Bio-Impedance Spectroscopy (BIS) Measurement System for Wearable Devices

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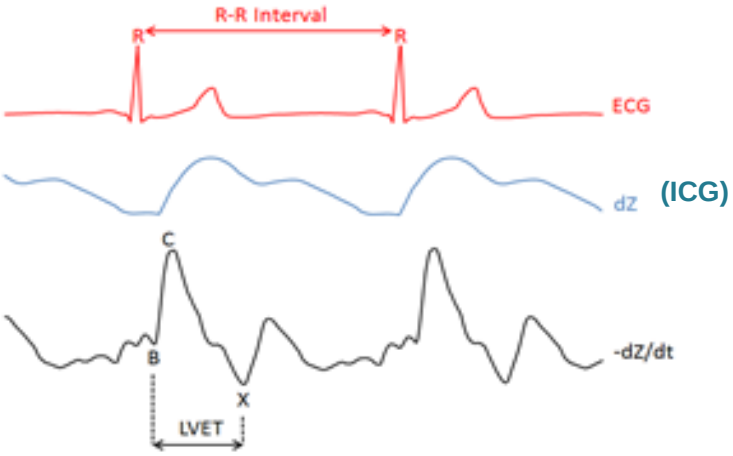
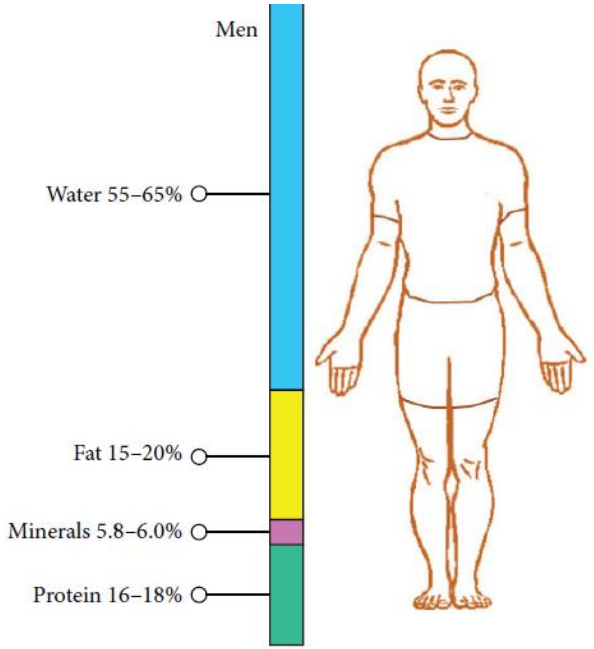
Outline

- Motivation
- Objective
- Background
- Specific Aims and Novelty
- System Description
- Performance Evaluation
- Experimental Results
- Conclusions

Motivation

- Examples on Bio-Impedance Applications
  - Cardiovascular diseases diagnosis
    - Using Impedance Cardiogram (ICG)
  - Body Cell Mass (BCM) Composition
    - Dehydration detection
    - Calories consumption



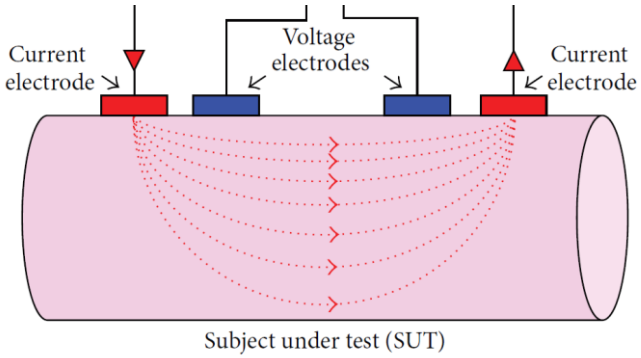


- Advantages
  - Low power
  - Low cost
  - Small size
  - Suitable for wearable devices

