Towards a Broadly Configurable Wearable Device for Continuous Hemodynamic Monitoring

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Outline

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3. Comparison
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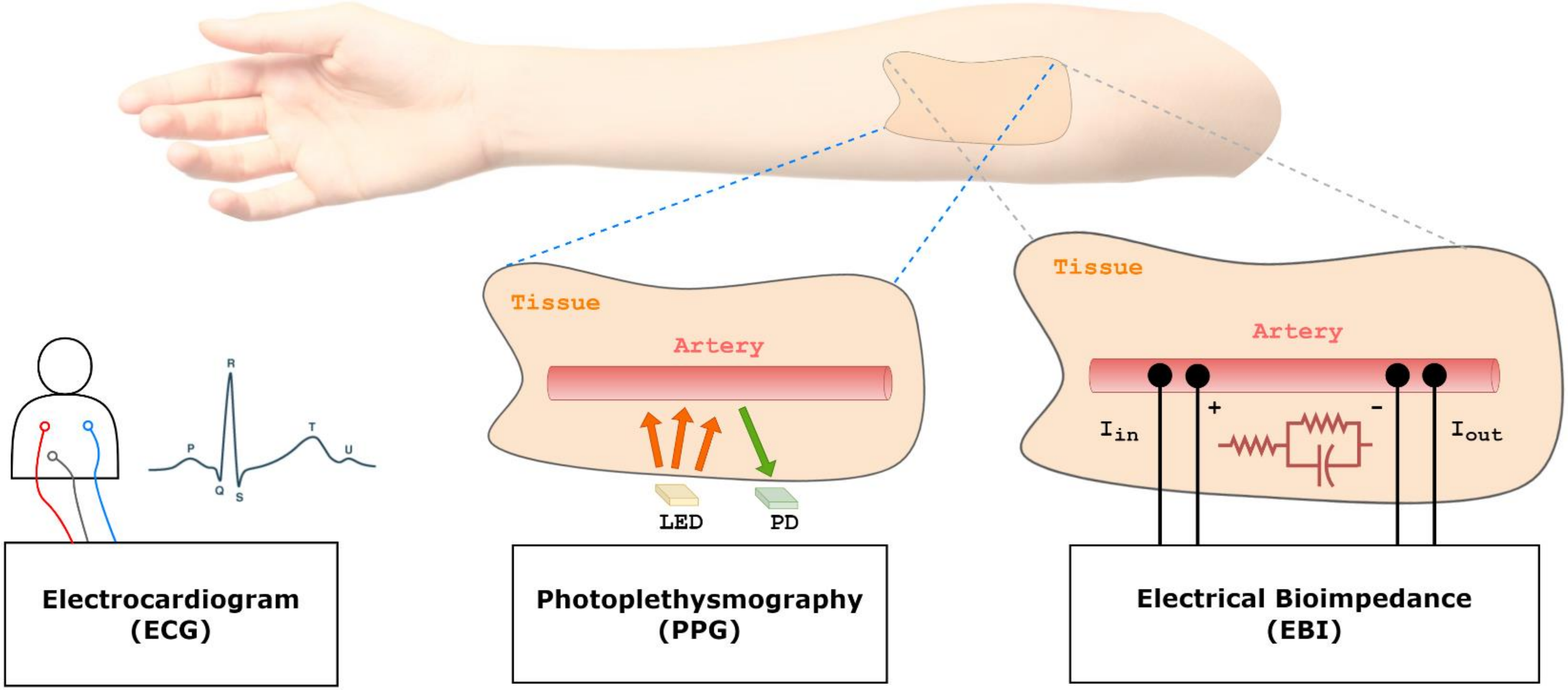
Introduction

- Cardiovascular diseases take ~20.5 million lives yearly

- Hemodynamically based signals are essential to early diagnostics
  - Most efficient method is through non-invasive, continuous monitoring, wearable devices

*Hemodynamic – blood related

Three Critical Biosignals



- **Heart Arrhythmia**
- **Cardiovascular Disease**

- **Heart Rate**
- **Blood Oxygen Saturation**

- **Edema**
- **Vascular Flow**

Improvement Opportunity for Wearables

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Typical Wearables	Proposed Wearable
Measure a single biosignal ○ Nonconfigurable	**Multi-channel biosignal acquisition** ○ Broader hemodynamic monitoring applications
No onboard processing ○ Only front end sensing	**Onboard processing before wireless transmit** ○ Lower power ○ Better data security ○ Less latency
Proprietary Hardware	**Open-source Hardware**

