

Packaging strategy for maximizing the performance of a screen printed piezoelectric energy harvester

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Abstract: This paper reports the extended design and simulation of a screen printed piezoelectric energy harvester. The proposed design was based on a previous credit card sized smart tag sensor node, and packages the power conditioning circuit in the free space above the tungsten proof mass layer. This approach enables electronic components to be mounted onto the cantilever beam. These are used to provide additional weight at the tip of the cantilever structure. The design structure contains a T-shape cantilever beam with size of 47 mm x 30 mm x 0.85 mm which is fabricated using screen printing. The original smart tag energy harvester has been tuned to have a resonant frequency around 67.4 Hz at which it obtains a RMS Voltage of 5.2 V in open-circuit condition and 243.3 μ W. ANSYS simulation results predict the revised architecture can generate 421.9 μ W approximately twice of the RMS power produced by the original design along with a higher open-circuit RMS Voltage of 8.0 V. The resonant frequency is dropped to 53.4 Hz.

1. Introduction

Piezoelectric materials are well suited to energy harvester application and the majority of energy harvesters reported use this approach. Research activities focus on methods to enhance the output power and scaling down the size of harvesters. Methods include utilizing d_{33} piezoelectric configuration instead of the d_{31} mode [1], developing more effective beam shapes, refining the power conditioning circuit designs to match the impedance between the circuits and generators and using more efficient piezoelectric materials [2]. This paper reports a strategy for moving the power conditioning electronics onto the energy harvesting structure which reduces system size and increases the inertial mass. Conventionally, circuit are placed separately and realized on traditional PCB boards which increases system size. The conventional approach is also a waste of material that can increase the seismic mass since circuits can be utilized as extra weight to increase the power output of generator along with lowering resonant frequency.

Zhu et al. reported [3] a smart tag sensor node which was developed to harvest vibration energy to supply to a Health and Usage Monitoring Systems (HUMS) for aeronautical applications. The system contained a screen-printed bimorph piezoelectric energy generator which is the subject of this paper, and used a thick-film PZT paste, previously developed at the University of Southampton. A 70 μ m thick PZT layer was printed on each side of the beam with a d_{31} coefficient -60CN^{-1} after polling. The total dimension of the harvester was 45 mm x 30 mm x 0.85 mm and this produced 243 μ W RMS

power at its resonant frequency of 67.4 Hz under an input acceleration of 3.9 ms⁻². In the system, the power conditioning circuit and super capacitor were placed separately to the side of the harvester. In this paper, an initial investigation, simulation and design of a novel architecture that utilizes the free area of 47 mm x 10 mm on the proof mass to integrate the power management circuit and increase the seismic mass of the harvester.

2. Design structure

The proposed new architecture consists of 14 different layers to be fabricated one above the other. Each layer requires a specific pattern which was designed via L-Edit. The generator is a bi-morph with each side of the substrate containing the same amount of structural layers excluding the circuit and encapsulation (figure 1). The circuit and encapsulation layer use polymer materials which avoid high temperature and associated thermal stresses and are printed on one side only whilst super capacitor is placed on the other side. The sequence of layer fabrication is shown in figure 1 which also indicates the number of different layers.

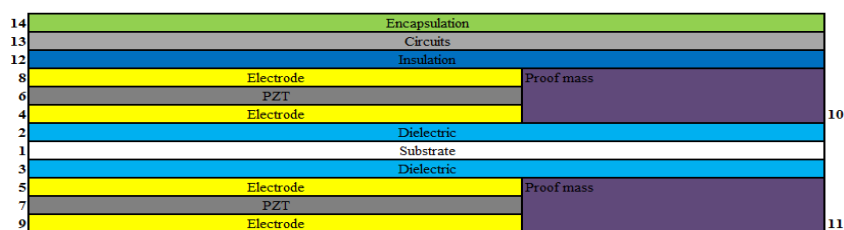
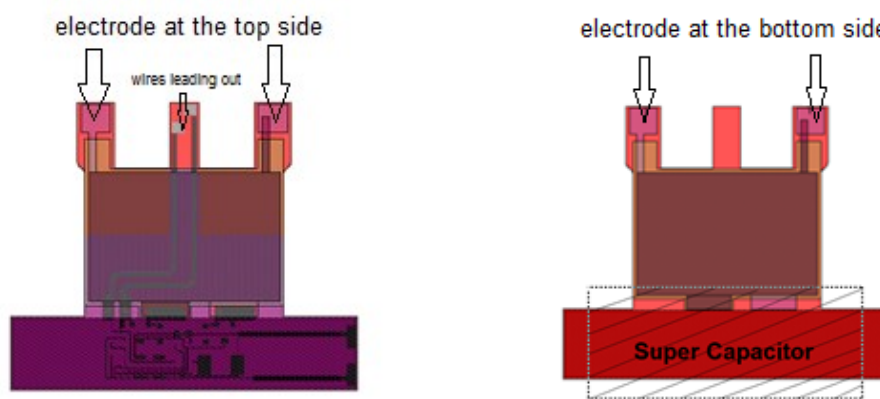


Figure 1. A cross-section of the harvester showing the material layers used (Numbers illustrate the fabrication sequence)

An overall view of the new generator architecture designed using L-edit is shown in figure 2. From the top view, a circuit layer can be seen on top of the proof mass with two wires leading out to connect other peripheral circuits. Four electrodes (two on each side), are provided to enable polling of the PZT material (see figure 2(a)).



