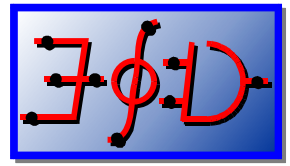

BMAS 2007

# An Integrated Approach to Energy Harvester Modeling and Performance Optimization

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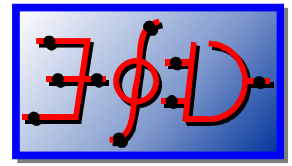
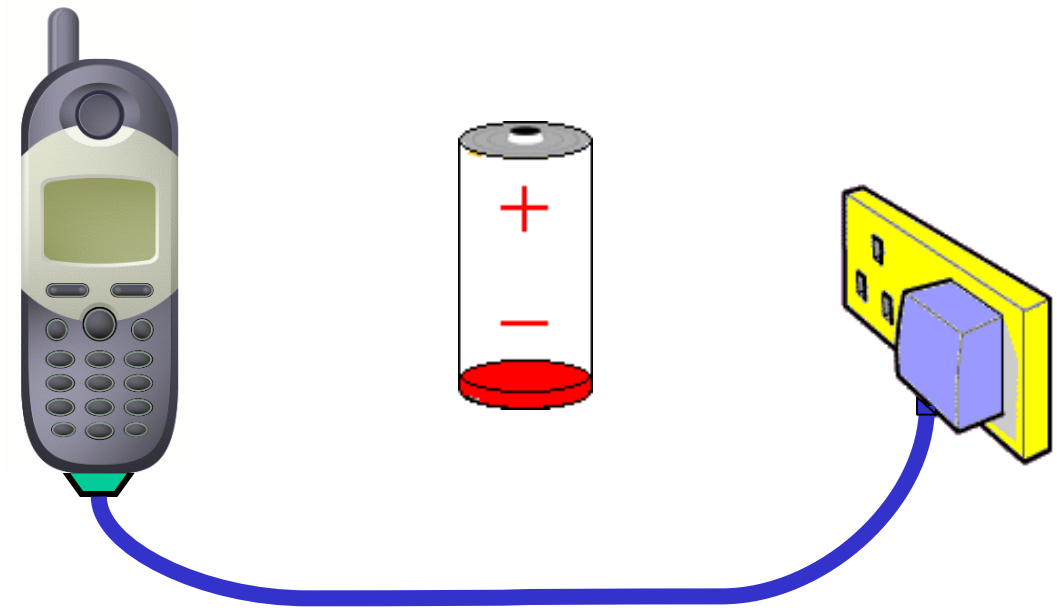


# Outline

- Introduction
- Energy harvester (EH) modeling approaches
- Simulation and comparison
- EH performance optimization
- Conclusion