Concurrent Acquisition Examples

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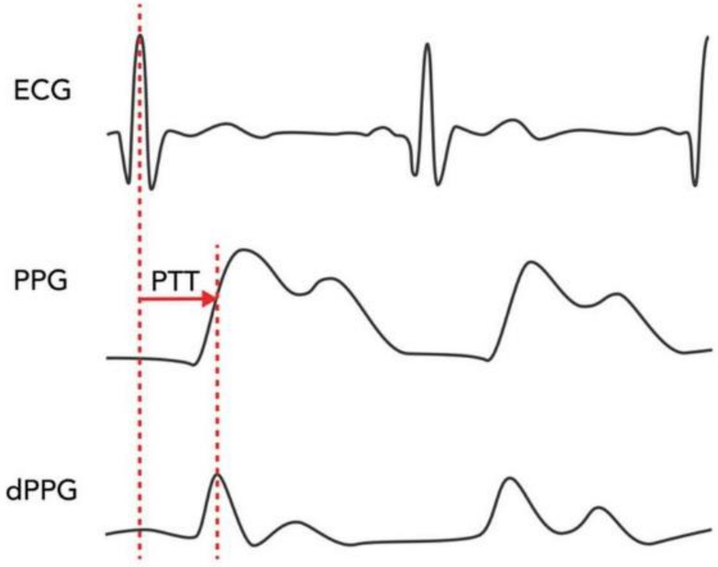
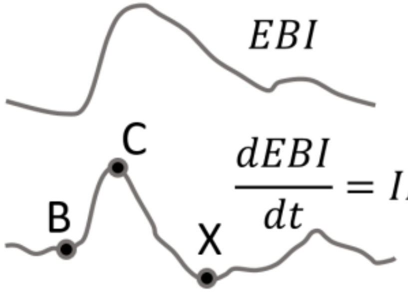
Pulse transit time (PTT) for blood pressure estimation

- Requires Δt between ECG R-peak & PPG rising edge



Impedance plethysmography (IPG) for blood flow monitoring

- Requires EBI and heart rate from ECG or PPG



$$\frac{dEBI}{dt} = IPG$$

$$\Delta V_{bd} = \rho \left(\frac{L}{R_{dc}}\right)^2 \Delta t_{BX} \left(\frac{dIPG}{dt}\right)_{max}$$

