Product Document

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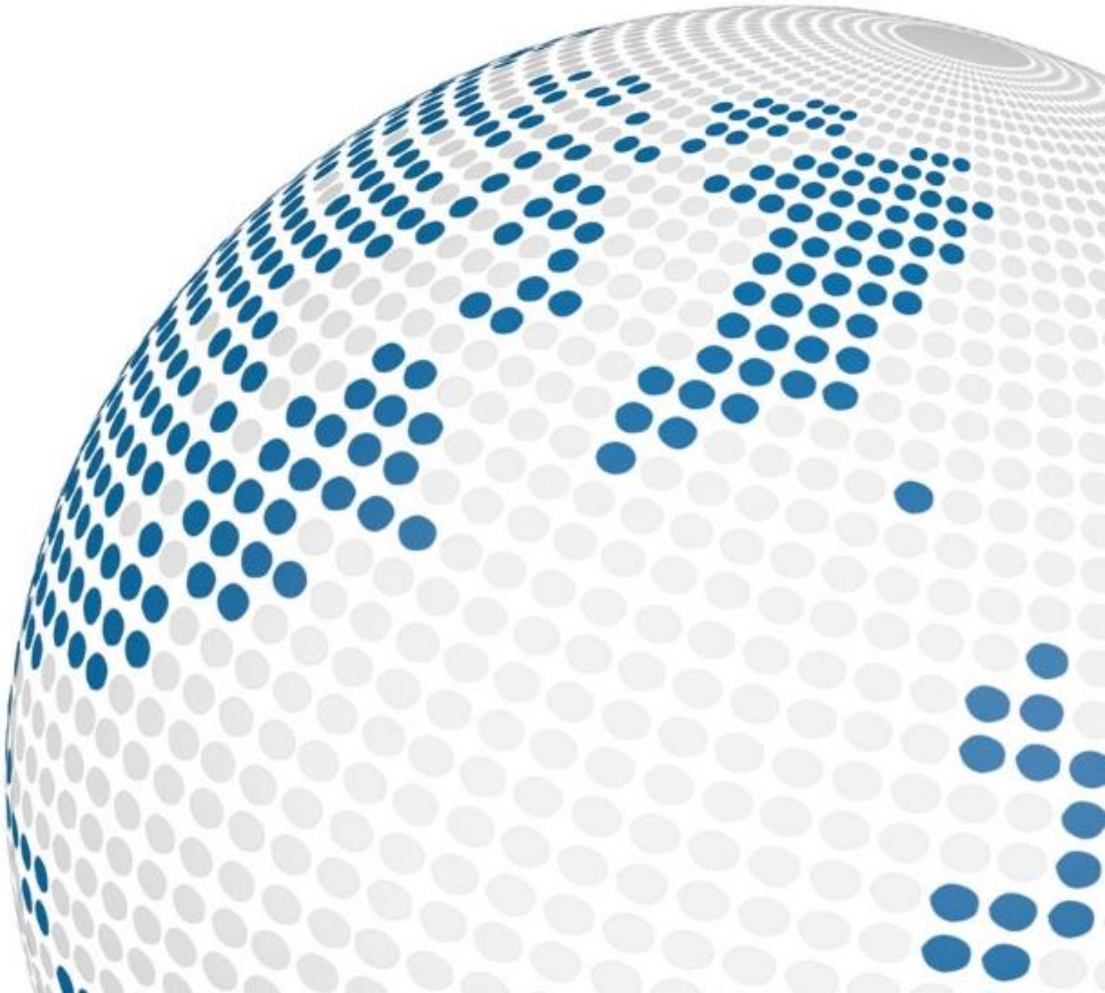
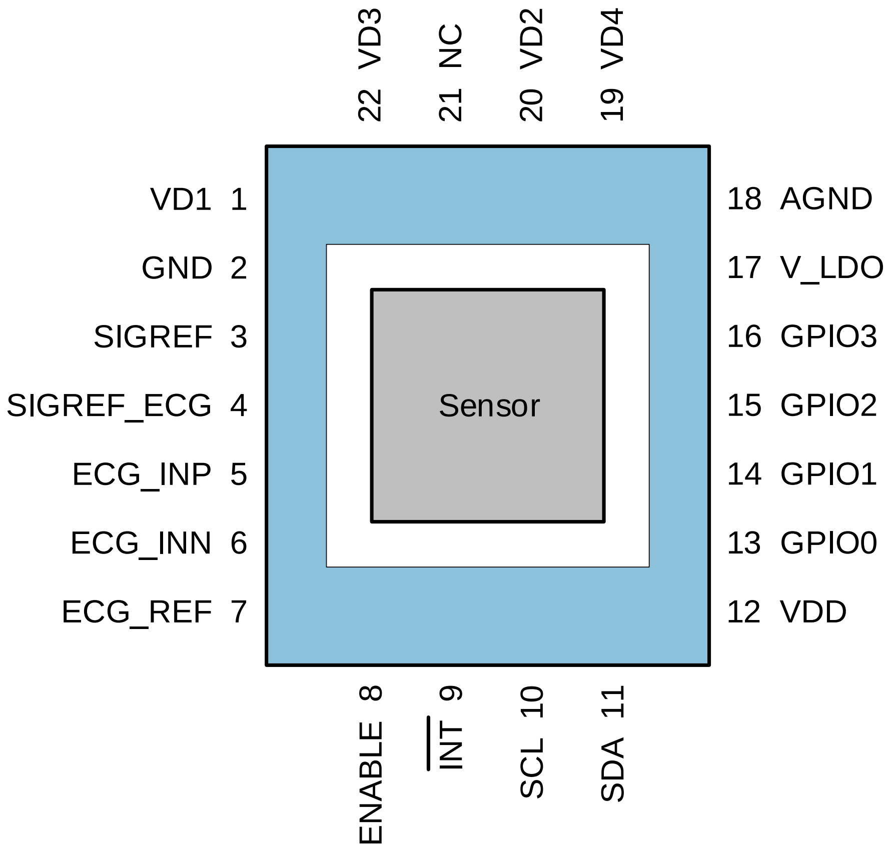


Kumud Dey
June 2020

AS7038GB/RB Design-in Guidelines

AS7038GB/RB

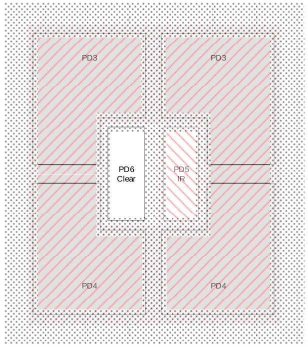
Overview

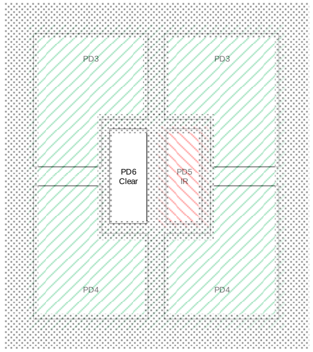


AS7038GB/RB
Pin Description

AS7038GB/RB

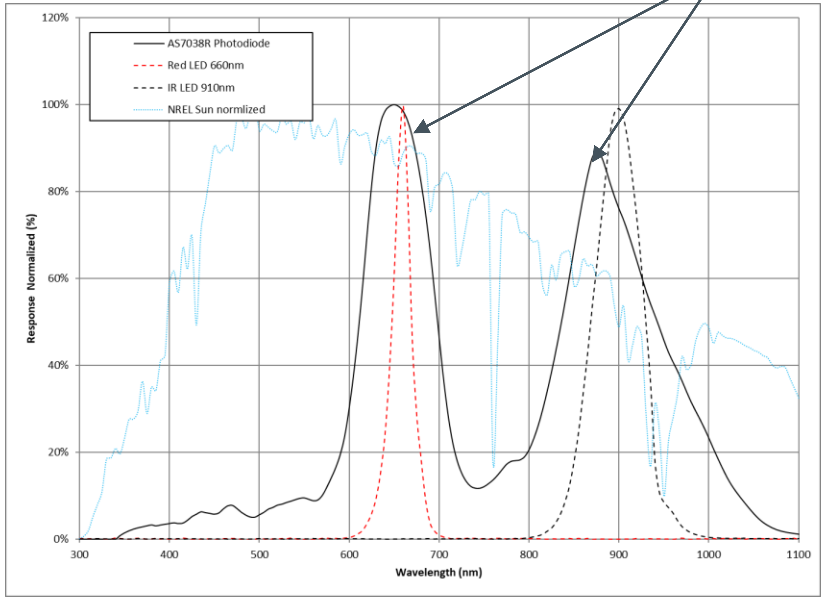
Filter description – interferometric filter





