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# Live Demonstration: An ECG-on-Chip for Wearable Wireless ECG Sensor

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**Track: Biomedical and Life-Science Circuits, Systems and Applications**

## I. Demonstration Setup

We are demonstrating a wearable wireless ECG sensor prototype based on a highly integrated, ultra-low power ECG-on-Chip. The demonstration setup (as shown in Fig. 1) of the prototype sensor consists of 1) ST-Electromedicina ST-10 ECG signal generator 2) Prototype Sensor with the proposed ECG-on-Chip 3) Gateway application running in a notebook PC / Android smartphone. The signal output from the ECG generator is amplified, converted to digital domain and compressed by the ECG-on-Chip and streamed live via Bluetooth. The signal is received by a notebook PC with Bluetooth interface running the gateway application. The compressed signal is decompressed by the gateway application and displayed for observation/diagnostic purposes. This data can be uploaded to cloud server for long-term storage and more complex signal analysis. The signal transmitted by the sensor can also be received by a smartphone application in Android to visualize and analyze the signal further. A live subject will wear one of the sensors to demonstrate the ECG acquisition under normal daily activities like walking, running, jumping. ECG signals acquired during activities are shown in Fig 2.

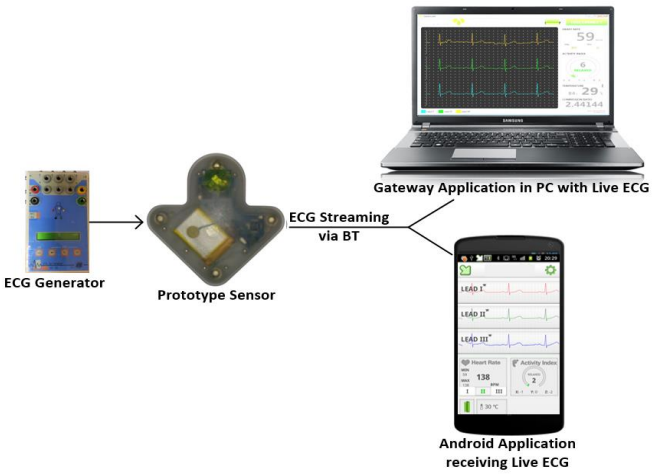



Fig 1. Demonstration Setup

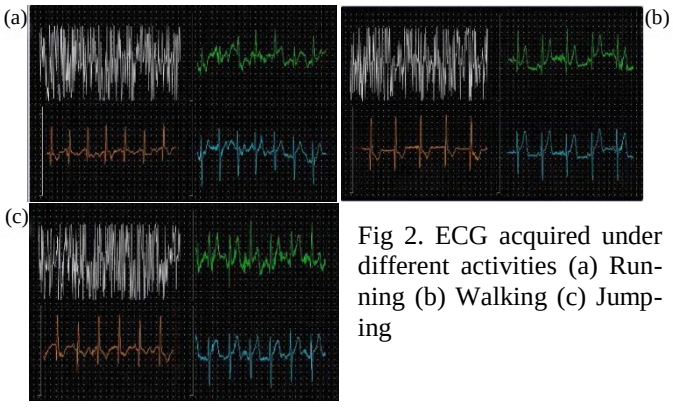



Fig 2. ECG acquired under different activities (a) Running (b) Walking (c) Jumping

## II. Visitor Experience

The setup is highly interactive. Visitors will give the opportunity to experience the wearable wireless ECG sensor in action. A video recording will show the overall performance of the ECG-on-Chip based wearable ECG sensor under different use cases. Visitors are also encouraged to observe and interact with our demonstration setup in 2 ways. For the setup in Fig 1, visitors are allowed to vary the type, beats/min etc of ECG signal generated and observe the corresponding changes in heart rate, compression ratio in the PC application. A live subject will be wearing the sensor to show the actual ECG recording, the variations in activity index (accelerometer data), heart rate, dynamic compression ratio etc. when the subject is moving or performing normal activities like jogging, jumping etc.

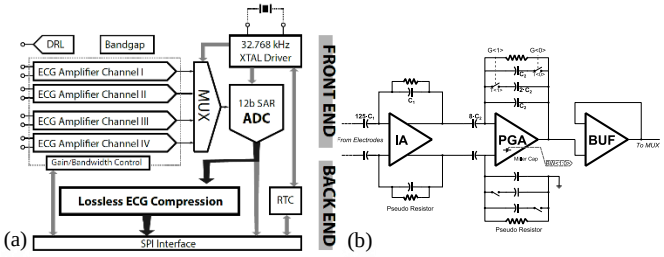
## III. Earlier Publication

The technical details of ECG-on-Chip were published in 2013 IEEE A-SSCC [1]. This work was motivated by the increasing costs and risks of cardiovascular diseases (CVD). According to WHO report [2] , CVD causes more than one-third of all deaths and is a leading contributor to healthcare costs. An effective way to reduce the costs and risks associated with CVDs is to use low-cost wearable sensors for real-time monitoring of CVD patients, as shown in Fig. 3. In such a sensor, the power consumed by the wireless transceiver often dominates, which results in a short sensor battery life or a bulkier device. Therefore we developed an ultra-low power ECG-on-Chip with integrated Amplifier, ADC and lossless compression that can reduce the amount of data to be transmitted by more than 50%, improving the sensor battery life.

