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Energy Harvesting and its impact on low power devices

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Abstract: *The advances in sensor technologies, embedded processing and wireless connectivity have added to the emergence of wearable, bio implantable devices. These devices actually live on and in us and hence become part of our daily life. They have found use in a large number of domains including personalized health-care, fitness and multimedia. The electronics of a biomedical device consist of energy delivery, analog-to-digital conversion, signal processing, and communication subsystems. Each of these sub blocks must be designed for minimum energy and low power consumption. Dynamic voltage and frequency scaling, clock gating power gating, energy efficient signaling are advanced low power design techniques frequently employed to achieve the stringent energy requirements of bio medical devices. There are limitations to the energy source, and hence harvesting energy presents better promise toward implantable and wireless systems. In this paper we review modern and relatively cheap solutions for powering as alternative to battery power source and other powering options when not applicable.*
Keywords - *bio medical, dynamic voltage, energy harvesting, energy storage, power gating*

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I. INTRODUCTION

With the rapid advancement of biomedical systems during the recent years, low power high-performance implantable medical devices like digital hearing aids, sensors and neuromuscular stimulators play a more important role in modern medicine. Implanted sensors and actuators are most in contact with sensitive organs such as the heart, arteries, nerves, or the brain, and therefore must satisfy requirements and design parameters for safety. Today batteries are the dominant energy source for these devices. In spite of the fact that energy density of batteries has increased by a factor of 3 over the past 15 years, their presence has a large impact, and dominate, size and operational cost. Implantable medical devices have established applications that range from cardiac monitoring to neurological stimulation as well as controlled drug-release.

All the wireless devices need a compact, low-cost and lightweight energy source, which helps in portability and energy consumption. Batteries with limited capacities will drain away long before the service life of the system. Hence wireless penetrations through the skin power supplies based on a modulated carrier is rectified to power the implant. This wireless technology improves mobility quality of life and increases safety of patient. Most implanted devices make use of radio frequency inductive coupling to deliver power. A tissue's temperature increases because of heat dissipation and implies higher electromagnetic field density which can harm biological tissues.

II. Energy Harvesting Systems

Energy scavenging or harvesting (EH) is the process of generating electrical energy from environmental energy sources. Alternate energy sources such as thermal energy, solar energy, kinetic energy exist. Energy harvested from these sources can be used to charge or replace batteries in portable devices. A human body is a source of energy, which can be harvested to power biomedical devices such as body sensor networks, implants, and even wireless sensor nodes. The energy harvesting system extracts discontinuously available energy from these ambient energy sources and harvests this energy to power bio medical implants and body sensor networks. As the modest ambient energy is available it will be an attractive alternative for low power applications such as mobile phone, MP3 players to health monitoring and embedded bio wearable implants. The average power consumption of a mobile phone ranges from 1W to 10 microwatt .The life of implanted medical devices is enhanced without the need for battery replacement or recharging by harvesting body energy. The two different mechanisms of human body energy releasing are heat and motion such as breathing and body heat, released continuously and involuntarily. This kind of energy source, called involuntary, does not require a conscious action. Voluntary energy sources, such as spontaneous activities, walking, jumping depend on the human to provide the energy and can generate a larger amount of energy.

TABLE II. Comparison of energy requirement of battery operated systems [3]

Device type	Power consumption	Energy autonomy
Smart phone	1W	5h
MP3 Player	50mW	15h
Hearing aid	1mW	5days
Wireless sensor node	100µW	7 years
Quartz watch	5µW	5years

Depending upon the nature of the harvester, the characteristics of electrical variables like output voltage and current can vary. To either power the system directly or to charge an energy storage device a very high enough voltage is needed. There are many systems which include analog and mixed mode components like wireless sensor node which are sensitive to power supply noise. Therefore, Linear Voltage regulators are used to reduce the gap between the supply and the need. Inspite of their low conversion efficiency and dissipation of heat linear regulators supply stable power and noiseless output which are required by analog RF components. Digital systems make use of switching regulators such as buck, boost converters of higher efficiency. To supply power to an embedded system it is required to modify the output of the harvester. The output from the harvester is not always continuous and hence has to be stored. The storage element could be a rechargeable battery or a super capacitor. Rechargeable batteries such as nickel-metal hydride (NiMH), thin film batteries and Lithium-Ion (Li-Ion),are utilized as energy buffers for energy harvesting. The main factors for selecting the energy storage elements for energy harvesting applications include output voltage rating, capacity, energy density and power density.