AS7038RB Filter response

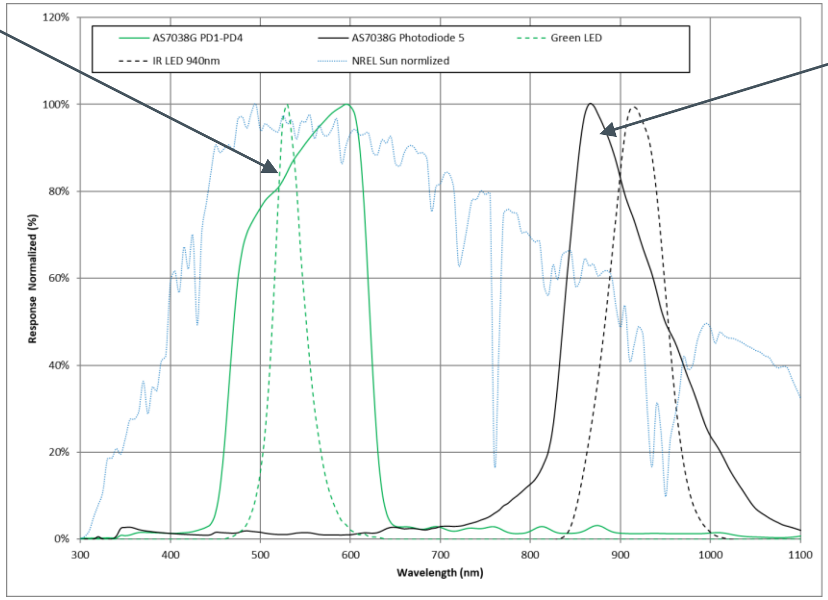
PD1..PD4 Photodiode



AS7038GB Filter response

PD1..PD4 Photodiode for PPG

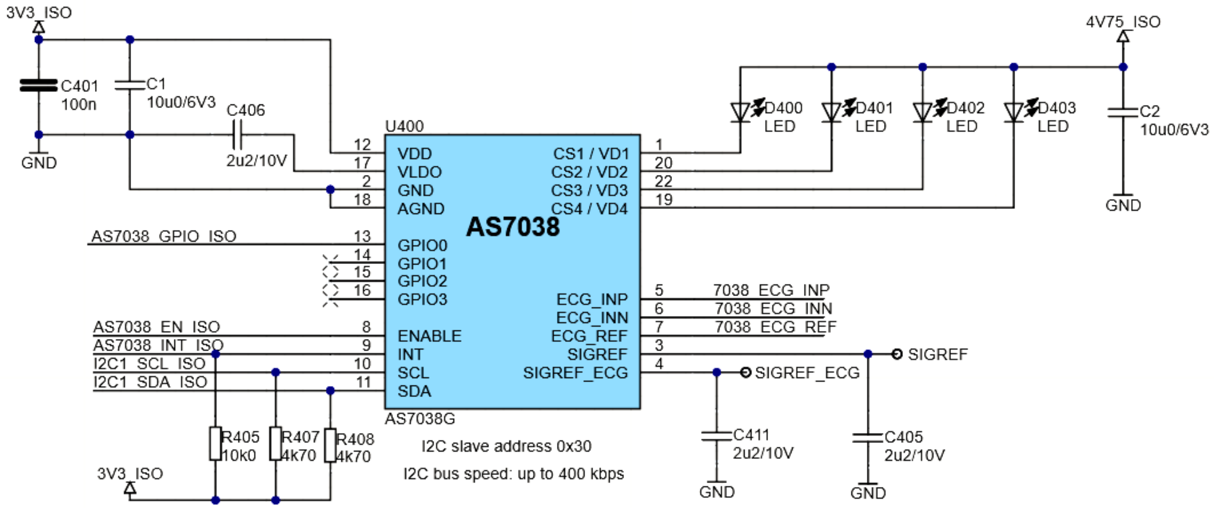
PD6 Photodiode for proximity detection



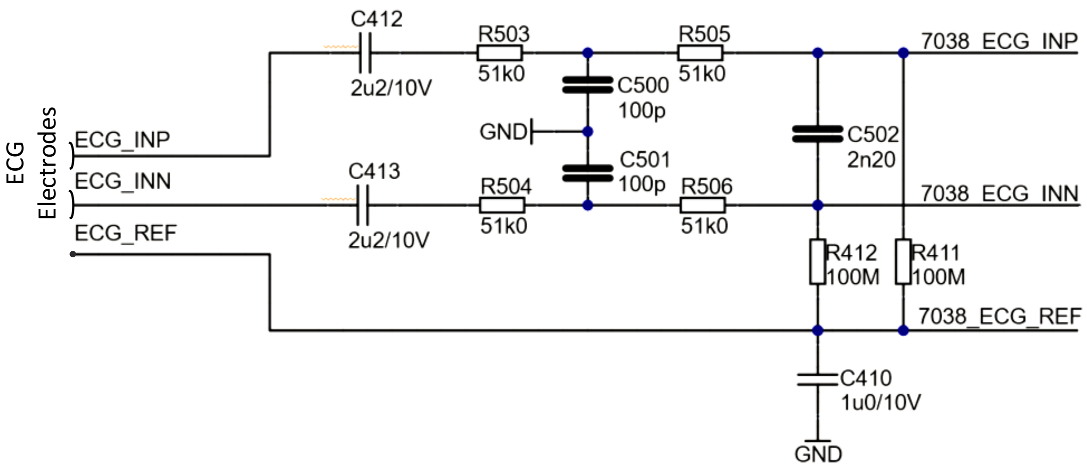
AS7038GB/RB

Recommended design

AS7038GB/RB Design

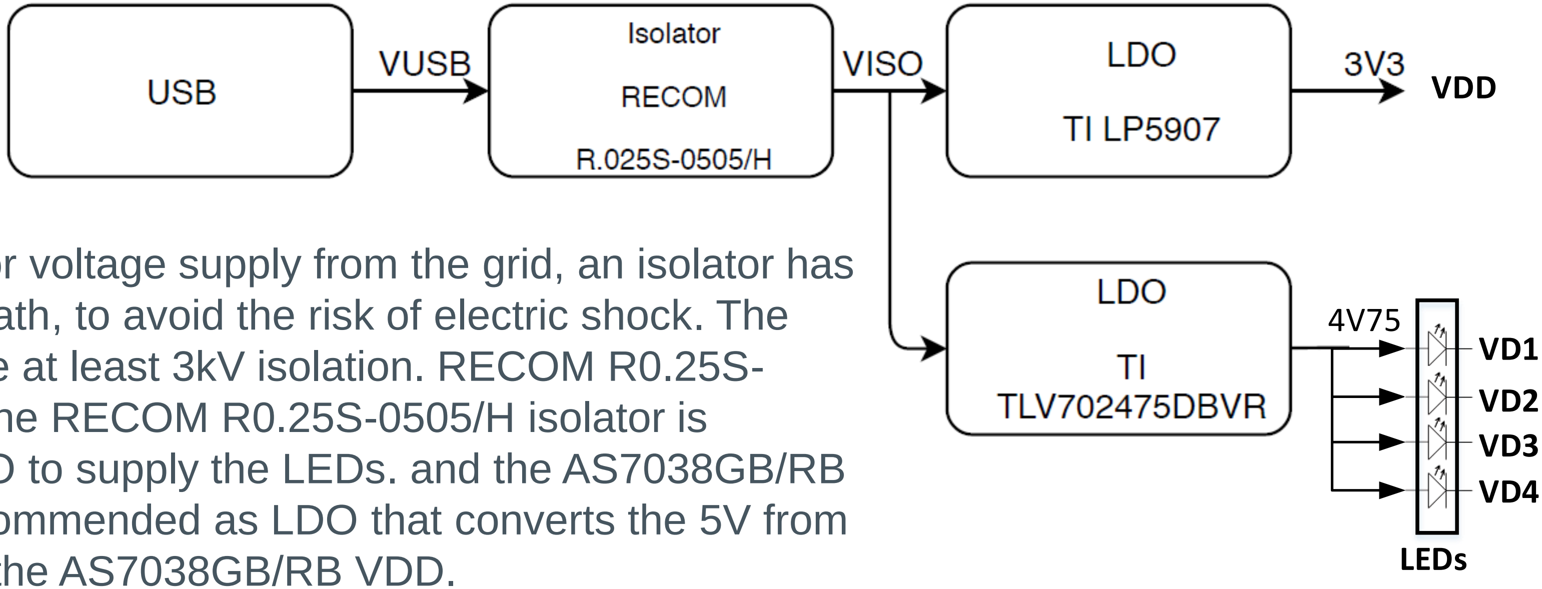


Recommended ECG Signal Filter Design



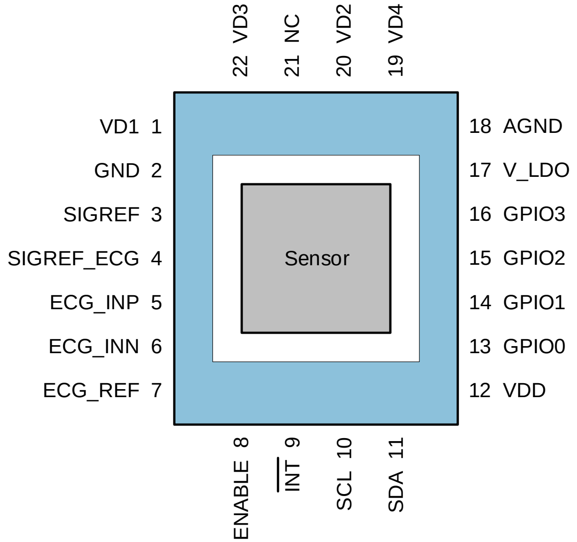
Power Supply Scheme

Pin description



- **USB supply with Isolator**

In case the AS7038GB/RB is supplied by USB or voltage supply from the grid, an isolator has to be used in the power path as well as signal path, to avoid the risk of electric shock. The isolator must be medically approved and provide at least 3kV isolation. RECOM R0.25S-0505/H is recommended. The 5V coming from the RECOM R0.25S-0505/H isolator is converted to 4V75 by an TLV702475DBVR LDO to supply the LEDs. and the AS7038GB/RB VDD. TI LP5907 with fixed output voltage is recommended as LDO that converts the 5V from the RECOM R0.25S-0505/H isolator to 3V3 for the AS7038GB/RB VDD.



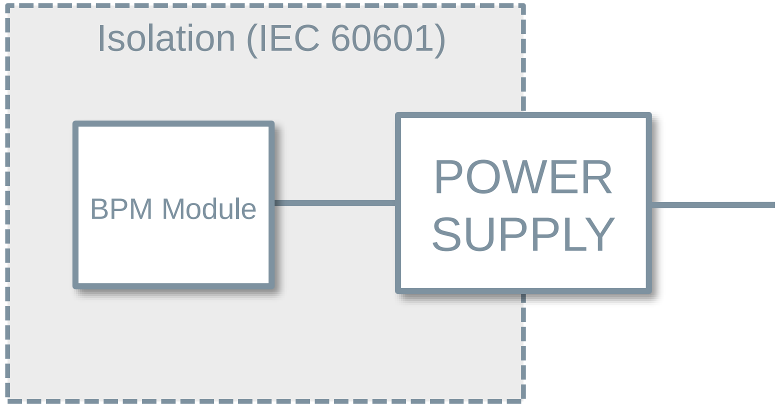
Pin No.	Pin Name	Description	Recommended Voltage [V]	Decoupling Capacitor [F]
1	VD1	Supply Voltage for LED D1	4V75	10u to GND
2	GND	Power Supply ground	connect to GND	-
12	VDD	Supply Voltage for AS7038	2V7 - 5V5	2.2u to GND
17	V_LDO	1.9V output voltage. Connect 2.2uF capacitor to GND	connect to GND	2.2u to GND
18	AGND	Analog Ground. Connect to low noise GND	connect to GND	-
19	VD4	Supply Voltage for LED D4	4V75	10u to GND
20	VD2	Supply Voltage for LED D4	4V75	10u to GND
22	VD3	Supply Voltage for LED D2	4V75	10u to GND

*Recommended design Schematics on Page 4

Safety Requirements

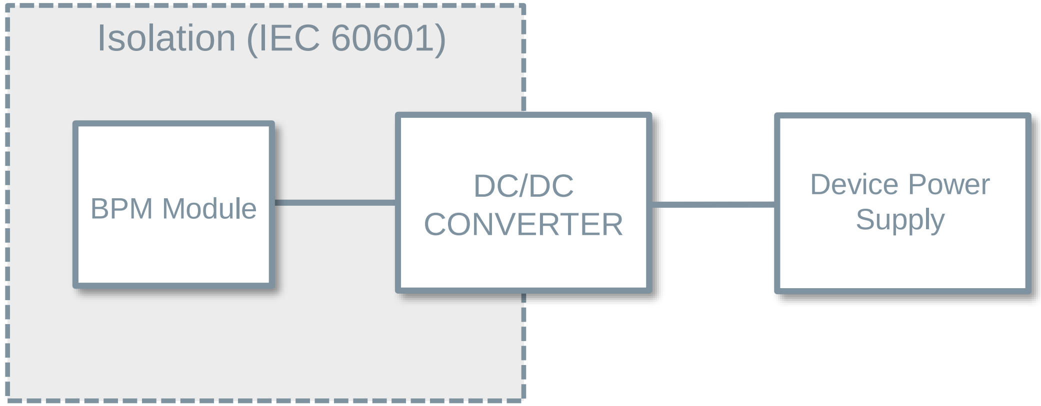
USB with Isolator

The power supply used to power the BPM Module must be IEC 60601 certified, if the end device is connected to a wall plug, in order to guarantee isolation from the electricity network when touching the electrodes.



Application option 1:

Device internal power supply compliant to IEC 60601 with separated ground.



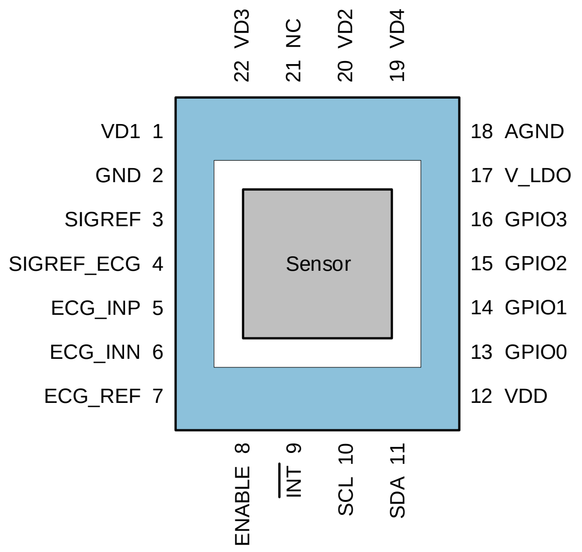
Application option 2:

Additional DC/DC-Converter (IEC 60601 certified), to power the BPM Module in the device.

IO Signals

Pin description

- After setting the pin ENABLE=1 the AS7038GB/RB registers can be accessed by the I2C interface. Before enabling any additional function (current source, TIA, ADC…) set the bit ldo_en=1 to set the internal LDO to normal mode. For operating the ADC or the sequencer enable the oscillator by setting osc_en=1.
- An interrupt output pin INT can be used to interrupt the host.
- The AS7038GB/RB includes an I2C slave using an I2C address of 0x30 (7-bit format; R/W bit has to be added) respectively 60h (8-bit format for writing) and 61h (8-bit format for reading). Fast mode (400kHz) and standard mode (100kHz) support.