Objective

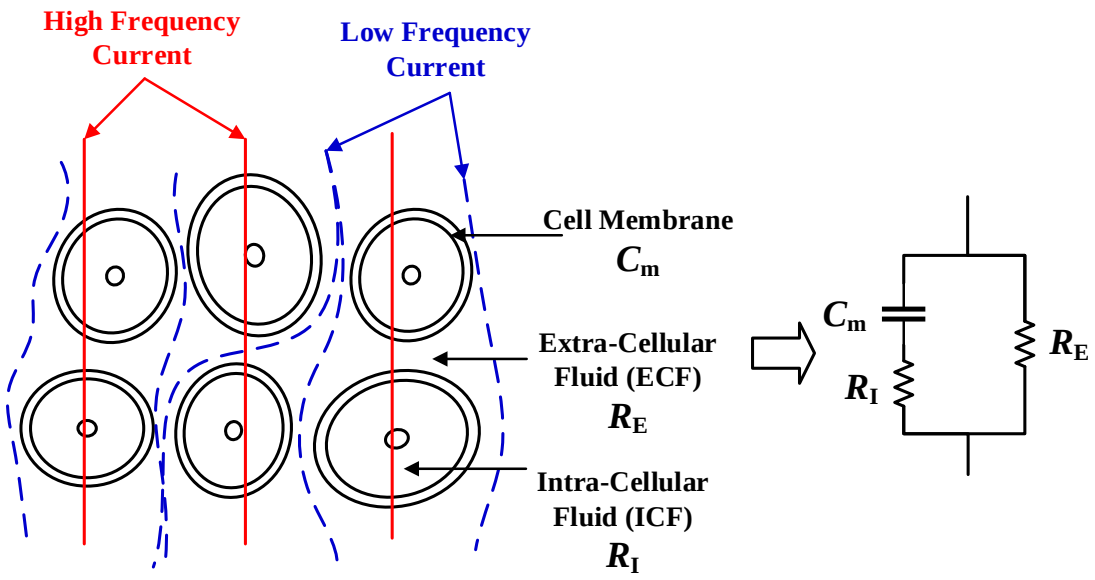
Conventional Method		Proposed Method
Whole body - Bulky Devices		Body Segment - Wearable Device
	→	
Bio-Impedance Analysis (BIA) Single fixed frequency	→	Bio-Impedance Spectroscopy (BIS) Multiple frequencies → More Accurate
Single Time Measurement	→	Continuous Monitoring

Background



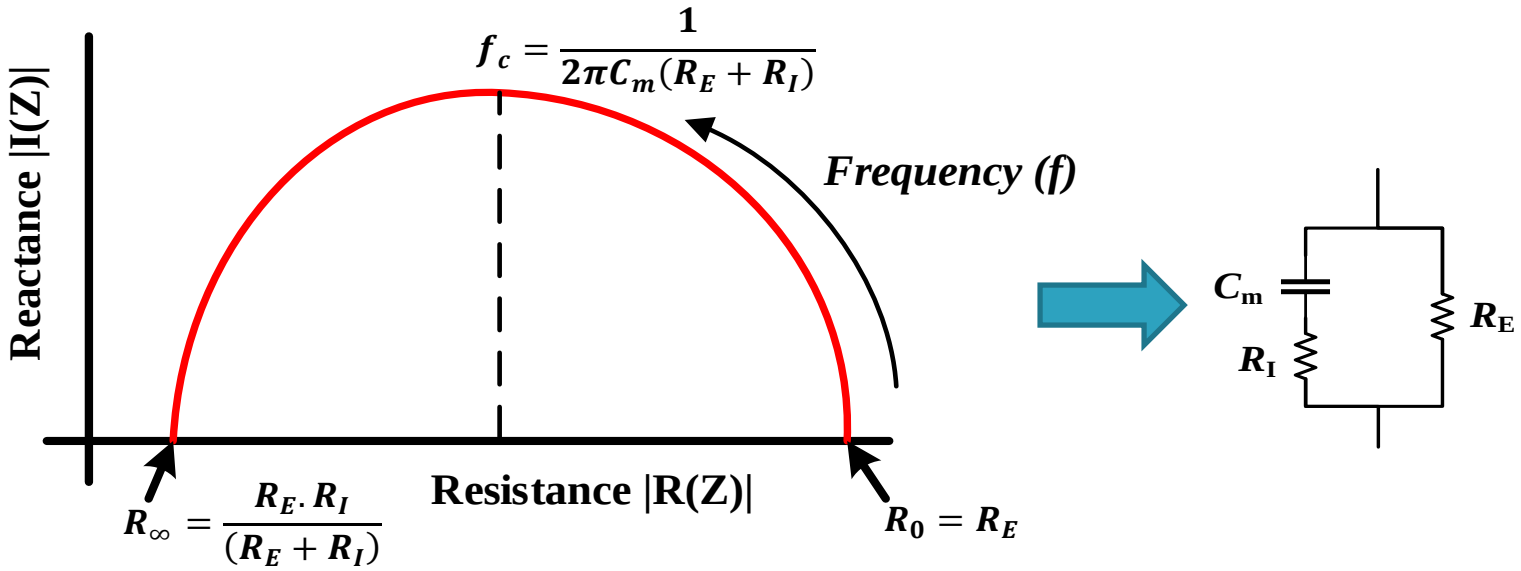
- Bio-impedance = resistance of tissue to an applied external current
- Measure fluids inside the body
- Measured by
  - Injecting AC current from the current electrodes
  - Voltage sensed between voltage electrodes is proportional to bio-impedance

Bio-Impedance



- Bio-Impedance is modeled as R_I, R_E and C_m
- Low frequency → ECF current (R_E)
- High frequency → ECF and ICF current ($R_I \| R_E$)

