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A review of studies on low-level vibrations as a source of electric power generation

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Abstract. Recent advances in low power VLSI design, with a low duty cycle has been able to resolve wireless sensor problems. In addition, researchers are looking to generate electrical energy from vibrations. The present paper discusses the low level vibration sources and their use in piezoelectric circuit for the production of electrical energy. The simulation results show that this scheme can convert low-level vibrations in nature, home environment, workplace, etc. into electrical energy.

Keywords: vibration, piezoelectric, electric power, wireless sensor

1. INTRODUCTION

In the past few years, researchers have increasingly focused on network and wireless sensors. Notably, the emergence of wireless networks and elimination of some of the physical parts can contribute to further environmental beauty and monitoring. Advances in low power VLSI design with short duty cycle can significantly reduce energy requirements [1, 2]; it can also enhance environment protection by reducing energy waste and the use of batteries.

2. VIBRATION SOURCES

Vibration occurs when it is possible to measure it by using existing facilities, otherwise as it is negligible it is said that no vibration has occurred. The vibration that is emitted from common sources is categorized as a low level vibration. Given that the majority of existing equipment (industrial, residential, commercial, etc.) working with electrical energy, generation of the electrical energy produced from low level vibrations is under study. Figure 1 shows a number of different types of vibration [16]. In Figure 2, there are two considerable points: one is the existence of a high peak of displacement in the frequency lower than 200 HZ, that could be named as basic mode, and another is the flatness of the acceleration spectrum with frequency, meaning that the displacement spectrum falls by $\frac{1}{\omega^2}$. Information about potential sources of vibration is useful for three reasons: first, the device should be accelerated at basic vibration frequency which this amount is roughly $0.5\ cm^3$. Second, the vibration frequency mode should be lower than that of basic frequency mode; thirdly to generate electrical energy, magnitude and frequency of vibration should be known. Therefore, a number of vibration resources in frequency and acceleration, and also some of the sources of energy generation are shown in Table 1 & 2, respectively [16].

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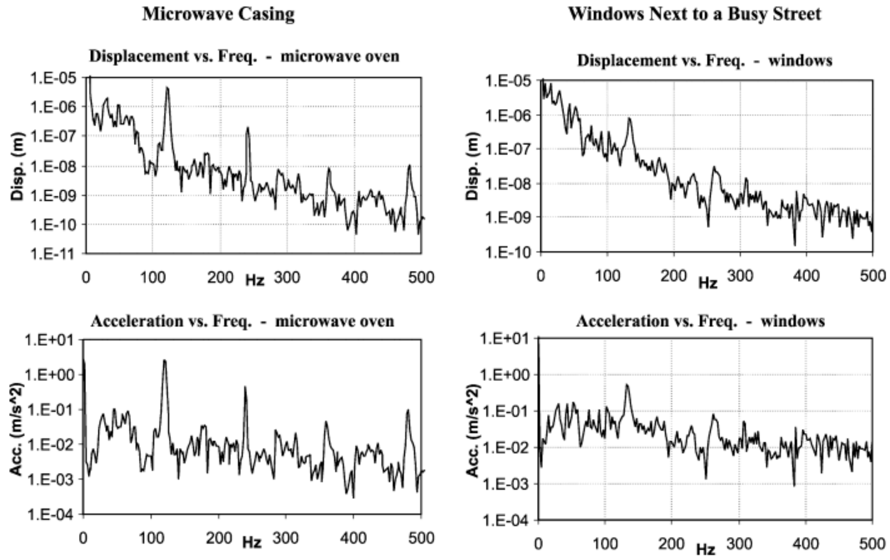

Figure 1. The vibrational spectrum of a macro wave and a window on a busy street [16].

Table 1. The frequency of vibration in terms of frequency and acceleration.

F_{Peak}	$A(m/s^2)$	Vibration source
Car engine compartment	12	200
Blender casing	6.4	121
Clothes dryer	3.5	121
Door frame just after door closes	3	125
Small microwave oven	2.5	121
Windows next to a busy road	0.7	100

Table 2. Some sources of energy generation.

