A Low Power Wearable Respiration Monitoring Sensor using Pyroelectric Transducer

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Abstract*— This paper presents a fully integrated low-power wearable respiration monitoring system using a pyroelectric transducer. Many chronic respiratory diseases such as asthma and apnea are leading causes of death worldwide which are even more critical for premature neonatal infants. Currently, the diagnosis of apnea requires the infants to go through overnight clinical sleep analysis, also known as polysomnography for 12 to 24-hour period. During this process numerous sensors are attached to the sensitive skin of the infants resulting in irritation and inconvenience. To overcome this problem a novel point-of-care respiration monitoring system has been proposed. At the front-end of the sensor a PVDF (Polyvinylidene Fluoride) based pyroelectric transducer is used which could be placed under the nasal cavity or inside a cannula of the subject. The charge generated by the transducer due to the nasal air flow is then converted to a proportional voltage signal by an operational transconductance amplifier (OTA) based charge amplifier. The subsequent signal processing blocks detect and process the signal coming out of the charge amplifier if it lies within the voltage range that corresponds to an apneic event. Once the signal is detected an alarm signal is generated indicating the occurrence of an apneic event. The light-weight design and smaller footprint of the transducer as well as the integrated devices make it suitable as a wearable sensor for non-invasive respiration monitoring. A prototype device with the integrated circuit fabricated using 0.5µm CMOS process is presented in the paper which can prevent many major disorders that can lead to neonatal mortality.

I. Introduction

Non-invasive evaluation of vital signals is a new frontier of patient health monitoring. In particular, for health monitoring of premature infants (which includes the respiratory rate, temperature and blood pressure monitoring) non-invasive nature of the sensor device is critically important. Apnea, which is one of the most chronic disorders prominently common in neonatal infants, is characterized by the partial or complete cessation of breathing. Statistics show that almost all of the infants who are under 1000 gm in weight with less than 29 weeks of gestational age develop apnea syndrome [1]. To detect apnea, these infants need to go through a sleep study named polysomnography (PSG), which is a cumbersome process that requires numerous wires and electrodes to be placed in their chests and bodies. It also requires a specially trained sleep expert to analyze the acquired respiration data to detect apnea. Since the skin of premature children is exceptionally delicate, the obtrusiveness of the procedure makes it truly uncomfortable for them. In this paper we have proposed a miniaturized wearable respiration monitoring sensor that can be placed inside a mask or nasal cannula and thus eliminates the need for attaching electrodes to skin. The front-end of the sensor is a PVDF based pyroelectric transducer. Unlike the PVDF based piezoelectric transducer which has been used in chest belt for pulsatile vibration monitoring due to respiration [2], pyroelectric transducer based system does not require high precision filters to eliminate the noise and artifacts due to other body movements which are not associated with respiration. The proposed sensor detects the change in temperature due to breathing and detect an apneic event if the amplitude of the respiratory signal is lower than the 20% of the regular breathing amplitude for consecutive 10 – 15 seconds. It consists of a front-end charge amplifier for converting the charge signal produced by the transducer into a voltage signal, a hysteresis comparator (Schmitt trigger) to identify if that voltage signal lies within the threshold limit that indicates apnea or hypoapnea and a time to voltage converter (TVC) and a counter block to detect the time duration of an apneic event. In section II, a brief description of the functional components of the system is presented and the acquired breathing signal is analyzed.

II. Overview of the System

The proposed pyroelectric transducer made of poled PVDF is placed under the nasal cavity to monitor the temperature change due to respiration. A thin film of PVDF (5cm in length, 1.5cm in width and 20µm in thickness) attached to a soft bandage is used to verify the proper functionality of the sensor. Fig. 1 shows the schematic of the proposed charge amplifier [3]. A folded-cascode OTA with high open-loop gain is utilized as the core block of the charge amplifier. To achieve the lower cut-off frequency as low as 0.1 Hz, pseudo-resistors, implemented using diode connected PMOS transistors, are placed in the feedback path to achieve high impedance. Acquired breathing signal using the front-end transducer and the charge amplifier is shown in Fig. 2. The average amplitude of the respiratory signal is 400 mV_{pp}. Since the respiration rate for infants is much higher compared to adults (about 80 breaths per minute), the sensor is tested for fast breathing signal. Fig. 3 depicts the 1024 point FFT of the breathing signal. From the plot it can be seen the breathing signal frequency lies in the sub-Hz range. The tunable hysteresis comparator (Fig. 4) block follows the charge amplifier and detects the breathing signal if it falls within a certain threshold voltage range. Tunable hysteresis comparator ensures the re-configurability of the sensor as different infants have different breathing patterns. For an apneic event, the output of the comparator will remain high (1.2V) for consecutive 10 -15 seconds. To measure this duration, the time-to-voltage converter (TVC) generates a voltage signal which is proportional to the time duration when the hysteresis

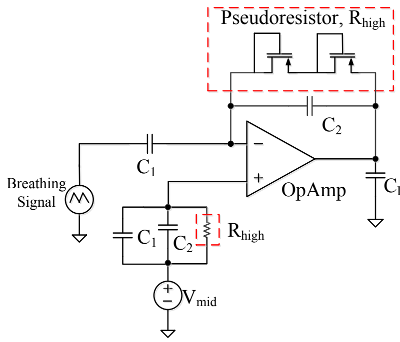

Fig. 1: Proposed charge amplifier.