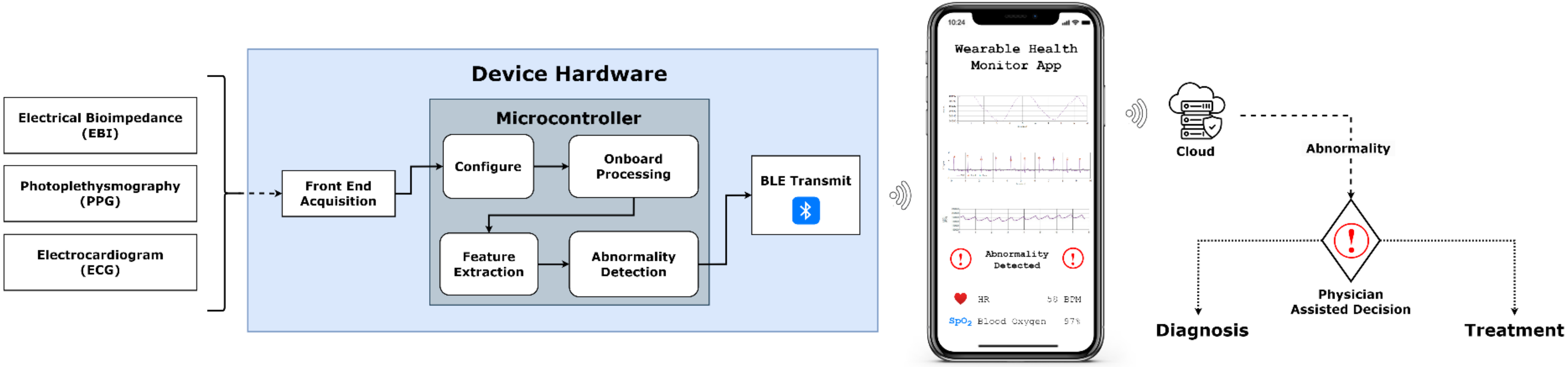
$$BFV = BVV \cdot HR$$

BFV: Blood Flow Variable

HR: Heart Rate

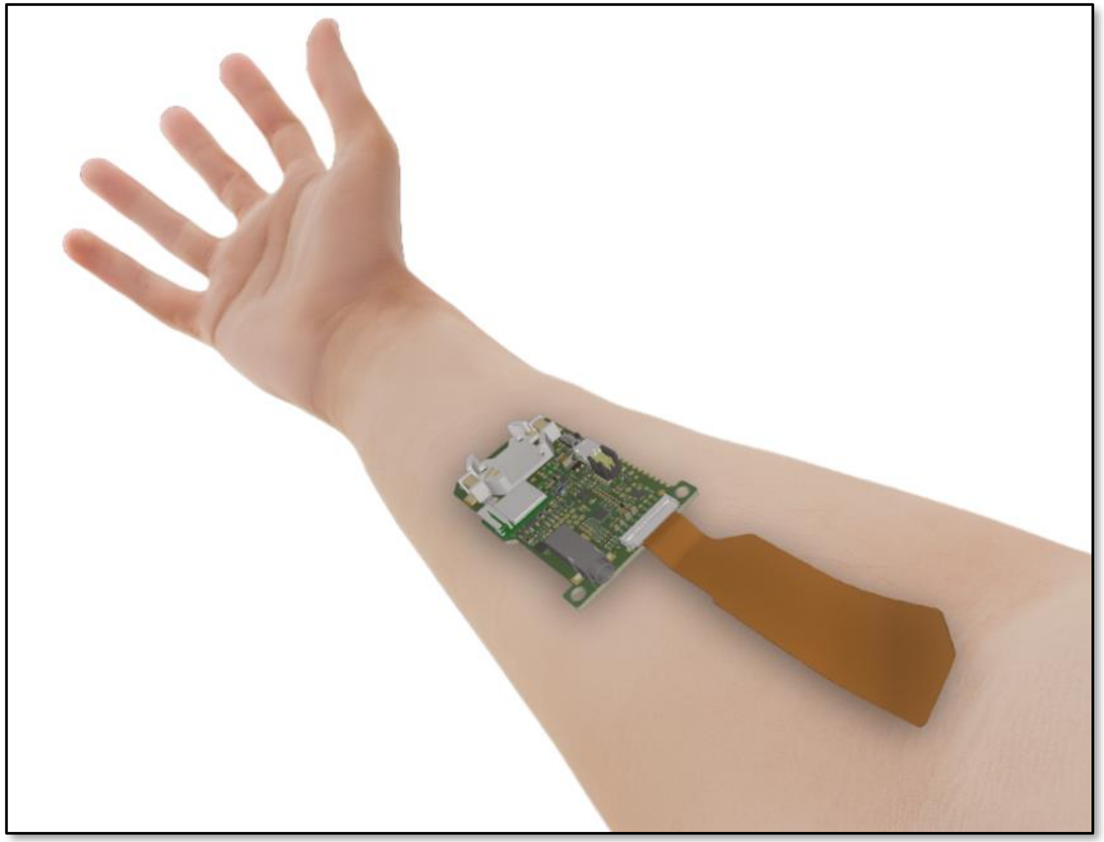
Proposed System Flowchart

*mobile app is for visual illustration only



Wearable Device Hardware

- 60.5mm by 38.75mm
- Integrated commercial ECG, EBI, PPG front ends
- Onboard microcontroller (MCU)
- Wireless transmit
- Power management system
- Open-source hardware



Hardware Architecture

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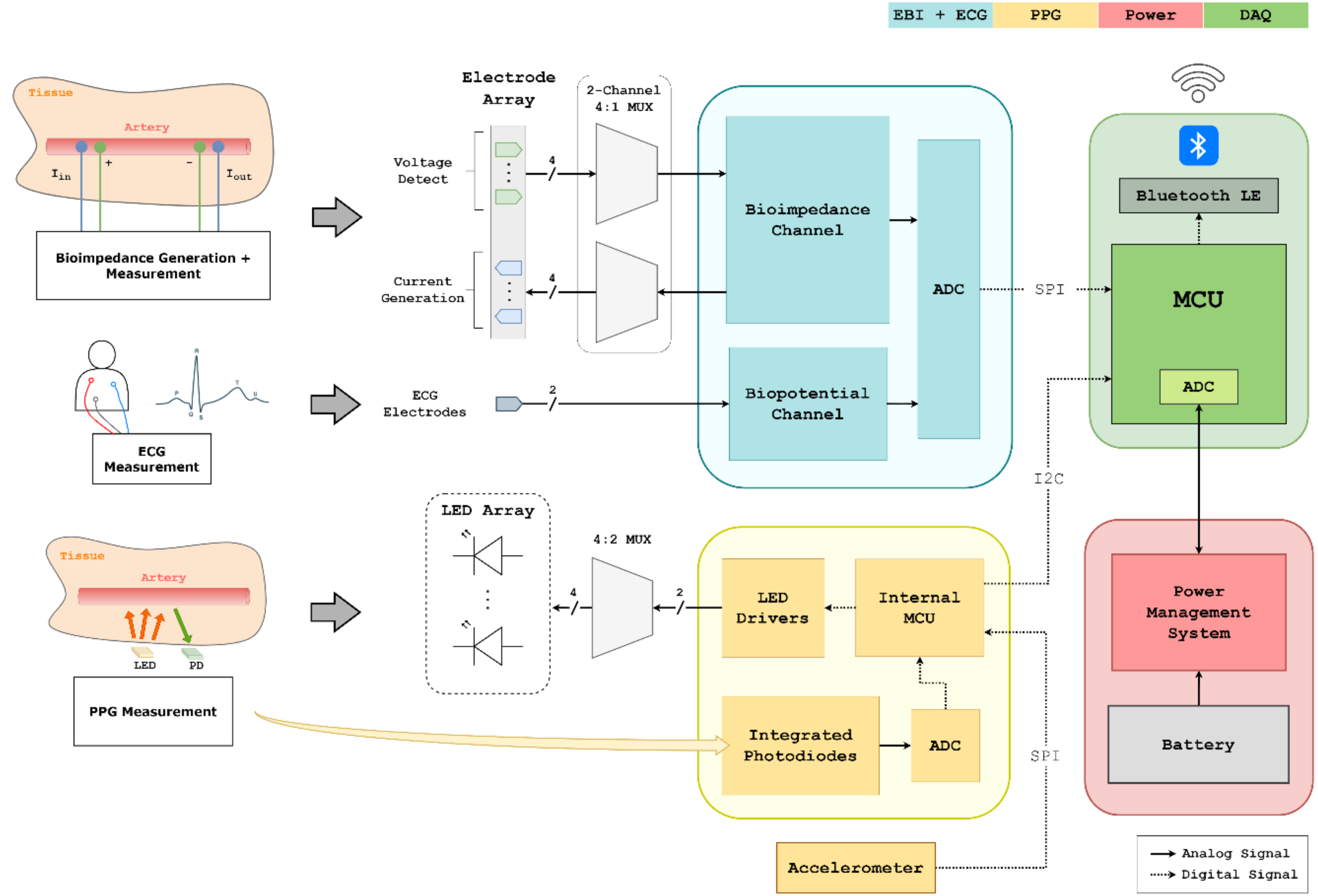

