

# A MICROMACHINED ELECTROMAGNETIC AND PIEZOELECTRIC POWER HARVESTER FROM KEYBOARD

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**Abstract:** This paper describes a novel micromachined power harvester, which can harness energy from inherent typing motions in a computer keyboard. It converts the mechanical energy from a reciprocating z-directional motion of each key into electrical energy by utilizing piezoelectric as well as electromagnetic methods simultaneously on a single chip. We have fabricated a small power harvester chip and tested it in a computer keyboard. The maximum power obtained is about  $40.8\mu\text{W}$  at  $3\text{M}\Omega$  load and  $11.6\text{pW}$  at  $700\Omega$  load from the PZT substrate and planar micro-spiral coils, respectively. Array of the chip harvesters can be integrated in a keyboard under each key button.

**Key Words:** keyboard, electromagnetic, piezoelectricity

## 1. INTRODUCTION

As microsystem technologies has been remarkably grown in recent years, advances in self-powering, micro power generation and energy micro harvesting technologies are necessary for the reliable and stable capacity of the micro systems. Various micro power generators use electrochemical, photovoltaic, electromechanical, thermoelectric, pyroelectric, or other exotic energy conversion mechanisms. Likewise, energy harvesting has been explored actively from numerous resources such as solar power, electromagnetic fields, thermal gradients, fluid flow, energy produced by the human body, and the action of gravitational fields [1]. In addition, the micro energy scavengers would be potential power sources for many micro wireless devices that require self-supportive power to receive and transmit RF signal. Moreover, it is well known that piezoelectric materials are most competitive materials for harvesting power from ambient vibration sources due to the high conversion efficiency from mechanical strain to an electrical energy [2].

## 2. BACKGROUND AND DESIGN

Among the various energy scavenging methods, both electromagnetic and piezoelectric conversion methods from mechanical vibration are getting more attentions due to the higher electromechanical coupling and no need of external voltage sources.

While electromagnetic approach for scavenging energy uses variation of magnetic flux from the movement of permanent magnet, piezoelectric materials transform mechanical strain to the electrical energy which is shown as either charge or voltage drop. In this paper, a power scavenging way from the both methods at the same time is described. Energy from a single stroke (typing motion) is collected and characterized separately from electromagnetic and piezoelectric conversion. Our new micro power scavenging device utilizes the continuous and repeating inherent vertical motions when we are typing a keyboard.

Various researches have been tried in the fundamental scaling various electromechanical effects in use of the magnetism [3-6]. When a permanent magnet moves inside of winding, the change of magnetic flux induces electromotive force according to Faraday's law of induction. If it has a connected load, the circuit starts to flow current so that electrical power is delivered to the load.

In order to verify the power level that we can obtain from the inherent typing motions in a computer keyboard, the harvesting power from typing motions in a computer keyboard is theoretically derived and estimated based on the finger force exerted by each finger which is summarized in table 1. For example, on a keyboard, if the thumb is used to type the key, the force is  $16\text{N}$  to apply in order to depress a key and  $5\text{mm}$  to move to register. Therefore,  $16\text{N} \times 0.005\text{m} = 80\text{mJ}$  is necessary for each keystroke,

where 0.005m is the average distance traveled per keystroke. For a moderately skilled typist, who types 40 words per minute (considering multiple keystroke combination), an average of  $80\text{mJ} \times 5.3 \text{ keystrokes/s} = 0.424\text{W}$  is available for scavenging from the typing motions.

Table 1: Statistical magnitude of force of each fingertip

Finger	Thumb	Index	Middle	Ring	Pinkie
Force(N)	16	10	10	9	8

The conversion from mechanical kinetic energy to electrical energy is that, according to Faraday's law, the electromotive force induced by varying magnetic field is

$$\varepsilon = -N \frac{d\Phi_B}{dt} \quad (1)$$

where  $d\Phi_B/dt$  is the time-rate of change of the magnetic flux  $\Phi_B$ , N is the turning times of the coil. The direction of the electromotive force is decided by Lenz's law, which is expressed as the negative sign in the equation. Also  $\Phi_B$  is expressed as

