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Crosstalk Current Measurements using Multi-Electrode Arrays in Saline

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Abstract — **This paper investigates how the configuration of return electrodes in an electrode array affects the amount of current crosstalk when electrodes are driven simultaneously in saline. Two pairs of electrodes in different return configurations were stimulated with different-amplitude biphasic currents. Stimulating electrodes were controlled by current sinks and current sources while return electrodes were connected to supply voltage or ground. Measurement results show that no matter what return configuration was used, the return current was almost equally distributed amongst the return electrodes, which is problematic in bipolar concurrent stimulation, at least in saline. This result is due to the fact that the spreading impedance of saline solution is small compared to the electrode-electrolyte impedance, which makes the saline solution have almost the same potential. This result suggests that monopolar stimulation using a common remote return electrode be used in simultaneous stimulation to avoid crosstalk.**

I. Introduction

Retinal prostheses using electrical neural stimulation of retinal ganglion cells offer the possibility of restoring partial sight to sufferers of diseases such as Retinitis Pigmentosa and Macular Degeneration where photoreceptor functionality has been lost [1]. Achieving high visual acuity requires a large number of stimulating electrodes and these need to be driven sufficiently quickly. This can necessitate the simultaneous stimulation of a number of electrodes if a sufficient pulse repetition rate is to be achieved without unduly reducing pulse duration. For example, in a 1024-electrode epiretinal prosthesis [2, 3], using a pulse repetition frequency of 60Hz with a biphasic pulse duration of 1ms, on average 64 electrodes need to be driven at one time. This requirement for simultaneous stimulation can have the difficulty that undesired currents can flow in the tissue between pairs of electrodes. There are two main issues. Firstly currents wandering through neural tissue could elicit unwanted percepts. This effect is termed crosstalk. Secondly, charge balance on electrodes could be adversely affected.

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A hexagonal arrangement of electrodes into groups of seven where each centre electrode is driven and the surrounding six electrodes are connected together to form a return electrode has been proposed, simulated [4] and tested in vivo [5].

A neurostimulator chip [6] developed in our Lab allows very flexible selection of return electrodes and the purpose of this paper is to examine the effectiveness of different return electrode configurations on crosstalk. Section II of the paper describes the methods used in the studies, Section III presents measurement results, Section IV presents discussions, and Section IV concludes the paper.

II. Methods

A. Neurostimulator

A neurostimulator has been fabricated using 65 nm Complementary Metal Oxide Semiconductor (CMOS) process. The stimulator is very flexible in terms of providing different stimulation parameters. The stimulator includes 64 electrode drivers which can control 64 electrodes independently. The maximum stimulating voltage is 3V and stimulating current varies from 80nA to about 600µA. Both bipolar stimulation where return electrodes are from the array and monopolar stimulation where return electrode is a remote one are supported by the stimulator. The stimulator allows freedom in selecting return electrodes, and this is the main feature we applied to investigate current crosstalk in different return configurations. More details about this stimulator can be found in our previous work in [6].

B. Electrode Arrays

Two electrode arrays were used in the studies. Their details are in Table 1. The selection of these kinds of electrode arrays helps quickly investigating the current crosstalk issue.

TABLE I. **Electrode Array Specifications**

Parameter	Array 1	Array 2
Electrode diameter	1 mm	250 µm
Shape	Thin disc	Thin disc
Pitch	2 mm	1 mm
Material	Gold	Gold
Number of electrodes	8x8	8x8
Electrode arrangement	Square	Hexagonal

C. Measurement setup

The neurostimulator chip was attached on a printed circuit board (PCB) for easy access to its inputs and outputs.

The chip was controlled from a personal computer (PC) using LabVIEW programs via a data acquisition device made by National Instruments (NI-DAQ USB-6363). Figure 1 shows the measurement setup. The electrode drivers were connected to the electrode arrays on another PCB where cylindrical saline baths were attached surrounding the arrays. The cylindrical baths have diameter of 2.5 cm and height of 3 cm which were half filled with 0.9% physiological saline solution. Current at each electrode was measured via a 1-kΩ series resistor at the output of each electrode driver.

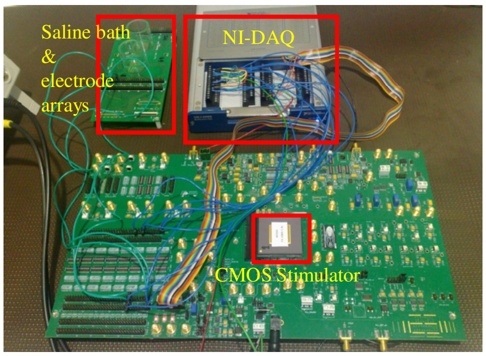

Fig. 1. Measurement setup.