Bio-Impedance Spectroscopy (BIS)

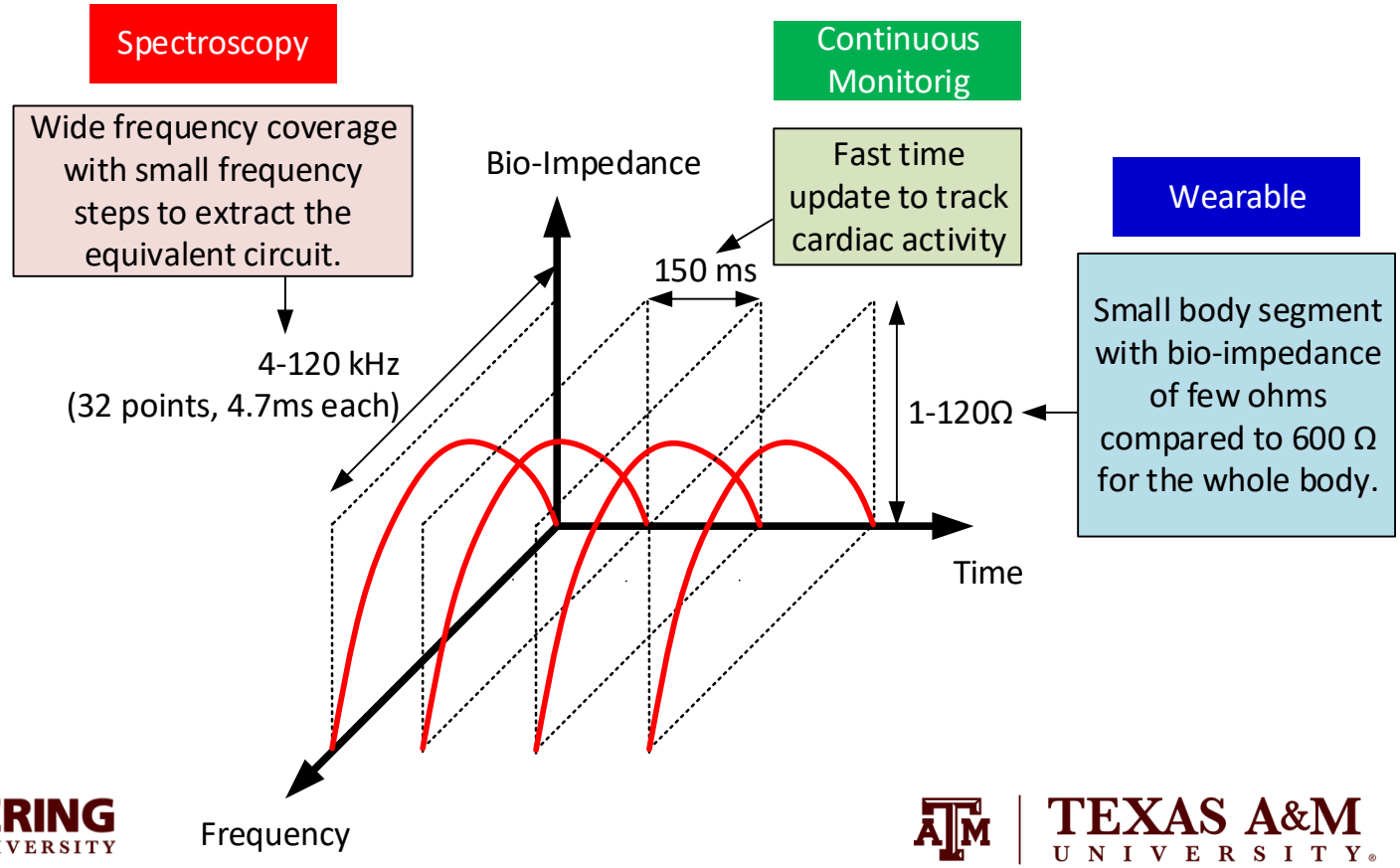


- Bio-Impedance Spectroscopy (BIS) = Bio-Impedance response with frequency

→ Accurate estimation of (R_I, R_E and C_m)

Specific Aims

- Develop Bio-Impedance Spectroscopy (BIS) device with
  - continuous-time update (every 125 ms)
  - wide frequency (4-120 kHz) to enable extraction of bio-impedance equivalent circuit
  - from small body segment → wearable applications

