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Highly Integrated BioSoC System for Health Monitoring

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ABSTRACT

We present a project of a system for measurement of ECG, EMG, Skin temperature and Respiration rate signals. The system is divided into measurement, communications and powering units. The measurement system was designed as a potable and battery powered devices. The highly integrated SoC consist of analog front ends, analog to digital converters and 32-bit microcontroller. The designed IC allows for dynamic acquisition and processing of the most important human physiological parameters. The measured parameters are analog signals then the signal is further allowed for sampling and digitization. The clock frequency is from 32KHZ to 16MHZ. The highly integrated circuit in the field of telemedicine is made possible by using system on chip.

Keywords: System on chip (SoC), Biomedical circuit and systems, Analog front end (AFE) and Microcontroller.

1. Introduction

The increasing human life expectancy, leading to the ageing of the population creates the increasing demand for portable monitoring devices and brings more challenges in the area of the health monitoring and remote diagnosis. The person's ability to perform a given task is crucial, especially when it involves high risk or much physical or intellectual effort. New technologies in the area of sensor electronic and data processing provides the solution. It is necessary to monitor the health of the person those are in the group of higher risk of having a heart attack, fainting or suffering from other life threatening situations, could be lifesaving. Another group of people are those working in harsh or demanding environment, such as drivers, firefighters, soldiers and pilots.

The fast growing wearable sensor in the market is an important driver for the development of highly integrated health monitoring devices. Because of this more people are interested in monitoring their health parameter during their sports or event daily activities.

The increasing demand for highly integrated health monitoring system among the users increases the development of highly integrated circuits for the data acquisition and measurement of physiological signals. A typical highly integrated circuit is built using different ICs for analog front ends, signal processing and communication. As the small number of parameters are measured, the interfaces lack for additional peripheral sensors and poor data processing capabilities this SoC s still do not respond to the demand for highly integrated health monitoring devices. The SoC consists of analog front ends for ECG, EMG, Skin temperature, and resistance and respiration rate measurement, analog to digital converters, 32-bit microcontroller and interfaces. The 32-bit microcontroller was used to increase the data processing capabilities. It meets the need for complex and portable system for acquisition, processing and monitoring of physiological signals.

2. SYSTEM ARCHITECTURE

The analog parts in the BioSoC block diagram are

- Analog front end (AFE)
- Analog to digital converters (ADC)
- Voltage and current reference sources
- Clock signal generators
- Power on reset (POR)

The system is made flexible and allows the user to choose between functionality, performance and power consumption, the analog blocks are configurable. The behavior and parameters of each analog block is changed by analog control registers. The user can turn on and off each analog block, control the bandwidth, gain and bias current of the AFEs are change the sampling frequency of the ADCs. Inside the chip the voltage and current references are generated. The reference voltage for ADC is only generated from external references.

The AFEs are divided in two groups, each having one multiplexed analog to digital converter:

- Four electrocardiography (ECG) and electromyography (EMG) analog front ends, with a right leg drive amplifier (RLD), sharing a 4-channel, 16- bit ADC.
- Skin resistance (RES) ,two skin temperature (TEMP) and respiration rate(RR) analog front ends, sharing a 4-channel,12-bit ADC.

The presented microcontroller consists of a high-performance, low power 32-bit custom designed RISC processor core, the Interrupt controller, Power Management Unit (PMU) and 4KB of Scratch Pad RAM (SPRAM) memory. Direct Memory Access Controller (DMA) and the

Debug Unit of memory controller access the embedded instruction and data memory areas. Advanced Microcontroller Bus Architecture (AMBA) and Advanced Peripheral Bus (APB) are used as communication buses. The analog control register are also connected to the APB Bridge. The communication with other off-chip peripherals and sensors is possible using BioSoC digital interfaces:

- Two serial peripheral interfaces (SPI)
- Two universal asynchronous receiver and transmitter controllers (UART)
- 16 general purpose input output ports (GPIO)

The SoC does not offer a non-volatile memory so the user's program is downloaded from an external serial flash memory using serial peripheral interface (SPI) .To do this, the program memory is mapped to the boot memory area on a power on event. When the user's program is downloaded, the program memory is remapped back to the regular program memory area and user program is executed.

Each register or memory location is accessible by using the serial debug interface. Consequently, the debugger can program the external serial flash memory with the user's program and test all of the embedded memory areas.

Two different voltages are supplied to SoC 3.3V and 1.2V. 3.3V is used for all digital IOs core digital circuits. The RLD amplifier and current source of skin resistance AFE is supplied with 1.2V.

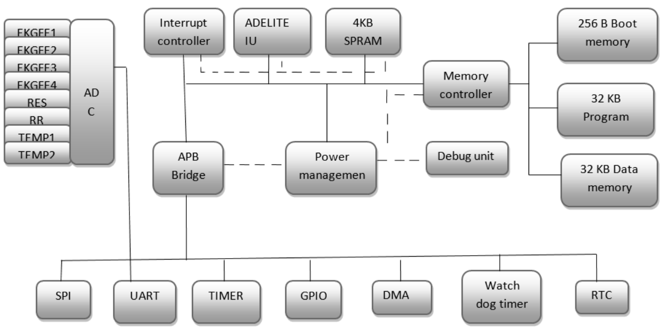

Fig.1. Block diagram of BioSoC

3. ANALOG FRONT ENDS

A. ECG/EMG ANALOG FRONT ENDS

The low noise instrumentation amplifier (IA), a low pass filter (LPF) and a programmable gain amplifier (PGA) are the blocks of AFE. Bandwidth for LPF is configurable from 150Hz to 250Hz and has a sharp characteristic. The total front end gain is programmable from 42db to 66db with the 6 db step. The AFE offset is determined by IA inputs which get allowed by signal routing block.

