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# Multi-purpose and multi-source energy management system for biomedical implants

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**Abstract**

This paper describes a multi-purpose energy management system that can harvest energy from a multitude of power sources. In order to suffice power needs of a smart hip prosthesis, a prototype was built considering the use of two types of power sources: energy harvesting micro-power generators for intermittent implant electronics powering; wireless energy, by means of an activation system, responsible for, when needed, continuously powering the implant electronics and also configuring its mode of operation. Intermittently or continuously, it is now possible to energize more power demanding systems as the ones that uses a RF transceiver. The smart hip prosthesis can now become a wireless body sensor network node using LR-WPAN protocols such as Bluetooth low energy as is intended in this work. Preliminary results proved that is possible to energize a Bluetooth low energy module, for over 100 s, solely using the stored energy produced by one of the micro-power generators.



Keywords: Energy harvesting; power management; wireless communications

## 1. Introduction

More and more energy harvesting solutions are being presented as the natural way of powering devices that are ubiquitous in the environment as biomedical implants. As they become more efficient when converting energy, more electrical energy becomes available which widens a range of functions that a smart implant can implement. It's now possible energize systems that make use of LR-WPAN protocols, such as Bluetooth low energy protocol, a possible solution to connect a biomedical device to create a Wireless Body Sensor Network (WBAN) [1], which opens a wider range of new implementations not possible before. Nevertheless, and since energy is not always present or abundant, any chunk of energy must be harvested and preserved so it can be made available when needed. Efficient power management systems are then essential, especially in systems that make use of harvested energy through micro-power generators such as smart implants. This paper describes a power conditioning architecture used to convert multiple energy sources to suffice a smart hip prosthesis power need.


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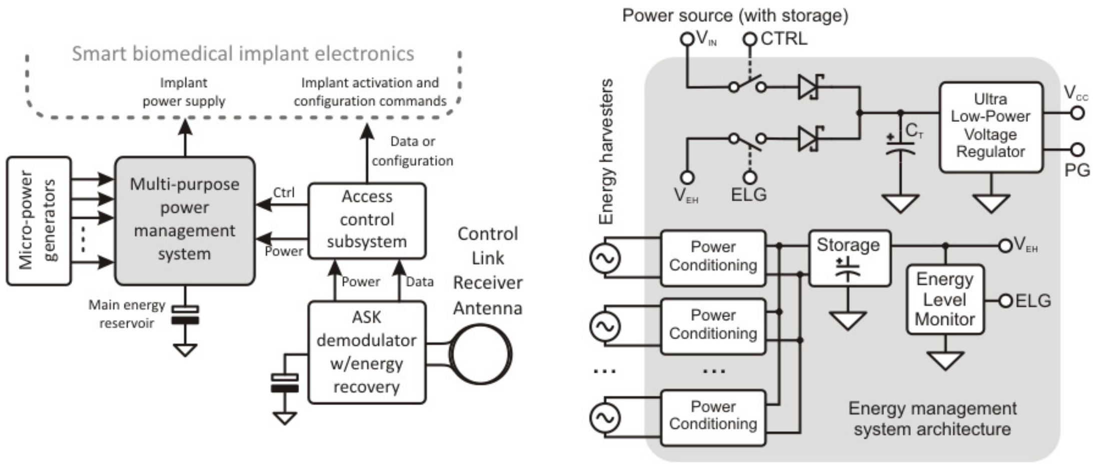
## 2. System overview and power management system

The smart prosthesis implant is composed by 4 main modules: an acquisition and data processing module with RF communication capability, an activation circuit [2], an energy harvesting module, and the power management module, all schematically described in Fig. 1 (a). The electronics of the implantable system was redesigned from previous versions [2], introducing the use of a multi-sourced micro-power generators scheme and a Bluetooth low energy System-on-Chip (SoC) solution for data acquisition and communications. With this solution, the smart hip prosthesis can now establish a low-power, low-range wireless communication with other Bluetooth v4 compliant devices such as iPhone 4S.




