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XXXVII Cycle

Smart Active Implantable Medical Devices towards precision medicine

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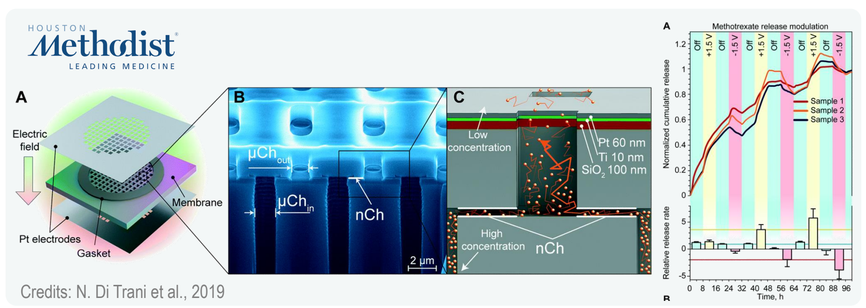
Research context and motivation

- Active Implantable Medical Devices (**AIMDs**) treat pathologies with minimal impact on the patient's everyday life.
- This research work focuses on two non-clinical stage AIMDs.
- Nanochannel Delivery System (**nDS**) is a **drug delivery** device, to maintain optimal plasma concentration of drugs. It is based on a voltage-controlled silicon membrane.
- **ReWire** is a **nerve bypass** for functional recovery after peripheral nerve injuries. It is based on a bidirectional neural interface, capable of both neural recording and stimulation.
- The objective is to **enable their chronic in-vivo study**.



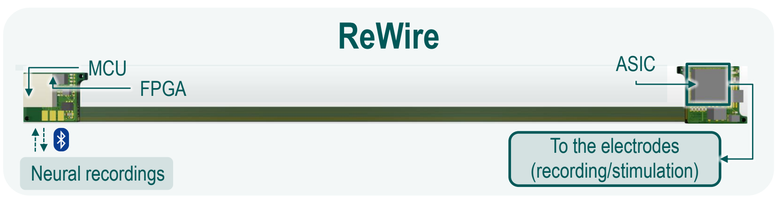
Credits: N. Di Trani et al., 2019

Credits: I. Williams et al., 2016

Novel contributions

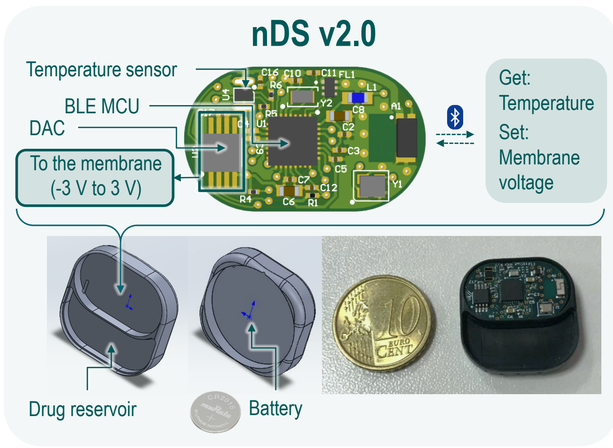
ReWire

- Implantable **rigid-flex PCB** for fully in-vivo recordings through transdermal port



nDS

- Development of **nDS v2.0** system with BLE MCU, **power efficient HW/FW** design, featuring:
  - Introduction of **temperature sensing**
  - Increase of membrane **voltage range**

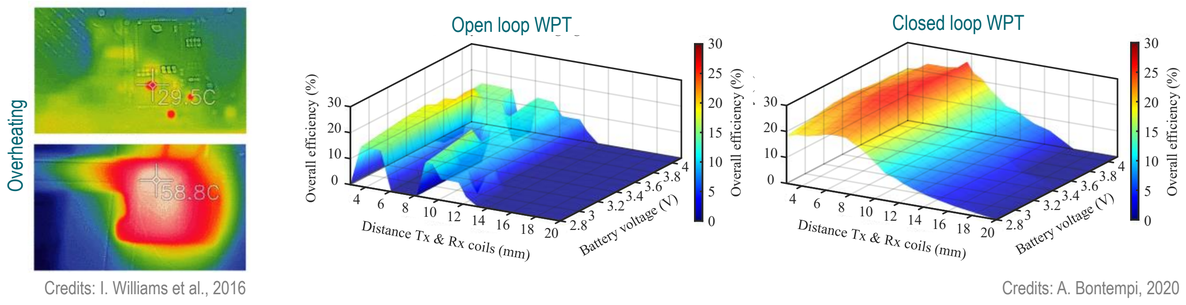


WPT

- Development of BLE-based closed-loop Near-field Resonant Inductive Coupling (**NRIC**) WPT starting from COTS system
- Application of the WPT system to the nDS **battery recharge**, exploiting onboard MCU

Addressed research questions/problems

- Fulfil the **miniaturisation** and **low-power** demands, and guarantee **long-term** implantation and **remote control,** for both nDS and ReWire.
- Improve nDS, refining control on membrane and introducing feedback from the implant.
- Design ReWire for compliance with in-vivo neural recording with cuff electrodes.
- Remotely power both devices, overcoming limitations of commercial off the shelf (COTS) inductive Wireless Power Transfer (**WPT**) systems, like overheating and limited efficiency on low-power (<100 mW) applications.



