Fluid-Structure Interaction Modeling for an Optimized Design of a Piezoelectric Energy Harvesting MEMS Generator

I. Kuehne[1], A. van der Linden[2], J. Seidel [1], M. Schreiter[1], L. Fromme[2] and A. Frey[1]

[1]Siemens AG, Corporate Technology, Otto-Hahn-Ring 6, 81730 Munich, Germany

[2]COMSOL Multiphysics GmbH, Berliner Straße 4, 37073 Goettingen, Germany

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Outline

Introduction

MEMS generator concept and design

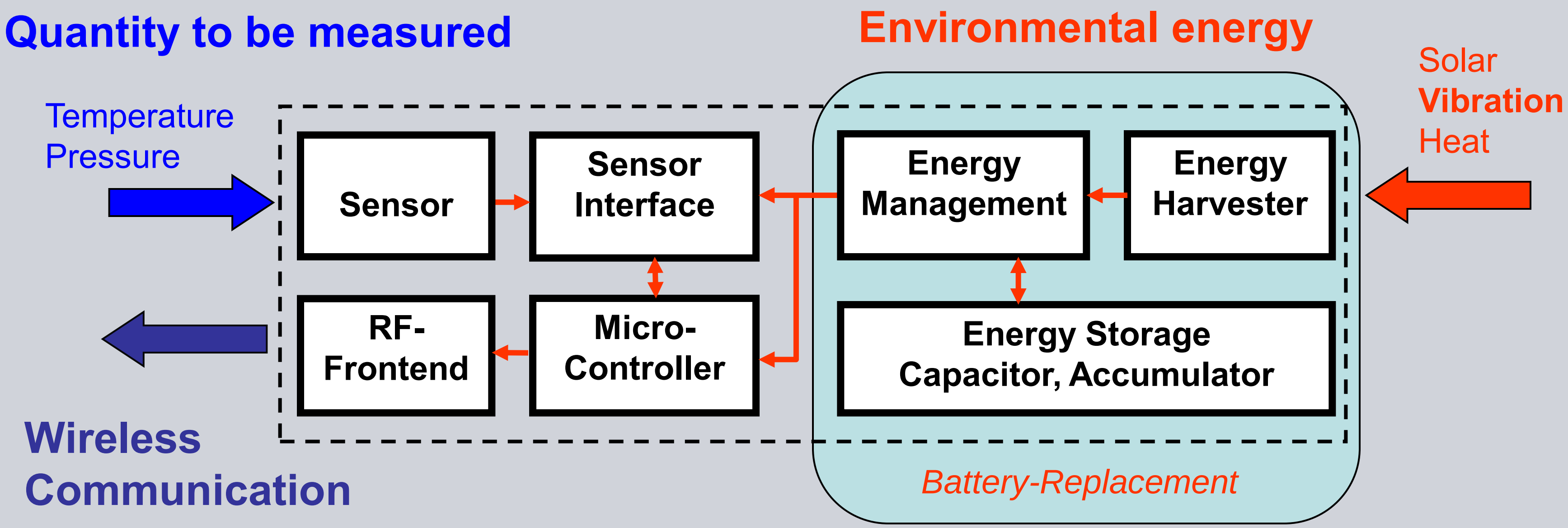
FSI simulations

Experimental results

Summary

Introduction

Energy autonomous sensor node

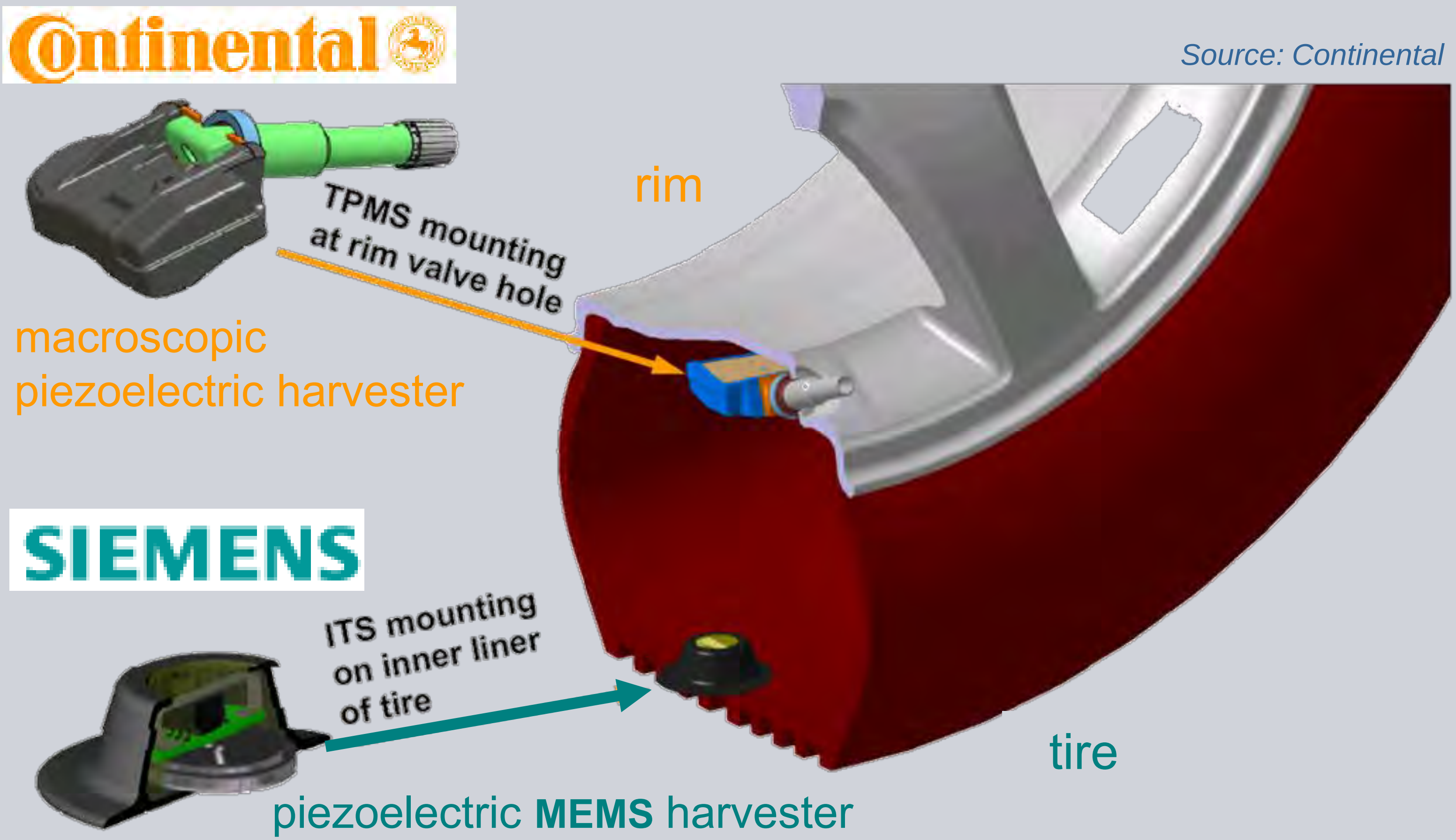


Benefits:

- Maintenance free
- Costs
- Environmental friendly

Tire pressure monitor system (TPMS) for automotive applications

Source: Continental



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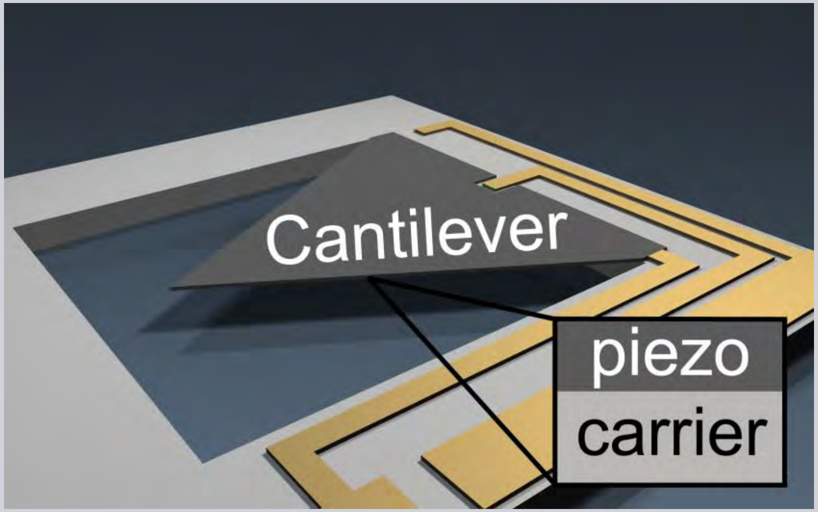
Requirements