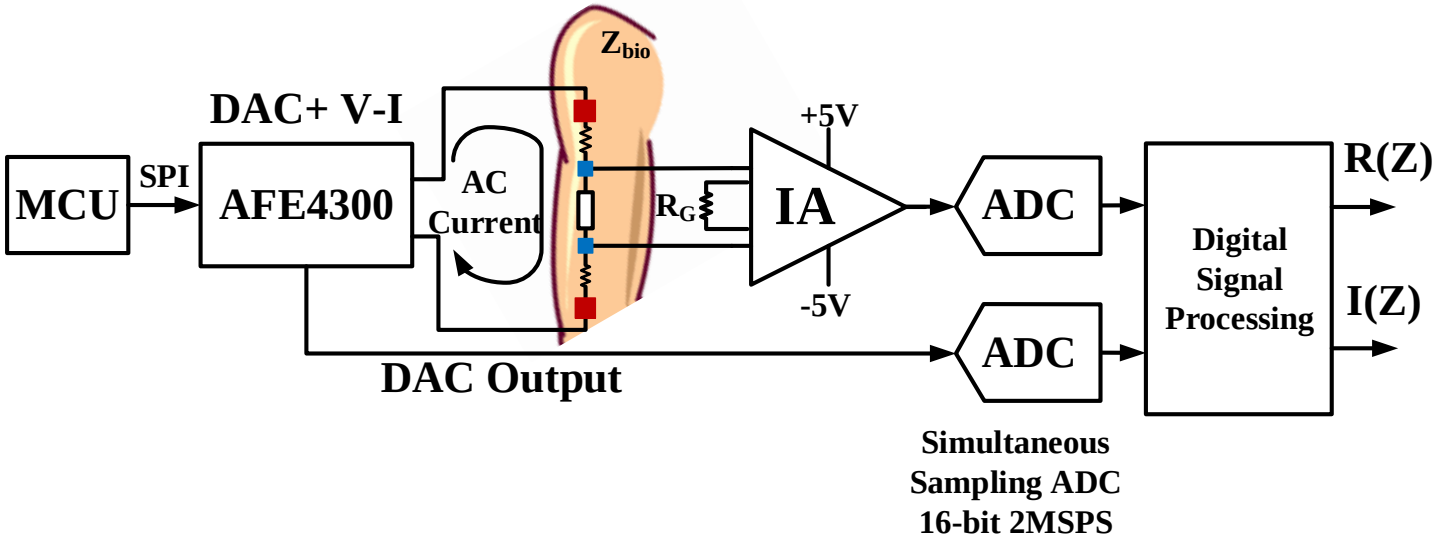


Novelty

- A BIS system for measurements from small body segments is presented for the first time, which can be integrated into a wearable device.
  - The detailed design and implementation of the circuits and signal processing are discussed
  - Measuring very small variations of bio-impedance across wide frequency range in a short time.

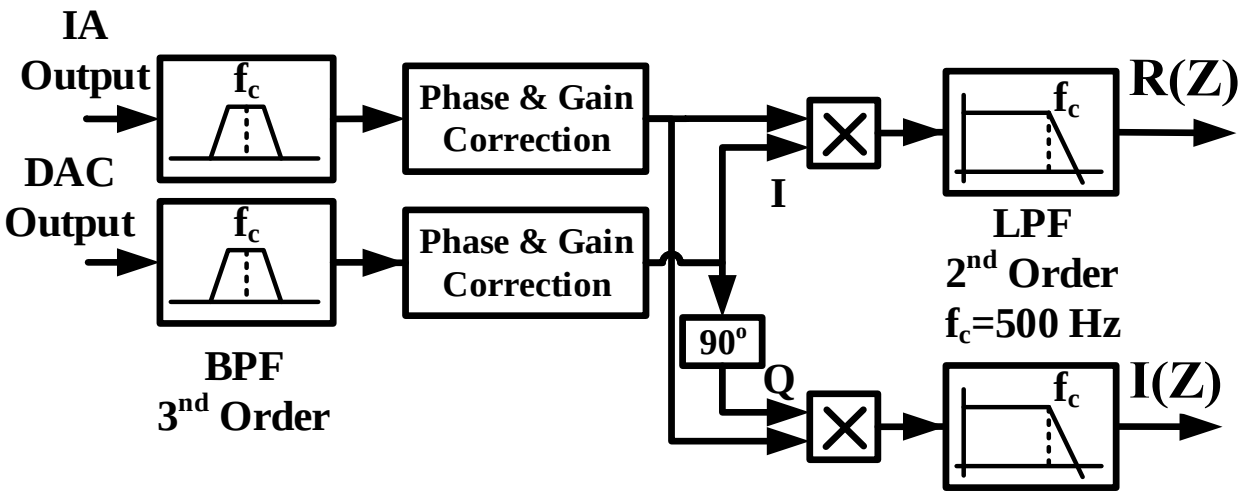
- Experimental measurements of upper arm BIS with 4 cm distance between electrodes to accurately capture physiological signals such as:
  - Heart rate, respiration rate, and muscle contractions.

