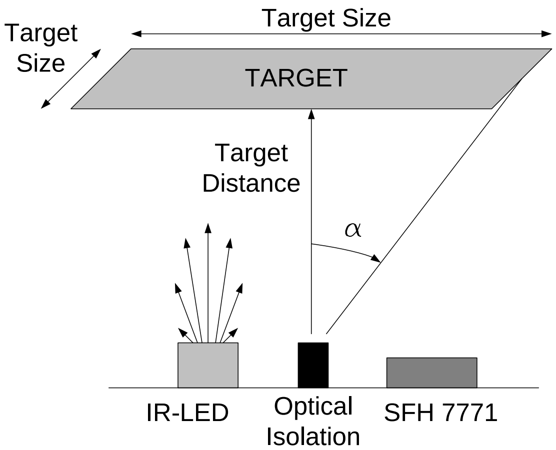


Fig. 28: Typical proximity setup.

Another topic might be that the so called 'blind spot' or black hair problem might be easier to tackle at 940 nm due to higher reflectivity of black hair/dark skin at 940 nm vs. 850 nm.

10.6 Ultra-Long Detection Range: Driving the IR-LED beyond 200 mA

There can be various reasons to operate the IR-LED via an external driver. One might be the need for larger detection distances, subsequently resulting in an IR-LED operation beyond the sensors direct driving capability of 200 mA.
Alternative options to increase the detection distance without external driver (higher LED current) is to use more than one LED in series or LEDs using a stacked emitter. Last but not least an external lens on top of the SFH 7771 can also increase the overall detection distance on the expense of added package height.

Depending on the desired target size and distance the use of narrow angle / high radiant intensity LEDs might also help to improve the situation. These LEDs include - but are not limited to - SFH 4059S (stacked LED) and SFH 4550 (radial), see Tab. 9.

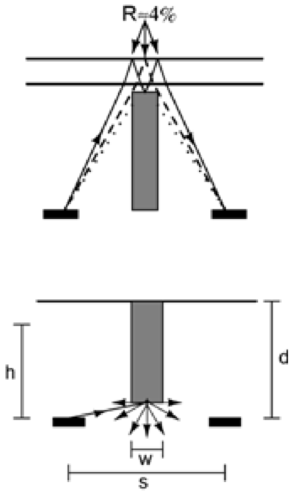


Fig. 29: Typical sources of optical crosstalk. Top: Crosstalk via cover glass & separators top surface. Bottom: Crosstalk via bottom side of a separator.

The circuit in Fig. 27 presents an easy to realize solution for driving an IR-LED beyond 200 mA. It features a high-speed PMOS-FET as a logic switch. R_{PMOS} adjusts the threshold according to $V_{GS(th)}$ of the PMOS-FET. For the FET a V_{GS} < -2.0 V should be sufficiently conductive to support the desired LED current (e.g. R_{PMOS} = 1 k).

The LED peak pulse current is simply set via V_{LED} (limited by the SFH 7771 to max. 5.5 V), R_{LED} and V_{SD} of the FET.

Using e.g. the setup in Fig. 27 with the NX2301P PMOS FET with V_{LED} = 4.7 V, R_{LED} = 1.7 Ω and the SFH 4650 would result in a pulse current of approximately 1000 mA.

Fig. 16 to 26 present typical PS counts vs. target distance graphs for various target reflectivities obtained with the circuit in Fig. 27.

Depending on the setup, i.e. the angle α (refer to Fig. 28 for definition), ***the SFH 4550 provides the best solution at 850 nm***, but focuses on a very small target area (α < 5°).

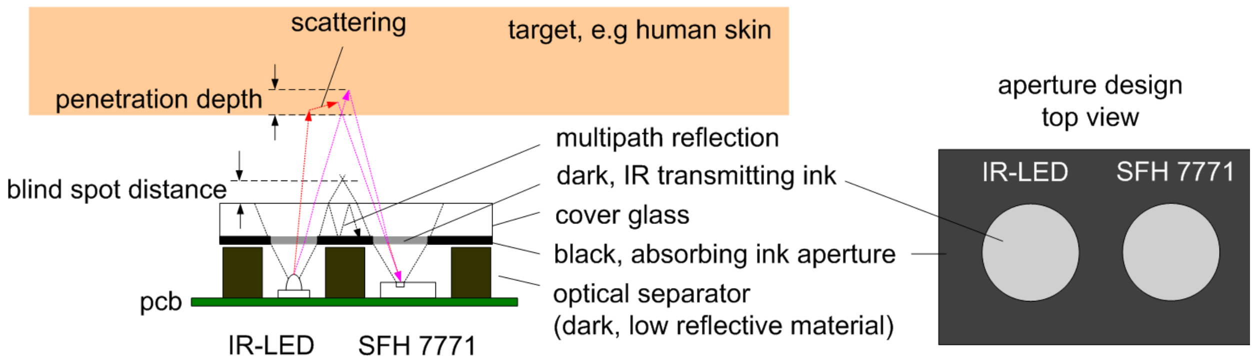


Fig. 30: Typical setup to avoid optical crosstalk by using a two-hole aperture design and optical separators. The blind spot ensures that the cover glass doesn't cause any crosstalk. On the other side the blind spot should be minimized to allow zero-distance detection (see Sec. 10.8). The penetration depth into e.g. human skin helps to overcome the blind-spot issue and ensure zero-distance detection. Note: The central (black, absorbing) area between the two circular aperture holes must be wide enough to suppress multipath reflection (especially important if large detection distances are desired).

