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An 8-channel skin impedance measurement system for acupuncture research

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***Abstract*—An 8-channel skin impedance measurement system for acupuncture research has been developed. The underlying model of the skin used is a parallel R & C network. Pulses are used to measure the R and C values. The measurement circuit is time multiplexed across the 8 channels at the rate of 2 measurements per second, leading to a complete set of measurements every 4 seconds. In static tests, the system has been operational for over 2 days of continuous measurements. In preliminary human tests, measurements over 2 hours have been collected per subject.**

I. Introduction

SKIN impedance has been used to differentiate between acupuncture points and the surrounding skin [1,2]. In a previous paper, the authors presented preliminary results on a single channel skin impedance measurement system [3]. For acupuncture research, it was felt that simultaneous measurement of 32 acupuncture and non-acupuncture points would be needed to detect sensitive and specific changes due to a intervention such as needle manipulation at related acupuncture points. As a first step, an 8 channel system was developed.

In this paper, we present the rationale and trade-offs in the development of this 8 channel impedance measurement system and some preliminary human test results.

II. Rationale and Design Trade-offs

A. Model

Previous authors have reported resistance measurements [4-6] using pulse input, or impedance measurements [6-9] at frequencies ranging from 0.5Hz to 1 KHz. The model we chose is based on the observation that when the two probes of an ohmmeter are placed on the skin, a relatively slow decrease in "impedance" is observed, until a steady state resistance value is reached. Thus, this implies that a simplified model of the skin impedance would be either a parallel R-C network, the RC model, or a parallel R-C followed by another R [10] network, the RC-r model, as illustrated in Fig. 1. Reichmanis et al. [10] reported that the series r in the RC-r model is significantly smaller than the parallel R.

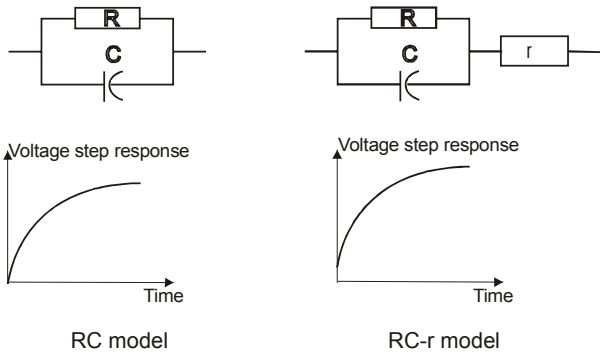

Fig. 1. Two possible models of skin impedance.

The difference in the pulse response between the RC model and the RC-r model is the presence of a pedestal at the beginning of the voltage response of the skin. In our measurements, due to the steep initial curve, it was difficult to differentiate between the pedestal and the beginning of the RC curve. Thus for the sake of simplicity, we adopted the simpler RC model.

B. Design of the 8-channel skin impedance measurement system.

From our previous work [3], we knew that a measurement of about 0.5 second would be required. This is significantly longer than the 1000 μs used by Reichmanis [10]. But Reichmanis used a complex analysis of the voltage and current waveforms, whereas we decided to use a simple rise time (10% to 90% of the RC voltage curve) measurement to determine the values of capacitance, following the resistance measurement, according to the equation

$$R_{skin}\, C_{skin} = \text{RiseTime}/2.197 \qquad (1)$$

For 8 channels of measurement a time multiplexed system was deemed sufficient. Reichmanis [10] reported that pulses must be separated by an interval greater than 5 times the pulse duration. In our case, multiplexing 8 channels results in the pulse being applied $1/8^{th}$ of the time at a particular skin location, meeting the mentioned off time requirement.

The basic measurement system is illustrated in Fig. 2. A small fixed R_i resistor is used to measure the current through the skin. Only 2 waveforms need to be measured, namely the skin voltage, V_{skin}, and the voltage V_i across the R_i

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resistor.

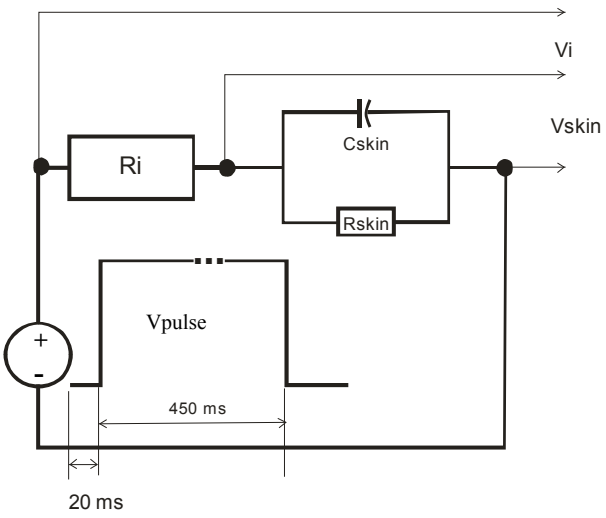

Fig. 2. Basic skin impedance measurement system.

