**Energy Harvesting from Passive Human Power**

**ABSTRACT**

Portable equipments are the first evolution from fixed equipments to make possible that some day computers are part of our everyday lives. The trends in technology allow the decrease in both size and power consumption of complex digital systems. This decrease in size and power gives rise to the concept of wearable devices in which digital systems are integrated in everyday personal belongings, like clothes, watch, glasses, etc. Power is a limiting factor in this kind of devices. Wearable computers are distributed devices in clothes and therefore the power must be distributed and supplied over the body.Human power is defined as the use of human work for energy generation to power an electronic device. One possible division is to distinguish between active and passive harvesting energy method. The active powering of electronic devices takes place when the user of the electronic product has to do a specific work in order to power the product that otherwise the user would not have done. The passive powering of electronic devices takes places when the user doesn't have to do any task diferent to the normal tasks associated with the product. The energy is harvested from the user's everyday actions (walking, breathing, body heat, blood pressure, finger motion). Once the power is harvested it must be stored and there are many possibilities (capacitors, rechargeable batteries, etc.)

**I.INTRODUCTION**

Energy harvesting, scavenging, and harnessing – these are all almost analogous terms related to research and engineering activities aimed at extracting energy in electric form from various ambient energy reservoirs, which generally cannot be scaled up for full-size, power-plant energy generation schemes.There are many ambient energy pools that could be exploited by autonomous, low-power fuel-less generators: waste heat,vibrations, localized air movement or human-generated power. In addition, traditional “renewable energy resources” like water flow, tidal and wind energy or sun radiation can also be exploited at the miniature scale by energy micro-harvesters. All environments are now being populated by miniaturized, micro-power electronic devices working in wireless sensor networks or just as mobile gadgets. A dream to power all those devices without batteries making them perpetual or at least to supplement mobile supply scheme is the driving force of the research oriented on ambient energy harnessing. Serious interest in those problems, partially motivated by climate change and global warming, is also reflected by several R&D organizations (e.g. DARPA, CEALITEN) and companies aiming at harnessing energy from ambient vibrations, leg and arm motion, shoe impacts, and blood pressure for self-powered systems.

**II. KINETIC ENERGY HARVESTING**

Different techniques are being proposed for powering up remote, unattended, implantable or wearable sensors, short distance wireless communication stations, RFID tags or personal health monitors. Generating electricity from ambient vibrations or kinetic motion is one of those approaches applicable as a renewable substitute for batteries in micropower electronic products making timed use of accumulated energy. Kinetic energy in the form of motion or vibrations is generally the most versatile and ever-present. Operating principles of motion-driven ambient energy microscavengers relay on utilization of inertial forces acting on a proof mass fitted with a damper which simultaneously serves as an electromechanical transducer converting kinetic into electrical energy. Vibration stimuli are extensively present but vary widely in amplitude and frequency thus micro-generators are designed as resonant systems matched to vibration spectrum of the source. Non-resonant or dynamically tunable devices are also being designed, as broadband operation is required for maximizing output power when the source has a complex or time-variable vibration spectrum.

**III. PIEZOELECTRIC HARVESTERS**

When a mechanical vibration stimulates a piezoelectricmaterial, the internal charge configuration changes to generate a voltage across the surfaces ; in other words, an ac current charges and discharges the capacitance between the surfaces . The purpose of a piezoelectric harvester is to transfer the energy in the form of charge to an intermediate reservoir, such as a capacitor or battery. The harvester does not supply the load directly because the mechanical input is unpredictable and therefore unreliable for on-demand loading events . Considering its aim, the system must therefore condition and rectify an ac source into a dc output without losing considerable energy, which is why efficient rectifiers and rectifiers with the conditioned input and output voltages that produce higher power are the subject of ongoing research.

**A. Rectifier-Free, Switched-Inductor System**

While the efficiency of rectifiers can be high, the power they draw is not because the rectifier only transfers energy when the input voltage exceeds its output. In other words, the rectifier can only harvest for a fraction of the vibration cycle,when the piezoelectric cantilever bends enough to generate a voltage that surpasses the rectified output. To circumvent this fundamental limitation, the harvester, as shown in Fig.1,can temporarily store the transduced energy in an inductor before delivering it to the storage capacitor or battery.