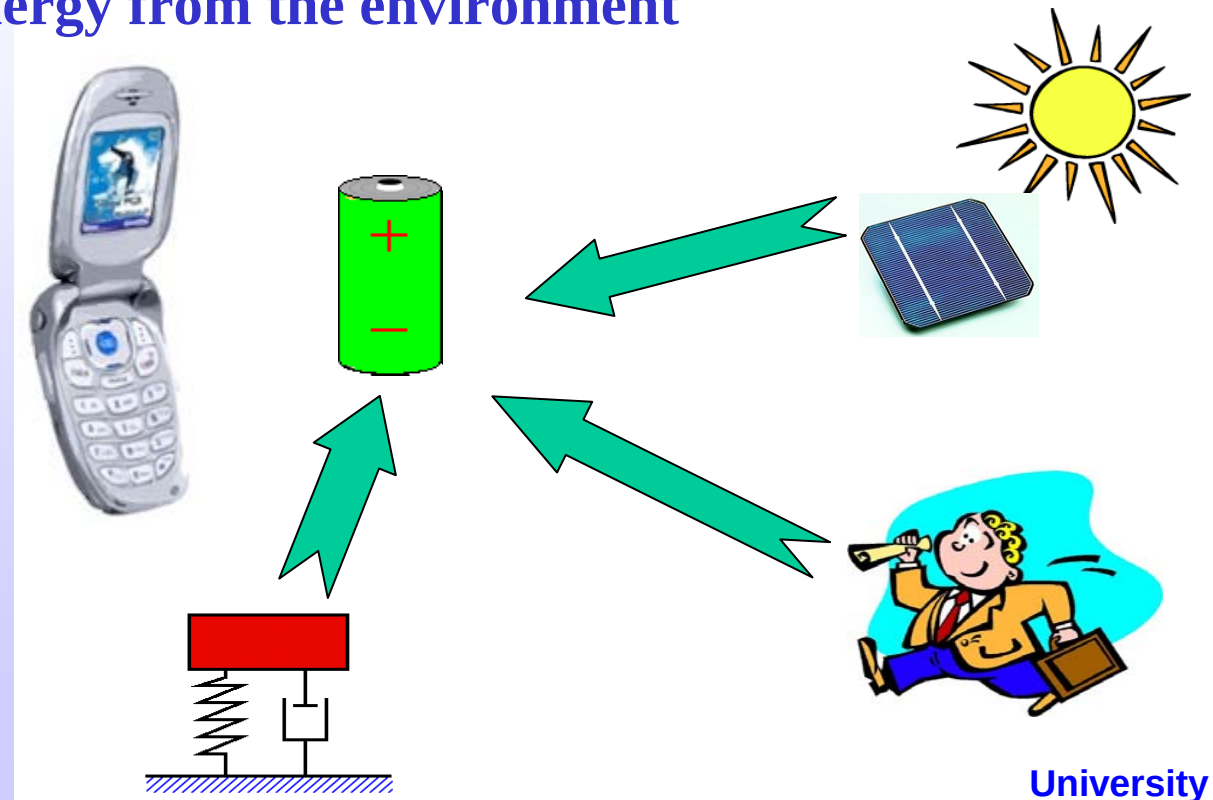
# Introduction

- Energy harvesting
  - State of the art



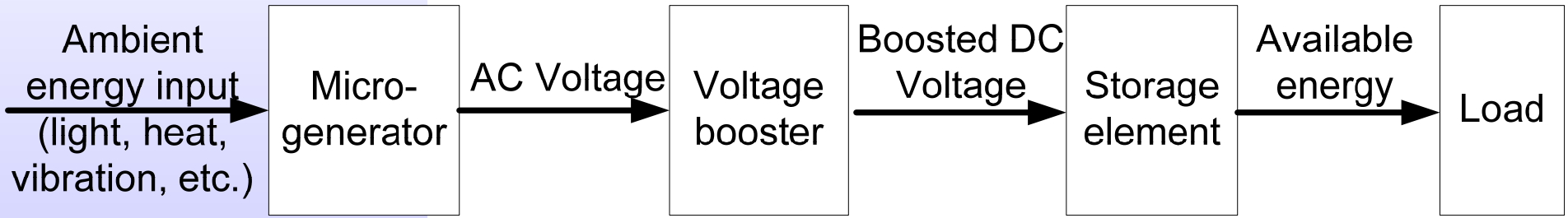
# Introduction

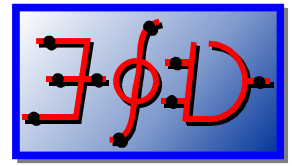
- Energy harvesting
  - Harvesting energy from the environment



# Introduction

## •Diagram of an EH





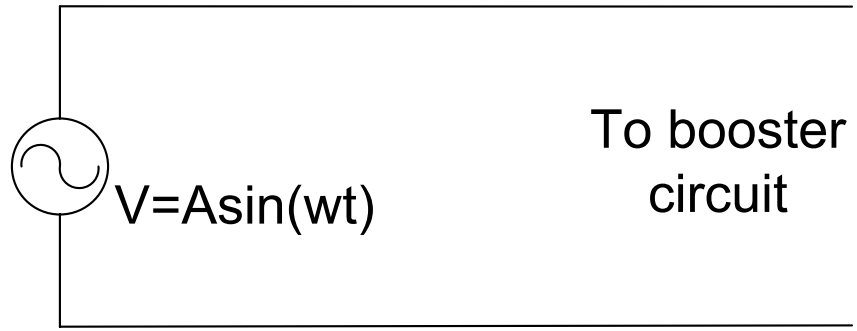
# Introduction

- **VHDL-AMS as modeling language**

- **Genetic optimization completely implemented in VHDL-AMS testbench** (*L. Wang and T.J. Kazmierski, VHDL-AMS based genetic optimization of a fuzzy logic controller for automotive active suspension systems, BMAS 2005*)

