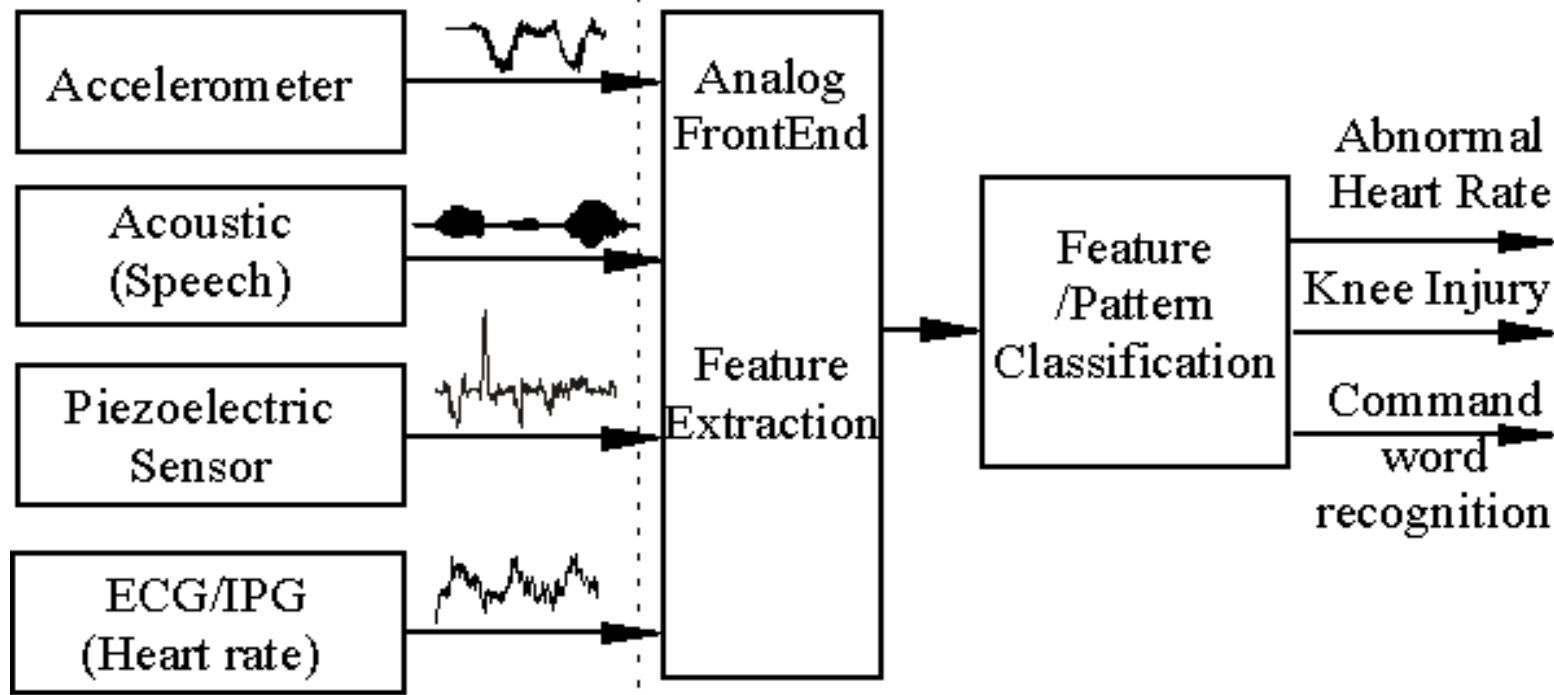
