Features and Application of ADAS1000/ADAS1000-1/ADAS1000-2 Low Power-Five Electrode ECG System

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Abstract - **This paper presents the features of Analog Devices ADAS1000 Family - Low Power, Five Electrode ECG Analog Front End, which includes pace and respiration detection. It summarizes some of the main hardware and software features of the devices - mainly those related to ECG processing.**

Keywords – **pacemaker, pace, respiration, detection, ECG, thoracic impedance measurement.**

I. INTRODUCTION

The ADAS1000/ADAS1000-1/ADAS1000-2 is an Analog Front End system which has the possibility to measure electro cardiac (ECG) signals, thoracic impedance (respiration), pacing artifacts, and lead "on/off" status.

It is small in size and requires very few external elements. In low power mode it can be used in portable, battery-powered designs. In high performance mode it has the potential to deliver vast amount of data - up to 128 ksps per ECG channel - and can be used in higher end diagnostic applications.

There are three devices from the family available:

- ADAS1000 is a full-featured, 5-channel ECG including respiration and pace detection.
- ADAS1000-1 offers only ECG channels without respiration or pace detection.
- ADAS1000-2 can only work as a slave, to extend ECG to more leads, and needs to be interfaced to an ADAS1000 or ADAS1000-1 master device. It has only the ECG channels enabled, no respiration, pace or right leg drive (RLD)

Some of the possible applications, as stated in [1], may include bedside patient monitoring, portable telemetry, Holter, cardiac defibrillators, ambulatory monitors, pace maker programmer, patient transport, stress testing.

The devices have a Serial interface which is SPI-/QSPI™-/DSP-compatible and come in 56-lead LFCSP package (9 mm × 9 mm) 64-lead LQFP package.

The system has a lot of built-in features, as will be discussed further in this paper, thus minimizing the need for other components. This way a fully working device can be developed with minimum additional components.

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II. FEATURES RELATED TO ECG PROCESSING

ECG Inputs, ECG Channel

A single chip has 5 ECG inputs and a RLD. In a typical 5-lead connection, it will use four of the ECG inputs (ECG3_RA, ECG1_LA, ECG2_LL, ECG4_V1) and the RLD. This leaves one spare ECG path available for other purposes - calibration, temperature measurement, if needed.

By coupling one master ADAS1000 or ADAS1000-1 chip together with one ADAS1000-2 slave chip a 12-lead (10-electrode) system can be realized - 9 ECG electrodes and one RLD electrode. This is called Gang Mode. This way all the lead information is available without the need to derive it from other lead measurements.

The ECG channel consists of:

- Pre-amplifier - programmable gain, low noise, differential pre-amplifier which uses 256kHz chopping frequency to minimize 1/f noise contributions in the ECG band.
- Filter - fixed gain 2-pole, anti-aliasing filter with ~65 kHz bandwidth.
- Buffer - differential amplifier buffer with 1,4 gain
- ADC - 14-bit, 2 MHz Successive Approximation Register type, with 1024 × oversampling to help achieve the required system performance.

Lead-Off Detection

Lead-Off detection is used to sense if an electrode is disconnected from the patient. The ADAS family has two methods for such detection - AC and DC. They can be used individually or simultaneously.

DC Lead-Off detection injects in every electrode a small current (10 to 70 nA) which in case of disconnection charges the lead capacitance, increases the voltage at the corresponding pin and is detected by a comparator circuit. The detection time is a few milliseconds.

AC Lead-Off detection injects AC current into each channel and measures the amplitudes of the resulting voltages. The carrier frequency (2.039kHz) is chosen so that it can be fully removed by the on-chip digital filters. The detection time is less than 10 ms.

Common-Mode Selection and Averaging

The common-mode signal can be derived from:

- Combination of electrode channel inputs (one or more)
- Fixed internal common-mode voltage reference
- External source connected to the CM_IN pin.

Wilson Central Terminal (WCT)

Using the first option of common-mode selection and averaging a Wilson central terminal voltage between the ECG1_LA, ECG2_LL, ECG3_RA electrodes the WCT can be calculated.

Right Leg Drive/Reference Drive

The RLD amplifier:

- is used as part of a feedback loop to force the patient's common-mode voltage close to the internal 1.3 V reference level and this centers all the electrodes inputs relative to the input span, providing maximum input dynamic range.
- helps to reject noise from external sources, patient-connected instrumentations and absorbs the DC or AC lead-off currents injected through the ECG electrodes.