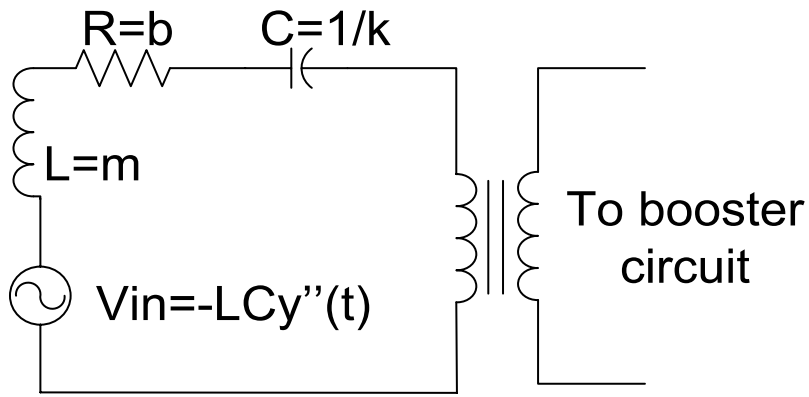
# EH modeling approaches

- **Micro-generator models**
  - **Ideal voltage source**




(a) Ideal voltage source

  - **Equivalent circuit**

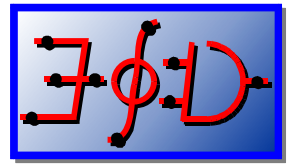



(b) Equivalent circuit model

# EH modeling approaches

- **Proposed HDL model**


(c) Proposed HDL model

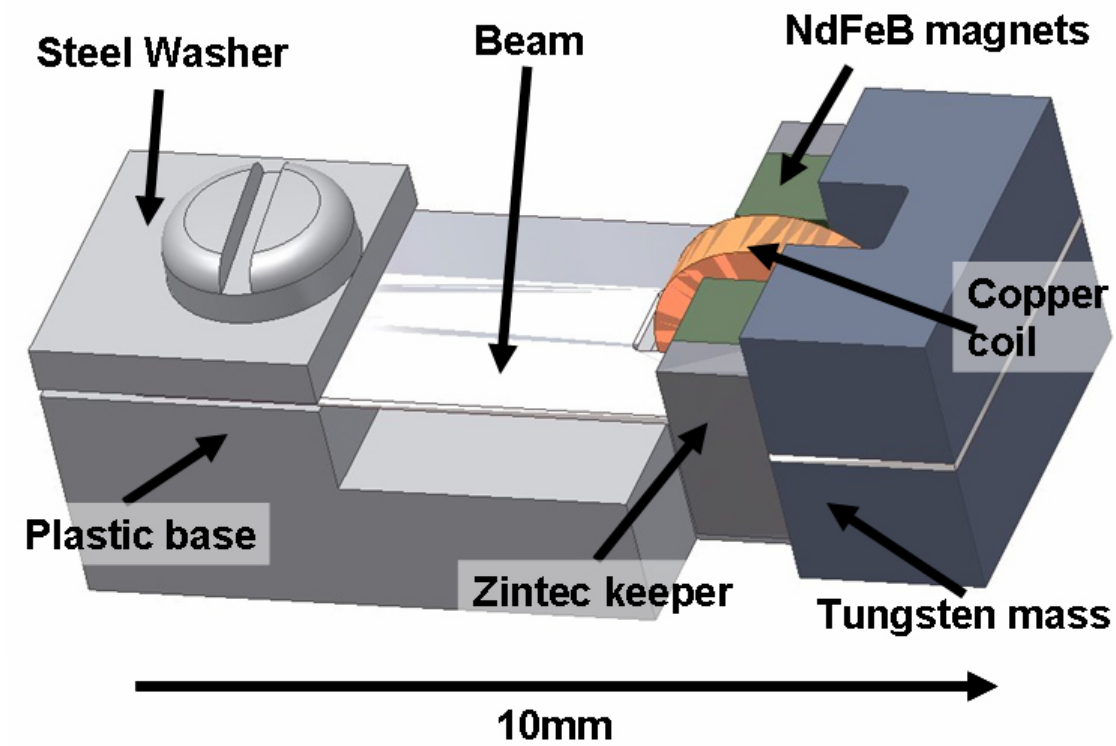


# Case study

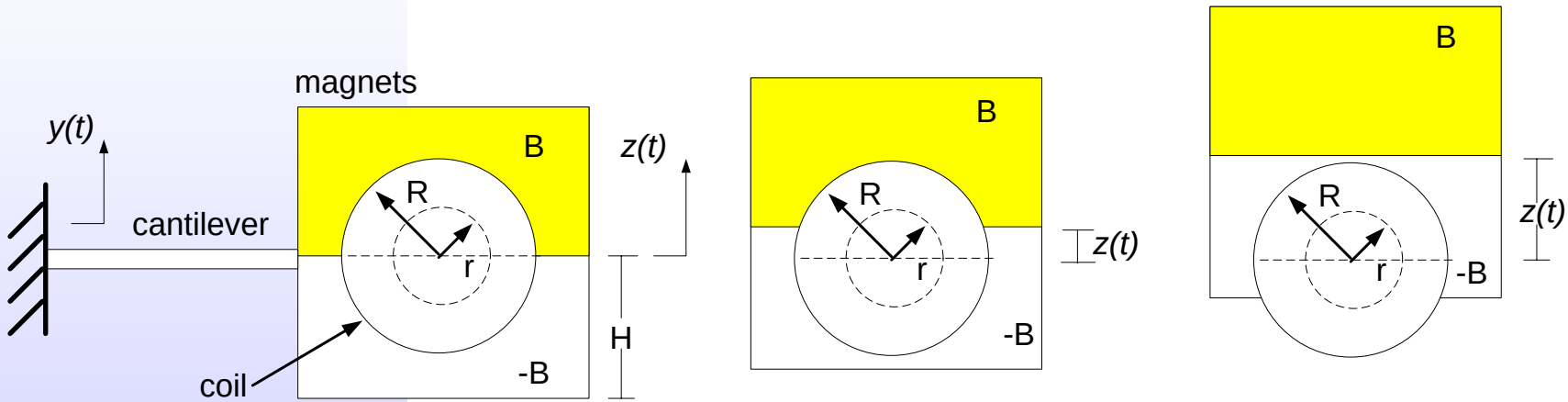
- **State-of-the-art EH** *(R. Torah, et.al, Development of a cantilever beam generator employing vibration energy harvesting. In Proceedings of The 6th Int. Workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Applications, 2006.)*
- **Vibration-based**
- **Electromagnetic micro-generator**
- **Voltage multiplier as booster**
- **Super capacitor**