$$\Phi_B = A \times B \quad (2)$$

$$B = \mu H \quad (3)$$

where B is the magnetic flux density, A is the area magnetic flux passes through,  $\mu$  is the permeability, and H is the magnetic field intensity. To increase the induced voltage from a given permanent magnet, the number of turns, N can be adjusted. We have several designs with various numbers of turns and multiple layers. When a cylindrical shaped permanent magnet is used, its magnetic field at the top (or bottom) surface is expressed as

$$B = \frac{B_r}{2} \left[ \frac{(l + L_m)}{\sqrt{(l + L_m)^2 + (D/2)^2}} - \frac{l}{\sqrt{l^2 + (D/2)^2}} \right] \quad (4)$$

where  $B_r$  is residual magnetic flux density,  $L_m$  is the length of the magnet, D is the diameter of top surface, l is the distance from center of magnet. For neodymium iron boron magnet the  $B_r$  is about 1100~1500mT.

$$\varepsilon = -\sum_{i=1}^N A_i \frac{dB}{dt} \quad (5)$$

$$= -\frac{d}{dt} \left[ \sum_{i=1}^N (a_i - i \times b)^2 \frac{B_r}{2} \left[ \frac{(l + L_m)}{\sqrt{(l + L_m)^2 + (D/2)^2}} - \frac{l}{\sqrt{l^2 + (D/2)^2}} \right] \right]$$

where N is the number of turns,  $a_1$  is the length of the side of the first turn (a square shape), b is the difference between  $a_N$  and  $a_{N+1}$ .

On the other hand, the electrical behavior of a piezoelectric material can be modeled by a linear constitutive equation. The equation modeling the converse effect is as follow:

$$E = -g \cdot T + \varepsilon_T^{-1} \cdot D \quad (4)$$

where E is the electric field, g is piezoelectric coupling coefficient matrix, T is the stress,  $\varepsilon_T^{-1}$  is electric permittivity matrix, D is electric charge density displacement. For simplicity, when no electric charge presents,

$$E = -g \cdot T \quad (5)$$

$$V = E \cdot d \quad (6)$$

Thus, induced strain determines the electric field so that voltage across the PZT can be derived. A voltage of  $V=0.733\text{V}$  can be obtained when  $g=0.024\text{V}\cdot\text{m}/\text{N}$  and  $T=F/A=16\text{N}/\text{cm}^2$ .

### 3. FABRICATION AND TESTING

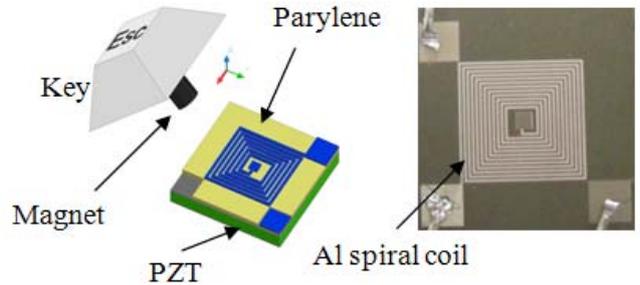


Fig. 1: 3-D view of the micromachined power harvester integrated micro coils on PZT and a picture of fabricated device.

For the power harvesting experiment, a micromachined electromagnetic and piezoelectric power harvester (MEPPH) prototype is developed. As shown in Fig. 1, on a single substrate, both piezoelectric components (PZT sandwiched by two electrodes) and electromagnetic elements (micro spiral coils) are integrated together.

A brief fabrication process is illustrated in Fig. 2. First, a 191 $\mu\text{m}$  thick of lead zirconate titanate (PZT) is sandwiched by 0.2 $\mu\text{m}$  nickel electrodes. After the surfaces are treated with an adhesion promoter (A-174 Silane, Specialty coating system inc.), a 0.5 $\mu\text{m}$  thick parylene is deposited and

patterned by Reactive ion etching (RIE) to open contact pads for electrical measurement. Then, 0.6 $\mu\text{m}$  thick aluminum is deposited by sputtering and patterned in a wet etchant (10:1:300,  $\text{K}_3\text{Fe}(\text{CN})_6$  :  $\text{KOH}$ :  $\text{H}_2\text{O}$ ). Another deposition and patterning of a thin (0.5 $\mu\text{m}$ ) insulating parylene layer is followed by 0.6 $\mu\text{m}$  thick top aluminum is deposited and patterned for a micro spiral coil. In the final step, 0.5 $\mu\text{m}$  of passivation layer of parylene is deposited to protect the electrodes.

