Development of multifrequency device for bioimpedance measurements

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Abstract: Bioimpedance measurements are usually performed on cell cultures, tissues, and human body, measuring sequentially the impedance at different frequencies. However, when stationary conditions are violated these measurements are not consistent. Here we develop a custom device based on an multifrequency approach.

1 Introduction

Bioimpedance is measured through the injection of small alternating currents into tissues or human body. For safety concern these currents are limited by the IEC 60601 standard to the milliampere or sub-milliampere range [1].

The measurements can be performed with either two or four electrodes, where the latter is usually preferred. On the other side, the impedance is usually measured sequentially at different frequencies. However, if the bioimpedance changes even slightly with time, the measurement is no longer consistent and different approaches are necessary to validate the quantities measured.

The multifrequency approach overcomes this problem. In fact, all the frequencies of interest are injected simultaneously through a broadband signal. Such approach is developed here in a custom device whose functional schematic is depicted in Fig. 1, where the operational amplifier OPAMP1 functions as voltage controlled current source converting an arbitrary waveform at v_{in} into the current i. The magnitude of this current is set by the size of the sensing resistor R. The impedance to determine is depicted by Z while the four $Z_{cont.}$ represent the contact impedances of the four electrodes and are usually unknown. Two of these electrodes are connected directly to an instrumentation amplifier (INA1) which measures the ohmic drop across Z. The other two electrodes carry the current i through the system. A second instrumentation amplifier (INA2) measures the ohmic drop across R which is proportional to the injected current i.

A Field-Programmable-Gate-Array (FPGA) –powered device provides the digital-to-analog and the analog-to-digital conversion for v_{in}, v_{Ch1}, and v_{Ch2}, together with the power rails to feed the circuit (not showed).

2 Methods

An LMC6001 and two INA128P were used for OPAMP1 and INA1–2, respectively and several resistor values were tested for the sensing resistor R. The broadband multifrequency signal was a multisine comprising 19 sinusoidal waves with equal amplitude and frequencies distributed quasi-logarithmically between 0.5 kHz and 400 kHz. The acquisition was performed at 1 MHz with the Analog Discover 2 from Digilent controlled using the library `pydwf`. The performances of the device were characterized with several passive elements to substitute Z and $Z_{cont.}$.

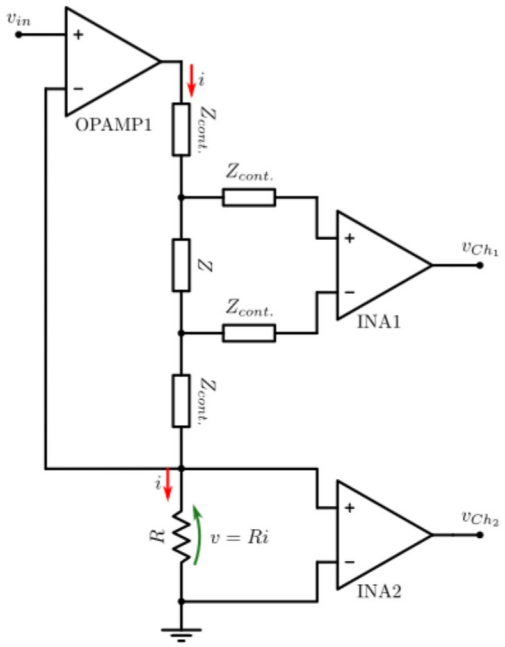

Figure 1: Functional schematic of the custom bioimpedance device. Z represents the impedance to measure.

3 Results

The system performs well up to a sampling rate of 1 MHz. However for accurate measurements a calibration is required well below that value. In fact, at frequencies higher than 100 kHz, the measurements depart from ideality and a inductive behavior is observed. This is characterized by an extra apparent $R \parallel L$ component in series with the measured impedance.

Calibrated measurements give an error in the range of 0.01 % at the lowest frequencies and of 0.07 % at the highest. On the other hand, the maximum phase error is 0.02° at 400 kHz.

4 Conclusions

We successfully developed and characterized a custom device for bioimpedance measurements in four electrodes configuration. This device is capable of accurate measurements employing a broadband multisine with frequencies between 0.5 kHz and 400 kHz.

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References

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