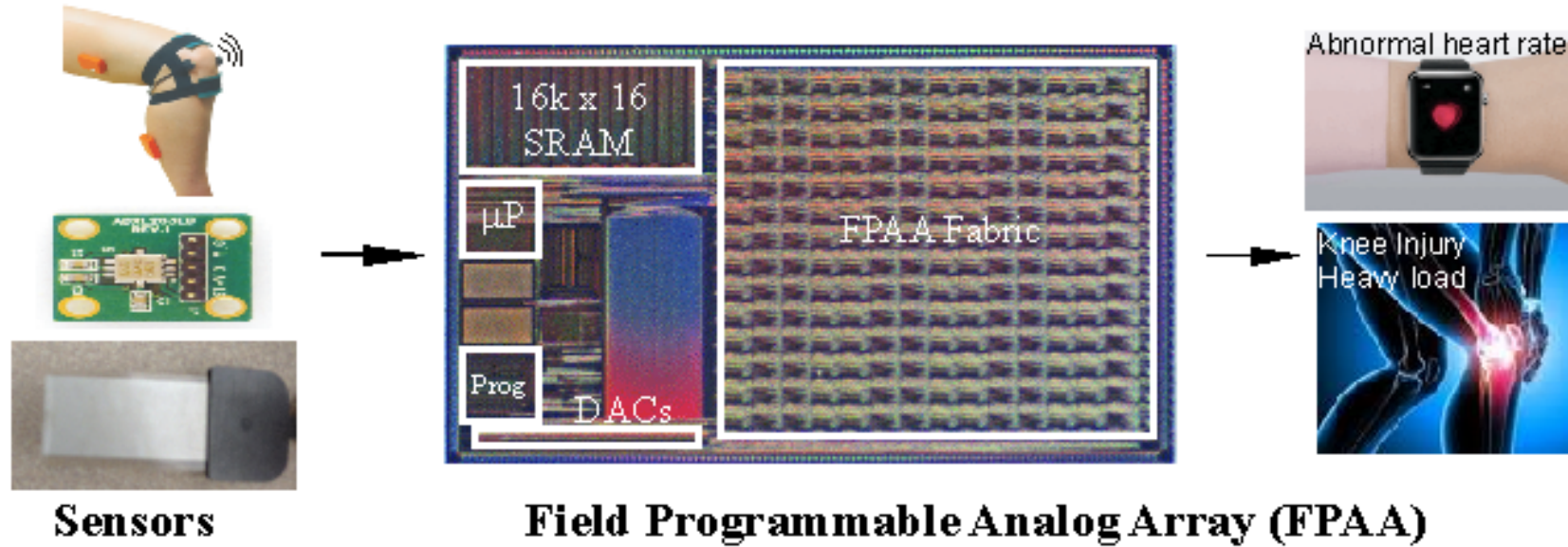




