FINAL REPORT

Project: Wireless Sensor Microsystem for Measuring the Effects of Vitamins on the Aging Process

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Abstract: Under this project, we have developed wireless wearable biosensors for assessing the potential benefits of vitamins and micronutrient supplementation to increase the time of one's life spent free from disease and deficits of daily living. The biosensor developed under this research was intended to enable the continuous monitoring of the most important bio-potential signals in the elderly, and also to make it possible to evaluate the effects of vitamins and micronutrients on ambulatory patients.

I. Results and Conclusions

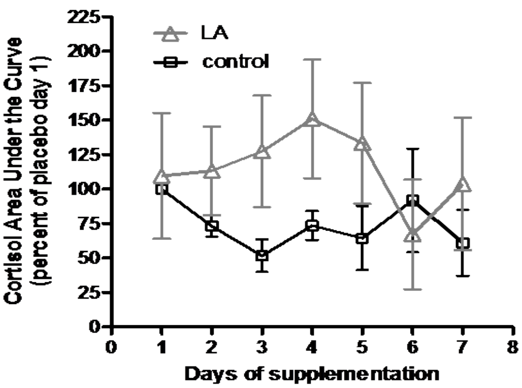


Fig.1 LA supplementation effects.

The biosensor was used in conjunction with a small-scale placebo-controlled clinical trial conducted on the OSU campus which examined the effect of (R)-α-lipoic acid (LA) on circadian cortisol production in older adult (>70 years of age) men. Results showed that LA supplementation indeed restored circadian cycles (as opposed to placebo) (Fig. 1). This set of data further implies that LA should re-entrain elder sleep-wake cycles. The activity monitors were worn throughout the study and gathered supporting data on general activity, which was reflected in salivary cortisol output. Further improvements in the activity monitor should allow discernment of overall sleep patterns and will thus be highly useful in determining the efficacy of LA for maintaining sleeping patterns which otherwise become disrupted with advancing age.

II. Miniature Flexible Heart Rate Monitor

We have developed a miniature, flexible and orientation-less heart rate sensor that uses the principals behind electrocardiograph technology to measure heart rate. Just 1.1 inches in diameter and less than a quarter inch thick, when covered with adhesive medical tape, the entire sensor platform can be easily be affixed to the wearer's chest.

The electrodes along with their digital processing and radio components will be mated to a flexible substrate which will allow the device to curve and fit a variety of users and also ensure correct operation even under moderate physical activity such as walking or jumping. The sensor electrodes are designed redundantly and oriented in such a way that the system can self-orient based on the best signal achievable. This means that the user needs no prior knowledge about the device and can simply stick it on the left side of their chest approximately over their heart and achieve full functionality. This device provides a simple, low cost, comfortable and robust solution to heart rate monitoring.

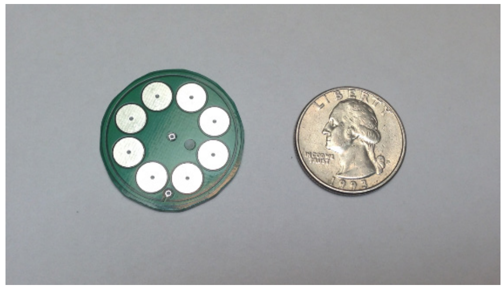
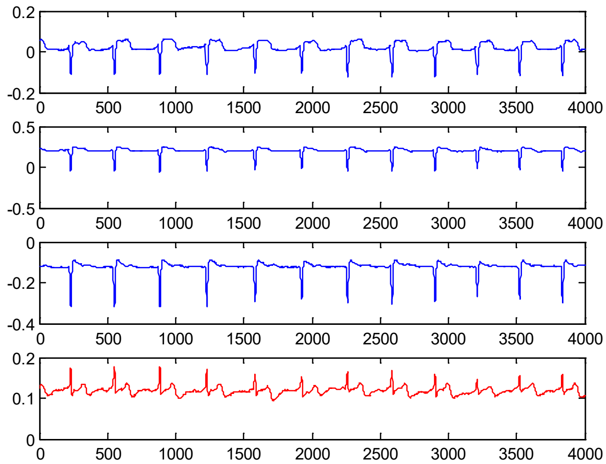
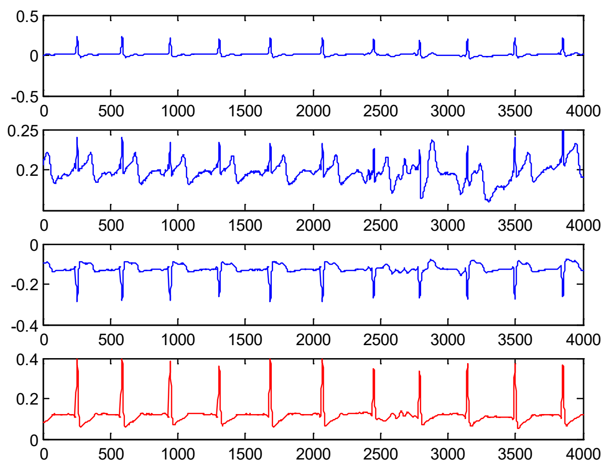


Fig. 2. The bottom side of the sensor showing its circular electrode array

Measurements were done for three orientations of 0, 45 and 90 degrees. For each orientation, four ECG signals captured with three motion conditions: resting, walking and jumping. Two measurement results are shown below for the biggest sensor size:



0 degree, resting



90 degree, jumping

Fig. 3. ECG signals for resting and jumping.

