Energy Harvesting in Aeronautical Applications

Dr Dibin Zhu

SEVENTH FRAMEWORK PROGRAMME

TRIADE

Electronics & Computer Science
University of Southampton

Content

- Overview
- Thick-film piezoelectric generator
- Multilayer piezoelectric generator
- A Self-Powered Smart Tag
- Future work
- Conclusions

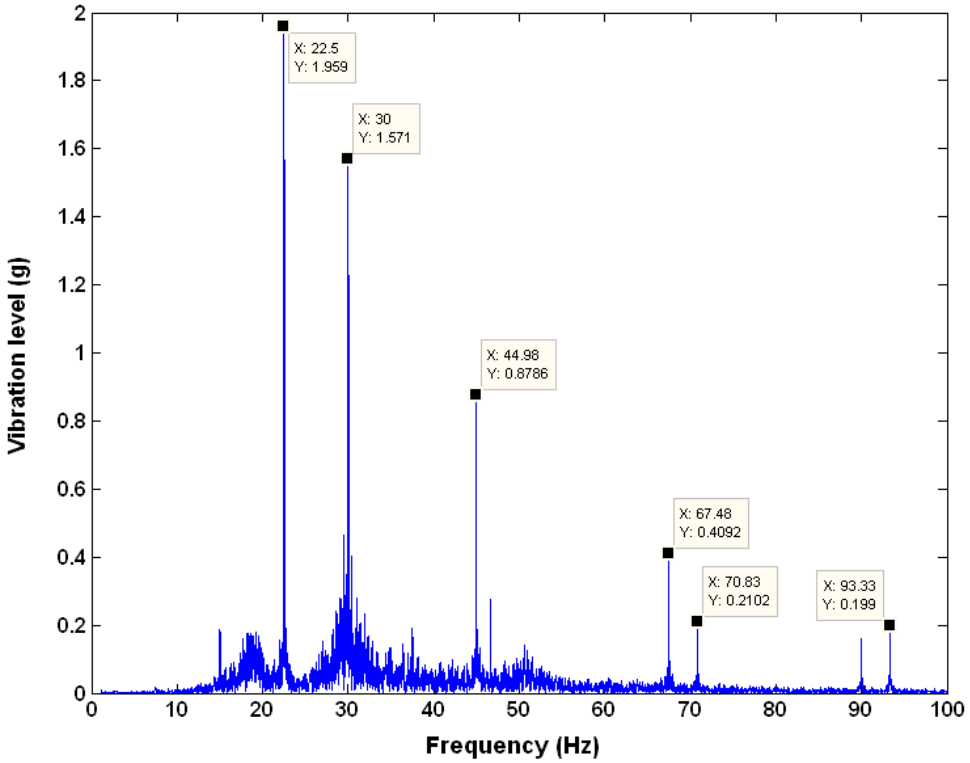
Overview: Project TRIADE

DEVELOPMENT OF TECHNOLOGY BUILDING BLOCKS FOR STRUCTURAL HEALTH MONITORING SENSING DEVICES IN AERONAUTICS

Overview: Application

Application: PZL SW-4 helicopter

Overview: Vibration spectrum



Frequency (Hz)	Vibration level (*g*)
30	1.58
45	0.88
67	0.41
70	0.21
93	0.2

Frequency spectrum taken from the vertical stabilizer on a PZL SW-4 helicopter*.

$1g = 9.8ms^{-2}$

* The helicopter was flying horizontally at 200km/h and at an altitude of 1000m with an outside air temperature of 10.5°C. The main rotor rotational speed was 103% where 100% = 7.288Hz.

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Design: Requirement

- Design Requirement
  - The thickness of the generator plus the displacement of the generator must be 3mm or less.
  - The generator should produce a minimum power of 100μW to enable periodic sensing and RF transmission.
- Bimorph thick-film piezoelectric generator

Design: Modeling

Linear model of cantilever-based bimorph piezoelectric generator

$$\ddot{z} + 2\zeta_n \omega_n \dot{z} + \omega_n^2 z - \frac{\theta_{31}\omega_n^2}{t_{pzt}} \cdot v = \gamma^* \cdot a$$

$$R_L C_p \dot{v} + v + mR_L \frac{d_{31}\omega_n^2}{t_{pzt}} \dot{z} = 0$$

Non-linear model of cantilever-based bimorph piezoelectric generator

Non-linear term

$$\ddot{z} + 2\zeta_n \omega_n \dot{z} + \omega_n^2 z + \boxed{\alpha} - \frac{\theta_{31}\omega_n^2}{t_{pzt}} \cdot v = \gamma^* \cdot a$$

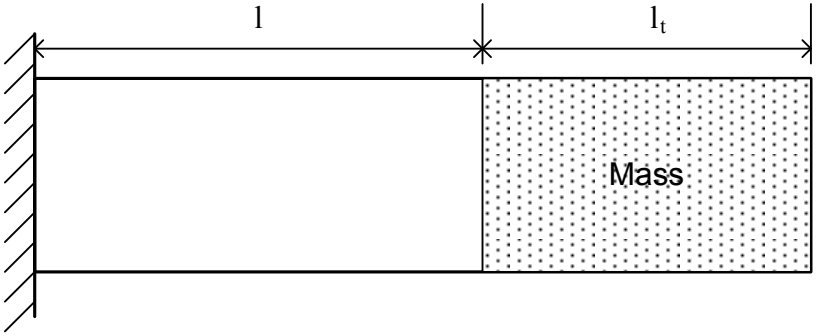
$$R_L C_p \dot{v} + v + mR_L \frac{d_{31}\omega_n^2}{t_{pzt}} \dot{z} = 0$$

α- The non-linear spring factor $\sim 10^{10}$

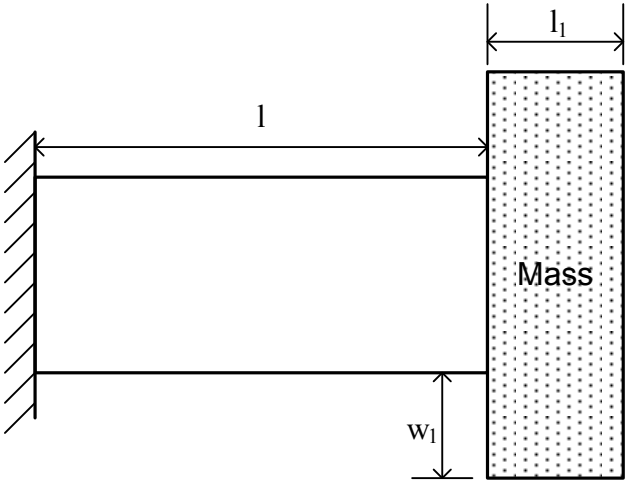
The non-linear model can be solved using numerical method.

Design: Optimisation 1

General cantilever



T-shape cantilever



Design: Optimisation 2

Simulation results show that:

- T-shape cantilevers have less tip displacements than general cantilevers.
- With given size constraints, T-shape generators can produce more than 100μW power and have tip displacements less than 2mm only when they worked at the vibration of 0.41g@67Hz.