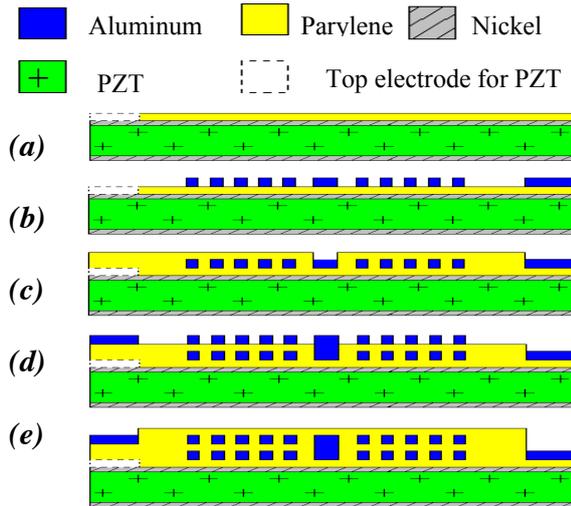


Fig. 2: Fabrication process of a power harvester, (a) deposit parylene on the PZT, and open the corner with RIE for PZT electrode, (b) deposit aluminum coil for bottom electrode and pattern (c) deposit parylene and open the center connection area with RIE, (d) deposit another layer of aluminum coil for top electrode and pattern (e) deposit parylene and pattern the opening of electrodes.

The micromachined power harvester is then mounted and tested in a test stage. The experimental set up consists of a sample mount board, a multimeter (HP 34401A), and a programmable resistance box as shown in Fig. 3. A data acquisition (GPIB) connection to a PC and a software (LabView 8.2) are used to characterize the response of the micromachined power harvester over a wide range of load resistances.

The experimental setup is based on the single key element of a real keyboard and the small magnet is customized to readily fit underneath the key. In order to obtain the maximum, and consistency force to the vertical direction directly from fingertip, the prototype device was attached on to the solid structure composed of key guiding structure, rubber ring, rubber question spring.

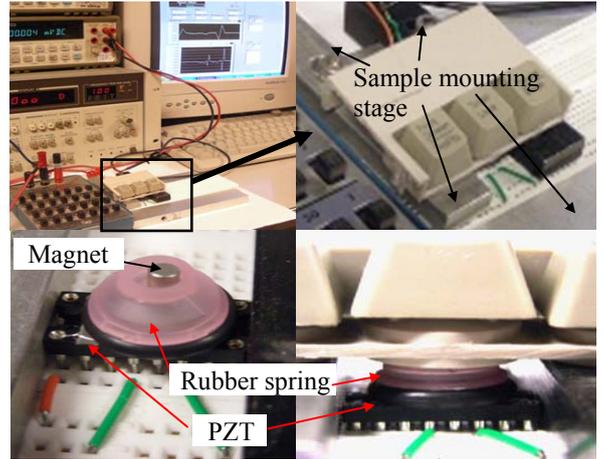


Fig. 3: The experimental set up for key board testing

## 5. RESULTS AND DISCUSSION

The experimental power values from the piezoelectric components (Fig. 4) and electromagnetic elements (Fig. 5) represent the instant power transferred to the load. The maximum power is 40.8 $\mu\text{W}$  when 3M $\Omega$  resistance is loaded, which is closed to theoretical value of 44.8 $\mu\text{W}$ .