Results showed that when we change orientation of sensor patch, the highest quality ECG signal appears in different channels. A simple algorithm running on digital signal processing portion of SoC can automatically detect the best channel for each condition and use that channel to capture ECG signal for further processing.

III Low-Power Low-Voltage 2.4GHz DPSK Sub-Sampling Receiver

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Fig. 4 shows the block diagram of the sub-sampling PSK receiver. The input signal is amplified by a Q-enhanced LNA and fed to a sample-and-hold circuit (SHC) that sub-samples the 2.4GHz RF signal at a sampling frequency of f_s = 309.7MHz. Aggressive Q-enhancement in the LNA mitigates impact of noise-folding in the sub-sampling SHC. System-level studies show that an effective Q above 100 in the LNA output tank ensures that excess noise due to noise folding is negligible, as the overall RX noise is dominated by LNA noise at the RF frequency. The SHC output is directly fed to dynamic comparators that perform 1-bit A-to-D conversion, with the sampling frequency of f_s = 309.7MHz implying that the 1-bit ADC oversamples the WBAN baseband signal with an oversampling ratio of 512. The over-sampled 1-bit ADC approach is adopted to minimize power consumption, while ensuring that non-linearity arising from 1-bit quantization does not degrade equivalent ADC resolution. Decimation filtering of the oversampled baseband leads to an equivalent ADC resolution of 5.5-bits in the RX. Fig. 5 shows the die photo of this RX.

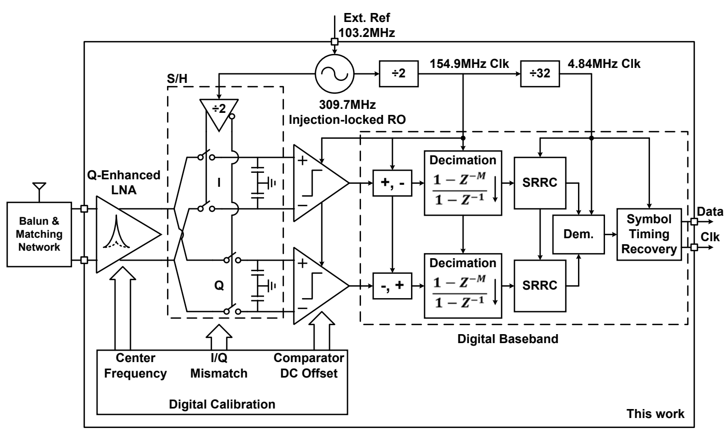

Fig. 4. System block diagram of 2.4GHz sub-sampling DPSK receiver.

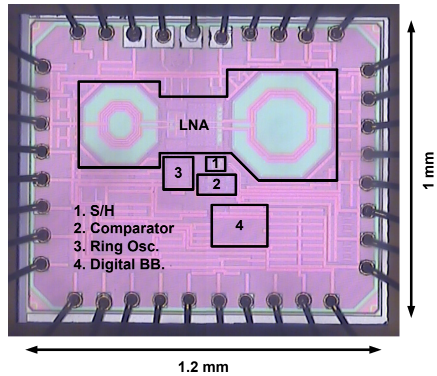

Fig. 5: Die photo of the 2.4GHz sub-sampling receiver.

IV Bandpass Input Amplifier for Biosensors

A key building block of the biosensor electronics is the analog front-end circuit which processes the physiological signals. The main challenge is that the electrode-skin interface usually introduces a high DC component in the input signal which has to be removed by an in-chip high-pass filter with cutoff frequency below 1 Hz. This requires that a tera-ohm resistance be implemented in chip in order to save capacitor area. Earlier, we proposed a switched-capacitor ladder realization which can achieve exactly the desired tera-ohm resistance; also a linear tuning methodology was proposed. This scheme has now been successfully implemented.

Fig.6 shows the input amplifier in the biosensor front end. The SC ladder is used to realized an equivalent feedback resistor with an approximate value $R=(C_2/C_1 + 1)^n/(f_sC_1)$.