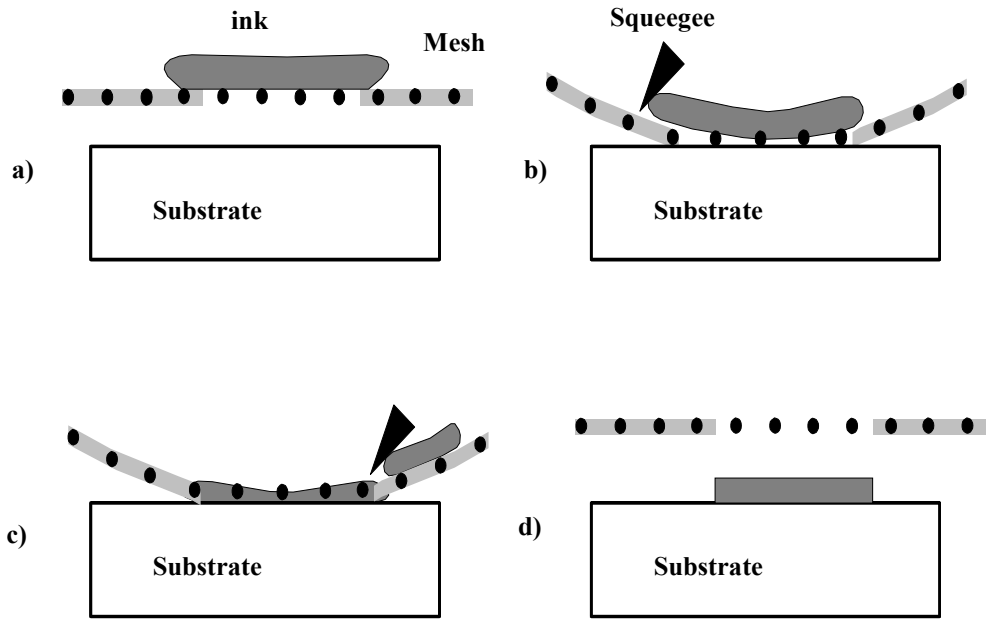
Optimized parameters:

Generator	Substrate thickness (μm)	Dielectric thicness (μm)	Electrode thickness (μm)	PZT thickness (μm)	Mass layer thickness (μm)	Beam length (mm)	Mass length (mm)	Beam width (mm)	Output power (μW)	Tip displacement (mm)
A	100	20	10	75	500	20	10	27	261.34	1.96
B	100	20	10	75	500	22	8	23	109.35	1.34

Fabrication: General

Fabrication of the Generator

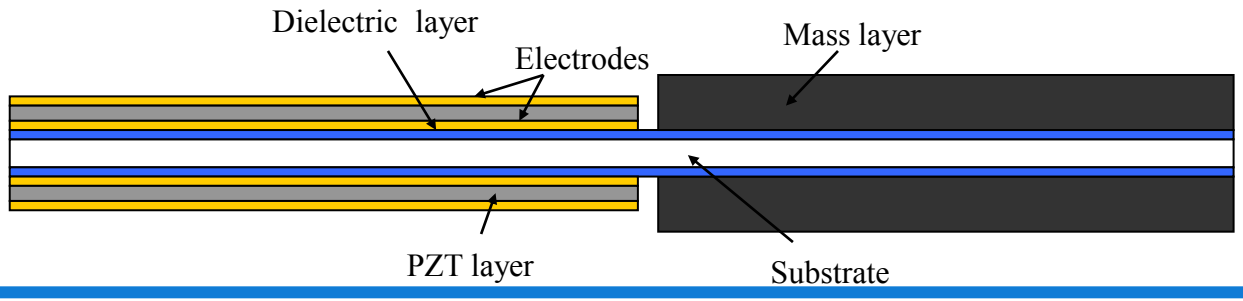
Screen Printing Process



Fabrication: Substrate and paste

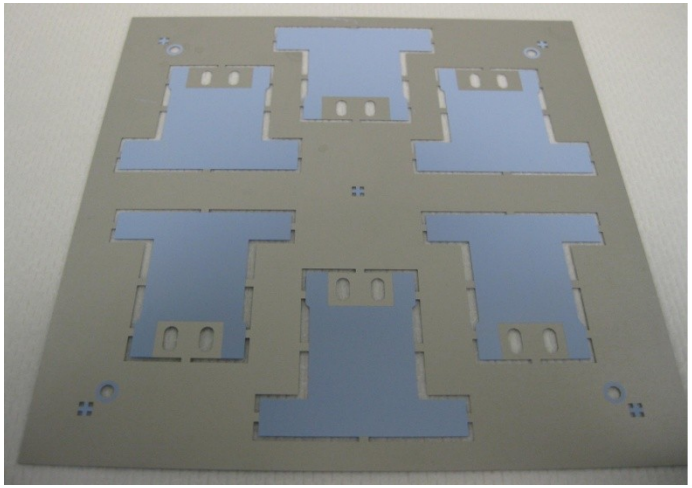
Substrate: Stainless Steel 430S17

Layer	Paste	
Dielectric	ESL4924	Off the shelf
Bottom electrode	ESL8836 (Gold)	
Top electrode	ESL1901-S (Silver polymer)	
PZT	PZT-5H, glass, thinner	Homemade
Mass	Tungsten power, thinner Density = 10,000 $kg \cdot m^{-3}$	