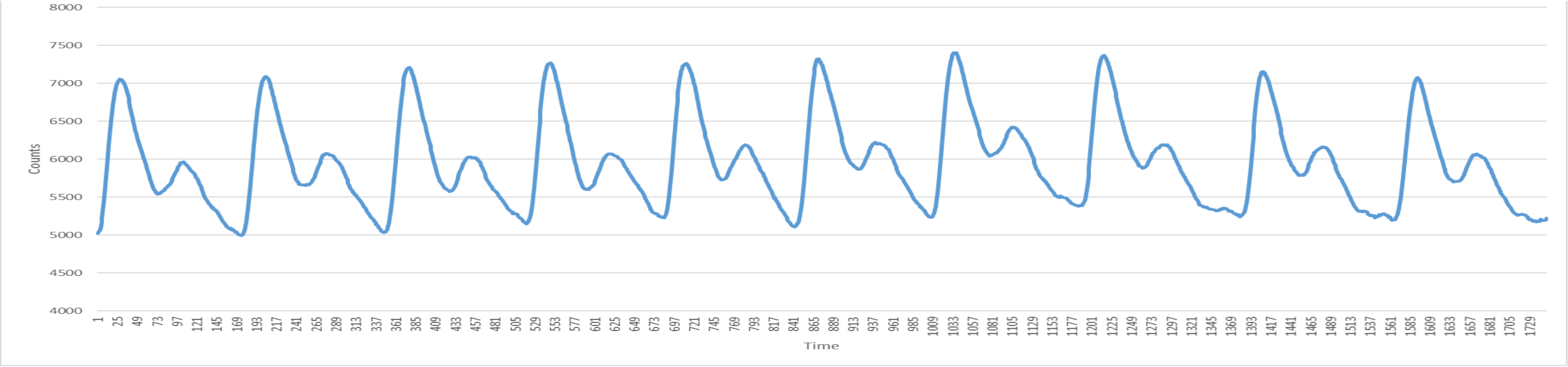
Pin No.	Pin Name	Description	Decoupling Capacitor [F]	Pull-up Resistor [Ohm]
8	ENABLE	Enable input for AS7038. Active High. If ENABLE is not used, connect to VDD	-	10K
9	INT	Open drain interrupt output pin. Active Low	-	10k
10	SCL	I2C serial clock input terminal	-	4K7 Resistor value depends on I2C bus
11	SDA	I2C serial data I/O terminal - open drain	-	4K7 Resistor value depends on I2C bus
13	GPIO0	General purpose input/output	-	-
14	GPIO1	General purpose input/output	-	-
15	GPIO2	General purpose input/output	-	-
16	GPIO3	General purpose input/output	-	-

*Recommended design Schematics on Page 4

PPG Signal

General Information

- Make sure your fingers are warm -> a pulse signal cannot be detected on cold fingers
- Do not press the finger too hard on the sensor -> if pressed to hard, the blood flow may be disrupted and no signal can be detected

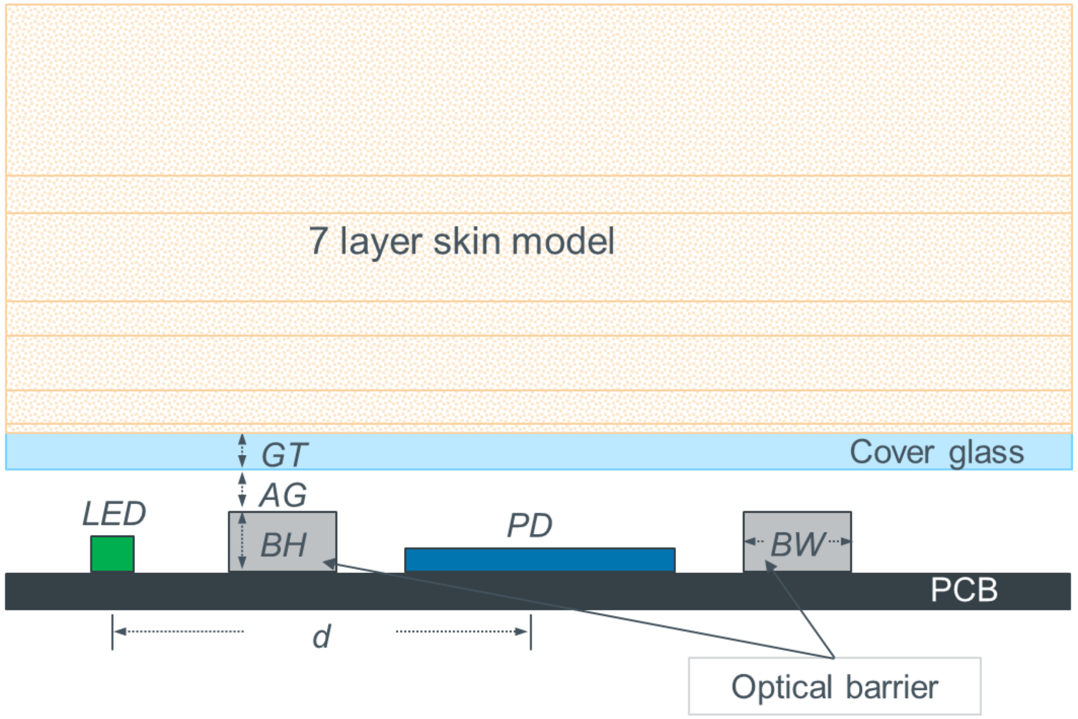


PPG signal

Counts vs Time

Optical Simulations

Optical system components



GT = Cover glass Thickness; AG = Air-gap; BH = Barrier Height; BW = Barrier Width; LED = light source; PD = detector; d = distance between LED and PD

- Optical system consists of a AS7038GB placed on a PCB along with the LED and the 1 mm high optical barrier that surrounds the photodiode.
- A cover glass is placed in between the source and detector and the 7-layer skin model.
- The optical properties of each optical component is provided in the table in next slide.
- Assuming symmetrical system, only one LED was used as light source.
- Optical simulations were carrier out using Zemax ray tracing software.
- Signal is defined as the optical power detected on the surface of the PD when skin is in contact with the cover glass.
- Cross-talk is defined as the detected optical power without the skin. This represents the light rays reaching the detector without hitting the skin surface.
- A ratio of signal to cross-talk (SXR) is used for comparing the effect of parameters such as d, GT, AG and BW for different LEDs.

Optical Simulations

Optical properties of the system components

Sensing is life.

Skin Parameters*

Skin Layer	Layer thickness (mm)	Refractive Index (generic)	skin reflectivity generic (diffused)	Absorption coefficient (1/mm)			Scattering coefficients	
				at 525 nm	at 660 nm	at 940 nm	generic	*g*
1 - Stratum corneum	0.02	1.5	0.07	0.4493	0.5488	0.7408	1.00	0.86
2 - Living epidermis	0.09	1.34	0.00	0.1353	0.4493	0.6065	1.00	0.8
3 - Papillary dermis	0.175	1.4	0.00	0.7788	0.8869	0.4966	1.00	0.9
4 - Upper blood net dermis	0.09	1.39	0.00	0.6376	0.8958	0.4966	1.00	0.95
5 - Reticular dermis	1.5	1.4	0.00	0.8607	0.8869	0.4966	1.00	0.8
6 - Deep blood net dermis	0.105	1.38	0.00	0.5488	0.9048	0.4966	1.00	0.95
7 - Subcutaneiuous fat	6.25	1.44	0.00	0.8607	0.9048	0.4966	1.00	0.75

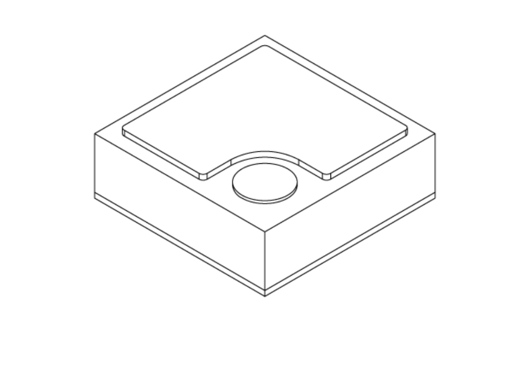
* Reference for skin parameters: I.V. Meglinski and S.J. Matcher, Computer Methods and Programs in Biomedicine 70 (2):179-186, 2003.

Optical properties of PCB and Barrier

System Component	Reflectivity		Absorption	Transmission	Remarks
	Diffused	Specular			
PCB	0.5 of 50%	0.5 of 50%	50%	0	PCB is considered to be 50% reflective
Optical Barrier	0.5 of 20%	0.5 of 20%	80%	0	Barrier is considered to be 20% reflective
Cover glass	As per Fresnel equations		0%		

Optical Simulations

LEDs used for the simulations

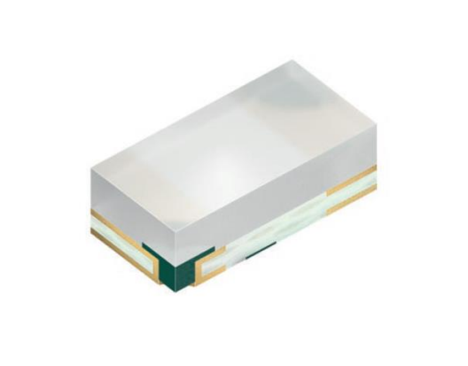


ODT1313UX3.A3
OS-CORE UX:3

- True green (λ_{dom} = 530 nm) LED chip
- 13 mil x 13 mil
- 0.335 mm x 0.335 mm x 0.12 mm
- Used in AS7030

CT DELSS1.12
FIREFLY E1608

- True green (λ_{dom} = 530 nm) LED module in white SMT package and colorless clear resin
- 0.8 mm x 1.6 mm x 0.6 mm
- Used in AS7038G EVKs

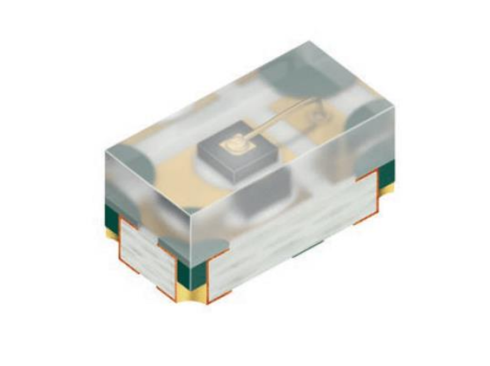


LT QH9G
CHIPLED 0402

- True green (λ_{dom} = 530 nm) LED module in SMT package, colorless diffused resin
- 0.6 mm x 1.1 mm x 0.4 mm

CH DELSS1.12
FIREFLY E1608

- Hyper red ($\lambda_{centroid}$ = 657 nm) LED module in white SMT package and colorless clear resin
- 0.8 mm x 1.6 mm x 0.6 mm
- Used in AS7038R EVKs



