Towards Batteryless Wearables and Implants

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***Abstract*—Powering of wearables and implants is a critical challenge. Conventional batteries are rigid and require frequent recharging and/or replacement, making their use cumbersome and obtrusive for body-area applications. Instead, this paper discusses three novel technologies that we have recently explored towards batteryless wearables and implants, viz. a) DC power generation using fabric electrochemistry, b) RF power harvesting, and c) fully-passive RF backscattering. Notably, the proposed technologies bring forward transformational possibilities in batteryless sensing and stimulation.**

Keywords—batteryless, wireless powering, power harvesting, RF backscattering, wearables, implants, electrochemistry.

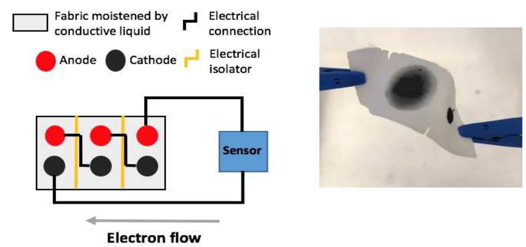
I. Introduction

Wearable and implanted electronics are recently gaining significant attention for a wide range of applications (medical, sports, tracking, consumer electronics, etc.) [1],[2]. Such devices may operate as sensors of human vitals (temperature, glucose levels, brain signals, etc.), or as stimulators of the central or peripheral nervous system. In either case, powering of wearables and implants is a critical challenge. The conventional way of powering such devices entails use of batteries. Expectedly, batteries are typically bulky and rigid, and require frequent recharging and/or replacement. As such, they are cumbersome, obtrusive, and thus, undesirable for body-area applications.

With these in mind, this paper discusses three novel technologies that we have recently explored towards batteryless wearables and implants, viz. a) DC power generation using fabric electrochemistry, b) RF power harvesting, and c) fully-passive RF backscattering. Notably, the proposed technologies bring forward transformational possibilities in batteryless sensing and stimulation.

II. DC Power Generation Using Fabric Electrochemistry

We have recently introduced a new class of electrochemical fabrics which, when moistened by a conductive liquid, generate DC power capable of powering wearable electronics [3]. Contrary to conventional rigid power generation techniques (batteries), the proposed electrochemical fabrics are fully-flexible, feel and behave like regular clothing, do not include any heavy or rigid components, and provide DC power via moistening by readily available conductive liquids. Generation of DC power is achieved via a redox reaction, which occurs between the Zinc to Silver Oxide-printed electrodes (anodes and cathodes), facilitated by a conductive liquid that enables electron movement. These anodes and cathodes are ‘printed’ onto the flexible fabrics with the use of polyvinyl binders, and can further be inter-connected via conductive E-threads to boost the generated voltage/current.



(a) (b)

Fig. 1. (a) Proposed concept of ‘printed’ battery cells wired in series on a fabric connected to a sensor, and (b) a single ‘printed’ battery cell deposited on a fabric as a proof-of-concept.

Fig. 1 (a) shows the proposed concept of inter-connecting multiple ‘printed’ batteries on flexible fabrics, while Fig. 1 (b) shows a single ‘printed’ battery cell created as a proof-of-concept. Notably, the latter single cell has been demonstrated to generate voltage and current levels as high as 1.4 V and 100 μA, respectively. Higher voltage and current levels can be achieved in future via the inter-connections mentioned above.

III. RF Power Harvesting

Wireless activation of implanted stimulators/actuators can significantly improve their practicality and unobtrusiveness while dissolving critical concerns associated with patient safety. As an example, Fig. 2 shows an implanted and wirelesss actuator placed right under the skin, and incorporating a miniaturized implanted antenna and a rectifier (rectenna). The first is responsible for capturing the Radio Frequency (RF) waves transmitted by an exterior antenna placed in close proximity, and the latter converts the RF energy to DC. This DC power may then be either stored in a low-leakage capacitor as in [4], or used in real-time for medical device actuation. The external transmitter can be placed in very close proximity to the implant and fabricated on e-textiles for unobtrusive integration into shirts, wrap-around garments, etc.