# Micro-generator

- Cantilever based electromagnetic



# Micro-generator




(a) Initial position $z(t)=0$

(b) Small displacement $|z(t)|<r$

(c) Large displacement $H-r<|z(t)|<H$

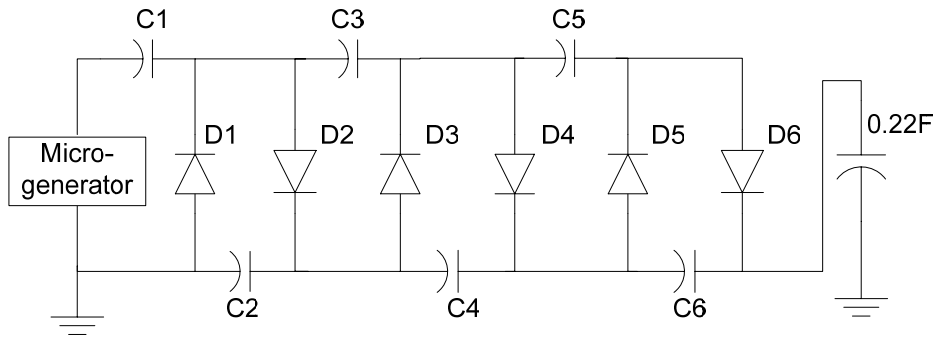
- **(b)** $$\Phi = (\sqrt{R^2 - z^2(t)} + \sqrt{r^2 - z^2(t)}) * 2 * B * N$$

- **(c)** $$\Phi = -(\sqrt{R^2 - (H - |z(t)|)^2} + \sqrt{r^2 - (H - |z(t)|)^2}) * B * N$$

