AS7038GB/RB Design-in Guidelines

Overview
Power supply Scheme
IO Signals
PPG Signal
Optical Simulation
Experimental Study
ECG
SpO2
Optical-Mechanical Integration
AS7038GB/RB

Overview

AS7038GB/RB

Pin Description

VD1 1
GND 2
SIGREF 3
SIGREF_ECG 4
ECG_INP 5
ECG_INN 6
ECG_REF 7
ENABLE 8
INT 9
SCL 10
SDA 11
18 AGND
17 V_LDO
16 GPIO3
15 GPIO2
14 GPIO1
13 GPIO0
12 VDD

Sensor

VD4 19
VD2 20
VD4 22
NC 21
VD3 22
GPIO0 14
GPIO1 15
GPIO2 16
GPIO3 17
SIGREF_ECG 4
SIGREF 3
ECG_INN 6
ECG_REF 7
ENABLE 8
INT 9
SCL 10
SDA 11
12 VDD
AS7038GB/RB

Filter description – interferometric filter

AS7038RB Filter response

AS7038GB Filter response
AS7038GB/RB Design

Recommended ECG Signal Filter Design

Assemble the following components:

- C412
- R503
- R505
- C500
- 2n20
- C501
- 100p
- R506
- 51k0
- 2n2/10V
- 7038 ECG INP
- 51k0
- 2n2/10V
- 7038 ECG INN
- 100M
- R411
- 100M
- C410
- 1k0/10V
- GND

IC3 slave address 0x00
DC bus speed up to 400 kbps
**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 Table

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

*Recommended design Schematics on Page 4*
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.

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Description</th>
<th>Decoupling Capacitor [F]</th>
<th>Pull-up Resistor [Ohm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>ENABLE</td>
<td>Enable input for AS7038. Active High. If ENABLE is not used, connect to VDD</td>
<td>-</td>
<td>10K</td>
</tr>
<tr>
<td>9</td>
<td>INT</td>
<td>Open drain interrupt output pin. Active Low</td>
<td>-</td>
<td>10k</td>
</tr>
<tr>
<td>10</td>
<td>SCL</td>
<td>I2C serial clock input terminal</td>
<td>-</td>
<td>4K7 Resistor value depends on I2C bus</td>
</tr>
<tr>
<td>11</td>
<td>SDA</td>
<td>I2C serial data I/O terminal - open drain</td>
<td>-</td>
<td>4K7 Resistor value depends on I2C bus</td>
</tr>
<tr>
<td>12, 13</td>
<td>VDD</td>
<td>Power supply</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14, 15</td>
<td>GPIO0-1</td>
<td>General purpose input/output</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Recommended design Schematics on Page 4*
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 too hard, the blood flow may be disrupted and no signal can be detected

PPG signal
Counts vs Time
Optical Simulations

**Optical system components**

- Optical system consists of an 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 carried 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.

---

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

<table>
<thead>
<tr>
<th>Skin Layer</th>
<th>Layer thickness (mm)</th>
<th>Refractive Index (generic)</th>
<th>skin reflectivity generic (diffused)</th>
<th>Absorption coefficient (1/mm)</th>
<th>Scattering coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>at 525 nm</td>
<td>at 660 nm</td>
</tr>
<tr>
<td>1 - Stratum corneum</td>
<td>0.02</td>
<td>1.5</td>
<td>0.07</td>
<td>0.4493</td>
<td>0.5488</td>
</tr>
<tr>
<td>2 - Living epidermis</td>
<td>0.09</td>
<td>1.34</td>
<td>0.00</td>
<td>0.1353</td>
<td>0.4493</td>
</tr>
<tr>
<td>3 - Papillary dermis</td>
<td>0.175</td>
<td>1.4</td>
<td>0.00</td>
<td>0.7788</td>
<td>0.8869</td>
</tr>
<tr>
<td>4 - Upper blood net dermis</td>
<td>0.09</td>
<td>1.39</td>
<td>0.00</td>
<td>0.6376</td>
<td>0.8958</td>
</tr>
<tr>
<td>5 - Reticular dermis</td>
<td>1.5</td>
<td>1.4</td>
<td>0.00</td>
<td>0.8607</td>
<td>0.8869</td>
</tr>
<tr>
<td>6 - Deep blood net dermis</td>
<td>0.105</td>
<td>1.38</td>
<td>0.00</td>
<td>0.5488</td>
<td>0.9048</td>
</tr>
<tr>
<td>7 - Subcutaneous fat</td>
<td>6.25</td>
<td>1.44</td>
<td>0.00</td>
<td>0.8607</td>
<td>0.9048</td>
</tr>
</tbody>
</table>


