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BIOFY® Opto-mechanical integration of the SFH 7070

Application Note

Valid for:
SFH 7070

Abstract

This application note describes the use of the SFH 7070 as the sensor element for a photoplethysmography (PPG) system.

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A. Introduction

This application note describes the use of the SFH 7070 as the sensor element for a photoplethysmography (PPG) system, and focuses on the integration of such biomonitoring sensors in wearable devices.

Several elements are necessary for the successful integration of a BIOFY® sensor in a device. After briefly introducing the SFH 7070, we are describing BIOFY® ecosystem — namely all the components that are necessary to build a complete PPG measurement system.

The opto-mechanical integration of the sensor is a fundamental step in the design process, as the quality of the PPG measurement mainly depends on the quality of the optical measurement. This application note discusses in detail different opto-mechanical sensor cover prototypes, used to compare the optical performances of the SFH 7070 (or other BIOFY® sensors) in a realistic context. The performances of these opto-mechanical covers were tested and compared. Finally, health & safety considerations are briefly discussed and conclusions are drawn.

B. SFH 7070

The SFH 7070 (Figure 1) is an integrated optoelectronic sensor, specifically designed and optimized for reflective PPG measurements. It features two green LEDs and a large area photodiode (PD). The device design includes light barriers to minimize internal crosstalk between LEDs and the PD, thus enhancing the signal-to-noise ratio.

The sensor allows the precise measurement of the heart rate thanks to its optimized design and technical specifications.

Figure 1: SFH 7070 sensor with integrated LEDs and photodiode for heart rate and other biological monitoring applications

Table 1: SFH 7070 technical specifications. For a complete list, please refer to the data sheet

	Parameter	**Symbol**	**Value**	**Unit**
	Package dimensions	W x D x H	7.5 x 3.9 x 0.9	mm x mm x mm
LED	Total radiant flux (I_F= 20 mA, t_p= 20 ms	φ_e	11.7	mW
	Centroid wavelength (I_F= 20 mA)	$\lambda_{centroid}$	530 (± 10)	nm
	Forward voltage (I_F= 20 mA)	V_F	3 (≤ 3.4)	V
Photo-diode	Photodiode Area	A	3.46	mm^2
	Dimensions of radiant sensitive area	L x W	1.29 x 2.69	mm x mm
	Photocurrent (E_e= 530 nm, VR= 5 V)	$I_{P,530}$	0.985	µA
	Wavelength of max. sensitivity	$\lambda_{S\ max}$	635	nm
	Chip spectral sensitivity (λ= 530 nm)	$S_{\lambda 530}$	0.31	A/W
	Chip spectral sensitivity of the chip (λ > 690 nm)	S_{IR}	0.02	A/W

The most important technical specifications are listed in Table 1. The white package contributes to the overall total radiant flux. The photodiode suppresses Infrared (IR) light to reduce IR interference from external light sources, e.g. sunlight. The combination of these features make the SFH 7070 an excellent candidate for PPG measurements.

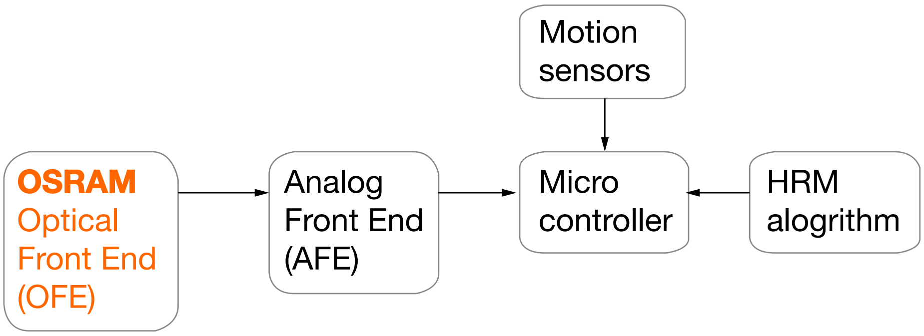
C. BIOFY® ecosystem

Figure 2 shows the functional building blocks of a biomonitoring system, which are:

- Optical Front End (OFE), i.e. the BIIOFY® sensor: The optoelectronic sensor is the heart of the biomonitoring system, as the quality of the measurements depends to a large extent on the quality of the optical PPG signal.
- Analog Front End (AFE): A chipset provides the analog signal processing (photodiode signal amplification and analog-to-digital conversion) and programmable LED driving. Several commercial chipsets are available (e.g. Texas Instruments).
- Micro controller
- Heart rate and motion compensation algorithm.
- Motion sensors: In dynamic situations, measurement artefacts arise from the user motion. A motion compensation feature is therefore necessary to obtain an accurate PPG measurement in these circumstances.

In addition to the building blocks described in Figure 2, it is important to note that the OFE must be integrated successfully from an opto-mechanical point of view to guarantee a reliable and precise optical signal. In the next section, we will present and analyse different opto-mechanical sensor encapsulation specifically designed for this purpose.

Figure 2: Biological monitoring sensor ecosystem

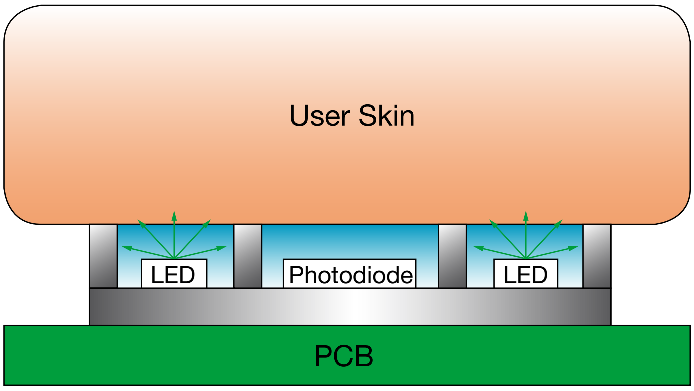


D. Opto-mechanical designs

For the purpose of evaluating a successful integration, we designed different opto-mechanical cover prototypes, which complete CAD models can be found in the appendix of this application note. It is important to note that the presented opto-mechanical designs offer reliable and accurate performances for PPG measurements. A commercial 3D-printer was used to fabricate the opto-mechanical packages. The material of choice is a black polymer.

