Blood Impedance Characterization from Pulsatile Measurements

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Introduction

Bioimpedance Measurements have been widely applied because of

- low cost
- easy application
- non-invasiveness
- on-line monitoring
- etc

Introduction

- Bioelectrical impedance analysis (BIA)
- Bioelectrical impedance spectroscopy (BIS)
  - Body fluid measurement

    e.g. ECF, ICF, TBW.

  - Tissue volume change

    e.g. cardiac stroke volume

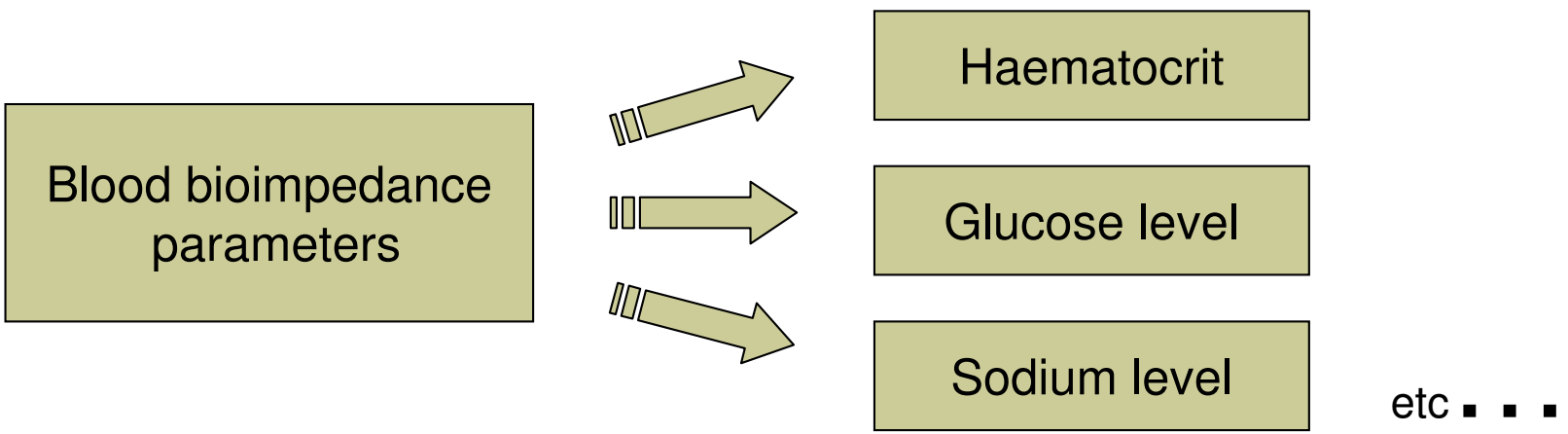
  - Tissue characterization

    e.g. ischemic organ identification.

Introduction

Why do we characterize blood by bioimpedance method ?

-- to find correspondence between clinical indices and blood bioimpedance parameters.