OSRAM recommends evaluating the impact of different IR-LEDs as target size and target distance strongly influences the detection distance and area.

10.7 Optical Crosstalk

One of the biggest challenges designers face in implementing a proximity sensor behind a glass is optical crosstalk. In this section, several sources of crosstalk and actions to avoid / minimize any crosstalk are discussed.

Usually, the IR-LED and the SFH 7771 are operated behind a cover glass, which has a reflectivity of typically 4% at each glass-air interface. If there is an air gap between the IR-LED / SFH 7771 and the glass, a considerable portion of light gets reflected directly to the detector by the glass surfaces, see Fig. 29. In extreme cases, the signal reflected via the cover glass exceeds the signal of interest. The result is a decreased operating range for the detection distance. In general, the signal of interest should exceed the noise floor / crosstalk. Crosstalk often depends on the mechanical arrangement and may vary from setup to setup which makes it difficult to define a general threshold.

The crosstalk can be reduced by introducing a separator between IR-LED and the detector, see also Fig. 30. A careful design of separator (width, height) in combination with e.g. a two-hole aperture can eliminate the crosstalk. Any minor remaining crosstalk may be suppressed by offset subtraction (but may vary from cover glass to cover glass).

Additional sources of crosstalk:

a) Since the reflection of the IR light occurs not only at the bottom surface of the cover, but also on the top side, a separator design is recommended, which is blocking both reflections. The separator material should be absorbing and preferably diffusely reflecting. This also leads to the attenuation of multiple reflected light.

b) If an air gap between separator and cover glass exists, additional light paths between emitter and detector may be created. Especially, when the surface of the separator is reflective, light from the emitter may reach the detector via multiple reflections (see also Fig. 29 and 30). In order to avoid this, the surface of the separator should be diffusely reflective.

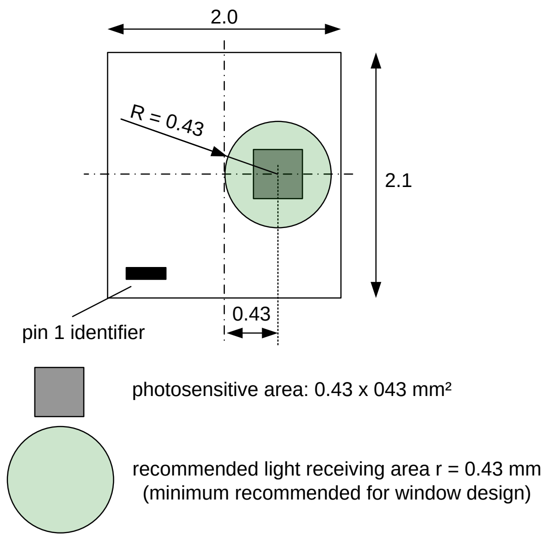


Fig. 31: Location of the photosensitive area of the SFH 7771.

Additionally, it should be placed as close to the cover glass as possible.

c) If there is a gap between the separator and the PCB upon which the IR-LED and the SFH 7771 are mounted, some reflection may occur also at the bottom of the separator. The height of this air gap should be minimized as well.

d) Depending on the quality and scattering properties of any dark, IR transmissive ink on the bottom side of the cover glass, additional crosstalk may be caused by this ink. To overcome such problems it is recommended to use aperture holes where the ink is only located above the emitting IR-LED resp. SFH 7771. Two separate circular apertures are preferable (see Fig. 30) compared to one oval aperture covering the IR-LED and the SFH 7771. For recommended aperture diameter please see Eqs. (16) to (19). If crosstalk is still a problem, a move to a 940 nm emitter can reduce the ink-related crosstalk by around a factor of two compared to a 850 nm IR-LED.

In general to achieve low crosstalk it is mandatory that the immediate vicinity of the sensor is also low reflective (e.g. dark black, see Fig. 30). In this context OSRAM recommends to avoid placing the sensor close to other components or objects as their reflections might impair the performance of the sensor. Further details can also be found in [3].
For further design-in support contact you local OSRAM OS team at http://www.osram-os.com.

10.8 Zero-Detection Distance

In some cases the detection of objects is required, which are in direct touch with the cover glass. This 'object' can be a finger, hair or the human ear. In particular the so called "black-hair" detection at zero-distance above a cover glass presents some challenges, especially as a proper separator design inevitably creates some kind of "blind-spot" directly above the cover. In principle, the SFH 7771 is capable of detecting the presence of objects in direct contact with the cover. It is important to design the separator between IR-LED and SFH 7771 carefully. If it is too wide, it will block the signal reflected by the object. If it is too narrow, the crosstalk signal will increase and thus mask the signal of interest.
The light path for reflection from the zero-distance object is very similar to the reflection at the top side of the cover glass. Nevertheless, zero-distance detection is made possible by the following effects (see Fig. 30):

a) The reflecting object (e.g. hand) is not placed exactly above the separator / cover glass.