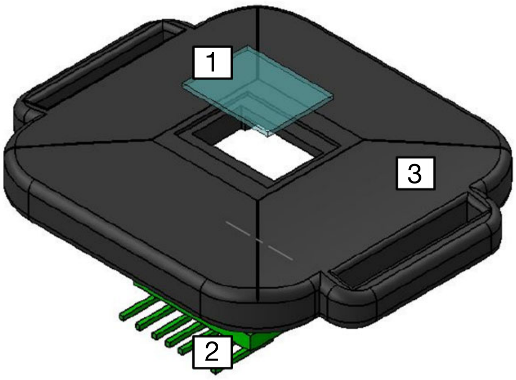
First of all, the bare SFH 7070 mounted on a PCB has been considered (cover #1). BIOFY® sensors can be used in direct skin contact configuration (see Figure 3). Light barriers already included in the sensor package limit the crosstalk between emitters and detector, thus providing solid and accurate PPG measurements.

Figure 3: Opto-mechanical cover, #1. The SFH 7070 sensor is in direct contact with the user skin



The opto-mechanical enclosure #2 is shown in Figure 4. Here the sensor lies beneath a transparent cover that has been attached with two-component adhesive glue to the 3D-printed case. Different materials have been evaluated for the transparent cover: glass, PMMA and transparent silicone. While PMMA and glass exhibit almost the same optical characteristics (i.e., transmission spectra were evaluated to make sure that the materials considered are transparent to wavelengths used for PPG measurements), transparent silicone was discarded due to its poor optical performances. Glass was found to be the most resilient material physically, and has therefore been elected as the material of choice for the design presented here.

Figure 4: Opto-mechanical cover, #2. The SFH 7070 sensor is placed behind a transparent cover. 1: Transparent cove glass. 2: SFH 7070 mounted on a PCB and equipped with external light barriers. 3: Opto-mechanical 3D-printed case. For side and top-view of this cover, please consult the appendix of this document



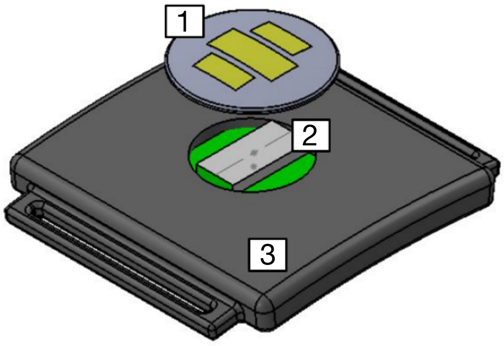
Due to mechanical tolerances, an air gap is needed between the sensor top and the transparent cover. In order to maintain a low level of crosstalk, external light barriers made of silicone have been fabricated on top of the SFH 7070 to act as extensions of the light barriers located between the LEDs and the photodiode. These external light barriers play an important role for the optical performances. They are analysed in details below. The influence of glass covers of different thickness over the PPG signal quality is analysed in the following sections.

Opto-mechanical cover #3 is presented in Figure 5. Here the optoelectronic sensor lies beneath a cover featuring three optical windows, each one located above the optical components of the SFH 7070 (i.e., LEDs and photodiode) and separated by means of light barriers to minimize the crosstalk between emitters and detector. Due to fabrication tolerances, external light barriers fabricated on top of the SFH 7070 are an integral part of this design as well.

From an industrial design point of view, cover #3 represents an interesting possibility while offering solid and reliable measurement quality.

All the cover prototypes presented here are also suitable for the integration of other BIOFY® sensors from the optical point of view after small design modification. It is important to note that an optimal contact between the user skin and the measurement device is necessary in all cases. Thus, all the opto-mechanical covers presented here show a curved surface to ensure a good contact with the user skin.

Figure 5: Opto-mechanical cover, #3. The SFH 7070 sensor is placed under an opto-mechanical cover. 1: 3D-printed opto-mechanical cover. The cavities highlighted in yellow can be filled with transparent material (glass, PMMA), but here were left hollow. 2: PCB mounted SFH 7070 equipped with external light barriers. 3: Opto-mechanical 3D-printed case. For side and top view of this cover, please consult the appendix of this document