ECG & EBI Front End

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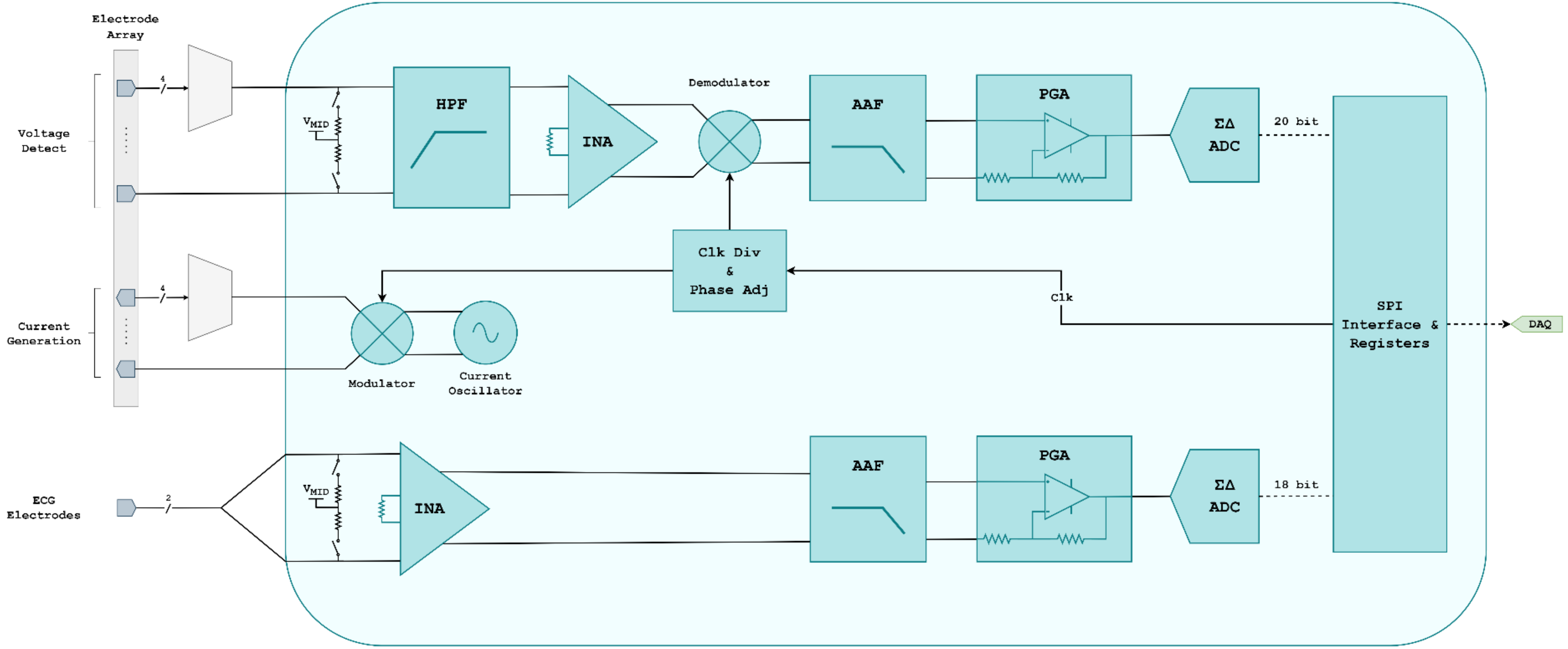
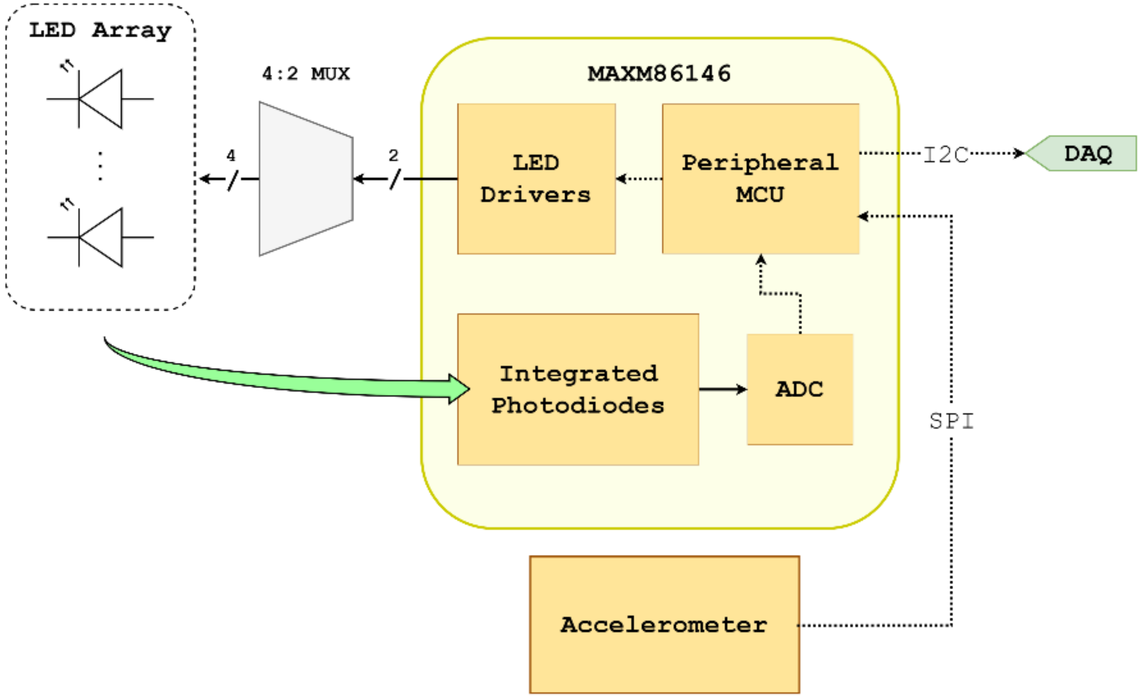


