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Power Density Improvement of a Piezoelectric Energy Harvester through use of a Micropower Switch-Mode Interface

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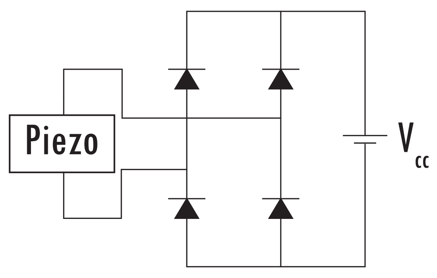
Motivation and Theory

- Improving the power density of energy harvesters is critical to increasing functionality of self-powered sensors.
- Improvements to the interface circuit can increase the power density of piezoelectric harvesters.
- Charge modification techniques have successfully increased the output power limit under situations where high electrical damping is required.
- Here a technique called Single Supply Pre-biasing (SSPB) is described which has twice the theoretical output power limit of any other circuit.

Candidate Interface Circuits

Bridge Rectifier

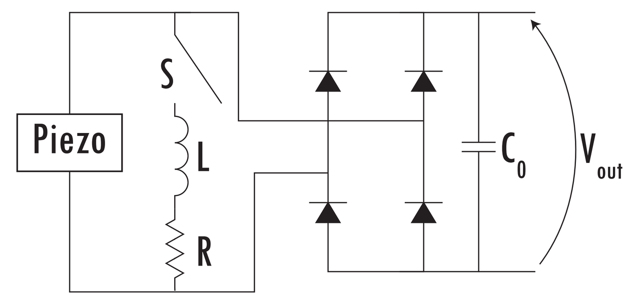


$$P_{RECT}=f_0C_p(V_{po}-2V_D)^2$$

- V_{cc} set to optimal output voltage [3].

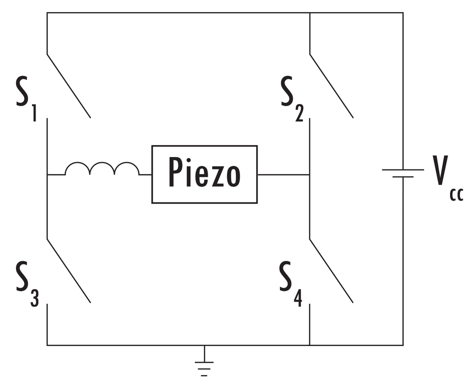
SSHI-DC

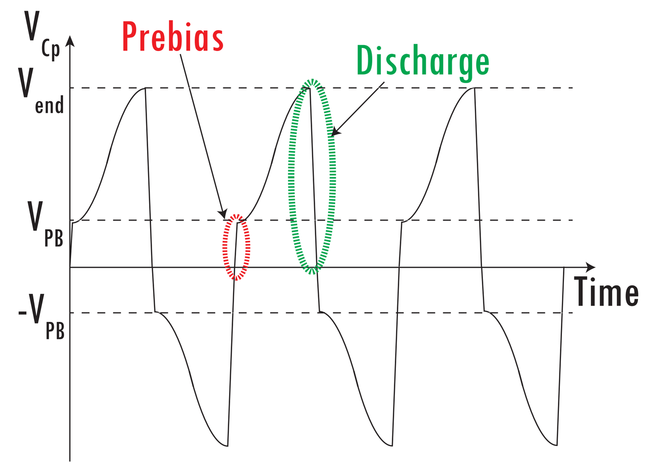
$$P_{SSHI}=V_{po}^2f_0C_p(4Q/\pi)$$



- Flips the charge on the piezo beam at the extreme points of travel. However a rectifier is still required to extract power [1].