Technical comparison of opto-mechanical designs

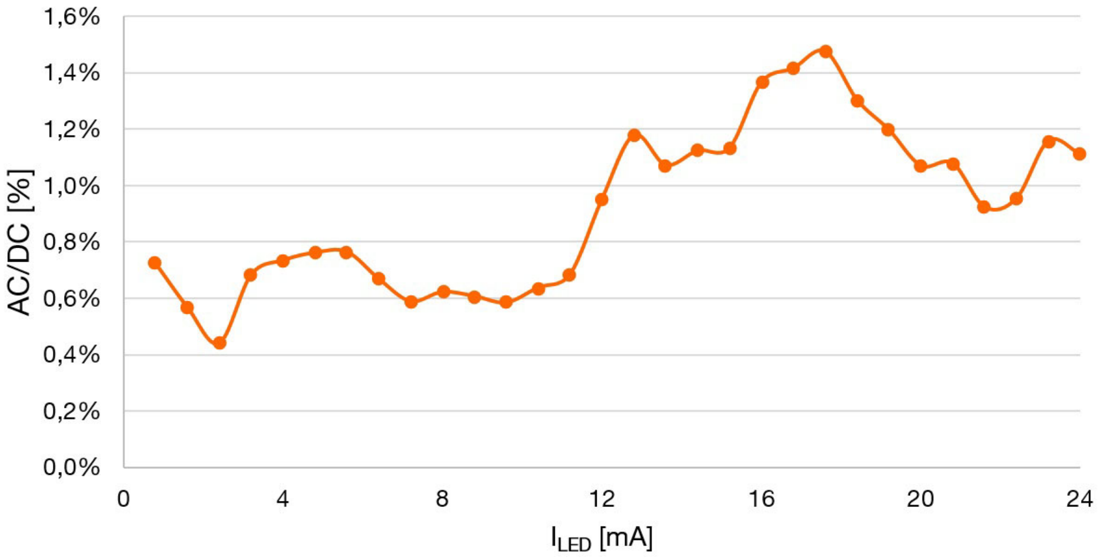
In order to compare the performances of the different opto-mechanical designs presented above it is necessary to define the key parameters for PPG measurements. The optical signal measured by the photodiode generates a photocurrent, which is then split into a DC and an AC component. The DC component contains no heart rate information, while the AC represents the heart rate information. As the AC component is small compared to the DC signal the AC/DC ratio is one of the key parameters for the performance of an optoelectronic sensor.

For a detailed description of such parameters, please refer to the application note SFH 7050 Application Note [1]. The testing procedure for all the measurement here presented is the following:

- All measurements presented here have been taken at the user's wrist, and are therefore applicable to wearable devices such as smart watches and fitness bands.
- A mechanical test fixture has been used to apply the same force on the opto-mechanical devices, thus keeping the pressure on the user's skin constant for all measurements.
- The AFE 4404 EVM from Texas Instruments was used for all measurements along with a LabVIEW GUI dedicated to heart rate measurements. For more information, please refer to [2]. Both green LEDs are connected in series.
- Transimpendance amplifier settings were kept constant for all measurements ($R_F = 50$ kΩ, $C_f = 5$ pF).
- LEDs timing: pulse repetition frequency was chosen to 100 Hz, duty cycle 1 % ($T_{pulse} = 100$ µs).
- The heart rate was measured in static conditions, and the results were verified by using an external reference device (Masimo Set Rad-8®).

First, the impact of different LED driving currents on the AC/DC ratio was analysed to understand the correlation between the amount of LED light and the quality of the PPG signal.

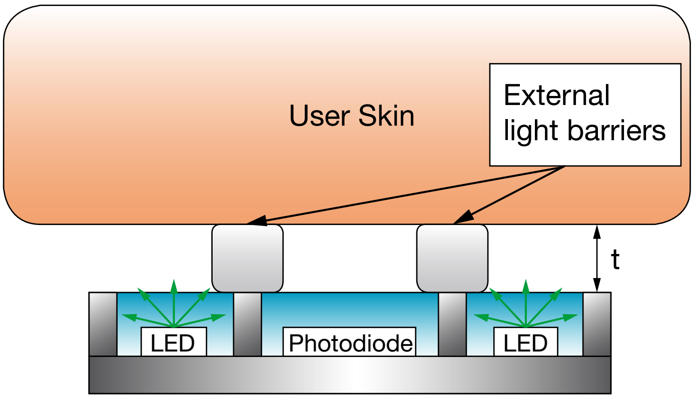
Figure 6: Quality of the PPG signal compared to the LEDs driving current. The AC/ DC is mostly independent of the LEDs driving current



For this purpose, the I_{LED} was increased in regular steps from 0.8 mA up to 24 mA. Figure 6 shows that the AC/DC ratio does not change one to one with the amount of emitted LED light. This implies that in order to have a functioning optoelectronic PPG sensor it is possible to drive the LEDs with a relative low current, thus reducing power consumption. This allows for a longer battery life, an important factor for all wearable devices.

As discussed above, the crosstalk between the LED light and the photodiode needs to be minimized. Direct reflections from the skin surface add to this crosstalk. Light barriers are already integrated in the SFH 7070 and in other OSRAM Opto Semiconductors BIOFY® sensors. When these sensors are placed in direct skin contact the crosstalk is already kept to a minimum. However, in more complex opto-mechanical designs (e.g., #2 and #3) it is good practice to incorporate external light barriers, as shown in Figure 7. These external light barriers were fabricated by dispensing silicone on top of the SFH 7070 using a globtop dispensing machine. Although this solution is unpractical for fabrication purposes, it offers some insightful details for what concerns the optical performances.

Figure 7: Reflections in the gap between the SFH 7070 and the user skin can significantly increase the DC component of the signal and therefore reducing the AC/DC ratio. The external light barriers help to suppress such crosstalk



In order to evaluate the crosstalk reductions by adding external light barriers, several tests with different opto-mechanical covers have been performed. Figure 8 shows for enclosure #3 the AC/DC ratio with and without external light barriers. While both measurements give the same heart rate value, the AC/DC increased by a factor of 3.59 when external light barriers were included in the design. The DC signal decreases by a factor of 2.56. The higher DC signal originates from crosstalk between LEDs and photodiode due to air gap created by mechanical tolerances of the opto-mechanical cover and of the SFH 7070.

These measurements show that crosstalk between LEDs and photodiode is indeed detrimental to the quality of the optical PPG signal, and therefore must be addressed properly in order to obtain reliable performances.

Biological differences influence the AC/DC ratio as well. Each individual responds slightly different to the same sensor due to skin type and body build. We present results for a large number of test subjects: 22 users have participated and got their heart rate tested using opto-mechanical devices #1, #2 and #3. A constant I_{LED} of 4.8 mA was used for each measurement, in order to obtain a realistic comparison.