PPG Front End

- Built around the MAXM86146 Optical Biosensing module
- Pulse heart rate and SpO_2 modes
  - Multiwavelength LED array
- Integrated motion & ambient light compensation
- Peripheral 3-axis accelerometer



Data Acquisition Unit (DAQ)

- nRF52840 microcontroller (MCU) SoC
  - Bluetooth (BLE) capable
  - Extensive development resources
    - Arduino library compatible
    - Wearable & IoT heritage

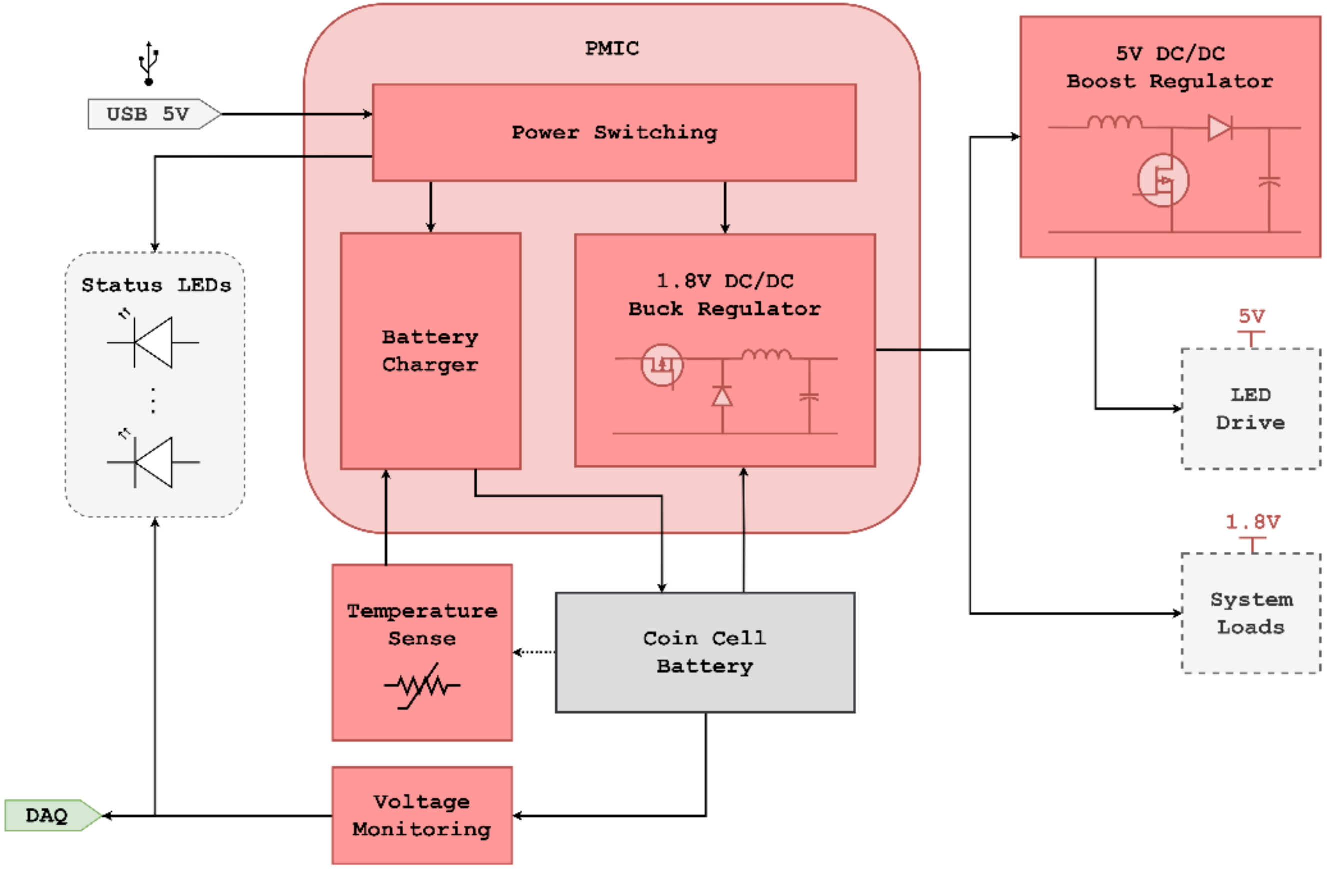
- Processes input from front ends
  - Feature extraction

