

ENHANCED WIRELESS POWER TRANSFER SYSTEM FOR IMPLANTABLE MEDICAL DEVICES

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Abstract: An implantable medical device to monitor the vital signs such as blood pressure, pulse rate, body temperature and respiration rate is developed and its performance is estimated. A rechargeable battery is also embedded with the device so as to support uninterrupted monitoring of the signs. The status of the battery can also be monitored externally. The information gathered by the device is transmitted to the PC or mobile with the help of RF transceiver and a portable Wi-Fi based module. The system is optimized to operate at a nominal input power, achieve quick response and provide accurate output.

Keywords: Implantable Medical Devices, Wireless Power Transfer, Wireless Charging, Biomedical Instruments

1. INTRODUCTION

Wireless transfer of power from a source to a destination can be done in the absence of interconnecting cords via electromagnetic energy through air medium. Due to better user experience and convenience, from high power electric automobiles to low power toothbrushes, this technology has been attracting several applications [1]. Neural recording and retinal prostheses based implantable medical devices (IMDs) use wireless power transfer (WPT) in order to avoid the usage of bulky batteries [2]. The high efficiency and inductive-near field coupling features makes WPT the best choice for near-skin IMDs. These implants require power in the range of 10-100mW.

Enhancement of safety of patients and healthcare professionals, reliability improvement in rechargeable implant devices, facilitation of implant surgeries where it is impossible to use interconnecting wires, and several such biomedical applications has drawn remarkable attention towards WPT [3]. The technology also ushers its way into the medical devices of the new generation due to its increasing efficiency and safety. Cardiac pacemakers, endoscope, capsule robots and other micro medical robots can be recharged with the help of cordless power transmission [4].

In comparison to non-implantable devices, the size of implants are very small. This leads to low system efficiency due to smaller receiving coils and weak coupling between the receiving and transmission coil [5]. A regulatory metric termed Specific Absorption Rate (SAR) is to be considered during utilization of wireless powering technology and IMDs as it causes crucial safety concerns such as tissue heating [6]. The demand of consumption for IMDs is around 5% in industrialized countries and it is experienced by around 10% citizens in America [9].

The operation of certain devices are restricted based on the battery longevity or device size [13]. Several IMD applications require lifetime operation. Wireless recharging is the optimal solution even with the use of implanted batteries. Due to these the features of WPT, the risks of transcutaneous wiring or surgery for battery replacement can be avoided. Several energy transfer means such as electromagnetic waves, Radio-Frequency, biological sources, ultrasound and so on can be used for this purpose. Since magnetic field does not affect the biological matter, it is the most preferred type of power transfer [15]. This technology is advancing at a fast phase that even artificial hearts are discussed on this context as medical implantable microsystem (MIM) [20]. Visual prosthesis and ingestible devices are other MIM systems that can use WPT.

2. LITERATURE REVIEW

Ahire et al [1] improved the distance of power transfer and improved the efficiency by optimization of compensation network, frequency selection, circuit structures and coil parameters. Xing Li et al [2] worked on improving the fast load-transient response and energy efficiency by proposing backscattering uplink techniques based on the rectifiers mode switching characteristics. The maximum receiver efficiency obtained is 92.6% and maximum power is 102mW. The settling time for huge load transients is less than 130s and less than 110mV for overshoot and undershoot.