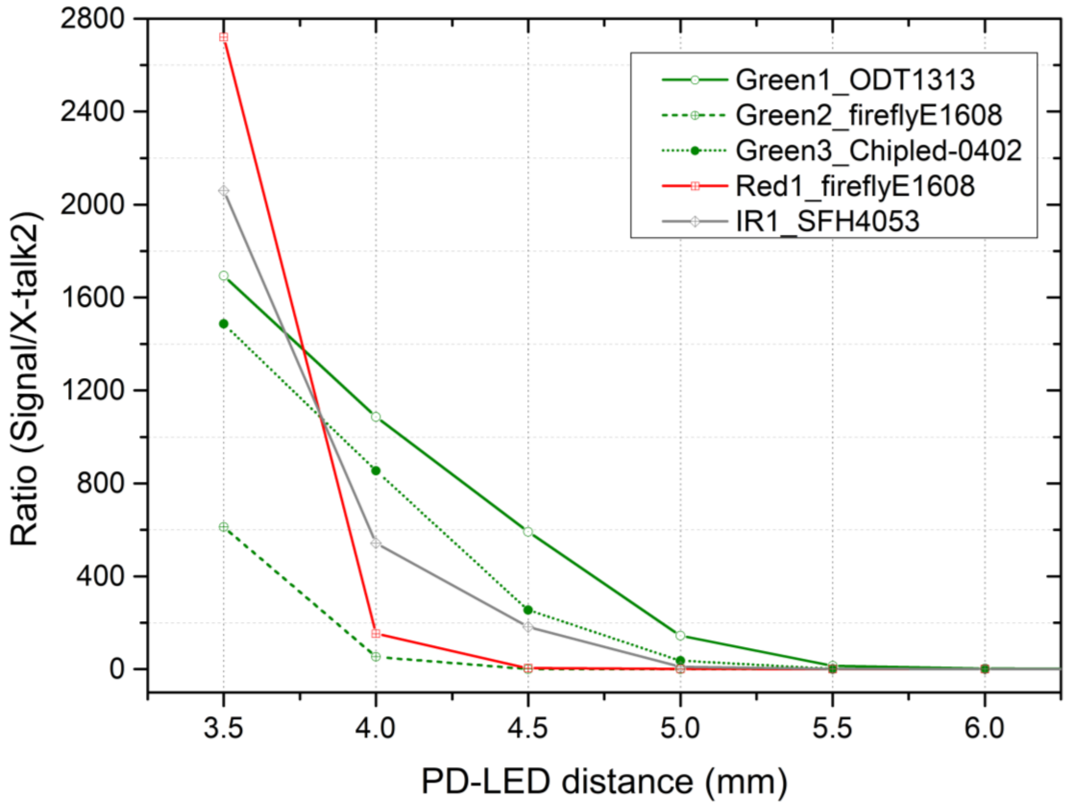
SFH 4053
CHIPLED

- Infrared ($\lambda_{centroid}$ = 850 nm) LED module in SMT package and clear resin
- 1.0 mm x 0.5 mm x 0.45 mm
- Used in AS7038R EVKs

- Each LED is assumed to emit 1 W optical power.
- Ray-files corresponding to each LED was available and used for simulating the source characteristics

Optical Simulations

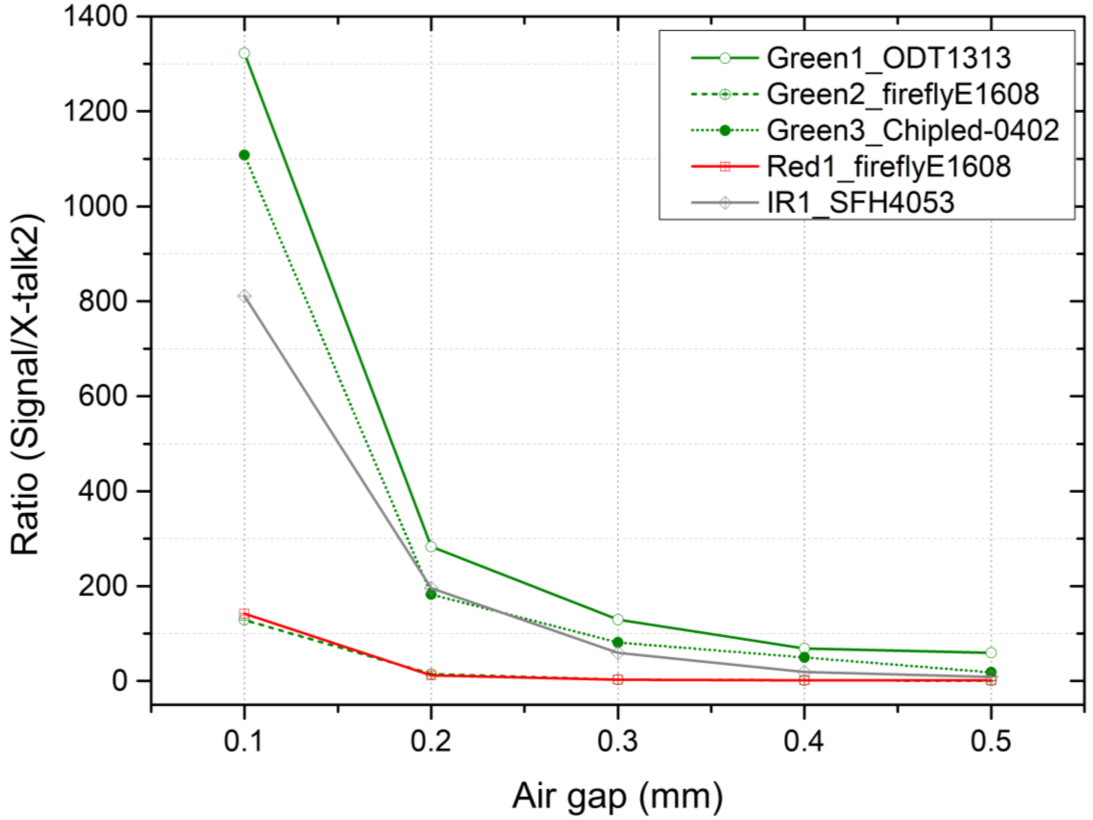
PD-LED distance dependence of SXR



- In this graph, SXR values are presented for various LEDs as a function of PD-LED distance.
- System: AG = 0.1 mm; GT = 0.3 mm; BW = 1 mm
- The minimum simulated distance is 3.5 mm.
- It is clear that the SXR values decreases rapidly with increasing PD-LED distance.

Optical Simulations

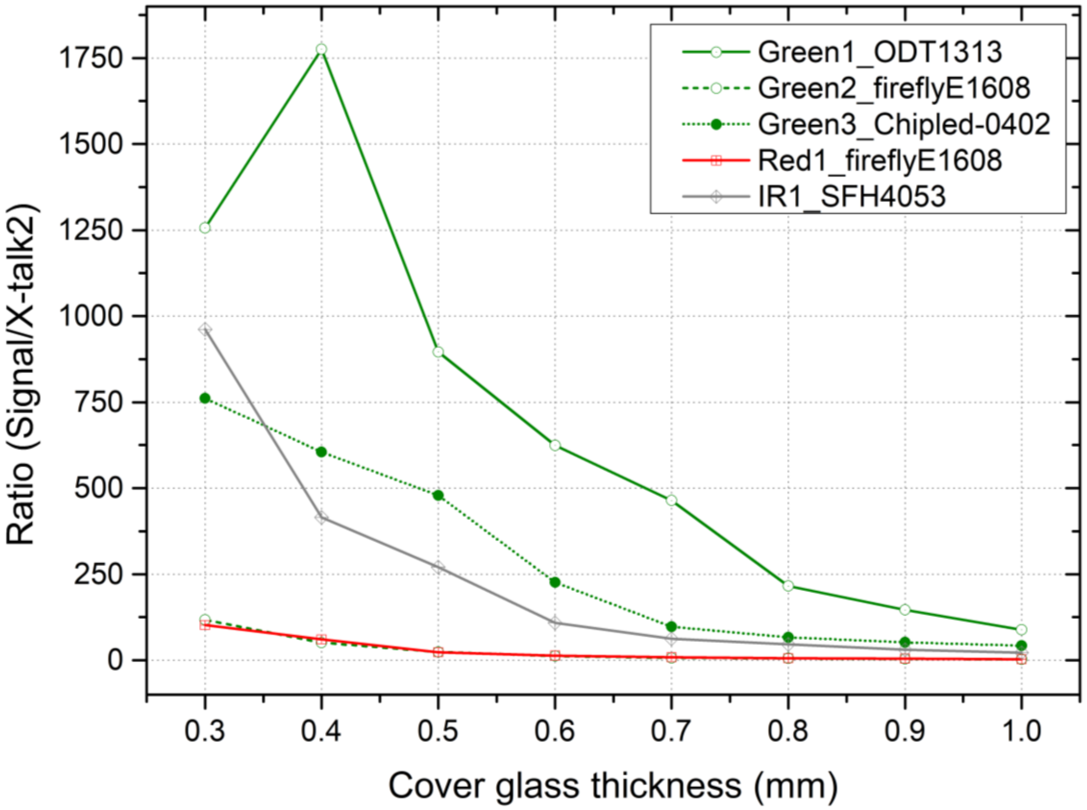
Air Gap dependence of SXR



- In this graph, SXR values are presented for various LEDs as a function of air gap.
- System: d = 0.4 mm; GT = 0.3 mm; BW = 1 mm
- The minimum simulated air gap (AG = 0 mm) results in a X-talk value of 0. Hence, the SXR values for AG starting at 0.1 mm is presented.
- It is clear that the SXR values decreases rapidly with increasing AG value.

Optical Simulations

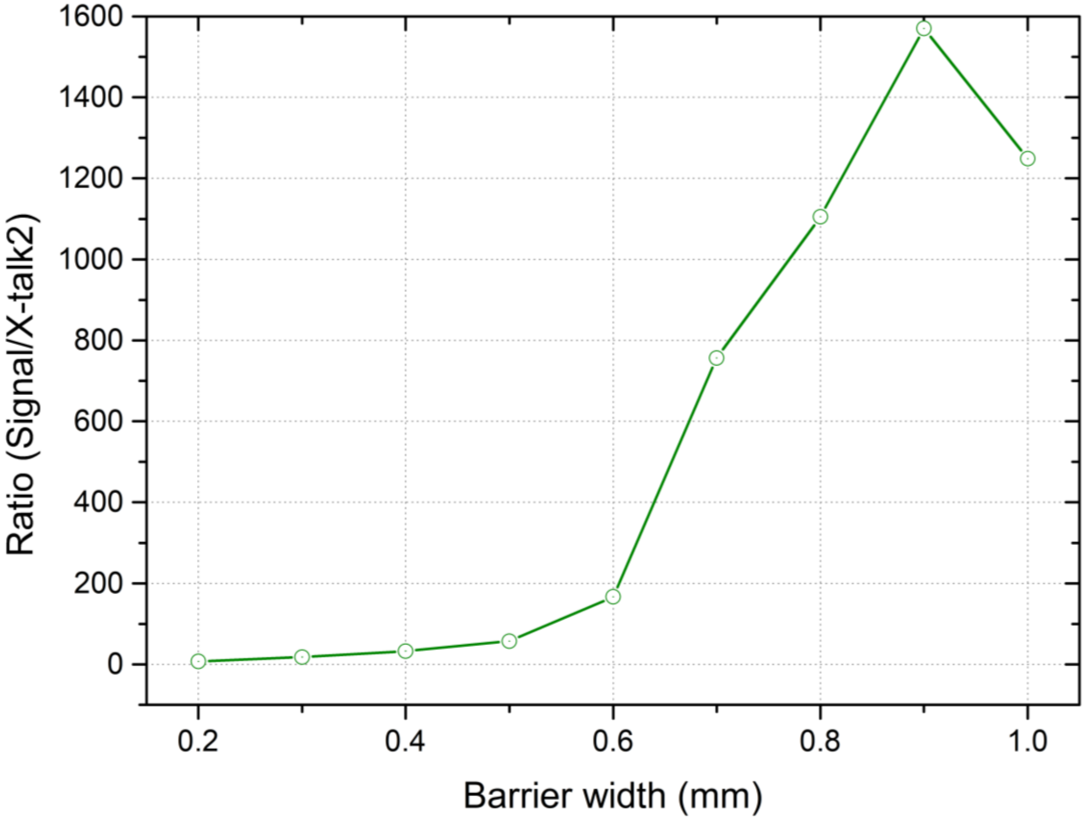
Cover Glass Thickness dependence of SXR



- In this graph, SXR values are presented for various LEDs as a function of cover glass thickness.
- System: d = 0.4 mm; AG = 0.1 mm; BW = 1 mm
- The minimum simulated GT is 0.3 mm.
- It is clear that the SXR values decreases with increasing CT except for the green LED chip (ODT1313UX3.A3).
- The reason for this exceptional behavior needs further investigation.
- It can also be seen from the graph that the LEDs in similar package results in similar SXR values.