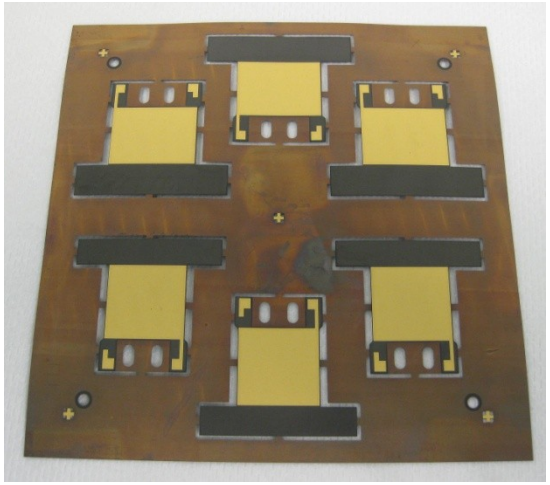


Fabrication: Printing process

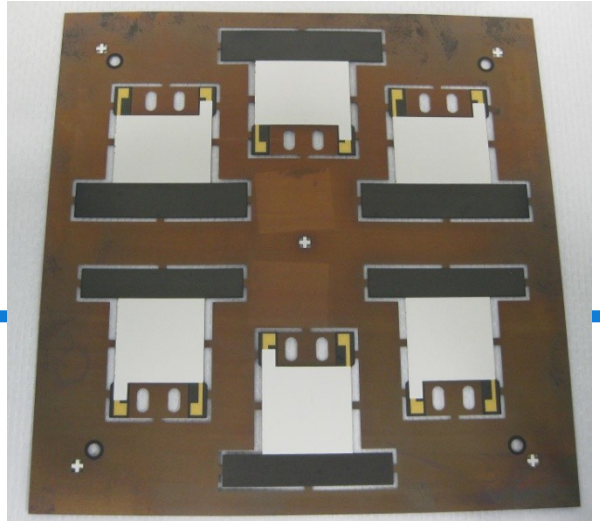
Dielectric layer



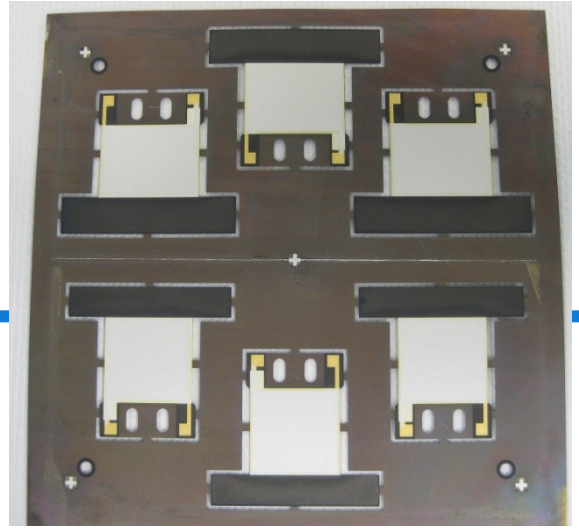
Bottom electrode



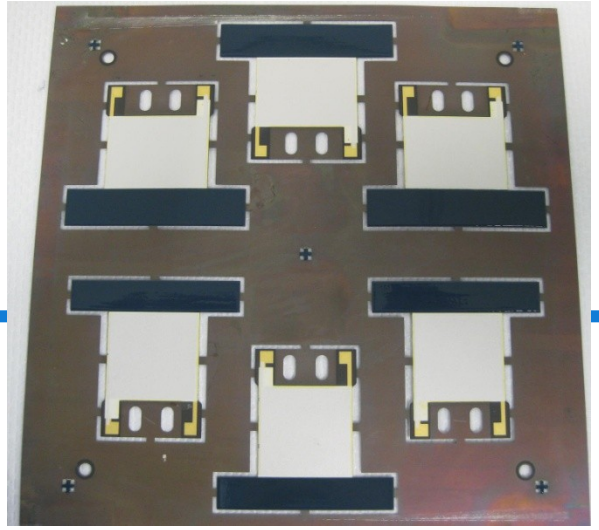
PZT layer



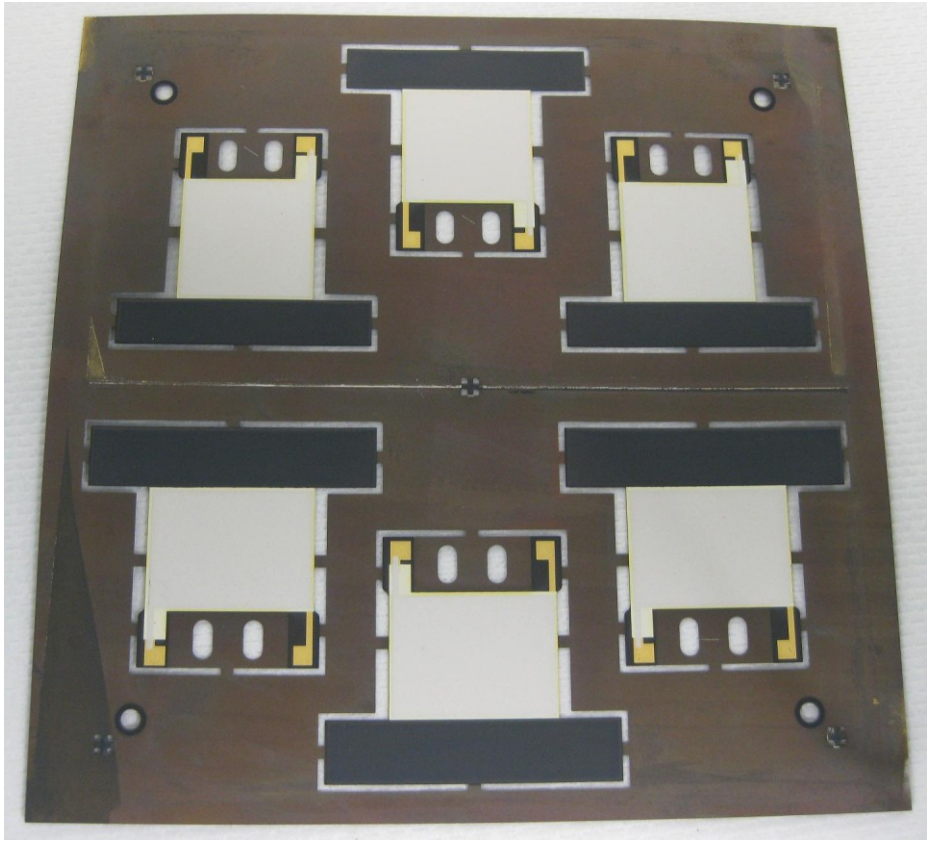
Top electrode



Mass



Fabrication: Finished devices

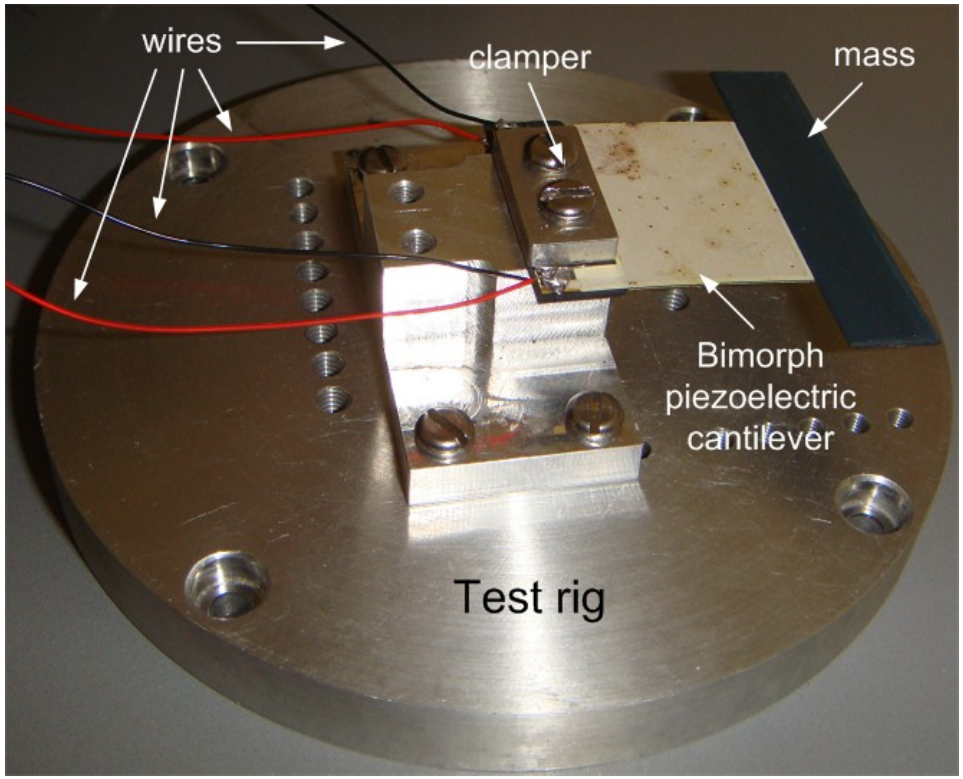


Polarization: 4 MV·m^{-1} at 200 C, 30 minutes
4 MV·m^{-1} cooling down, 20 minutes.

d_{33} coefficient: 131 pC/N

Test: Setup results

The generator was tested on a shaker.
The excitation level was $0.29 g_{rms}$, i.e. $0.41 g_{pk}$.