A proof-of-concept implanted and batteryless actuator has already been demonstrated. At this stage, it occupies a 15 mm x 25 mm footprint, and can be encapsulated into polymers for biocompatibility and improved matching. We have also demonstrated low power rectifiers with conversion efficiency above 70% [5]. In this particular case, the RF device operated at 2.4GHz.

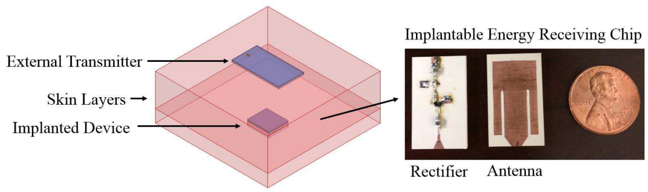


Fig. 2. RF power harvesting technology used to activate a batteryless device implanted inside the human body.

IV. Fully-Passive RF Backscattering

Fully-passive RF backscattering is recently gaining significant attention in the area of batteryless brain implants. The conventional way of detecting deep brain signals relies on integrated circuits (IC) chips [6]. However, the latter consist of a multitude of power-hungry components (pre-amplifier, multiplexer, analog-digital converters etc.), that require batteries and generate excessive amounts of heat in the surrounding tissues. As an alternative, we recently proposed batteryless and wireless brain implants that rely on fully-passive RF backscattering for signal acquisition [7]-[9].

The block diagram of our proposed neuropotential monitoring system is depicted in Fig. 3. The system is comprised of two sub-systems: the brain implant and the exterior interrogator. The interrogator sends a carrier (2.4GHz) to activate the implant. That, in return, detects the neural signals (f_{neuro}). To receive these signals at the interrogator, they are first mixed with the carrier at the implant prior to transmission. To do so, we employed an anti-parallel diode pair (APDP) mixer within the implant. The latter captures both positive and negative legs of the 2.4GHz carrier, allowing for high-efficiency harmonic mixing at 4.8GHz. We note that the latter is a unique aspect of our design. Subsequently, the mixed (4.8GHz$\pm f_{neuro}$) signal is transmitted to the exterior interrogator. The ~2X difference in frequency between the transmitted (2.4GHz) and received (4.8GHz$\pm f_{neuro}$) signals is used for isolation. For wireless communication, a dual-band (2.4/4.8GHz) patch antenna is employed both in the implanted device and interrogator. The designated geometry of the patch antenna and the matching circuit between the APDP and antenna further reduce the transmission loss and mismatch loss respectively. The reduced system loss enhances the sensitivty to $20\mu V_{pp}$, implying detection of almost neural signal generated by human body. The received signal on the interrogator can eventually be viewed on a spectrum analyzer (frequency domain) or on a oscilloscope (after demodulating in time domain).

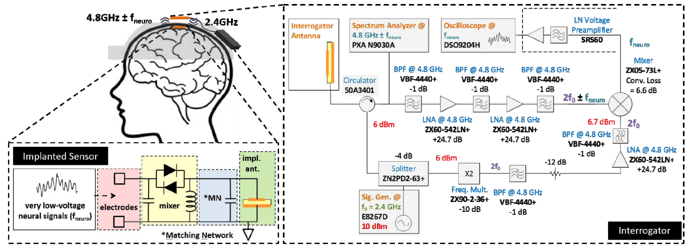


Fig. 3. Fully-passive RF backscattering technology used to collect deep-brain signals via a batteryless implant.

V. Conclusion

This paper discussed three novel technologies used for unobtrusively powering wearables and implants, viz. a) DC power generation via fabric electrochemistry, b) RF power harvesting, and c) fully-passive RF backscattering. At the conference, we will show experimental proof-of-concept results for each of these methods. Overall, the proposed technologies are expected to be of utmost significance for powering electronics in several military, healthcare (e.g., electroceutical), entertainment, arts, sports, and emergency applications, among others.

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