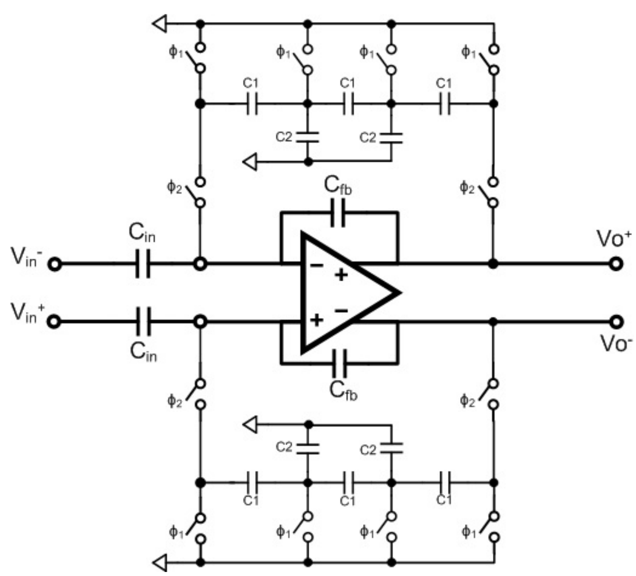

Fig.6. Input amplifier with switched-capacitor ladder

Here, n is the number of stages in the ladder. Choosing f_s = 1 kHz, n = 2, C_1 = 25 fF and C_2 = 75 fF, a desired value R = 0.64 tera-ohms results. This gives f_{HP} ~ 0.25 Hz for C_{fb} = 1 pF. The cutoff frequency of the filter can be tuned by the choice of the sampling frequency f_s. The gain of the input amplifier can be tuned by an off-chip capacitor C_{in}.

This amplifier was fabricated in a 0.18um 1P4M CMOS technology. The measured results are shown in Fig. 7. They indicate that linear tuning can be achieved with the new scheme, and a minimum cutoff frequency well below 1 Hz can be realized by the filter.

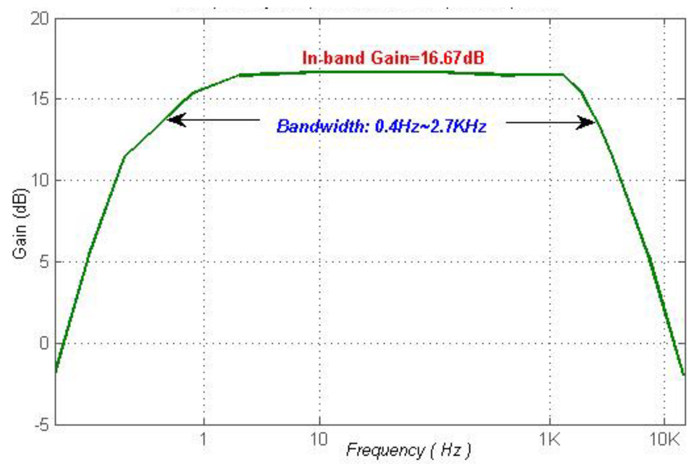

Fig.7. Frequency response of the input amplifier

V 15-Bit Micro-Power Incremental ADC for integrated Sensor Interface

An incremental ADC (IADC) using two-step operation was designed. A 2nd–order IADC performs coarse conversion and then it is reconfigured as a 1st-order IADC to perform fine conversion. It achieves 3rd-order noise-shaping performance with the 2nd-order IADC circuits. With an oversampling frequency 96 kHz, 15-bit accuracy was achieved for signals from 1Hz to 250 Hz.

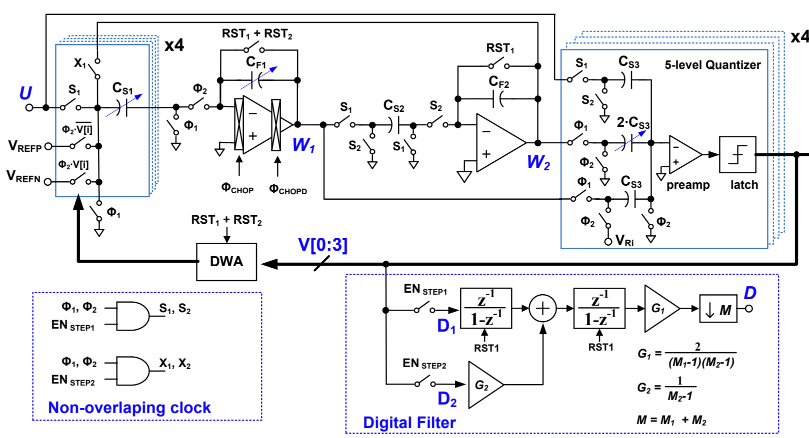

Fig.8. IADC circuit with digital filter.

The complete circuitry with decimation filter is shown on Figure 8. Implemented in 65 nm CMOS, with OSR =192, a 2nd-order IADC achieves 89dB SQNR and a 3rd-order IADC achieves 125dB. With the same OSR (192), the two-step operation can achieve 118 dB, which is comparable to a third-order IADC's performance. The 1st-step operation with OSR = 128 achieves an SQNR about 82 dB, and the 2nd-step with OSR = 64 OSR provides an additional 36 dB.