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Demonstration of Self-Powered Accelerometer Using Piezoelectric Micro-Power Generator

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Abstract- This paper demonstrates the operation of a self-power vibration measurement system. A piezoelectric material in the form of a cantilever is being used as a generator which harvest energy from ambient vibration source and transform into useful electrical output. The vibration sources is measured with a MEMS based accelerometer, which is powered up by the transformation of electrical energy derived from the mechanical vibration source itself. It has shown that at a resonant frequency of 78 Hz with an acceleration level of 1g (9.81 m/s^2), the piezoelectric generator is able to produce rms output voltage of 5.20 V and successfully operating ADXL335 with the assistance of energy harvesting conditioning IC, LTC3588-1 equipped with rectifying as well as DC-to-DC step-down functions.

I. INTRODUCTION

Self-powered system is remarkable attractive for building a sustainable and environmental concern application to replay batteries, particularly those employ in a big number such as wireless sensor node in a wireless sensor network, which is able to be powered with low level electrical power [1].

Notably, vibration source is one of the common source uses to transform into useful electrical energy from ambient environment due to its availability in almost everywhere as long as there is moving mechanisms, as have been surveyed in [2] include those home appliances, industrial environment as well as human activities. Piezoelectric material in the form of a cantilever is one of the popular mechanisms used to transform vibration or kinetic energy into electrical energy based on direct piezoelectric effect. Maximum output power can be generated when the device is operated at its resonant frequency, however it has also shown the possibility to harvest multiple frequencies from vibration sources [3].

There have been quite a number of researches working toward self-power system as described by Chao P. [4], which operated for a long time on the same entities which can be embedded into structure or human bodies. The extension of the research has gone into maximizing the by using maximum power point tracking as described by Kong, N. [5]. The advancement of integrated circuit performance has also enabled self-power electronic system to be applicable for harvesting vibration energy in short duration as described in [6].

In this paper, the combination of piezoelectric generator and energy harvesting condition circuit are used to verify the functionality of self-power accelerometer in measuring acceleration level of a vibration source.

II. SELF-POWERED SYSTEM COMPONENTS

The system consists of Piezoelectric Generator, energy harvesting conditioning integrated circuit (LTC3588-1) from Linear Technology, Inc. and MEMS accelerometer, ADXL335 from Analog Devices, Inc. The connection is show in Fig.1 the block diagram of the overall system.

The block diagram of the system is shown in Fig. 1, where the vibration source will be transformed into alternating current (AC) voltage output. The AC voltage output will be converted to direct current (DC) by energy harvesting integrated circuit, LTC3588-1 and DC to DC step down before being used to power up accelerometer, ADXL335 for measuring the vibration amplitude.

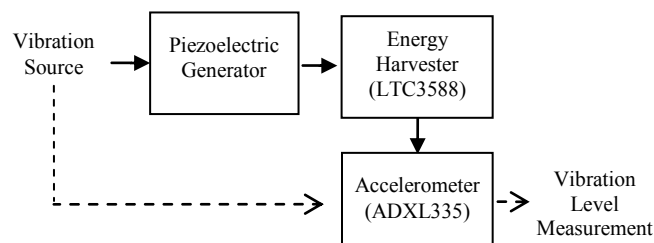


Fig. 1. A block diagram of the self-power vibration measuring system. The bold arrow representing the energy flows whereas the dotted arrow representing the signal flows.

The concern of the energy flows is the minimum requirement for powering the accelerometer. From the data sheet of ADXL335 [7], the operating voltage range is 1.8 V to 3.6 V. The output voltage from the energy harvesting conditioning integrated circuit, LTC3588-1 has to be set to operate in this range, it may not functioning properly if voltage level is lower than 1.8 V and may damage the accelerometer if voltage level greater than 3.6 V.

A. Piezoelectric Generator

The piezoelectric generator that is being used in this system is a standard quick-mount bending generator with pre-mounted and wired at one end (Q220-A4-503YB) from Piezo Systems, Inc [8]. The piezoelectric generator operates when the mechanical force is applied on it and causes the polarized 2-layer part to bend. Charge develops when one layer is stretched and the other is compressed to counteract the strain. This charge is collected for power generation when external

electrical load is connected to the terminal of the generator. The dimension of the Q220-A4-503YB piezoelectric generator is show in Fig.2 and its performance guideline is show in Table 1.

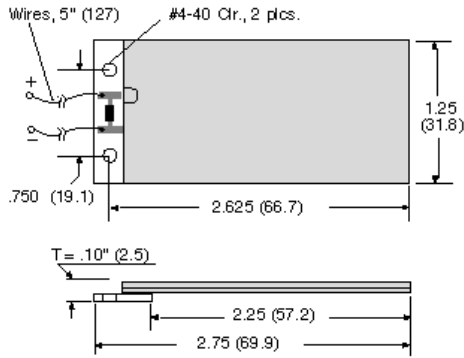


Fig. 2. Dimensions of the piezoelectric generator Q220-A4-503YB used in this project.