System Description



- Frequency sweeping from 4 to 120 kHz controlled by MCU
- Based on discrete components
- Sensed voltage and DAC output sampled simultaneously using 16-bit ADC @ 2MSPS .
- AC current amplitude = 375μA_{RMS}
  - Compliant with safety limits

Digital Signal Processing



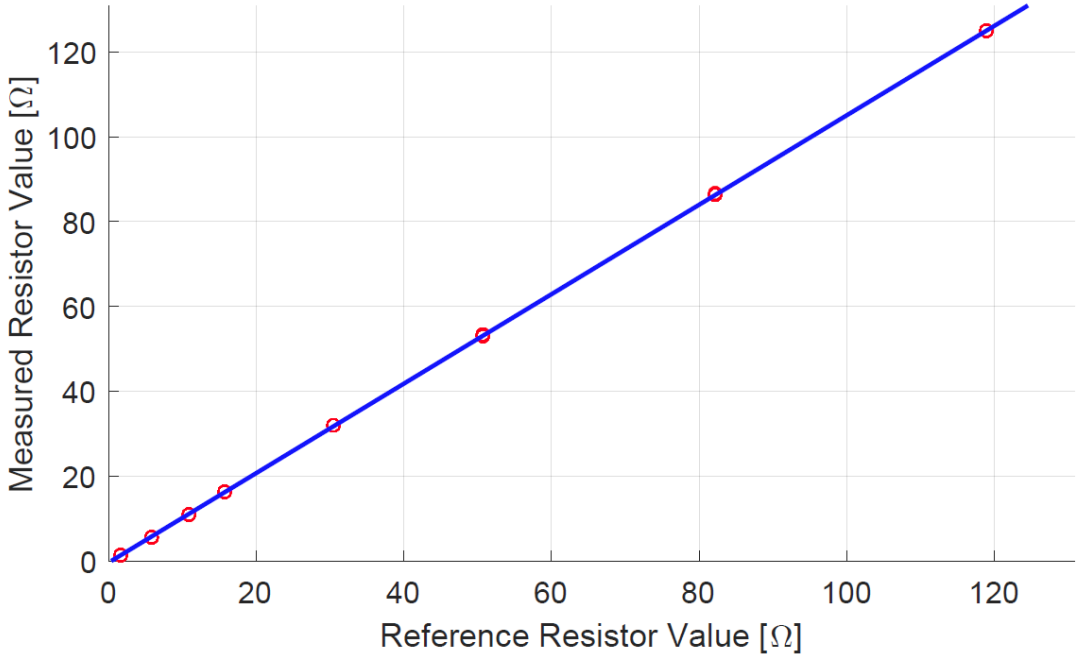
- Band pass filters to remove DC, 60 Hz interference and high frequency noise.
- Digital quadrature demodulation to get the real and imaginary parts of impedance
- Phase and gain correction were done to compensate for errors.
- Low pass filtering with fc=500Hz to allow for fast output every 4.7 ms

Phase and Gain Correction

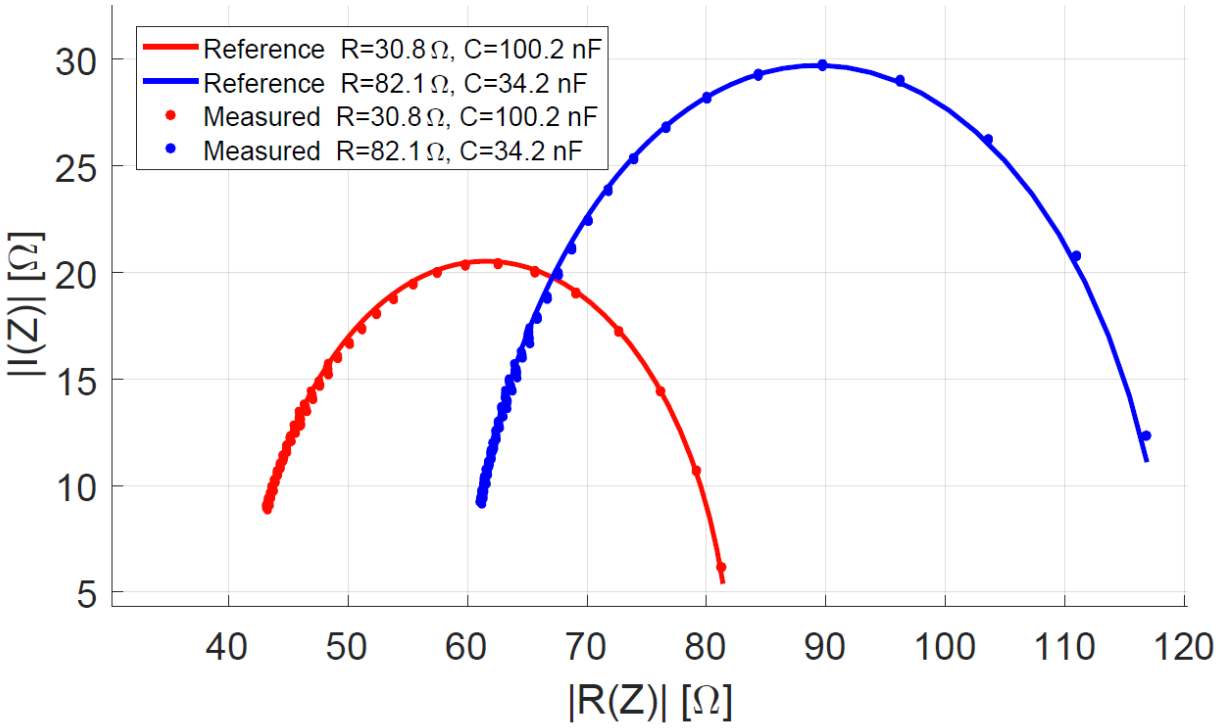
- Impedance measurement sensitive to phase and gain error
- Error is measured by a reference resistor (R_{ref}) for all frequency points
- Phase error: $\emptyset_{\mathrm{err}}(f) = tan^{-1}\frac{I(Z)}{R(Z)}$
- Gain error: $G_{\mathrm{err}}(f) = \frac{1}{R_{\mathrm{ref}}}\sqrt{R(Z)^2 + I(Z)^2}$
- Phase was corrected before demodulation by fractional time delay using an all-pass digital filter with a variable phase shift.

