

Summary

This thesis explores Wireless Power Transfer (WPT) technologies for emerging wearable and implantable applications, with an emphasis on design methodologies ranging from macro-scale devices to miniaturized biomedical systems. The work is divided into three primary domains, each associated with a research project: a wearable safety system (SPAS4S project), a subcutaneous drug delivery implant (nDS project in collaboration with Houston Methodist Research Institute), and a miniaturized neural interface for new brain imaging technology (EU CEREBRO project).

The first part investigates the suitability of RF-based WPT for Smart Personal Protective Equipment (Smart PPE). The wearable system is battery-free, powered via wireless by exploiting the RF communication of UHF-RFID. It is capable of receiving power from several meters away and monitoring the correct use of personal protective equipment in real time.

The second part presents a resonant inductive WPT solution designed for a subcutaneous nanofluidic drug delivery system. It focuses on the development of an adaptive closed-loop control mechanism for optimal power transmission under dynamic operating conditions. Regulating the transmitted power is crucial for enhancing system efficiency while ensuring that temperature rise remains below 2°C.

The final section presents the CEREBRO project, which aims to realize a new type of medical neural imaging that can have both good spatial and temporal resolution in real time of neural activity without craniotomy. Two distinct approaches were explored: an active solution and a passive one. The active approach tackles the challenge of powering ultra-miniaturized free-floating neural implants. The active solution incorporates a low-noise amplifier and a voltage-controlled oscillator to upconvert neural signals from low to high frequencies. Special attention is given to simulation. For power transmission, WPT systems employing miniaturized coils and magnetoelectric antennas were investigated, with device dimensions ranging from $200 \times 200 \mu\text{m}^2$ down to $10 \times 10 \mu\text{m}^2$. The passive approach explores a minimalistic solution based solely on the nonlinear behavior of a diode. By applying an external high-frequency carrier signal to the brain, the diode injected into the brain acts as a frequency mixer, converting low-frequency neural signals into a

higher-frequency domain. This technique eliminates the need for conventional amplification stages, significantly simplifying the system architecture. Experimental validation was carried out to assess the viability of passive frequency translation as an effective alternative to traditional active solutions.

WPT systems for biomedical applications still encounter significant challenges, particularly in implantable and wearable technologies. For implants, miniaturization is the main obstacle, requiring solutions that are minimally invasive, biocompatible, and capable of stable long-term operation. As device dimensions shrink, ensuring efficient, safe power delivery without overheating becomes increasingly complex. The integration of power, sensing, and communication components in a tiny footprint demands advanced materials and novel design strategies. Wearable devices, while less constrained in size, must maintain low power consumption, high user comfort, and reliable operation over extended ranges. Their use in dynamic environments makes wireless power link stability a key concern. Overcoming these issues requires interdisciplinary collaboration and co-design across multiple fields to enable the next generation of safe and efficient WPT systems.