# Proof-of-Concept Energy-Efficient and Real-Time Hemodynamic Feature Extraction from Bioimpedance Signals using a Mixed-Signal Field Programmable Analog Array

Hakan Töreyn, *Member, IEEE*, **Sahil Shah**, *Student Member, IEEE*,  
Sinan Hersek, Omer T. Inan, *Senior Member, IEEE*, and Jennifer Hasler,  
*Senior Member, IEEE*

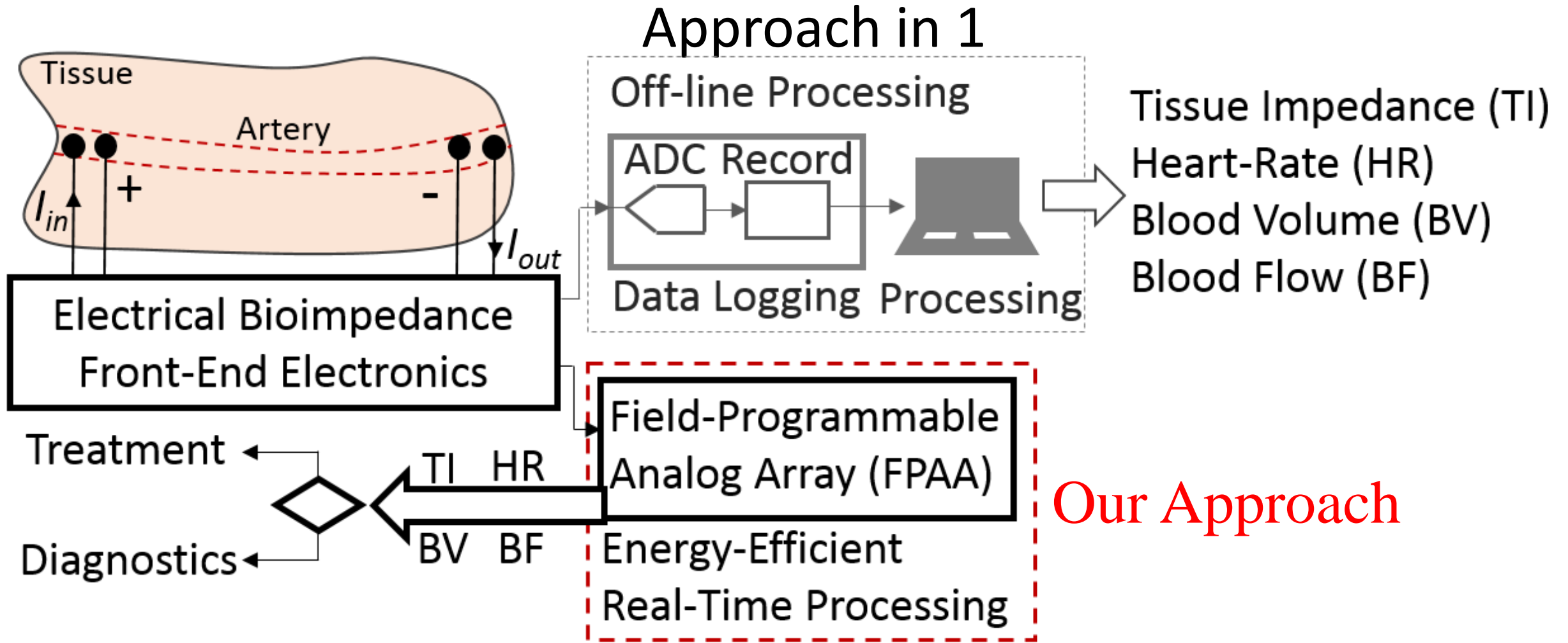
# Continuous monitoring of vital signs using wearable devices