Optical Simulations

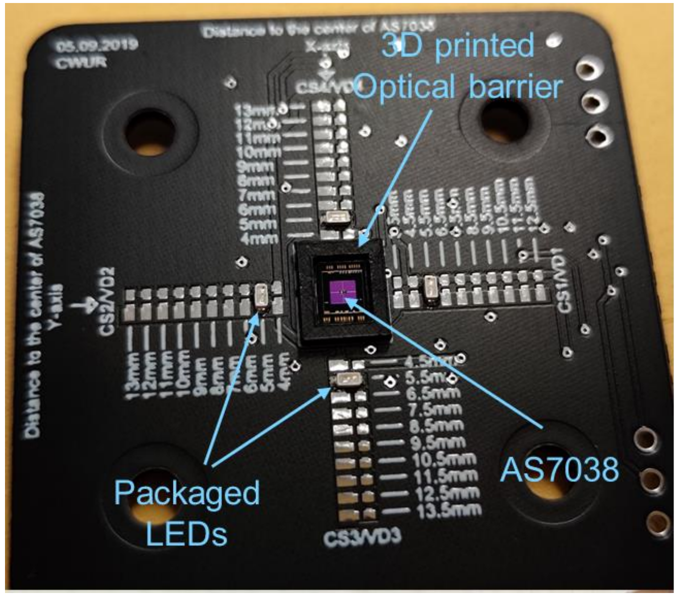
Barrier Width dependence of SXR

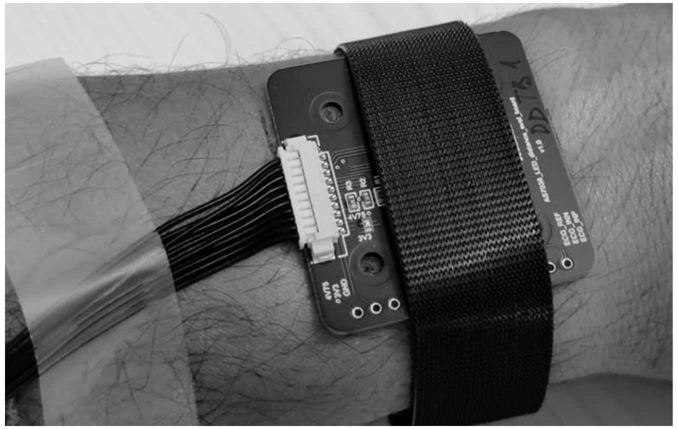


- In this graph, SXR values are presented for the green LED chip as a function of optical barrier width.
- System: d = 0.4 mm; AG = 0.1 mm; GT = 0.3 mm
- The minimum simulated BW is 0.2 mm.
- The SXR values increases with increasing optical barrier width till BW = 0.9 mm. A further increase in BW results in a decrease of SXR value.

Experimental Study

AS7038GB: PD-LED distance dependence of PPG signal





Measurement setup

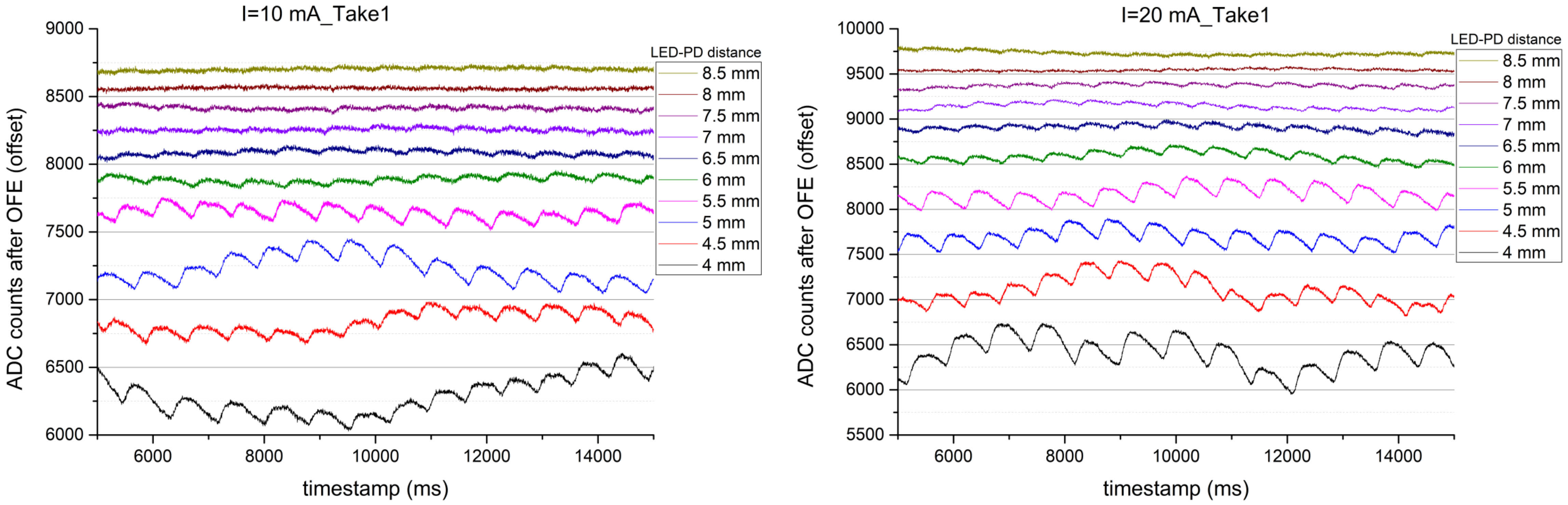
- AS7038GB and LEDs are soldered on distance-dependence-test boards (DDTB) with LED distances as indicated in the below table.

Test Board Number	Distance @ pin VD1 (mm)	Distance @ pin VD2 (mm)	Distance @ pin VD3 (mm)	Distance @ pin VD4 (mm)
DDTB1	4.5	4	4.5	4
DDTB2	5.5	5	5.5	5
DDTB3	6.5	6	6.5	6
DDTB4	7.5	7	7.5	7
DDTB5	8.5	8	8.5	8

- A rectangular 3-D printed optical barrier (height = ~ 1 mm; width = ~ 1 mm) is placed around the sensor.
- The test board is placed on the wrist and secured with a strap. For subsequent measurements, care is taken to place the test boards at the same measurement site.
- Fore each measurement, the LED pair at the same distance from the PD (Ex. VD1,3 and VD2,4) are simultaneously switched ON.
- Multiple measurements are taken for a given PD-LED distance.
- PPG measurements are done with two LED drive currents (I_LED = 10 mA, and 20 mA).
- 'AS703x Vital Signs Sensor' application software is used for controlling the device parameters and recording the PPG signal.
- ADC counts after the OFE1 is used for comparing the PPG signal.

Experimental Study

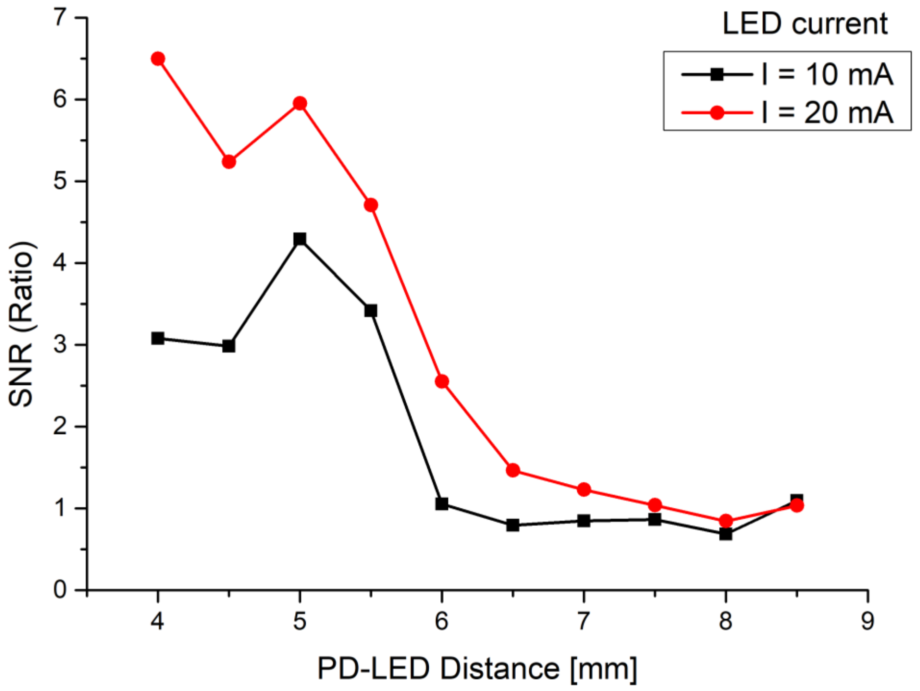
AS7038GB: PD-LED distance dependence of PPG signal



Two sets of graphs here show the PPG signal recorded with I_LED = 10 mA and 20 mA, and at various PD-LED distances. Each graph is offset along Y-axis for clarity. Qualitatively, the PPG amplitude decreases with increased PD-LED distance.

Experimental Study

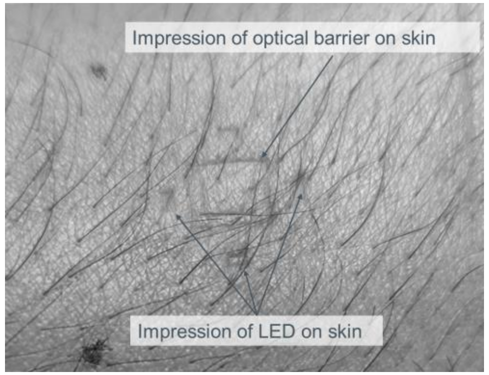
AS7038GB: PD-LED distance dependence of PPG signal



More data here: \\fsjedata\Project\AS7038\14_SYSTEM\DistanceDependence\7038g-doe1

SNR Analysis:

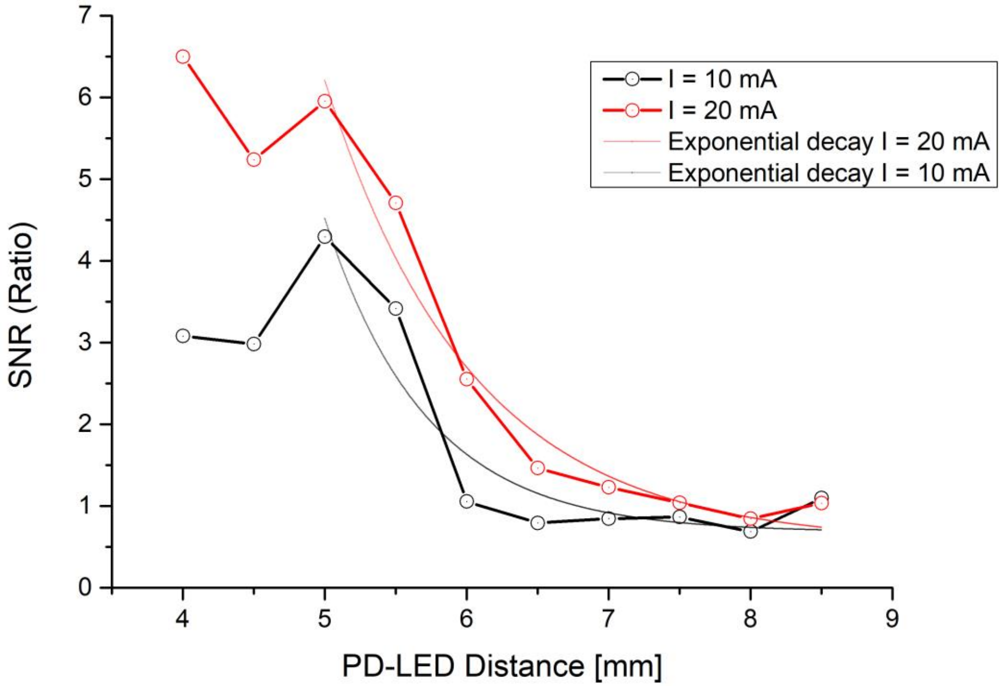
- The graphs here are the plots of PPG signal-to-noise ratio (SNR) for various PD-LED distances.
- SNR plotted here is an average of 5 individual measurements at each position.
- SNR values for both I=10 mA and I = 20 mA are shown.
- Starting at PD-LED distance of 4 mm, for both sets of measurements, the average SNR decreases when the distance is increased to 4.5 mm and increases again.
- The increase in SNR when the distance increases from 4.5 mm to 5 mm could be due to improved contact between the skin and the LED. Farther away the LED from the optical barrier, it can be pressed against the skin efficiently. (picture below)
- After an initial increase, the SNR seems to decrease exponentially with increasing PD-LED distance.