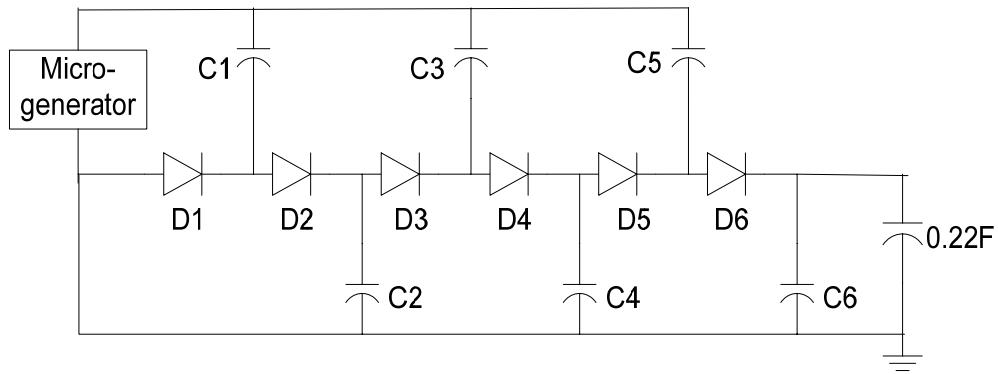
# Voltage booster

## •6 stage voltage multiplier (VM)

- **Villard**

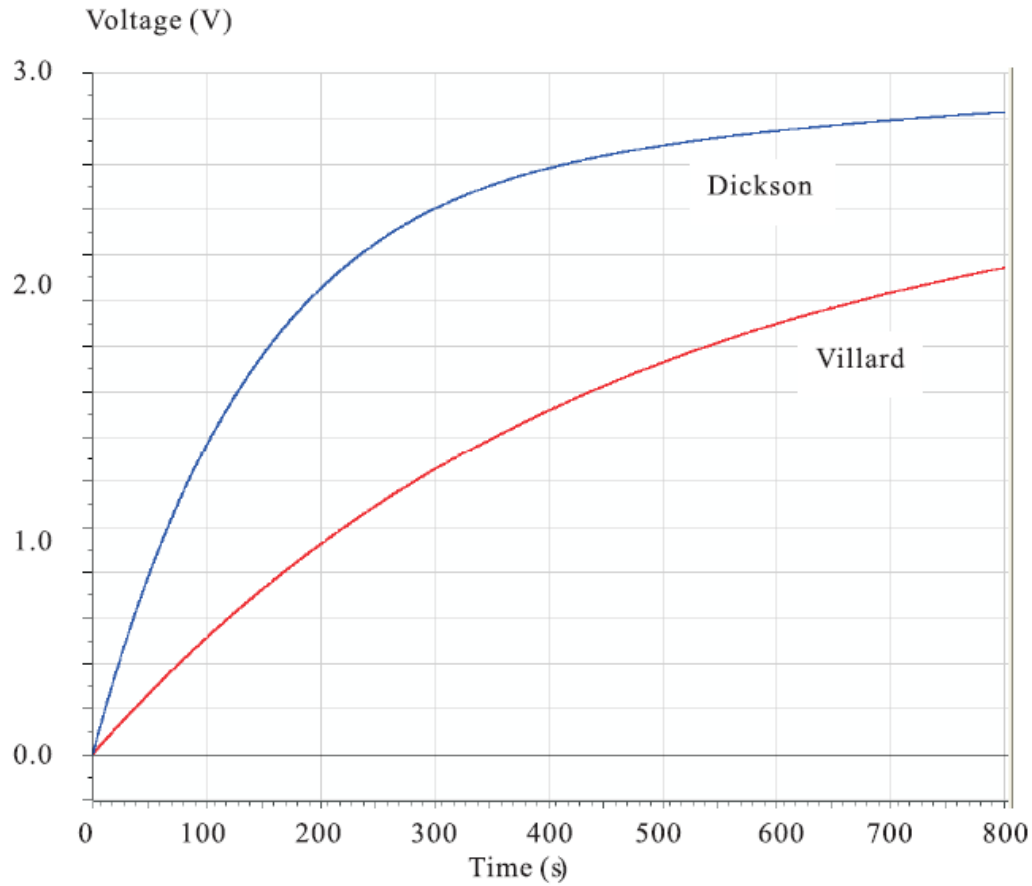



- **Dickson**



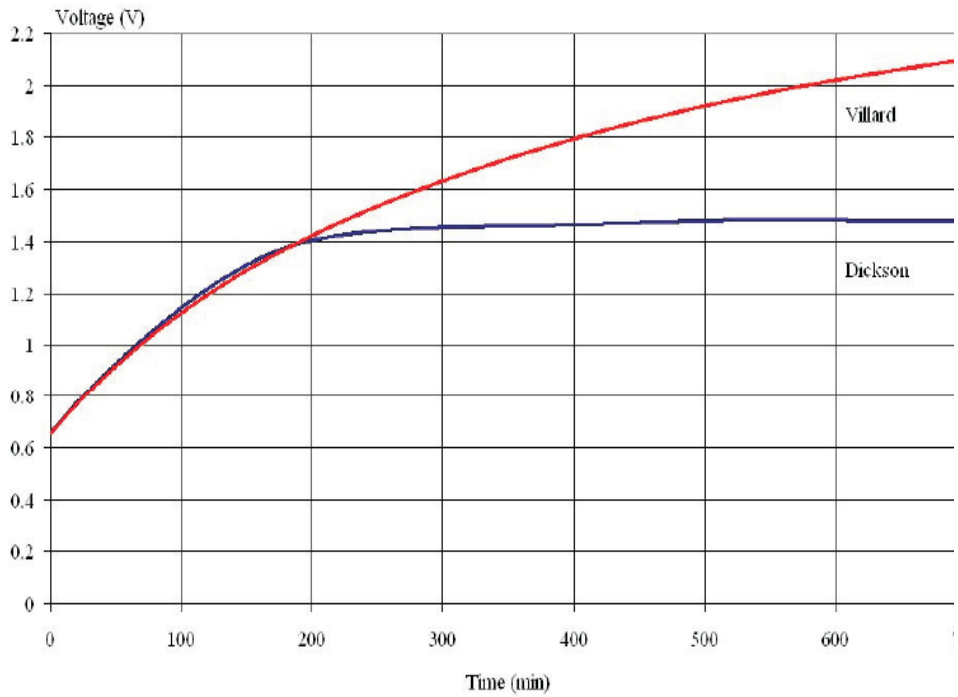
# Simulation and comparison

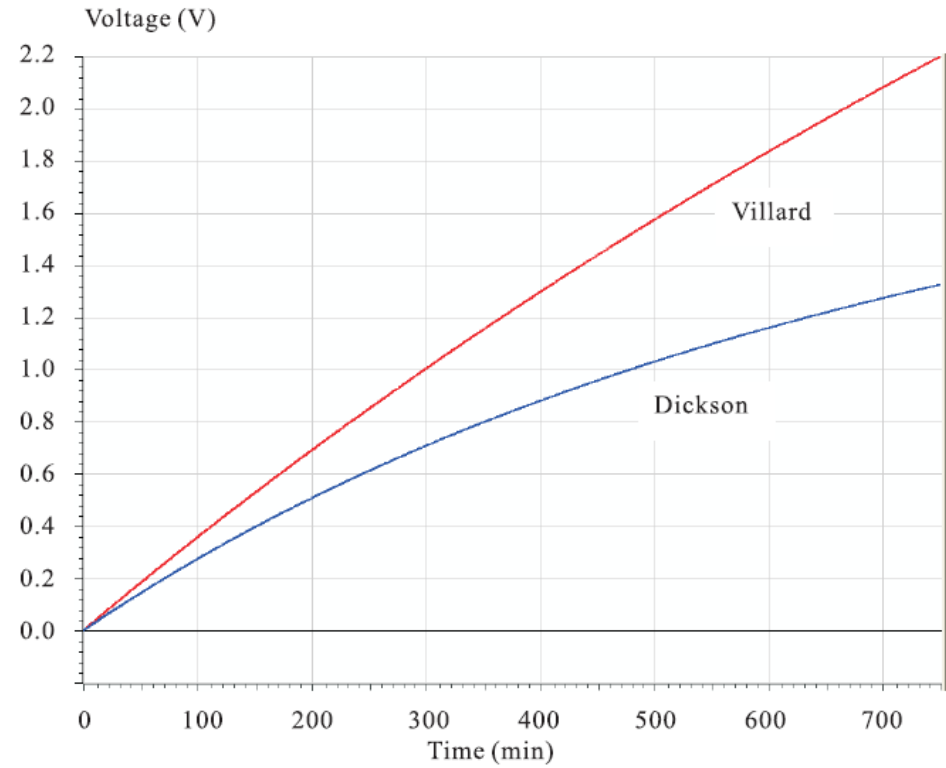
- Ideal voltage source
  - Villard: 11 min 14 sec
  - Dickson: 3 min 9 sec



