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Electromagnetic Energy Harvesting System Enabling 20mW Output Power for IoT Applications

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Mahmoud Shousha

- B.Sc., M.Sc. (Cairo University), and Ph.D. (The University of Toronto), all in Elec. Eng.
- Joined MagI³C Product Unit, Würth Elektronik eiSos Group in 2015.
- Is now the R&D Team Leader in MagI³C.
- Has more than 40 refereed conference and journal publications.
- Has 4 granted US patents and 2 pending.
- Tech. Interests include high efficiency low volume dc-dc converters, battery management systems, energy harvesting, and magnetics design.



- 1. Introduction**
- 2. Electromagnetic Energy Harvesters – State of the Art**
- 3. Rotational Electromagnetic Harvester**
- 4. Results & Application**
- 5. Conclusions & Future Work**



Introduction

- Energy harvesting can extend battery life time, store energy, or omit energy storage/battery completely



Source:
quick cool

Thermal/TEG



Source:
Ikea

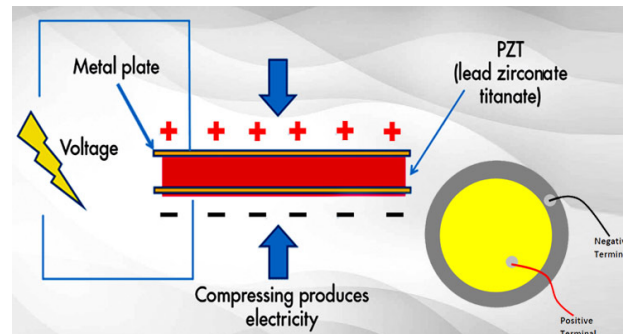
Solar



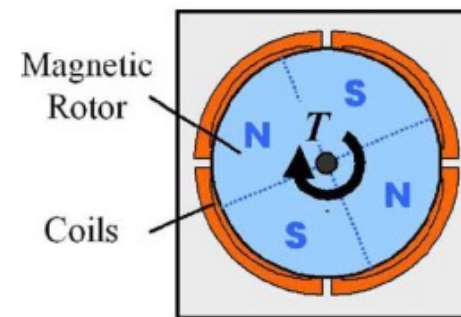
Source:
Wikipedia

Wind

Source:
www.components101.com



Mechanical/PZT



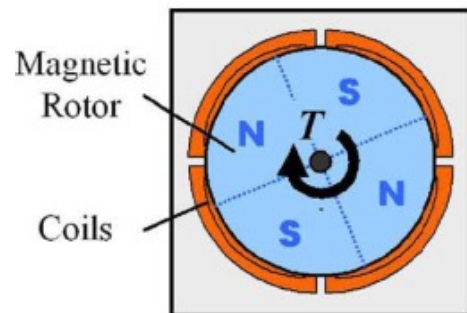
Source: D. Arnold

Mechanical/Electromagnetic

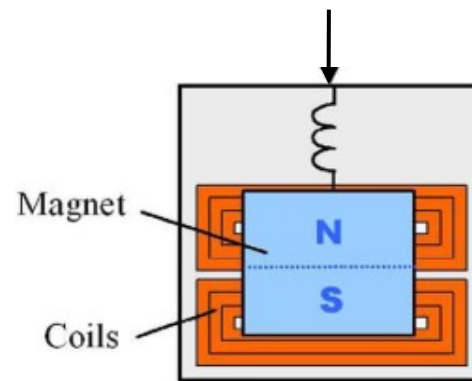


Electromagnetic Energy Harvesters – State of the Art I

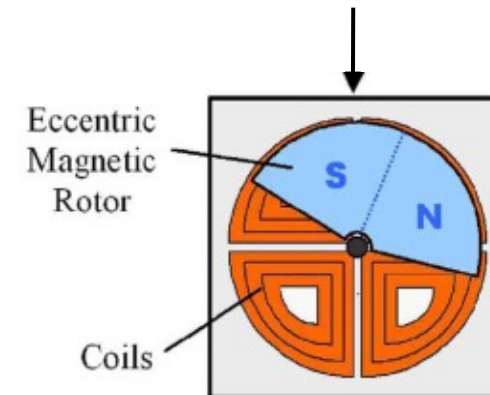
- Electromagnetic EHs consist mainly of movable permanent magnets and coils
- Permanent magnets are needed to generate magnetic flux
- Electromagnetic harvesters are classified into three types:
 - Rotational Harvester
 - Oscillatory (vibrational) harvester
 - Hybrid harvester(transformation of oscillations in to rotational movement)



Rotational Harvester



Oscillatory Harvester



Hybrid Harvester

Source: D. Arnold



Electromagnetic Energy Harvesters – State of the Art III

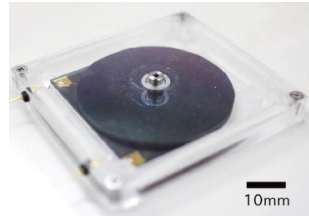
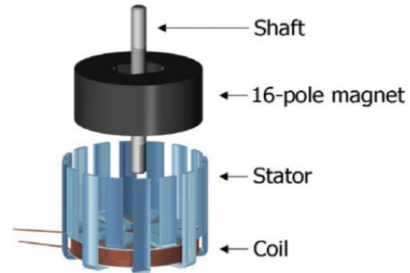
Electromagnetic Energy Harvesters

Rotational

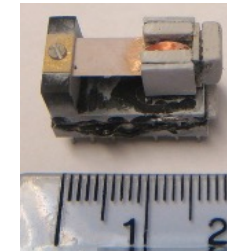
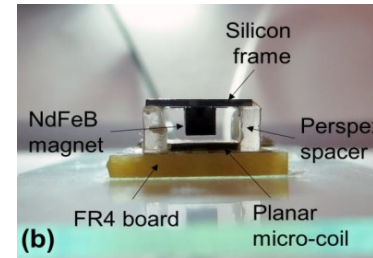
Vibrational