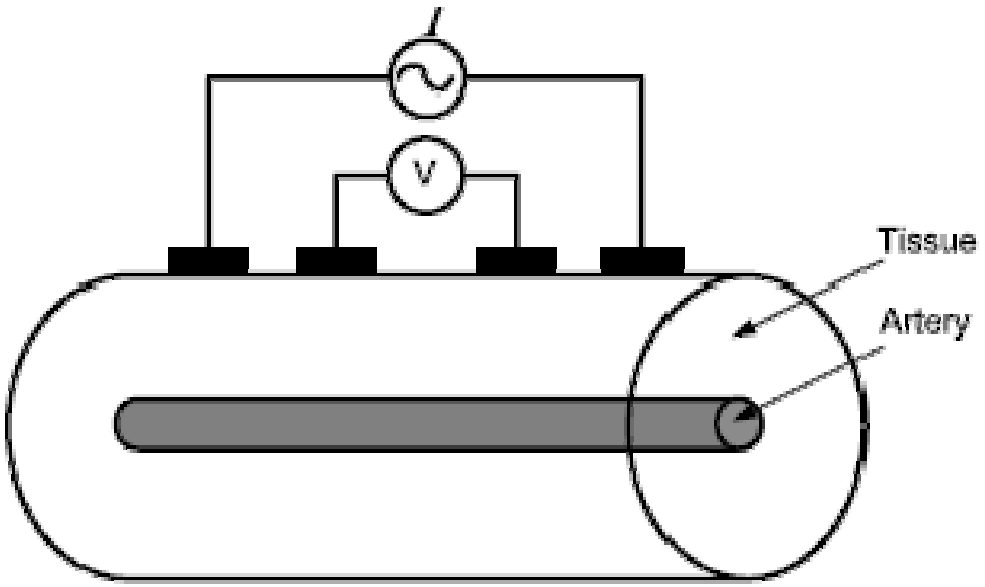


Introduction

Difficulties to measure blood impedance ***in vivo***

- *Physiological noises*
- *Body disturbances*
- *Heterogeneity*

Modeling



A tetrapolar BIS sensor is applied on a finger segment (cylindrical model)