# Simulation and comparison

## •Experimental measurement and HDL model simulation

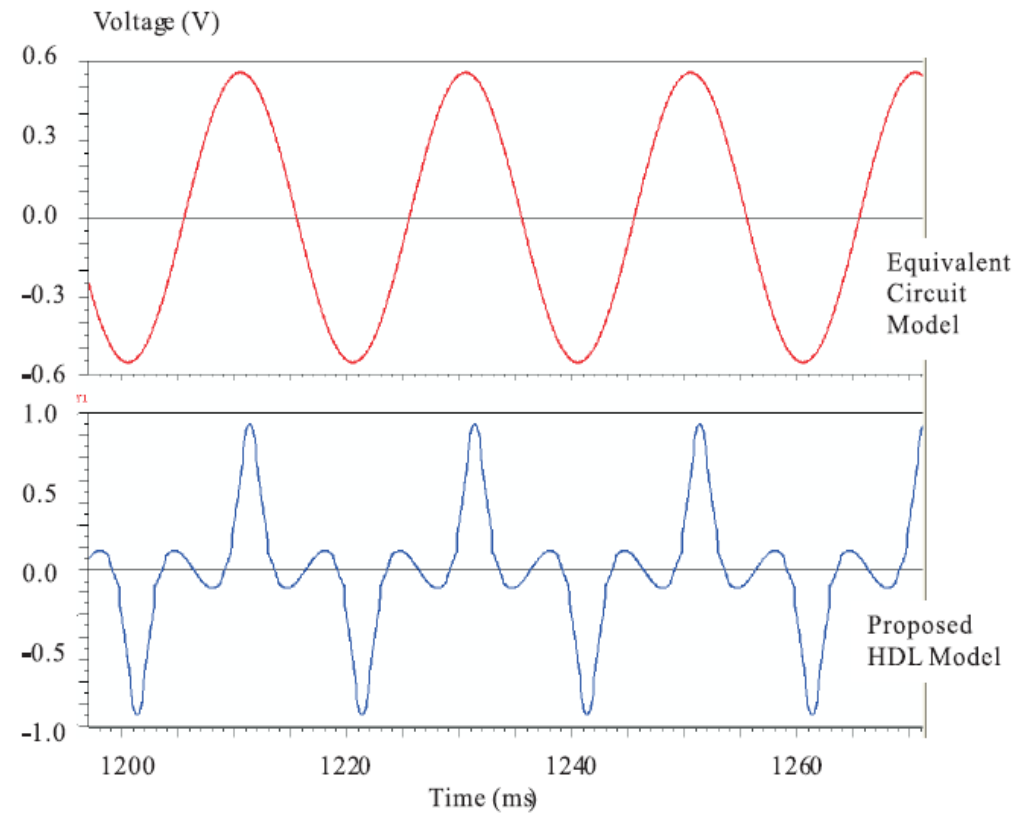


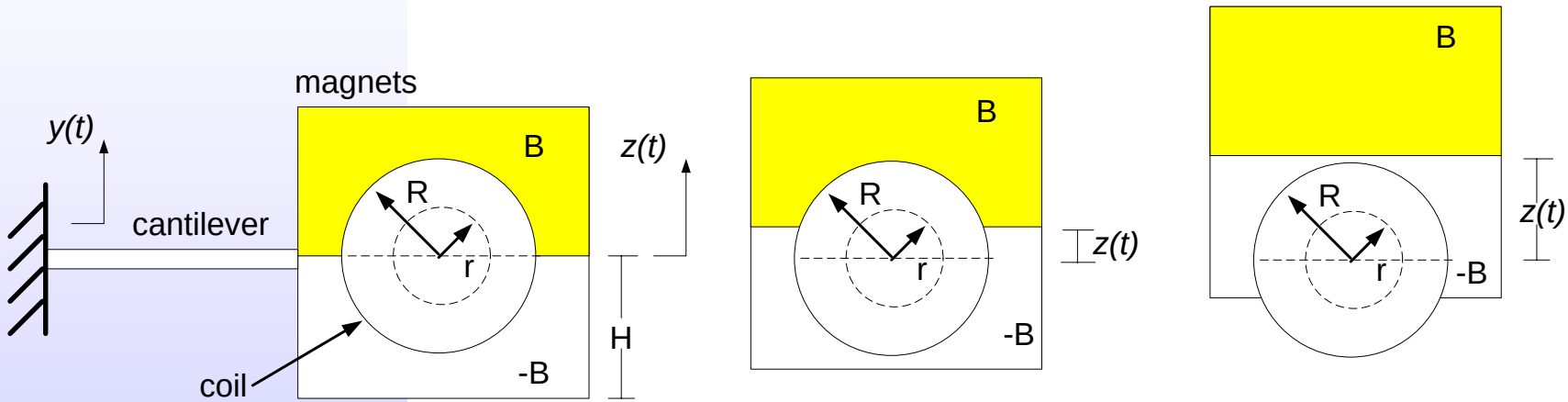
# Simulation and comparison

- Equivalent circuit model and HDL model simulation

$$L = m, \quad C = 1/k, \quad R = b$$