Photograph of the PPG measurement site on wrist where the optical barrier and the LED leave impressions

Experimental Study

AS7038GB: PD-LED distance dependence of PPG signal



SNR Analysis:

- The graphs here show an exponential decay fit to a part of the SNR data at PD-LED distance ≥ 5 mm.
- The solid lines represent fit of the measured data.
- The average SNR appears to decay exponentially with increasing PD-LED distance.

Note:

While for this PD-LED distance dependence analysis it is assumed that the optical system remains constant, there are several factors that affects the PPG signal. These are:

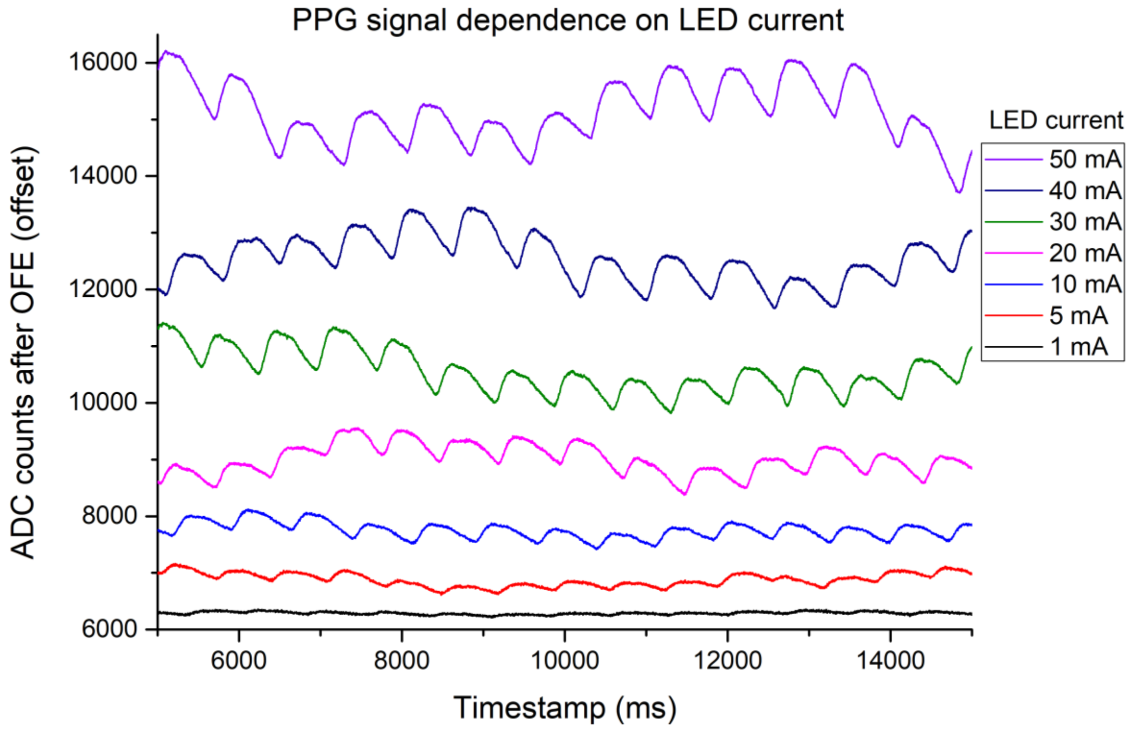
- Device to device variation
- LED intensity differences
- Device placement inaccuracy (on skin) – position, pressure etc.
- Skins spatial and temporal variations – perfusion, tissue structure etc.

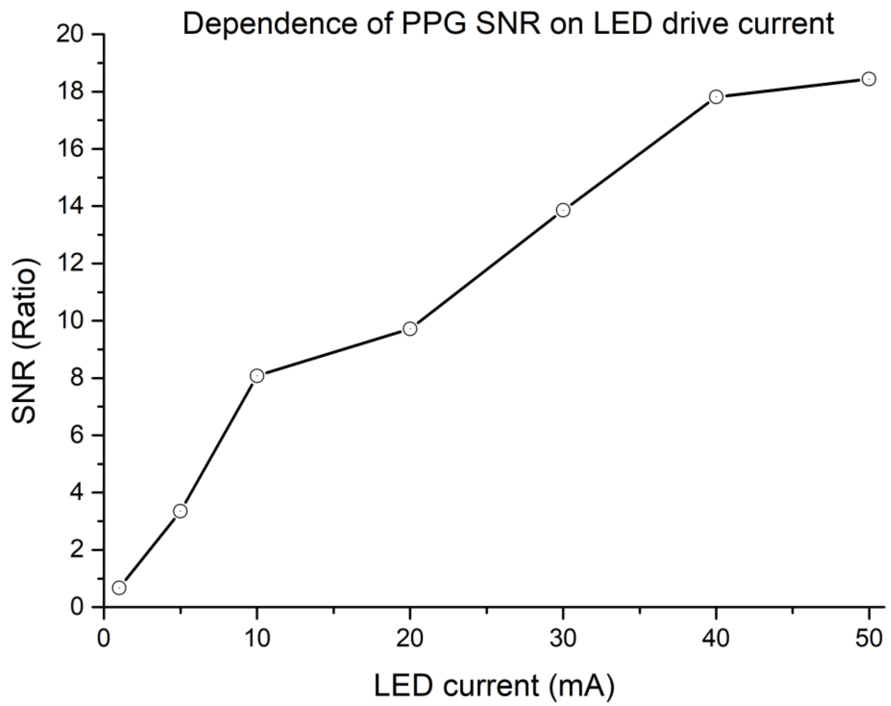
Thus, for an accurate SNR comparison the dependencies on the above factors must be minimized.

Experimental Study

AS7038GB: PD-LED distance dependence of PPG signal

To understand the dependence of PPG signal on I_LED, measurements were done with one of the test boards (DDTB1) at different LED drive current. All the 4 LEDs were switched ON simultaneously during the measurements.



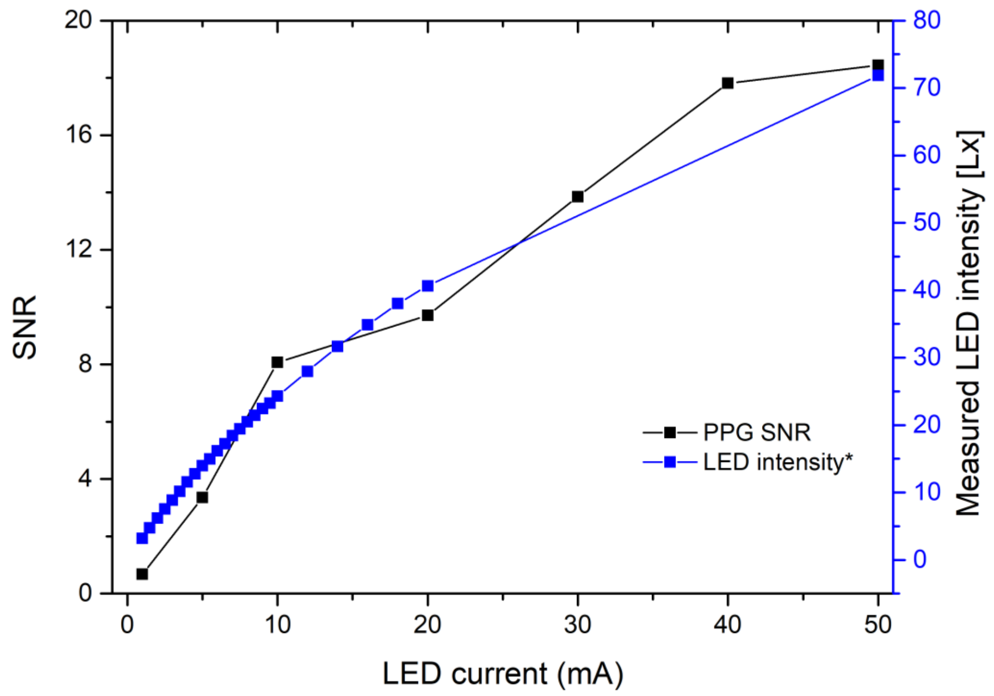


The above graphs show the PPG signal measured with increasing LED current. Each graph is offset along the Y-axis for clarity.

In the above graph the average PPG SNR values are plotted for various LED current. The SNR doesn't increase linearly with the I_LED.

Experimental Study

AS7038GB: PD-LED distance dependence of PPG signal



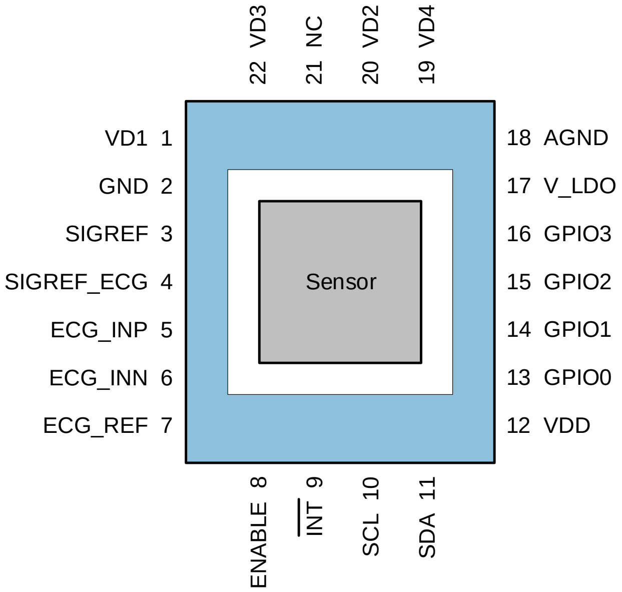
- Average SNR seems to follow similar trend as measured light intensity for increasing I_LED.
- * SNR is compared with the current vs light intensity measured on AS7030GB. It is expected that the LEDs on AS7038GB test boards also show similar behavior.
- For a proper comparison the light intensity measurements must be done on AS7038GB test boards as well.

ECG

Pin description

- The ECG (electro cardiogram) amplifier is a high impedance, low noise instrumentation amplifier with analog circuitry to bandpass filter the signal and amplify it before converting it with the ADC.

- The ECG lead OFF detection can be used for detection if the user actually touches the leads. It is a circuitry to measure the capacitor and/or resistance between the two lead inputs ECG_INP and ECG_INN.