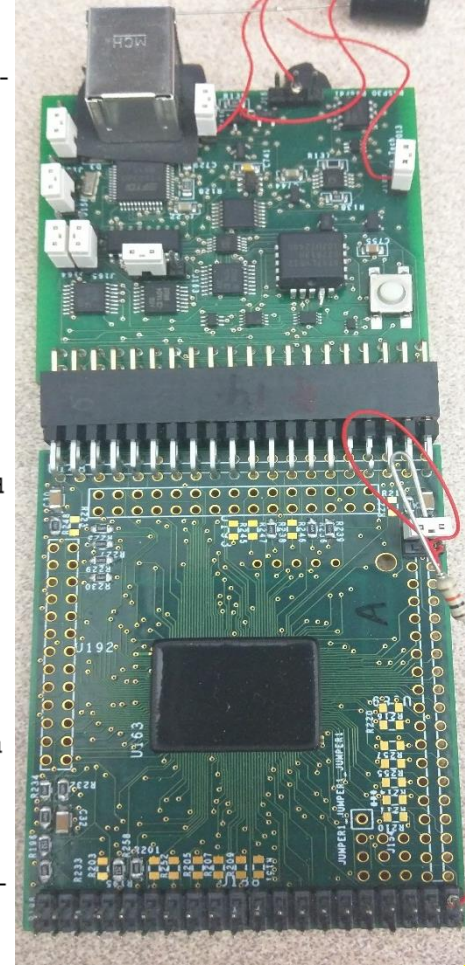
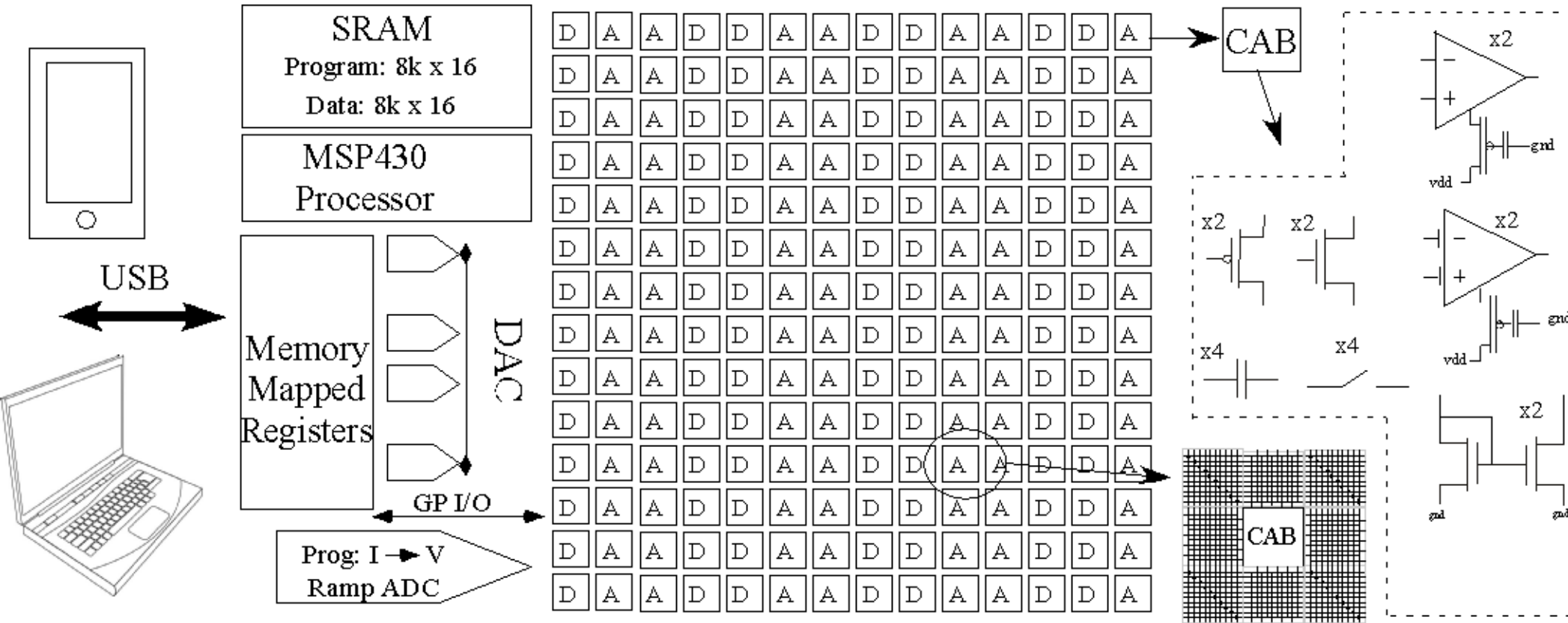
## Challenges

- Power Consumption
- Accuracy
- Sensor variability

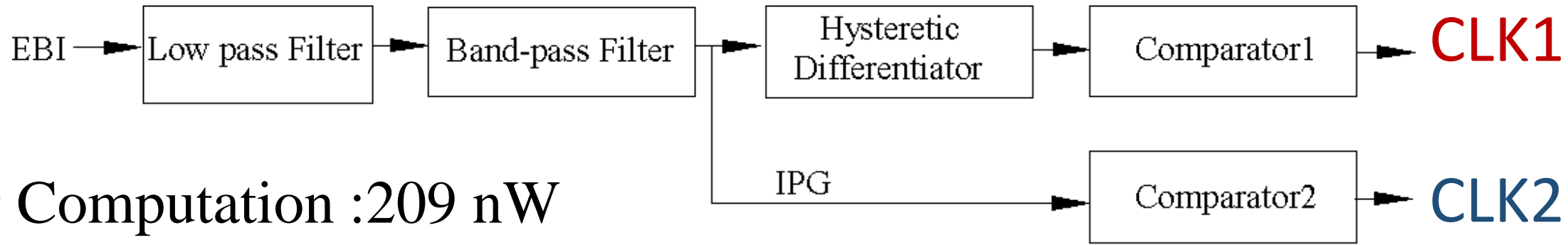
# Recording Electrical BioImpedance (EBI)