System Evaluation

- Linearity was tested using reference resistors from 1 to 120 Ω
- Resistance RMSE = 0.07 Ω



System Evaluation



- Impedance was measured for reference resistors and capacitors similar to bio-impedance (R=30.8 Ω, 100.2 nF & 82.1 Ω, 34.2 nF) from 4-120 kHz

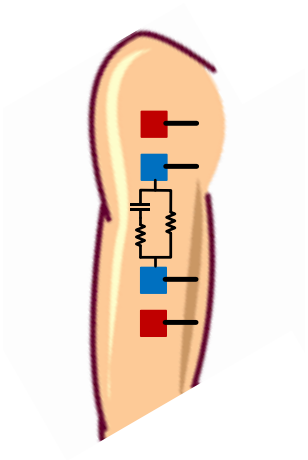
Performance Summary

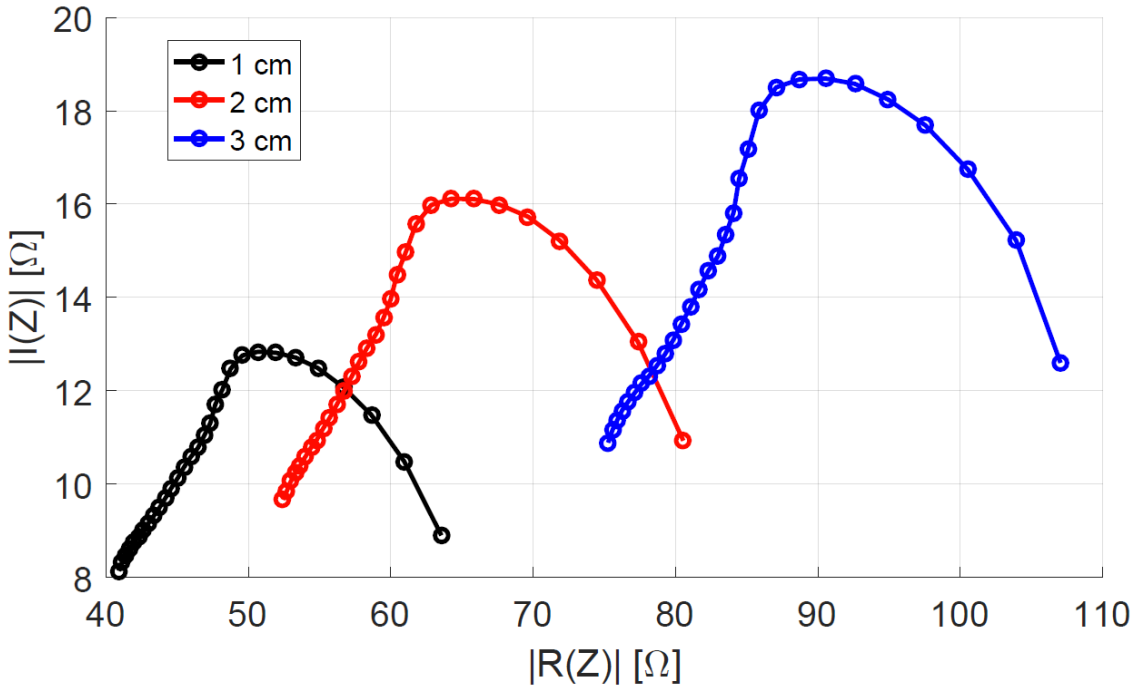
	This work	[1]	[2] AFE4300
Frequency	4 – 120 kHz	1 – 125 kHz	<150kHz
Current	$375\mu A_{RMSE}$	$1\mu – 100\mu A_{pp}$	$375\mu A_{RMSE}$
Impedance Range	1Ω – 120Ω	1Ω – 10kΩ	0 – 2.8kΩ
Resolution	70mΩ	100mΩ	100mΩ
Experimental Results	Yes	No	NA