Hybrid

Kinetron



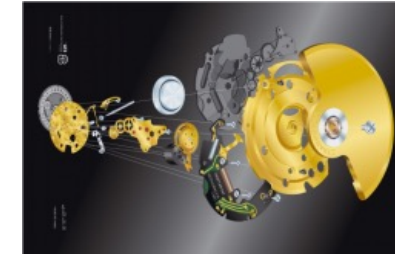
Tokyo University



Tyndall, University Southampton

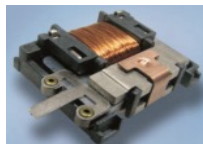


Seiko



ETA Autoquartz

Push-Button Electromagnetic Harvesters



EnOcean ECO 200



Cherry (ZF)

This work (WE)

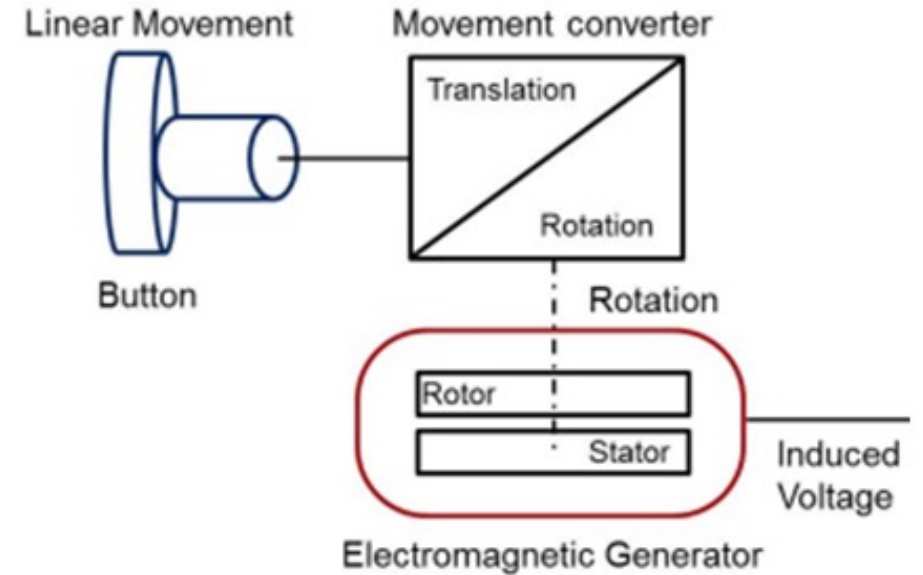
Linear movement

Rotational movement

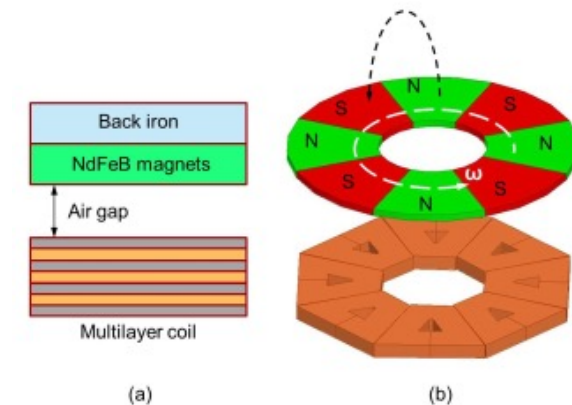


Rotational Electromagnetic Energy Harvester I

- The rotational electromagnetic EH consists of two subsystems:
 - Mechanism for movement conversion
 - Electromagnetic converter (generator)
- The electromagnetic generator consists of a rotor and stator
- The rotor consists of hard magnets mounted on high saturation flux density metal sheet
- The stator consists of a coil system with 8 windings on a multi layer PCB



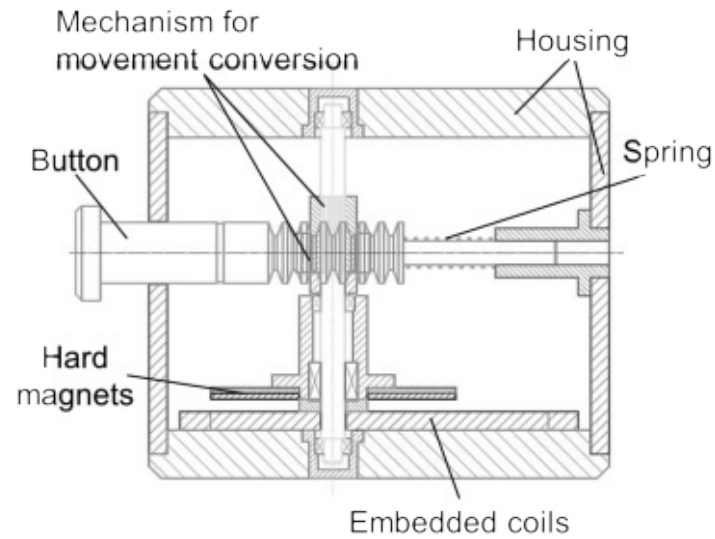
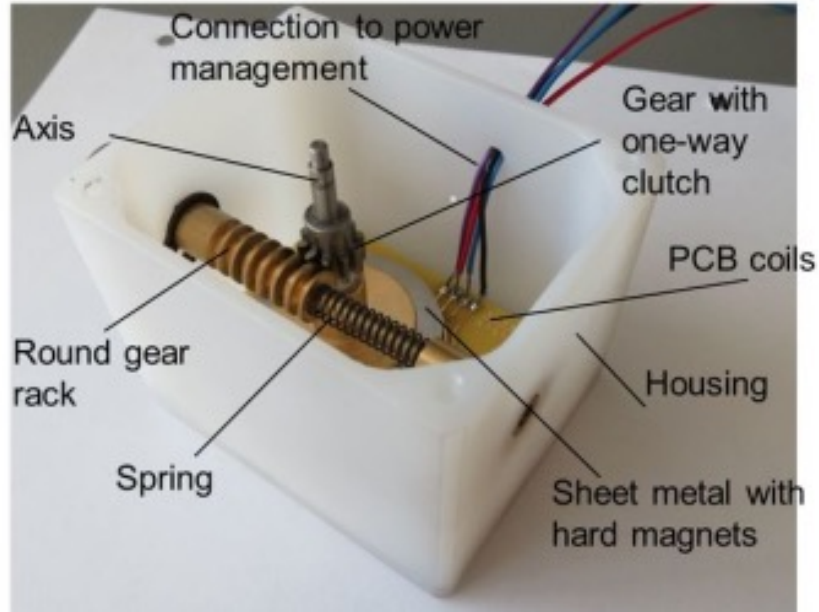
Schematic of energy harvesting system



