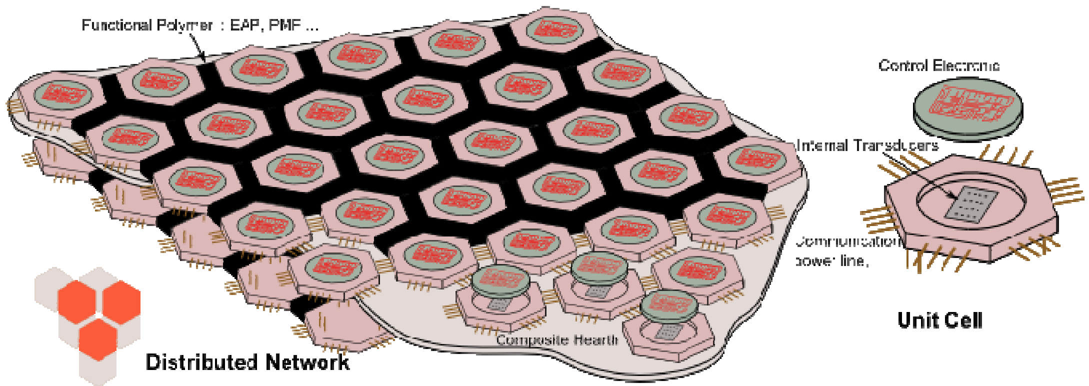
LTDS
Laboratoire de Tribologie et Dynamique des Systèmes

# Activités "Méta" LTDS





**Manuel COLLET** (Senior Researcher CNRS, LTDS, ECL, Ecully, FR)

With contributions from M. Ouisse, F. Tateo, K. Billon, A. Khelif, G. Matten (FEMTO-ST), M. Ichchou , Fan Yu (LTDS), Kaijun Yi (LTDS)


Laboratoire de Tribologie et Dynamique des Systèmes
LTDS UMR 5513
http://ltds.ec-lyon.fr

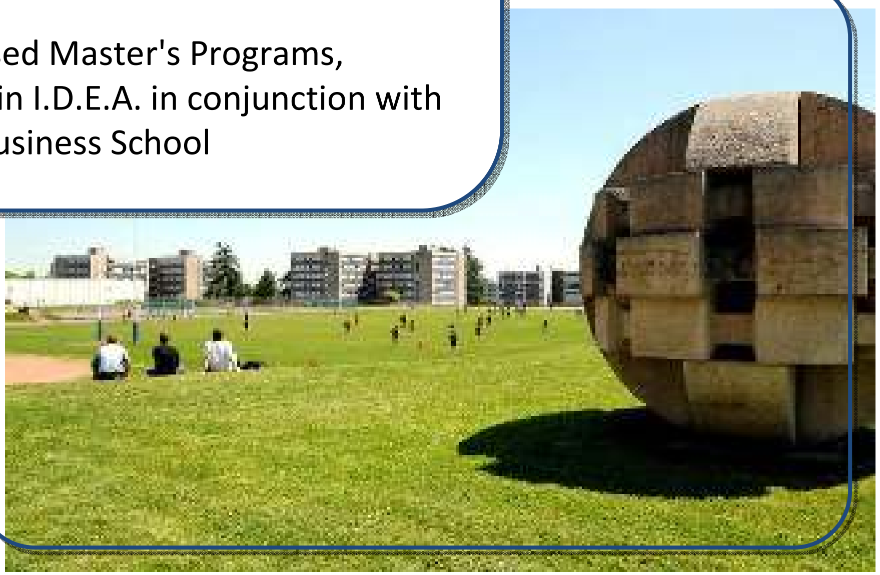
cnrs ÉCOLE CENTRALE LYON ENISE ENTPE Université de Lyon

# Ecole Centrale de Lyon

ÉCOLE CENTRALE LYON

**Created in 1857**
**1 500 students**
(25% international, 43 nationalities)
**Campus** of 16,2 hectares, 56 600 m2 Buildings
**Teaching :**

- 1 generalist engineering curriculum (1,205 students, 329 graduates / year)
- 6 Teaching departments :
- 4 Doctorate Faculties comprising 223 PhD Students
- 1 specialist engineering curriculum in Energy,
- 13 supervised Master's Programs,
- 1 Program in I.D.E.A. in conjunction with EMLYON Business School

