Suitability of the INPHAZE impedance analyzer for Bio-impedance and EIT

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Abstract: The suitability of a new impedance analyzer 'INPHAZE' for bio-impedance and Electrical Impedance Tomography (EIT) is investigated using measurements on simple resistive and capacitive models, and readily available biological objects. The INPHAZE is an impedance spectrometer developed to measure the impedance of thin films and layers but has been used in various applications. We found that it is superior to the UCL mk2.5 EIT system on measurements of resistive models and biological objects; however it is significantly over 10x slower as with each measurement checked for stability and SNR. We suggest that the device may provide significant improvements for bio-impedance. However for EIT we suggest exploration of expansion to more channels and the effect of reducing measurement times.

1.   Introduction

The purpose of this paper is to investigate the suitability of the INPHAZE impedance analyzer for bio impedance and Electrical Impedance Tomography EIT. The INPHAZE Impedance Spectrometer is a unique electrical impedance spectroscopy device developed at The University of Sydney. The INPHAZE device operates at level of accuracy that is orders of magnitude better than other impedance spectroscopy devices with impedance precision of 0.002% and phase resolution of 0.001degree over a large frequency range from 1mHz to 1MHz and impedance range of 0.1 to 10^{10} Ω [1-3]. The device performance was assessed in laboratory conditions using saline and simple resistive and capacitive models. The INPHAZE system consists of control panel software, Impedance Spectrometer Unit which yields high resolution impedance measurements, the amplifier unit which connects the signals between the Spectrometer Unit and the sample and the impedance analyzer software which is used to view the measurement data in a variety of plot types.

2.   Materials and methods

The INPHAZE EIS system can easily be calibrated using the supplied Control Panel software. Each calibration result is stored in the user's personalized protocol file, so the system can be personally calibrated under different loads and conditions depending on each user's application. The INPHAZE EIS system is supplied with a range of high-precision resistors and capacitors for calibration and measurement purposes. The system has been calibrated with the supplied 100Ω resistor as the calibration load for all of the following experiments. Preceding these measurements the current flowing through the electrodes was measured as 80μA RMS by measuring the voltage across a 1kΩ resistor connected between the electrodes. This current level is within the IEC60-601 safety regulations for frequencies 1kHz and above.

2. 1 Simple Resistor
The system was initially calibrated using two 100 Ω resistors, one as the sample and another as the standard. The resulting protocol file was used to measure the frequency response of resistors of values 10.003Ω, 20.3Ω, 31.3Ω, 50.1Ω, 59.4Ω, 73.5Ω. The experiment was performed over a frequency range of 10 Hz to 1MHz in steps of 1, over three spectra.

2.2 Contact Impedance Influence
The four terminal setup in Fig 1 was used to measure the contact impedance of a resistive sample. With the contact resistors R1, R2, R3 and R4 kept constant at 1k Ω, resistors of values 100 Ω, 73.5Ω, 59.4Ω, 50.1Ω, and 38.9Ω were used as the sample resistor. The experiment was performed over a frequency range of 1k Hz to 1MHz.
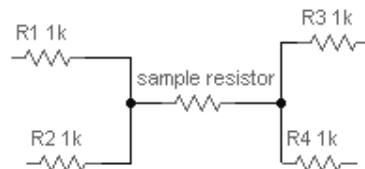

Fig 1: Arrangement used to measure the influence of contact impedance

2.3 Saline Solution
The impedance of various concentrations of salt solution was measured using the INPHAZE device by placing the salt solution in a 16 electrode cylindrical tank of 10cm diameter and connecting the I+ and V+ electrodes to two adjacent channels, and I- and V- electrodes to the diagonally opposite channels, a four terminal connection. Concentration of the salt solution was varied from 0.5g/L to 1g/L to 1.5g/L and for each concentration, the impedance was measured over a range of 1kHz to 1MHz.

2.4 Biological Object
The impedance of a simple biological material, a banana was measured by initially filling a plastic tube of 10 cm length and 2cm. At each end was a chloride silver disc electrode. All air bubbles were carefully eliminated. One end was permanently sealed, and the tube was filled with saline solution of 1g/L and the INPHAZE electrodes were connected to the tube, using a two terminal connection. This data was used to calibrate the measurements taken with banana. The measurement was then repeated by replacing a small quantity of the saline solution with a cylinder of banana of 1cm in diameter and 1.5 cm in length, followed by two pieces of banana of the same dimension, and then three. The measurement was taken over a frequency range of 20Hz to 1MHz.

3. Results
3.1 Simple resistor
The impedance vs. frequency response of all the simple resistors measured is shown in Fig 2
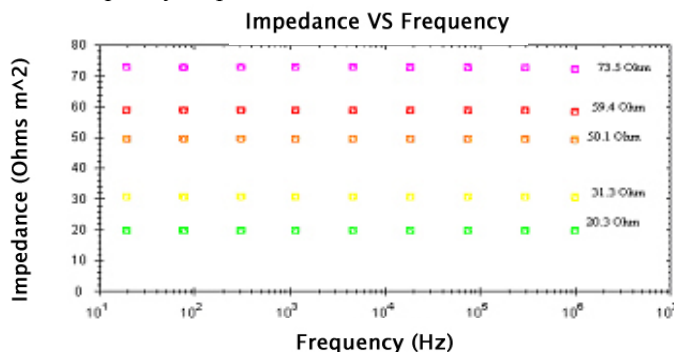

Fig 2: Plot of Impedance (Ω m^2) vs. Frequency (Hz) for simple resistors. The resistors used were 73.5, 59.4, 50.1, 31.3, 20.3 Ω from top to bottom.