Single Supply Pre-biasing



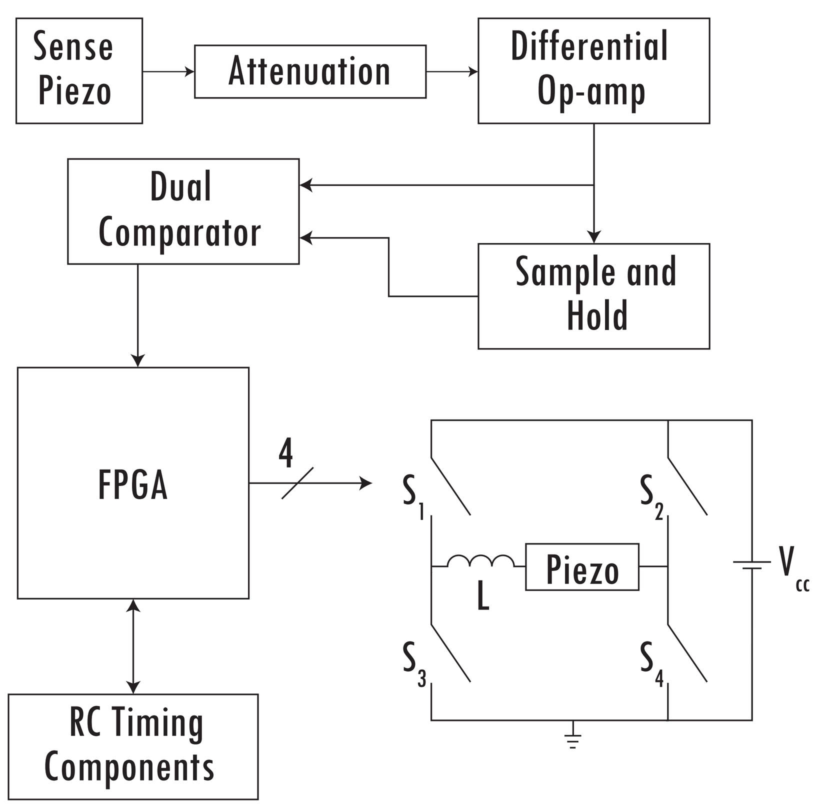


- Piezoelectric material is pre-biased at travel extremes with V_{PB} (polarity dependent upon maxima and minima position) by closing a switch pair (e.g. S_1 & S_4) briefly.
- Piezo then moves to its opposite extreme, thus causing the voltage on C_p to increase further, V_{end}.
- Same switch pair briefly closes again , discharging the piezo into V_{cc} before opposite switch pair (S_2 & S_3) are closed applying V_{PB} with the opposite polarity and repeating the cycle [3].

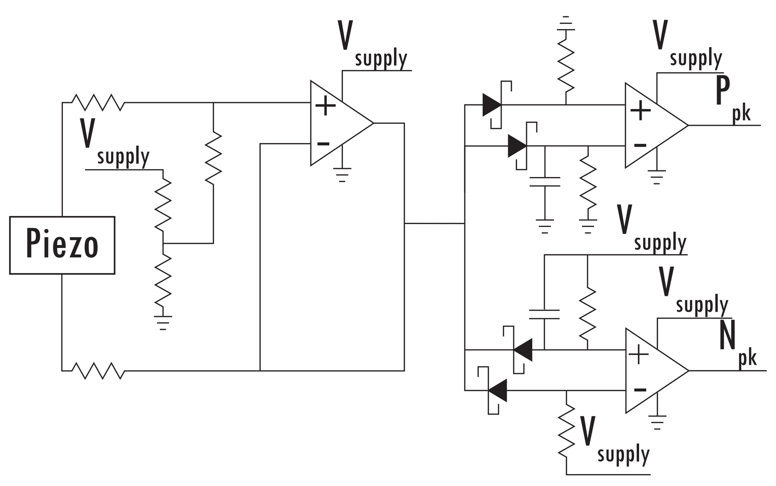
$$P_{SSPB}=V_{po}^2f_0C_p(8Q/\pi)$$

[1] D. Guyomar, A. Badel, E. Lefeuvre, and C. Richard, "Toward energy harvesting using active materials and conversion improvement by non-linear processing," IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, vol. 52, no. 4, pp. 584–595, April 2005.