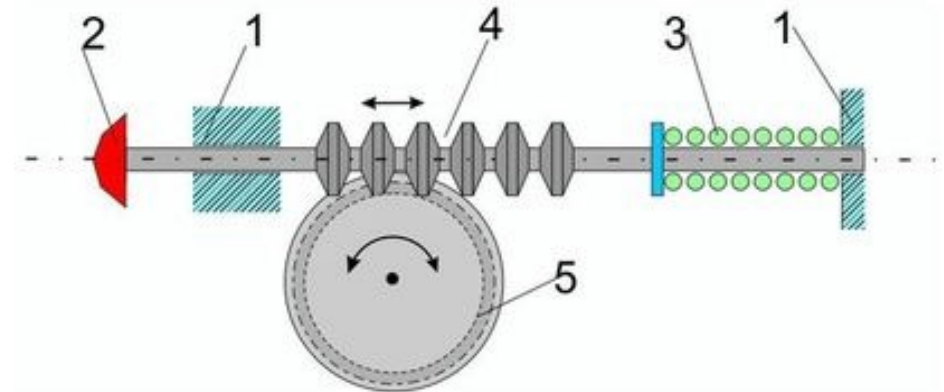
Design of electromagnetic part of the harvester



Rotational Electromagnetic Energy Harvester II



Components of the electromagnetic system: coil and hard magnets



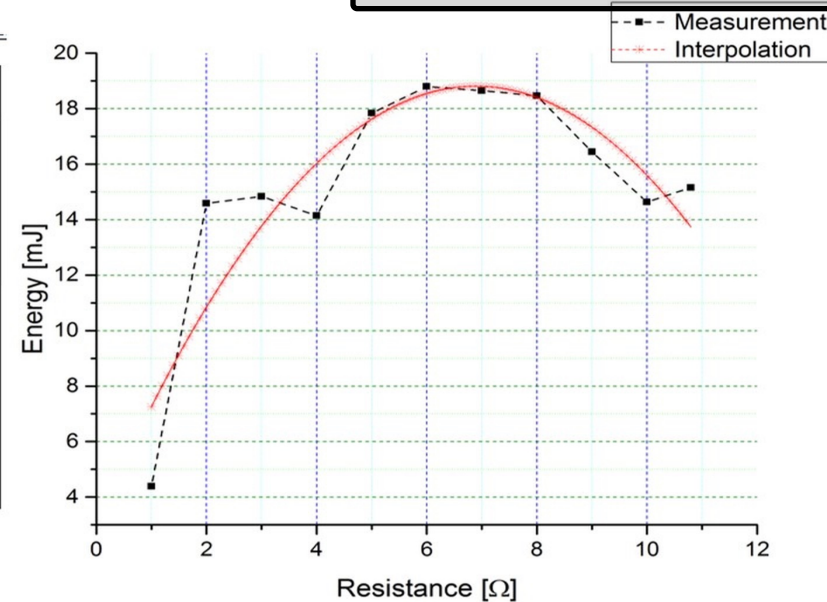
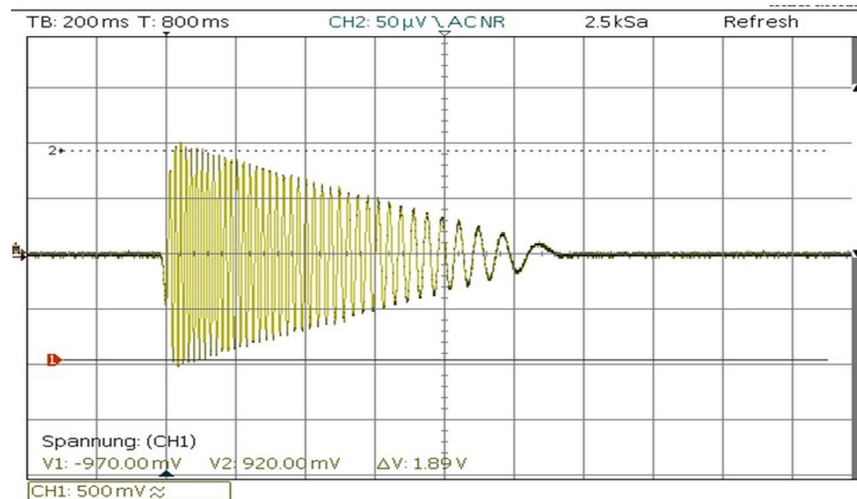
Kinematic mechanism for movement conversion

- 1 – Housing
- 2 – Button
- 3 - Spring
- 4 – Round gear rack
- 5 – Gear with one-way clutch

Rotational Electromagnetic Energy Harvester II

■ Challenges:

- Relatively low value damped ac voltage (no bridge rectifier)
- Maximum power appears at a certain range of loading (Impedance matching)