# Micro-generator

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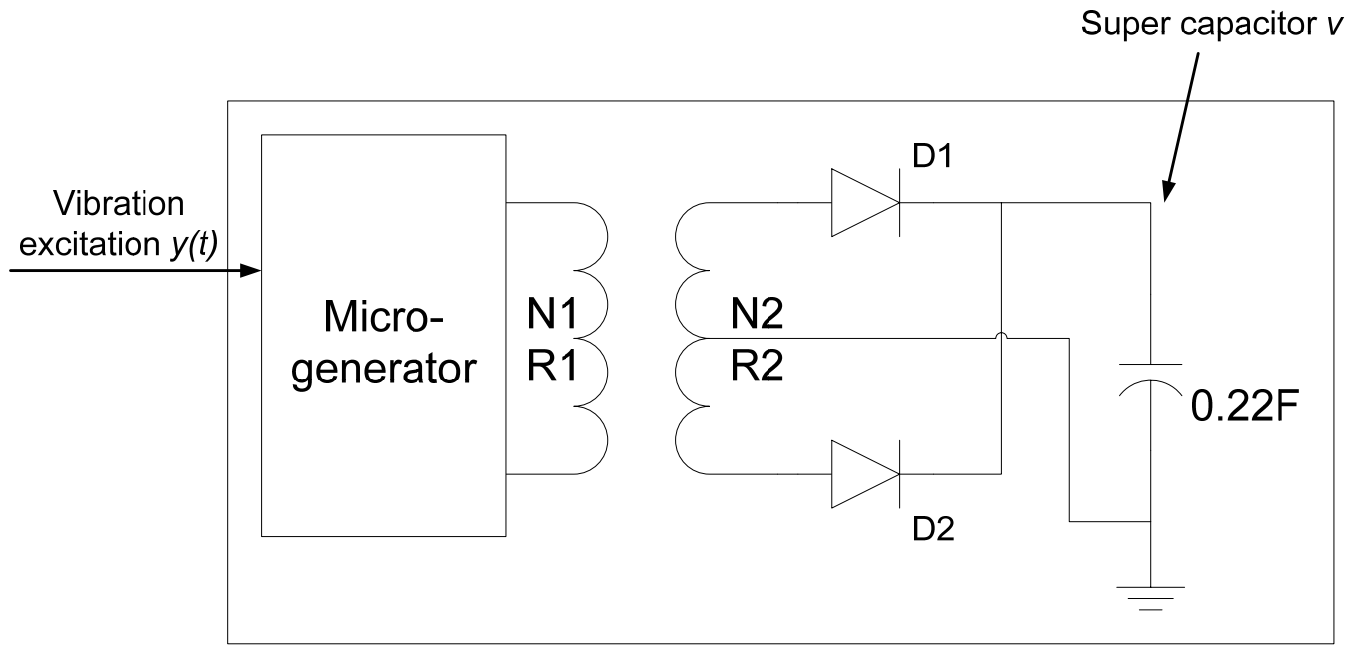
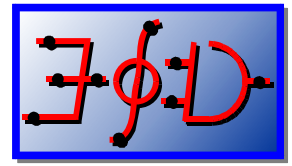
# EH performance optimization

- Voltage transformer as booster



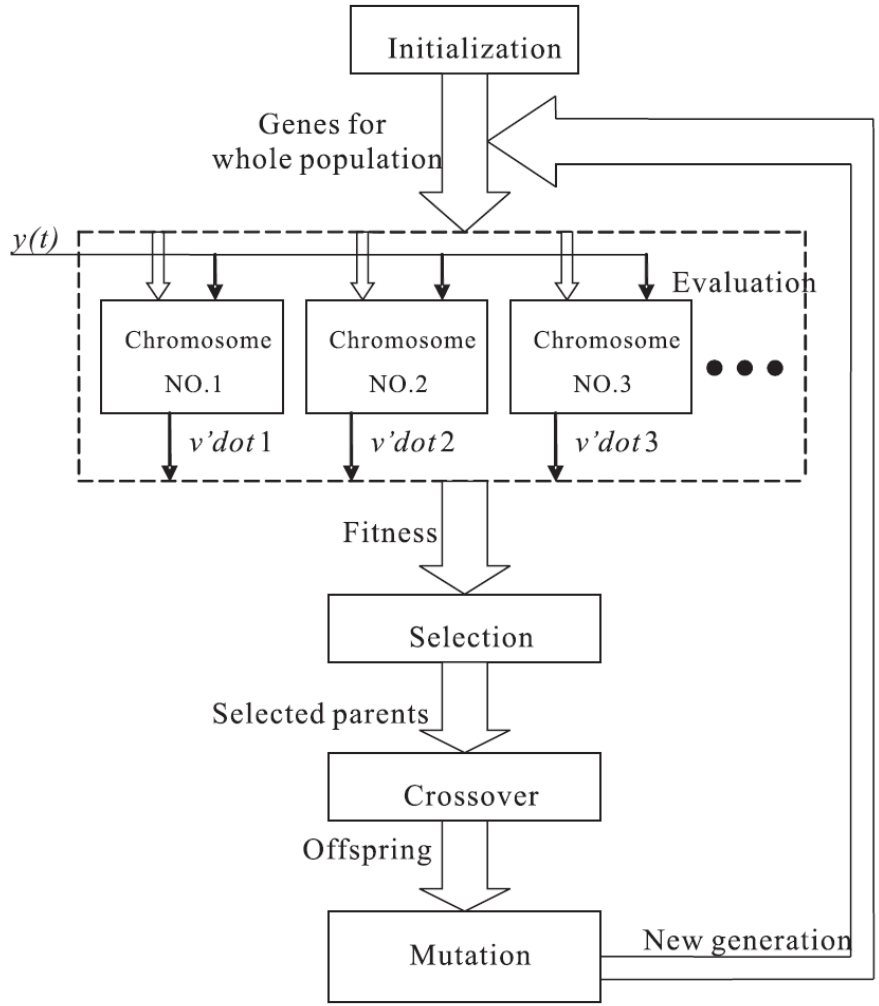


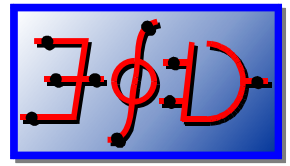
# Genetic optimization in VHDL-AMS testbench