The 16-bit Sigma delta ADC sampling frequency for multiplexing mode is 2 kHz per channel and 8kHz in the case of single channel operation. When the complete performance is not needed the power consumption for sampling frequency and ADC bias current is reduced. The ADC has 2 nodes such as automated mode and manual mode. In the automated mode, the channel is only defined by the users to be sampled the remaining signal's are controlled by controller. In the manual mode, all the signals are get controlled by the users by setting the appropriate values to the analog control registers.

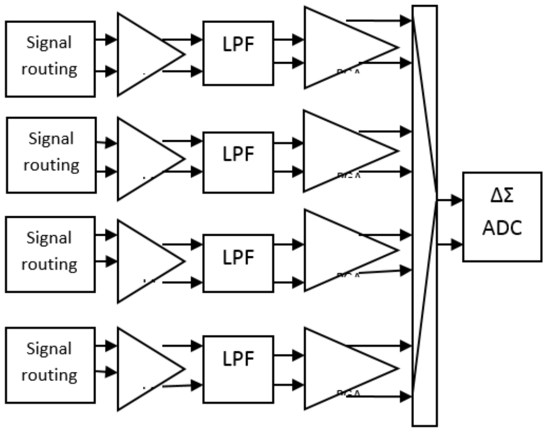

Fig.2. EMG/ECG analog front ends

B. RESPIRATION RATE, SKIN TEMPERATURE AND RESISTANCE

The signal routing block, a DC current source and a programmable gain amplifier (PGA) are analog chains in the skin temperature and resistance analog front ends. The resistance connected to input ports are measured by temperature and resistance AFEs. The nominal measurement current for skin temperature is set to 100µA,and the PGA gain is set to 6db.The electrodes in the skin resistance AFEs are able to measure resistance from 1kΩ to 4MΩ.The purpose of signal routing block of the respiration rate AFE is same as skin temperature and resistance AFE and programmable gain amplifier.

For signal acquisition a 12 bit multiplexed four channel Sigma Delta ADC is used. The required sampling frequency for the respiration rate, sampling rate is 1Hz.

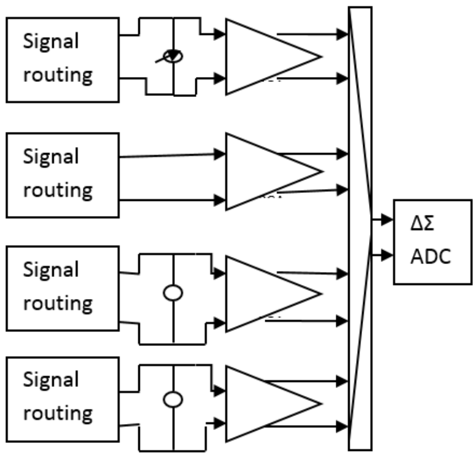

Fig.3. Respiration rate, skin temperature and resistance analog front end

Only during the measurement of signal, the ADC and AFEs is powered on to save the power.

4. MEASUREMENTS

The BioSoC has been fabricated, packed and assembled on a measurement PCB board. It has two packages they are JLCC package and QFN package. In JLCC package the ICs convenient for measurement is packed. The remaining ICs were packed in a QFN package, more suitable for the health monitoring device integration. The flash memory using SPI interface for communication purpose, and analog connectors for testing and measurements.

The current consumption of the microprocessor is 100µA/MHz, which gives 800µA with 8MHz clock. Adelite performance is measured by two benchmarks, CoreMark and Dhrystone. The microcontroller achieved 1.75 CoreMark/MHz and 1.25 DMIPS/MHz The AFEs bandwidth can be tuned from 60Hz to 290Hz, which covers the desired range from 150Hz to 250Hz.The measured gain can be tuned from 41db to 65db with a step of 6db.

Low pass filter is the main source of noise, which is get reduced by using capacitors. The current consumption for the ECG/EMG AFEs is 63µA per channel and 127µA for the ADC working in 4-channel mode with sampling rate of 2KHz per channel. Decade resistors are used to measure the skin resistance and temperature. About 180µA and 59µA are the power consumption for skin temperature and resistance. All analog front ends on and the microcontroller set to 8MHz clock is around 1.7MA.

5. CONCLUSION

The BioSoC chip integrates four ECG/EMG, one respiration rate, two skin temperatures, and one skin resistance analog front ends. Two multiplexed analog-digital convertors allow signals to be acquired from all channels. Data processing can be implemented in the 32 bit Adelite microcontroller. The BioSoC is designed for portable health monitoring system. High configurability and low power techniques are clock gating for digital blocks and power gating for analog blocks, allows the user to maintain the performance and power consumption trade-off based on application. The BioSoC has been fabricated in UMC CMOS 130nm technology. All analog channel performance are satisfied. The ECG signal on which QRS complex has been successfully identified. The Adelite microcontroller achieves 1.75 core Mark/MHz and 1.25 DMIP/MHz in CoreMark and Dhrystone benchmarks, respectively.

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