### Optical properties of PCB and Barrier

<table>
<thead>
<tr>
<th>System Component</th>
<th>Reflectivity</th>
<th>Absorption</th>
<th>Transmission</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diffused</td>
<td>Specular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCB</td>
<td>0.5 of 50%</td>
<td>0.5 of 50%</td>
<td>50%</td>
<td>0</td>
</tr>
<tr>
<td>Optical Barrier</td>
<td>0.5 of 20%</td>
<td>0.5 of 20%</td>
<td>80%</td>
<td>0</td>
</tr>
<tr>
<td>Cover glass</td>
<td>As per Fresnel equations</td>
<td></td>
<td>0%</td>
<td></td>
</tr>
</tbody>
</table>
Optical Simulations

LEDs used for the simulations

- ODT13UX3.A3 OS-CORE UX:3
  - True green ($\lambda_{\text{dom}} = 530$ 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 ($\lambda_{\text{dom}} = 530$ 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 ($\lambda_{\text{dom}} = 530$ nm)
  - LED module in SMT package, colorless diffused resin
  - 0.6 mm x 1.1 mm x 0.4 mm
  - Used in AS7038G EVKs

- CH DELSS1.12 FIREFLY E1608
  - Hyper red ($\lambda_{\text{centroid}} = 657$ 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 ($\lambda_{\text{centroid}} = 850$ 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
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.
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.
In this graph, SXR values are presented for various LEDs as a function of cover glass thickness.

- System: $d = 0.4 \text{ mm}; AG = 0.1 \text{ mm}; BW = 1 \text{ mm}$
- 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.
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.

<table>
<thead>
<tr>
<th>Test Board Number</th>
<th>Distance @ pin VD1 (mm)</th>
<th>Distance @ pin VD2 (mm)</th>
<th>Distance @ pin VD3 (mm)</th>
<th>Distance @ pin VD4 (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDTB1</td>
<td>4.5</td>
<td>4</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>DDTB2</td>
<td>5.5</td>
<td>5</td>
<td>5.5</td>
<td>5</td>
</tr>
<tr>
<td>DDTB3</td>
<td>6.5</td>
<td>6</td>
<td>6.5</td>
<td>6</td>
</tr>
<tr>
<td>DDTB4</td>
<td>7.5</td>
<td>7</td>
<td>7.5</td>
<td>7</td>
</tr>
<tr>
<td>DDTB5</td>
<td>8.5</td>
<td>8</td>
<td>8.5</td>
<td>8</td>
</tr>
</tbody>
</table>

- 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.
- For 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.
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

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.

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

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 affect 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.
To understand the dependence of PPG 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.
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.

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Pin Name</th>
<th>Description</th>
<th>Capacitors [F]</th>
<th>Resistors [Ohm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>SIGREF_ECG</td>
<td>Analog reference output</td>
<td>2.2u to GND</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ECG_INP</td>
<td>ECG amplifier positive input</td>
<td>2.2u in series 100p to GND</td>
<td>51k + 51k in series 100M to ECG_REF</td>
</tr>
<tr>
<td>6</td>
<td>ECG_INN</td>
<td>ECG amplifier negative input</td>
<td>2.2u in series 100p to GND</td>
<td>51k + 51k in series 100M to ECG_REF</td>
</tr>
<tr>
<td>7</td>
<td>ECG_REF</td>
<td>ECG amplifier reference output</td>
<td>1u to GND</td>
<td></td>
</tr>
</tbody>
</table>
**ECG**

**Pin description**

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

**Recommended ECG Frontend Filter**

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

- 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
  \[ R = \frac{A_{C_{r ed}}}{D_{C_{r ed}}} / \frac{A_{C_{ir}}}{D_{C_{ir}}} \]

- SpO2 value is calculated based on
  \[ \text{SpO2 (\%)} = a \cdot R^2 + b \cdot R + c \]

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\text{pp} @ 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

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

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

Please visit our website
www.ams.com