(a) (b)

Fig. 1 (a) System overview; (b) Power conditioning module architecture

As depicted in Fig. 1 (b), the power conditioning system was developed so it can manage the energy provided by some already installed micro-power generators. Each generator has its own power conditioning sub-module in order to optimize the efficiency of each energy harvester. Any active generator contributes to the fulfilling of a main energy reservoir. An energy level monitor is permanently monitoring the energy level of the storage element and when it reaches a pre-established high level its energy is delivered to the load through an ultra low-power and low dropout, voltage regulator. When the stored energy decreases below an also pre-established low voltage level, the energy level monitor restrains the use of the remaining energy. This procedure allows a faster recovery to ready state by avoiding the complete discharge of the reservoir element.

It should be noted, as seen in Fig. 1 (b), that power management system can also retrieve energy from a power source that includes its own energy storage element. There are two main reasons to include this possibility: patient examination for extended periods and; when implant remote configuration is needed. In these cases, a constant, stable and without interruption, power source is required. However, this condition cannot be guaranteed since energy source is random in nature. In the presented architecture, this stable power source is achieved by the activation system which receives energy, by wireless means through an inductive link.

## 3. Micro-power generators

In order to suffice the required power needs of the presented implantable system, three micro-power energy harvesting generators were developed and implemented inside a hip prosthesis (Fig. 2). Two of them are based in the electromagnetic principle [3] and the third one uses the piezoelectric effect [4]. The electromagnetic generators make use of the available kinetic energy when the patient is in motion. The piezoelectric one makes use of the forces available on the head of the prosthesis.

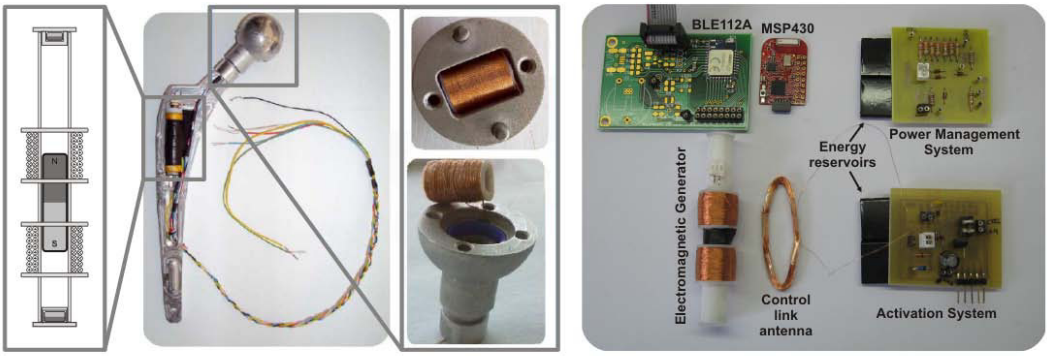
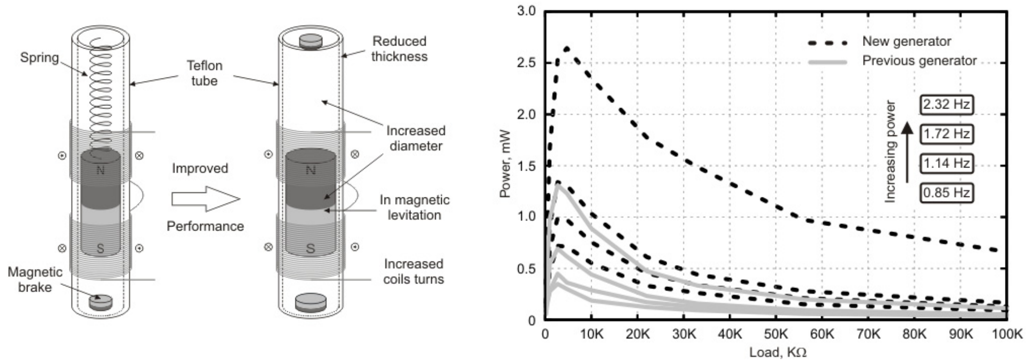