b) Although a finger is placed on the cover, light scattering takes place within the skin, and not on its surface.

c) Infrared light has some penetration depth into human hair and human skin. This can be used to overcome the so called 'blind-spot'. In general, 940 nm has a larger

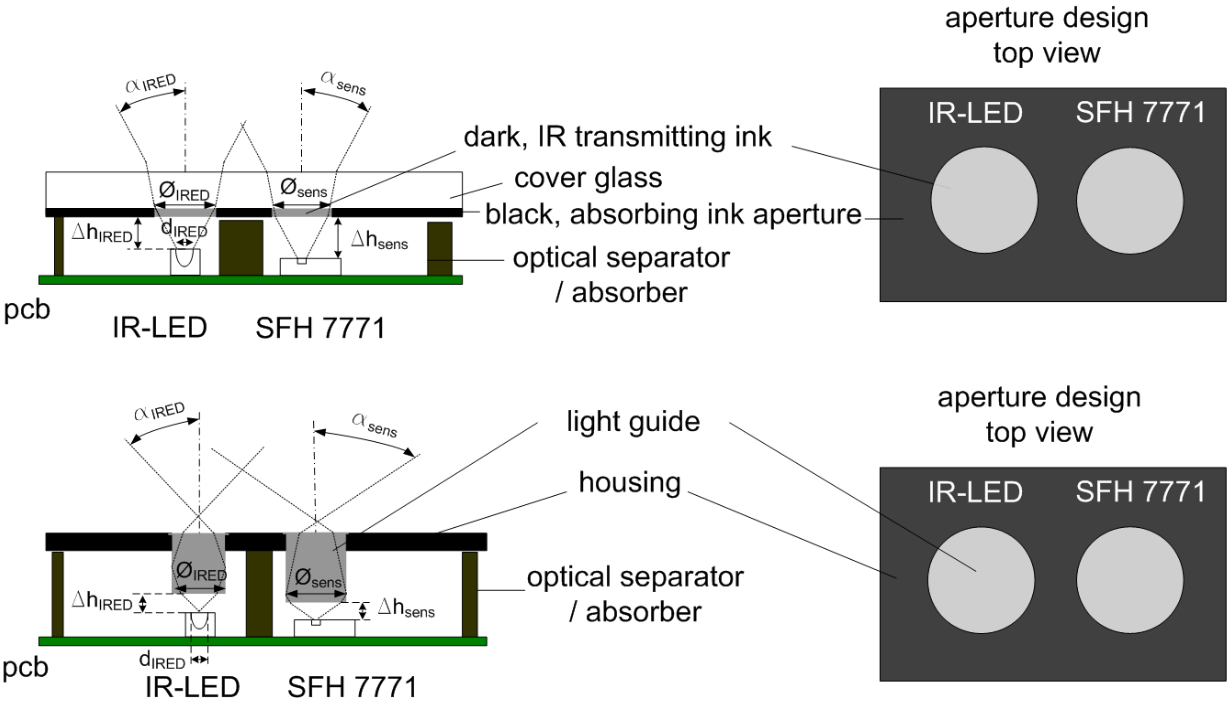


Fig. 32: Typical setup to avoid optical crosstalk by using a two-hole aperture design and optical separators. The required typ. aperture diameter resp. light guide diameter can be obtained according to Eqs. (16) and (17). In general the width of the optical separator between emitter and detector must be wide enough to suppress multipath reflections (see Fig. 29 and 30).

penetration depth as well as black hair reflectivity compared to 850 nm.

10.9 Photosensitive Area and Aperture Design

The photosensitive area of the ALS_VIS, ALS_IR and PS detectors are located within a square of 0.43 mm x 0.43 mm off-package center. Fig. 31 indicates the position of the sensitive area. In general, OSRAM recommends illuminating a circular spot of around 0.43 mm radius to account for any component tolerances.
By designing aperture openings only this sensitive area has to be taken into account. The same applies for placing the part behind a light guide.

Below are some aperture / light guide design guidelines:

For a proper light guide design it is recommended that the outer surface of the (cylindrical) light guide is not coated with any dark, absorbing material to ensure proper internal reflection.

Recommended estimates of typ. aperture diameters ($\varnothing_{sens}$, $\varnothing_{IRED}$) / light guide diameters ($\varnothing_{sens}$, $\varnothing_{IRED}$) are stated in Eq. (16) to (19). The diameter depend on the air-gap between the component top and the bottom side of the cover glass resp. light guide (Δh_{sens}, Δh_{IRED}), the active emitting width of the IR-LED (d_{IRED}) and the desired radiation angle (α_{sens}, α_{IRED}), as depicted in Fig. 32.

$$\varnothing_{sens} \approx 0.86\,mm + 2 \cdot \Delta h_{sens} \cdot \tan(\alpha_{sens}) \qquad \text{Eq. (16)}$$

$$\varnothing_{IRED} \approx d_{IRED} + 2 \cdot \Delta h_{IRED} \cdot \tan(\alpha_{IRED}) \qquad \text{Eq. (17)}$$

Combining a MiniMIDLED (SFH 4451 / SFH 4441) or MIDLED (SFH 4650 / SFH 4640)

