shimmer
DISCOVERY IN MOTION

ECG Respiration User Guide

Revision 1.1

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1. Introduction

The *Shimmer3 ECG* unit can be configured to measure respiration. This document provides recommendations regarding electrode placement, configuration settings for respiration detection, as well as an illustration of the signals that can be achieved from the device before and after post-processing.

The respiration detection method used, is called "impedance pneumography". The *Shimmer3 ECG* unit measures the impedance across the chest, using adhesive ECG electrodes. During the inhalation/exhalation phases, this impedance increases/decreases respectively. The impedance change is correlated to the volume of air that is inhaled [1].

2. General Information

2.1. Safety Information

As a precaution it is important to note that the ECG leads are not to be applied to the subject's body while the unit is in a USB dock or multi-charger.

2.2. Pre-Requisites

- A compatible *Shimmer3 ECG unit* programmed with up-to-date firmware.
  - The Shimmer's firmware can be updated using our Consensys application - available for download from www.shimmersensing.com.
  - In order to check if respiration detection is supported on your Shimmer3 ECG unit, please use Consensys and, with your Shimmer unit docked, refer to the "Expansion" board information shown on-screen. If the expansion board appears as "ECG/EMG/Respiration", respiration mode is supported.
- Five DIN snap leads.
  - 9-inch and 18-inch leads are shipped with *ECG Development Kits*.
  - Replacements can be purchased from www.shimmersensing.com.
- Surface ECG electrodes.
  - Disposable electrodes are shipped with the *ECG Development Kit*.
  - For replacements, see www.shimmersensing.com. Alternatively, the Covidien Kendall Disposable Surface EMG/ECG/EKG electrodes 1" (24mm) or Covidien Kendall Disposable Surface EMG/ECG/EKG electrodes 1 3/8" (35mm), available on www.bio-medical.com with product codes 'BRD H124SG' and 'BRD H135SG', respectively, and the Ambu Blue Sensor T electrodes, available from various suppliers, are all suitable options and have been validated for use with Shimmer equipment.

2.3. ECG Unit Specification Overview

The *Shimmer3 ECG* unit contains two ADS1292R chips from Texas Instruments. Throughout documentation and software applications these are referred to a 'Chip1' and 'Chip2'. The respiration circuitry is connected to Chip2 [2].

For detailed specifications of the *Shimmer3 ECG* unit or for more detail on the standard electrode placement for ECG measurement, please refer to the *Shimmer3 ECG User Guide*.

3. Electrode Placement

3.1. Preparation

Prepare the skin by cleaning with an alcohol wipe or similar.

3.2. Recommended Placement

To detect respiration, the Shimmer3 ECG unit measures the impedance across the chest using three electrode connections. The respiration detection circuitry is hard-wired to the **RA** (white) and **LA** (black) inputs. In addition, the **RL** (green) input serves as reference.

The optimal electrode placement for respiration detection is two locations across the chest whereby the Shimmer can measure the largest range of chest activity due to respiration (*i.e.*, the maximum change in impedance due to inhalation/exhalation). In this guide, we recommend the top of the mid-axillary line on either side of the chest. Other locations can also be used [3]. Figure 3-1 provides a side view of the axillary lines.