[1] J. Xu, P. Harpe, J. Pettine, C. Van Hoof and R. F. Yazicioglu, "A low power configurable bio-impedance spectroscopy (BIS) ASIC with simultaneous ECG and respiration recording functionality," *ESSCIRC Conference 2015 - 41st European Solid-State Circuits Conference (ESSCIRC)*, Graz, 2015.

[2] AFE4300, Integrated Analog Front-End for Weight-Scale and Body Composition Measurement , Texas Instruments

Experimental Results

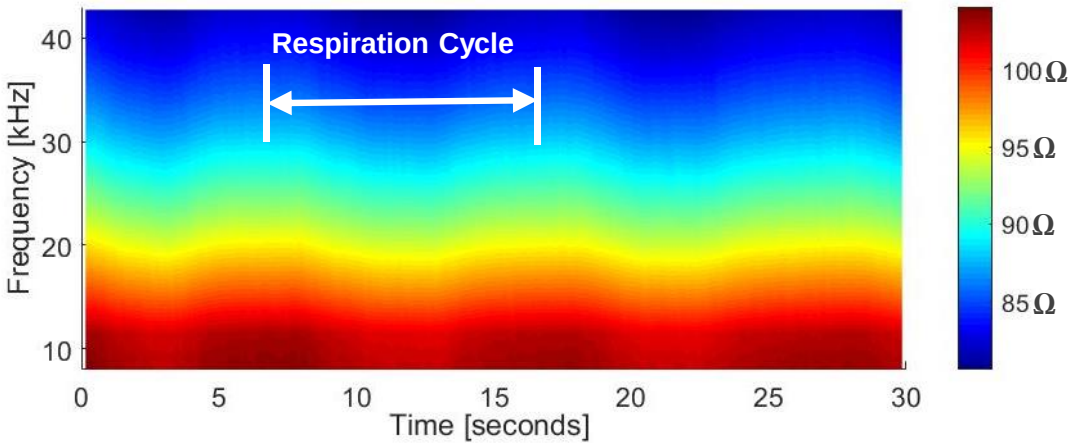




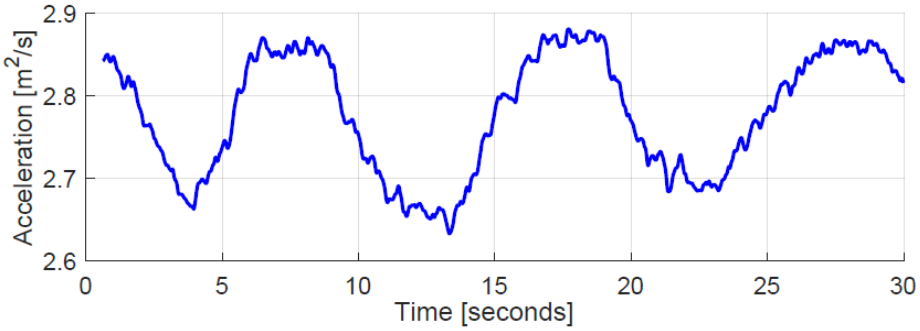
- Actual Bio-Impedance measurements on the upper arm with variable distance between sensing electrodes (1,2 and 3 cm)

Experimental Results

- Respiration Rate
  - Real part of Bio-Impedance (R(Z)) across frequency for 30 seconds
  - Verified by accelerometer placed on the chest