Fig.3 Wireless ECG Monitoring System

The system architecture of the ECG-on-Chip is shown in Fig. 4(a). The frontend consists of 4 recording channels, a multiplexer (MUX) and a 12-bit successive approximation (SAR) ADC. The backend includes a lossless compression block, a real-time clock (RTC) module, and a SPI interface. To improve the ECG signal quality and reduce 50- or 60-Hz power-line noise, a driven-right-leg (DRL) is included. Also

a low-power 32.768 kHz crystal oscillator driver and band-gap reference are implemented. The whole chip is designed to work under 2.4 ~ 3.0 V power supply.




(a) (b)

Fig. 4 a) Architecture of ECG-on-Chip, b) ECG amplifier channel

The architecture for the analog front-end amplifiers is shown in Fig. 4(b), which includes an instrumental amplifier (IA), a programmable gain amplifier (PGA), and a rail-to-rail output buffer (BUF). The capacitively coupled IA blocks the DC offsets and improves the signal dynamic range. The overall ECG gain is dynamically tunable through the PGA's switches T<1:0>.

The design is implemented in a 0.35µm process and the measurement results are shown in Table 1. The input referred noise from 0.05 Hz to 150 Hz is less than 1.5 µVrms. The high-pass corner is less than 0.01 Hz, and the full-scale 3V THD is only 0.08 %. The total front-end current, including all four channels, ADC, DRL, band-gap, and crystal oscillator circuit, is only 12.5 µA. The backend consumes 0.89 µA. The die photo is shown in Fig. 5, and it has a core area of is 2.94 × 2.15 mm$^2$.

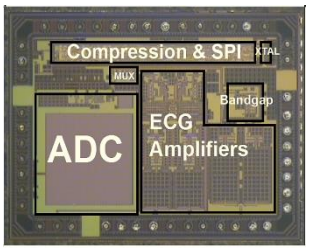



Fig.5 Chip Die photo

Table I: Chip measurement Results

| | |
|---|---|
| Supply Voltage | 2.4~ 3.0 V |
| Technology | 0.35 µm CMOS |
| High-Pass Frequency | 0.0075 Hz |
| Low-Pass Frequency | 35 ~ 175 Hz |
| Pass-Band Gain | 47 ~ 66 dB |
| Input-Referred Noise (0.05 ~ 250 Hz) | 1.46 µVrms |
| Common-Mode Rejection Ratio (CMRR) | 65 dB |
| Power Supply Rejection Ratio (PSRR) | 76 dB |
| Total Harmonic Distortion (THD) | -64 dBFS |
| Sampling Frequency | 256/512 Hz |
| Total Front-End Current | 12.5 µA |
| Total Back-End Current | 0.89 µA |
| Effective Number of Bits (ENOB) | 9.3 |

## IV. PROTOTYPE SYSTEM

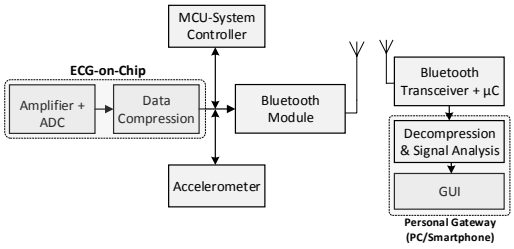
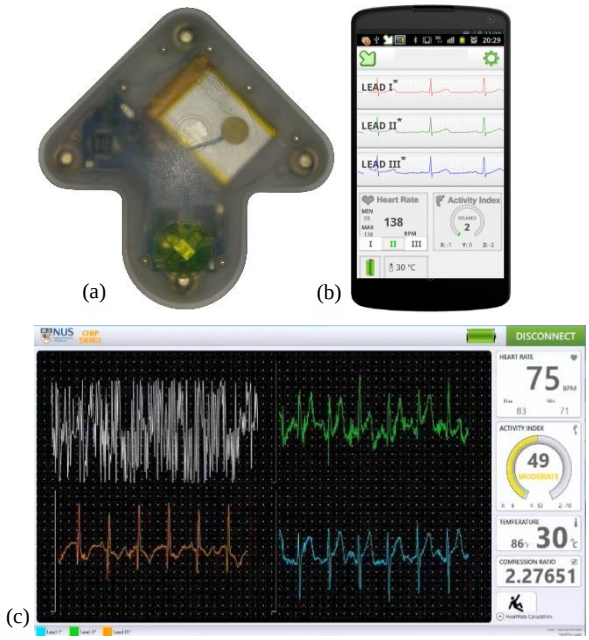



Fig.6 Sensor prototype block diagram

A prototype sensor have been developed using the ultra-low power ECG-on-Chip described in Section III. The block diagram of the sensor is shown in Fig 6. The sensor consists of Bluetooth module for streaming the ECG data to a gateway. The sensor integrates an accelerometer for activity detection and monitoring. An MCU from Maxim is used for the overall system control. The personal gateway is implemented as a software application running in a PC or smartphone (Figs. 7(b), (c)). The gateway application decodes the compressed signal in real-time and computes the current heart rate, activity index (based on accelerometer data) and skin temperature. The sensor prototype is shown in Fig 7(a)




(a) (b) (c)

Fig.7 (a) Sensor Prototype photo (b) Android APP GUI (c) PC Gateway application GUI

## V. CONCLUSION

A wearable wireless sensor for real-time cardiac monitoring has been developed using the ultra-low power ECG-on-chip with integrated lossless compression. The sensor along with the gateway applications running on PC and Smartphone environments have been demonstrated.

## VI. REFERENCES

[1] C. J. Deepu, X. Zhang, W.-S. Liew, D. L. T. Wong, and Y. Lian, "An ECG-SoC with 535nW/channel lossless data compression for wearable sensors," in *2013 IEEE Asian Solid-State Circuits Conference (A-SSCC)*, 2013, pp. 145–148.

[2] "World Health Statistics 2013," *World Health Organisation*. .