Pin No.	Pin Name	Description	Capacitors [F]	Resistors [Ohm]
4	SIGREF_ECG	Analog refernce output	2.2u to GND	
5	ECG_INP	ECG amplifier positive input	2.2u in series 100p to GND 2.2n to ECG_INN	51k + 51k in series 100M to ECG_REF
6	ECG_INN	ECG amplifier negative input	2.2u in series 100p to GND	51k + 51k in series 100M to ECG_REF
7	ECG_REF	ECG amplifier refernce output	1u to GND	

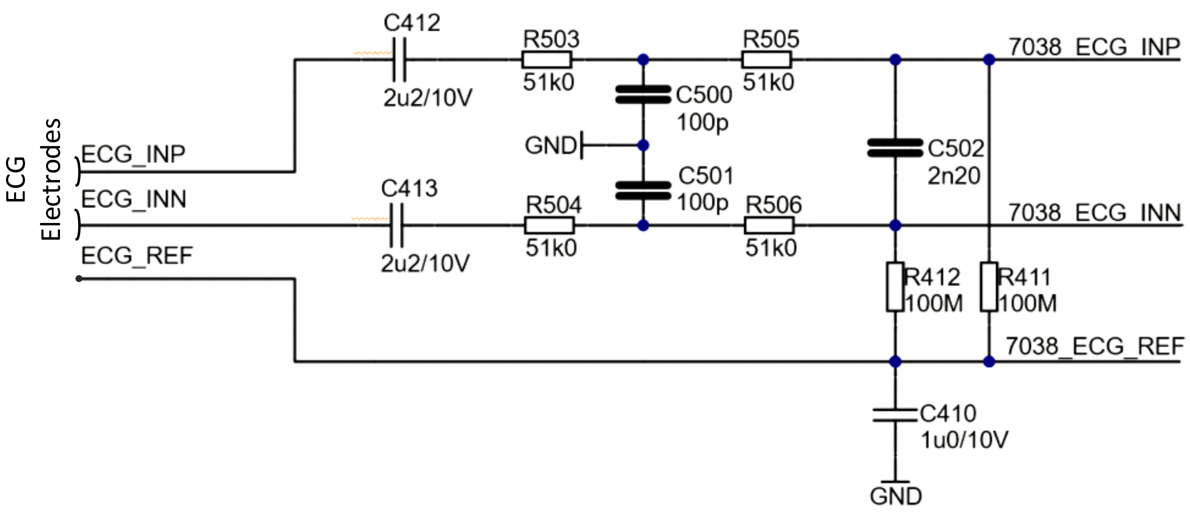
*Recommended design Schematics on Page 4

ECG

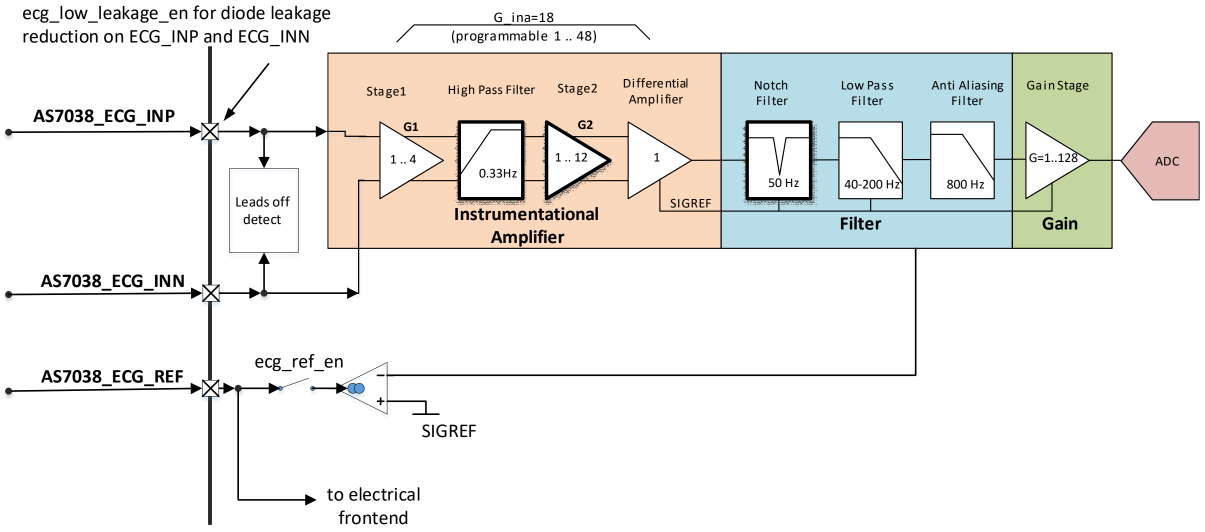
Pin description

- ECG amplifier is very sensitive to noise. Therefore, it is important to have an ECG frontend fitler to reduce the noise

Recommended ECG Frontend Filter

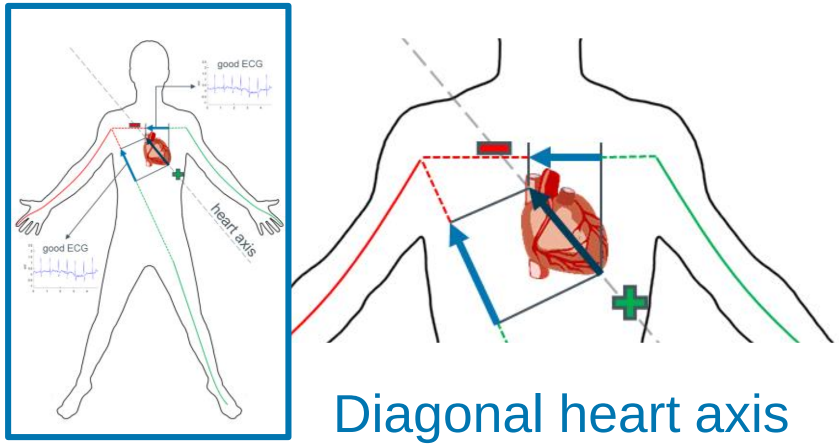


ECG Amplifier Circuit

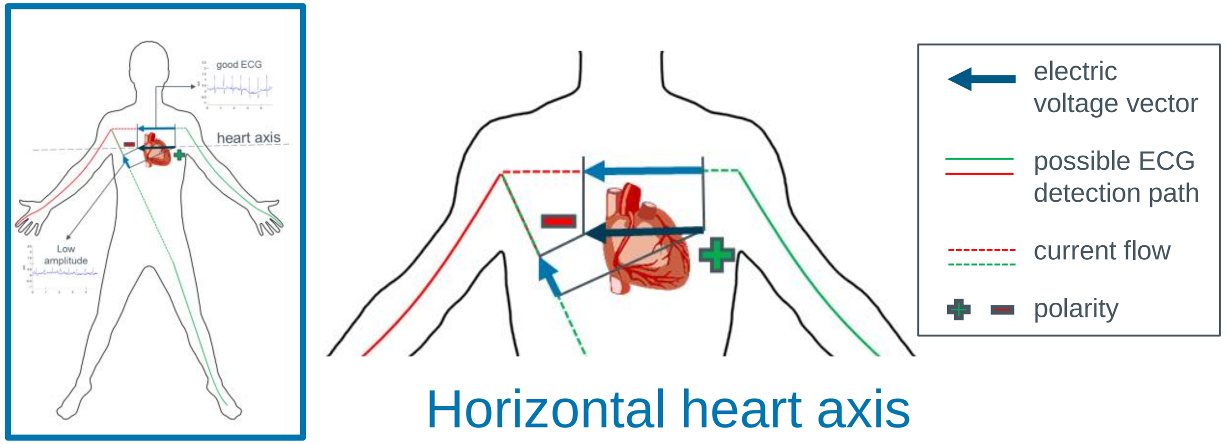


Note: As the ECG signal lines are very sensitive to noise, it is very important to pay attention of the layout. ECG frontend filter might be changed based on the application and noise sensitivity.

ECG Signal



Diagonal heart axis



Horizontal heart axis

- ECG recording is similar to voltage measurement in batteries
- The recorded amplitude depends highly on the orientation of the electrical heart axis relatively to the recording axis of the electrodes.
- There is considerable variation of the axis orientation even in healthy people.
- A reference electrode is used to filter out pick-up noise (common mode rejection)
- Make sure the electrodes are clean and do not have any kind of fat film on them
- The ECG signal may be too weak to be detected due to dry skin
- The signal strength of the ECG signal depends on orientation of the heart axis, which varies from individual to individual and may not be detectable in some cases

Signals

- Weak signals ranging from 0.5mV to 5.0mV
- High DC component of up to +/- 300mV (electrode skin contact)
- Common-mode component up to 1.5V (potential electrodes – ground)

Noise

- Power-line interference: 50-60 Hz
- Electrode contact noise (baseline drift)
- Motion artifacts (shifts in baseline)
- Muscle contraction
- Electromagnetic interference from other electronic devices (higher frequencies)

Electrode Properties

Recommendations

Electrodes

- Based on our measurements with 20 subjects, a skin-to-electrode resistance up to 350-400kΩ is recommended
- Based on this we recommend a round electrode of >14mm for each ECG contact.
- A differently shaped electrode with equivalent surface area is also possible
- A typical material to use would be stainless steel sheet electrodes (material 1.4301)

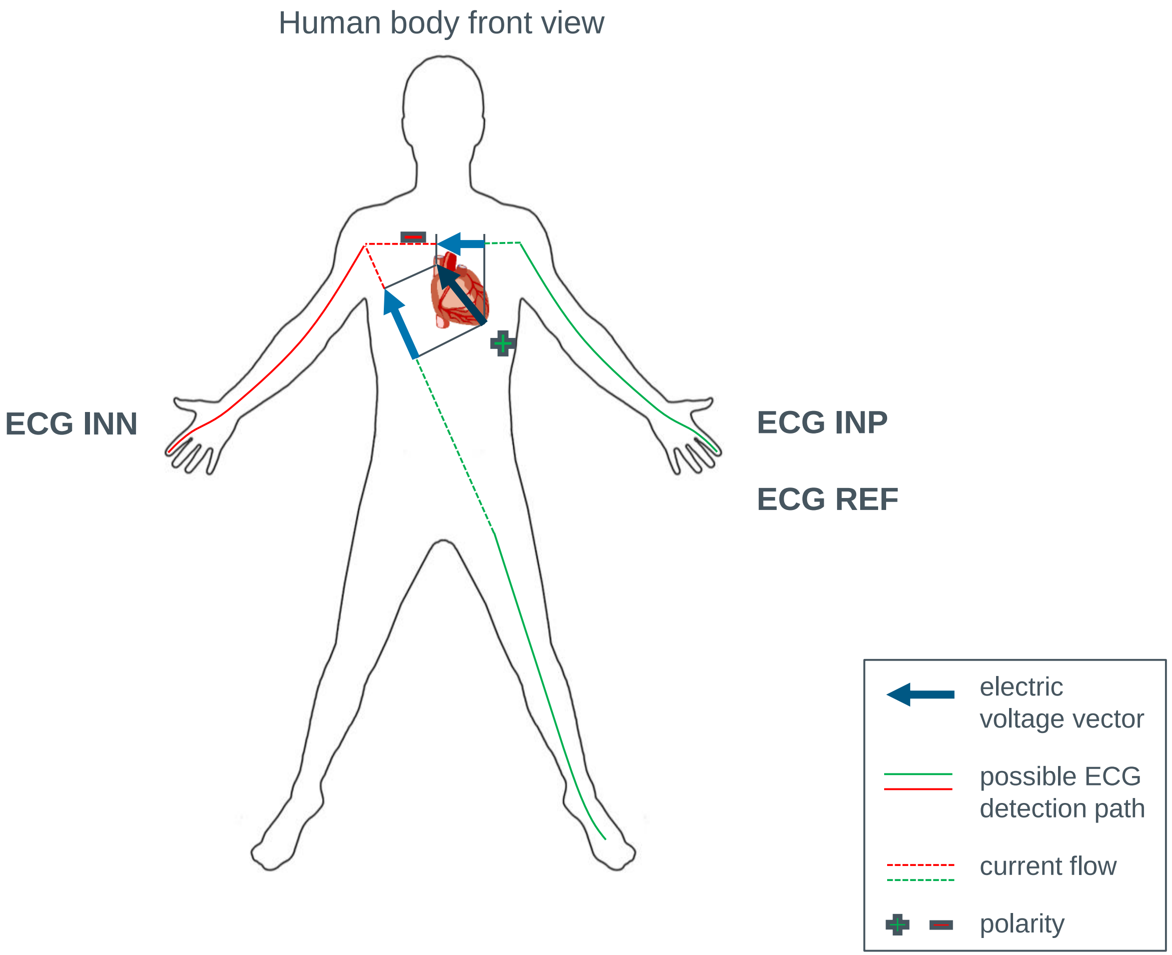
Electrode Cables

- For longer electrode cables (>20cm) or in EMC polluted environments a shielded cable is highly recommended
- The shield should be connected to GND