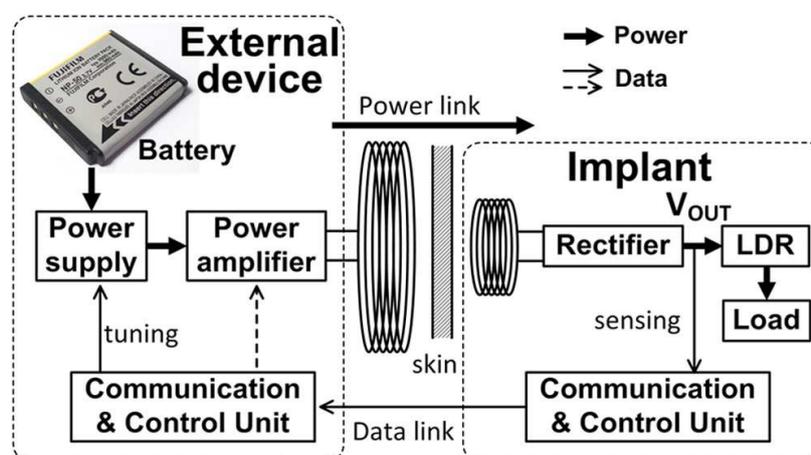


Figure 1: Wireless power transfer (WPT) system for IMDs [2]

Zhenzhong Chen et al [3] investigated a WPT for biomedical applications. The paper studies an implantable antenna with improved gain for receiving signals. With this, a transmission antenna array is designed that can enhance the power transmission efficiency of the system. 0.28% is the maximum value achieved by the system within a 150mm transmission distance at centre frequency. This system offered higher efficiency of power transfer when compared to the existing systems. This system can also be employed immediately for charging IMDs.

Chunhua Lie et al [4] recommended a sandwiched WPT that offered a 5W stable power for charging various types of IMDs. This system is shown in Figure 2. Siyu Peng et al [5] presented a dedicated optimized parameter design for a 6.78MHz IMD-WPT system. The paper also derives the accurate input impedance of the matching networks transmitting coil.

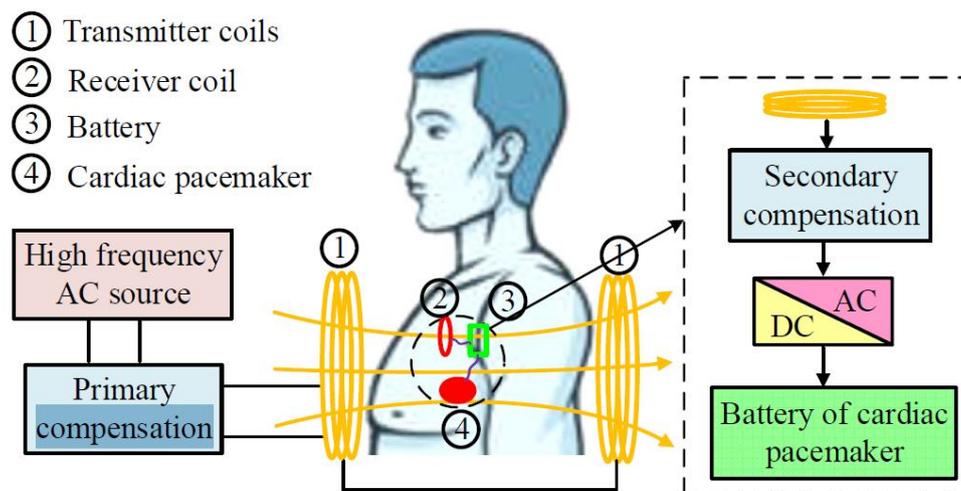


Figure 2 WPT with stable power [4]

Xin Zan et al [6] used piecewise resonant wireless power transfer (PR-WPT) for achieving reliability, simplicity and efficiency in WPT. The system uses a 6.78MHz class D amplifier operating in current-mode for the generation of peak-to average power ratio (PAPR) waveform. Using analysis of closed-form impedance and the waveform's harmonic elimination, a passive 4th order filter is coordinated to the transmitter's third harmonic and fundamental voltages. The conversion of matched voltage into its corresponding DC component is done by a full-bridge Schottky rectifier. The efficiency of the rectifier is increased with a 30% increase in DC output voltage by the use of PR-WPT technique.

Xiu Zhang et al [9] introduced a WPT system with three coils for the purpose of improving the distance of power transfer to IMDs. The paper uses a memetic algorithm to optimize the shape and size of transmitter and receiver coils when the distance of power transfer and size of the receiver coil is predefined. Anil Kumar et al [13] recompensed the contrary low coupling effects amongst the load coils and source by the high quality factor using resonance based coupling method. The authors use a four-coil WPT system to overcome the drawbacks of the traditional two-coil system. In the traditional system, the distance between the coils largely affects the efficiency of power transfer by. The four coil system overcomes this drawback and provides optimization even if the operating distance is large.

