Impedance Characterization of Bipolar Implantable Nerve Cuffs for Neuroscience Applications

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Nerve cuff electrodes can be used in neuroprosthetic applications, treatment of chronic pain, acquiring sensory feedback, and recording electroneurograms. The nerve cuffs are not dependent on the muscle length and limb position compared to the surface and muscle electrodes; they are fixed around the nerve which reduces the relative movement caused by muscle contraction. In addition, it can reduce the required magnitude to stimulate nerves [1].

These cuffs can be considered as an internal perturbation while animal running to study how they can recover from this type of internal perturbation or provide a wealth of information about how an animal responds to a treatment or from an injury [2], [3], [4].

There have been some studies to characterize the electrical cuffs [1], [5], [6], [7], [8], [9]. However, these methods have been limited to monopolar electrodes, bigger cuffs for human applications, or a narrow frequency range. Here, we present the electrical characterization of Platinum (Pt) bipolar cuffs for a wide frequency range.

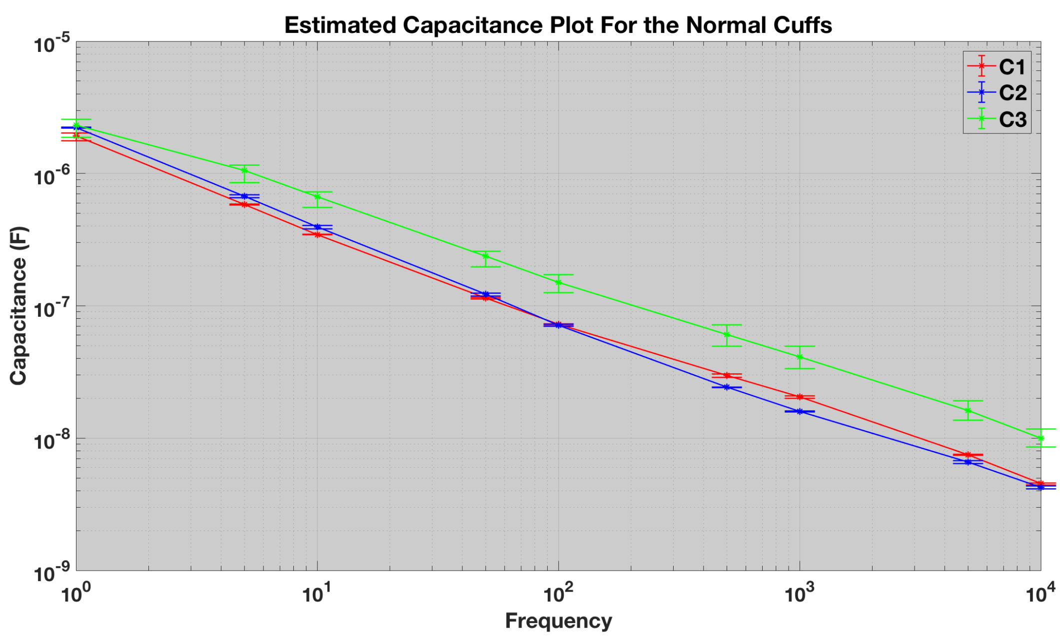

Fig. 1: This graph shows the interference capacitance of three cuffs calculated for different frequencies. Each of the cuffs was measured three times and the error bars show the related changes for repetition of measurements.

1. This material is based upon work supported by, or in by, the U.S. Army Research Laboratory and the U.S. Army Research Office Under Contract/grant number W911NF140141, proposal 64929EG, to A. Spence.

A Randles equivalent circuit was used to model the electrode-electrolyte interface [8], [6]. The equivalent circuit represents the interface capacitance impedance (Z), shunted by a charge transfer resistance (R_{ct}), together in series with the solution resistance (R_s).

To simulate the body medium, we used the physiological saline, 0.9% NaCl [6].

We used National Instrument (NI) Elvis II to generate sine wave signals with different frequencies. We used a Tektronix oscilloscope with a sampling rate of 1GB/s.

Three bright Pt nerve cuffs each having 2 × 2 × 0.025 mm3 were used to evaluate the cuff impedance properties. We swiped the frequency from 1 Hz to 100 kHz and measured two frequencies per decade. The capacitance (Z) has been calculated and illustrated in Fig. 1. The R_{ct} average was 320 ± 72 kOhm and this number for R_s was 52 ± 15 Ohm.

We evaluated three bipolar nerve cuffs by swiping the frequency of input sine wave signal. The results showed the same decreasing pattern for the cuffs, each measured three times. Having these results will help us to design an open source software to examine the characterization of cuffs before and after implanting which can provide an important tool for neuroscience studies. The animal behavior can be monitored and tracked using image processing techniques to provide kinematics information [2], [3], [4], [10]. We would try to use the signal processing techniques to develop an automatic cuff characterizer toolbox [11].