D. *Protocols*

In the stimulator, stimulating electrodes are controlled by current sinks and current sources while return electrodes are connected to supply voltage or chip ground. Any electrode can act as stimulating or return. The remote common return electrode is connected to supply voltage or chip ground only. Figure 2 shows the electrode driver's topology which was used throughout our studies.

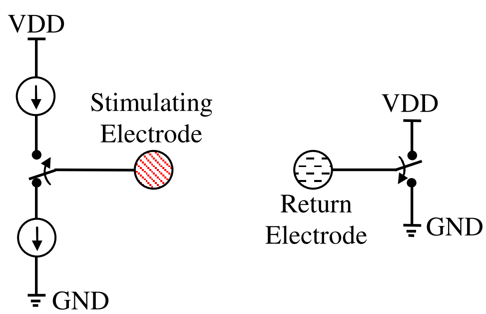

Fig. 2. Electrode driver's topology.

Well-balanced biphasic stimulus currents with amplitudes of 100 µA and 200 µA were used in the measurements. The balance between two phases in stimulus currents was achieved by adjusting the digital input values of the current sources and sinks in bench-test until the matching was found. Stimulus pulse duration was 400 µs per phase, and interphase delay was 50 µs.

Figure 3 shows a protocol where two pairs of electrodes were stimulated. Current amplitudes were 100 µA at one pair and 200 µA at the other pair. The separation between pairs was varied from 2 mm to 14 mm. This measurement was to investigate how crosstalk mitigates over distance.

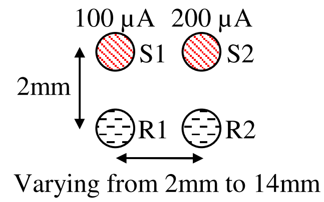

Fig. 3. Protocol for crosstalk current measurement with varying gaps between two pairs of electrodes.

Different single return configurations were investigated as shown in Figure 4. These configurations were tested to see how different relative locations of return electrodes effect current crosstalk.

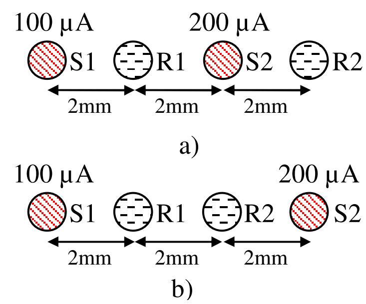

Fig. 4. Different single return configurations.

The neurostimulator supports flexible selection of return electrodes, hence a surrounding return configuration was studied as shown in Figure 5. In this configuration, 2 groups of 9 electrodes were stimulated with the centre electrodes acting as stimulating and the surrounding electrodes functioning as return. This configuration helps looking into whether surrounding return configuration can effectively prevent current crosstalk.

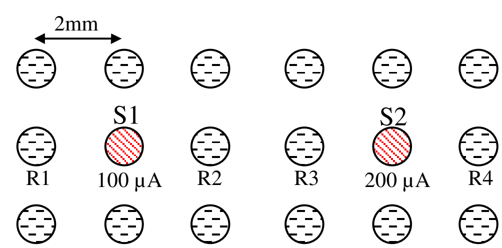

Fig. 5. Protocol of surrounding returns.

Saline spreading resistance can have big affect on current crosstalk due to its high conductivity. Therefore, a protocol to find out saline spreading resistance was also proposed and tested. In this protocol, a pair of electrodes was stimulated with distance between them varied from 2 mm to 14 mm. The current amplitudes were 100 µA and 200 µA.

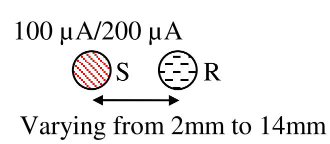

Fig. 6. Protocol for measurement of access resistance and saline spreading resistance.

III. RESULTS

A. Current crosstalk

Current and voltage waveforms were acquired in LabVIEW programs. Figure 7 shows measurement results for the protocol in Figure 3 where gap between two pairs of electrodes was varied from 2 mm to 14 mm. It can be clearly seen that the total stimulating current of 300 μA was split into two almost equal currents flowing in the two return electrodes for all separations, which means the gap between electrode pairs has no effect on current crosstalk. This seems to indicate that the resistance of the physiological saline solution is very low compared with the electrode-electrolyte impedance, which will be investigated further in the next sections. For the different single return configurations shown in Figure 4, the results were the same as when varying distance between pairs, so its results are not shown here.