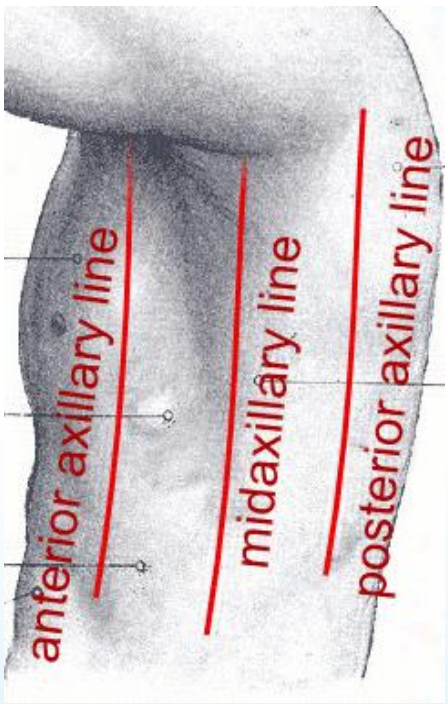

Figure 3-1 Axillary lines

Figure 3-2 shows a recommended electrode placement layout on the body. The reference electrode, **RL** (green), input should be placed on the top of the right leg. The **LA** (black) electrode should be placed in the "V6" ECG electrode position (*i.e.*, on the top of the mid-axillary line, on the left side of the body, at the sixth inter-costal space). The **RA** (white) electrode should be placed at the same location on the right-hand side of the body.