High level SSPB circuit implementaion



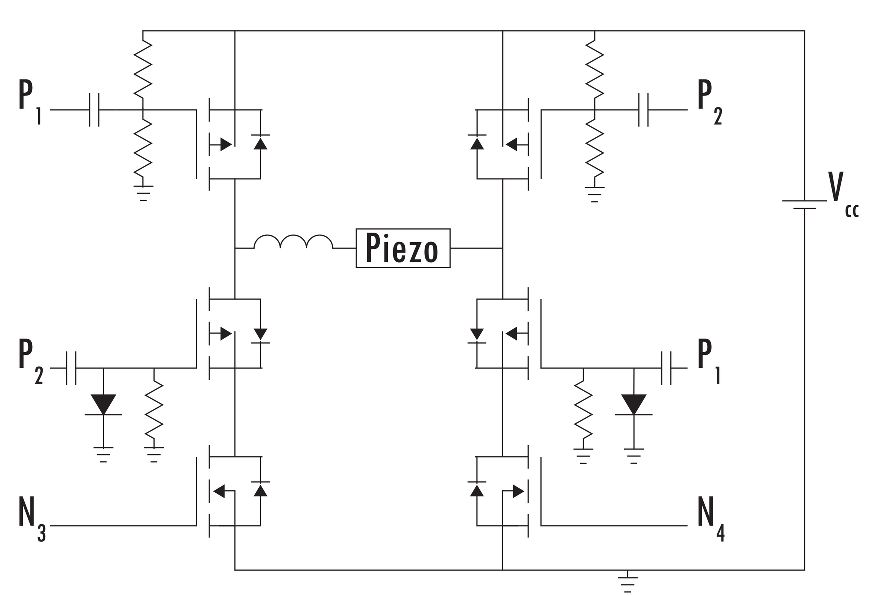
Peak detection circuit



- Instantaneous differential sense piezo voltage compared with lossy peak-hold copy to detect peaks [2].

- Switching circuit implemented from a H-bridge, p-type and n-type MOSFETs connected in series to form bi-directional blocking and conducting switches.

Resonant H-bridge circuit



SSPB Practical Design

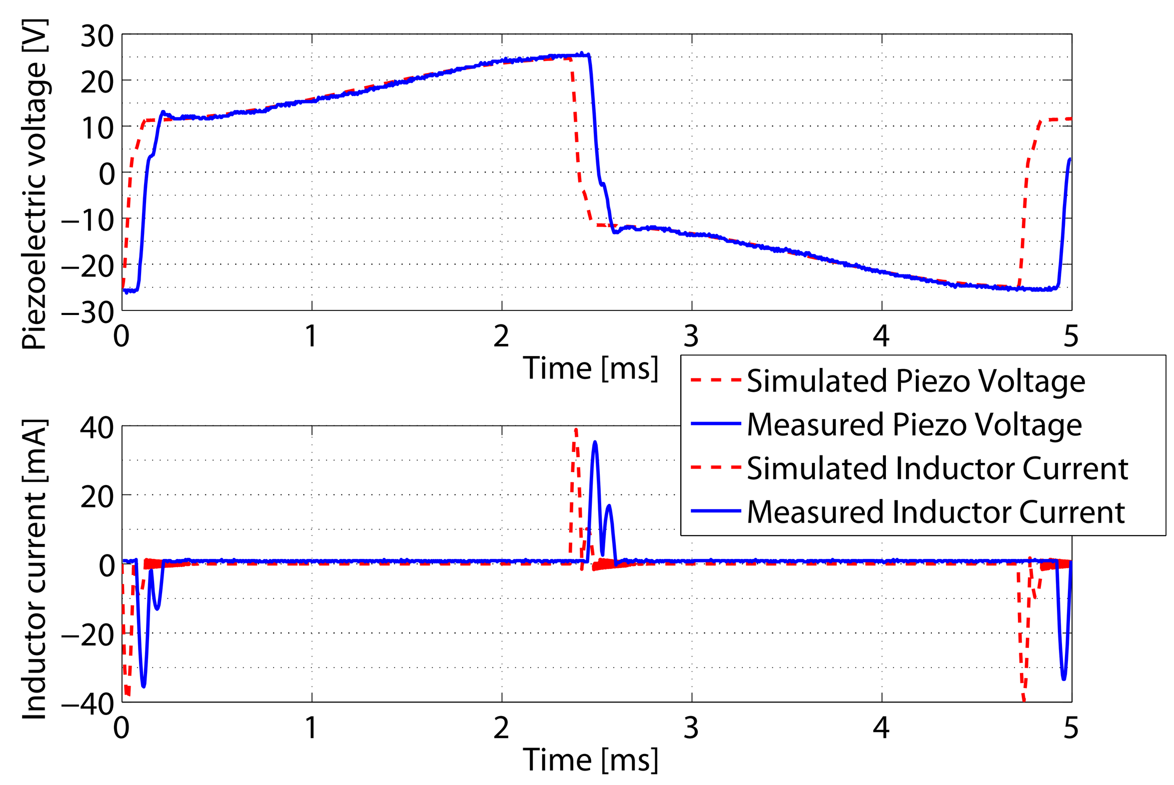
- Crucial switches are fired at travel extremes corr-esponding to voltage waveform extremes.
- A second piezo mechanically coupled but electrically isolated from generation piezo provided in-phase sense voltage for determining switch firing.
- Switches held on for one electrical resonance half cycle (ensures zero current conditions) by micro-power FPGA triggered by peak detector with time delay set by external resistor and capacitor.
- Series connected n-type and p-type MOSFETs create bidirectional conducting and blocking switches required for operation whilst,minimising switch voltage drop.