(a) Top view

(b) Bottom view

Figure 2. L-edit design of the new architecture generator

Paste selections for each layer

The substrate is 110 μm thick and is fabricated from stainless steel 430S17 without excessive oxidation which can withstand the high firing temperature at 850 °C during the printing process. Stainless steel is conducting and must therefore be insulated before the bottom electrode can be deposited and fired. The dielectric paste ESL4924 from Electro Science Laboratories was used to insulate the particular stainless steel substrate. The other pastes used a high temperature gold

conductor (ESL8836) for the bottom electrode and a low temperature silver polymer (ESL1901-S) for the top electrode. The PZT paste which was specific made in out lab. It was blended with different particle size based upon a piezoelectric powder type (PZT-5H). This composite enhanced the piezoelectric coefficient d_{33} up to 131pC/N^{-1} and d_{31} coefficient of -60C/N^{-1} [4, 5]. The proof mass layer was made of a bespoke tungsten paste with a density of 9550kgm^{-3} [3]. DuPont 5000 silver polymer was used to print the circuit tracks in this design because it has a low sheet resistance of $15\text{m}\Omega\text{sq}^{-1}$ and can be cured under $120\text{ }^\circ\text{C}$ in box oven.

3. Simulation

The proposed architecture was simulated using ANSYS APDL to investigate how the new design would impact on the performance of the original energy harvester of the smart tag. The influence on the center of gravity was also investigated using Autodesk INVENTOR. A comparison of results has been plotted in figure 3 showing the peak power and peak voltage output generated in the original design, with the circuit only placed on the inertial mass, with the super capacitor only placed on and with both circuit and super capacitor placed on the energy harvester.