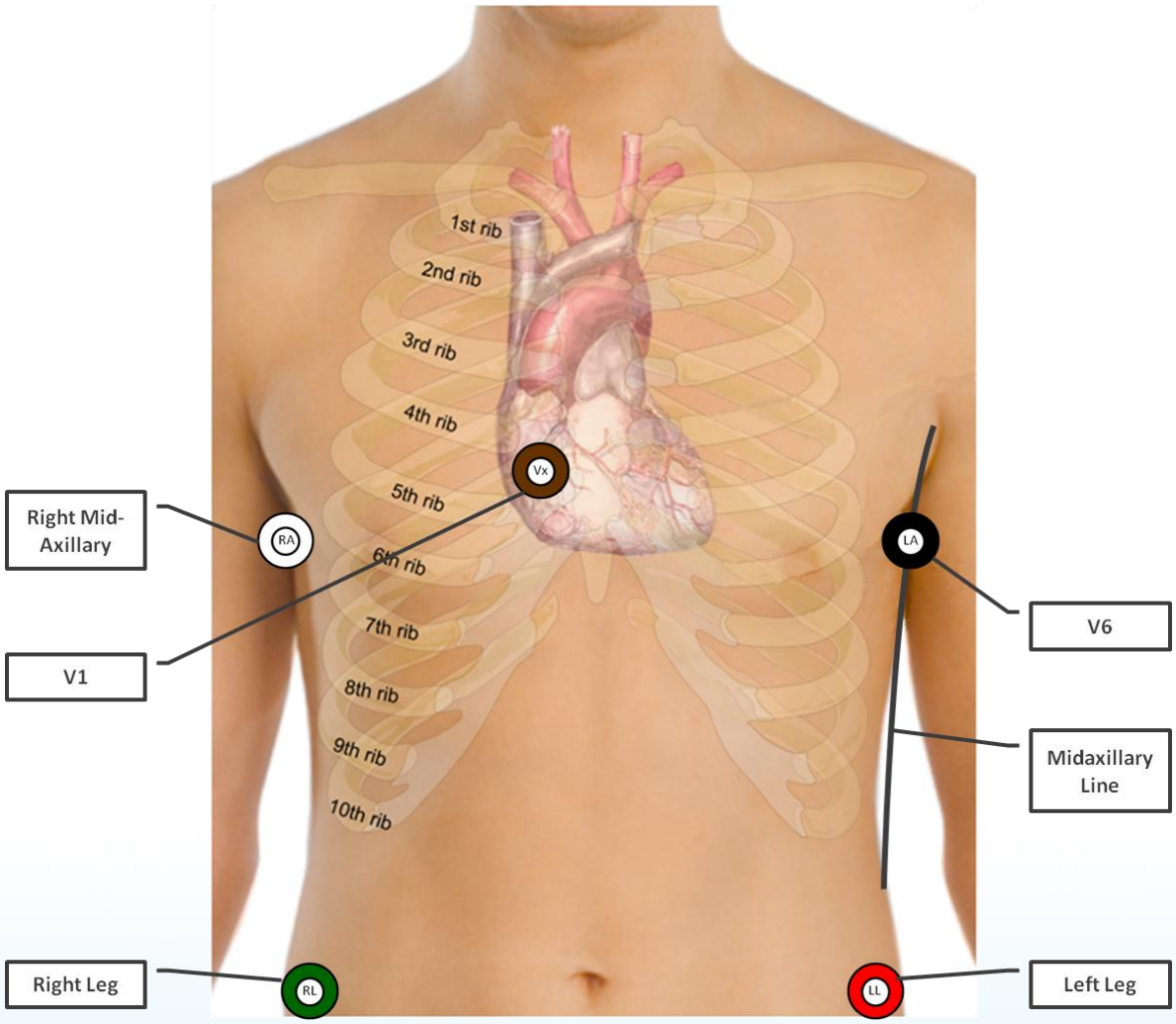

Figure 3-2 Recommended electrode placement

Although inputs **LL** (red) and **Vx** (brown) are not required for respiration detection, both inputs can be used as additional ECG channels. If this these are in use, it is recommended to connect these to the typical locations used for most clinical ECG electrode placements; the **LL** (red) input at the top of the right leg and the **Vx** (brown) input at the standard "V1" ECG electrode position (*i.e.*, at the fourth inter-costal space, to the right of the sternum).

Note: In case **Vx** or **LL** are not connected to the body, make sure there is no electrode cable connected to the corresponding input on the *Shimmer3 ECG* unit as this can introduce additional noise in the system.

Table 3-1 gives an overview of the input connectors and the recommended electrode positions for achieving the best respiration signal quality.

Input	Electrode Position
	Mid-Axillary line - right-hand side
	Mid-Axillary line - left-hand side ("V6")
	Right Leg
	Left Leg (Optional electrode)
	V1 (Optional electrode)

Table 3-1 Input connectors and electrode positions

4. Configuration

4.1. Default configuration

This section describes how to enable respiration detection with default settings using our Consensys software. Refer to section 4.2 for advanced configuration when using software other than Consensys or non-default settings.

Figure 4-1 shows the configuration menu that can be accessed through either MANAGE DEVICES or LIVE DATA.

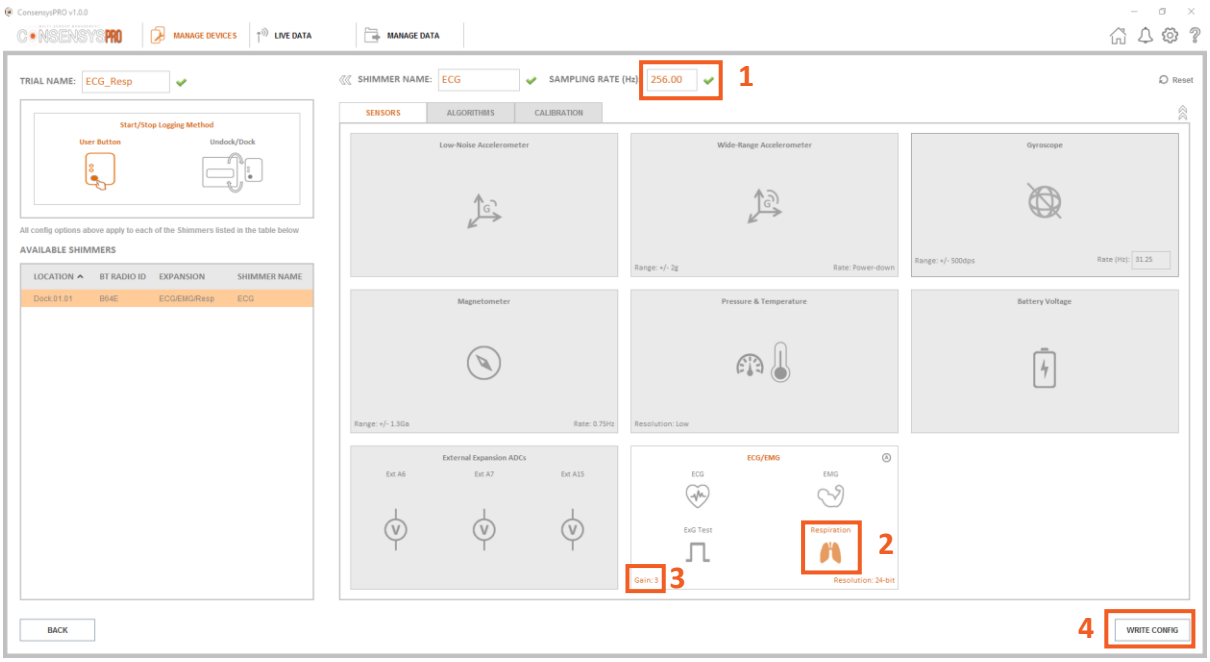

Figure 4-1 Default Respiration Detection configuration.