Properties of MEMS harvester to enable tire-based TPMS application

MEMS Generator Concept



Design Characteristics

- Minimized mass in the micro gram range
- Non-resonant excitation scheme
- Decoupling of primary tire forces
- Overload protection
- CMOS compatible voltage level
- Good “aero dynamic” (high Q value)

What is a suitable geometry of the generator: shape, area, layer thicknesses?

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MEMS generator design

Generator “aero dynamic”

The generator Q-value is a design parameter which critically affects the power output.

COMSOL Multiphysics„ Fluid-Structure Interaction (fsi) Interface is used to investigate the dependency of the generators Q-value from the

- Cantilever shape
- Cantilever area
- Cantilever thickness
- Ambient pressure

MEMS generator design

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Fluid-Structure Interaction Simulations

Essential model settings include:

- Compressible flow (Ma < 0.3); no turbulence settings.
- Geometric Nonlinearity included in the Linear Elastic Material definition
- Fixed Wall (No slip) to which the deformable solid is attached.
- For the remaining external boundaries: Open Boundary with Normal stress condition
- Specific manual scaling settings for the dependent variables in order to enable the efficient solution process for both the stationary and the time-dependent simulation.

Procedure:

- Stationary study to simulate the initial deformation of the solid object.
- Stationary result serves as of initial values, for a subsequent time-dependent study.