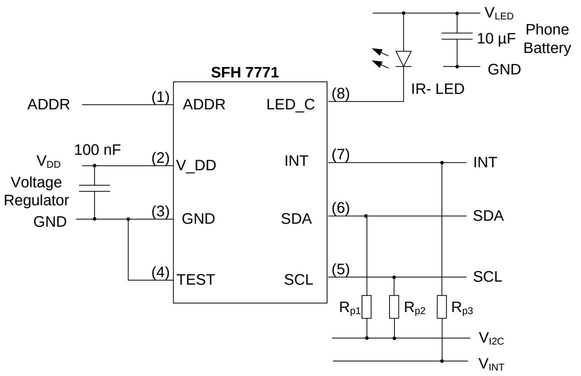


Fig. 33: Recommended implementation into a mobile phone environment.

with the SFH 7771 yields the following Eqs. for the IR-LED aperture (resp. light guide) diameter:

$$\varnothing_{SFH\ 4650/\ 4640} \approx 1.90\,mm + 2 \cdot \Delta h_{IRED} \cdot \tan(\alpha_{IRED})$$

Eq. (18)

$$\varnothing_{SFH\ 4451/\ 4441} \approx 1.65\,mm + 2 \cdot \Delta h_{IRED} \cdot \tan(\alpha_{IRED})$$

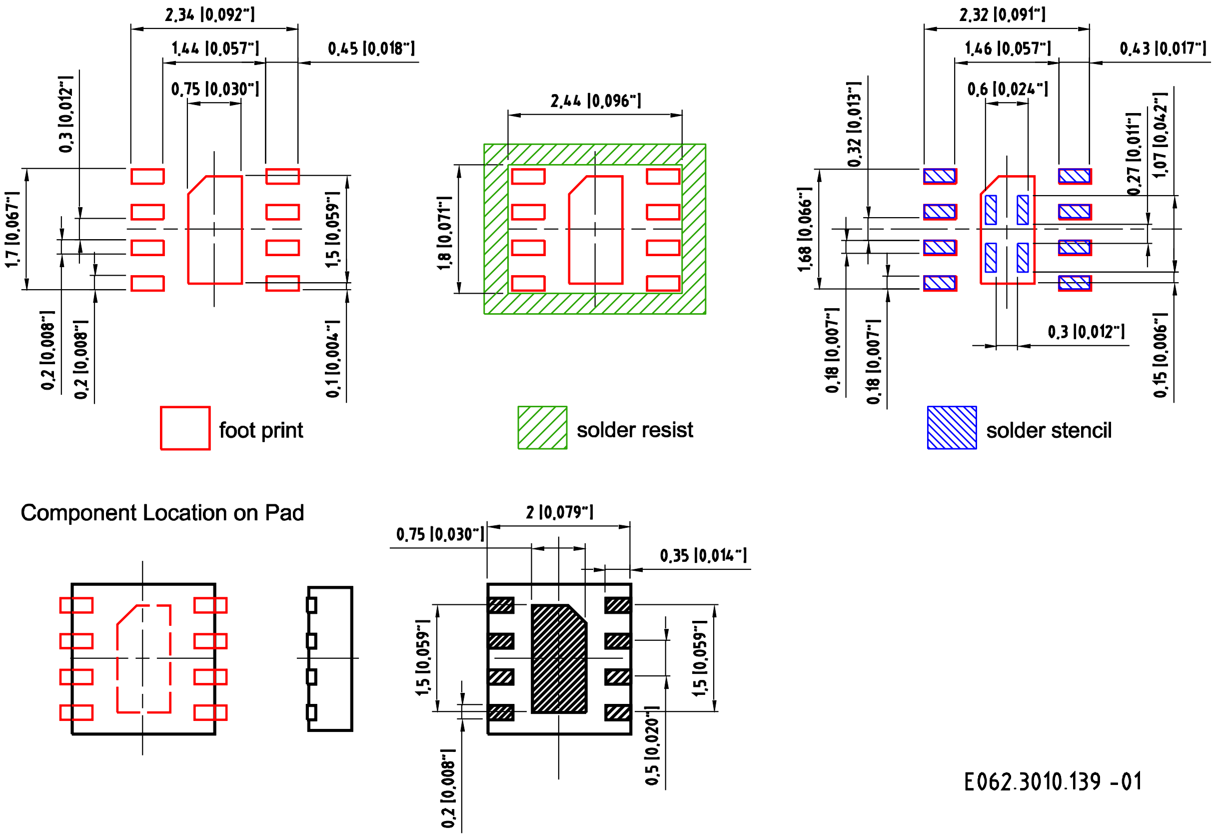
Eq. (19)

Above Eqs. don't consider any mechanical alignment tolerances.

Notice that a small aperture angle (α) can impact the max. detection distance and the target areas geometric circumference. In any way the setup should be verified to ensure that it is working in the application.