To determine the steady state current, only the steady state value of V_i is needed. To determine the rise time, only the V_{skin} waveform is used.

To reduce any static voltage during the off-time when the large reference electrode is not connected to the measurement point, immediately after the signal is applied across the skin, the pulse value is kept at 0 volt for about 20 ms. A longer duration of 0 volt could have been used, but was not felt to be necessary. Actually, any residual voltage on C_{skin}, due to a high R_{skin} value would not have theoretically affected the steady state V_i value nor the rise time of V_{skin}. However, in practice, a residual voltage on C_{skin} would affect the rise time, because of the implicit assumption made that V_{skin} starts with a value of 0 Volts. So, this can potentially cause an erroneous slightly larger value of C_{skin}.

With a pulse 450 ms long, and a 500 ms measurement cycle, the 8 channels can be measured once every 4 seconds.

Our design goal is to be able to measure skin resistance values from 100KΩ to 50 MΩ. In the low resistance value range, we try to comply with the Committee on Electrocardiography guideline [11] to restrict the current to be < 10 μA, which is very conservative since we are making limb measurement and there is no direct circuit through the heart. 100 μA would have been acceptable. This has led us to use at the low resistance range a pulse input voltage of 2 Volts, and a resistance R_i of 100 KΩ. At the high end of the skin resistance value, >10 MΩ, we are concerned about the voltage drop V_i across the R_i resistor being too small. Thus, for large skin resistance value, we choose an input pulse voltage of 5 Volts together with a 1 MΩ R_i value. To prevent frequent switching back and forth, we chose a hysteresis from 850 KΩ to 2.9 MΩ, as illustrated in Fig. 3.

To accommodate 8 channels of multiplexed measurements at a multiplexing rate of 2 Hz, the Octopus

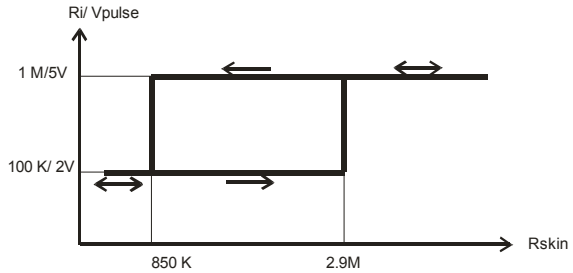

Fig. 3. R_i and V_{pulse} hysteresis as a function of measured R_{skin}.

board, diagrammed in Fig. 4 was constructed and interfaced to a National Instrument (Austin, TX) PCI-6251 acquisition board. This is shown in Fig. 5.

The control and measurement software chosen was LabView, National Instruments, Austin, TX, running on a quad core Intel processor workstation under Microsoft Windows XP Professional.

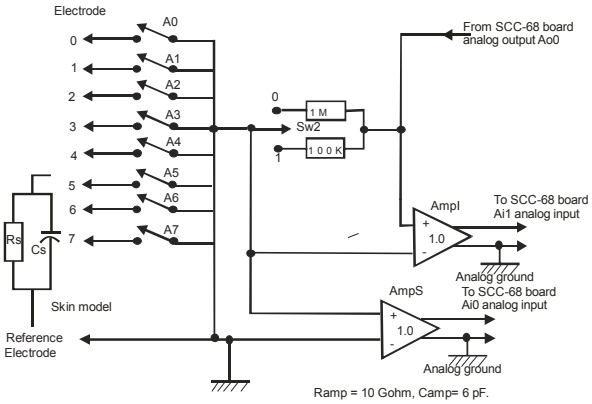

Fig. 4. Block diagram of 8 channel system.

Fig. 5. Octopus system. On the left is the National Instrument SCC-68 I/O screw terminal board with its cable interface (black cable on top of figure) to the PCI card inside a desktop computer. On the right is the custom designed Octopus board diagrammed in Fig. 4, on top of the cover for the white SCC box. The 8 leads leading to skin electrodes, and the ground connector on the right, are shown on top of the Octopus board.

C. Validation of instrument

In the validation test, we ran the Octopus with

• 9.1 MΩ + 8.2 nF across all channels … this was inserted after the switches to the electrodes

• In channel 1: before the switch, in parallel to the above, a 150 KΩ resistor was inserted

• In channel 5: before the switch, in parallel with the common load, a load of 680 KΩ + 220 nF was added

Thus, we would expect to measure during our 50 hour test

- 9.1 MΩ + 8.2 nF in channels 2-4, 6-8. Measured 9.2 MΩ + 9.1 nF
- For channel 1, we expect roughly 148 KΩ + 8.2 nF. Measured 152 KΩ + 8.3 nF
- In channel 5, we expect 632 KΩ + 228 nF. Measured 632 KΩ + 243 nF

Consistency, as measured by the standard deviation of the measurements in a particular channel was good, with standard resistance measurement within about 2.5%. Capacitance measurements could be off by 10%. This 10% difference could be caused by

- discrepancy between the capacitor nominal value and its real value,
- our "known" R_i value may not be as precise as we would like
- inaccuracy in rise time measurement, possibly due to residual charge on the capacitor.