Shield Driver

The ADAS family features a shield drive amplifier to drive the shield of the ECG cables. To save power, it can be disabled if not in use. The SHIELD pin is shared with the respiration pin function, so only one option can be used at a time.

III. Respiration Detection

Respiration detection is available on ADAS1000 only. Thoracic impedance is measured the following way - ADAS1000 generates a high frequency differential current between two electrodes [1]. The breathing of the patient causes variance in the body impedance, which itself causes the differential voltage to vary at the same rate as the breathing. The frequency used can be programmed from 46.5 kHz to 64 kHz.

The system measures small ohm variation connected in series with big resistance - the body itself, as well as cable and electrodes. If the total impedance is kept under 5 kΩ, the internal respiration measurement circuit is capable of 200 mΩ amplitude resolution.

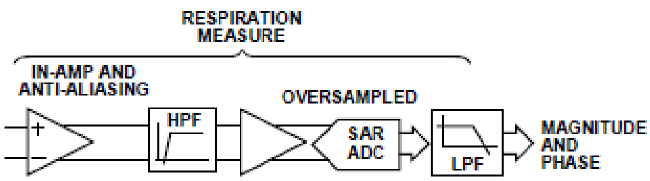

Fig. 1. ADAS1000 Respiration Measure

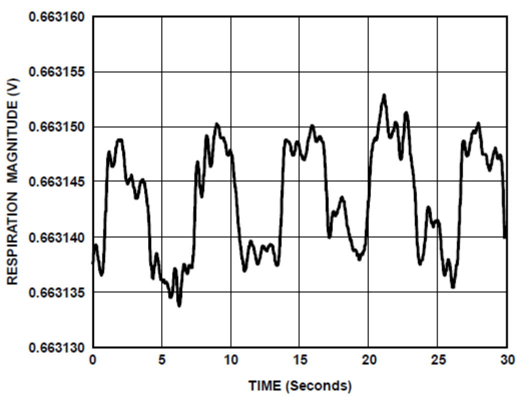

Fig. 2. Respiration Measure

The system returns a digital signal that represents the total respiration impedance - incl. cables and electrodes.

There is no detection algorithm applied, so the user needs to implement his own methods in the device.

Respiration measurement can be performed on one lead (Lead I, Lead II, or Lead III) or on dedicated pins.

IV. Gang Mode Operation

A single ADAS1000 or ADAS1000-1 supports 5 electrodes plus one RLD, or up to 8-leads. The system is designed so that it can be easily and safely extended with one or more slave devices. In gang mode, master and slave devices must operate in the same power mode and the same data rate, and the user must collect the ECG data directly from each device.

All the devices must share a common clock signal to ensure that they are synchronized - either the master CLK_IO or an external 8.192 MHz.

SYNC_GANG pin is used to synchronize the start of the ADC conversion on all devices. It is an output for the master and an input for all the slave devices.

The calibration DAC signal from the master device can also be used as input for slave devices.

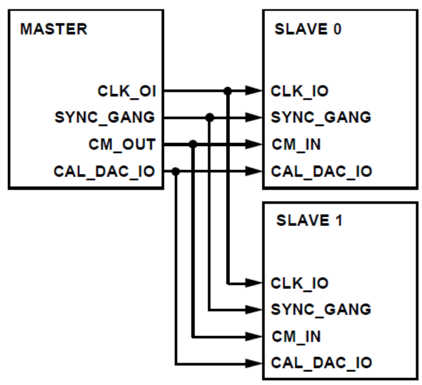

Fig. 3. Gang Mode Master-Slave Interfacing

V. Pace Detection Algorithm

Pace Detection Algorithm is featured on ADAS1000 only. It detects pacing artifacts with widths in the range (0.1 – 2) ms, and amplitudes in the range (0.4 – 1000) mV. The pace-detection algorithm runs on three of four possible leads (I, II, III, or aVF). This is due to the fact that different pacemaker leads do not have the same vectors, and align better with some ECG leads than with others.

- Right atrium – Lead II or one of the chest leads;
- Right ventricle – Lead II;
- Left ventricle is actually placed out of it and is best captured by Lead II or one of the chest leads;
- Pacing leads of implantable defibrillators and resynchronization devices are sometimes placed in areas of the heart that do not have an infarction, and it may be hard to choose the correct ECG Lead.