	Power density ($\mu W/cm^3$)	References
Solar (outdoors)	15,000—Direct sun, 150—Cloudy day	[16]
Solar (indoors)	6—Office desk	[16]
Vibrations (piezoelectric conversion)	250	[4,5]
Temperature gradient	15 at 10 8C gradient	[3]
Hydrocarbon fuel (micro heat engine)	333	[6]

3. GENERAL MODEL FOR VIBRATION

Using different resources we can present a general model for formulating the kinetic energy of a vibrating mass into electrical energy on the basis of the linear systems theory. For this purpose, a simple schematic is used as shown in Figure 2 [8].

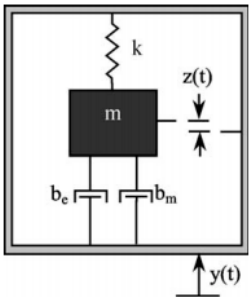

Figure 2. Schematic model of the vibration transducer.

The general formula for this model is as follow [8]:

$$m\ddot{z} + (b_e + b_m)\dot{z} + kz = -m\ddot{y} \tag{1}$$

Here, z is reflection, y is displacement, m is mass, b_e electrical damping, b_m mechanical damping and k is spring constant. This model can also be extended to a piezoelectric transducer with the difference that the system is non-linear due to the fluctuations of the piezo. The converted power is determined by the following equation:

$$P = \frac{1}{2} b_e \dot{z}^2 \tag{2}$$

By combining and taking the derivative of the relations (1) and (2) the following equation is obtained:

$$|P| = \frac{m\xi_e w_n w^2 (\frac{w}{w_n})^3 Y^2}{\left(2\xi_T \frac{w}{w_n}\right) + (1 - (\frac{w}{w_n})^2)^2} \tag{3}$$

Where |P| is power output, input vibration displacement power, ξ_e electrical damping ratio ($b_e = 2m\xi_e w_n$), ξ_T damping ratio combining ($\xi_T = \xi_e + \xi_m$), w input frequency and w_n natural damping frequency. As can be seen, in order to improve power, ξ_m amount must be minimized, i.e. the model has to be a large mass in space. Figure 3 shows the results of simulation on this overall model which has been obtained from macro wave waves and the mass limited to the space of $1\ cm^3$. In addition, this result is used as the basic model in all simulations in the present paper. As seen in Figure 3, 3 for having the maximum power, values should be $\xi_m = \xi_e$

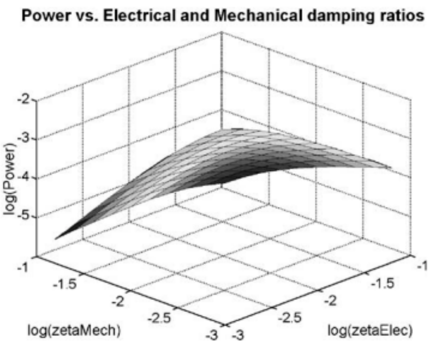

Figure 3: The power output simulation and electrical & mechanical damping.

4. USE OF PIEZOELECTRIC TRANSDUCER

When a piezoelectric transducer is placed under mechanical load, it seems like a generator of open circuit voltage. Therefore, this property can be used to produce electrical energy. For this purpose, the model in Figure 4 is used which was utilized for the production of electrical energy from a resistance placed in the Piezoelectric terminal.

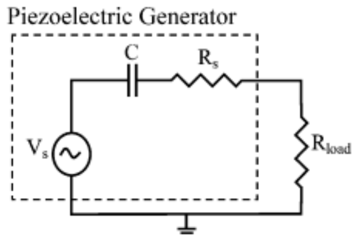

Figure 4. Generator of piezoelectric.

So the electrical and mechanical equations of a piezoelectric model are as follows:

$$\delta = \sigma/Y + dE \tag{4}$$

$$D = \varepsilon E + d\sigma \tag{5}$$

The mechanical stress is δ, σ is mechanical stress, Y elasticity module, D electric charge density, E the electric field, ε the dielectric constant and d is piezoelectric strain coefficient. These equations are elastic only for dielectric materials. In addition, the equations with the existence n of series capacitor and the output of AC voltage are as follows:

$$\ddot{\delta} = \frac{-k_{sp}}{mk}\delta - \frac{b_m}{m}\dot{\delta} + \frac{k_{sp}\,(d)}{mc}V_R + \frac{3b}{2l^2}\ddot{y} \tag{6}$$

$$\dot{V}_R = \frac{-Yd_{31}}{k\varepsilon}\dot{\delta} - \frac{1}{RC}V_R \tag{7}$$