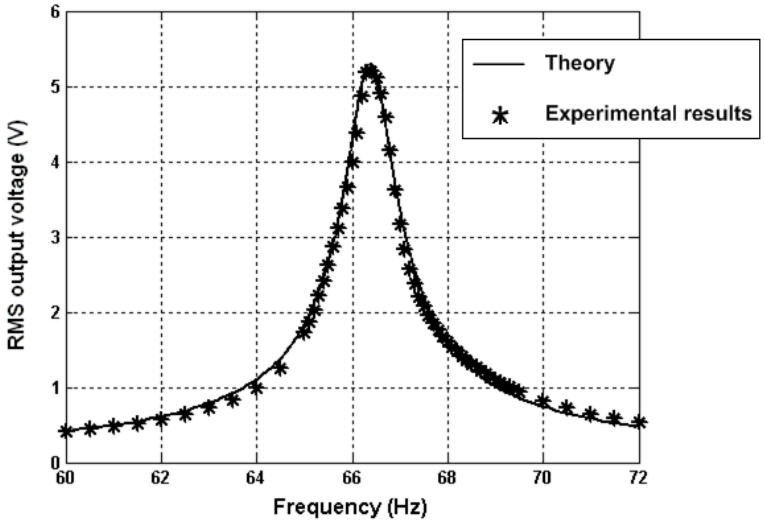


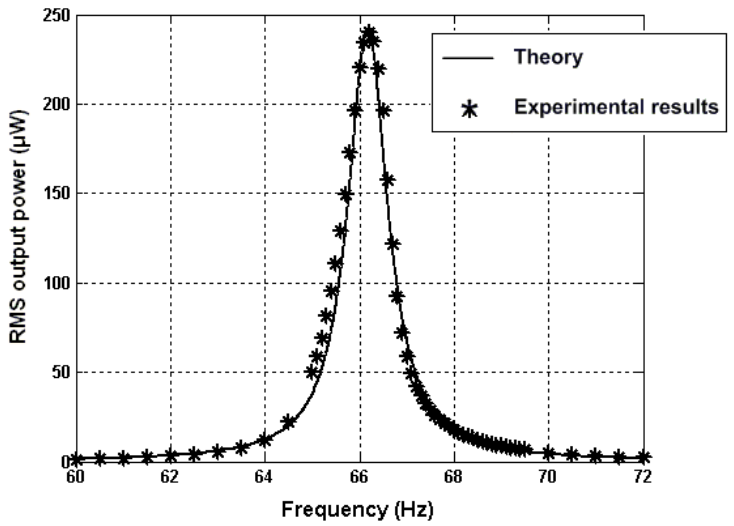
Test: Results

Open circuit voltage

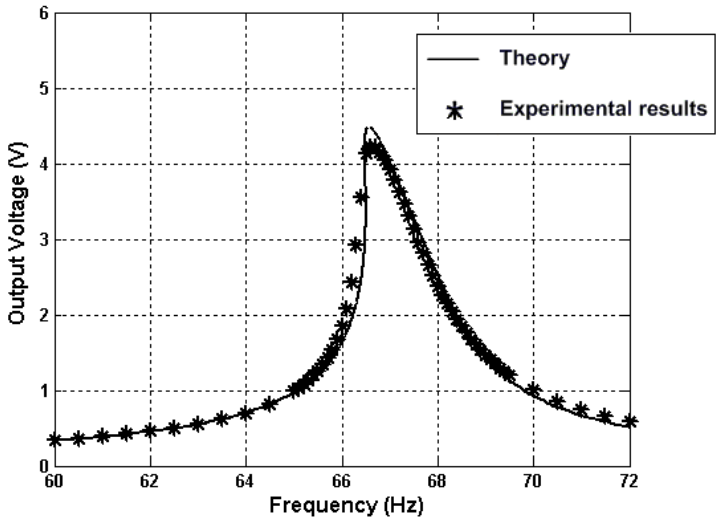
Output power

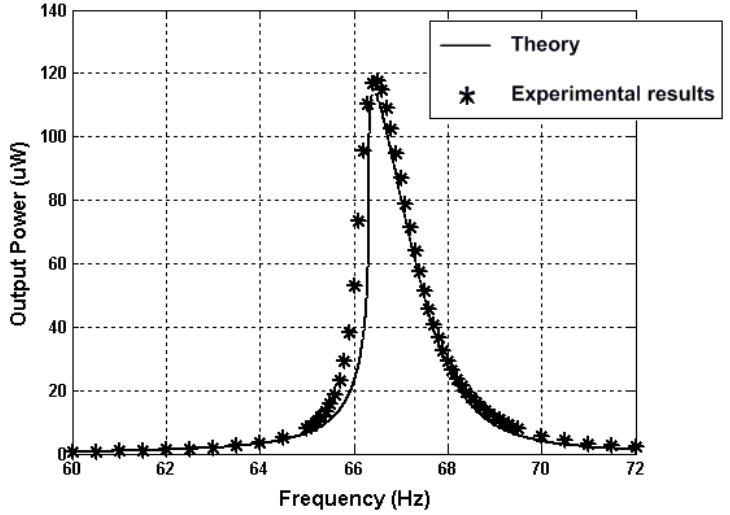
A





B





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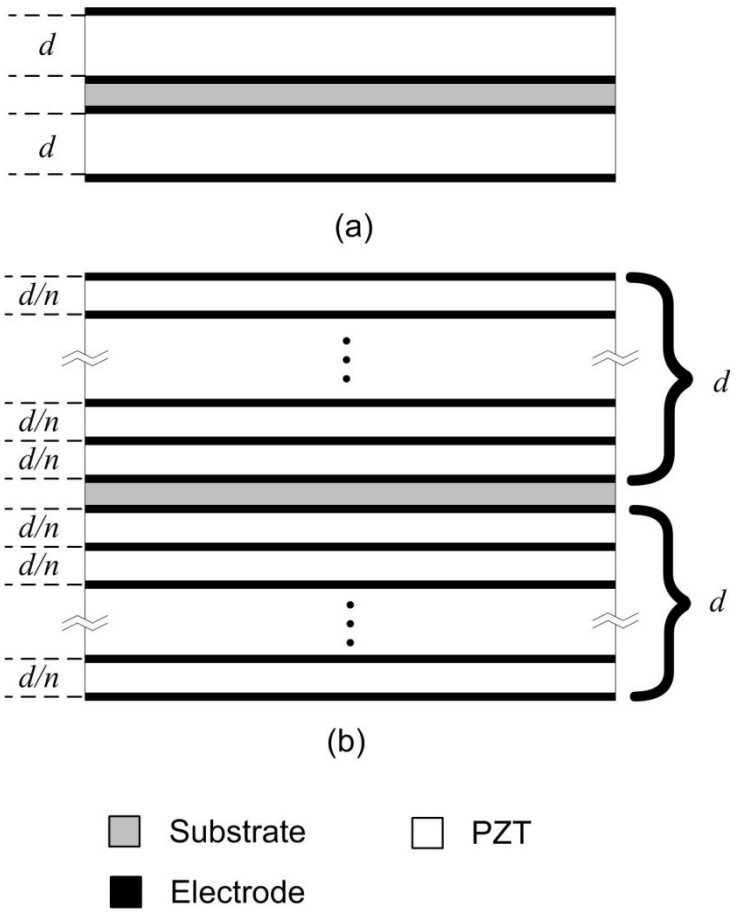
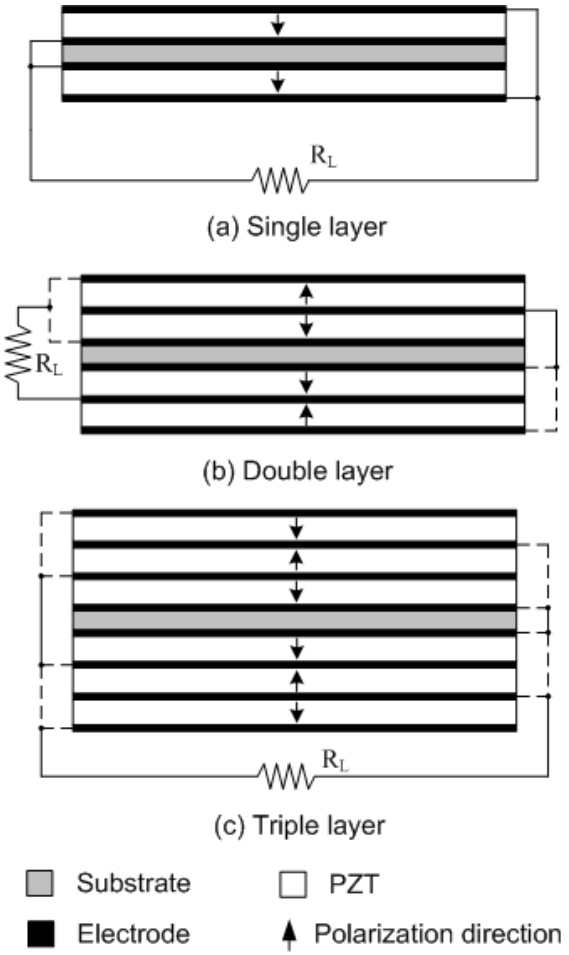
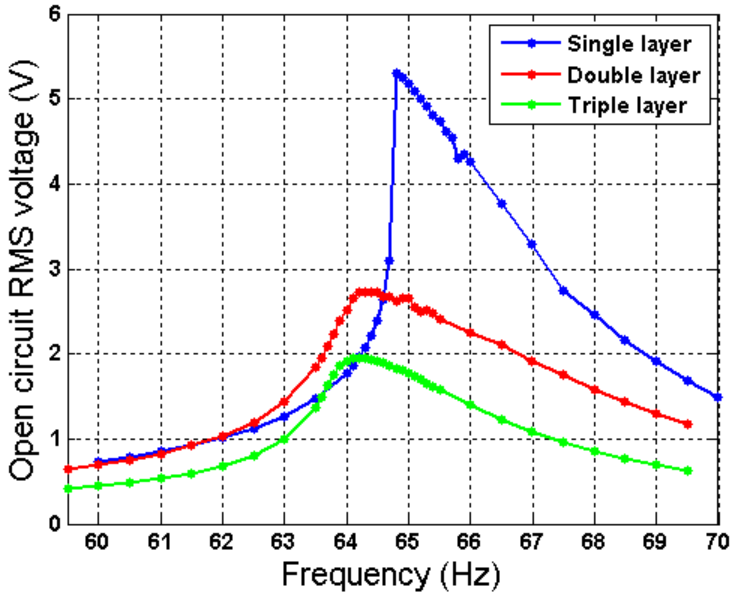
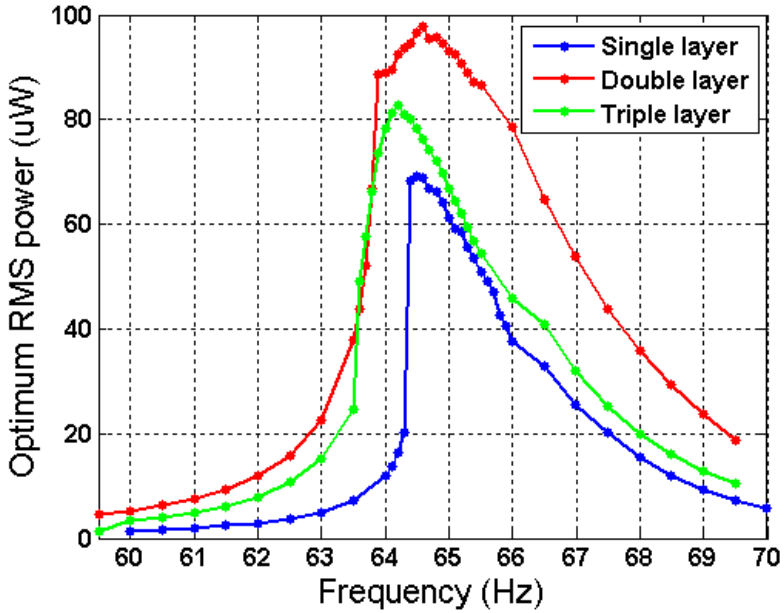
Multilayer piezoelectric generator

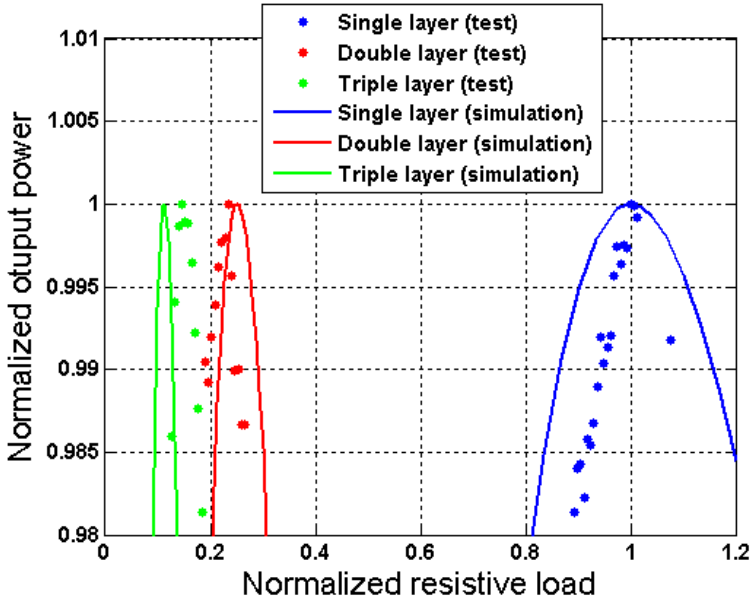




Multilayer piezoelectric generator: Results







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Multilayer piezoelectric generator: Summary

	Single-layer	*n*-layer
Overcall capacitance	1	n^2
Optimum resistive load	n^2	1
Open circuit voltage	n	1

- Maximum output power of a double-layer generator is about 40% more than that of a single-layer generator while a triple-layer generator has about 20% more output power than a single-layer generator.
- It is not worth fabricating triple (or more) layer piezoelectric generators unless low input impedances are required.