However, our measurements are very consistent, with standard deviations of less than 0.5% making the Octopus definitely more than adequate for trend measurements, which is our goal.

III. RESULTS

30 healthy volunteers were recruited at the Helfgott Research Institute from the National College of Natural Medicine community under a test protocol approved by the IRB of NCNM. Preliminary results from a group of 16 subjects are presented in this paper.

Each volunteer was monitored for 2 hours. They were free to read materials of their choice while sitting comfortably in an arm chair. The skin impedances at the following points at the right side of the body were measured with 4 mm Ø unshielded cup Biopac EL 254 silver-silverchloride electrodes, from Biopac Systems, Inc, Goleta, CA, shown in Fig. 6.

- LU(ng) 9, P(eri)C(ardium) 6 on the wrist area, together with 1 additional dummy point
- L(ive)R1, SP(leen)1, SP6 on the toe, leg area, together with 2 additional dummy points
- The ground reference is a standard ECG electrode taped on the arm.

Skin preparation consisted of cleaning with isopropyl alcohol. Signal Gel (from Biopac Systems) was used to contact the electrode to the skin.

The typical data of one subject and from the 5 acupuncture points and 1 non –acupuncture point are shown in Fig. 7

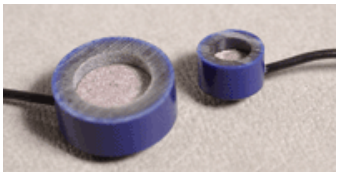

Fig. 6. Biopac electrodes.

IV. DISCUSSION

The measurements in Fig. 7 show consistency over short period of time. Over long period of time, there is significant variation due physiological changes. While the resistance measurements are consistent, the hysteresis switching diagrammed in Fig. 3 (a) has pointed out a problem with capacitance measurements. Skin capacitance is apparently voltage dependent. Due a sudden surge in resistance at time 100 s beyond 2.9 MΩ, the system switched to a pulse of 5V, leading to the steady state voltage across the skin to jump from 2V to 3.7V. This caused the capacitance to jump from about 15 nF to 22 nF. At time 6700 s, as the skin resistance falls below 850 KΩ, the system switched back to a 2V pulse, causing the voltage across the skin to fall from 2.3V to 1.8V, resulting in the capacitance falling from 29 nF down to 17.5 nF. A software fix is planned for the next software release, after all the human tests have been completed, is to inhibit switching after the first set of measurements.

V. CONCLUSION

An 8 channel skin impedance measurement system was successfully developed. A new set of measurements can be collected every 4 seconds. Consistent measurements are obtained. Skin capacitance appears to be voltage dependent, requiring a software fix in the next software release so as to inhibit pulse amplitude switching after the start of measurements.

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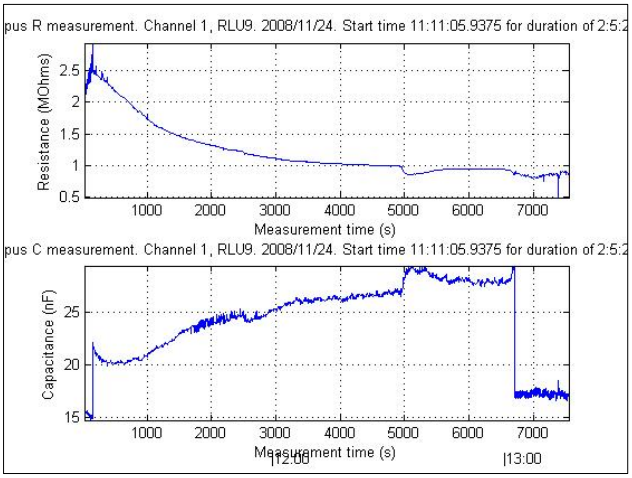
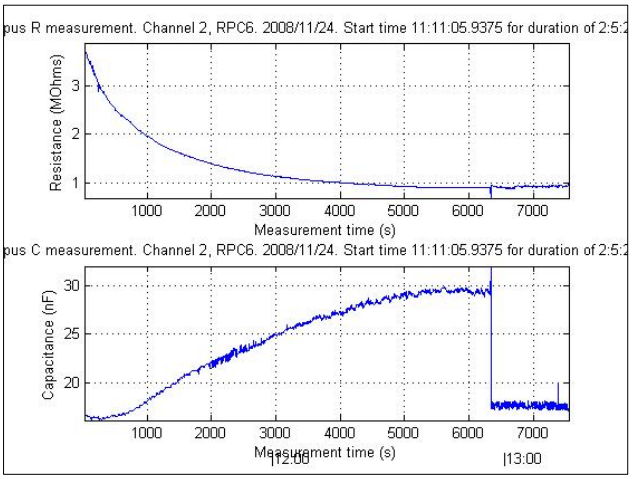
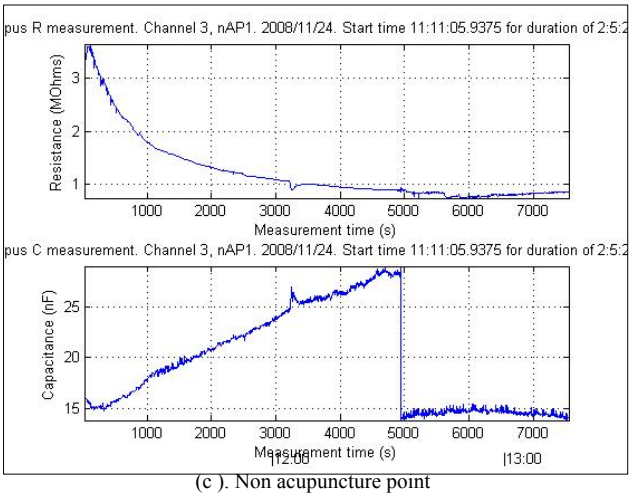