- Performs battery monitoring

Power Management System

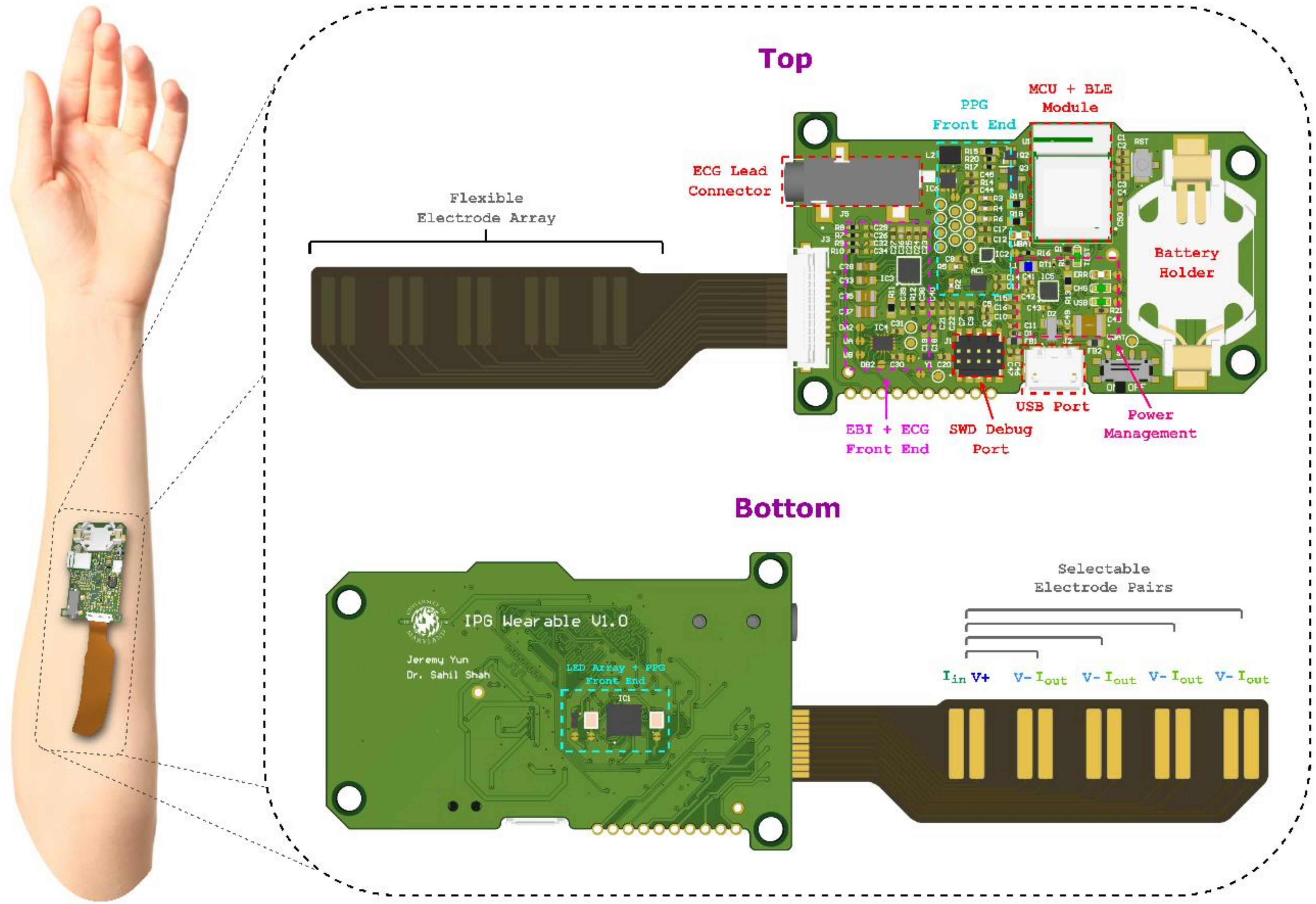
- Battery either:
  - CR2032 coin cell battery
  - LIR2032 rechargeable coin cell

- Monitoring requires only a few seconds of measurement every few hours
  - 2 min/day
    - CR2032 last over 2.5 months*
    - LIR2032 need recharge every 2 weeks*



