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Bioimpedance Analysis: A Guide to Simple Design and Implementation

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Background. **Bioimpedance analysis has found utility in many fields of medical research, yet instrumentation can be expensive and/or complicated to build. Advancements in electronic component design and equipment allow for simple bioimpedance analysis using equipment now commonly found in an engineering lab, combined with a few components exclusive to impedance analysis.**

Materials and methods. **A modified Howland bridge circuit was designed on a small circuit board with connections for power and bioimpedance probes. A programmable function generator and an oscilloscope were connected to a laptop computer and were tasked to drive and receive data from the circuit. The software then parsed the received data and inserted it into a spreadsheet for subsequent data analysis. The circuit was validated by testing its current output over a range of frequencies and comparing measured values of impedance across a test circuit to expected values.**

Results. **The system was validated over frequencies between 1 and 100 kHz. Maximum fluctuation in current was on the order of micro-Amperes. Similarly, the measured value of impedance in a test circuit followed the pattern of actual impedance over the range of frequencies measured.**

Conclusions. **Contemporary generation electronic measurement equipment provides adequate levels of connectivity and programmability to rapidly measure and record data for bioimpedance research. These components allow for the rapid development of a simple but accurate bioimpedance measurement system that can be assembled by individuals with limited knowledge of electronics or programming.**

Key Words: **Bioimpedance; Instrumentation; Current source; Design.**

INTRODUCTION

Electrical impedance of biological tissue has been a subject of research for more than 40 y [1, 2] with applications ranging from respiratory plethysmography [3] to cardiac stroke volume measurement [4] to detection of bladder cancer [5]. Original bioimpedance analyzers were cumbersome, requiring careful matching of resistors and a large overall number of components. Currently, advancement in miniaturization techniques and improvements in component accuracy make the design and fabrication of a bioimpedance analyzer much simpler [6]. Devices such as oscilloscopes and function generators now include connectivity to a host PC and are now able to be programmed using a simple graphical programming language.

Electrical impedance (Z) is a measure of the opposition to electrical flow through a substance. This value can be broken down into 2 elements, resistance (R) and reactance (X_c). Resistance has passive characteristics, in that its value does not change with frequency. Alternatively, the value of reactance does change with frequency and is found in sources of capacitance. The conventional electrical model for tissue includes resistors and capacitors, as shown in Fig. 1. Therefore, both resistive and reactive components are present in tissue.

The value of impedance is conventionally represented as a complex number, with the real component being resistance and the complex component being reactance ($Z = r + X_c i$). Alternatively, polar coordinates can be used with resistance and reactance being

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$Z \cos(\theta)$ and $Z \sin(\theta)$, respectively, where Z is the magnitude of the impedance and θ is the phase angle. Fig. 2 gives a graphical representation of impedance and its components.

Measurement of electrical impedance takes advantage of the relationship between impedance, voltage, and current. Ohm's law states the relation $V = IZ$, where V is voltage, I is current, and Z is impedance. By injecting a controlled amount of current into a section of tissue, the resulting voltage across that tissue provides an easily acquired signal for recording and subsequent analysis. Alternating current (AC) is used as the source of electrical current because it prevents iontophoresis and allows determination of the phase angle shift, a property that cannot be measured if direct current (DC) is used. Modern oscilloscopes have the ability to automatically measure phase angle differences between 2 signals. Knowledge of the amount of injected current, the subsequent voltage generated, and the phase angle allows one to fully characterize the impedance profile of the tissue being examined.