TABLE I

PERFORMANCE GUIDELINE OF PIEZOELECTRIC BENDING GENERATOR (Q220-A4-503YB)

Element	Value
Piezo Material	5A4E
Weight (grams)	9.5
Stiffness (N/m)	2.4×10^2
Capacitance (nF)	260
Rated Tip Deflection (mm_{peak})	± 1.57
Rated Frequency (Hz)	45
Open Circuit Voltage (V_{peak})	± 18.1
Closed Circuit Current ($\mu A_{peak}/Hz$)	± 46
Rated Output Power (mW_{rms})	4.7

B. Energy Harvesting Conditioning Integrated Circuit

Piezoelectric energy harvesting conditioning integrated circuit being used in this project is LTC3588 from Linear Technologies, Inc. LTC3588-1 combines a low-loss full-wave bridge rectifier and a high efficiency buck converter to create an energy harvesting devices optimized for large output impedance energy source. It is designed for energy harvesting that has ultra-low quiescent current (I_q) power supply. It can be used by directly connecting it to the piezoelectric or AC power source. The LTC3588 will rectify the voltage waveform and store the harvested energy in the capacitor. Besides that, it can also cut off any excess power through its internal shunt regulator and maintain regulated output voltage by using nano power high efficiency synchronous buck regulator. Fig.3 shows the block diagram of LTC3588-1. The IC has selectable output voltages of 1.8V, 2.5V, 3.3V and 3.6V, depends on the configuration of the D1 and D0 pins with a range of voltage input threshold of 3.77V to 5.37V [9].

In this project, output voltage of 3.3V will be selected, as it falls in the middle of the range of operating voltage for ADXL. Whilst at the output voltage of 3.3V, the IC needs an

input range of 4.73V to 5.37V from the piezoelectric generator. The regulator start-up profile of the LTC3588-1 is shown in Fig. 4.

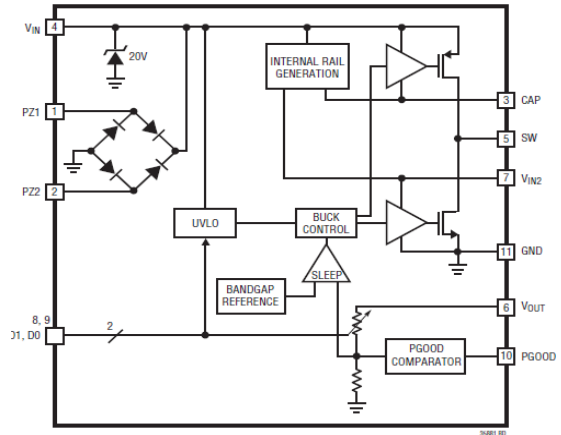


Fig. 3. Functional Block Diagram of LTC3588-1[9]

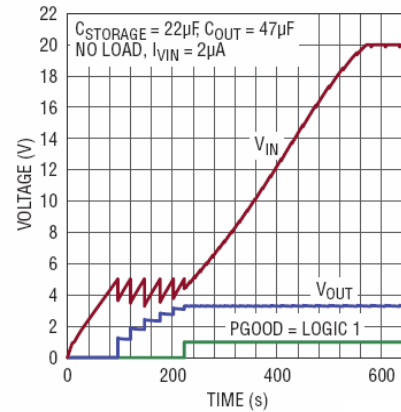


Fig. 4. LTC3588-1 regulator start-up profile [9].

C. MEMS Accelerometer (ADXL335)

ADXL335 is a low power 3-axis MEMS accelerometer, based on the principle of capacitive transduction. It can measure acceleration with minimum full-scale range of $\pm 3g$, the static acceleration of gravity, and the dynamic acceleration from shock, motion, or vibration. Besides that, it also produces signal conditioned voltage outputs. The block diagram of ADXL335 is show in Fig.5.

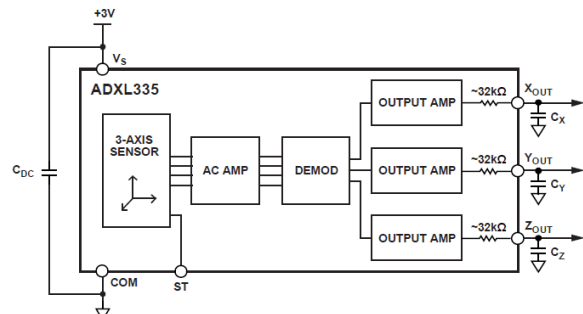


Fig. 5. Functional Block Diagram of ADXL335

III. EXPERIMENTAL SET-UP

The self-powered acceleration measurement system consists of 3 parts as discussed in Fig. 1, is presented in schematic diagram as shown in Fig. 6.