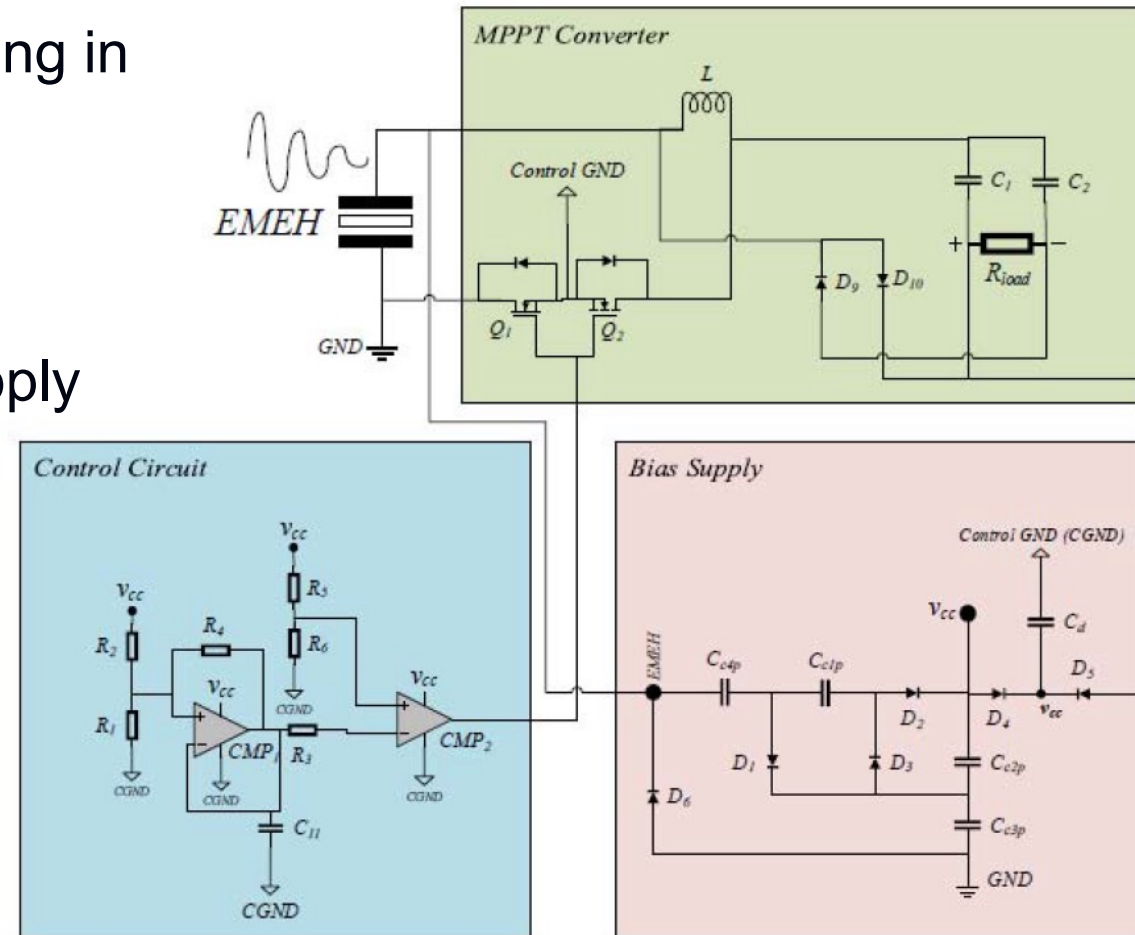
■ Benefit

- High energy (Stand-alone applications)



Rotational Electromagnetic Energy Harvester – Power Management I

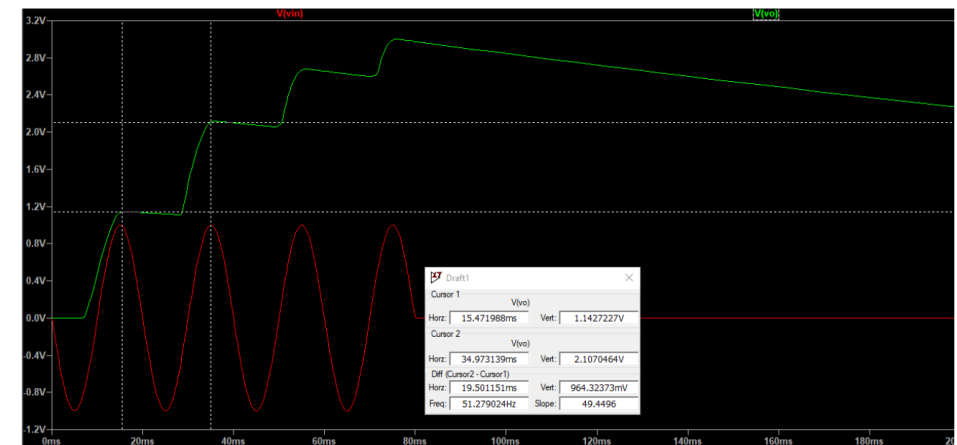
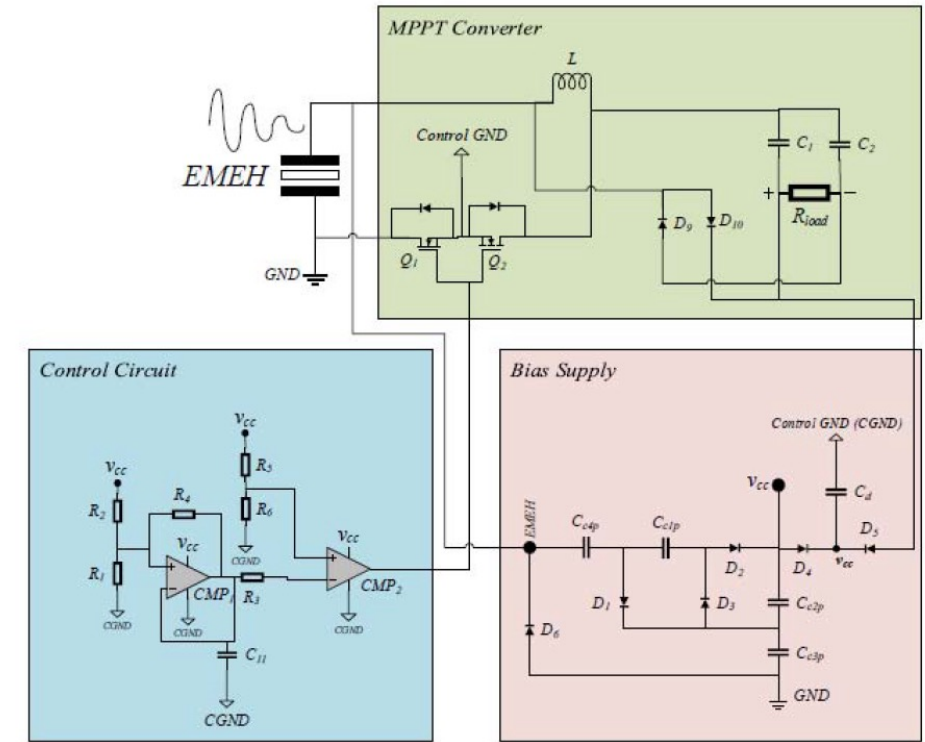
- Shared inductor based PMS
- Impedance matching (MPPT) is achieved by running in DCM
- Control is done with nano-power comparators
- Floating ground multi stage charge pump bias supply scheme to enable cold start
- Low $V_{gs,th}$ MOSFETs