MEMS generator design

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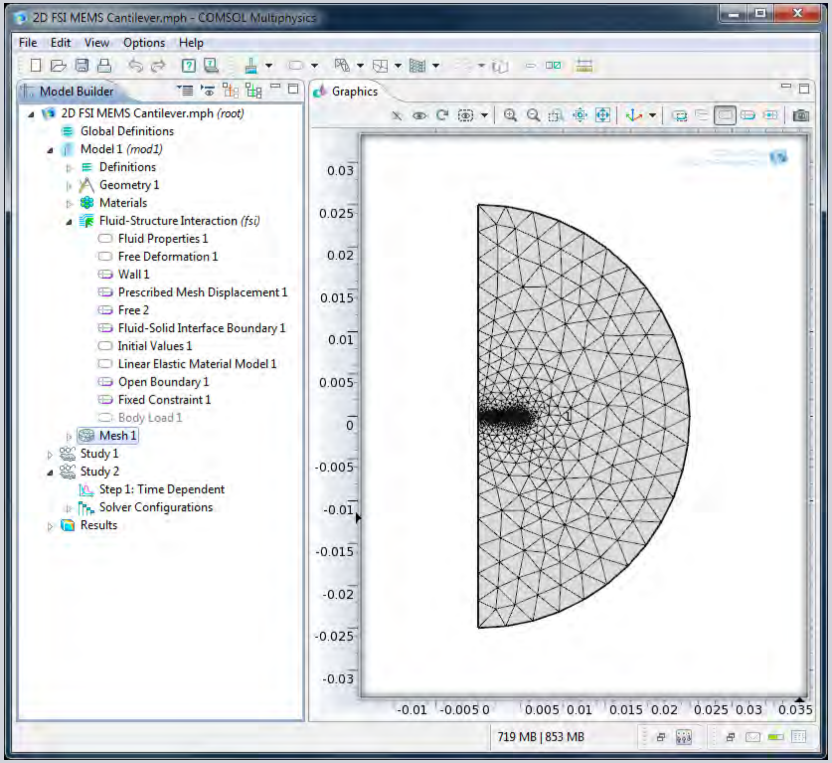
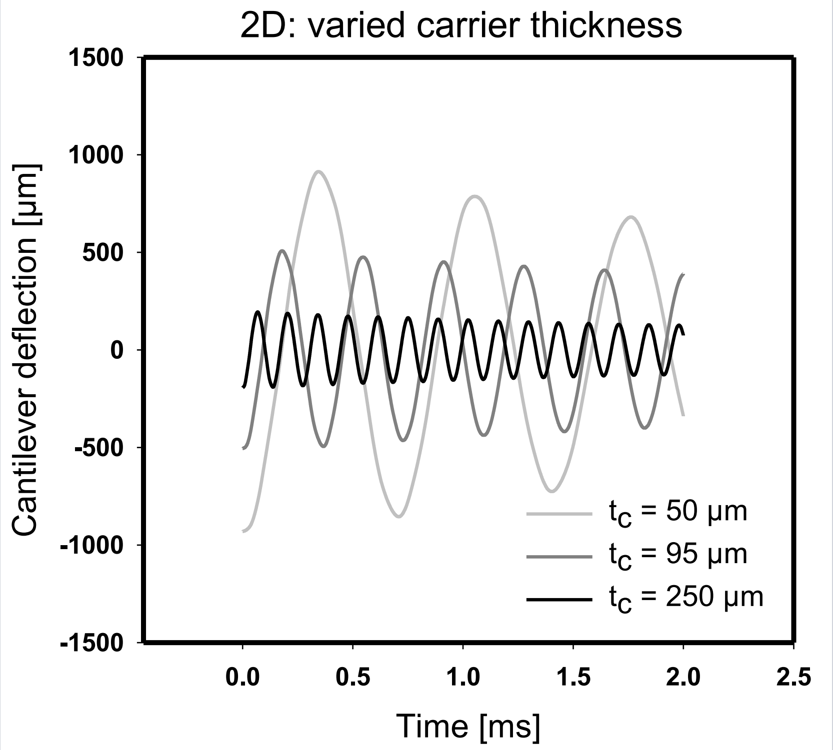
2-D Fluid-Structure Interaction