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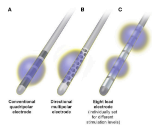
Background

- Activity of muscles and neurons with electrical devices
  - neurobiological and neuromuscular world



- Electrodes
  - Deep brain electrodes
  - Nanoelectrodes
  - Surface type electrodes

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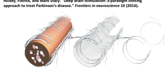
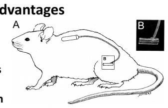
- Nerve Cuff
  - Neuroprosthetic applications
  - Treatment of chronic pain
  - Providing sensory feedback
  - Recording electroneurograms
  - Internal source of neural noise



World Precision Instruments Company

- Impedance Measurement Advantages
  - Cell impedance changes
  - Cuff impedance changes
  - Cuff interaction with cells
  - Adjusting stimulation parameters
  - Giving answer to some events
  - Before, during, after Implantation



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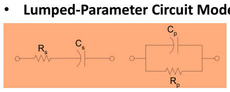
The Method

- Lumped-Parameter Circuit Models (Warburg circuit)



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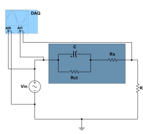

Omid Haji Maghsoudi, et. al., "A Matlab Software to Characterize Electrode Impedances for Neuroscience Applications", Under Review for Publication.

$$\frac{V_{cuff}}{V_{in}} = \Big[\frac{(R_{ct}+R_s)(R_{ct}+R_s+R_e)}{(R_{ct}+R_s+R_e)^2+(2\pi f R_{ct}C(R_s+R_e))^2} + \frac{(2\pi f R_{ct}C)^2(R_s(R_s+R_e))}{(R_{ct}+R_s+R_e)^2+(2\pi f R_{ct}C(R_s+R_e))^2}\Big] + j\times\Big[\frac{-(R_{ct}+R_s)(2\pi f R_{ct}C(R_s+R_e))}{(R_{ct}+R_s+R_e)^2+(2\pi f R_{ct}C(R_s+R_e))^2} + \frac{2\pi f R_{ct}CR_s(R_{ct}+R_s+R_e)}{(R_{ct}+R_s+R_e)^2+(2\pi f R_{ct}C(R_s+R_e))^2}\Big]$$

$$T_1 = (R_{ct}+R_s)(R_{ct}+R_s+R_e)+(2\pi f R_{ct}C)^2(R_s(R_s+R_e))$$

$$T_2 = -(R_{ct}+R_s)(2\pi f R_{ct}C(R_s+R_e))+2\pi f R_{ct}CR_s(R_{ct}+R_s+R_e)$$

$$T_3 = (R_{ct}+R_s+R_e)^2+(2\pi f R_{ct}C(R_s+R_e))^2$$

$$Amp = \frac{\sqrt{T_1^2+T_2^2}}{T_3}$$

$$Phase = tan^{-1}(\frac{T2}{T1})$$

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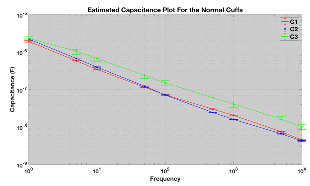
Results

- 3 Bright Platinum Nerve Cuffs
- $2 \times 2 \times 0.025\ mm^3$
- Saline solution, 0.9% NaCl
- NI Elvis board to generate
- Tektronix 1052 TBS To acquire
- 1 Hz to 100 kHz
- Two frequencies per decade
- R_{ct} was 320 ± 72 kOhm
- R_s was 52 ± 15 Ohm

Micro probes for life science

Tektronix Company

National Instrument Company



Limitations

- Manual frequency sweep
- Mistake in reading
- Limited frequency range to be studied
- Required time
- Hard to use for implanted cuffs

Acknowledgements

This material is based upon work supported by the U. S. Army Research Laboratory and the U. S. Army Research Office under contract/grant number 64929EG to A.J. Spence.

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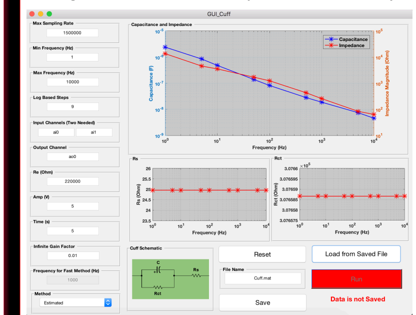
Future Directions

- Design a GUI to measure the Impedance Automatically



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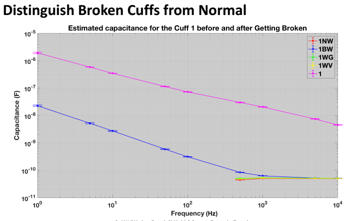
- Distinguish Broken Cuffs from Normal



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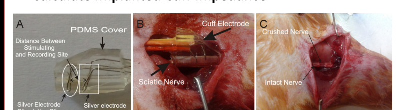
- Calculate Implanted Cuff Impedance



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