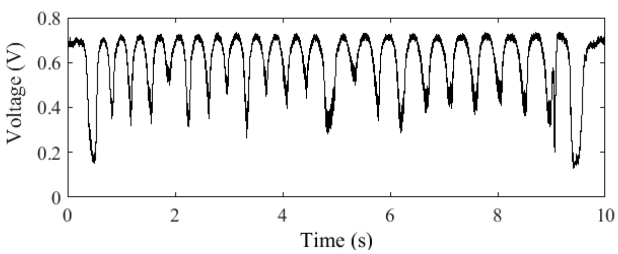

Fig. 2: Respiration signal from charge amplifier output.

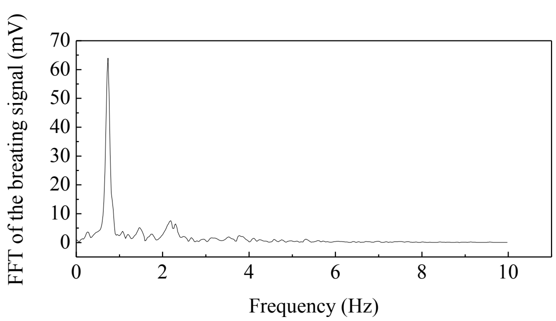

Fig. 3: FFT of the breathing signal.

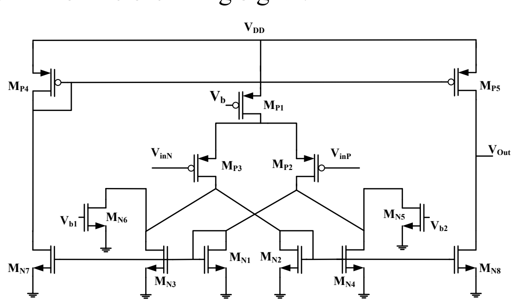

Fig. 4: Tunable hysteresis comparator.

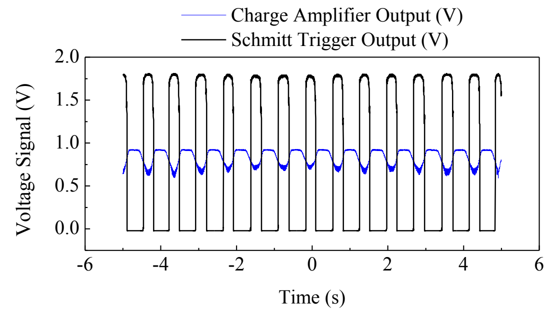

Fig. 5: Charge amplifier and Schmitt trigger signal transmitted and received by the nRF24L01 module.

comparator output is high. Then the falling edge detector block detects the falling edges of the output signal coming from the hysteresis comparator and resets the TVC. The counter block increases the count value every second when there is an absence of breathing. If a valid respiratory signal arrives before the counter counts to 10, the counter and the TVC blocks are reset to zero. On the other hand, if the counter value reaches 10, an impulse signal is created and then an alarm signal is generated. The alarm signal also turns on a motor that can vibrate the patient bed in NICU (Neonatal Intensive Care Unit) to wake up the infant. The acquired breathing signal is transmitted wirelessly using nRF24L01 module from Nordic Semiconductor. Arduino UNO launchpad is used to program the ATMEGA328p-PU microcontroller from Atmel. The system uses a 2.4GHz GFSK RF transceiver IC for both sending the respiration data to a distant receiver which is another nRF24L01 module connected to a PC. Fig. 5 shows the transmitted charge amplifier and the hysteresis comparator signal acquired from the receiver end. From this received data various physiological parameters of the patient such as respiration rate, number of apnea and hypoapnea events per sleep hour etc. can be detected.

III. CONCLUSION

This proposed system presents a novel approach of continuous respiration monitoring using pyroelectric polymer transducer and low power CMOS integrated circuits. Thermal properties of the transducer as well as the front-end circuitry can be adjusted to make the sensor appropriate for different patients. In future the transmitter would be incorporated in the same CMOS chip to make the footprint even smaller.

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