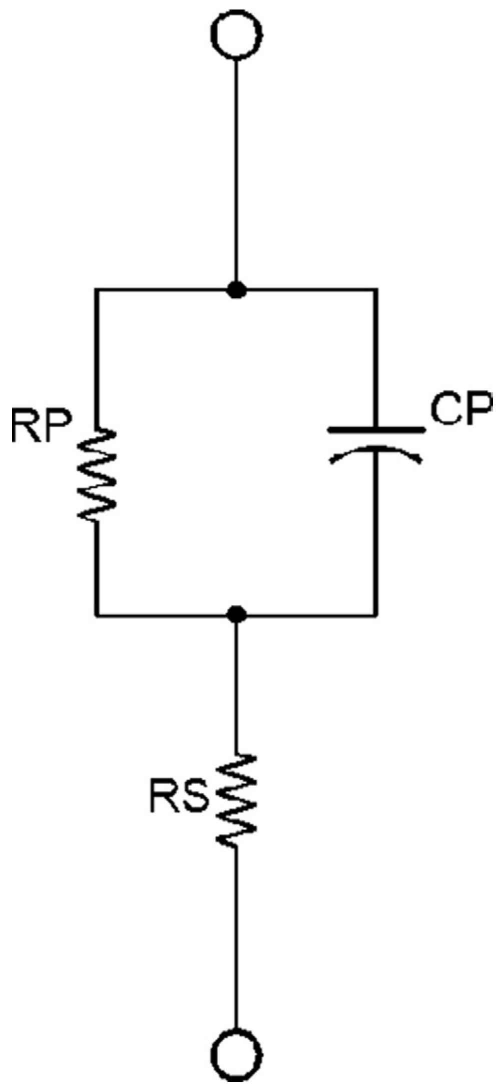

FIG. 1. A simple model used to replicate impedance in tissue. RS and RP are the series and parallel resistance components, and CP is the parallel capacitance component. This circuit was used in the calibration and verification of the VCCS.

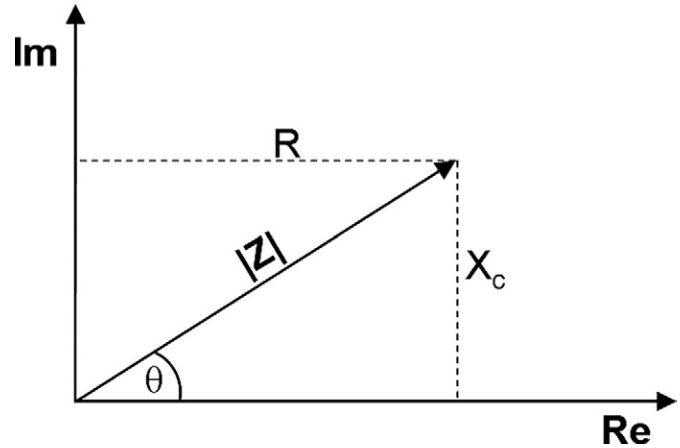

FIG. 2. The impedance vector Z can be split up into real and imaginary components R and X_C, respectively. Phase angle is labeled as θ. By measuring the impedance and resulting phase angle, a polar representation of the impedance vector is created, and with simple trigonometry, the separation of resistance and reactance can be determined.

A pilot study was recently performed at our institution to examine the bioimpedance properties of brain tissue subjected to traumatic brain injury (unpublished data). Our laboratory first used impedance analysis to examine the change in impedance within edematous intestinal tissue [7]. Originally, the design of the impedance measuring system required manual switching of frequencies and recording of voltages. The system described in this article automates the sequence, resulting in a significant reduction in measurement time. It also organizes the data in a spreadsheet for easy analysis.

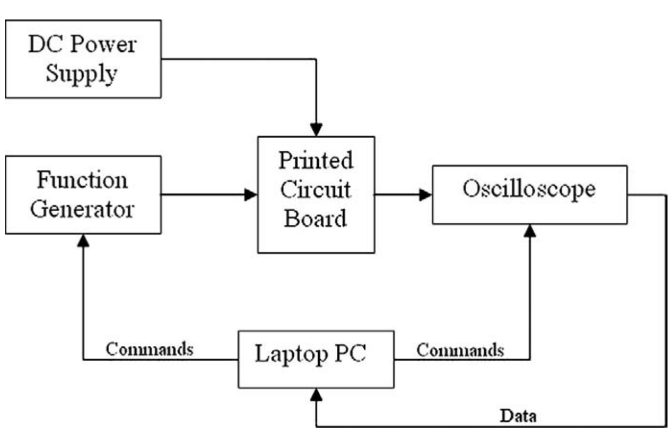

FIG. 3. Block diagram describing major components of the bioimpedance measurement system. A Printed Circuit Board (PCB) contains the current source and connections for the electrode probes. Attached to the PCB are a DC power supply, function generator, and an oscilloscope, which are controlled and monitored by a program running on a laptop PC. Data from the experiment is automatically uploaded to the laptop throughout the measurement.