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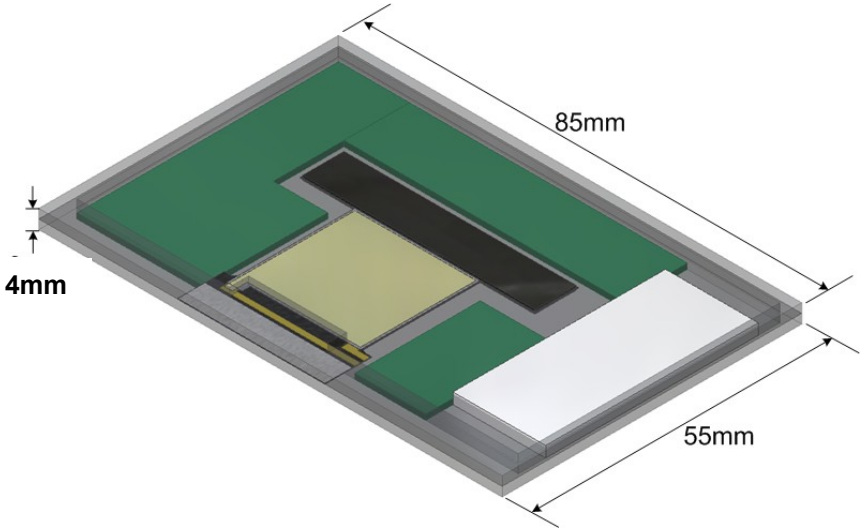
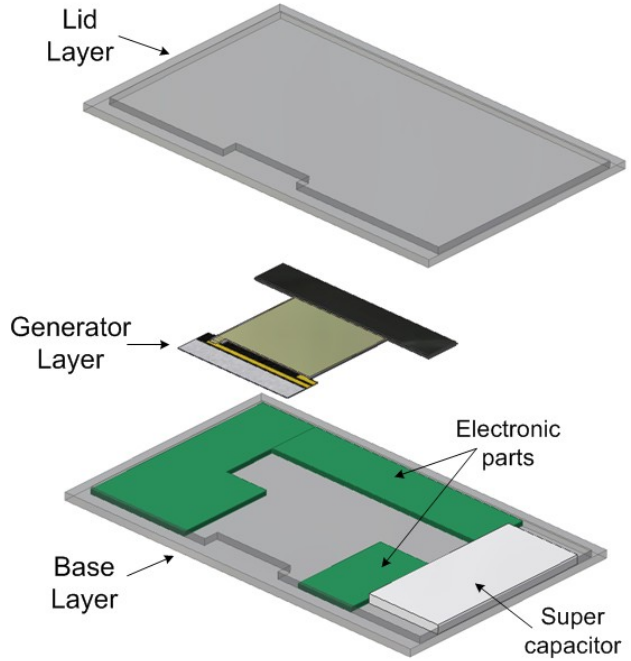
A Self-Powered Smart Tag