Figure 8: Comparison of PPG signal measured with and without external light barriers for the opto-mechanical cover #3. Light barriers limit crosstalk, therefore allowing a larger AC/DC signal while lowering the DC signal of the measured light

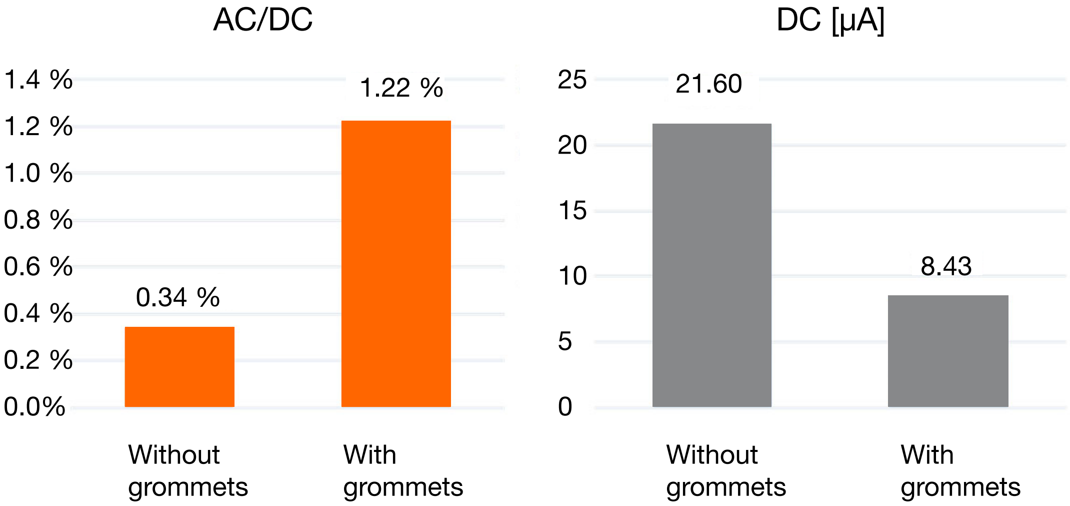
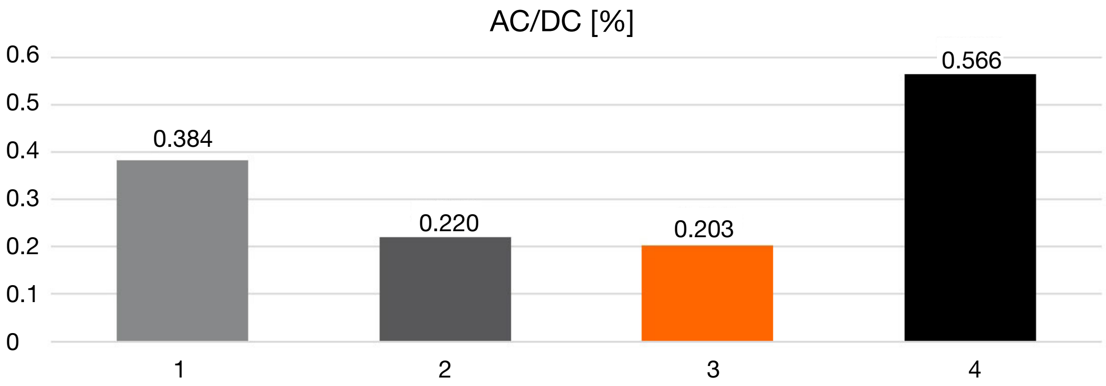


Figure 9 shows the average AC/DC ratio for each cover. Performance wise, all variants were capable of effectively measuring the heart rate. The sensor behaves relatively well when placed in direct skin contact, thanks to the integrated light barriers inside the package (cover #1).

As expected, we can observe that the performance of the sensor slightly declines when placed behind a transparent glass cover. This is due to the crosstalk introduced by the glass cover: light is guided inside the glass and travels from the LEDs to the photodiode. This crosstalk increases with the glass thickness, therefore it is necessary to find a trade-off between mechanical stability and crosstalk. We found that the best performances were given by 300µm thick glass. Thinner glass covers start to become too fragile below 300 µm.

Figure 9: AC/DC comparison between 1. Opto-mechanical cover #1, 2. Opto-mechanical cover variant #2 with 300 µm thick glass cover, 3. Opto-mechanical cover variant #2 with 550 µm thick glass cover, 4. Opto-mechanical cover #3



Opto-mechanical cover #3 showed the best results in terms of a high AC/DC ratio, as the complex 3D-printed cover seems to absorb more light than the other covers as shown in Figure 10 and Figure 11. The DC signal is by a factor of 4.28 smaller than for enclosure #1, while the AC signal by a factor of 2.98.

Figure 10: DC signal comparison between 1. Opto-mechanical cover #1, 2. Opto-mechanical cover variant #2 with 300 µm thick glass cover, 3. Opto-mechanical cover variant #2 with 550 µm thick glass cover, 4. Opto-mechanical cover #3