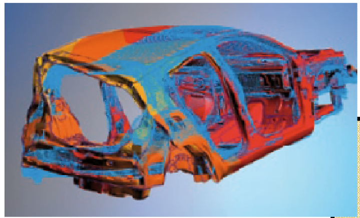


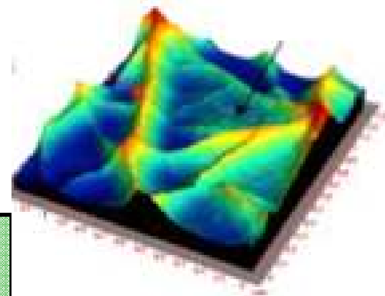
**6 Joint Research Units (CNRS) :**
•The Ampère Laboratory
•ICJ - Camille Jordan Institute
•LTDS - Laboratory of Tribology and Systems Dynamics
•LMFA - Laboratory of Fluid Transfer and Acoustics
•INL - Lyon Institute of Nanotechnology
•LIRIS - Computer Science Laboratory
**4 Associated International Laboratories (LIA):**
LIA CPN in Seoul - Corea
LIA ElyT Lyon Tohoku, in Tohoku - Japan
LIA 2MCSI , in Beihang - China
LIA Maxwell, in Sao Paulo - Brazil
**1 International Joint Research Unit in Sherbrooke - Québec**

# LTDS

Laboratoire de Tribologie et Dynamique des Systèmes

- Created in 1970
- 330 people
- 4 research Team grouped in one single institute
- Budget 14 M€/year





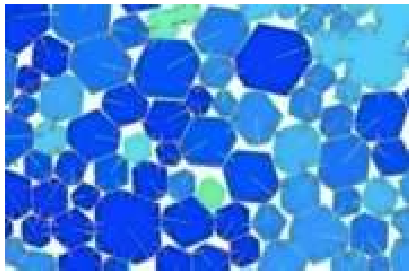
*Tribology*

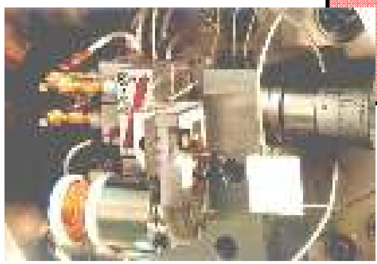
*Mechanics & materials science*

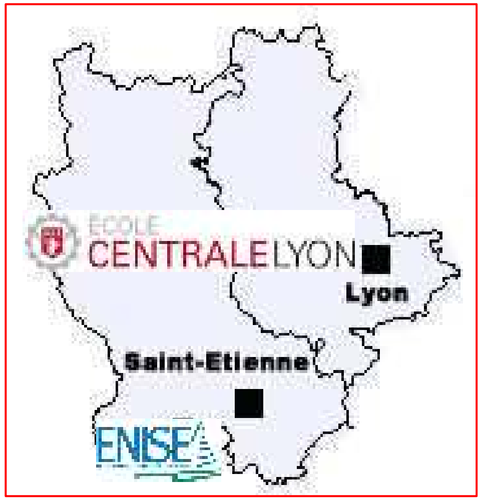
*Civil engineering*

*Dynamics of Complex Systems*

Interactions with life sciences







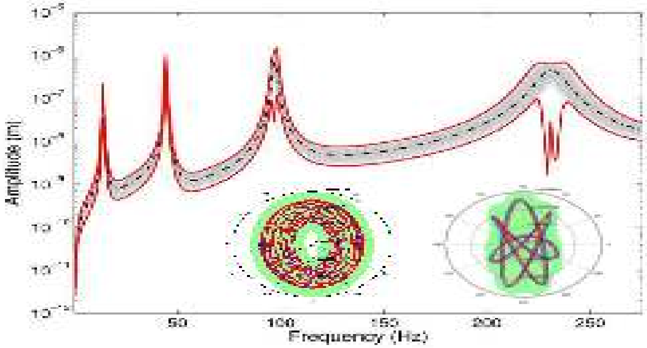

4 institutions

CNRS · ECOLE CENTRALE LYON · ENISE · ENTPE

# Dynamics of Complex Systems

19 Professors, Researchers
10 Engineers and Technicians
39 PhD
**Research Domains:**
•Non Linear Dynamic with uncertainties
•Localization/transfer/control of energy into distributed and adaptive systems Sciences
•Technologies for industrial innovations

## Uncertain Systems with non-linear interfaces




## Vibroacoustics and architected Materials

## Non-linear Dynamics – Control - Rotor

## Innovation and Design

# Context and Issues

**« Green » Aerospace technologies– structural weight reduction**

(decrease $CO_2$ emission (5-15%), noise control….)