Erik Gamez et al [14] Enhanced the efficiency of power transfer in resonant inductive coils used in IMDs by means of negative permeability slab. Along with a meta-material, a WPT system that is resonant and inductive is built. Efficiency of the WPT system is discussed on the availability and unavailability of the meta-material design. John S Ho et al [15] performed a survey for optimization of efficiency by near-field power transfer and related techniques. In mid electromagnetic fields, it is possible to achieve higher efficiency using analytical models. It is feasible to use millimetre sized modules in case of cardiac implants by optimizing the source.

Md. Rubel et al [16], in his paper titled, “An Improved Wearable Resonant Wireless Power Transfer System for Biomedical Capsule Endoscope.” Presented an advanced wearable WPT system for applications based on wireless capsule endoscopy. For enhancing the performance of the system, the authors used a 3-coil inductive WPT. The system uses the configuration of combining powers with 2-3D coils for receiving power. This system offers better stability of received power and efficiency of power transfer. With a transfer of 758mW power, the system offered 8.21% efficiency with the help of power transfer coil (PTC). The power stability was improved by over 10% with this system in comparison with the existing system.

Farid Jolani et al [17], in the paper “Design of Wireless Power Transfer Systems Using Magnetic Resonance Coupling for Implantable Medical Devices” discusses systems with different receiver and transmitter coil sizes. Pacemakers and such tiny IMDs can use this system and the paper promises over 50% of transfer efficiency even in reduced size of receiver coil up to 2.5cm. Guoxing Wang et al [18] proposed a retinal prosthetic system that is implantable and uses a closed loop inductive WPT technology. Despite the load current variations and displacement in coil, optimal power transfer is ensured and the sensitivity to process and component variation is minimized.

Yue Yu et al [19] enhanced the relationship between conversion efficiency, load resistance and coupling coefficient by presenting an inductive transcutaneous WPT technique that uses two compensative capacitors, one in series and another in parallel as primary and secondary coils respectively. Je-Dok Kim et al [20] summarized

the major design deliberations of MIM based applications and their corresponding WPT techniques were discussed after being reviewed, analysed and classified.

3. PROPOSED SYSTEM

In this paper, we propose an implantable medical device that can continuously monitor the vital signs of the human body as well as transmit it to an external medium. We also develop a wireless power transfer system that can charge the inbuilt rechargeable battery. Figure 1 represents the architecture System on a Board and WPT Reception Unit for IMDs. It consists of sensors and electrodes to gather the vital signs and its related information from the body, an amplifier to improve the strength of the received signals, a filter to remove the noise and a microcontroller for processing the signals.

The processed information is transmitted through the RF transceiver. A crystal oscillator and JTAG are connected to the microcontroller. The secondary battery that is rechargeable is connected to the coil, a matching network, rectifier and charge management unit. Further, with the help of a low dropout, the secondary battery is connected to the microcontroller and the RF transceiver. Figure 2 represents a portable Wi-Fi module that is connected to the Microcontroller and RF transceiver. The MCU is connected to the USB, Rechargeable battery and Low Dropout.