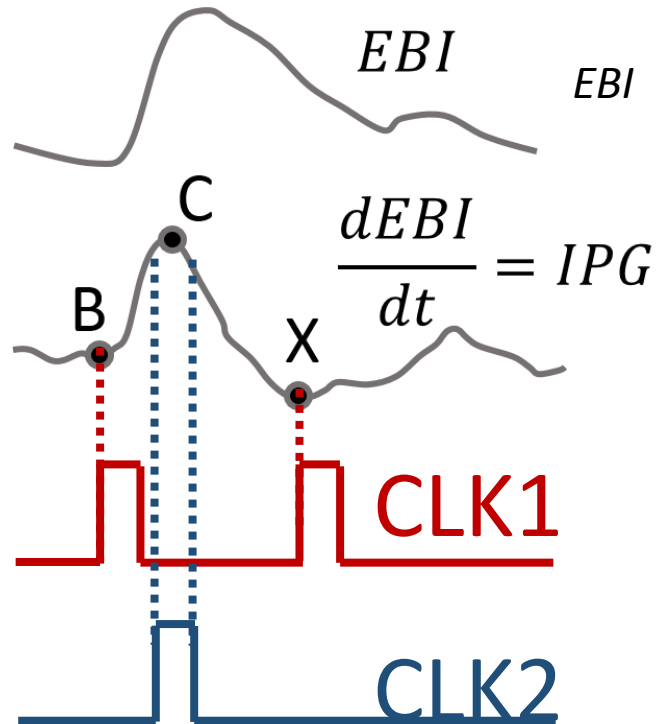
# Field Programmable Analog Array (FPAA)



# Extracting Physiologically-Relevant Features **in Hardware**



Analog Computation :209 nW



Pulsatile Calibration Blood Volume  
Blood Constant Variable (BVV)