Simulation setup



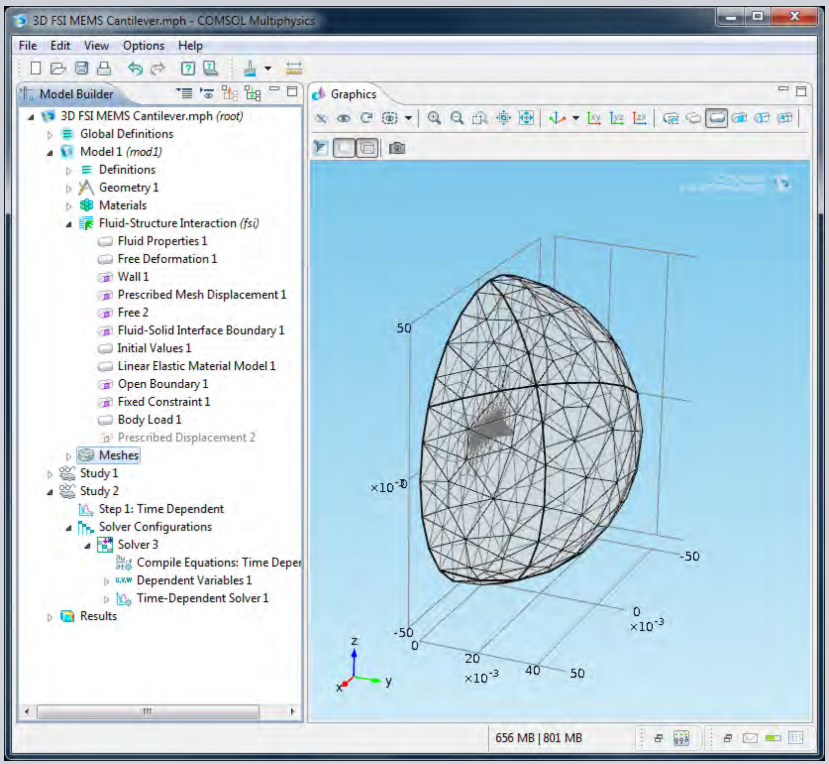
Results



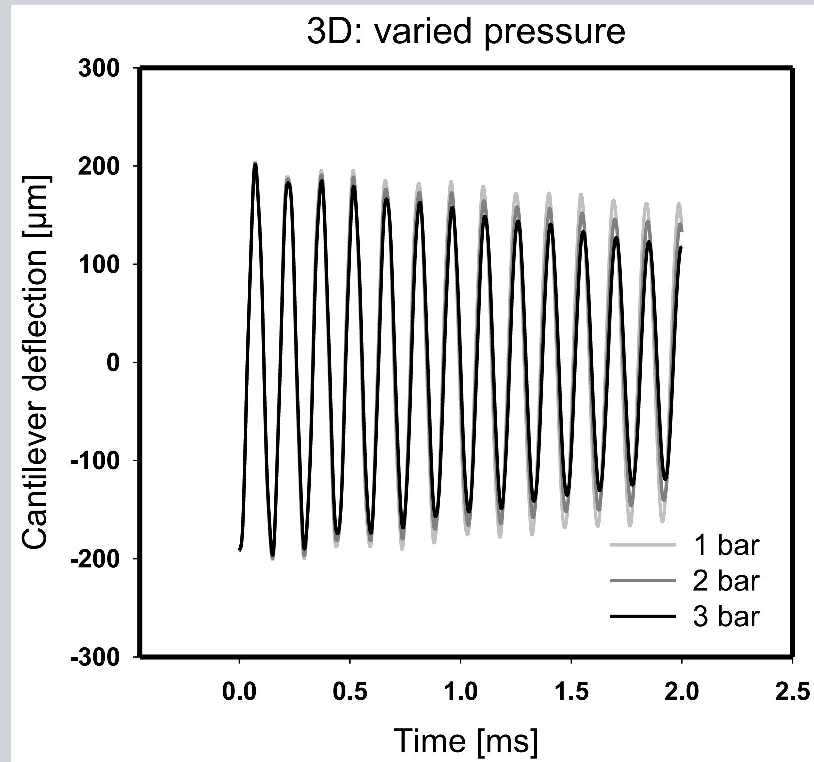
MEMS generator design

3-D Fluid-Structure Interaction

Simulation setup



Results



MEMS generator design

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Fluid-Structure Interaction

Summary of Q-value simulation results:

pressure	2D (rectangular)			3D (triangle)
	50 µm	95 µm	250 µm	250 µm
1 bar	21.1	62.3	100.2	188.8
2 bar				114.6
3 bar				78.0

Q-value improved for

- increased carrier thickness
- triangular shape instead of conventional rectangular

Q-value reduced for

- increased pressure

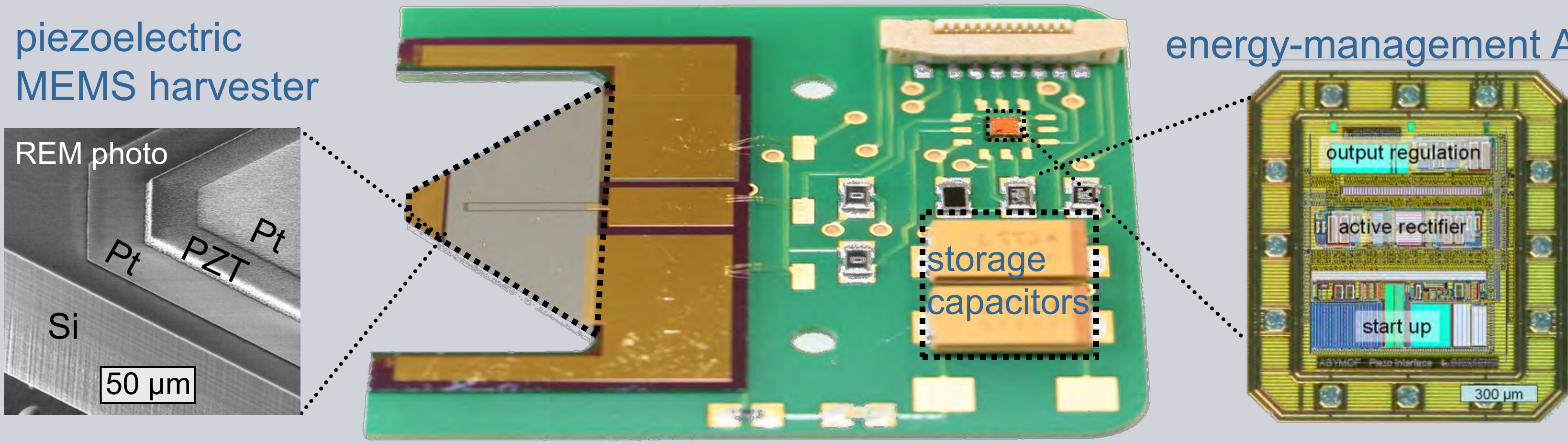
How fit the simulations with experimental results?