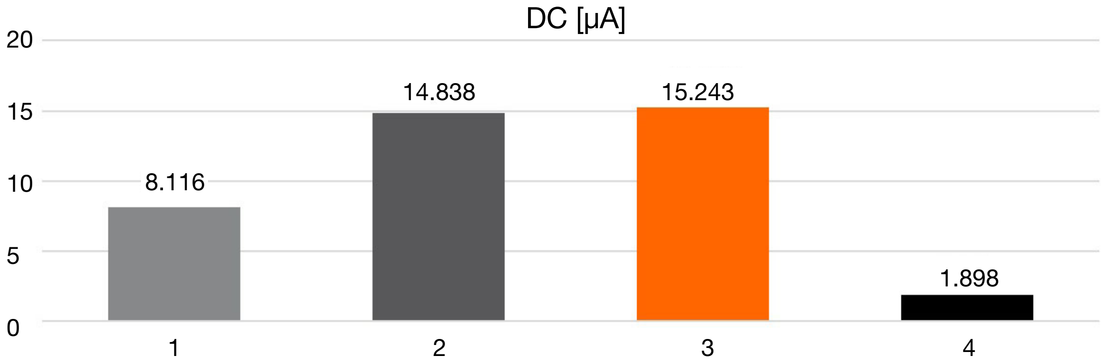
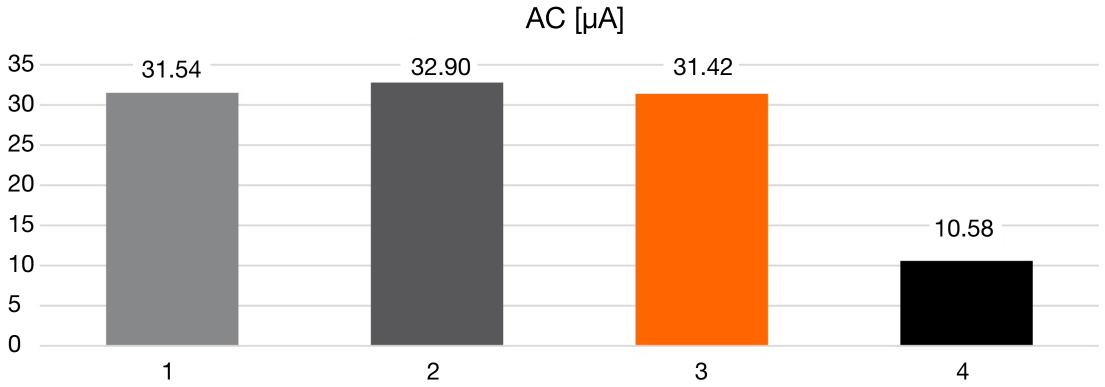


Figure 11: AC signal comparison between 1. Opto-mechanical cover #1, 2. Opto-mechanical cover variant #2 with 300 µm thick glass cover, 3. Opto-mechanical cover variant #2 with 550 µm thick glass cover, 4. Opto-mechanical cover #3



Health & safety regulations

Recent market research shows that optoelectronic PPG sensors are currently being used in more and more devices. Almost each wearable wrist device (such as smartwatches, fitness bands) will have heart rate measurement as a standard feature. Some specific health & safety certifications are required in addition to reliability reports for medical devices in some circumstances (e.g., direct skin contact).

OSRAM Opto Semiconductors BIOFY® sensors are currently undergoing a series of cytotoxicity and toxicology tests to obtain the ISO 10993-1 biocompatibility. For more information, please refer to the official ISO website [3].

BIOFY® sensors are IPX7 compliant, and have undergone several tests to demonstrate their robustness and reliability:

- Storage in water
- Solvent resistance test
- Chemical stain test

For the complete reliability report, please refer to the appendix of this document.

E. Summary

BIOFY® sensors are components specially designed as reflective PPG sensors to allow heart rate and other vital sign measurements.

The optical performances of BIOFY® sensors depend greatly on the integration design. By carefully designing different opto-mechanical cover prototypes, we have shown how it is possible to obtain a high-quality signal. External light barriers helps greatly to reduce the crosstalk between emitters and detector, one of the most limiting optical parameters for PPG measurements. Ideas for the realization of opto-mechanical covers were shown and the optical performances of such prototypes were discussed.

In addition to optical performances, other important key factors have to be considered for the successful integration of a BIOFY® sensor: fabrication costs and processes, industrial design, reliability, and many more. Nonetheless, as the quality of PPG measurements depends largely on the quality of the optical signal, an efficient opto-mechanical integration is a key requirement for wearable devices incorporating biological monitoring functionalities.

F. References

[1] SFH 7050 — Photoplethysmography Sensor

[2] Biomon Sensors evaluation board http://www.ti.com/tool/AFE4405EVM#technicaldocuments

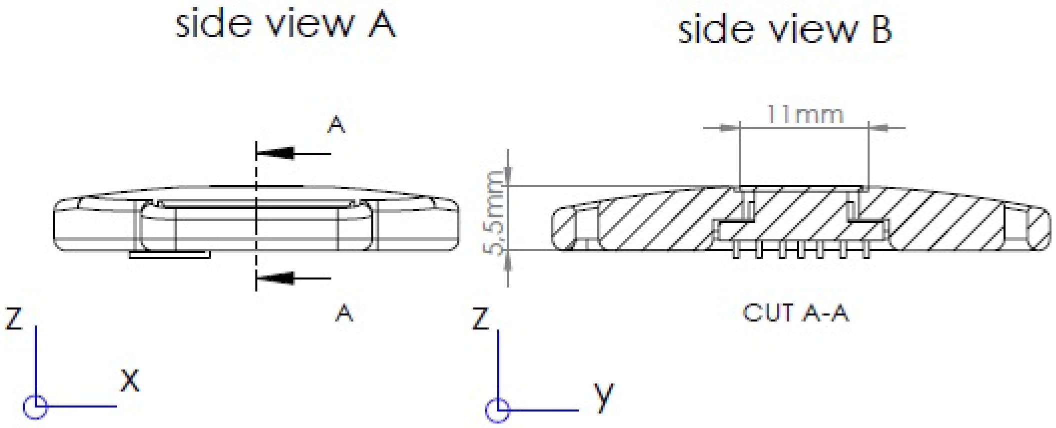
[3] ISO 10993-1:2009, https://www.iso.org/standard/44908.html