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

Events to  
 $\mu P$

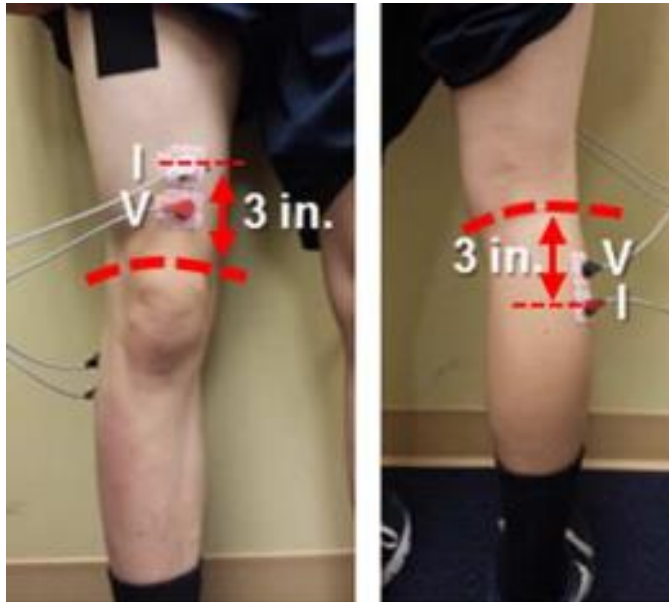
$$BFV = BVV \cdot HR$$

Blood Flow  
Variable

Heart  
Rate

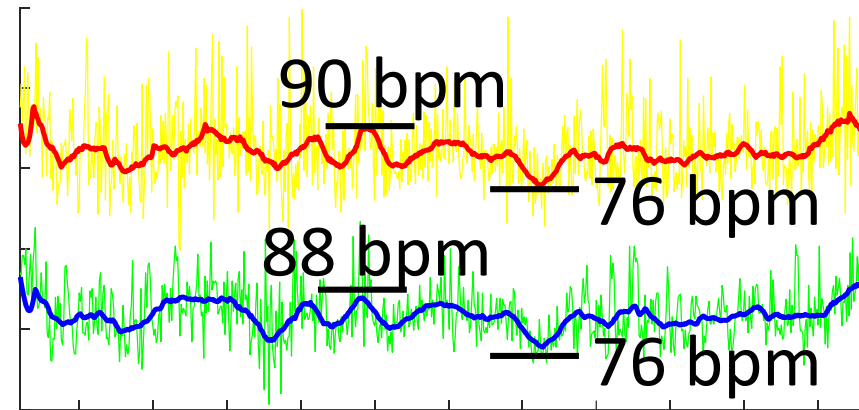


# Measurement Results from a Healthy Subject



Quadripolar Electrode  
Placement

**Heart Rate**

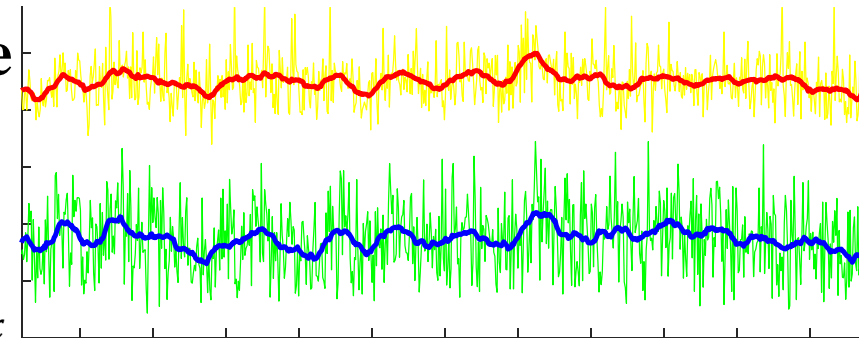


MATLAB

Analog Processor

**Blood Volume  
Variable**

$$\Delta t_{BX} \left( \frac{dIPG}{dt} \right)_{max}$$

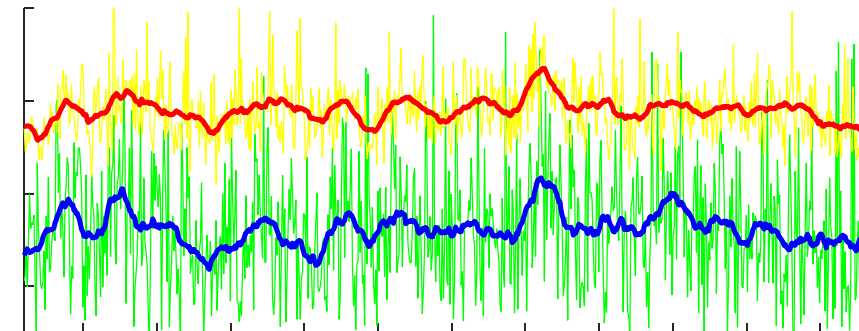


MATLAB

Analog Processor

**Blood Flow  
Variable**

$$BVV \cdot HR$$



MATLAB

Analog Processor

← ~10 min. →



# Next Set of Questions

- Variability among patients.?



- Can re-configurability help with it.?



- Usability outside lab as a wearable device.?