Which k_{31} is piezoelectric coupling coefficient, V_R is the load resistor voltage, C piezoelectric capacitor, R is load resistance, I the moment of inertia, T material thickness and and Y is displacement of input vibration. Using the equations (6) and (7), (8) can be obtained to analyze the power output; also to obtain the optimum load resistance the equation (9) can be applied.

$$|P| = \frac{RC^2\left(\frac{Yd_{31}}{k\varepsilon}\right)^2}{(2\xi w^2 RC) - (w^2 RC(1-k) + 2\xi w)^2}\frac{3b}{2l^2}|A|^2 \tag{8}$$

$$R_{opt} = \frac{1}{wC}\frac{2\xi}{\sqrt{4\xi^2 + k_{31}^2}} \tag{9}$$

Where A is the input acceleration; in addition, according to Figure 4, if couple does not occur 0 k_{31} resistance value will be equal to $1/_{wC}$. This model is somewhat like a general model and equation (1). Now, the electrical damping rate is calculated as follows:

$$\xi_e = \frac{wk_{31}^2}{\sqrt{w^2 + 1/_{RC^2}}} \tag{10}$$

5. SIMULATION RESULTS

In this paper, as shown in Figure 5, for the production of electrical energy from the vibrations, in the piezoelectric transducer, titanium zirconium transducer (PZT) is used as the mass in the transducer. In addition, 100 HZ input vibration is considered with acceleration power of $2.25\ ms^{-2}$, input voltage 50 V the damping ratio 0.01. As seen in Figure 6, this transducer is able to produce about 250 µw power in its output. Also, Figure 7 shows the simulation results of the output power with different values of the load resistance, and Figure 8 depicts the input voltage in the different values of load resistance.

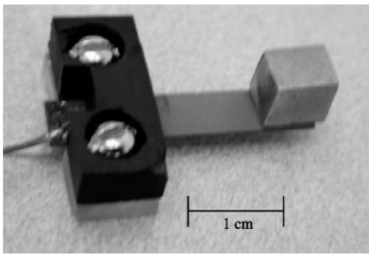

Figure 5. A view of the piezoelectric with zirconium mass.

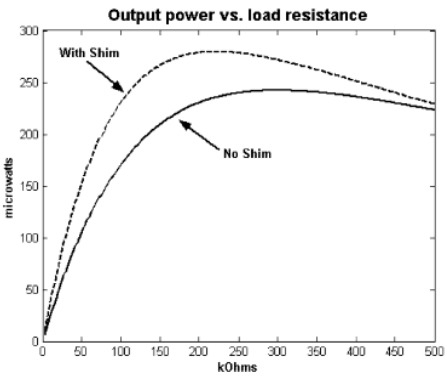

Figure 6. A representation of output and different ohmic load.

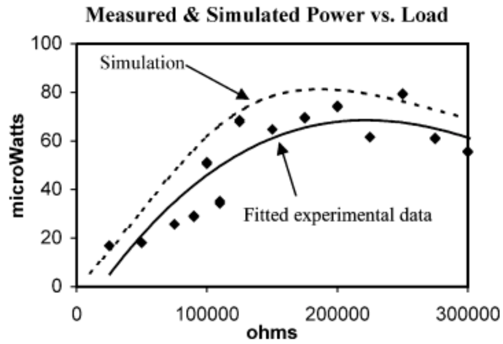

Figure 7. Output power of resistance.

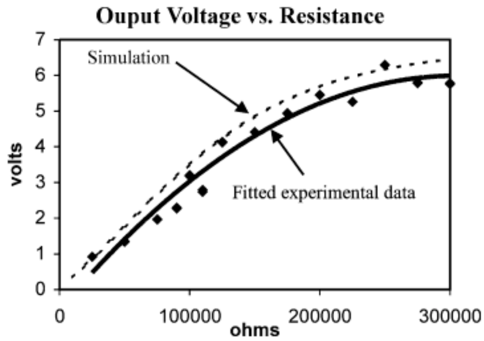

Figure 8. The output voltage of the resistance.

6. CONCLUSION

The electrical energy generation from non-fossil sources is one of the major concerns of researchers, and some solutions have been suggested in this regard. In this paper, electrical energy generation from the low level vibrations was studied. For this purposed, first, a simple linear model was used and finally for a non-linear model, electrical energy generation was generalized. As can be seen from the results, this model is able to generate electrical energy from the vibrations.

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