10.10 Electrical Circuit and Layout Considerations

Fig. 33 illustrates a recommendation for implementing the SFH 7771 into a mobile phone environment.
To achieve best proximity functionality it is mandatory to have a stable (battery-like) power supply. The recommendation therefore is to connect V_{LED} directly to the



34: Recommended soldering pad design for the SFH 7771.

battery. This ensures the necessary LED current during the pulsed operation (up to 200 mA peak, depending on the actual settings of the proximity sensors LED current). It is further recommended to use capacitors as close to the component as possible. Typ. values are 10 µF at the V_{LED} side (for up to 200 mA pulse current) and 100 nF for the V_{DD} circuit (ASIC supply). The 10 µF capacitor depends on the impedance of the voltage source and can e.g. be reduced if the LED pulse current is reduced to lower levels, e.g. 50 mA.
This is especially important in a ***laboratory environment***, as regulated power supplies often have poor pulse current capabilities.

The SCL, SDA and INT lines require pull-up resistors to the logic voltage (V_{IO}). The limits for the logic levels are according to the I^2C-bus specification (1.65 V to 2.0 V) [2]. A recommended value for R_p is e.g. 10 kΩ. Please note the actual value of the pull-up resistor depends - among other issues - on the total load and communication speed of the I^2C-bus.

Fig. 34 presents a reference soldering-pad design. Please refer to the SFH 7771 datasheet for the most up-to-date recommendation.

11 Sample Software Code

Below are simple C-codes which can be used to operate the SFH 7771 in connection with a microcontroller (e.g. PIC18F46J50 from Microchip). The program consists of the commented main micro C-code for the microcontroller, using the two subroutines

`I2C_w_3`: 3 write statements
`I2C_w_2_r_1`: 2 write and 1 read statement.

The main program can be implemented into a repeating loop to get the actual PS resp. ALS data or operate in interrupt mode.

11.1 Operating the ALS

11.1.1 C-code in main program:

```
sfh_address = 0x38;                      // address of SFH 7771 (ADDR connected to GND)
I2C_w_3 (sfh_address*2, 0x41, 0x08);     // initiate ALS: 400ms rep rate, T_int=100ms
I2C_w_3 (sfh_address*2, 0x42, 0x28);     // set ALS_VIS=ALS_IR GAIN = 64
I2C_w_2_r_1 (sfh_address*2, 0x46);       // read lsb of ALS_VIS, register 0x46
Content1  =  Content;
I2C_w_2_r_1 (sfh_address*2, 0x47);       // read msb of ALS_VIS, register 0x47
ALS_VIS  =  (Content * 256 + Content1); // combining LSB+MSB byte to decimal value
I2C_w_2_r_1 (sfh_address*2, 0x48);       // read lsb of ALS_IR, register 0x48
Content1  =  Content;
I2C_w_2_r_1 (sfh_address*2, 0x49);       // read msb of ALS_IR, register 0x49
ALS_IR  =  (Content * 256 + Content1);  // combining LSB+MSB byte to decimal value

// Lux Calculation based on ALS Gain = 64 and ALS_Int_Time = 100 ms
// Lux value in front of sensor, no cover glass
IF ((ALS_IR / ALS_VIS) < 0.25)
       {LUX = (0.712 * ALS_VIS / 64 - 1.034 * ALS_IR / 64 ) * 1};
ELSE IF ((ALS_IR / ALS_VIS) < 0.59)
       {LUX = (0.601 * ALS_VIS / 64 - 0.551 * ALS_IR / 64 ) * 1};
ELSE IF ((ALS_IR / ALS_VIS) < 0.72)
       {LUX = (0.533 * ALS_VIS / 64 - 0.434 * ALS_IR / 64 ) * 1};
ELSE IF ((ALS_IR / ALS_VIS) < 1.36)
       {LUX = (0.469 * ALS_VIS / 64 - 0.343 * ALS_IR / 64 ) * 1};
Else {LUX = 0};
```

11.1.2 I2C_w_3 subroutine

```
void I2C_w_3     (unsigned char addw, unsigned char com, unsigned char daw)
{
   unsigned char var;
   OpenI2C (MASTER, SLEW_ON);     // Configures I2C bus module, 100 kHz transfer
   SSP1ADD  = 0x27;               // setting I2C 100 kHz frequency with f osc = 16 MHz
   StartI2C ();                   // Generates I2C bus start condition
   IdleI2C ();                    // Loop till I2C bus is idle
   var = WriteI2C(addw);          // Microchips' Write command to write device address
   if (var ==  0) write_s++;      // var =  0: no bus error
   if (var == -1) write_c++;      // var = -1: slave did not acknowledge write
   if (var == -2) write_ac++;     // var=-2:write collision (bus not ready to tx)
   if (var  <  0) goto stop;      // stop further transmission if error occurred

   var = WriteI2C(com);           // write device register address
   if (var ==  0) write_s++;      // counting of good transmissions
   if (var == -1) write_c++;      // counting of no acknowledge errors
   if (var == -2) write_ac++;     // counting of write collision errors
   if (var  <  0) goto stop;

   var = WriteI2C(daw);           // write register content
   if (var ==  0) write_s++;
   if (var == -1) write_c++;
   if (var == -2) write_ac++;

   stop:
   StopI2C ();                    // generates I2C bus stop condition
   CloseI2C ();                   // master I2C module disabled
}
```