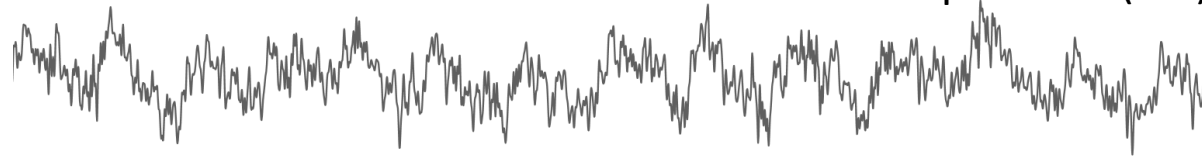


Thanks

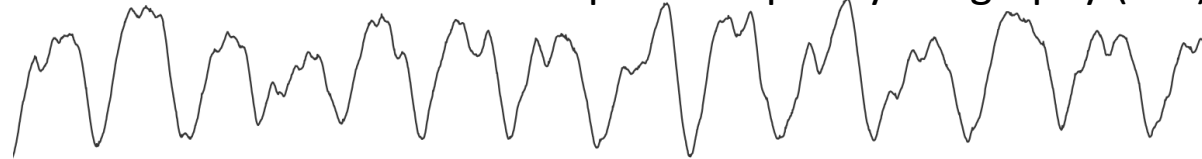




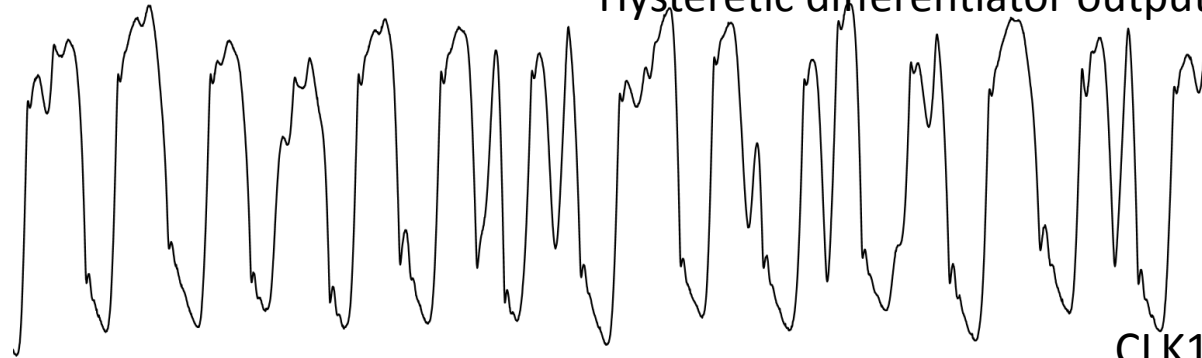
Electrical Bioimpedance (EBI)



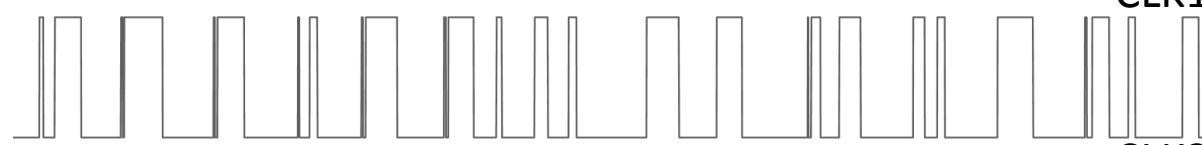
Impedance plethysmography (IPG)