*Calculated from datasheets

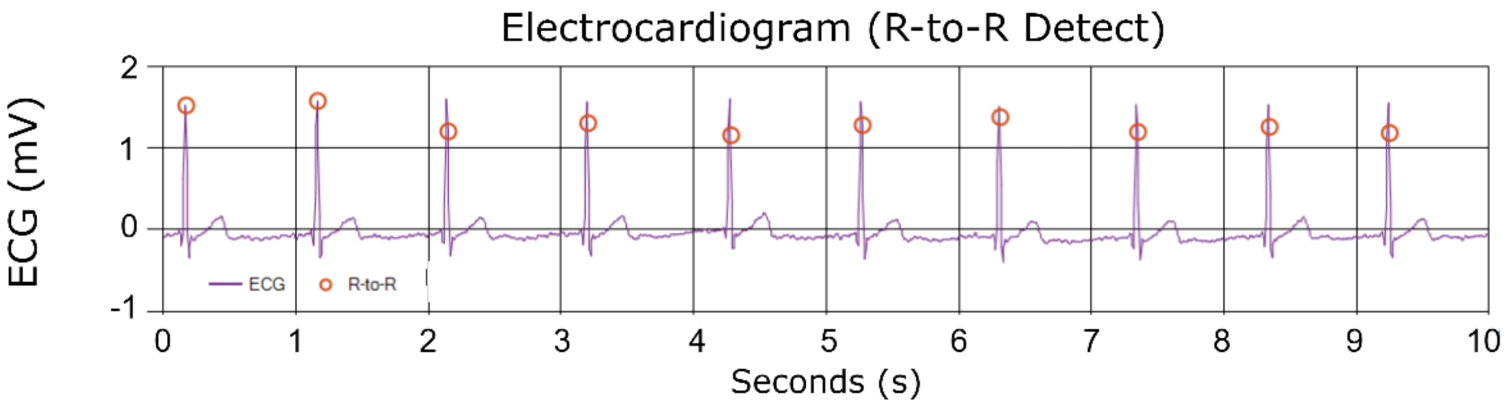
Device Physical Model

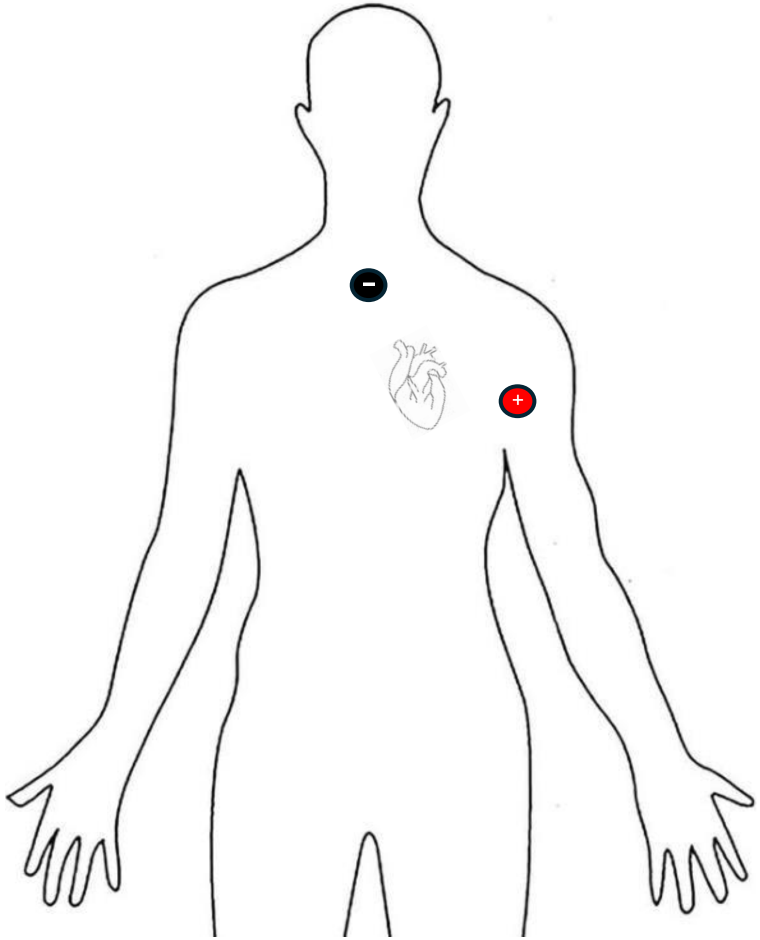


*electrode array may be customized to other shapes

Results

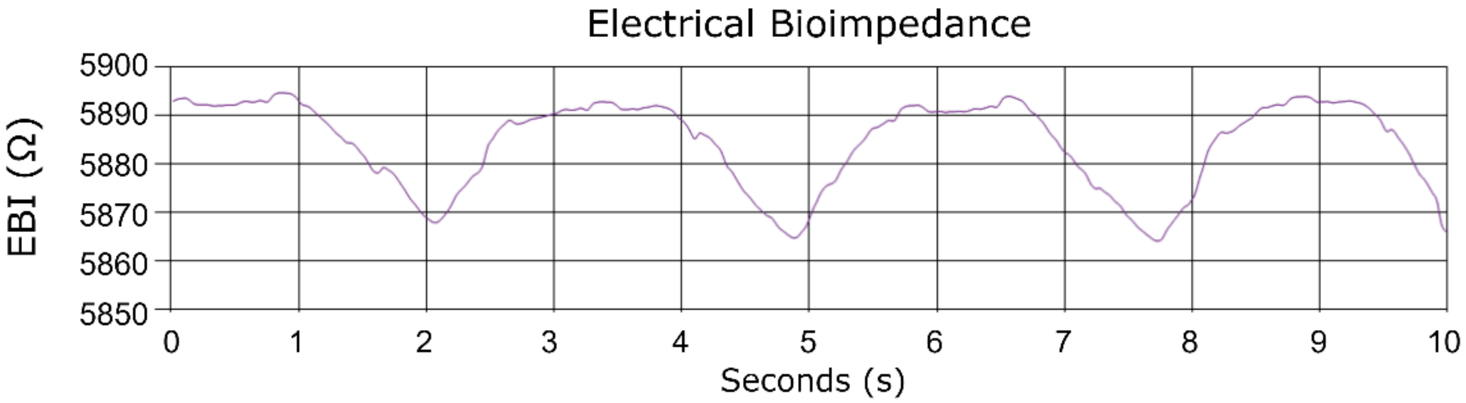
- ECG signal from the analog front end
  - Real time R-to-R detection
  - Onboard signal filtering & noise removal

