Laboratory Project 3:
Model of Tissue Impedance

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***Abstract*-You will build a oscillator circuit that generates a 25 kHz sinusoid. Using electrodes and a series resistor, you will pass the 25 kHz sinusoid through your arm and derive a numerical model of our arm's impedance. You will compare these numbers with published tables to estimate the makeup of tissue in your arm.**

I. PREPARATION

For Lab 3, which will last about three weeks, you will need the parts listed in Table I, (in addition to the breadboard and wire kit from Lab 1). You may purchase these parts from the stockroom next to the lab or purchase them elsewhere.

TABLE I
PARTS LIST

Item	Qnty	Description
1	1	LF353 Operational Amplifier
2	2	250 pF Capacitor
3	1	2 kΩ Resistor
4	4	Resistors (values determined during lab)
5	2	electrodes

II. LEARNING OBJECTIVES

1) Learn about impedance circuits.
2) Learn how to design a Wien-bridge oscillator circuit with an op-amp.
3) Learn how to interpret published data on impedance versus tissue type.

III. INTRODUCTION

A. Electromagnetic Fields and Tissues

Understanding the effects of electromagnetic radiation on tissues is valuable for determining safety parameters for wireless devices and for creating effective tools for modern medicine. Modern humans are immersed in an environment filled with a background of electromagnetic radiation. Some sources of this electromagnetic radiation are low in public exposure intensity (TV, radio and other communication stations; 60-Hz power lines), some are moderate in public exposure intensity (cell phones when placed against the head), and some are intentionally strong (MRI imagers; radio-frequency tissue ablation for cancer treatment). Around the world, research teams study how exposure to this electromagnetic radiation affects the body. Numerical modeling of the effects requires knowledge of tissue impedances at the frequencies of the electromagnetic radiation.

Because cells are the building blocks of tissues, insight into the impedance of cells aids in creating viable models. By investigating the structure of cells, modelers create simplified equivalent circuits suitable for numerical simulations. A single cell (Fig. 1A) may be viewed as a fluid-like substance with several species of mobile ions (the cytoplasm) contained within a semi-permeable cell wall (the cell membrane). Outside the cell is more fluid (the extracellular fluid), with again several species of mobile ions. Electrically, the cytoplasm can be modeled to first order as a conductive medium—due to the presence of the large concentrations of ions—characterized by a given value of conductivity, σ, (or its inverse, resistivity, ρ). The extracellular fluid can also be modeled as a conductive medium. The cell wall, on the other hand, is relatively insulating and, since it is a thin layer, is modeled as a capacitive medium with a given relative permittivity, $\square_{\mathrm{r}}$.