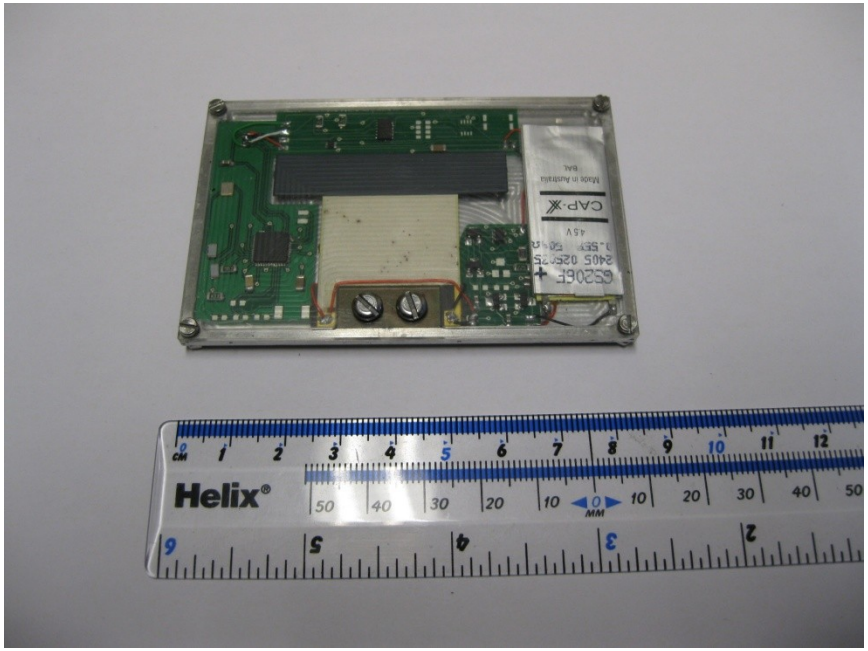
Perspective view of the smart tag



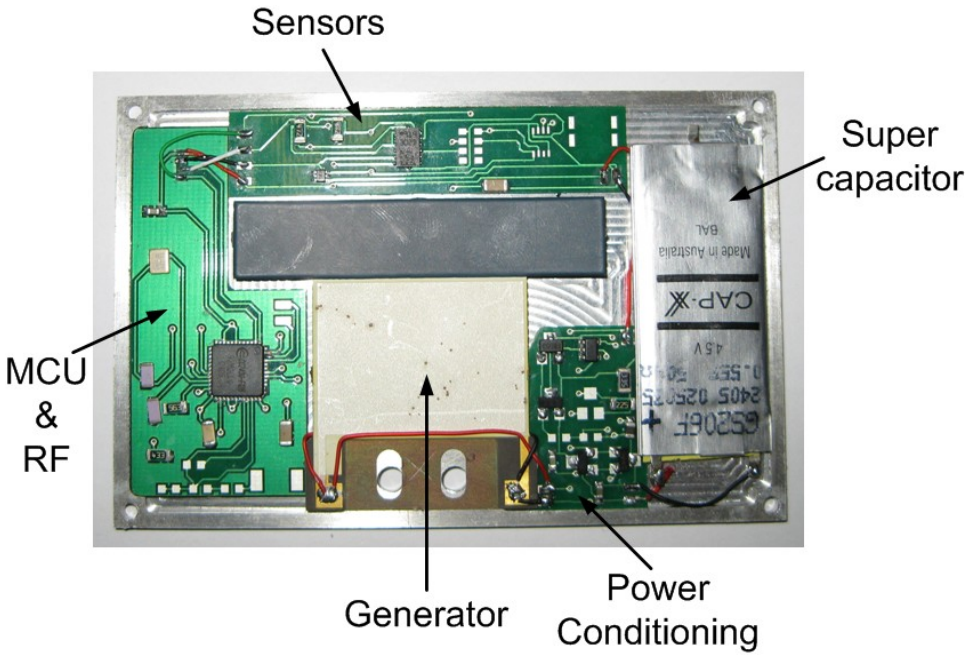


Integration concept of the smart tag: lamination of different layers

A Self-Powered Smart Tag



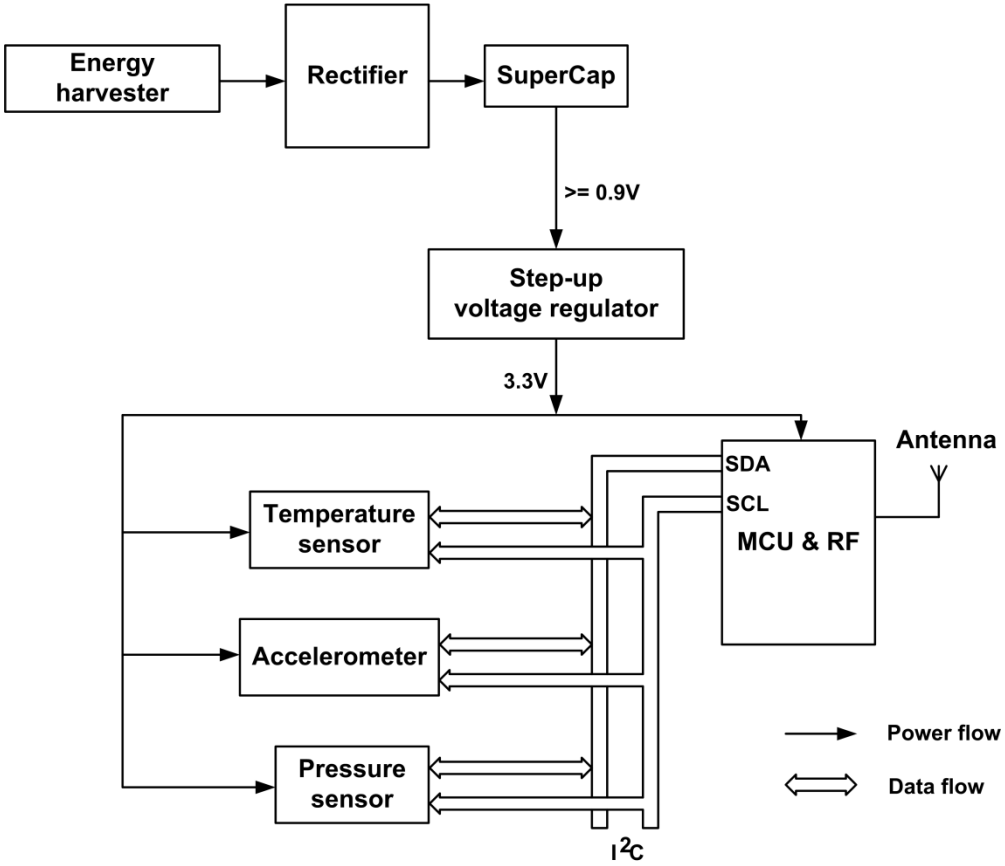
Practical device



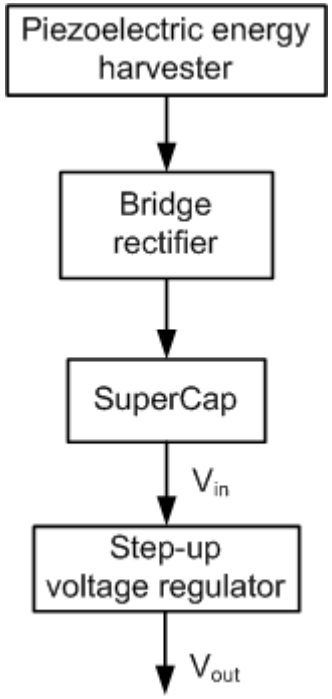
Layout of the smart tag

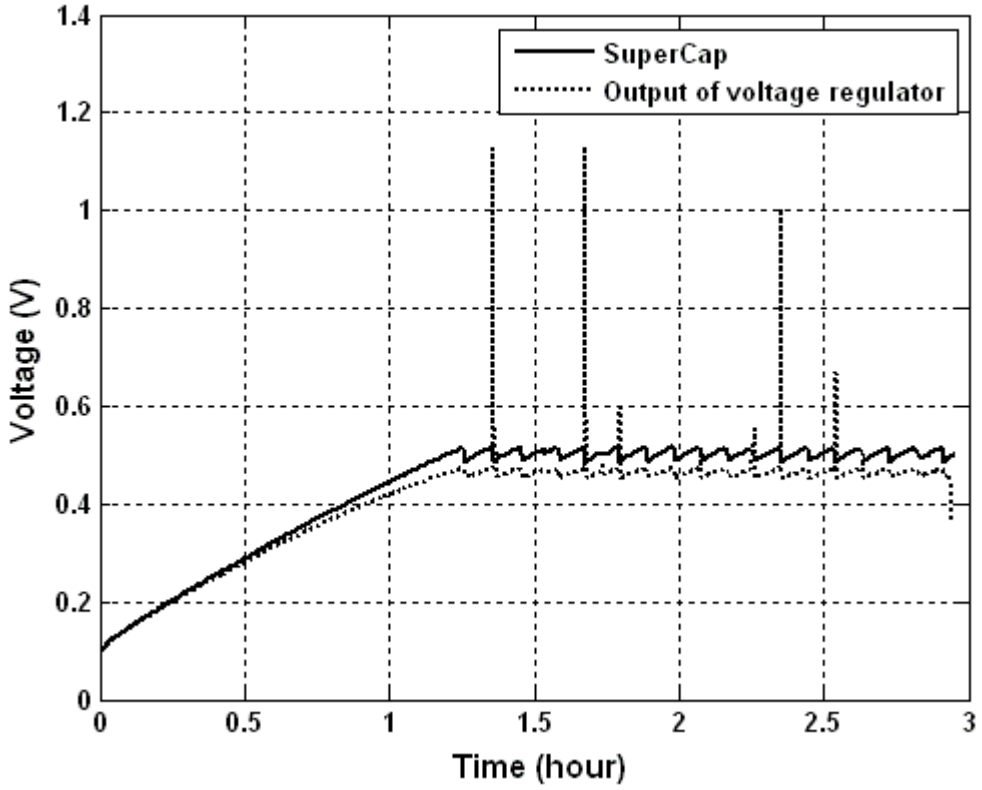
A Self-Powered Smart Tag

System Description

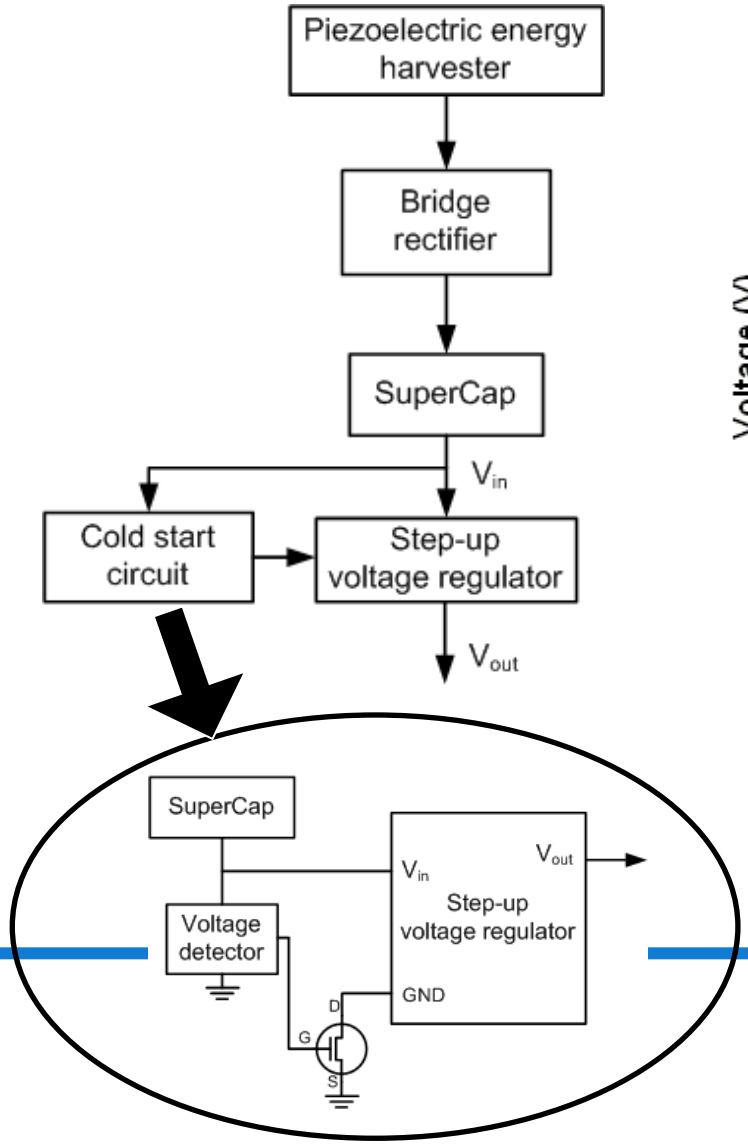


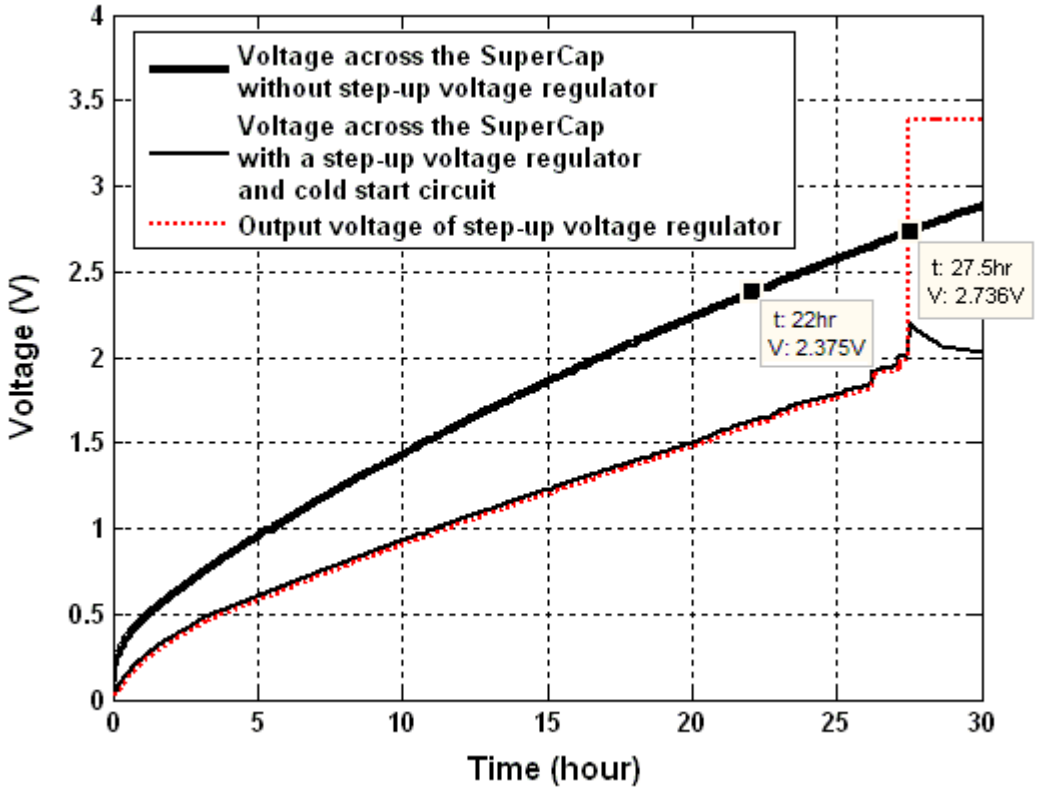
A Self-Powered Smart Tag





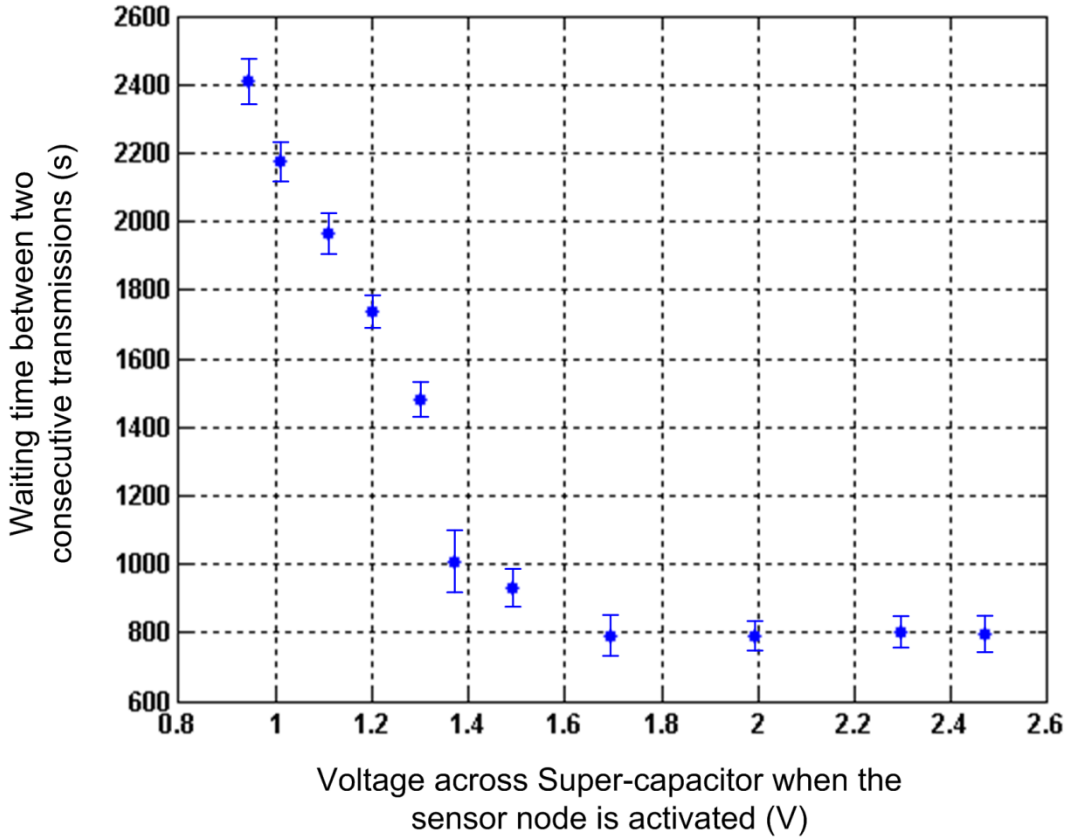
A Self-Powered Smart Tag





A Self-Powered Smart Tag

Waiting time between two consecutive transmissions



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Future work

- Energy harvesters for other applications,
  e.g. fixed wing aircrafts.
- Planar electromagnetic energy harvesters.
- Resonant frequency tuning.

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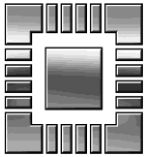
Conclusions

- TRIADE
- Thick-film piezoelectric generator
  - 0.41g@67 Hz
  - Tip displacement < 2 mm
  - Output power > 100 μW
- Multilayer piezoelectric generator
  - Double-layer piezoelectric energy harvesters have the highest output power
- A Self-Powered Smart Tag
  - Credit card size
  - Integration of an energy harvester, power conditioning circuit, sensors, a microprocessor and a transceiver



Thank you for your attention!