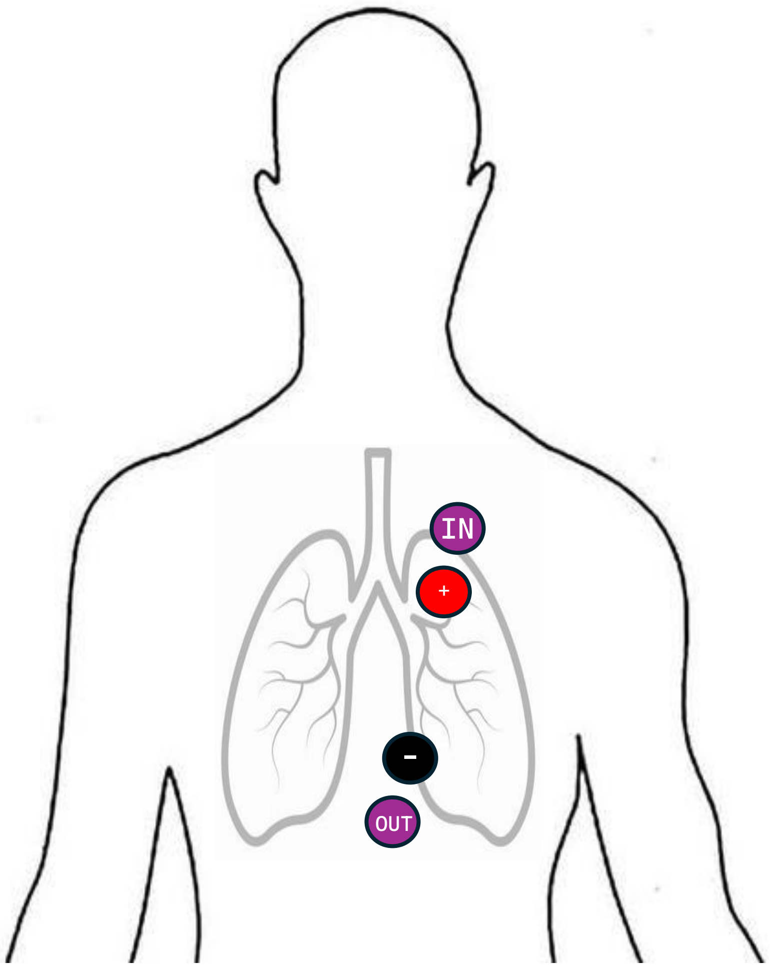




Results

- EBI signal from the analog front end
  - Electrodes placed across thoracic cavity during respiration
  - Current injection configured to 8μA amplitude at 16kHz
    - Within IEC-60601 standard





Comparison Table

	[1]	[2]	[3]	[4]	Proposed Device
Sensor Type	ECG, EBI, PPG	EBI	ECG, EBI	ECG, EBI, PPG	ECG, EBI, PPG
EBI Resolution [mΩ]	200	100	N/A	66	40
Size [mm^2]	130 x 70 x 20	Nonintegrated	50 x 90 x 15	29 x 90 x 20	60 x 39 x 15
Current Draw [mA]	23.6	50	440	25	0.221*
Open-Source HW?	No	No	No	No	Yes

***Not including LED drive (will depend on application)**

[1] G. Squillace et al., "Bio-impedance System for Wearable Vital Sign Monitoring", 16th International Conference on Electrical Bio-Impedance (ICEBI), pp. 60, 2016.

[2] S. Hersek et al., “A Robust System for Longitudinal Knee Joint Edema and Blood Flow Assessment Based on Vector Bioimpedance Measurements,” IEEE Transactions on Biomedical Circuits and Systems, vol. 10, no. 3, pp. 545–555, Jun. 2016, IEEE Transactions on Biomedical Circuits and Systems

[3] J. Ferreira et al., "Portable bioimpedance monitor evaluation for continuous impedance measurements. Towards wearable Plethysmography Applications", Proceeding of the 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, pp. 559-562, 2013.

[4] S. Lee, B. Grundlehner, R. G. van der Westen, S. Polito and C. Van Hoof, "Nightingale V2: Low-power Compact-sized Multi-Sensor Platform for Wearable Health Monitoring," 2019 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Berlin, Germany, 2019, pp. 1290-1293, doi: 10.1109/EMBC.2019.8856847.

Conclusions & Future Work

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- **Proof-of-concept signal acquisition demonstrated**
- **Configurable open-HW platform can aid in rapid algorithm development**

- **Future steps:**
  - **More channels (e.g. ultrasound)**
  - **Use as a platform to target specific conditions**

Thank You!

Questions?

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