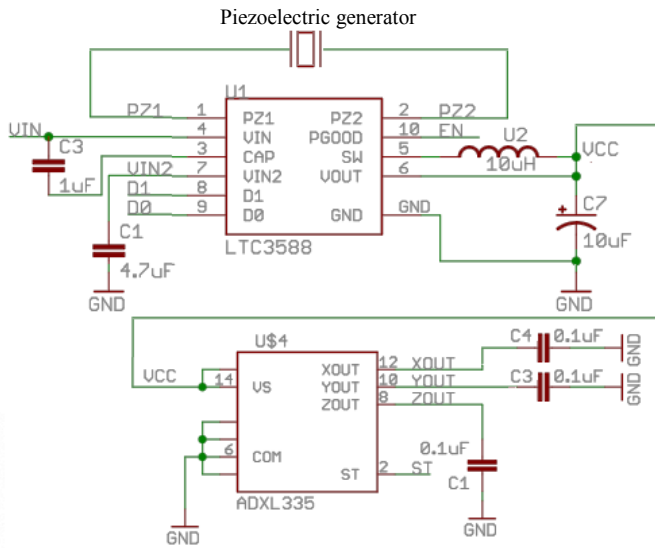


Fig. 6. Schematic Diagram of the combined Circuit

Before the electronic system is connected, the mechanical resonance frequency of the piezoelectric generator is determined by excited with electrodynamic shaker at a range of frequency from 20 Hz to 100 Hz with acceleration level (g-level) set at a constant magnitude at 1-g (9.81 m/s^2). The result obtained is as shown in Fig.7. The resonance frequency of the cantilever based piezoelectric generator with proof mass attached is at around 78 Hz with a bandwidth of 73Hz to 83Hz.

Throughout the experiment in the following section, the vibration source frequency is set at 78 Hz in order to generate maximum output voltage at its resonant.

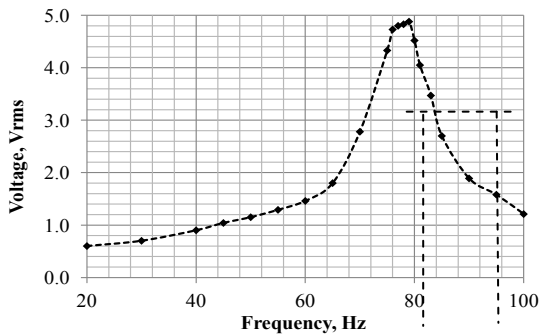


Fig. 7. Frequency response of cantilever based piezoelectric generator at a constant acceleration level of 1-g (9.81 m/s^2).

The g-level of the vibration source is measured with G-Link wireless accelerometer from LORD MicroStrain® [10] and the data collected in time domain is processed using FFT in Matlab to present in frequency domain as shown in Fig. 8.

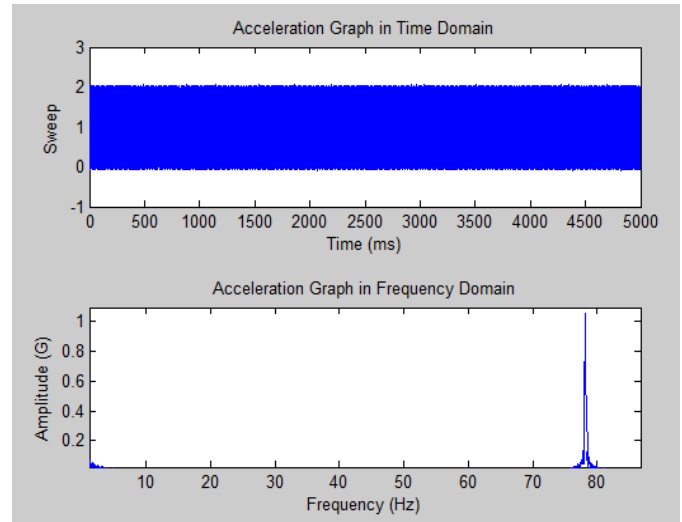


Fig. 8. Time and frequency domains of electrodynamic shaker vibration measurement data using G-link with

IV. EXPERIMENTAL RESULTS

The output from the piezoelectric generator is shown in Fig. 9 when being excited at the vibration source in Fig. 9. The result shows that piezoelectric generator produces AC voltage output at a peak-to-peak voltage of about 7.28V which derive Vrms value of 5.20V. This voltage value is too large to operate ADXL335 accelerometer which only support up to a maximum of 3.6V, hence step-down DC-to-DC converted is needed before supplying the voltage to the accelerometer. Besides that, accelerometer only support DC supply, hence the AC voltage from piezoelectric needed to be convert to DC first before feeding into the accelerometer.