11.1.3 Subroutine I2C_w_2_r_1

```
void I2C_w_2_r_1 (unsigned char addr, unsigned char com)
{
   unsigned char var;
   OpenI2C (MASTER, SLEW_ON);
   SSPADD  = 0x27;
   StartI2C ();
   IdleI2C ();
   var = WriteI2C(addr);
   if (var ==  0) read_s++;
   if (var == -1) read_c++;
   if (var == -2) read_ac++;
   if (var  <  0) goto stop;

   var = WriteI2C(com);
   if (var ==  0) read_s++;
   if (var == -1) read_c++;
   if (var == -2) read_ac++;
   if (var  <  0) goto stop;

   RestartI2C ();                       // generates I2C bus restart condition
   IdleI2C ();
   var = WriteI2C(addr+1);
   if (var ==  0) read_s++;
   if (var == -1) read_c++;
   if (var == -2) read_ac++;
   if (var  <  0) goto stop;
   Content = 0;
   Content = ReadI2C ();
   SSPCON2bits.ACKDT = 1;               // No master Acknowledge to terminate sequence
   SSPCON2bits.ACKEN = 1;               // sending No Acknowledge bit
   PIR1bits.SSPIF = 0;
   while (SSPCON2bits.ACKEN == 1);
   PIR1bits.SSPIF = 0;                  // waiting till NA causes interrupt
   stop:
   StopI2C ();
   CloseI2C ();
}
```

11.2 Operating the PS

Below is a small C-code for the main program to operate the proximity sensor of the SFH 7771. The two subroutines, I2C_w_3 and I2C_w2_r1 are the same as above (see Sec. 11.1.2 and 11.1.3).

C-code for main program:

```
sfh_address = 0x38;                      // address of SFH 7771 (ADDR connected to VDD)
I2C_w_3 (sfh_address*2, 0x41, 0x03);     // initialize PS (100ms repetition rate)
I2C_w_3 (sfh_address*2, 0x42, 0x30);     // run PS with 200 mA IR LED current
I2C_w_2_r_1 (sfh_address*2, 0x44);       // read LSB data byte of PS, register 0x44
PS  =  Content;
I2C_w_2_r_1 (sfh_address*2, 0x45);       // read MSB data byte of PS, register 0x45
PS  =  (PS + Content* 256);              // combining low+high byte to decimal value
```

11.3 Operating the ALS and PS in Interrupt Mode

The small C-code below operates the SFH 7771 in the interrupt mode. The ALS and PS are in free-running mode. The interrupt event can occur through an ALS or PS event. The interrupt event limits for ALS and PS are to be set within the program (variables: **`LSB_UP`**, **`MSB_UP`**, **`LSB_LOW`**, **`MSB_LOW`**, **`LSB_Prox_Limit_Int_On`**, **`MSB_Prox_Limit_Int_On`**, **`LSB_Prox_Limit_Int_Off`**, **`MSB_Prox_Limit_Int_off`**). After the interrupt has triggered the microcontroller the relevant sensor is determined and the ALS or PS value is read out. The calculated illumination value (**`lux`**) assumes no cover above the sensor.

C-code for main program:

```
// General:

I2C_w_3         (0x38*2, 0x41, 0x09);
// ALS: 400ms repetition rate, T_int=100ms, PS: 100ms repetition rate
I2C_w_3         (0x38*2, 0x42, 0x2B);           // ALS gain: 64, PS current = 200mA
I2C_w_3         (0x38*2, 0x4A, 0x13);           // set interrupt
// interrupt triggered by PS hysteresis and ALS, latched

// ALS:

I2C_w_3         (0x38*2, 0x4F, LSB_UP);         // setting LSB of upper ALS_VIS limit
I2C_w_3         (0x38*2, 0x50, MSB_UP);         // setting MSB of upper ALS_VIS limit
I2C_w_3         (0x38*2, 0x51, LSB_LOW);        // setting LSB of lower ALS_VIS limit
I2C_w_3         (0x38*2, 0x52, LSB_LOW);        // setting MSB of lower ALS_VIS limit

// Prox:

I2C_w_3         (0x38*2, 0x4B, LSB_Prox_Limit_Int_On);      // LSB for prox INT-ON limit
I2C_w_3         (0x38*2, 0x4C, MSB_Prox_Limit_Int_On);      // MSB for prox INT-ON limit
I2C_w_3         (0x38*2, 0x4D, LSB_Prox_Limit_Int_Off);  // LSB for prox INT-OFF limit
I2C_w_3         (0x38*2, 0x4E, MSB_Prox_Limit_Int_Off);  // MSB for prox INT-OFF limit


// Interrupt routine:                           // called when interrupt happened

I2C_w_2_r_1 (0x38*2, 0x4A);
// reading Interrupt (Status) Register,
// Function returns register value as variable Content
if ( (Content & 0x53) == 0x53)
// &=bitwise AND,check whether ALS triggered interrupt
{
      I2C_w_2_r_1 (0x38*2, 0x46);             // read LSB of ALS_VIS, register 0x46
      Content1 = Content;
      I2C_w_2_r_1 (0x38*2, 0x47);             // read MSB of ALS_VIS, register 0x47
      ALS_VIS = (Content * 256 + Content1);   // calc ALS_VIS in decimal
      I2C_w_2_r_1 (0x38*2, 0x48);             // read LSB of ALS_IR, register 0x48
```

```
        Content1 = Content;
        I2C_w_2_r_1 (0x38*2, 0x49);              // read MSB of ALS_IR, register 0x49
        ALS_IR = (Content * 256 + Content1);     // calc ALS_IR in decimal

        // Lux Calculation based on ALS Gain = 64 and ALS_Int_Time = 100 ms
        // Lux value in front of sensor, no cover glass
        IF ((ALS_IR / ALS_VIS) < 0.25)
               {LUX = (0.712 * ALS_VIS / 64 - 1.034 * ALS_IR / 64 ) * 1};
        ELSE IF ((ALS_IR / ALS_VIS) < 0.59)
               {LUX = (0.601 * ALS_VIS / 64 - 0.551 * ALS_IR / 64 ) * 1};
        ELSE IF ((ALS_IR / ALS_VIS) < 0.72)
               {LUX = (0.533 * ALS_VIS / 64 - 0.434 * ALS_IR / 64 ) * 1};
        ELSE IF ((ALS_IR / ALS_VIS) < 1.36)
               {LUX = (0.469 * ALS_VIS / 64 - 0.343 * ALS_IR / 64 ) * 1};
        Else {LUX = 0};
}

if ( (Content & 0x93) == 0x93)
// &=bitwise AND,check whether PS triggered interrupt
{
        I2C_w_2_r_1 (0x38*2, 0x44);              // read LSB of PS, register 0x44
        ContentP = Content;
        I2C_w_2_r_1 (0x3F*2, 0x45);              // read MSB of PS, register 0x45
        PS = Content * 256 + ContentP;
}

// end of interrupt routine
```