- **GA features:**
  - **4 genes: *N1, R1, N2, R2***
  - **Fitness: super capacitor charging rate *v'dot***
  - **Tournament selection**
  - **Elitism**
  - **Arithmetic crossover**
  - **Gene mutation**
- **VHDL-AMS finite state machine**

# GA optimization in VHDL-AMS testbench

- Parallel GA





# Optimization results

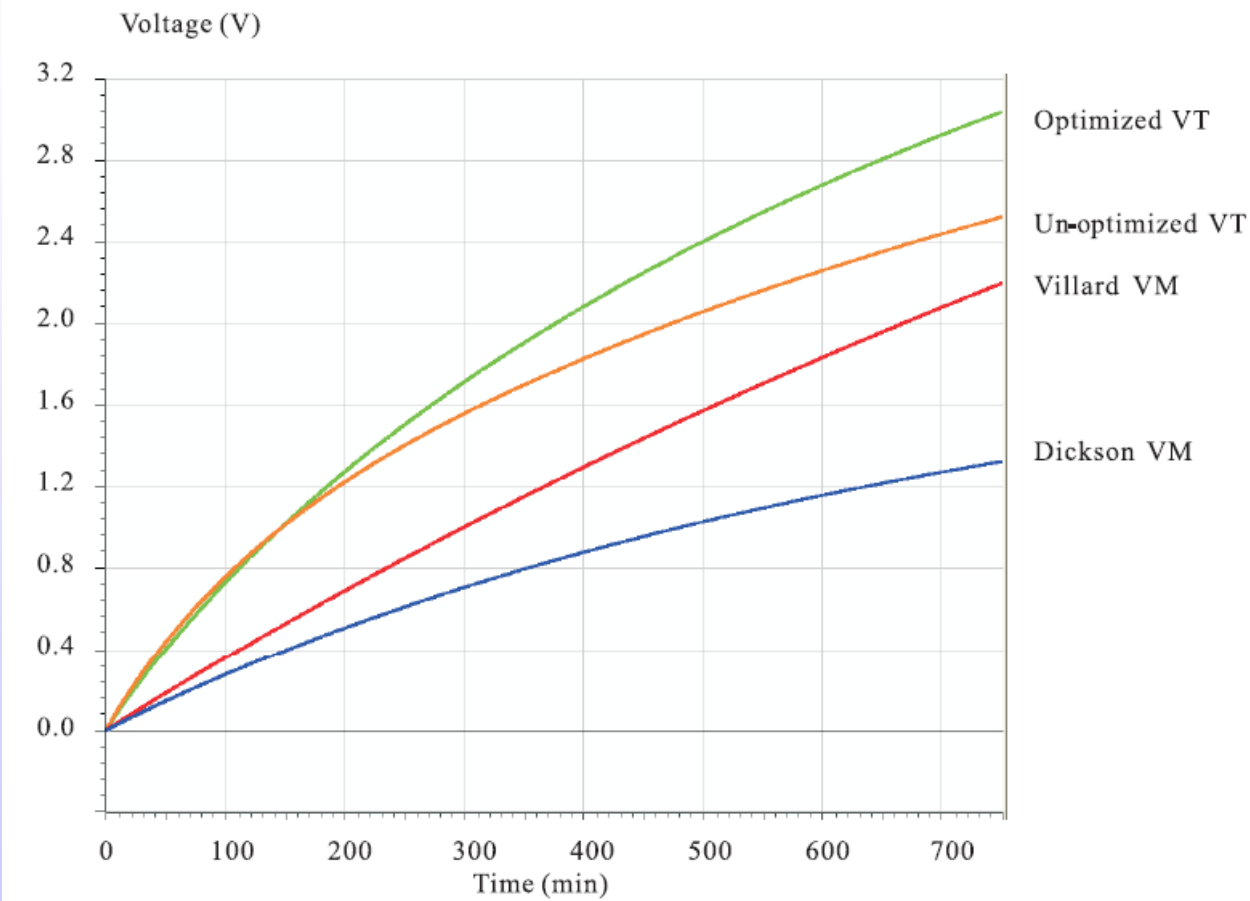
- **Parameters of un-optimized VT**

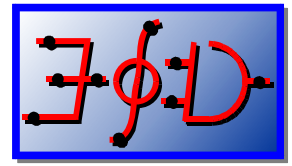
| | Resistance($\Omega$) | Number of turns |
|---|---|---|
| Primary winding | 400 | 2,000 |
| Secondary winding | 1,000 | 5,000 |

- **Parameters of optimized VT**

| | Resistance($\Omega$) | Number of turns |
|---|---|---|
| Primary winding | 140 | 1,500 |
| Secondary winding | 16,000 | 6,800 |

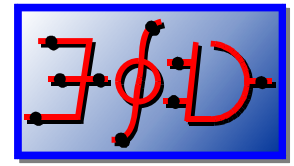
# Optimization results





# Conclusion

- Integrated approach to EH modeling and optimization
- Electrical equivalent circuit models of micro-generator cannot predict the voltage booster's performance accurately
- HDL model based on analytical equations can describe the actual shape and size of an EH
- Through performance optimization it is possible to increase the energy harvesting rate by 40%



# Acknowledgements

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Thank you!