Modeling

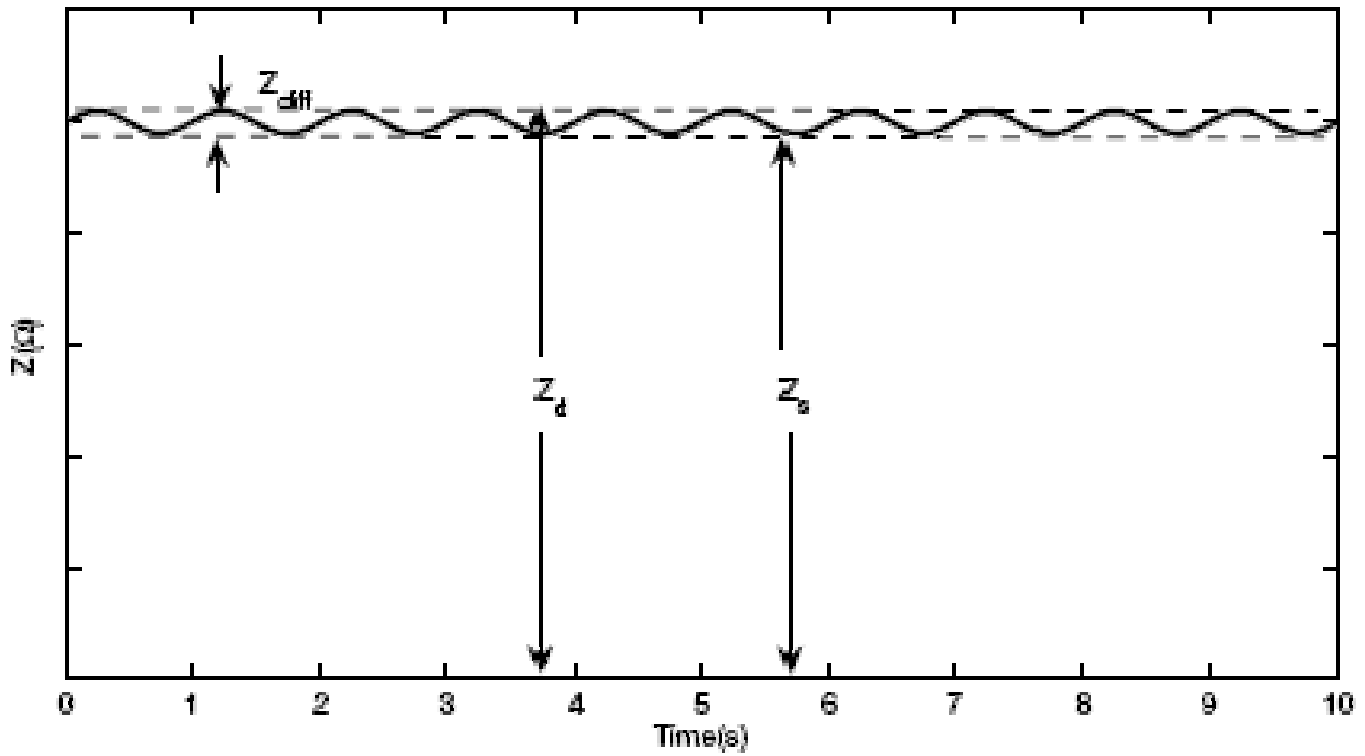
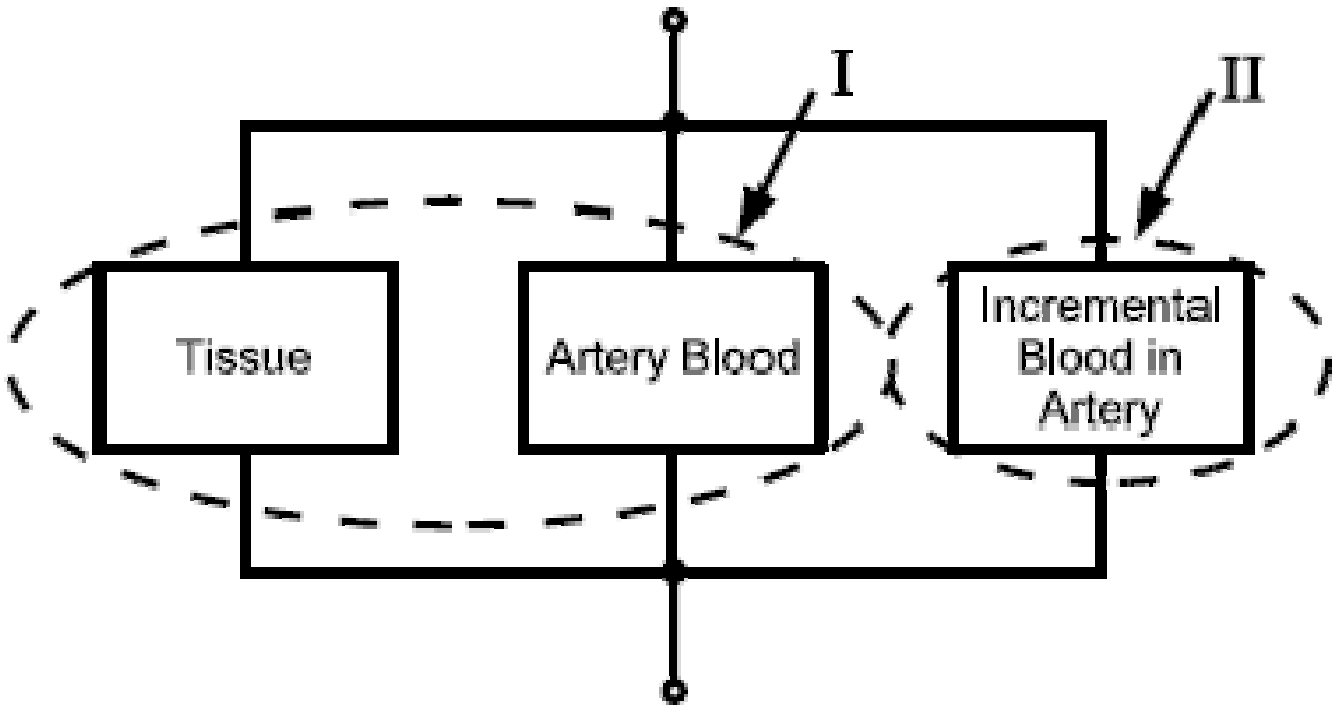


Illustration of the pulsatile impedance wave.
Z_d: impedance corresponding to the heart diastole;
Z_s: impedance corresponding to the heart systole;
Z_{diff}: The difference between Z_d and Z_s

Modeling



The bioimpedance model of pulsatile wave is composed of three parallel impedances.