Fig. 2 Micro-power generators developed to work alongside the multi-purpose power management system

The biggest generator, based in the translation movement, is placed in the body of the prosthesis. This generator was widely improved, Fig. 3 (a), from previous versions [5], and converts more the double of energy than the previous one, as depicted in Fig. 3 (b). The main improvements are described in Fig. 3 (a). Currently this generator is being modeled using non-linear techniques [6] for further improvements.



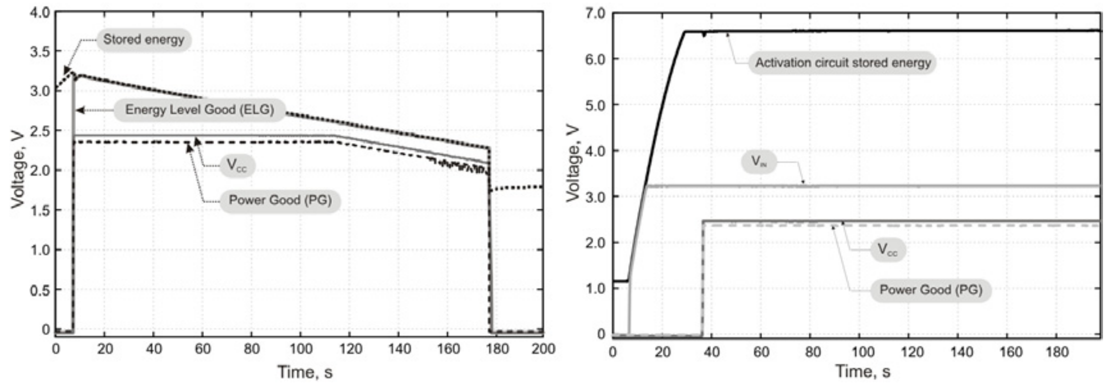

(a) (b)

Fig. 3 (a) Improvement procedures to the translation based electromagnetic generator; (b) Comparison between generator versions

The second generator is based in the rotational movement available in the head of the prosthesis. A set of magnets are embedded in the acetabulum and the coil is located inside the head of the prosthesis. The amplitude and angles of movement makes it possible to produce electrical energy yet in lower densities when compared with the previous generator. The third generator uses a piezoelectric transducer and is placed between the inferior half of the femoral head and the neck of the prosthesis. This generator also produces less energy than the one produced by the first electromagnetic generator.

## 4. Experimental results and discussion

A prototype was developed (Fig. 2), in order to test the generator in use and the functionality of the power management system. As the electrical load, two different RF transmission modules were used: a MSP430 eZ430-RF2500 module and a BLE112A$^{TM}$ Bluetooth low energy SoC module from BlueGiga. The analysis of the results presented in figure 4 (a) proves that it is possible to energize such modules, with a constant voltage for over 100 seconds solely by using the energy produced by the generator. When using the energy from the activation circuit, Fig. 4 (b), the modules can be energized without interruption.




(a) (b)

Fig. 4 (a) Wireless module energized by one generator; (b) Wireless module energized by the activation system

## 5. Conclusion

This paper has described a multi-purpose and multi-sourced power management system capable of supply energy to more power-demanding devices such as the ones that uses RF transceivers. Although with different energy densities, each generator contributes to recharge the main storage element, allowing better use of available energy and data transmission in a hypothetical scenario of a WBAN, created with implantable devices that use standards such as Bluetooth Low Energy. Each of the generators is being optimized for the types of movements that are exploited in energy conversion. The electromagnetic generator is being modeled using nonlinear techniques to further optimize energy conversion in low-frequency and low amplitude movements.

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