Time Dependent Skin Impedance Model

For the testing of electrocutaneous stimulating electrodes

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***Abstract*—Skin resistance changes dynamically during the time course of an external electrical stimulation. An embedded system was developed to provide a dynamic impedance in response to external stimulations. A microprocessor adjusts the series resistance component of an impedance based on a preprogrammed function. This skin impedance model is useful for testing devices involving electrocutaneous stimulation or functional electrical stimulation.**

Keywords—skin impedance; electrocutaneous stimulation

I. Introduction

Electrocutaneous stimulation passes current through the epidermis and dermis to evoke tactile sensations. The purpose of this model is to enhance the common resistor-capacitor (RC) skin impedance model to encompass the temporally variable impedance after the onset of electrocutaneous stimulation. The developed model extends the first-order skin model described by Polleto [1] to include a time dependent resistance measured by Mason [2].

Current and past electronic tissue models for electro-cutaneous stimulation focus on the fluctuation of skin resistance as a function of frequency. The purpose of this model is to enhance the common resistor-capacitor (RC) skin impedance model to encompass the temporally variable impedance after the onset of electrocutaneous stimulation. The developed model extends the first-order skin model described by Polleto [1, 3-5] to include a time dependent resistance measured by Mason [2]. The model employed in the present study expands on the first-order skin model described by Potello [1, 3-5] by adding a comparator for monitoring the time course of the external electrical stimulation. At the onset of a stimulation, a microprocessor initiates a program and a digital potentiometer to account for the temporal variance in impedance.

II. Methods

A. Device Design

As shown by the block diagram in Fig. 1, a first-order skin impedance model consists of three elements: a serious resistance (R_s), a parallel resistance (R_p), and a capacitance (C). While the skin resistance values of the electrode/skin interface vary greatly, as reported by Poletto [4], a value of 320 KΩ was selected for R_p and a 0.42 nF for C in the present model. The time-varying component is attributed to the series resistance R_s, which is implemented with a digital Potentiometer. The digital potentiometer (MCP4162,

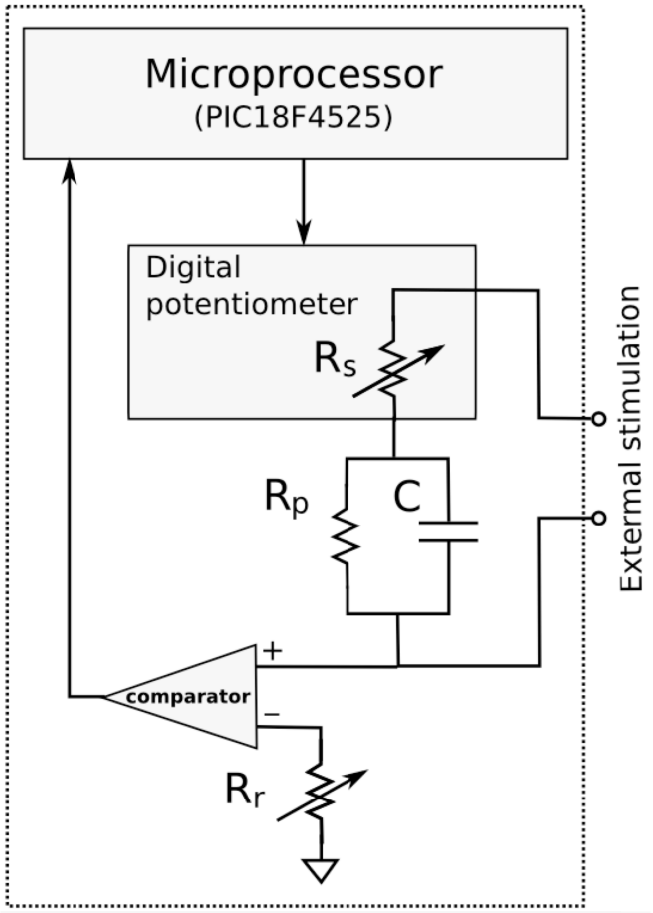

Fig. 1. Block diagram of the microprocessor based skin impedance model.

Microchip, Chandler, Arizona) is responsible for varying the series resistance consistent with Mason's results over the desired range of 24 KΩ to 27.5 KΩ.. A microprocessor (PIC18F4525, Microchip) selects one of the 69 different resistance values over a duration of 90 s from a look-up table.