Steps to enable respiration detection:

1. Set a minimum sample rate of 204.8Hz.
2. Enable "Respiration".
3. Set the gain to 3.
4. Write the configuration.

For the default configuration the Respiration Detection Frequency is 32 kHz and Respiration Detection Phase is 112.5°.

4.2. Advanced Configuration

This section describes how advanced configuration settings can be modified when the default configuration is not suitable or when software other than Consensys is used (*e.g.*, Shimmer APIs/Instrument Drivers).

The *Shimmer3 ECG* unit contains two ADS1292R chips from Texas Instruments. These chips are fully configurable in software by setting the byte values of their ExG Configuration registers - also called "ExG Configuration Bytes" in Shimmer documentation [2]. The values of the ExG Configuration Bytes can be changed in the Consensys "Advanced ECG/EMG" menu, which can be accessed by clicking on the corresponding icon on the "ECG/EMG" configuration tile, see Figure 4-2.

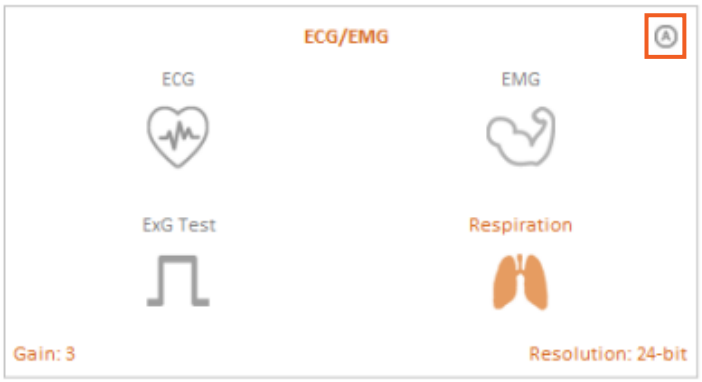

Figure 4-2 Advanced ECG/EMG icon

The adjustable parameters for Respiration Detection are:

1. Respiration Detection Frequency; Bit 2 of register "RESP2"
2. Respiration Detection Phase; Bits[5:2] of register "RESP1"
3. Gain of Programmable Gain Amplifier (PGA); Bits[6:4] of registers "CH1SET" / "CH2SET"

These parameters can be changed by modifying the values of the ExG Configuration Bytes directly, or by using the drop-down menus highlighted in Figure 4-3. The drop-down menu for the PGA gain can be found on the "ECG/EMG" configuration tile, see Figure 4-1 or Figure 4-2. For background information on the Respiration Detection signal, refer to [1].

For respiration detection the "Reference Electrode" needs to be set to "Fixed Potential", see Figure 4-3. (For non-Consensys users: Chip1 RLD_SENS = 0x20, Chip2 RLD_SENS = 0x00).