11.4 Implementation into a Mobile Phone Environment

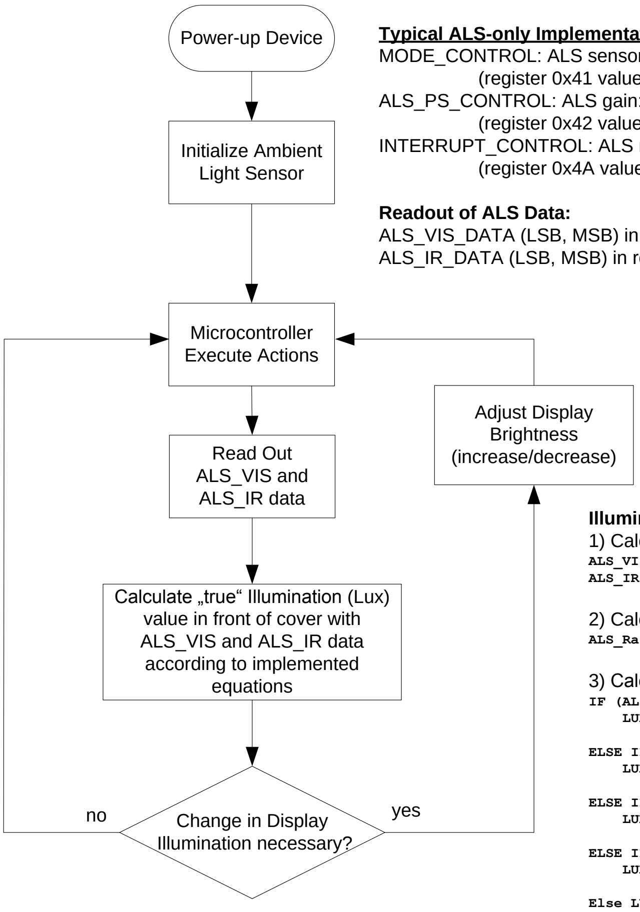
Below are two example flowcharts, describing how the SFH 7771 can be implemented into a microcontroller based mobile phone environment. The interrupt function allows for low-power stand-alone operation of the device.
The first flowchart illustrates a possible operation of the ambient light sensor, the second flowchart relates to the operation of the proximity sensor.

11.4.1 Operation of the ALS

Fig. 35 illustrates a flowchart for a microcontroller based ambient light sensing. The SFH 7771 is in the free-running mode, which helps to minimize traffic on the I2C-bus as well as to relieve the microcontroller from unnecessary work load. This arrangement helps to save valuable battery power.
From time to time the ALS_VIS and ALS_IR data sets are read from the SFH 7771. Based on the calculated ALS ratio (= ALS_IR / ALS_VIS) and by applying subsequently the Eqs. according to Sec. 10.1, the “true“ ambient light value (illumination) in front of the sensor can be calculated. These Eqs. need to be adapted in case of a dark cover glass with different spectral transmission properties (visible vs. IR) is used.

11.4.2 Operation of the PS

Fig. 36 illustrates the flowchart for a microcontroller based proximity-only sensing example.
The interrupt alerts the microcontroller only in case an object passes a certain distance threshold (e.g. towards the display). This allows the mobile phone to disable the touchscreen / turn-off the display illumination e.g. during a call to save battery power.
The setting of a user-defined hysteresis (e.g. two threshold levels) reduces the microcontroller – sensor interaction to a minimum, thus reducing the overall power consumption.