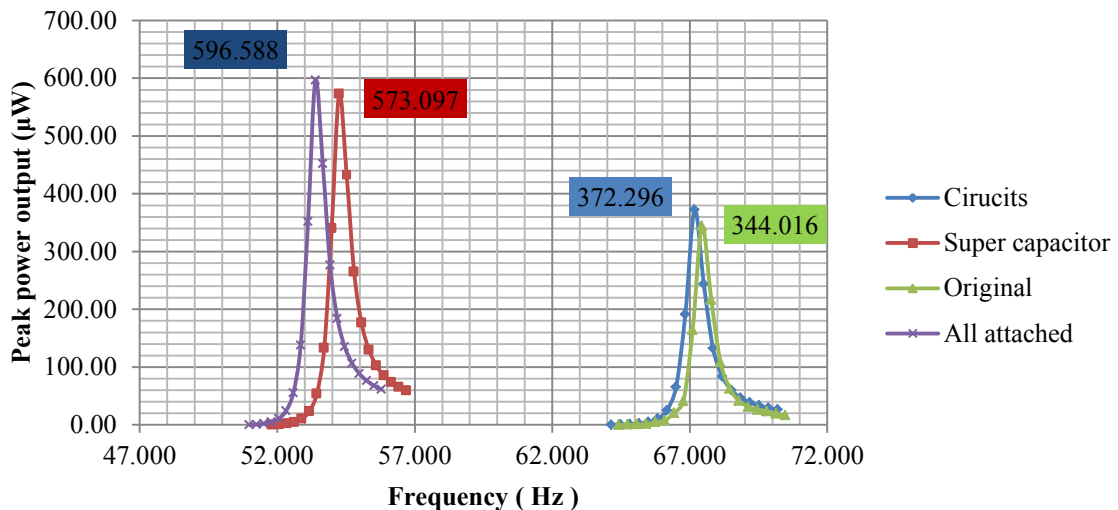


Figure 3. Comparison of peak power with different attachment

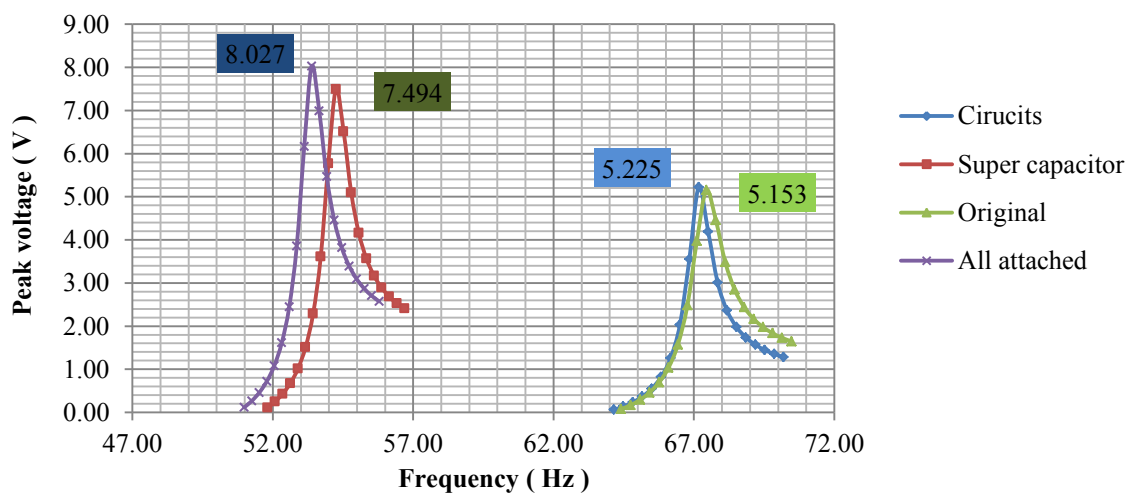


Figure 4. Comparison of peak voltage with different attachment

4. Discussion and Evaluation

Object attached	Weight attached (g)	Optimum Load (kΩ)	Peak Voltage (V)	RMS Voltage (V)	Peak Power (μW)	RMS Power (μW)	Resonant Frequency (Hz)
Original	0.0	77	5.15	3.64	344.02	243.26	67.44
Circuit	0.0494	77	5.23	3.69	372.30	263.30	67.32
Supcap	6.3313	97	7.49	5.28	573.10	405.31	54.25
Circuit+Supcap	6.3807	102	8.03	5.68	596.59	421.92	53.39

Table 1. Comparison of parameters of different attached object

A clear comparison of data has been provided in Table 1 numerically illustrating the impact of the different attached components to the generator. With the super capacitor attached on the generator, the RMS power has increased by 67% from 344.02 μW to 573.10 μW and RMS voltage has increased by 45%. Resonant frequency has reduced by 17%. The circuit on its own does not contribute much to power output (less than 1%).

The other improvement of this new architecture is the reduction in system area. An area of 345 mm² was used for the original power management circuit PCB and a further 520 mm² is saved by mounting the super capacitor. Overall, a total system area is reduced by 865 mm² of nearly 20% of the smart tag area. A reduced area of original energy harvester has been shown in figure 5. The volume of original smart tag device has a total volume of 14,025 mm³ and the new architecture takes 13,587.3 mm³. The volume has not been reduced much due to the increase thickness of placed super capacitor.

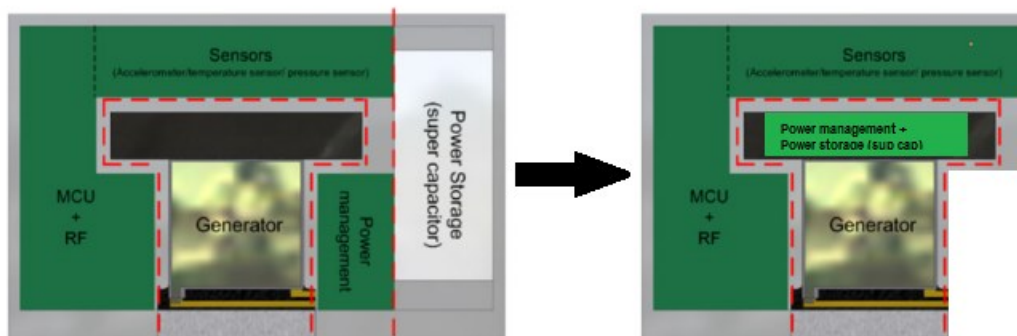


Figure 5. A reduction in size of the original energy harvester system

Table 2 shows the effect of the components and circuit has a small change on the center of gravity of the harvester. The effect of this change will be observed experimentally in the future.

	Original	Circuit components placed	Change (mm)
X	0	0.217	0.217
Y	8.138	8.41	0.272
Z	-1.068	-1.16	-0.092

Table 2. Centre of gravity changed with components placed.

5. Fabrication process

The screen printing process follows a sequence of layer by layer deposition with the paste, being dried and fired before each subsequent part. The dielectric insulating layer is firstly deposited on the stainless steel substrate and fired at 850 °C through the belt furnace giving a thickness of 20 μm on both side of the beam. The gold paste was deposited as the bottom electrode 10 μm thick. The PZT layer is sandwiched by the bottom and top electrode with a thickness of 70 μm. Then, the tungsten film is deposited to form up the proof mass and this is cured at temperature of 140 °C. A layer of

insulation using dielectric paste between top electrode and the circuit tracks is printed. Next, the circuit tracks are then printed and cured at 125 °C. Finally, the encapsulation is deposited which contains the same paste as insulation layer and is cured. Fabrication devices are currently being tested.

6. Conclusions and future work

The proposed architecture of integrating power management units on the generator was simulated and results were discussed. Both output power and voltage of the energy harvester are increased with a reduction of the system area. Increasing the inertial mass was for improving performance and this approach does so without increase total volume of the system. This is much more straightforward than, for example improving the PZT material properties. In the future, devices will be tested on a shaker (Labworks ET-126) with a programmable resistance box and a PC with LabVIEW software collecting data. The results of experiment and simulation will be compared to get a better understanding of its performance.

7. Acknowledgement

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