During diastole, $Z_d = Z_I$

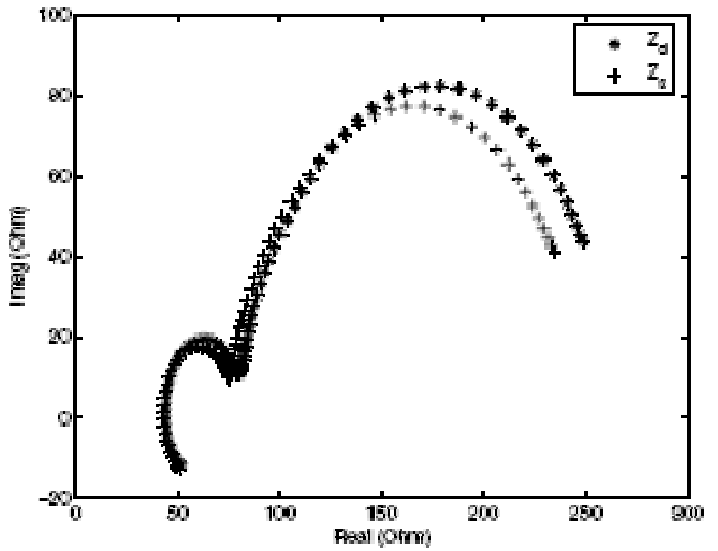
systole, $Z_s = Z_I \parallel Z_{II}$

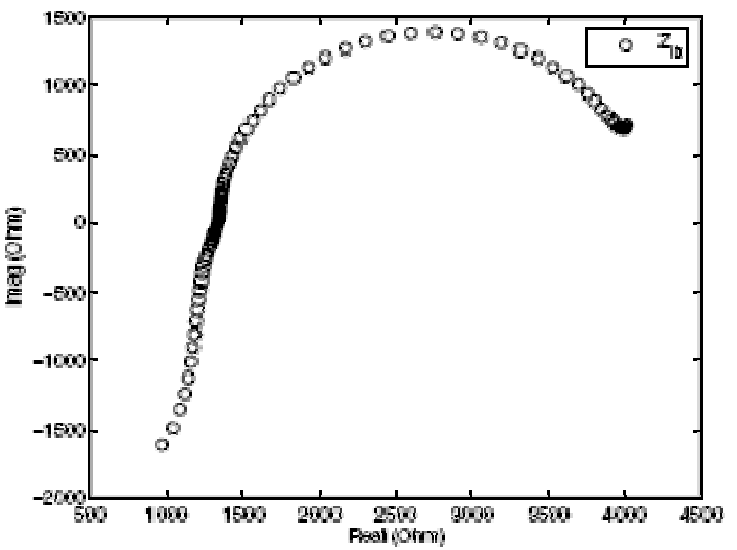
A impedance spectrum from blood

$$Z_d(f) // Z_{ib}(f) = Z_s(f)$$

$$\Downarrow$$

$$Z_{ib}(f) = \frac{Z_d(f) Z_s(f)}{Z_d(f) - Z_s(f)}$$





Cole-Cole Model

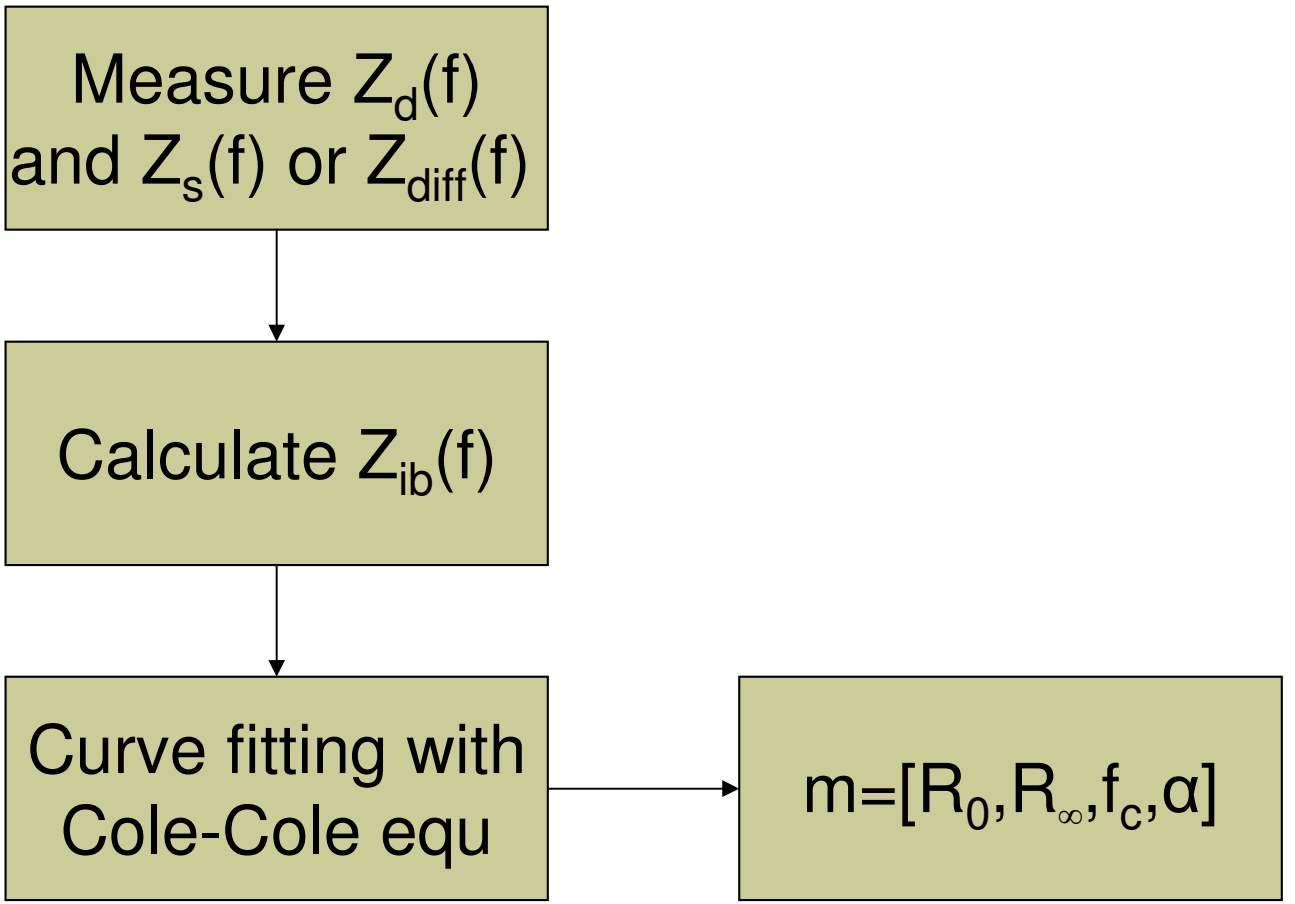
Cole-Cole equation

$$Z(f) = R_{\infty} + \frac{R_0 - R_{\infty}}{1 + j(f / f_c)^{1-\alpha}}$$

Cole-Cole parameters

$$m = \left[R_0 \; R_{\infty} \; f_c \; \alpha \right]$$

Method Description



Simulations