The rectifier-free, switched-inductor harvester in Fig. 1first allows the half of the vibration to induce the transducer to source current iPZT into piezoelectric capacitance CPZT. Once CPZT’s voltage reaches its peak, which corresponds to the transducer’s maximum displacement point, the system transfers CPZT’s stored energy into harvesting inductor LH,after which point the circuit reconfigures its switches to de-energize LH into the battery. Because energizing and delivering LH’s energy to the battery only requires a few μs and the vibration period is on the order of ms, the position of the cantilever practically remains unchanged through this LH’s entire energy-transfer process. Similarly, after the other half of the vibration cycle induces the transducer to maximally charge CPZT in the other direction, the harvester discharges CPZT into LH and then redirects LH’s energy into the battery.CPZT stores the electrical energy produced by the piezoelectric effect each half cycle, so input energy per cycle EIN is





**Fig. 1. Rectifier-free, switched-inductor v**

**piezoelectric harvesting cycle.**

where vPZT(PEAK+) and vPZT(PEAK–) are CPZT’s positive and negative peak voltages, respectively. Without the harvester,the quarter of the vibration cycle after the positive and negative peak points would be used to discharge CPZT from their respective peaks. In contrast, since the harvester extracts all the stored energy in CPZT and resets the voltage to zero at the peaks, the whole vibration cycle is exploited to generate the higher peak voltages compared to the open-circuited counterparts, the maximum input voltage a rectifier-based system can experience. Higher peak voltages thus indicate the harvester draws more energy from the environment.

The driving force behind adopting a switched-inductor topology is LH and its accompanying switches, which conduct with close to zero voltages across them, dissipate little power.Unfortunately, harvested power can also be low, so parasitic energy losses ELOSSES in LH’s equivalent series resistance (ESR), the switches’ turn-on resistances, driving parasitic capacitances of switches, and controller quiescent current IQ can use a considerable fraction of the energy harvested:

 

where REQ+/– represent the equivalent resistances that conduct peak inductor current IL(PEAK+/–) during conduction time TC+/– for positive and negative half cycles, and CEQ is the total equivalent parasitic capacitance present that must be charged to and discharged from battery voltage VBAT during the vibration period TVIB [7]. Thus, the net energy harvested ENET is necessarily below the energy the transducer avails (EIN):

 

**B. Circuit Embodiment**

In the circuit shown in Fig. 2, for example, after iPZT charges CPZT across half the vibration cycle to its positive peak voltage, switches SI and SN first energize LH, and SI and diode-switch DN then steer LH’s current iL into VBAT. Similarly, after iPZT’s negative phase charges CPZT to its negative peak voltage, SI and SN again energize LH but now SN and DI channel iL into VBAT. Notice asynchronous diodes DN and DI stop conducting when the system depletes LH: when iL attempts to reverse.



**Fig. 2. A rectifier-free switched-inductor piezoelectric power stage.**

Since LH energizes as soon as its terminal voltages surpass zero Volts, the converter avoids the input threshold voltage normally imposed by rectifier-based systems, whose piezoelectric input voltages must exceed their rectified outputs.Additionally, by inverting LH’s output conduction path (between DN and DI), the system harnesses energy during the positive and negative vibration cycle, effectively “full-wave rectifying” the ac input without a rectifier circuit.

From a time-domain perspective, piezoelectric voltage vPZT rises (as CPZT charges) through the positive half cycle, as Fig. 3a illustrates from approximately 10.7 to 15.7 ms. When vPZT peaks at 15.7 ms, SI-LH-SN discharge CPZT to ground abruptly. During this quick discharge, SI-SN first energizes LH in 10 μs, as Fig. 3b shows, and SI-DN then depletes LH into VBAT in 1 μs. Similarly, vPZT falls in the negative half cycle from 15.7 to 20.7 ms and SI-SN energizes LH in 10 μs and SNDI drains LH in 1 μs. The fact LH de-energizes means iL flows into VBAT, which is to say the harvester harnesses energy, as the gray rising staircase energy trace ENET in Fig. 3a corroborates.



**Fig. 3. Simulated waveforms of the piezoelectric harvester.**

C. Synchronization and Control

For the system to harvest, it must drain CPZT’s energy into LH when vibrations maximally charge CPZT. omparator CPPK in Fig. 4 therefore detects when vPZT peaks by comparing vPZT to its delayed counterpart vD. Since vPZT leads vD, the moment vPZT falls below vD (and CPPK trips) indicates vPZT reached its positive peak. Similarly, vPZT rising above vD implies vPZT just reached its negative peak. Although CPPK functions continuously, its low bandwidth requirement allows it to operate in subthreshold (with low power).



**Fig. 4. Switched-inductor piezoelectric harvester circuit.**

The system must also detect when to stop energizing LH.To this end, because CPZT transfers energy to LH in a quarter of its resonance period, the controller estimates LH’s energizing time by tuning adjustable delay τDLY in Fig. 4 to CPZT-LH. Note comparator-controlled switches DI and DN implement diodes by conducting current iBAT into VBAT only when switching signals vSW + and vSW – surpass VBAT. The power a conventional diode would otherwise dissipate can exceed the conduction loss across a MOS switch plus the quiescent power through its controlling comparator, which the system only powers on demand, when vSW + and vSW – surpass VBAT.

