IcyHeart, an ECG Sensor Interface in a SoC

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This article describes a System-on-Chip (SoC) developed within the IcyHeart European project to perform 3-lead ECG monitoring. The IcyHeart SoC incorporates a 3-lead ECG analog front-end and ADC, a 32-bit icyflex processor and a 863-928 MHz transceiver. It develops tiny battery powered smart portable ECG systems with on-chip ECG signal acquisition and processing.

With the increase of population aging, healthcare costs become a real issue. Tele-healthcare is seen as an answer for reducing hospitalization costs and to offer more autonomy to impaired people. The major concern for tele-healthcare systems is to achieve this purpose with a high accuracy and a long autonomy while being non-invasive. The objective of the IcyHeart project is to investigate and demonstrate a highly integrated and power-efficient microelectronic solution for remote monitoring of a subject’s electrocardiogram (ECG) signals. A complete System-on-a-Chip (SoC) has been developed based on the icycom[1] SoC. It incorporates on a single chip an ultra-low-power signal acquisition front-end with analog-to-digital converter (ADC) for 3-lead ECG, a low-power digital signal processor (DSP) and a low-energy radio frequency (RF) transceiver. These features, for the first time, coexist on a single die. The SoC runs from a 1 V supply, compatible with a single alkaline cell, and is optimized for long battery life.

The analog front-end is illustrated in Figure 1. It consists of 3 ECG leads, each followed by an amplification chain with a gain programmable up to 46 dB and an adjustable cut-off frequency from 100 to 480 Hz. It features a measured total harmonic distortion (THD) of 54 dB with the nominal gain setting and an input referred noise of 1 \( \mu \)V. For a maximal input voltage of 4 mV, the achievable resolution of the amplification chain is 12 bits.

The sensor interface also incorporates an active ground control to cancel large common voltage variations. It probes the common mode voltage of the three leads through a simple star connected resistors network and feeds back a signal corresponding to the inverted value of the common mode. Finally, the sensor interface also implements a lead-off detection by injecting an AC square signal via the active ground connection and detecting it on the 3 ECG leads.

A low power and low voltage sigma delta ADC was specifically designed to digitize the signals out of the 3 amplification chains. Measurements show that it achieves a resolution of 14 bits and a THD of 52 dB for an input signal of 300 mV.

The digital core of the Icyheart SoC is built around the icyflex\(^\text{®}\) DSP, a 32 bit low-power microcontroller with DSP functions (parallel dual MAC), whose purpose will be to analyse in real-time the ECG data provided by the analog front-end.

The low-power RF transceiver operates in the SRD 863-928 MHz range. The receiver part is ultra-low-power, not only optimized for continuous operation but also for RF channel power sampling. This allows efficient implementation of low-power protocols minimizing the receiver activity.

Additional peripherals such as a voltage-divider to also address lithium batteries, SPI, I2C, UART, I2S are all included on the same chip, resulting in a compact system solution.

The state-of-the-art 12 bits ADC based analog chain, the ECG optimized signal processing, the low-power microcontroller with dedicated instructions and the ultra-low-power wireless transceiver turn the IcyHeart SoC into a smart and novel “sensing-processing-transmitting” ECG product.

The outcome of the IcyHeart project is expected to create high societal impact for several categories of European citizens requiring miniature, comfortable and easy-to-use wireless tele-healthcare solutions.

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