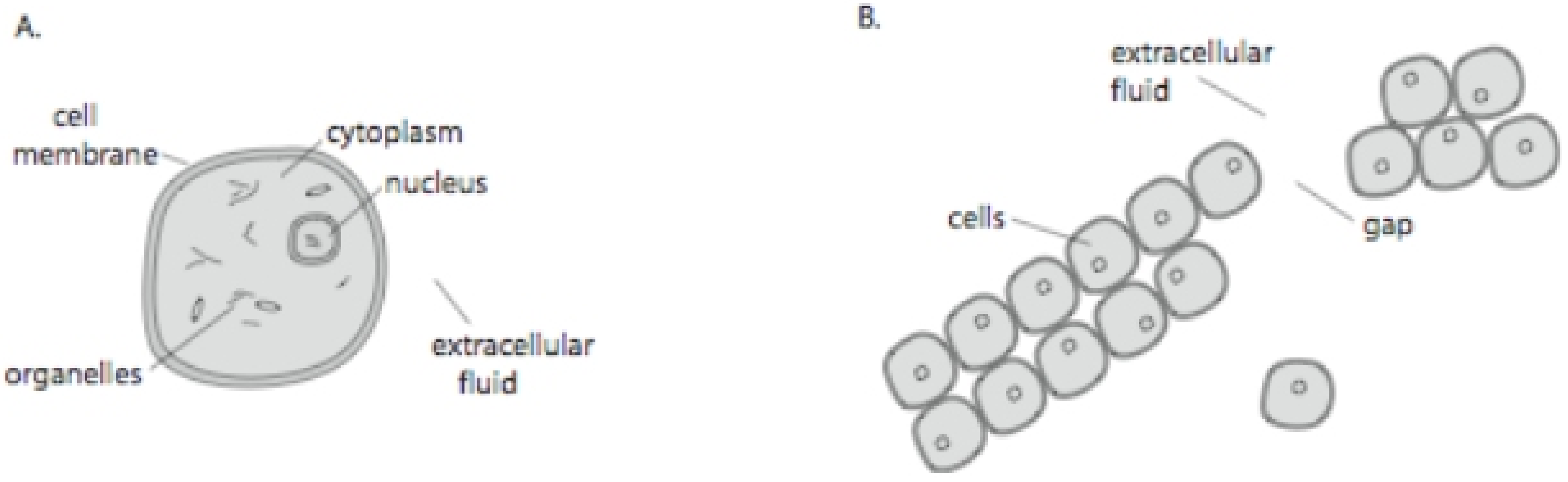

Fig. 1 – A) Simplified diagram of a single cell, whose size can vary between 10 µm to nearly 1 mm; B) Tissue is composed of collections of cells. Gaps between the cells allow current to flow through shunt paths.

Tissues are composed of arrangements of cells (Fig. 1B) surrounded by the conductive extracellular fluid. In some places, the cells are tightly bound together and any circulating current must pass through the cell membranes. In other places, there are gaps (shunt paths) through which current can flow. Modeling every detail of the cells and shunt paths would be impractical. We may, however, use simple circuits to obtain reasonable approximations to the aggregate behavior of cells in tissues.

We consider a region of the body where there is a volume of soft tissue (muscle and fat) covered by skin upon which two opposing electrodes can be attached, namely the biceps muscles of the upper arm. A simple equivalent electrical model of the tissue between the two electrodes is shown in Fig. 2A. This is a lumped-element model where all inner-tissue cells are combined together into a single series R_cC_c branch. This branch in turn is in parallel with a resistive branch, R_t, representing the shunt intracellular fluid paths. At both ends of this circuit are parallel R_sC_s segments representing the electrical properties of the thin skin directly underneath the electrodes.