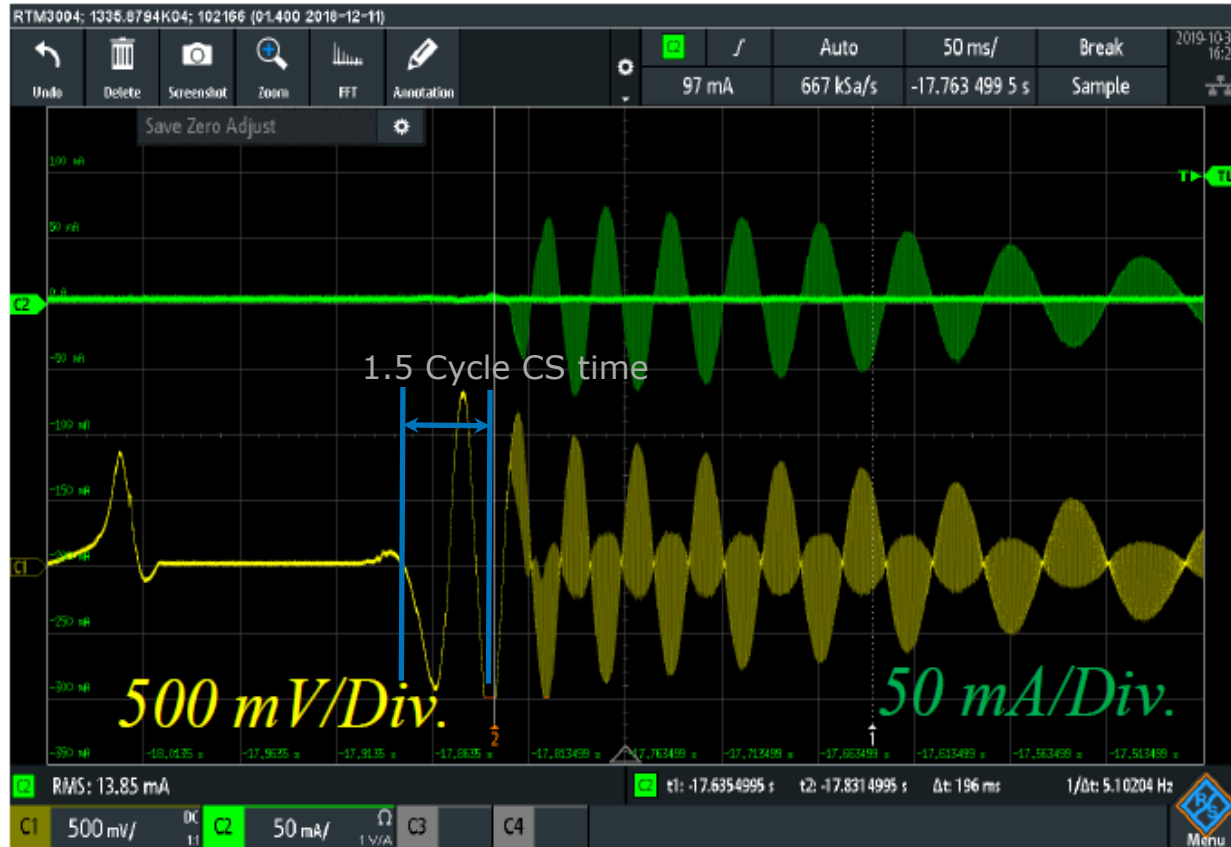
Rotational Electromagnetic Energy Harvester – Power Management II

Cold start design:

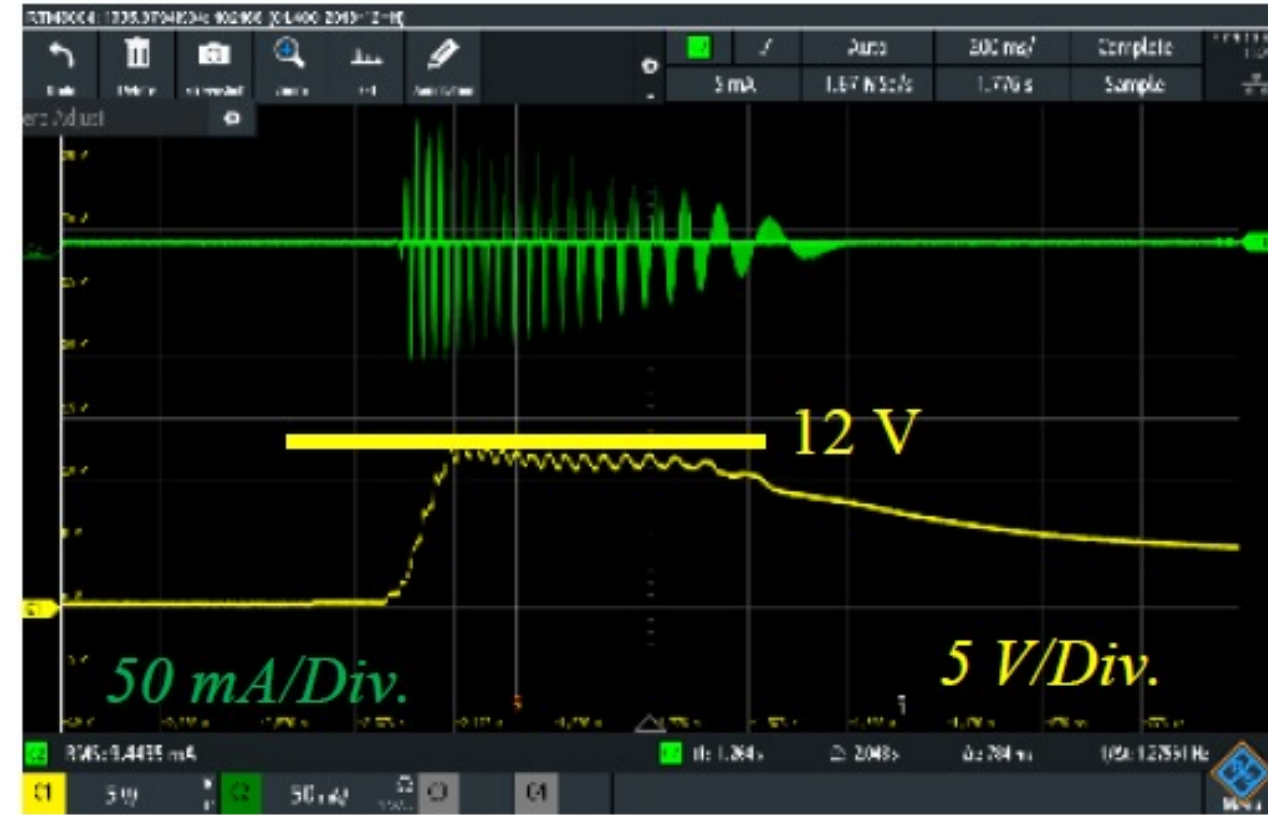
- Due to the low voltage of the EMEH ($<1V$ in the first two cycles), bias supply should be carefully designed
- After two cycles the output capacitors are charged and then used as a supply for the rest of the circuit
- The charge pump capacitors are optimized for fast charging and high steady state voltage at the same time



Rotational Electromagnetic Energy Harvester – Power Management III



Impedance matching & cold start



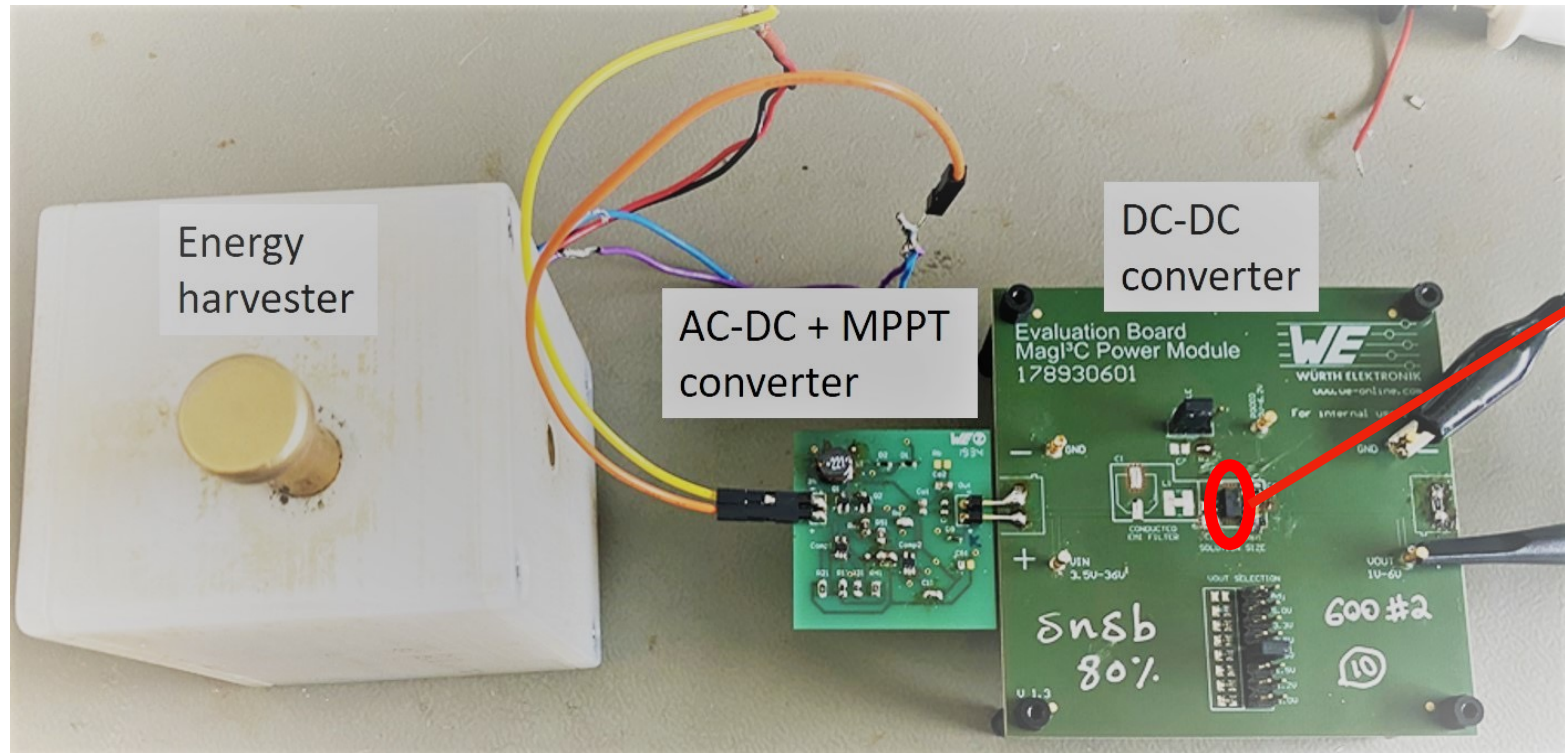
Output voltage at light load

References:

- M. Shousha, et. al. A Power Management System for Electromagnetic Energy Harvesters in Battery/Batteryless Applications, IEEE j. Emerging and Selected Topics in Power electronics, 2019
- M. Shousha, et. al. A miniaturized cost effective shared inductor based energy management system for ultra-low-voltage electromagnetic energy harvesters in battery powered applications, APEC 2018.
- M. Shousha and M. Haug Device for obtaining electric energy and energy generator comprising such a device, US Patent 2020



Results & Application I



Energy Harvesting System

- Energy Harvester
- Power Management System (PMS)
- Step-down DC-DC converter



WPME-VDMM

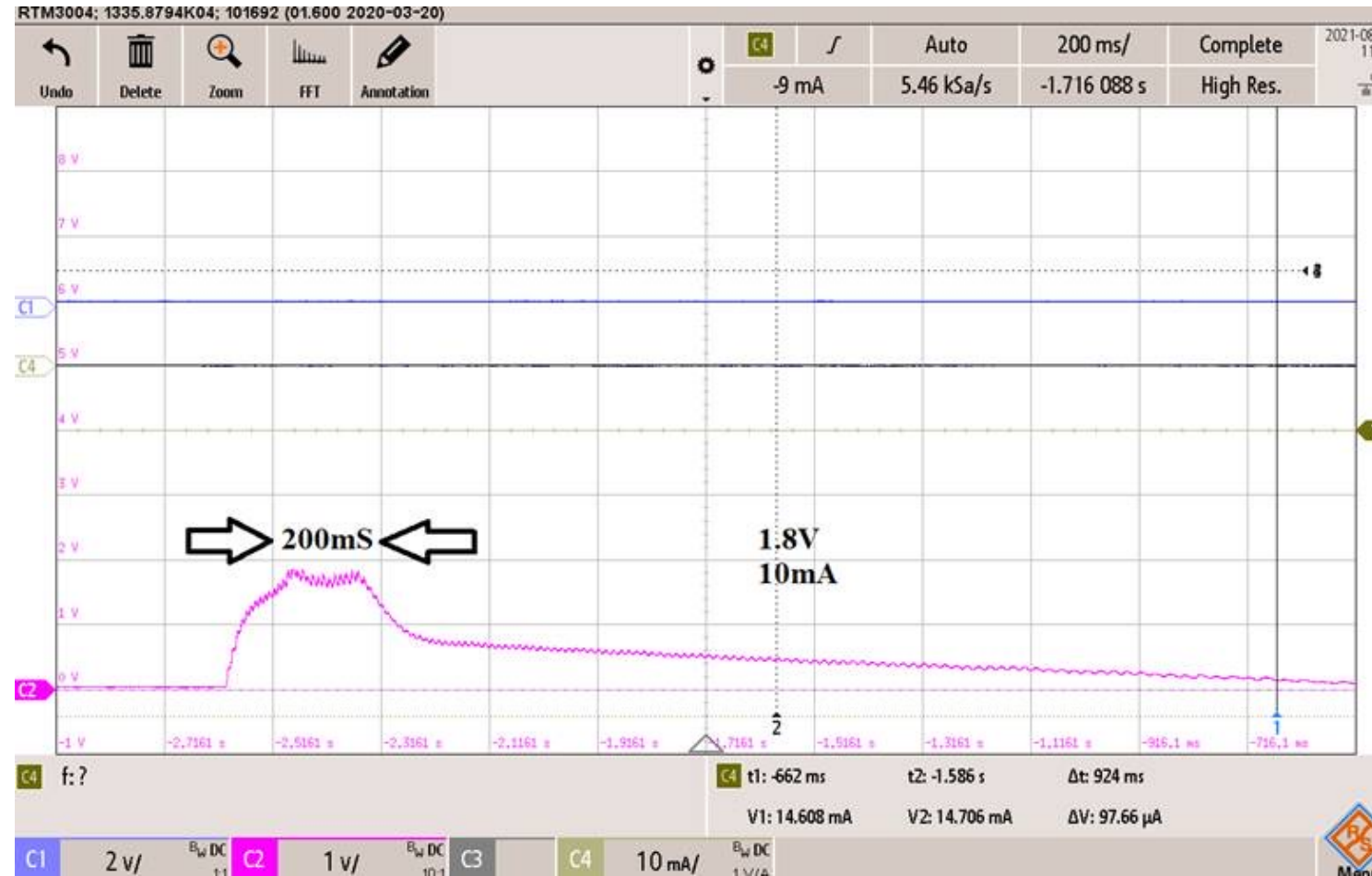
171930601

Parameter	Specs
VIN	3.5-36V
IOUT	0-0.3A
VOUT	1-6V
Size	2.5X5X1.8mm



Results & Application II

- Attenuated AC voltage signal from EH ($V_{max} \sim 1V$)
- PMS steps up the AC signal of the EH and converts it into DC
- To adjust the output voltage based on the application requirements DC-DC micromodule implemented
- The output voltage is 1.8V; output current 10 mA
- The output power is in this case 18mW
- Signal duration $\sim 170ms$



Output voltage of The EH systems

Results & Application III

- EH system tested in smart home application
- RF transmission system Easywave by ELDAT implemented
- Transmitter RTS17
- Receiver RCP05



RTS17 transmitter:

- Easywave telegram
- Frequency: 868MHz
- Range: 150m
- Input voltage: 5 – 24Vac
6 – 32Vdc
- Receiver current: 10mA