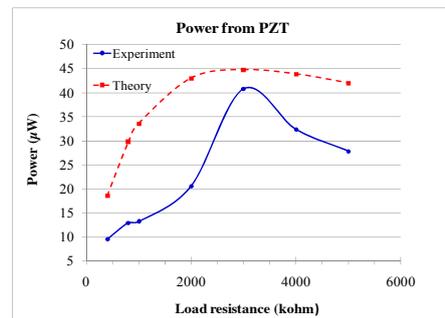


Fig. 4: Generated power from piezoelectric components

Additionally, the maximum power obtained from the electromagnetic elements is about 11.6 $\mu\text{W}$  when the load resistance is about 700 $\Omega$ . These experimental data follows theoretical predictions very much.

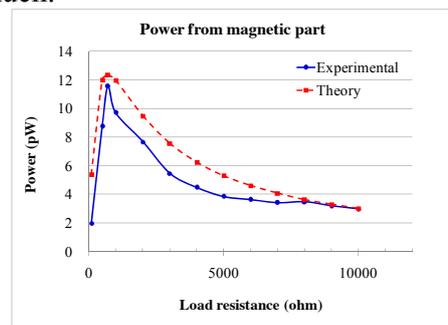


Fig. 5: Generated power from electromagnetic elements

Moreover, the voltage obtained from electromagnetic microcoils with various magnet sizes is shown in Fig. 6. As expected, the voltage gradually increases with the increased load, the maximum voltage generated is 5.28 mV at 5 M $\Omega$ . Figure 7 shows the induced power from various sized magnets (diameters are 3mm, 10mm, 18mm, lengths are 5mm, 3mm, 3mm respectively) with respect to the various load resistances. The power is a function of the magnet size which corresponded change of magnetic flux  $\Phi$  and area of microcoils. A maximum generated power 0.18 $\mu$ W is observed when the load resistance is 58k $\Omega$ .

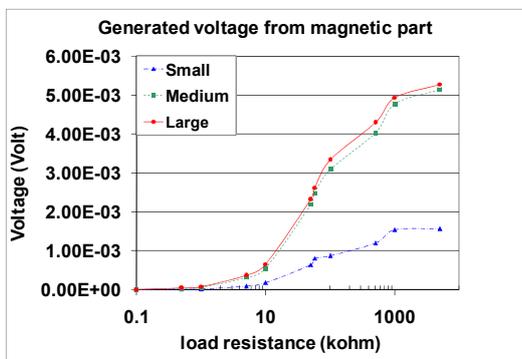


Fig. 6: Generated voltage against load resistance from varying magnet size of micro coil.

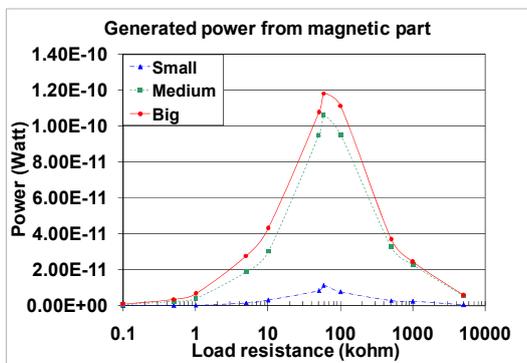


Fig. 7: measured power along the various load resistance under three different magnet size of micro coil.

Even though the device produces relatively small amount of electrical power, there are still many scopes to enhance the harvesting efficiency. For example, different magnetic materials with higher B would affect the performance pretty much. In addition, different designs of the micro-coil such as increasing the number of turns, reducing the turn spacing and circular spiral shape would increase the magnetic flux density. We expect that these modification would have power

several orders of magnitude higher than the one in the current design. Further performance enhancement is now in progress to improve the efficiency of the micro machined power harvester.

## 6.CONCLUSION

This paper describes a novel micro power harvester employing both electromagnetic and piezoelectric conversion to obtain maximum power from a typing motion of a key. A prototype of a micromachined electromagnetic and piezoelectric power harvester (MEPPH) has been successfully developed and demonstrated. The maximum power output from the prototype is 40.8  $\mu$ W from piezoelectric components, and 1.16nW from electromagnetic elements. With this approach, it is possible to extend the runtime of the battery operated system by recharging the battery during the normal operation time from the inherent typing (or push-button) motions in the system such as cell phone, remotes, notebook computer, wireless keyboard and mouse etc.

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