The block-diagram of the method embedded in ADAS1000 [2] is presented in Figure 4. The pace pulses detection algorithm searches for pulses by analyzing samples in the 128 kHz/16-bit ECG data stream. The first step is to search for a valid leading edge. Once a candidate edge has been detected, the algorithm begins searching for a second, opposite-polarity edge that meets with pulse width criteria and passes the (optional) noise filters. Only the pulses that meet all the criteria are flagged as valid.

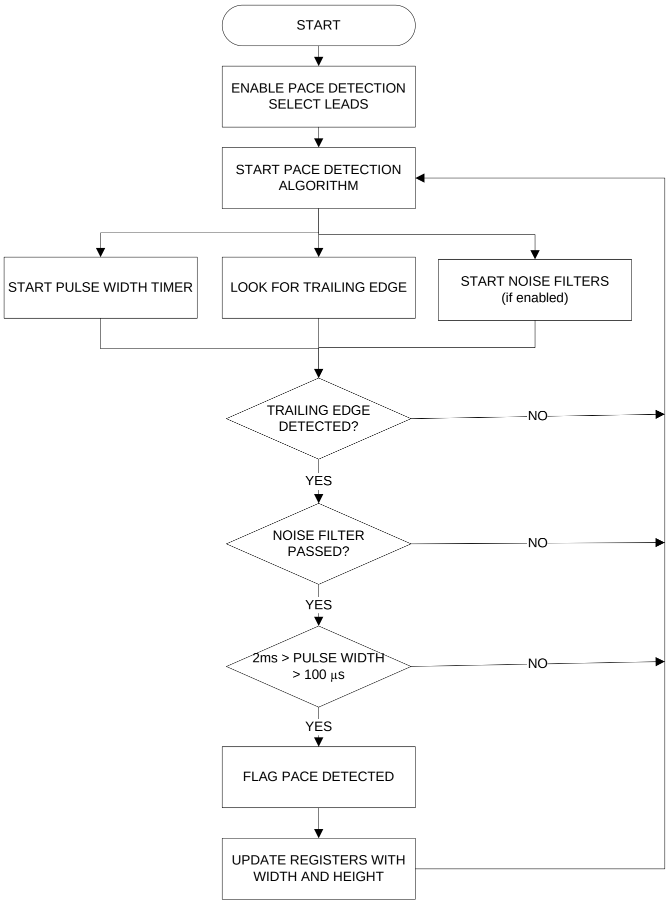

Fig. 4. Block-diagram of ADAS1000 pace detection algorithm

The artifact detection system has programmable threshold levels so it can be tuned:

- Pace Amplitude Threshold would typically be set to be the minimum expected pace amplitude:

$$PACEAMPTH\ setting = \frac{N \times VREF}{GAIN \times 2^{16}}$$

- Pace Edge Threshold is used to find a leading edge, denoting the start of a pace pulse:

$$PACEEDGETH\ setting = \frac{N \times VREF}{GAIN \times 2^{16}}$$

- Pace Level Threshold is used to find the leading edge peak:

$$PACELVLTH\ setting = \frac{N \times VREF}{GAIN \times 2^{16}}$$

where: N = 0 to 255 (8 bits);. GAIN = 1.4, 2.1, 2.8 or 4.2 (ECG acquisition programmable gain) and VREF = 1.8 V.

Some pacemakers use minute-ventilation pulses with length from 15 µs to 100 µs to detect respiration rates and to control the pacing rate (in rate-responsive pacemakers). The ADAS1000 has a minute-ventilation filter built into its algorithm. It also has algorithms for filtering the noise and the heartbeats. There is a specially designed “pace width” filter, which searches for an edge of opposite polarity to the leading edge that has at least half of its magnitude. The second edge must be between 100 µs to 2 ms from the original edge. When a valid pace width is detected, the width is stored.

VI. Application of ADAS1000 Module for Acquisition of ECG Signals from Patients with Pacemakers

The ADAS1000 module was applied for ECG signal acquisition. Signals from two patients with pacemaker are presented in Figures 5 and 7. The signals are acquired with 16 kHz sampling frequency. The normalized spectrum of the ECG for Patient 1 is presented in Figure 6. It shows presence of power-line interference harmonics up to 250 Hz A typical pace pulse [2] is presented in Figure 5 for comparison.