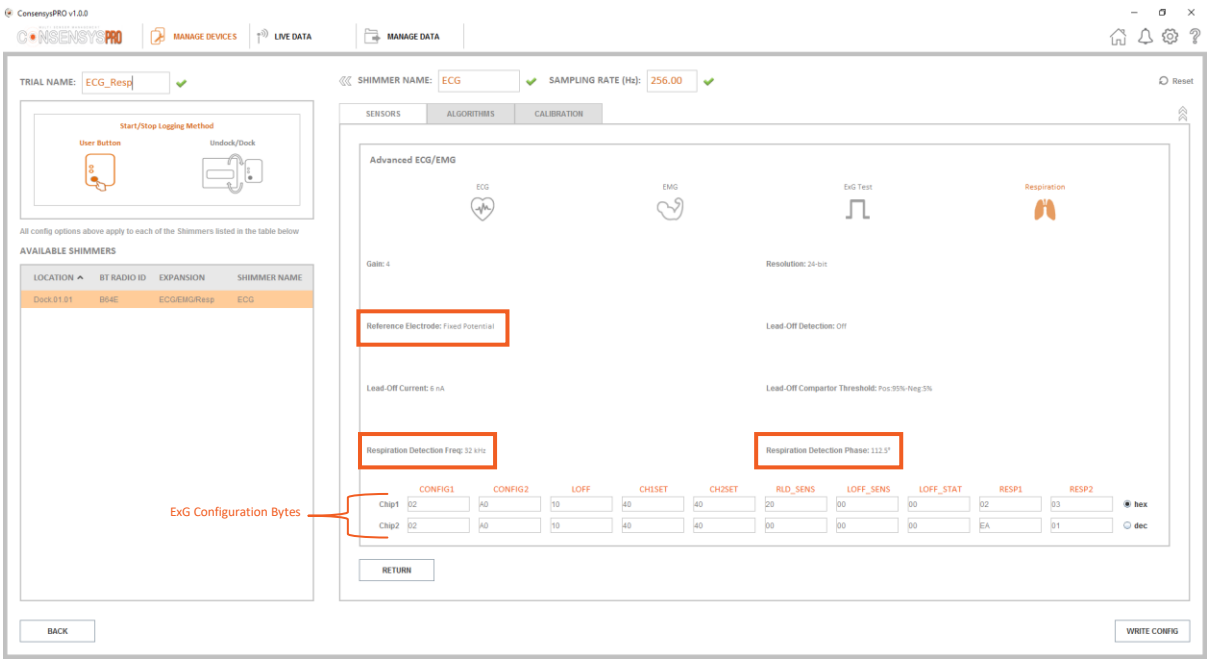

Figure 4-3 Advanced ECG/EMG menu

Respiration Advanced chip configuration bytes:

For respiration detection, the configuration bytes of the ADS1292R chips need to be configured as per Figure 4-4 below. This allows both chips to be synchronized at the same sampling clock and also reduces power consumption in SR47-4 and greater versions as a second internally generated clock does not need to be enabled (saving ≅ $30\mu W$).

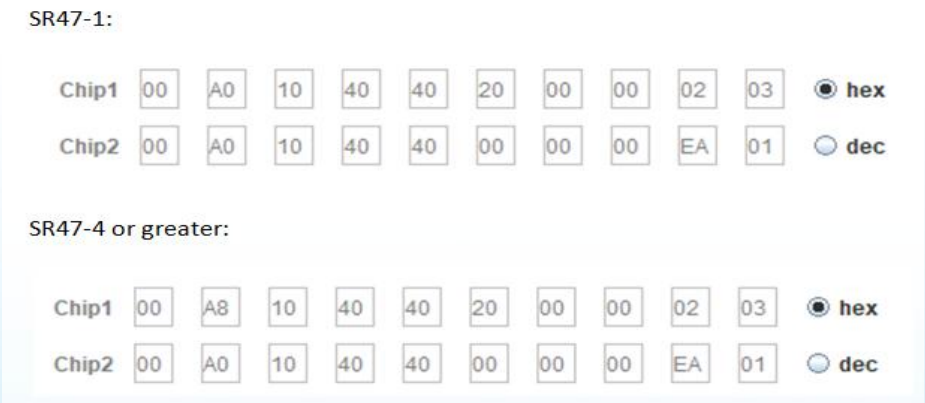

Figure 4-4 Chip configuration

The recommended combinations of settings provided by Texas Instruments are listed in Table 4-1. Alternatively, the user can experiment with values other than the ones recommended. Refer to section 7.1 for an overview of all possible values for the Respiration Detection Frequency and the Respiration Detection Phase.