<u>Typical ALS-only Implementation:</u>
MODE_CONTROL: ALS sensor free-running, repetition rate of 400 ms, T_int_ALS = 100 ms, no PS:
(register 0x41 value: [0x08])
ALS_PS_CONTROL: ALS gain: 64 (equal for ALS_VIS and ALS_IR)
(register 0x42 value: [0x28])
INTERRUPT_CONTROL: ALS not an interrupt source (no change necessary)
(register 0x4A value: [0x00])

Readout of ALS Data:
ALS_VIS_DATA (LSB, MSB) in register: 0x46, 0x47
ALS_IR_DATA (LSB, MSB) in register: 0x48, 0x49

Illumination / Lux – Calculation:

1) Calculate

```
ALS_VIS = LSB + 256 * MSB
ALS_IR = LSB + 256 * MSB
```

2) Calculate

```
ALS_Ratio = ALS_IR / ALS_VIS
```

3) Calculate “true-ALS“ (Lux) value by (e.g. no cover glass):

```
IF (ALS_IR / ALS_VIS) < 0.25
    LUX = (0.712*ALS_VIS/GAIN_VIS
           -1.034*ALS_IR/GAIN_IR)
ELSE IF (ALS_IR / ALS_VIS) < 0.59
    LUX = (0.601 * ALS_VIS / GAIN_VIS
           - 0.551 * ALS_IR / GAIN_IR )
ELSE IF (ALS_IR / ALS_VIS) < 0.72
    LUX = (0.533 * ALS_VIS / GAIN_VIS
           - 0.434 * ALS_IR / GAIN_IR )
ELSE IF (ALS_IR / ALS_VIS) < 1.36
    LUX = (0.469 * ALS_VIS / GAIN_VIS
           - 0.343 * ALS_IR / GAIN_IR )
Else LUX = 0

LUX = LUX * T_INT_ALS / 100ms
```

Note:
* in the above Eq. `ALS_VIS = GAIN_VIS = 64, T_INT = 100ms`
* in case of dark cover glass a scaling factor is necessary to account for atter
* in case of dark, IR-transmissive ink an adaption of above Eq. is necessary

*Fig. 35: Flowchart for a microcontroller based **ambient light sensing** example. After performing the ALS_IR/ALS_VIS ratio calculation the true illumination (lux) value can be directly calculated according to the Eqs. Please note that these Eqs. need to be adapted to the characteristic cover glass transmission properties (e.g. a simple gain factor to account for the attenuation if implemented behind a dark cover glass with flat transmission characteristics (visible to infrared range) or by adaption of the parameters if implemented behind dark, IR transmissive cover glasses). See Sec. 10.1 for more details.*

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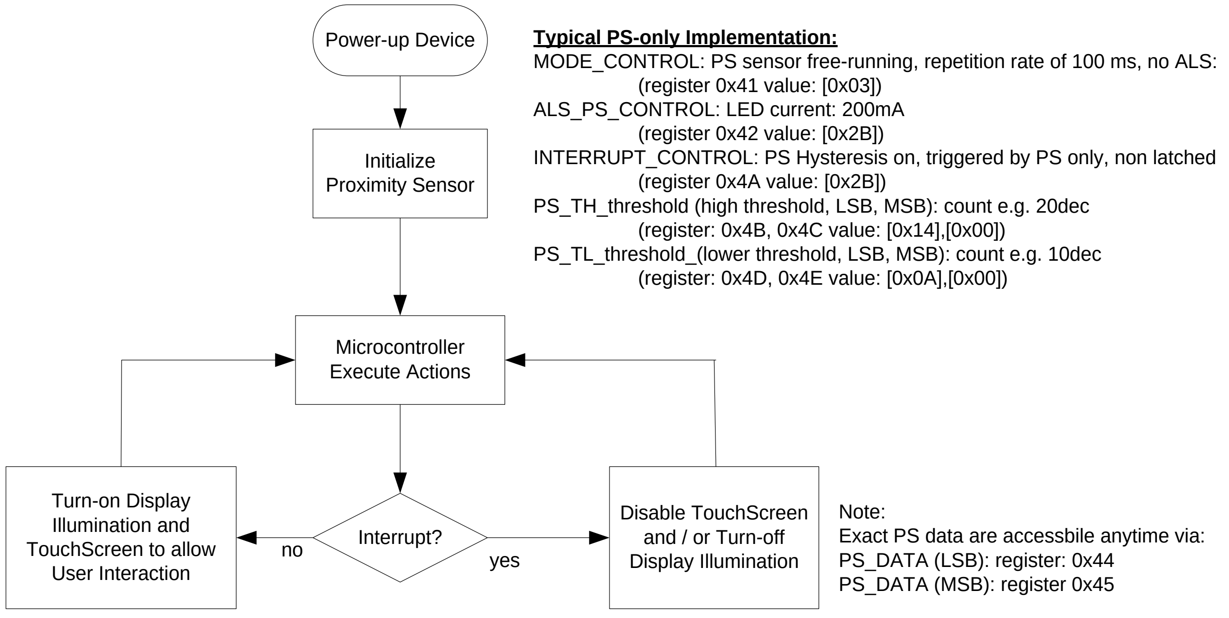

*Fig. 36: Flowchart for a microcontroller based **proximity sensing** example.*

12 Literature

[1] OSRAM-OS: http://www.osram-os.com.
[2] "UM10204 I^{2}C-bus specification and user manual" from NXP Rev. 03 – 19 June 2007
[3] Application Note SFH 7770: http://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

Author: Dr. Hubert Halbritter

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