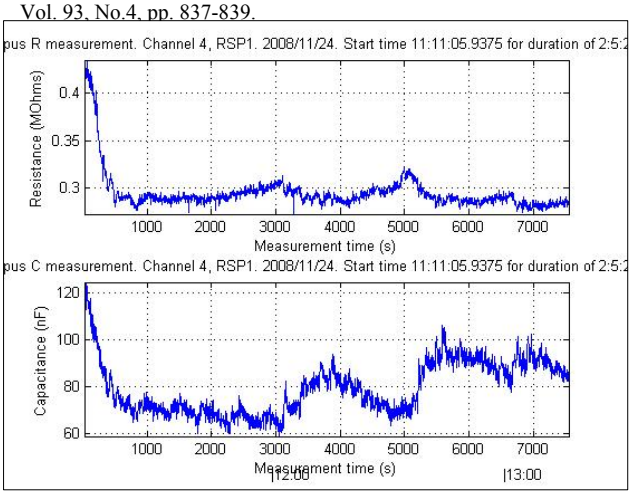
(a). right LU9



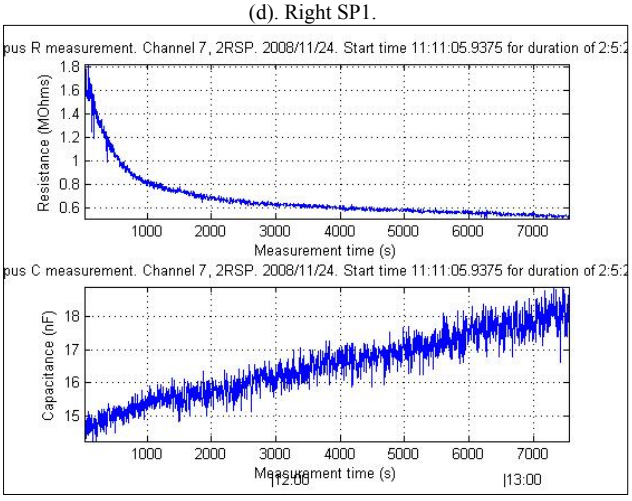
(b). right PC6



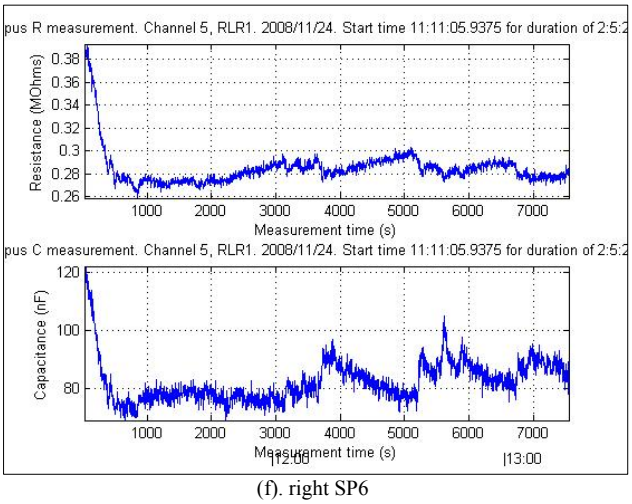
(c). Non acupuncture point



(d). Right SP1.



(e). right LR1



(f). right SP6

Figure 7. Typical data from one subject