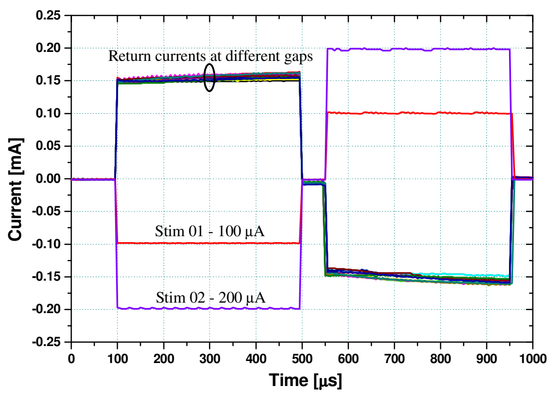

Fig. 7. Current measurement with varying gap between two pairs of electrodes with 1mm diameter.

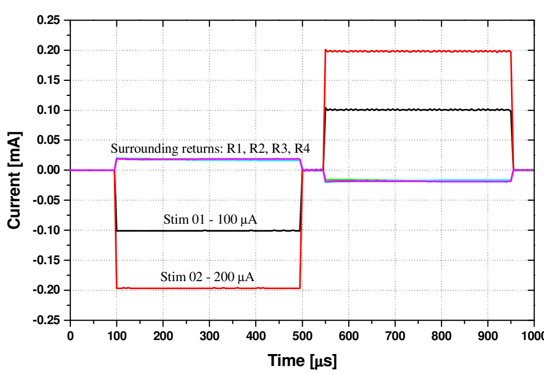

Fig. 8. Current measurement with surrounding returns.

Figure 8 shows current measurements with the surrounding return configurations. The total stimulating current of 300 μA was also distributed equally amongst 16 return electrodes regardless their locations. In the Figure, currents at return electrodes R1, R2, R3, R4 were captured for simplification but not reducing the overall accuracy.

B. Access resistance and saline solution spreading resistance

Figure 9 shows how the access resistance between two 1-mm diameter gold thin disc electrodes in saline varies with electrode separation from 2 mm to 14 mm. It appears that, over this range, the resistance changes by 10 Ω/mm.

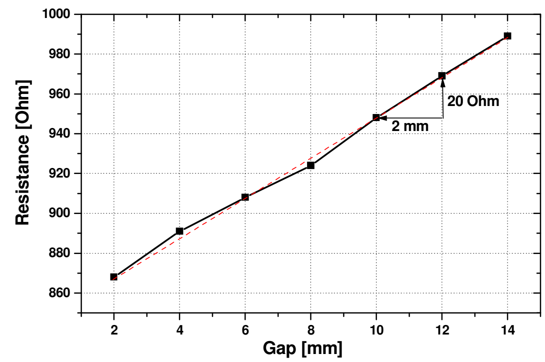

Fig. 9. Access resistance of 1mm gold electrode in saline.

Figure 10 shows the voltage between the electrodes for various electrode separations using a driving current of 100 μA. Figure 11 shows the voltage across an electrode pair using 100 μA. Doubling the current from 100 μA to 200 μA has increased the access voltage by only about 60% and the polarization voltage by only 33%. This indicates the voltage-current behaviour of the electrode-to-electrode impedance is far from linear. Also, it is obvious that the spreading resistance of saline is small compared to the electrode-electrolyte impedance, which makes the voltages almost the same at different electrode gaps.

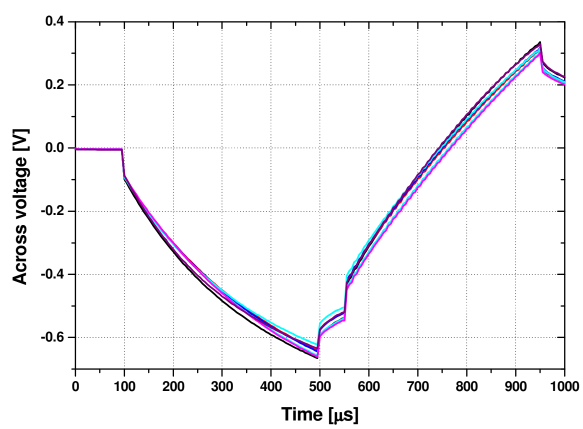

Fig. 10. Voltage across the electrode pair with varying gap from 2 mm to 14 mm when stimulated with 100μA biphasic current.