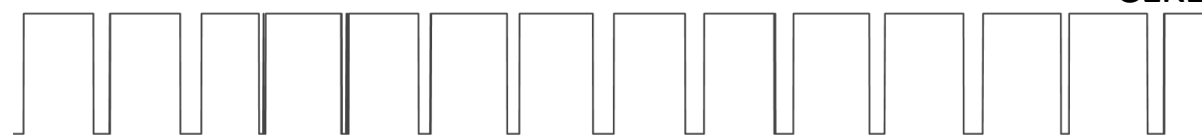
Hysteretic differentiator output

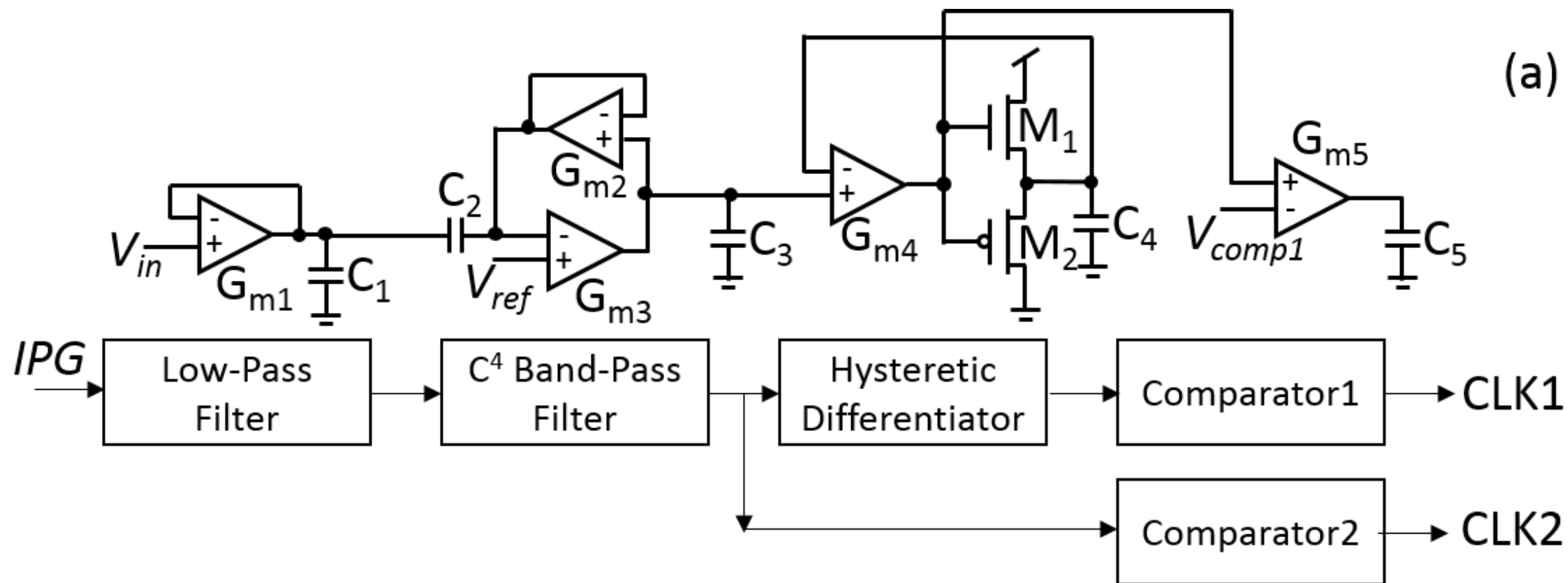


CLK1

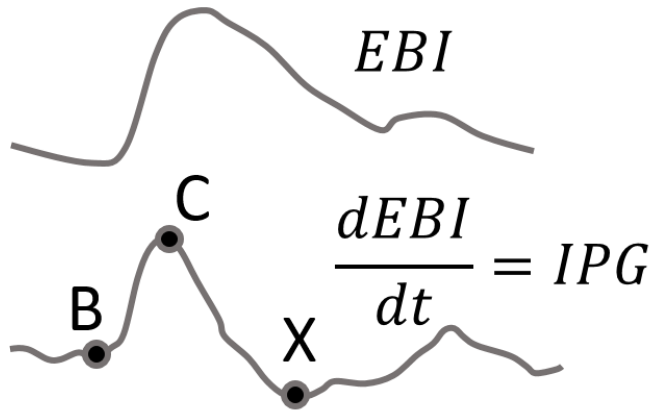


CLK2





# IPG Critical Features for Hemodynamic Parameters



Pulsatile Blood Volume      Calibration Constant      Blood Volume Variable (BVV)

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

$$BFV = BVV \cdot HR$$

Blood Flow  
Variable

Heart  
Rate

For Blood Volume Variable:

- Time duration between **B** and **X** features
- Magnitude difference of **B** and **C** features

For Heart Rate:

- Time duration between **C** features of consecutive heart beats