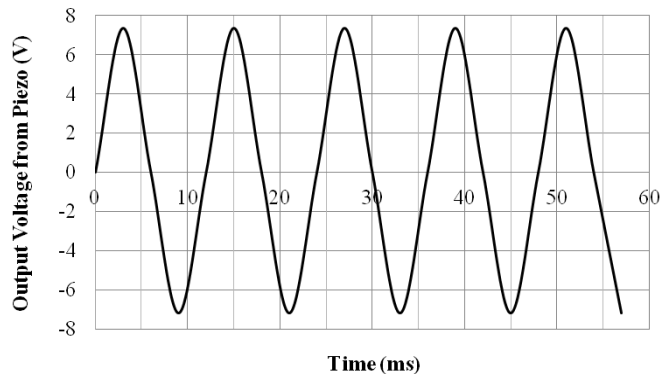


Fig. 9. AC output voltage from piezoelectric generator when excited at 78 Hz with an amplitude of 1-g.

The output from the piezoelectric generator was fed directly to the PZ1 and PZ2 pin of the energy harvester IC, LTC3588-1. The DC voltage output of LTC3588 is shown in Fig. 10. The voltage produced and average value of V_{dc} 3.34V, with maximum value of 3.52V and minimum value of 3.12V.

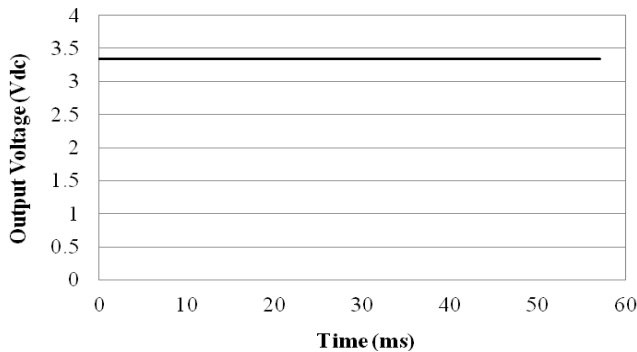


Fig. 10. Output voltage, V_{dc} from LTC3588.

The output voltage, V_{dc} from LTC3588-1 is then directly fed into V_{cc} pin of ADXL335 to operate the accelerometer. The output of the accelerometer is compared with the measurement value using G-link wireless accelerometer. However, if the acceleration drops to 0.8g, the supply voltage will not be able to power up the ADXL335, because the voltage produced by the piezoelectric generator during 0.8g is only 3.81V, which is lower than the minimum voltage input requirement of LTC3588-1.

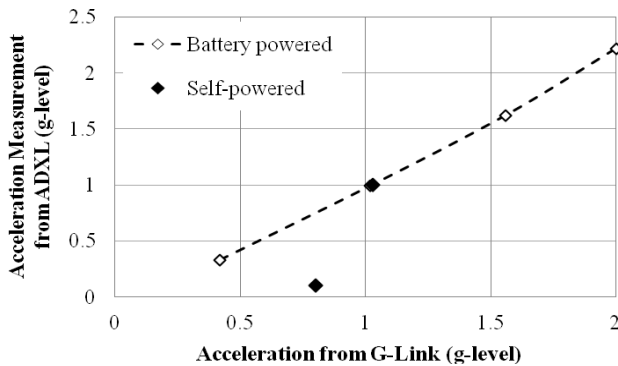


Fig. 11. Comparison of self-powered and battery powered ADXL measurement output for different level of acceleration using G-link wireless accelerometer as the standard reference.

V. CONCLUSIONS

The paper has demonstrated the application of self-powered accelerometer measuring acceleration level of a vibration source. The self-power system is using the same mechanical vibration source to transform into electrical energy

to power up the accelerometer. The major concerns of designing a self-power system are the minimum and maximum power or voltage requirement of the operation. In this case the ADXL335 needs minimum DC voltage of 1.8 V to operate and voltage above 3.6 V will damage the device. As the voltage output of a piezoelectric generator can be varied in a big range in an AC form, therefore a rectifier and DC-to-DC step down circuit is important to ensure proper operation of the accelerometer. In order to provide such stable DC voltage, LTC3588-1 IC is being used. The experimental results verified the operation of the self-power system, whereby when acceleration fell to 0.8g, the output voltage from the piezoelectric generator, which is 3.81V, is not able to step-down to 3.3V using LTC3588-1 and hence ADXL335 was not able to function properly.

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