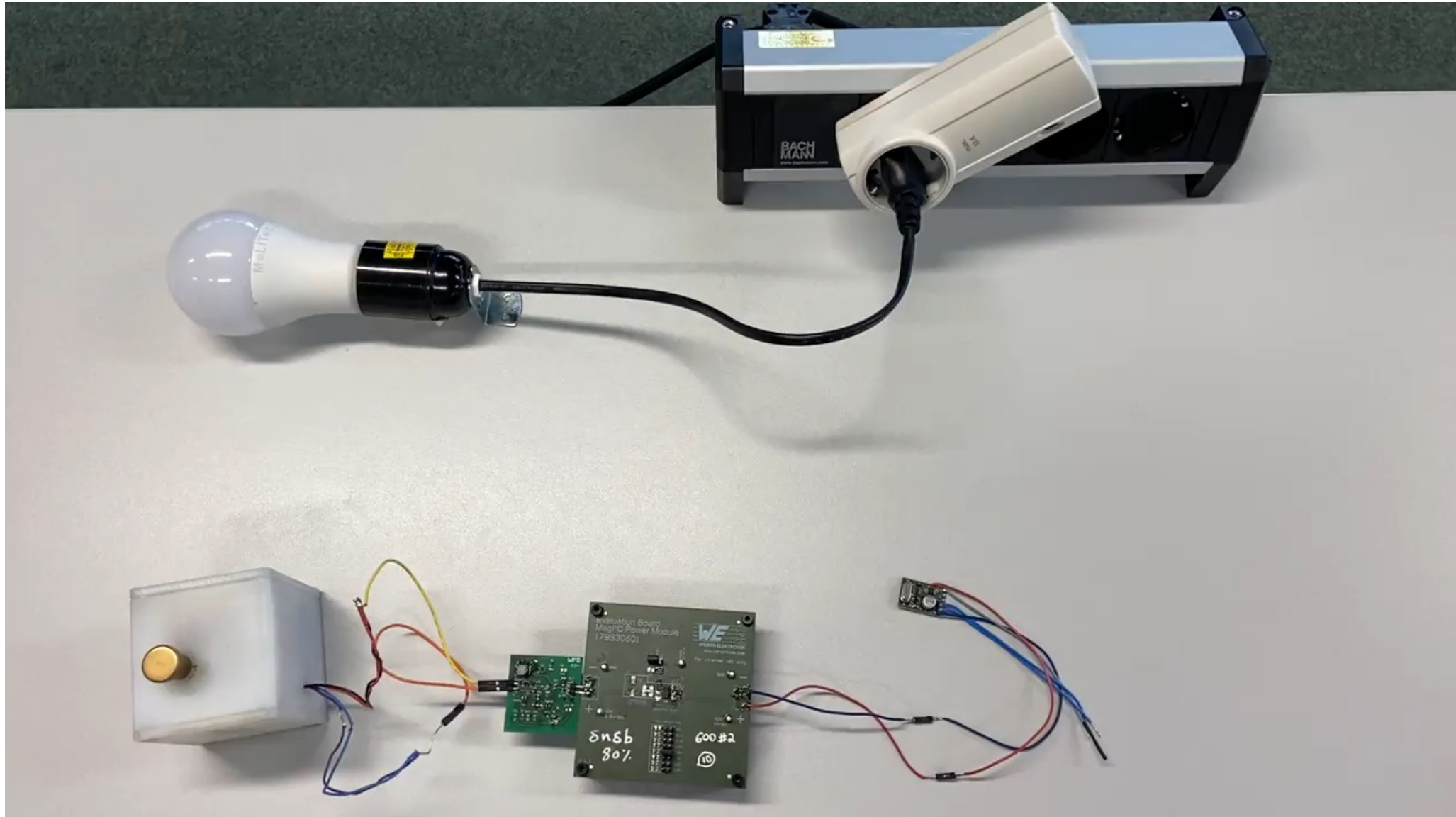
RCP05 receiver:

- Easywave telegram
- Frequency: 868MHz

https://www.eldat.de/produkte/sender/rts17e_de.html

https://www.eldat.de/produkte/empfaenger/rcp05e_de.html

Results & Application IV



Conclusions & Future Work

- Energy harvesting system is built and tested in real smart home application
- The system is capable of providing up to 20mW
- Next step is to test the EHS with different transmitter systems
- Assembly of EH and PMS in same package
- Work on miniaturization of the whole EMS system



Thank you for your interest.

By: Mahmoud Shousha

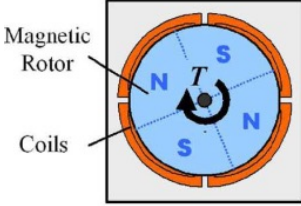
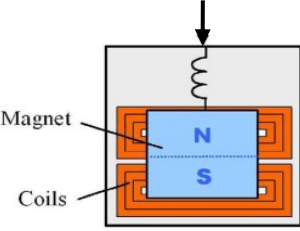
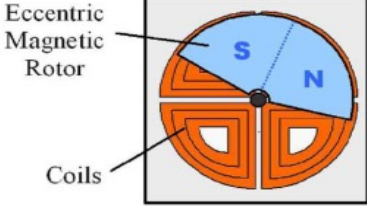
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Energy Harvesting Industry Session (IS24)



Electromagnetic Energy Harvesters – State of the Art II

<p style="text-align: center;">Rotational</p> 	<p style="text-align: center;">Oscillatory</p> 	<p style="text-align: center;">Hybrid</p> 
<ul style="list-style-type: none"> - Continuous rotational drive needed 	<ul style="list-style-type: none"> - Based on mass-spring oscillatory system 	<ul style="list-style-type: none"> - Transformation of oscillation into rotation by eccentric mass
<ul style="list-style-type: none"> - Not common energy source in the environment 	<ul style="list-style-type: none"> - Depends on frequency 	<ul style="list-style-type: none"> - since many years in use by watch industry
<ul style="list-style-type: none"> - Use at higher speeds (i.e. 1000 rpm up to 400 krpm) 	<ul style="list-style-type: none"> - Low oscillating frequency 	<ul style="list-style-type: none"> - Non resonant oscillations
<ul style="list-style-type: none"> - High energy density (10mW/cm³ - 10W/cm³) 	<ul style="list-style-type: none"> - Low energy density 	<ul style="list-style-type: none"> - Excitation frequencies 1Hz – 1kHz
<ul style="list-style-type: none"> - Maximum power is independent from frequency 	<ul style="list-style-type: none"> - Maximum power at resonate frequency 	<ul style="list-style-type: none"> - Complex mechanical design