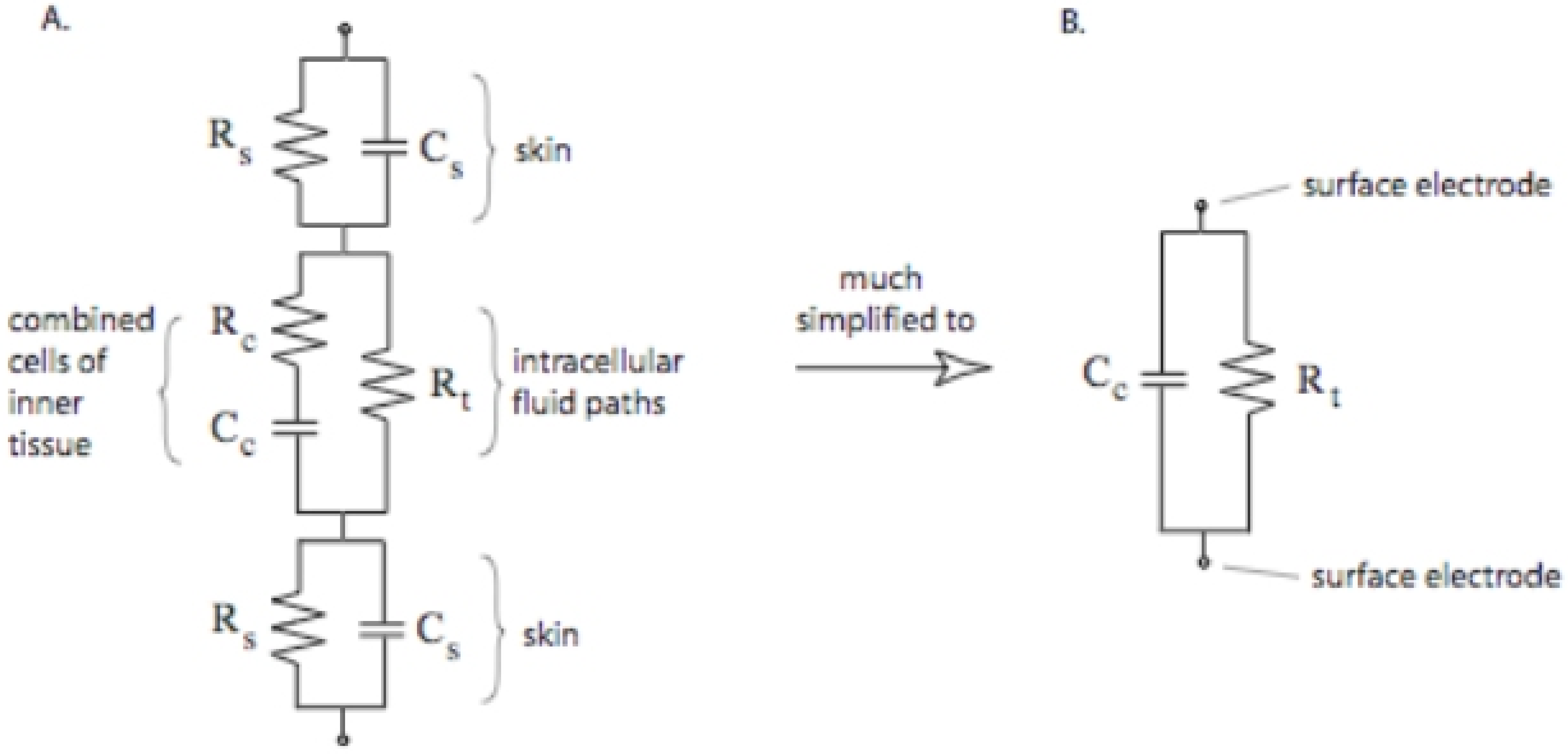

Fig. 2 – A) Lumped-element model of the electrical behavior of tissue bordered by skin, B) After several simplifications, the model reduces to its essence, a parallel *RC* circuit.

With some reasonable assumptions, this model can be greatly simplified. Assume that the combined resistance of the cell cytoplasm, R_c, is much lower than the reactance, $1/\omega C_c$, due to the cell membranes. Also, assume that the resistance of the thin skin, R_s, is much lower than both the skin reactance, $1/\omega C_s$, and the tissue resistance, R_t. (The validity of these assumptions depends very much upon the particular tissue region being modeled and the frequency of the electrical excitation, but for muscle and skin at a relatively low frequency of 25 kHz, these approximations are appropriate.) Then the model of Fig. 2A reduces to the simple R_tC_c parallel equivalent circuit shown in Fig. 2B. In the laboratory exercise detailed below, you will make measurements with the aim of finding typical values for the parameters of this simplified circuit.

B. Design Project Overview

Your project is to design an oscillator that will produce a sinusoidal waveform at a frequency of 25 kHz and use that signal to determine the value of resistance and capacitance for a model of tissue impedance based on measurements of your biceps. The oscillator is an op-amp Wein-bridge circuit that produces a sinusoid, as shown in Fig. 3. The sinusoidal output from the oscillator will drive a resistor in series with electrodes placed on both sides of your biceps. The resistor, whose value you will choose, and the tissue in your biceps will form a voltage divider. By measuring the magnitude and phase-shift of the voltage across the resistor relative to the 25 kHz sinusoid, you will be able to determine the value of R_t and C_c for a parallel RC model of the tissue. You will use an oscilloscope to make the necessary magnitude and phase-shift measurements.

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are needed to see this picture.

Figure 3. Block diagram of tissue measurement experiment.

IV. WEIN-BRIDGE OSCILLATOR

A. Wein-Bridge Oscillator Explanation

Fig. 4, below, shows the schematic diagram for the Wien-bridge oscillator (without the electrodes across the muscle and R) that you will build for Lab 3. The purpose of this oscillator is produce a sinusoidal signal at 25 kHz that can be used to measure tissue impedance. The oscillator has positive and negative feedback, and the op-amp may be thought of as trying to make the + and – input signals to the op-amp the same. If we think of the op-amp output, v_0, as a voltage source, then the Wien-bridge driven by the op-amp may be viewed as two voltage dividers producing v_- and v_+, as indicated by the shaded boxes. The bridge is said to be balanced when the two voltage dividers produce the same output voltages when driven by v_0. One's first impression upon viewing the circuit in Fig. 4 might be that the circuit should output $v_0 = 0$ V, whether the bridge is balanced or not, as this would result in $v_- = v_+ = 0$ V.

Note, however, that if the circuit is balanced, $v_0 \neq 0$ V would also be a solution. Since the left side of the Wien bridge is frequency dependent, this means there may be one frequency, ω_0, where the bridge is balanced and the