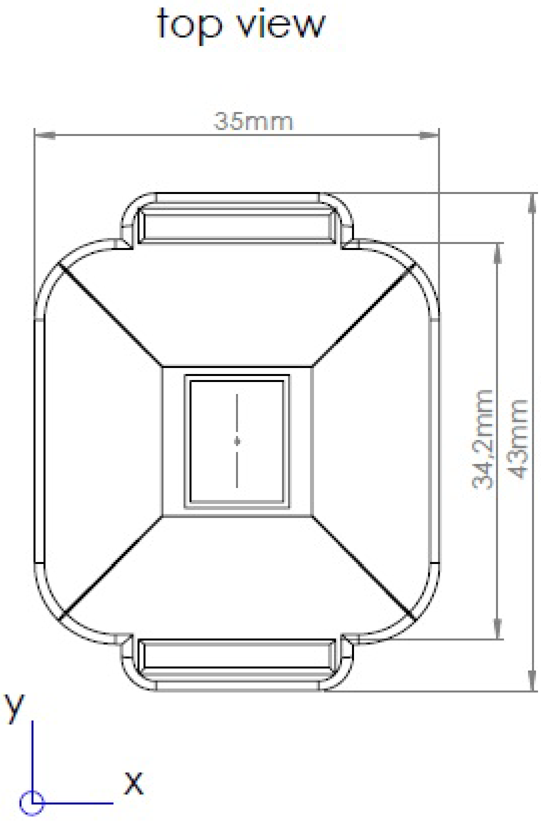
For further information concerning PPG and pulse oximetry the following reading is recommended:

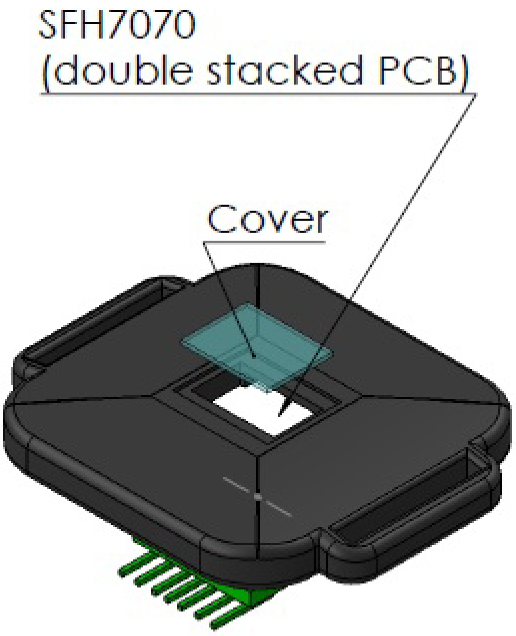
[4] J. G. Webster, “Design of Pulse Oximeters”, Series in Medical Physics and Biomedical Engineering, Taylor & Francis, New York, USA, 1997.

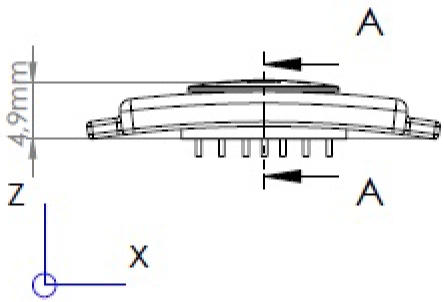
[5] T. Ahrens, K. Rutherford, “Essentials of Oxygenation”, Critical Concepts in Oxygenation: Implementations for clinical practise. Jones & Bartlett, Boston, USA, 1993.

