Ground Referencing in Multi-Module Closed-Loop Neuroprostheses: Design Challenges and Trade-offs

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***Abstract*— In this work we unpack the challenge of ground referencing in the design of multi-module implantable medical devices. We investigate how device-to-body interference can be mitigated through local grounding to minimise the impact on neural recording. We establish insights into how different ground reference configurations affect noise sensitivity through experimental measurements that are cross validated using a simulation model.**

I. Introduction

The remarkable success of Implantable Medical Devices (IMDs) as therapeutic and prosthetic devices, together with the need for both stimulation and monitoring of biosignal activity, has caused a recent surge in the creation of closed-loop neuroprosthetic devices. This relatively new category of IMDs, in addition to neuromodulation, also requires simultaneously front-end neural recording, signal conditioning, and real-time processing. The recent FDA approved and clinically available examples include": Medtronic DBS Activa PC+S (for Parkinson's) and NeuroPace Responsive Neurostimulation (RNS) system (for epilepsy). A key challenge in closed-loop devices is the need to observe biopotential signals in the levels of few microvolts through long implanted leads in presence of artefacts. To address this, a new generation of implantable medical devices is now emerging. Instead of a centralized approach that uses a single active implantable device, the system is now being partitioned and distributed across multiple active IMDs, each with specific functions, and located at different sites (concept shown in Fig.1).

II. Ground Reference Challenge

The active modules within the IMD system need to have DC isolation from each other to avoid direct current paths between them. This means each implantable module has its own power domain, and therefore different reference/ground potentials exist between the different circuits. The human body additionally has its own electric potential, which needs to be considered when dealing with ground referencing in neural implant networks. This is because the displacement (or clamping) of these different potential references may affect device reliability as well as patient safety. Moreover, ground referencing also has a significant impact on the recording performance. In the presence of multiple noise sources – including stimulation artefacts, inter-module communication interference, body potential fluctuation, a carefully designed ground reference can help to reduce coupling

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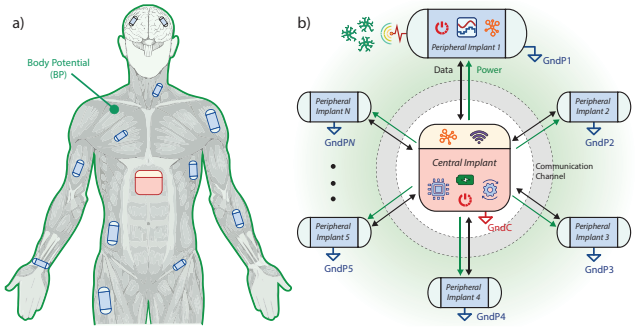

Fig. 1. Concept of the multi-module implantable system. (a) Conceptual body model with a distributed implant system; (b) iter-module connectivity.

of such noise sources to the front-end sensing circuitry, thus improving recording quality.

The work discussed hereby is part of the CANDO* Project, which aims to develop a first-in-man trial of a multi-module cortical implant to treat focal epilepsy using a closed-loop optogenetic system.

III. Methods and Results

Three ground referencing schemes are identified: (1) passive; (2) drive; and (3) sense. While the first scheme uses a hard connection between the module ground and body potential, the other two require active interfacing circuits. Such circuitry is implemented within a prototype of the CANDO closed-loop device, and experimental tests of the implant system are performed in a phosphate-buffered saline (PBS) solution in order to evaluate the recording quality in the three different schemes. The recording system is implemented using a differential amplifier that is capacitively-coupled to the PBS solution. Noise sources, for example due to communication and stimulation artefacts, are emulated using an external signal source in order to observe, measure and quantify each of the effects. Results reveal noise sensitivity of the recording to the different ground referencing parameters. A SPICE model of the system is then simulated to cross validate and reveal further insights such as technological constraints and non-idealities of the device-tissue interface.

References

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