Powering Methods for Implantable Biomedical Devices

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Introduction

The objective of this article is to highlight different methodologies that are currently used commercially and experimentally for powering biomedical devices but will also tangentially address the issues of providing a reliable and continuous data communication link, and how to optimize the power and communication systems together for implantable biomedical sensors. These powering methodologies will be broken down into two distinct (but large) categories – locally sourced supply and externally supplied power. This paper will outline different methodologies for powering devices through locally sourced methods, externally sourced methods, highlight the pros/cons/trade-offs of each, and then conclude with where both developments should be focused, and the system functionality is optimized.

Direct Implementation

Direct implementations powering sensors can include using chemical energy (through chemicals in the user's body or a battery), thermal energy, or mechanical energy to power a device. These methods remove the necessity to transmit power wirelessly and therefore only require wireless communication for the data link (though data could be stored on board and later retrieved). The most common of these methods of directly powering the device is through batteries. This introduces problems with platform size, biocompatibility of batteries, and complicates servicing the device.

One of the most prevalent uses of batteries in biomedical devices is in cardiac pacemakers. The device is fairly common; over 300,000 people get a pacemaker implanted every year. [1] The device is implanted in the upper left part of the chest and runs electrodes to the heart to stimulate nervous responses via electrical impulses. [2] Pacemakers currently use Lithium Iodine batteries [3] and need to be replaced every 5-12 years. [4] One of the issues with the lifespan of pacemakers is that they could be engineered to last longer but they are not. The reasons for this are both economic, companies make more money selling devices every 5 years than if they sold them every 30, and because the technological advances are so dramatic over a decade and the procedure is safe enough that the potential benefits for upgrading the device are greater than leaving the device in longer. [1]

Other types of energy can be harvested from the human body and converted into electricity. This could be achieved through the body's native chemical reactions, thermodynamics, or mechanical movements. An interesting example of this is using gastric acid to harvest energy for endoscopy application. Pooria Mostafalu and Sameer Sonkusale at the Tufts University NanoLab were able to design and produce a galvanic electrochemical cell battery, which uses gastric acid as an electrolyte. [5]

Electrical energy is being produced from waste thermal energy from the user's body. One lab was able to build a silk-based solution which could be integrated into a user's clothes and charge some batteries for a wearable device, however, the amount of electrical energy that could be produced is very limited (~15nW). [6] Another lab designed a thermoelectric generator specifically to be used with electrocardiograms to continuously monitor could be integrated into a user's clothes and charge some batteries for a wearable device, however, the amount of electrical energy that could be produced is very limited (~15nW). [6] Another lab designed a thermoelectric generator specifically to be used with electrocardiograms to continuously monitor heart rate and could be mounted on multiple locations in the body. They produced higher levels of power, up to 20 μW/cm2, which is dependent on generator area, so it can be scaled up to produce more power. [7]

Indirect Implementations

An alternative to directly generating energy in the body is to send and receive it through electromagnetic radiation. The power supply for biomedical devices is often the largest contributor to weight and size of the device. [3] Externalizing the bulk of this component of the device can help the designer to minimize the size of the device (helping maximize user comfort) and help reduce the degree of maintenance required on these devices (i.e., needing to get surgery to replace a pacemaker battery). These methods use a similar approach to wireless data communications, inheriting many of the constraints from this portion of the design, and increasing the amount of safety concerns the user may have about the device.

A significant problem is balancing signal attenuation with safety. The human body is resistive to electrical signals, so when trying to communicate or power devices through it, the body acts as a Faraday cage and can dramatically attenuate or eliminate signals the engineers want to go through. The power or frequency of the signal could be raised until it is able to penetrate the skin with little to no attenuation, however, this raises many safety concerns over the possibility of causing cell mutation (i.e. cancer) in the user. The frequency range that is used should ensure the user's safety.

The main methods of wirelessly transmitting power are through inductive, capacitive, or magnetic resonance coupling, and radio frequency power transfer. The coupling-based methods are non-radiative, but all have their own design constraints. Capacitive coupling produces power relative to the device area, so for biomedical applications this poses a serious design constraint. The inductive and magnetic resonance coupling methods require a near field, meaning that those powering methods are the majority of the electromagnetic field in the area. The near field power is attenuated by the reciprocal of the distance between the receiver and transmitter cubed. For inductively coupled schemes, the easiest to implement, the distance of operation is around 20cm, but when around one antenna coil diameter in distance, the power transfer efficiency is very high. [8]

RF power transfer allows for a much larger distance between transmitter and receiver, but the cost of this comes at increasing safety risks for the user. RF power transmission is also significantly less efficient than inductive coupling at close range. When transmitting longer distances the RF density near the transmitter needs to be increased, however, high RF density exposure is a big safety hazard (can cause cancer). [8]

The antennae for the data and power transmission and reception can be used for both purposes on either end. According to a paper by A. Yakovlev [9], the optimal power and data transmission reception frequency (assuming use of RF power transmission) is in the 1-10 GHz range, but to comply with FCC regulations, around 2.4 GHz can be used since it is the frequency range for the Industrial, Scientific, and Medical radio bands. This also allows for the antenna size to be much smaller than the alternative lower frequency methods, and the power and data transmission can be decoupled. In studies outlined in the same paper, the optimal power transfer ratio occurs in the same low gigahertz range.

Conclusion

Both the indirect and direct powering methods for implantable biomedical devices allow the designer to optimize the size and robustness of the device. The direct methods, in general, offer less complicated and more self-contained methods for powering. The battery power density is good enough to power some devices, such as the cardio pacemaker, for many years, and for the economic applications and to ensure safety of the user, the planned obsolescence may be beneficial. For the thermal or chemical generative methods, the designer is typically guaranteed a reliable and infinite source of potential energy for the generator, but the thermos methods are generally very low power producing, and the chemical methods are very application specific.

For the indirect methods, the powering options are more versatile. Once the link is designed to permeate the body safely and the source is appropriately placed, then the power can be transmitted in the appropriate area regardless of application. There is no need to have to remove the device to replace a power supply like there is with battery methods, and the potential size constraints can be dramatically decreased. Of the methods for indirect power transmission, inductive coupling and RF power transfer are most popular. Inductive coupling is limited by the necessity for a near field transfer link between the transmitter and receiver, meaning that the transmitter and receiver need to be in close proximity and produce the majority of the magnetic field of the region in between. To compensate for these major pitfalls, inductive coupling provides nearly lossless power transfer when in close proximity and is very biocompatible, both very important in the application of biomedical devices. RF power transfer can be done over much farther distances than inductive coupling, however, this comes at a huge loss in efficiency, where the power transfer efficiency is around 1-2%.

Author's Note

The optimal powering method for a device is highly dependent on the application, making it difficult to make any generalizations about what the best overall powering method is. Through the experience of my senior design project, we have found that for rapid prototyping of a system, directly powering devices through batteries is simplest and most effective.

For more information on our senior design project check out the Tickle Me Pink poster and project description. In general, our aim is to power and transmit data from a sensor inside of the user's mouth. We need the system to be small and require minimal maintenance in order for the user to wear it comfortably for a long period of time. Additionally, our team is limited in our experience with antenna design, which has limited our ability to use inductive coupling to jointly communicate and transmit power, which would be a very convenient solution. Our team is also limited by time and money so making a custom chipset for our own power and data communication system is unfortunately not possible so optimizing the size of the device became less of a concern. Fortunately, there is a large selection of potential batteries to be used and many low power communication systems/sensors, so we have been able to design a system which can run on a battery, still be relatively small, and work for a long period of time while being able to maintain a data communication stream from device to the user's phone through tissue.

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