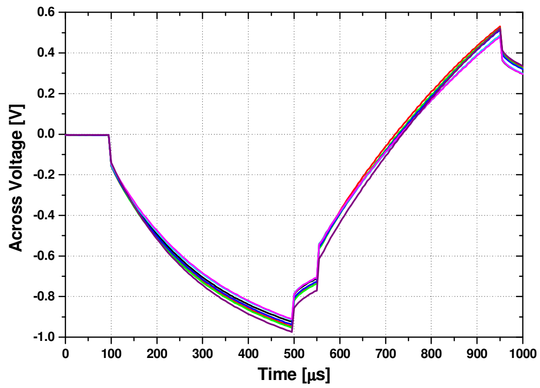

Fig. 11. Voltage across the electrode pair with varying gap from 2 mm to 14 mm when stimulated with 200µA biphasic current.

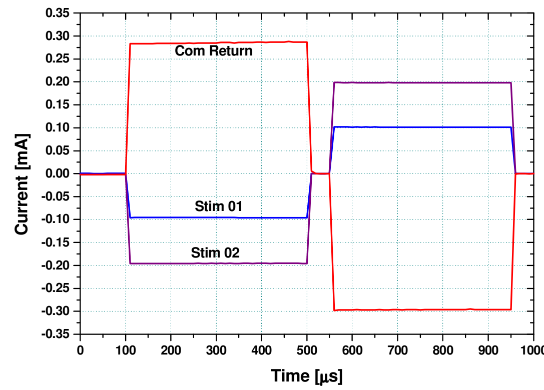

Fig. 13. Current measurement in monopolar stimulation with a common return electrode.

IV. Discussions

The results in which neither electrode distance nor different return configurations helped reducing crosstalk can be explained by the low spreading resistance of saline solution compared to the electrode-electrolyte impedance. Figure 12 shows the modeling of the electrode-electrolyte impedance when stimulated with 2 pairs of electrodes. Z_{ET} is electrode-electrolyte impedance and can be considered the same for all 4 electrode-electrolyte interfaces. From the voltage waveforms in Figure 10 and the results in Figure 9, the spreading resistance of the saline solution is small compared to Z_{ET}, and therefore the whole saline volume can be treated as a single point with only one potential, which causes the current equally distributed amongst the two return electrodes.

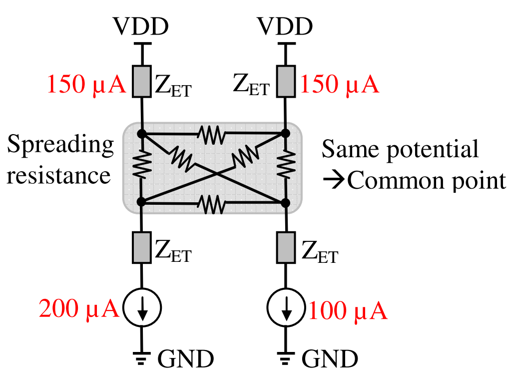

Fig. 12. Modeling of electrode-saline impedance in stimulation with 2 pairs of electrodes.

With the low resistance of the saline solution, configuring return electrodes does not help prevent crosstalk in simultaneous stimulation with the presented electrode driver's topology shown in Figure 2. Therefore, monopolar stimulation where all stimulating electrodes are controlled and only the common return electrode is uncontrolled by connecting to supply voltage or ground should be used for concurrent stimulation. Figure 13 shows currents measured in monopolar stimulation with two stimulating electrodes and one common return electrode. Crosstalk is excluded in this monopolar stimulation.

The main implication of these results for stimulator design is that for concurrent bipolar stimulation it is necessary to control the currents to the return electrodes and thus incur the voltage drop across the current drivers or those return electrodes. Monopolar stimulation should allow concurrent stimulation with no crosstalk while making full use of available voltage.

V. Conclusions

Electrode currents and voltages were measured over a range of geometric parameters in saline. It was found that the electrode voltage-current relation was quite nonlinear at currents of 100 µA and 200 µA for 1-mm diameter gold electrodes in saline.

Crosstalk currents arising in concurrent stimulation were measured using two different multi-electrode arrays in saline. It was found that there was no benefit from configuring those electrodes surrounding the stimulation electrodes to be return electrodes, at least in saline. The combined return currents were found to distribute equally amongst all the return electrodes.

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