3.2 Contact Impedance influence

The frequency response of the contact impedance influence measured using various resistor values for the sample resistor is shown in the plot in Fig 3.
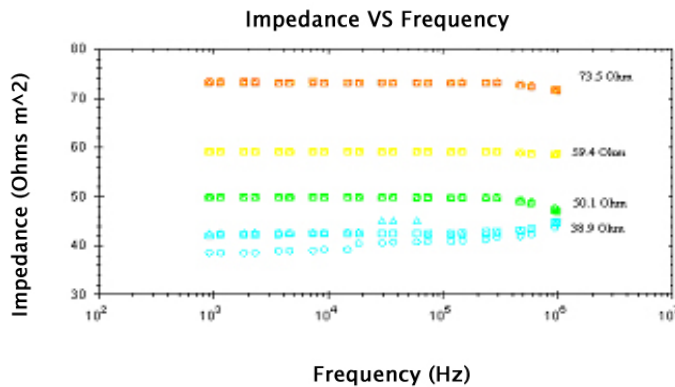

Fig 3: Plot of Impedance (Ω m^2) vs. Frequency (Hz) for contact impedance measurement. The resistors used were 73.5, 59.4, 50.1, 38.9, 31.3Ω from top to bottom.

3.3. Saline Solution

The frequency response of the impedance of the saline solutions of various concentrations is shown in the plot in Fig 4.
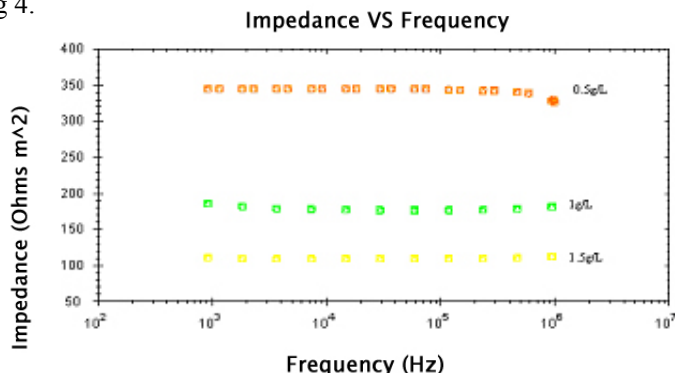

Fig 4: Plot of impedance (Ω m^2) vs. Frequency (Hz) of saline solutions of various concentrations.

3.4. Biological Object

The frequency response of the impedance of banana calibrated with the saline solution is shown in the plot in Fig 5.
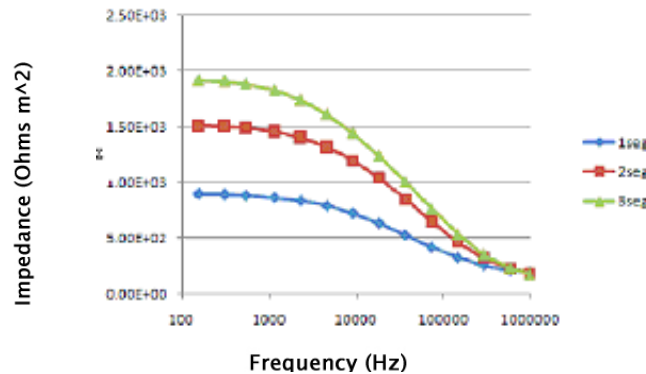

Fig 5: Plot of Impedance (Ω m^2) vs. Frequency (Hz) of saline solution with banana

4. Discussion

The suitability of the INPHAZE impedance analyzer for bio impedance and EIT measurements has been demonstrated. It is robust to the presence of contact impedance and able to measure the impedance spectra of biological objects. For the purpose this feasibility study, the amplifier unit included in the system was taken out of the INPHAZE Faraday Cage to resemble remote location applications. However, at the time of this study, the manufacturer had not released the INPHAZE External Amplifier Enclosure to the market yet. The scheduled release date of these external enclosures is mid-March 2010. With this enclosure, the amplifier unit would be properly shielded for remote setups, as they would be in the original Faraday Cage. As seen from the results, there is an effect, perhaps due to stray capacitance at frequencies above 100kHz, e.g. , a decrease by 6 % in the presence of a 1kΩ contact impedance with the 50.1Ω resistor. However, further studies are needed to confirm this as the sample load is only 50.1Ω and it should have overcome most of the impedance caused by the stray capacitance that is parallel to the sample load. In future studies, it would be advantageous to use the INPHAZE External Amplifier Enclosure to improve the measurement quality. And in cases where the effects of stray capacitances are observed, users can use the supplied Control Panel software to calibrate for the stray capacitances. It was suggested by the manufacturer to try the stray capacitance calibration after the amplifier unit has been put inside the dedicated enclosure, for a more stabilized result. As for the measurement taken with biological objects, varying concentrations of banana showed noticeable change in the impedance measured over a range of frequency. The centre frequency remains at 10kHz which compares well with previous measurements taken with the HP impedance analyzer (gold standard) [4]. The INPHAZE spectrometer is significantly over 10x slower as with each measurement checked for stability and SNR. We suggest that the device may provide significant improvements for bio-impedance. However for EIT we suggest exploration of expansion to more channels and an investigation into reduction of measurement times.

5. References

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