G. Appendix

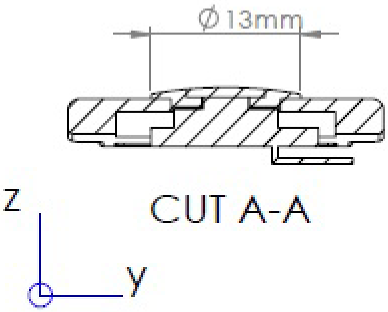

side view A
side view B
A
A
11mm
5,5mm
CUT A-A
Z
x
Z
y


top view
35mm
34,2mm
43mm
y
x

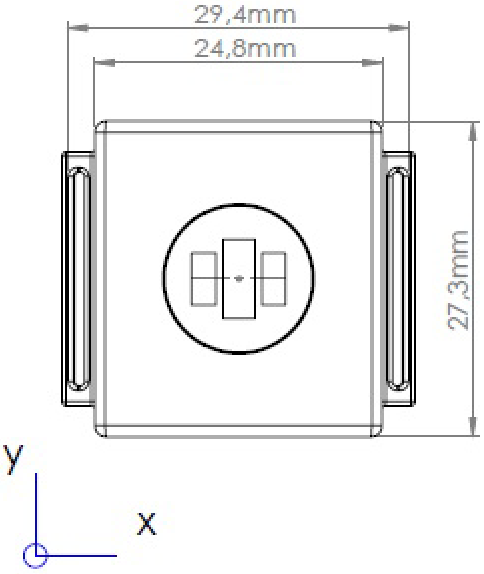

SFH7070
(double stacked PCB)
Cover



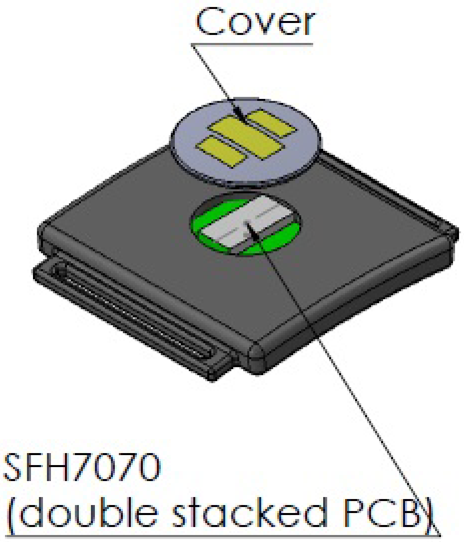
side view A



side view B



top view



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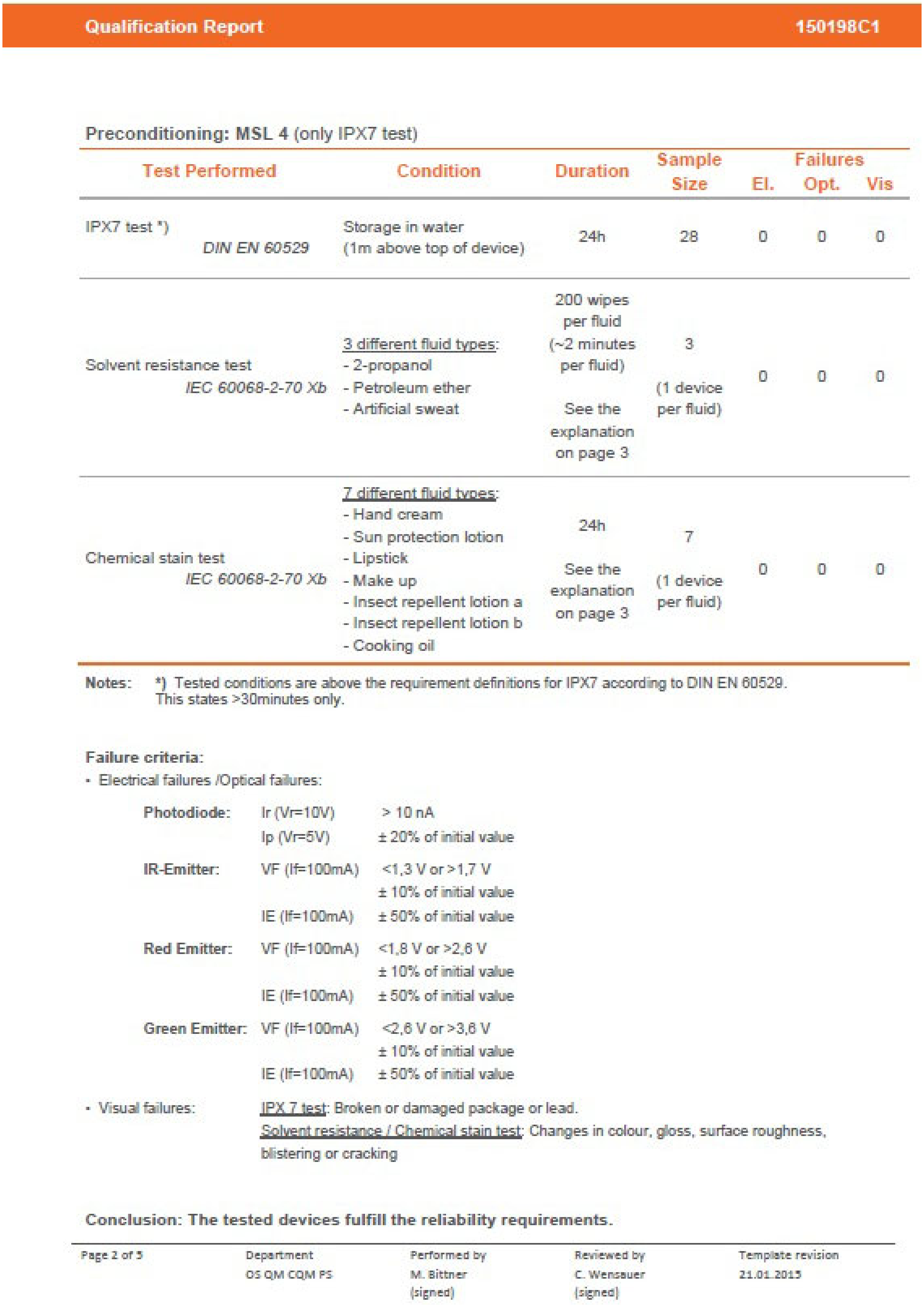
Reliability Report 150198C1

Subject	Reliability report according to DIN EN 60529 and IEC 60068-2-70 Xb for epoxy casted chip on board package
Date	27.04.2015
Tested device	SFH 7050
Brand (including sub brands)	Chip on board
Applies to	SFH 7050 SFH 7051 SFH 7060



Qualification Report 150198C1

Preconditioning: MSL 4 (only IPX7 test)

Test Performed	Condition	Duration	Sample Size	Failures El.	Opt.	Vis
IPX7 test *) *DIN EN 60529*	Storage in water (1m above top of device)	24h	28	0	0	0
Solvent resistance test *IEC 60068-2-70 Xb*	<u>3 different fluid types</u>: - 2-propanol - Petroleum ether - Artificial sweat	200 wipes per fluid (~2 minutes per fluid) See the explanation on page 3	3 (1 device per fluid)	0	0	0
Chemical stain test *IEC 60068-2-70 Xb*	<u>7 different fluid types</u>: - Hand cream - Sun protection lotion - Lipstick - Make up - Insect repellent lotion a - Insect repellent lotion b - Cooking oil	24h See the explanation on page 3	7 (1 device per fluid)	0	0	0

Notes: *) Tested conditions are above the requirement definitions for IPX7 according to DIN EN 60529. This states >30minutes only.