Credits: I. Williams et al., 2016

Credits: A. Bontempi, 2020

Adopted methodologies

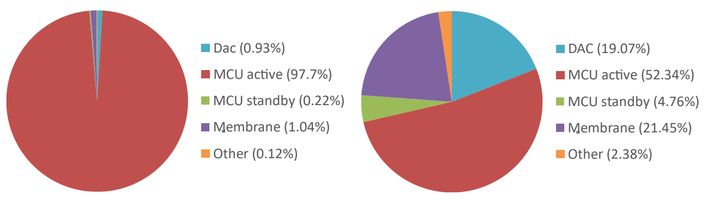
nDS v2.0:

- Employment of **power-efficient COTS** components.
- Dual-channel 12-bit ULP DAC was chosen for membrane control as a trade off between size, power, and MCU power mode and DIOs required. Previously, only 4 membrane voltage levels were admitted.
- **BLE application** was adjusted to manage membrane voltage and temperature measurement.
- The device exposes voltage, temperature and battery data directly in the **advertising** packets, saving power.
- Expected battery life is increased by >200%.

nDS Bluetooth profile

- Membrane voltage (R/W)
- Temperature (R/N)
- Measurement interval (R/W)
- WPT recharge power (N) [v3.0]

Power consumption summary



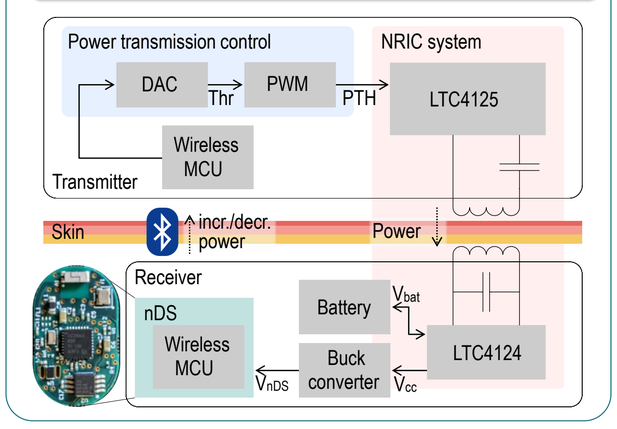
Closed-loop WPT

- NRIC, resonant frequency 200 kHz, coil diameters 17 mm (Rx) and 20 mm (Tx).
- nDS MCU measures the received power (comparing V_{cc} and V_{bat}), providing **feedback via BLE** to the transmitter.
- Efficiency optimised **reducing TX power**.

System performance:

- Overall efficiency in air between **25-30%** at 6.5 mm, safe temperature increase.
- Complete Lithium-ion battery (LIR2025) CC-CV charging with 10 mA current achieved in **250 min**.
- 25 mAh battery allows for up to 500 recharges, with projected **chronic duration >6 yrs**.

Closed loop wireless power transfer



d (mm)	nDS	P_{TX} max. (mW)	P_{RX} max. (mW)	η_{AVG} (%)	ΔT_{RX} max. (°C)	ΔT_{RX} max. (°C)
2.5	No	160	40.0	21.3	1.3	2.0
2.5	Yes	250	64.9	23.9	2.5	2.1
6.5	Yes	210	65.4	26.0	2.1	1.4

List of attended classes

- 02SFURV – Programmazione scientifica avanzata in matlab (26/05/2022, 6 CFU)
- 01QEZRV – Sviluppo e gestione di sistemi di acquisizione dati (23/09/2022, 5 CFU)
- 01LEXRP – Strumenti e tecnologie per lo sviluppo del prodotto (28/06/2022, 5 CFU)
- 01UIZRV – Microwave sensing and imaging for innovative applications in health and food insustry (22/03/2022, 4 CFU)
- 01RGGRV – Telemedicine and distributed healthcare (22/03/2022, 4 CFU)
- 01RHCRR – Principi, materiali ed applicazioni della robotica nella biomedicina (30/05/2022, 4 CFU)
- 01DNHRV – System level low power techniques for IoT (15/07/2022, 4 CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (03/08/2022, 1 CFU)
- 02LWHRV – Communication (31/01/2022, 1 CFU)
- 01SYBRV – Research integrity (03/08/2022, 1 CFU)
- 01RISRV – Public speaking (28/1/2022, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (03/08/2022, 1 CFU)
- 08IXTRV – Project management (03/08/2022, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (03/08/2022, 1 CFU)
- 01SWPRV – Time management (27/01/2022, 0.4 CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (03/08/2022, 0.4 CFU)
- 01UNYRV – Personal branding (03/08/2022, 0.2 CFU)

Submitted and published works

- Del Bono, F. , Bontempi, A.,Di Trani, N., Demarchi, D., Grattoni, A., and Motto Ros, P., "*Wireless Power Transfer Closed-Loop Control for Low-Power Active Implantable Medical Devices*", IEEE SENSORS 2022, Dallas TX (USA), 2022 [Accepted]
- Del Bono, F., Rapeaux, A., Demarchi, D., and Constandinou, T., "*Translating node of Ranvier currents to extraneural electrical fields: a flexible FEM modeling approach*", 2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC), Guadalajara (Mexico), 2021, pp. 4268-4272

Future work

nDS

- Towards version 3.0, with the inclusion of WPT system in the power management block of the PCB. Implementation of closed loop through BLE ADV data to reduce TX power. HW implementations to reduce current peaks during radio events, to extend battery life.

WPT

- Miniaturisation of the system, with use of smaller coils and 13.56 MHz resonant frequency.

ReWire

- Firmware development for neural recording and communication, application of the closed loop WPT system for batteryless powering during in-vivo experiments.

Politecnico di Torino

PhD program in
Electrical, Electronics and Communications Engineering