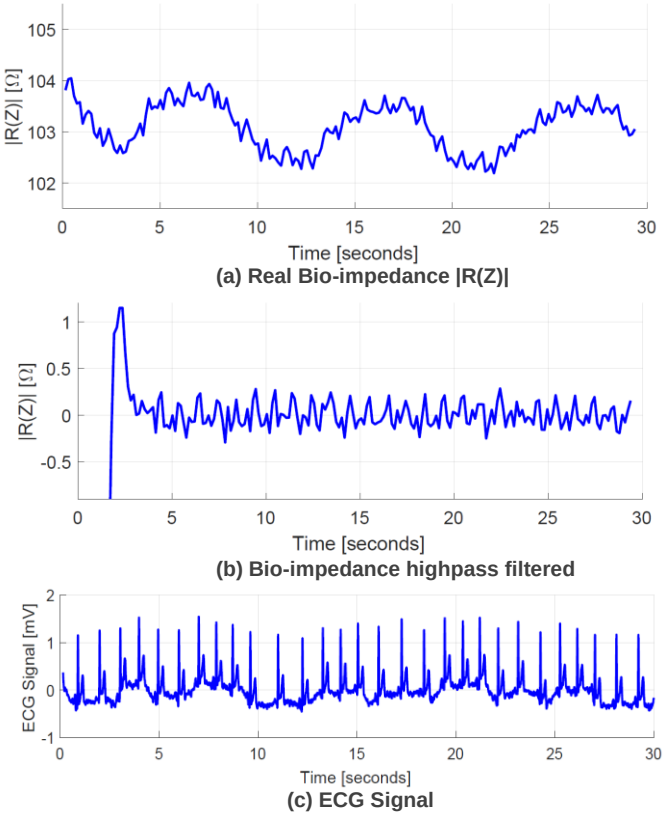
(a) Real Bio-impedance |R(Z)|



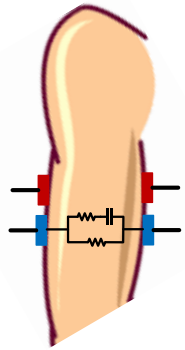
(b) Acceleration

Experimental Results

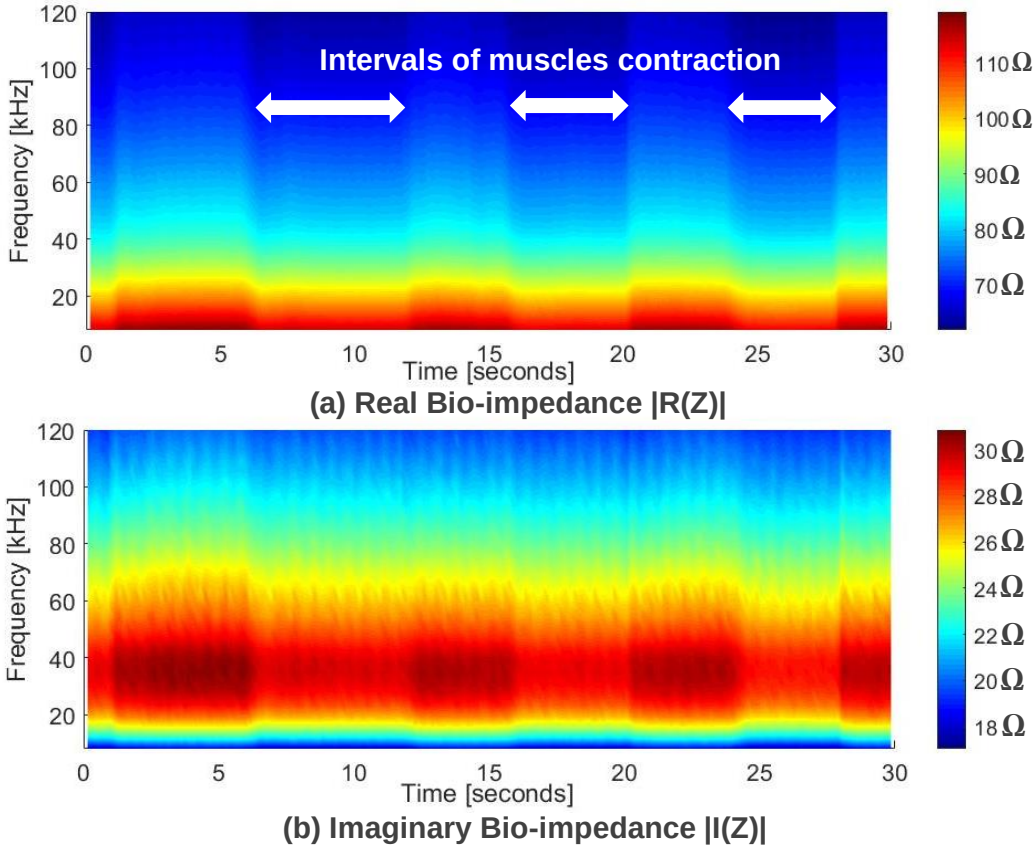
- Heart Rate
  - Real part of Bio-Impedance (R(Z)) shows the heart rate and the respiration rate at fixed frequency (8 kHz)
  - Heart rate extracted by a high pass filter
  - Verified by ECG



Experimental Results



- Muscles Contraction
  - The real and imaginary bio-impedance for 30 seconds



(a) Real Bio-impedance |R(Z)|

(b) Imaginary Bio-impedance |I(Z)|

Conclusions

- Bio-Impedance Spectroscopy was measured from upper arm for the first time
- A measurement system was presented with high accuracy of 0.07Ω for the frequency range from 4-120 kHz and update every 150 ms
- The System was evaluated using reference resistors and capacitors
- Experimental results of BIS from upper arm were presented

Thanks & Questions

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