Respiration Detection Frequency	Gain	Respiration Detection Phase
32 kHz	3	112.5°
32 kHz	4	135°
64 kHz	2	135°
64 kHz	3	157°

Table 4-1 Settings recommended by Texas Instruments

5. Example with post-processing

When the respiration detection circuitry is enabled, a very small high-frequency current is injected into the body of the test subject. This high-frequency current acts a carrier wave that is amplitude-modulated by the low-frequency respiration signal, *i.e.*, the signal of interest. The modulated signal is automatically demodulated within the Shimmer and the resulting respiration waveform is presented as an output channel from the Shimmer while streaming/logging, see page 3 of [1] for a block diagram of this concept. Since the ADS1292r chip does not contain a low-pass filter in the signal path between the demodulated respiration signal and the AD-converter (as shown in page 3 of [1]), unwanted high-frequency content is still present in the signals. Post-processing the signals afterwards in software can isolate the low-frequency respiration and ECG signals.

In this example the recommended electrode placement and the default configuration settings (and a sampling rate of 512Hz) are used. Respiration signals are capture from a person carrying out the following actions:

1. breathing normally for almost 80 seconds
2. followed by three pronounced inhalations and exhalations
3. followed by another 30 seconds of normal breathing
4. followed by three pronounced inhalations and exhalations

Figure 5-1 shows the resulting respiration signal after the signal has been post-processed using a low-pass filter.

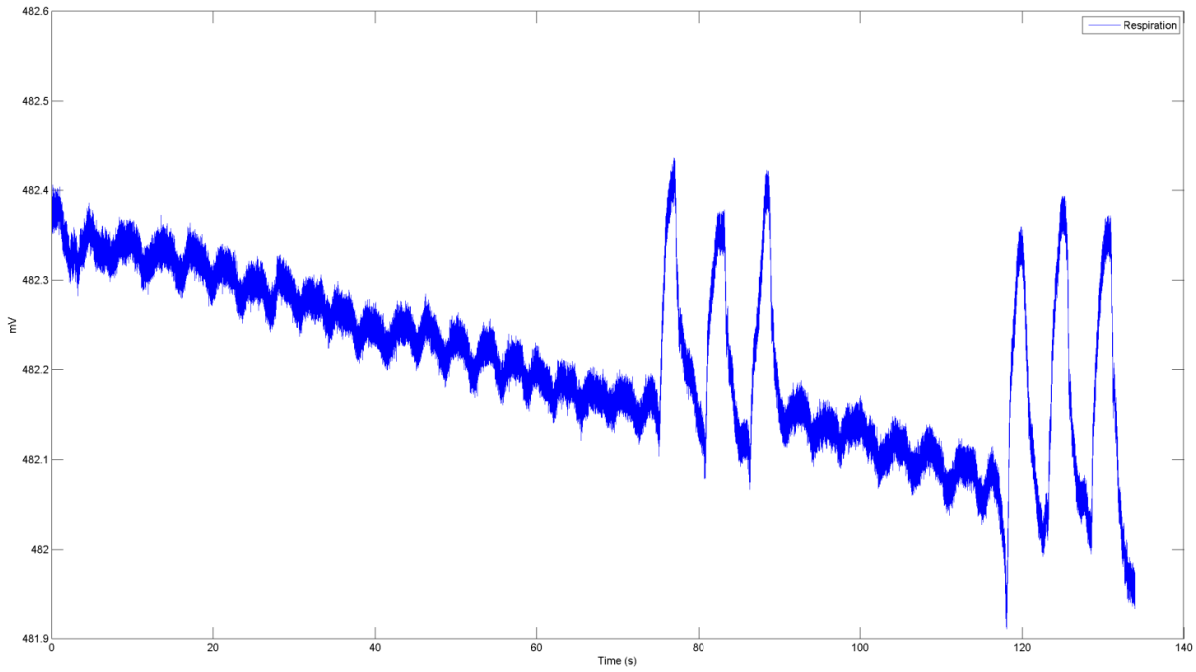

Figure 5-1 Respiration signal

Figure 5-2 zooms in on the last three pronounced inhalations and exhalations, before (top) and after filtering (bottom). The low-pass filter used to post-process the respiration signal is a low-pass Blackman-Windowed Sinc-filter with 120 taps and a cut-off frequency of 2Hz.