Electrode Connections

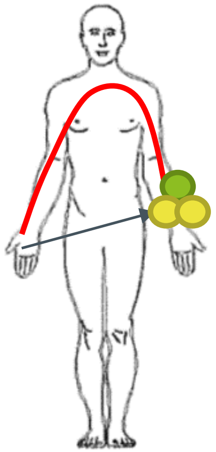
- Positive and negative electrode to detect ECG signal (across the heart)
- Reference electrode for common mode rejection

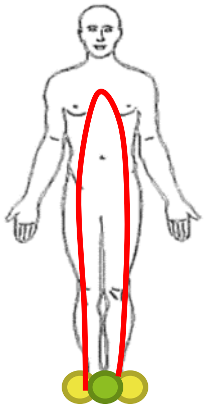
- ECG INN should be connected to the right hand of the user
- ECG INP and ECG REF should be connected to the left hand of the user
- ECG INP and ECG REF should not share an electrode but rather have individual electrodes that both connect to different parts of the left hand

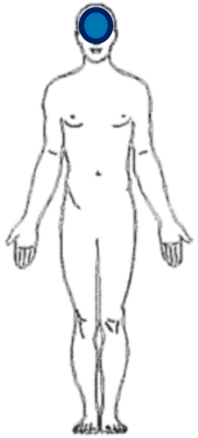


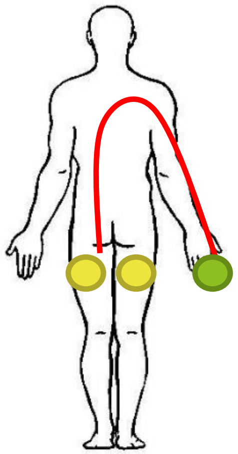
Electrode Positions

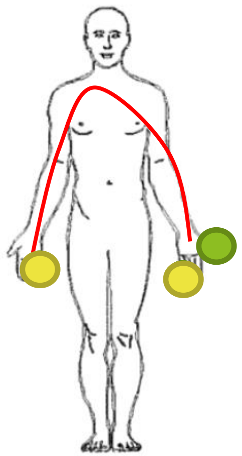
For various use cases











Electrode   PPG   Electrode + PPG

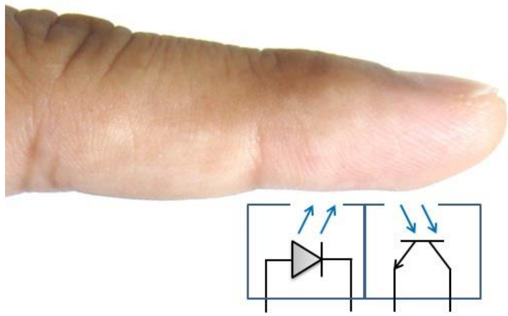
SpO2 algorithm

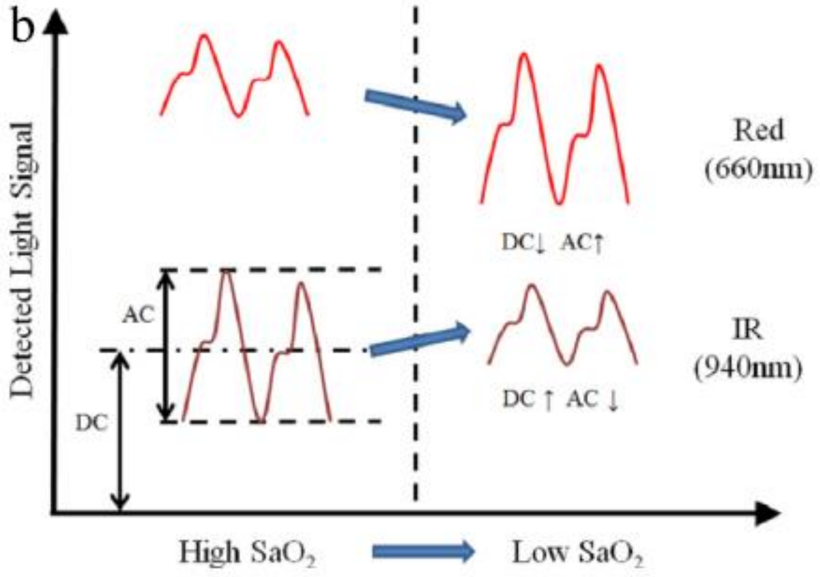
For AS7038RB reflective mode

SpO2 algorithm basic description

- ams algorithm provide as output the ratio of the ratio R
  - $R = {}^{AC_{red}}/_{DC_{red}} \Big/ {}^{AC_{ir}}/_{DC_{ir}}$
- SpO2 value is calculated based on
  - SpO2 (%) = a*R^2 + b*R + c

Reflective mode





Key Features

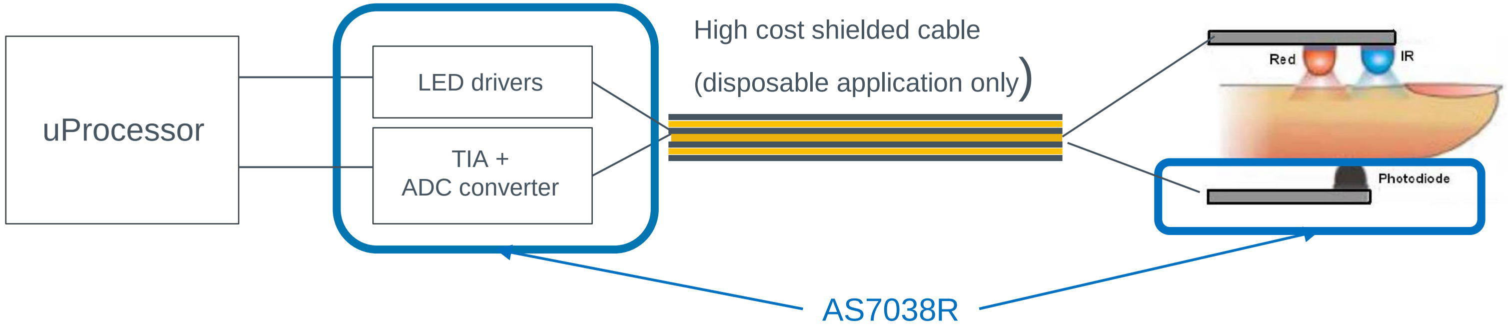
- Filter technology: Interference Filter
  - Spectral range: 590 nm – 710 nm (NIR: 800 nm – 1050nm)
  - Peak wavelength: 650 nm (NIR 950 nm)
- LED driver: 4x, max 100 mA, LED current is adjustable with 10 bits
- PPG noise performance: 80 dB
- ECG
  - noise performance: $50V_{p\text{-}p}$ @ 1Khz
  - Frequency range: 0.67 Hz to 40 Hz
  - DC offset input range ±300 mV
- Simultaneously measurements for PPG and ECG can have different sample rate for PPG and ECG

Oximeter – Disposable Oximeter

AS7038RB – Red and IR dedicated filter

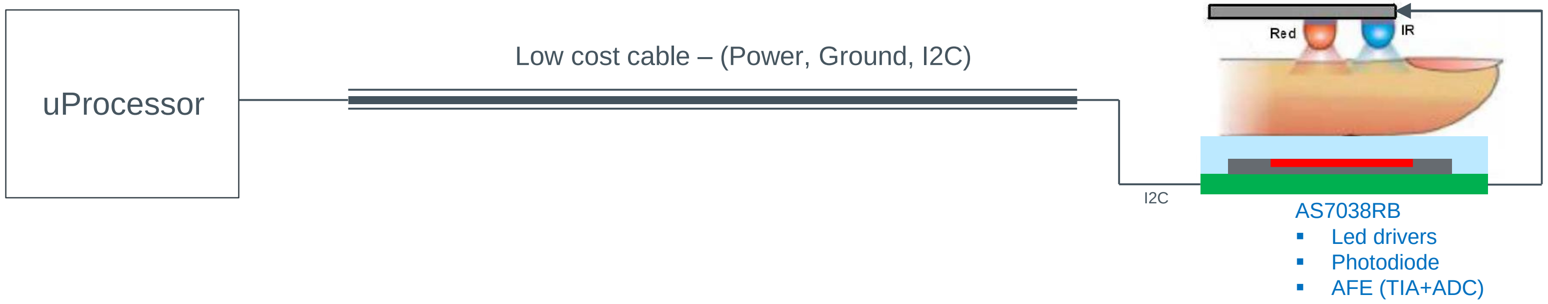
Oximeter (disposable and reusable) main blocks are:

- LEDs (RED/IR)
- Photodiode
- LED drivers
- High performance Analog Front End (TIA + ADC)
- Heavily shielded cable (disposable only) – to shield the weak signal coming from the Photodiode



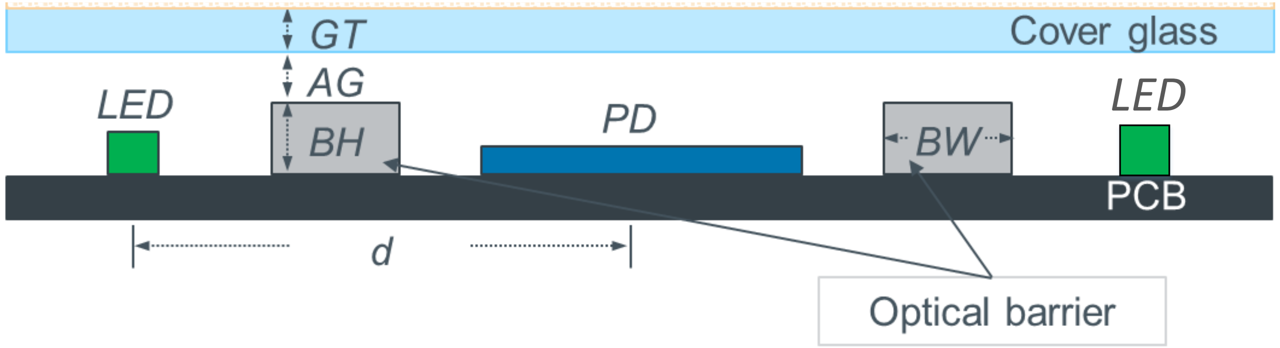
Shielded cable is a significant part of the total cost of the solution

AS7038RB
- **integrates most of the system blocks**
- **Allow to replace the high cost shielded cable with less expensive solution**

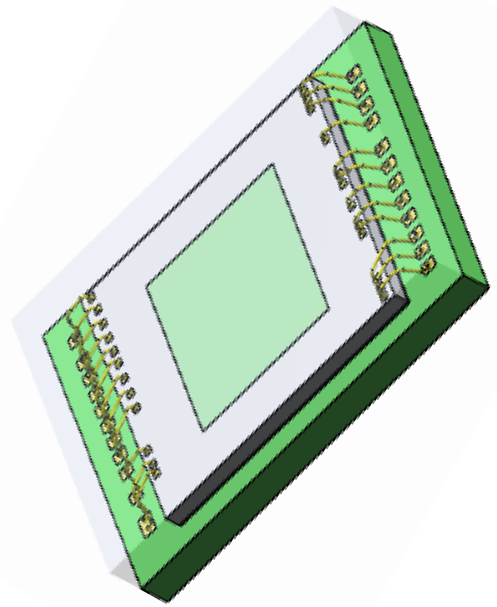


Optical-Mechanical Integration

- No air gap between glass and skin
- Do not make glass thicker or air gap wider to keep optical cross talk low
- Signal gets stronger with increasing air gap, but also cross-talk increases and SNR decreases
- The Thickness of the cover glass should be minimized for better performance & crosstalk. Also, airgap should be minimized.



GT = Cover glass Thickness; AG = Air-gap; BH = Barrier Height; BW = Barrier Width; LED = light source; PD = detector; d = distance between LED and PD



Thank you!

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