A Pspice model is designed to simulate

- physiology structure of finger
- skin-electrode contact interface

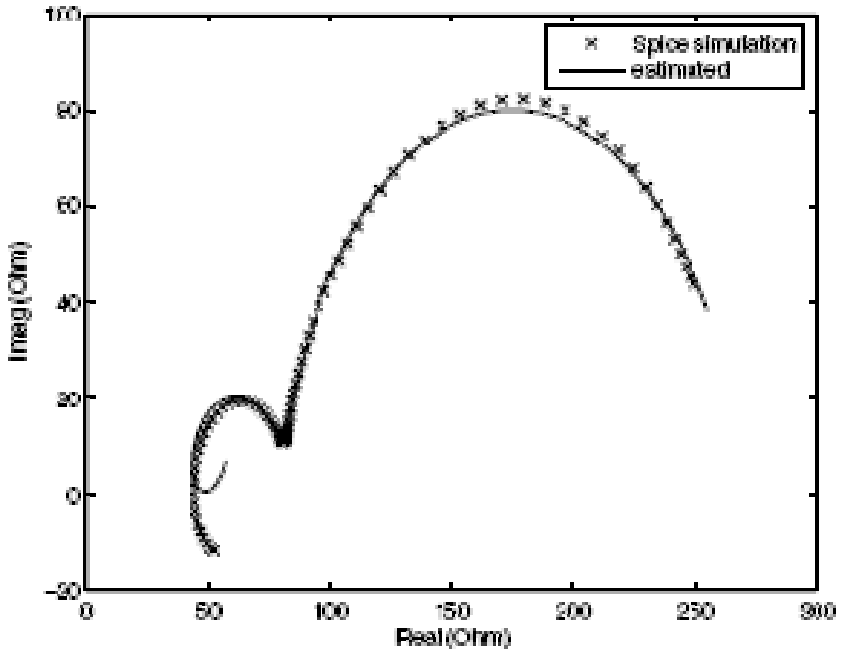
Frequency range: 5k~100MHz

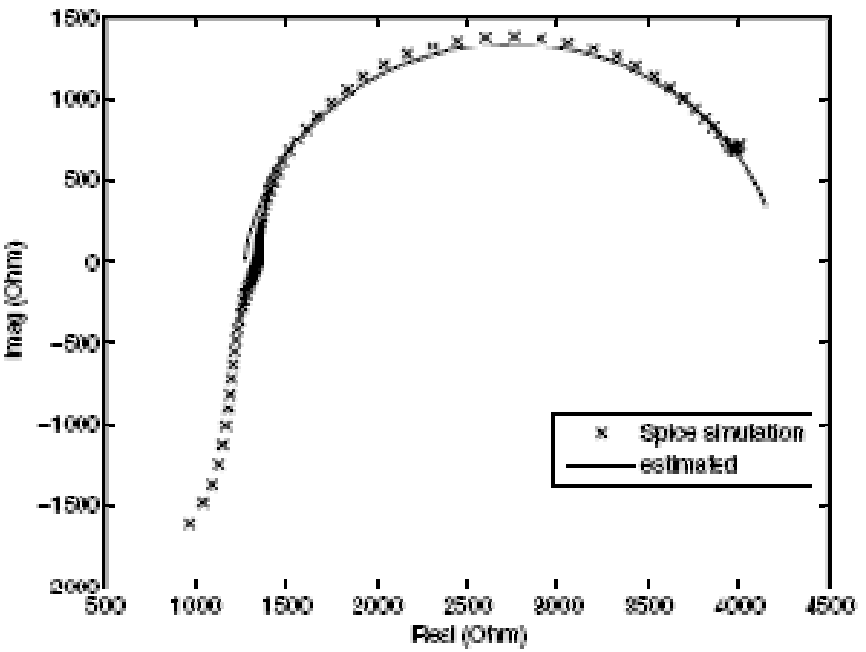
Sweeping frequencies: 88 points, logarithmly distributed

Artery volume change: 10%

Nonlinear curve fitting: LM (Levenberg-Marquardt) Method

Simulations





$Z_d(f)$ is fitted in an extended Cole-Cole model

the pulse curve $Z_{ib}(f)$ is fitted in a 1st order Cole-Cole model.

Simulations

NMSE-Normalized Mean Square Error: (1000 trials)

SNR(dB)	0	−5	−10	−20
Err $R_0(\%)$	0.1911	0.3240	0.6594	1.867
Err $R_\infty(\%)$	0.5772	0.9659	1.511	5.791
Err $f_c(\%)$	0.884	1.614	2.453	8.302
Err $\alpha(\%)$	5.588	11.76	17.70	62.37

Measurement error and corresponding Cole-Cole parameter error, as a function of SNR. (Sampling rate is 1*kHz)*

Conclusions

- Advantages:
  - Parameters estimated are of a homogeneous medium--blood;
  - Inductive effect is alleviated;
  - No need to use multiple Cole-Cole model
- Disadvantage:
  - Due to poor SNR in real measurements, it is hard to estimate pulsatile impedance wave amplitude.