III. Energy Storage

Devising power supplies with microenergy storage devices, in conjunction with energy harvesters to provide permanent power to for small, autonomous wireless systems is a challenge. For wireless micro devices typical power demands can vary, a few orders of magnitude from microwatts (µW) to milliwatts (mW) depending on the application. The need for a micropower source that can satisfy the power requirements of a wireless device is a latest research topic within the fields of micro fabrication, energy harvesting, and energy storage. Earliest high-power harvesting applications make use of NiMH battery technology with an output voltage of 1.2V[5]. These cells are very safe to use without causing safety hazard but have a high self discharge rate losing about 4%. Li-Ion batteries are well-suited for energy harvesting applications as well as for portable electronics. The output voltage is nominally 3.6V with operating voltage thresholds of 4.2V and 2.5V respectively. The capacity of single-cell Li-Ion batteries can be as low as 40mAh, making it suitable for a small form factor batteries. These cells suffer from safety hazards due to overcharging and hence need to utilize specialized circuits to monitor the battery voltage for various parameters like overvoltage, under voltage, over current, and over temperature conditions. Thin film batteries are fabricated using physical vapor deposition with output voltage and under voltage cutoff voltage of 4.2V and 3V, respectively. Because of the solid state nature of these batteries, they are generally considered safe and not a safety hazard. There are no safety hazards involved with these storage cells of limited capacity of 50uAh to 2.5mAh . Supercapacitors, also called ultra-capacitors, are portable sized of high-value from mF to hundreds of farads for buffering transient energy . Supercapacitors do not have the aging and rate-capacity problems but have limited energy capacity and higher leakage, When the capacitor has reached its maximum breakdown voltage, the interface circuit must stop harvesting. The self-discharge of super capacitors is similar to that of Li-Ion batteries, but is more than that of thin film batteries. The main disadvantage of these capacitors is the reduced voltage tolerance [4]. As the electrodes are placed very close to each other, the breakdown of the electrolyte material can occur at voltages as low as 3V. For high-voltage applications, two or three capacitors are connected in series to increase the overall voltage rating. When a large number of capacitors are connected in series, special circuitry is required to balance the voltage across each of the capacitors.

TABLE III. Characteristics of batteries and supercapacitors [3]

Device type	Battery		Super Capacitor
	Li-ion	Thin film	
Operating voltage (v)	3-3.70	3.70	1.25
Energy density (Wh/I)	435	<50	6
Specific energy (Wh/kg)	211	<1	1.5
Self discharge rate at 20°C(%/month)	0.1-1	0.1-1	100
Cycle life (cycles)	2000	>1000	>10000
Temparature (°C)	-20/50	-20/+70	-40/+65

IV. Ultra-Low Power Applications

The advancement in low power technology has resulted in numerous applications in tracking of birds and animals, aerial vehicles and implantable devices. Wireless sensor nodes (WSNs) and mobile electronic devices are becoming the obvious choice for remote data collection. In these applications the system should be autonomous and wireless. Conventional systems make use of batteries and their life time is limited. Also long term negative environmental short comings due to battery disposal are also a fact [6]. The Fig1. below explores a few applications where EH can be an enhancement. Generally bio medical implants are powered by batteries and replacement of batteries is infeasible in these applications due to invasiveness and size. Hence environmental energy harvesting is an effective solution. Solar energy is most suitable these applications. The efficacy of both the energy harvesting and the ultra-low power techniques is highly dependent on the efficiency of the power management circuits that deliver the energy from the harvester to various building blocks of the system.

V. Energy Harvesting Circuit

An energy harvesting circuit is essential to deliver the available input solar energy to supercapacitors. DC-DC converters are a specific type of energy transfer circuits that adjust the amount of energy taken from the input in order to keep their output voltage level at a certain value. A DC-to-DC converter is an electronic circuit device that converts direct current (DC) from one voltage level to another. DC to DC converters are used in portable electronic devices such as cellular phones, laptop- computers, military, aviation and other applications which are supplied with power from batteries and this battery-supplied systems demand fast, efficient, and compact power supplies. The three basic types of DC-DC converters are 1) Buck converter 2) Boost converter 3)buck-boost converter. Buck (Step-down) switching converters are integral to modern electronics. The Buck Converter is used in SMPS circuits where they can convert a voltage source (typically 8 V to 25 V) into a lower regulated voltage (typically 0.5 V to 5 V). Stepdown converters transfer small packets of energy using a switch, a diode, an inductor and several capacitors. The buck converter devices which have very good conversion efficiency, faster transient response, less components and simple architecture are of high demand in many bio medical applications.An energy harvesting sysrtem consists of five major components: the energy harvester, the energy storage element and power management circuitry, sensor, ultra-low power microcontroller, and low-power transceiver. The energy storage element is required in order to accumulate the energy for usage when the energy harvester is not harvesting energy, for example a solar panel system during the night. The energy storage element must be rechargeable. The power management is critical as it interfaces to the harvester, charges the storage element, and provides power to the system. Sensor data is recorded and processed by the microcontroller. Finally, the data is transmitted to a central host by the transceiver.

VI. Conclusions

Due to the development of low power devices, energy harvesting in embedded systems and VLSI design is the latest area of research. Advancements in material science and miniaturization of device sizes has also added to this development. The harvesting devices are capable of outputting the same level of power as the requirement of low power devices . The existing modules can be redesigned with energy harvesting modules for better power and energy efficiency. The entire system must be optimized in a top down approach from the design of the architecture to power management at the circuit levels. Development of low power implant devices with energy harvesting capability without incurring health hazard is a major challenge for current and future research. This paper reviews the energy harvesting systems available and its impact on low power wearable devices.

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