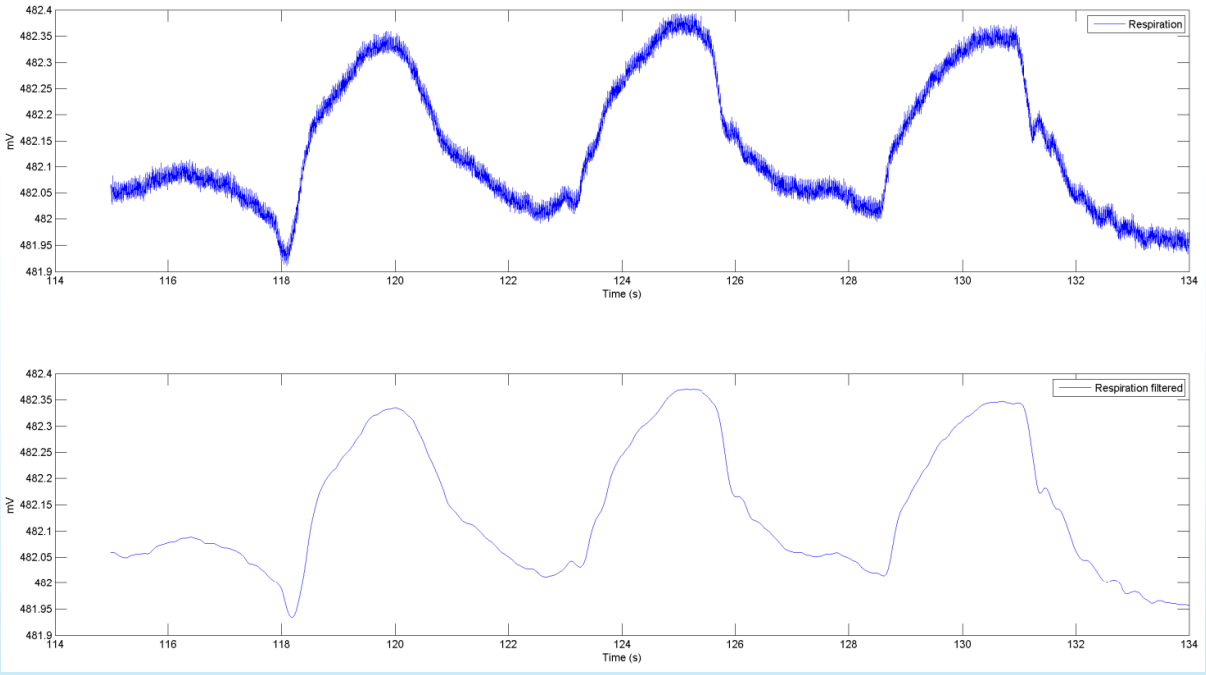

Figure 5-2 Low-pass filtered respiration signal

Finally, Figure 5-3 also includes the ECG "LL-RA" signal; before and after filtering. The filter used is a low-pass Blackman-Windowed Sinc-filter with 120 taps and a cut-off frequency of 30Hz.