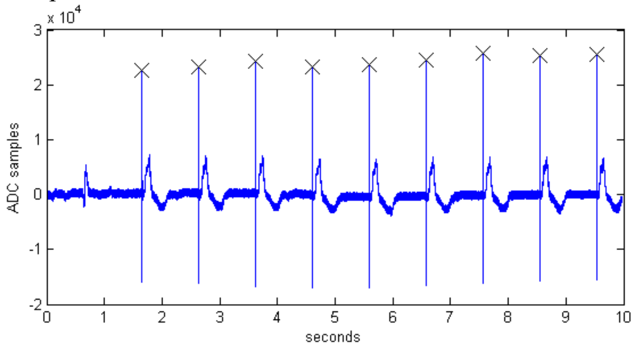

Fig. 5A. Patient No.1 - ECG signal with 10 heartbeats, 9 of which are stimulated by pace impulse (see the ‘X’ marks). There is a visible difference in the shape of the first (non-pace)d heartbeat and the rest.

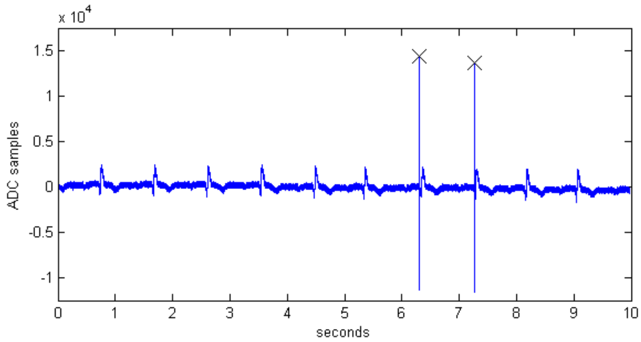

Fig. 5B. Patient No.1 - ECG signal with 10 heartbeats. two pace impulses are present (see the ‘X’ marks)

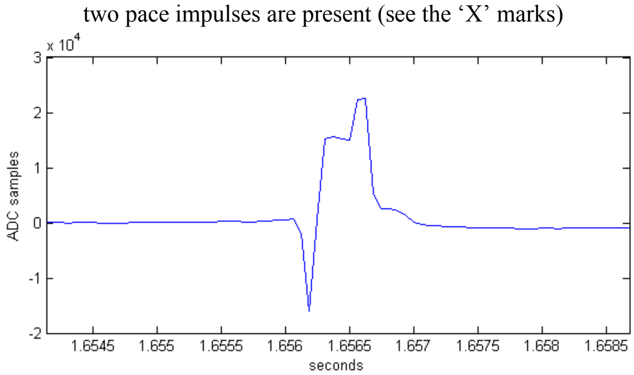

Fig. 5C. Patient No.1 - The pace pulse zoomed. Note the scale diffenece from the previous pictures. The whole impulse is less than 1 millisecond wide

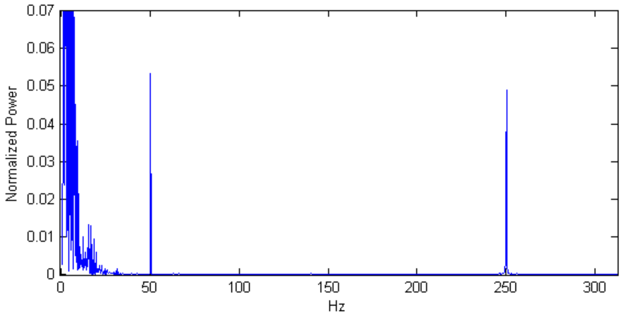

Fig. 6. The Normalized spectrum shows the presence of power-line interference harmonics up to 250 Hz which would require special ECG signal processing

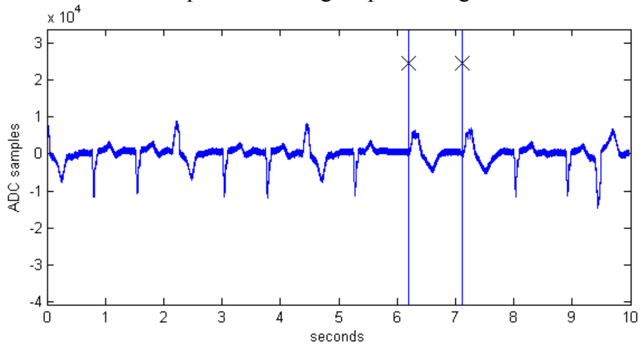

Fig. 7A. Patient No.2 - ECG signal with 13 heartbeats, two of which are stimulated by pace pulse (see the ‘X’ marks). This is an interesting example of ECG recording with trigeminy, which explains the shapes of the heartbeats.