4. ARCHITECTURE

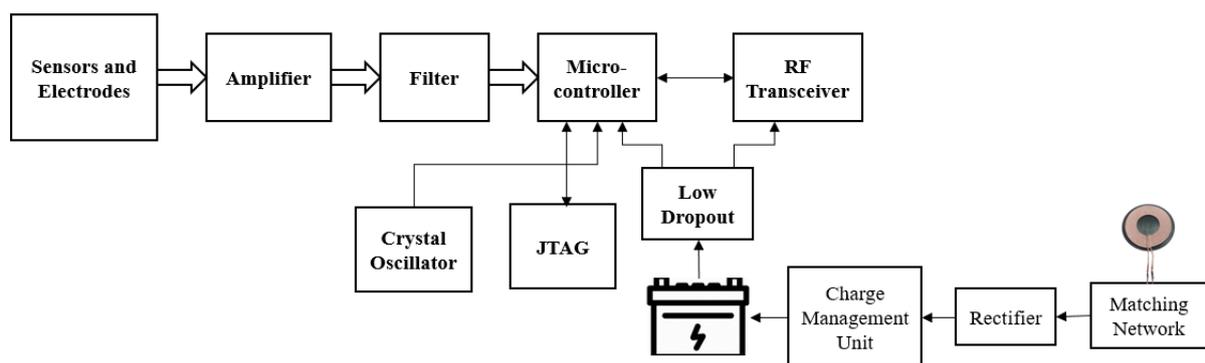


Figure 1: System on a Board and Wireless Power Transfer Reception Unit for Implantable Medical Devices

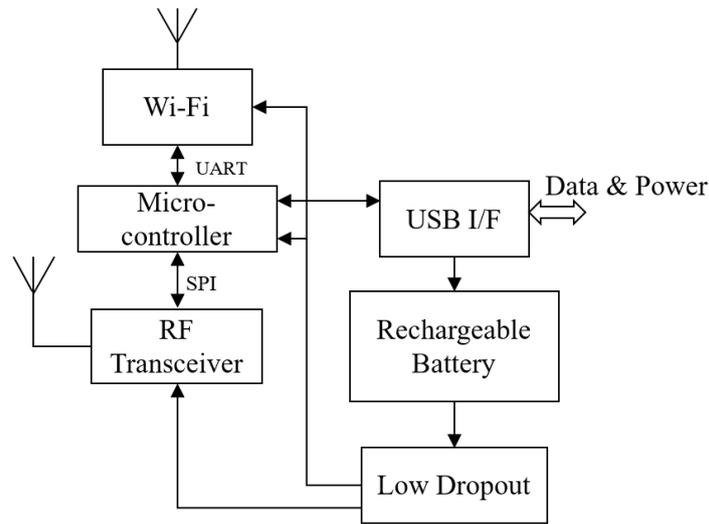


Figure 2: Portable Wi-Fi Module

These systems assist in receiving the information, processing and transmitting it to the external device. Also, using a coil, the internal coil is charged and the secondary battery and hence provide uninterrupted power to the internal module.

5. RESULT

The Lipo rechargeable battery can store up-to 300mAh power. The SoB module consumes about 5 mA power during active mode and 0.02mA during idle mode. In real time operation, uninterrupted monitoring does not take place. The device is active for a duration of 5 seconds and the idle mode lasts for a duration of 175s. With these factors, the lifespan of the battery without recharging can be done by using the following equation and is found to be approximately 79 days.

$$300mAh = Days \times 24 \text{ hours} \times \frac{5 \text{ mA} \times 5s + 0.02 \times 175s}{5s + 175s}$$

For charging the battery, the transmitting coil is placed on top of the skin where the implant is made. The power transmitting equipment generates a power of 250 mW of which 50% is estimated to be transmitted to the implant device wirelessly based on the specific absorption rate (SAR) of the receiving antenna. The charging status of the device can be monitored through the computer or mobile interface.

6. CONCLUSION AND FUTURE SCOPE

An enhanced system for wireless power transfer for monitoring the vital signs of human body through using implantable medical devices is developed and tested. A rechargeable battery is embedded in the implanted device that transmits data such as blood pressure, pulse rate, body temperature and respiration rate along with the charge status of the battery. The implanted device consumes very little power of around 5 mA during monitoring and the inbuilt rechargeable battery has a storage capacity of 300mAh power which allows continuous monitoring for a duration of up-to 2.5 months without recharging. Future scope of this paper is to further reduce the size of the system as well as the power consumption and improve the battery life so as to allow longer duration of continuous monitoring without the need of frequent recharging.

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