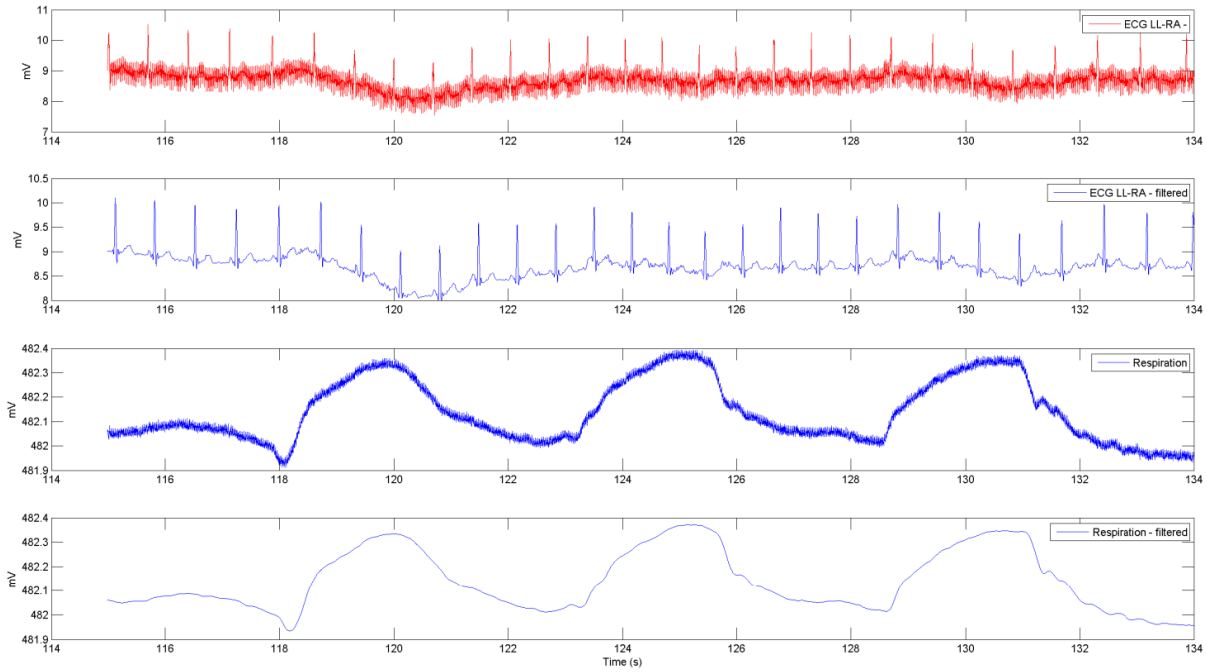

Figure 5-3 ECG "LL-RA" and respiration

6. References

[1] Texas Instruments, “Respiration Rate Measurement Based on Impedance Pneumography,” 2011.

[2] Texas Instruments, “Low-Power, 2-Channel, 24-Bit Analog Front-End for Biopotential Measurements,” 2012.

[3] G. B. Drummond, a F. Nimmo, and R. a Elton, “Thoracic impedance used for measuring chest wall movement in postoperative patients.,” *Br. J. Anaesth.*, vol. 77, no. 3, pp. 327–32, 1996.

7. Appendices

7.1. ExG configuration bytes

The relevant ADS1292R configuration bytes for respiration measurement are included in Table 7-1, Table 7-2 and Table 7-3, for convenience. Please refer to [2] for more detailed information.

On/Off	Mask (hex)	Byte Value (hex)	Byte Value (dec)
On	0xC0	0xC0	192
Off	0xC0	0x00	0

Table 7-1 Respiration Detection mode - Chip2 "RESP1" register

Frequency	Mask (hex)	Byte Value (hex)	Byte Value (dec)
32 kHz	0x04	0x00	0
64 kHz	0x04	0x04	4

Table 7-2 Respiration Detection Frequency - Chip 2 "RESP2" register

Phase @ 32kHz	Phase @ 64kHz	Mask (hex)	Byte Value (hex)	Byte Value (dec)
0°	**0°**	0x3C	0x00	0
11.25°	**22°**	0x3C	0x04	4
22.5°	**45°**	0x3C	0x08	8
33.75°	**67.5°**	0x3C	0x0C	12
45°	**90°**	0x3C	0x10	16
56.25°	**112.5°**	0x3C	0x14	20
67.5°	**135°**	0x3C	0x18	24
78.75°	**157.5°**	0x3C	0x1C	28
90°	N/A	0x3C	0x20	32
101.25°	N/A	0x3C	0x24	36
112.5°	N/A	0x3C	0x28	40
123.75°	N/A	0x3C	0x2C	44
135°	N/A	0x3C	0x30	48
146.25°	N/A	0x3C	0x34	52
157.5°	N/A	0x3C	0x38	56
168.75°	N/A	0x3C	0x3C	60

Table 7-3 Respiration Detection Phase - Chip 2 "RESP1" register

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