Failure criteria:

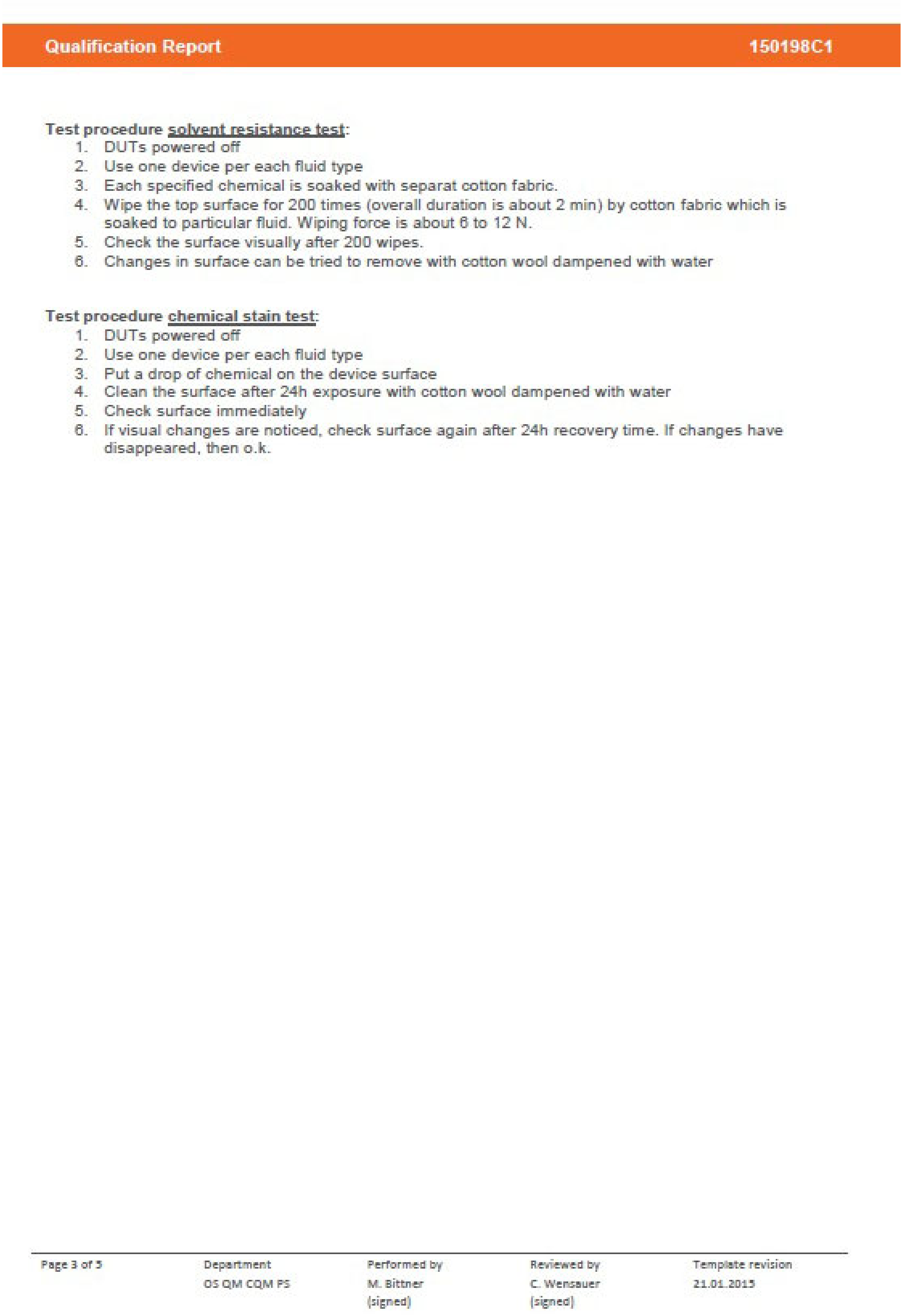
- Electrical failures /Optical failures:

Photodiode:	Ir (Vr=10V)	> 10 nA
	Ip (Vr=5V)	± 20% of initial value
IR-Emitter:	VF (If=100mA)	<1,3 V or >1,7 V ± 10% of initial value
	IE (If=100mA)	± 50% of initial value
Red Emitter:	VF (If=100mA)	<1,8 V or >2,6 V ± 10% of initial value
	IE (If=100mA)	± 50% of initial value
Green Emitter:	VF (If=100mA)	<2,6 V or >3,6 V ± 10% of initial value
	IE (If=100mA)	± 50% of initial value

- Visual failures: <u>IPX 7 test</u>: Broken or damaged package or lead.
  <u>Solvent resistance / Chemical stain test</u>: Changes in colour, gloss, surface roughness, blistering or cracking

Conclusion: The tested devices fulfill the reliability requirements.

Page 2 of 5	Department	Performed by	Reviewed by	Template revision
	OS QM CQM PS	M. Bittner (signed)	C. Wensauer (signed)	21.01.2015



Qualification Report 150198C1

Test procedure <u>solvent resistance test</u>:

1. DUTs powered off
2. Use one device per each fluid type
3. Each specified chemical is soaked with separat cotton fabric.
4. Wipe the top surface for 200 times (overall duration is about 2 min) by cotton fabric which is soaked to particular fluid. Wiping force is about 6 to 12 N.
5. Check the surface visually after 200 wipes.
6. Changes in surface can be tried to remove with cotton wool dampened with water

Test procedure <u>chemical stain test</u>:

1. DUTs powered off
2. Use one device per each fluid type
3. Put a drop of chemical on the device surface
4. Clean the surface after 24h exposure with cotton wool dampened with water
5. Check surface immediately
6. If visual changes are noticed, check surface again after 24h recovery time. If changes have disappeared, then o.k.

Page 3 of 5	Department	Performed by	Reviewed by	Template revision
	OS QM CQM PS	M. Bittner (signed)	C. Wensauer (signed)	21.01.2015

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