[2] A. D. T. Elliott and P. D. Mitcheson, "Implementation of a single supply pre-biasing circuit for piezoelectric energy harvesters," in EuroSensors 2012, September 2012.

Results and Future Work

- Output power of SSPB and bridge rectifier interface circuits were measured under optimal conditions.
- Harvester excited at 212 Hz with different peak accelerations (corresponding to different piezo open circuit voltages V_{po}).
- SSPB generated 11.3 times more power than bridge rectifier and 14% more than SSHI theoretical limit.
- Control power expenditure 126 μW (76% due to peak detector).
- Future work on peak detector power reduction and implementing maximum power point tracking.

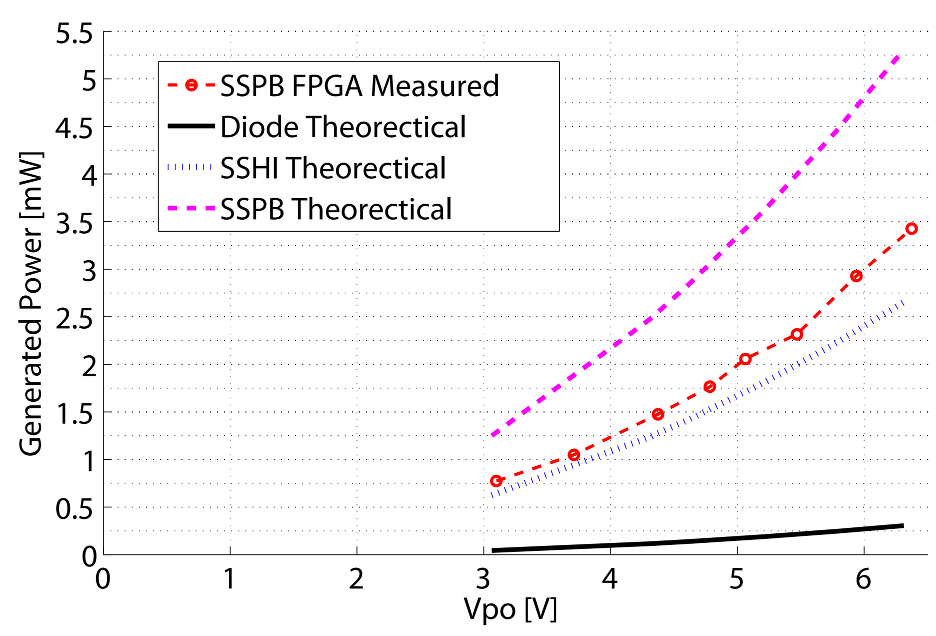
Piezo voltage and inductor current waveforms



- Measured and PSpice generated waveforms of the piezoelectric capacitor voltage and inductor current.

$$P_{SSPBmeasured}=1.14xP_{SSHITheorectical}$$

$$P_{SSPBmeasured}=11.3xP_{RECTTheorectical}$$



- Measured SSPB power output after control overhead versus theoretical bridge rectifier, SSHI and SSPB maximum power extraction limit [3].

[3] J. Dicken, P. D. Mitcheson, I. Stoianov, and E. M. Yeatman, "Power-extraction circuits for piezoelectric energy harvesters in miniature and low-power applications," IEEE Transactions on Power Electronics, vol. 27, pp. 4514–4529, 2012.

holistic energy harvesting

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