MEMS based piezoelectric energy harvesting module

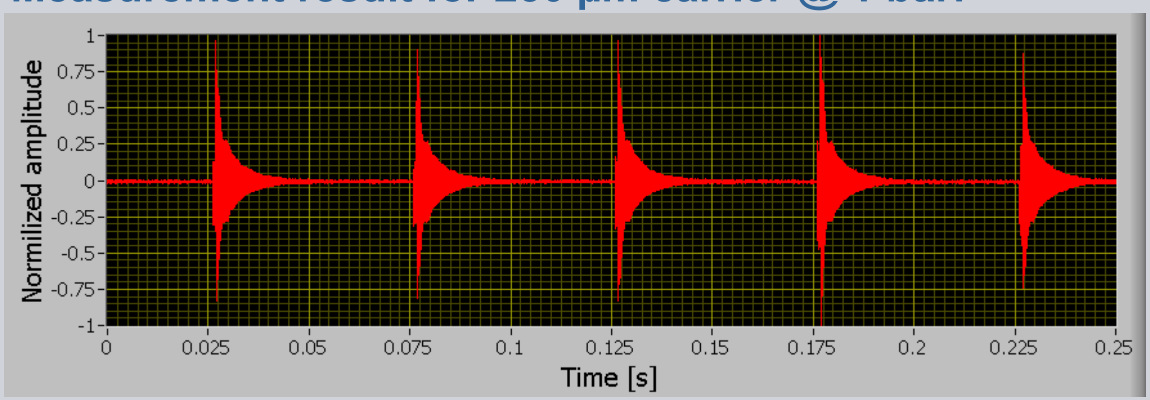
Realization and experimental results

piezoelectric MEMS harvester

energy-management ASIC



Measurement result for 250 µm carrier @ 1 bar:



$Q_{meas} = 97 \Longleftrightarrow Q_{sim} = 189$

$1 / Q_m = 1 / Q_{sim} + 1 / 199$

➡ Q of order 200 has to be included in the simulation.

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Summary

Design aspects of a piezoelectric energy harvesting micro generator for an energy autonomous tire pressure monitoring wireless sensor node were discussed. The generator Q-value is identified as a critical design parameter.

We used a COMSOL Multiphysics Fluid-Structure Interaction application mode to investigate the impact of the surrounding air to the damping behavior of a MEMS cantilever energy harvester operated in a new kind of pulsed excitation operation mode.

The combination of the predefined COMSOL FSI interface with the essential model settings has allowed the successful model development for the simulation of a strongly coupled FSI process including the effective damping of the FSI vibration.

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Thank You!

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Motivation

Intelligent MEMS based Tire System: Benefits

Body:

- Tire pressure monitoring
- Tire information
- Mileage of runflat tires
- Driver assist functions
- Tire maintenance

Chassis & Safety:

- ABS: shorter braking distance
- Improved driving dynamics
- Improved rollover protection

Environment:

- CO_2 information in display
- Reduced fuel consumption
- Reduced CO_2 emissions

Powertrain:

- Torque control
- Transmission regulation