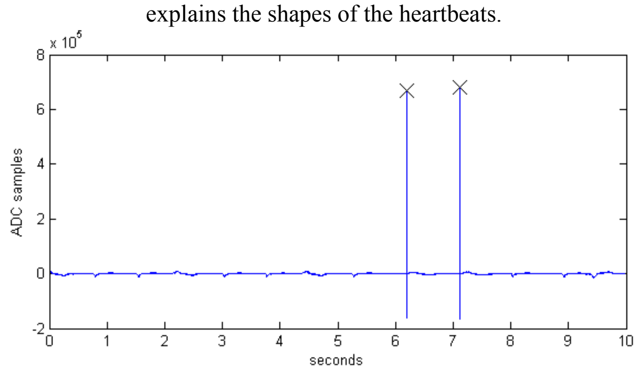

Fig. 7B. Patient No.2 - The same ECG signal zoomed out. The voltage range of the pace pulses (see the ‘X’ marks) is 40-45 times greater than that of the QRS-complex .

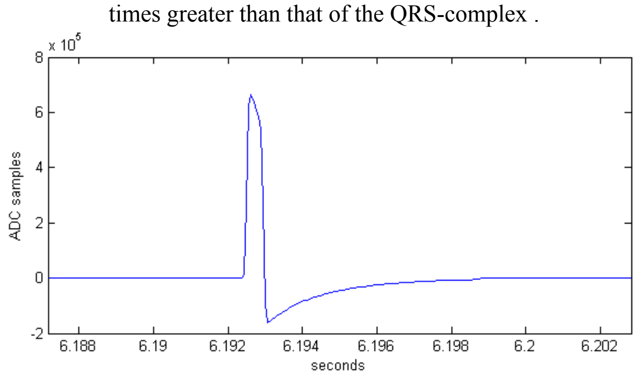

Fig. 7C. Patient No.2 - The pace pulse zoomed.
The whole impulse is less than 6 milliseconds wide.
The positive part is approximately 700 microseconds.
The rising edge is less than 150 microseconds.
Notice the strong resemblance with the typical pace pulse presented in Figure 8.

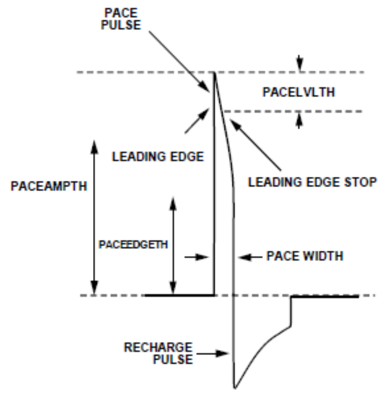

Fig. 8. Typical Pace impulse according to [2].

VII. Features Not Included

There are some features that are not included in ADAS1000, and should be added externally if needed:

- ESIS filtering or electrosurgical interference suppression is not included on chip. Again, if the developed application requires such protection it should be built with external components.
- Defibrillator protection is not included on chip. If the developed application requires such protection it should be built with external components.

VIII. Conclusion

The ADAS1000/ADAS1000-1/ADAS1000-2 offer a complete solution for measuring electro cardiac (ECG) signals. It has additional features like filters, pacemaker detection, AC/DC lead-off detection, thoracic impedance measurement and pacing artifacts detection. This means that if the system designed needs one of these functions there is no need to add extra components or design additional schematics. This simplifies the development and lowers the cost of the final product.

The small physical space required - up to 10x10mm chip size, the very few external components needed, as well as the low consumption (21 mW, all electrodes, in low power mode) make the device suitable for portable battery powered devices. High performance mode makes it suitable for higher end diagnostic machines.

It is highly configurable and can be shaped to a wide variety of projects.

Acknowledgement

This work has been supported by R&D Fund of the TU-Sofia, Grant 142ПД0005-03

References

[1] Analog Devices, *“Datasheet of ADAS1000 Low Power, Five Electrode Electrocardiogram (ECG) Analog Front End”*

[2] J. M. Kruse, C. Redmond, *"Detecting and Distinguishing Cardiac Pacing Artifacts"*, Analog Dialogue, vol. 46, no. 4, pp. 13-18, 2012.