**IV. ELECTROSTATIC HARVESTERS**

A motion-sensitive, parallel-plate variable capacitor (CVAR) draws kinetic ambient energy by dampening vibration forces [3]. More specifically, as motion separates CVAR’s plates, capacitance decreases and either CVAR’s voltage vC increases (because qC equals CVARvC) to increase its stored energy EC to CVAR(vFinal 2-vInitial 2) or charge qC decreases (i.e., CVAR releases qC) to generate current iHARV as SqC/dt. The challenge with keeping qC constant to augment EC is that vC can reach levels (e.g., 100 – 300 V) well above the breakdown voltages of high-volume, low-cost semiconductor technologies (e.g., 5 V).Although constraining voltage harvests less energy (at a linear rate, as opposed to the parabolic rise EC enjoys in the former case), SqC generates power in the more benign form of current:



A. Battery-Constrained and -Directed System

Constraining vC to a system-generated or intermediate source is possible [14] but fixing vC to VBAT by connecting CVAR to VBAT is more efficient because CVAR channels iHARV directly into VBAT [15]–[16]. Since CVAR generates qC when CVAR decreases, the system must first precharge CVAR to VBAT when CVAR peaks at CMAX, as Fig. 5 illustrates. Energizing CVAR, however, represents an energy investment EINV from VBAT:

 



**Fig. 5. Battery-constrained and -directed electrostatic harvesting cycle.**

**B. Switched-Inductor Circuit Embodiment**

Before attaching CVAR to VBAT, the system must precharge CVAR to VBAT with little to negligible losses, because charging CVAR directly from VBAT through a switch dissipates considerable power with respect to the little energy CVAR induces. As in the piezoelectric case, the switched-inductor harvester in Fig. 6 dissipates little power because energy transfer inductor LX and the switches, which conduct with close to zero Volts across them, are nearly lossless.Functionally, SE energizes LX from VBAT before disengaging and allowing SD to deplete LX into CVAR. Note this precharge phase only lasts a small fraction of the vibration cycle so CVAR remains virtually constant at around CMAX through this phase.



**Fig. 6. A switched-inductor, voltage-constrained electrostatic power**

**stage.**

C. Synchronization and Control

Notice the harvester must monitor CVAR to precharge and subsequently connect it to VBAT at CMAX. Fortunately, in the reset phase, because CVAR floats when it rises to CMAX and its voltage vC therefore decreases proportionately (since QCONST is CVARvC), sensing when vC reaches its minimum voltage indicates when CVAR peaks. To this end, as in the piezoelectric case, comparator CPP-STRT in Fig. 8 senses when vC, which leads its delayed counterpart vD, begins to rise above vD, prompting the logic to start the precharge phase.

Similar to the piezoelectric case, the system must also determine how long to energize LX to precharge CVAR to VBAT.Consider that undercharging CVAR means SH will first charge CVAR to VBAT inefficiently at the beginning of the harvesting phase, decreasing the net energy gain of the system.Unfortunately, overcharging CVAR likewise represents a loss.because SH discharges CVAR to VBAT inefficiently, again, at the beginning of the harvesting phase. Hence, the harvester must tune LX’s energizing time to precisely precharge vC to VBAT by adjusting delay τDLY in Fig. 8. Afterwards, CPP-END detects the end of precharging when LX depletes (i.e., iL=0) by comparing the switching node voltage vSW to 0 V, and prompt the harvesting phase to begin by setting SH’s S-R latch.



**Fig. 8. Switched-inductor, voltage-constrained electrostatic harvester**

**circuit.**

**V. CONCLUSIONS**

The fundamental challenge in harvesting ambient energy with microscale devices is producing a net energy gain, that is to say, conditioning and transferring energy and synchronizing the system to vibrations without dissipating considerable power in the process. Reducing losses is the driving force behind the adoption of switched-inductor circuits, because inductors and switches that conduct while dropping nearly zero Volts are quasi-lossless. The challenge is small-scale transducers generate little power, losing a considerable portion to otherwise negligible conduction, switching, and quiescent losses, even if functional blocks operate only a fraction of the vibration period with nA’s of current. Nevertheless,continuously producing a net output power of even a few μW’s can charge a battery so that, when a sensor needs energy, which does not typically happen often, the battery can readily supply it. The idea is to supplement the system with enough energy over time to extend its operational life and

avoid having to replace an otherwise easily exhaustible battery.

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