To derive the values for the look-up table of, an estimate of the resistance values were obtained from Mason's published results [2]. With theses results, R_s is approximated by the following function:

$$R_s = 12500\, t\, e^{-t} + 23000\ \Omega \quad (1)$$

where t is the elapsed time in seconds since the onset of an external stimulation. The desired time course of R_s is shown in Fig. 2.

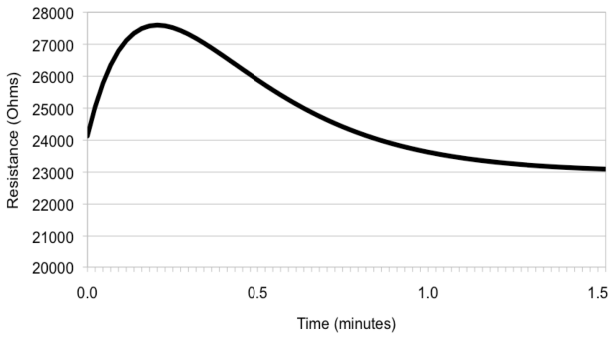

Fig. 2. Desired series resistance (R_s) based on equation (1).

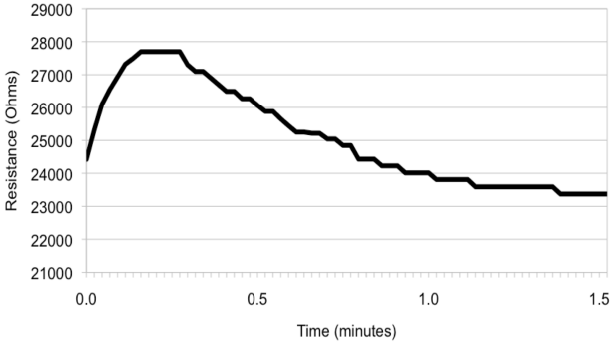

Fig. 3. Measured series resistance (R_s) from the skin resistance model.

B. *Electrode Sensing*

In order to make this model dependent on the onset of electrocutaneous stimulation, the embedded system incorporates a comparator that triggers upon the application of an external stimulus voltage. Once the comparator reads the applied stimulus voltage to be greater than the threshold voltage, the microprocessor initializes the generation of the skin response in the program. An interrupt-driven timer in the microprocessor keeps track of the real time. Values from the look-up table are sequentially outputted to the digital potentiometer to set the appropriate resistance as time elapses. If the end of the look-up table is reached, the last resistance value is maintained to mimic the homeostatic numbing response of the skin. The microprocessor will only reinitialize the array sequence when the present stimulus is removed followed by the detection of another stimulus. This specific function of the model allows for consecutive testings of electrocutaneous stimulation.

III. Results

The hardware was built according to the model presented above and the software was coded in the C language using the MPLab development tool (Microchip, Chandler, AZ). The system has demonstrated to respond to an applied stimulus according to the specifications. At the onset of a stimulus event generated with a function generator, the skin impedance progresses through the desired level changes as shown in Fig. 3. The system correctly restarts upon the removal of the applied stimulus.

IV. Discussion

This study has resulted in an embedded system that mimics the dynamic impedance properties of the skin in response to electrocutaneous stimulation. Compared to other skin models that focus on the variable change of skin resistance versus frequency, the presented approach has enhanced the model to include the temporal change of the skin impedance during the course of an stimulation episode.

This novel device can be used for testing electrocutaneous stimulation, which provides tactile sensation. By creating a dynamic skin impedance model, electrocutaneous stimulation devices can be evaluated in terms of their ability to adjust the desirable stimulation currents under a time dependent load. This skin impedance model can also be used to test functional electrical stimulation devices. The programmability of the model makes it very flexible for implementing different time courses of the impedance changes.

The limitations of the present model include the following. The output doesn't perfectly match Mason's data [2]. In reality there may exist a delayed response to the external stimulation. The onset of the waveform does not trigger on the electrode application to the skin, which is what Mason stated as his time 0. The accuracy of the time dependent resistance might be improved by increasing the size of the look-up table. This model is also limited because it assumes that only the series resistance (R_s) changes over time.

Future work on this model can be performed to examine the impact of time on the frequency response. Exploring the effects of skin moisture and environmental humidity on baseline skin resistance can make another addition to this model.

References

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