- Intensified dynamical environnement
- Fatigue and damage : security
- Stability problem
- Adapted design methodologies

FR & EC research strategies, Clean Sky , DREAM EU Project s, AIAA's Emerging Technologies Committee (ETC) …

**Transports**

**Nuclear**

**Civil Engineering**

**Aerospace**

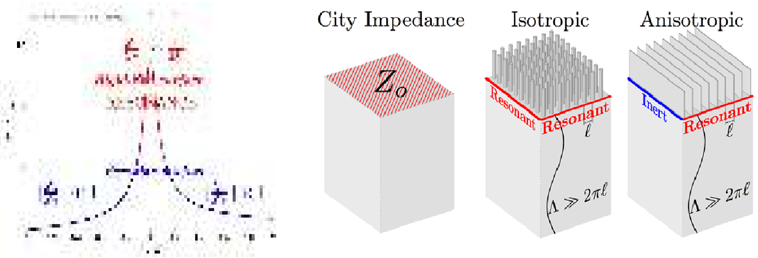
**New Integrated functionalities**

- **Active Vibration Control -AVC-**
- **Active Noise Control -ANC-**
- **Structural Health Monitoring -SHM-**
- **NDE, PHM**
- Shape Control
- Mechatronic
- **Energy harvesting/scavenging**

Meyer et al.: Advanced Microsystems for Automotive Applications 2009 - Smart Systems for Safety, Sustainability and Comfort, Springer 2009

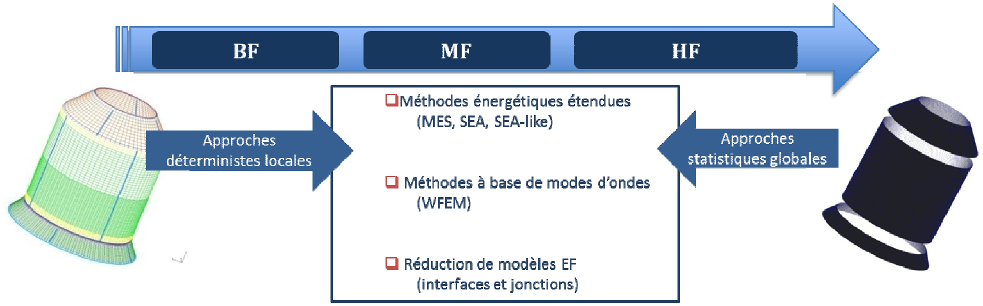
# Research Activity around Metamaterials and metastructures

## Homogeneization tools, Enriched Elasto-dynamic



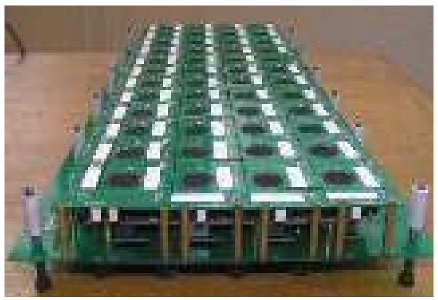

Dr C. Boutin, S. Hans

## Architected Composites For vibroacoustics



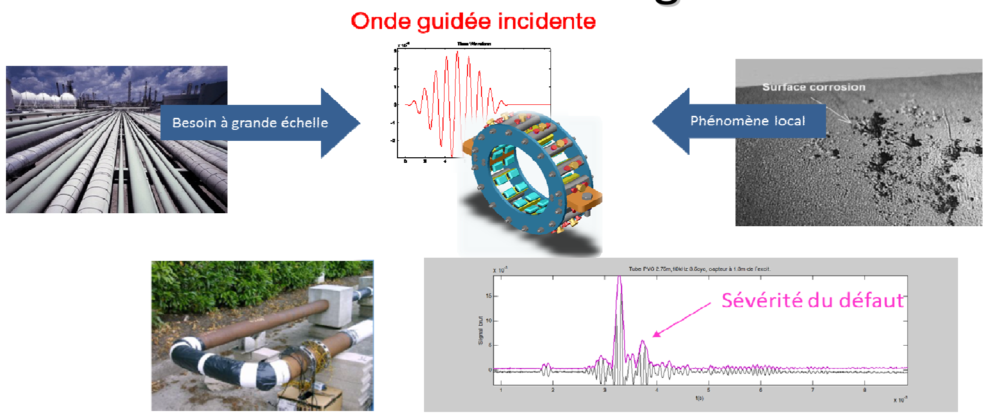

Prof Ichchou

## Metacomposites and Materials Programming for Vibroacoustic



Dr M. Collet

## Architected Materials for Structural Health Monitoring




Dr O. Bareille

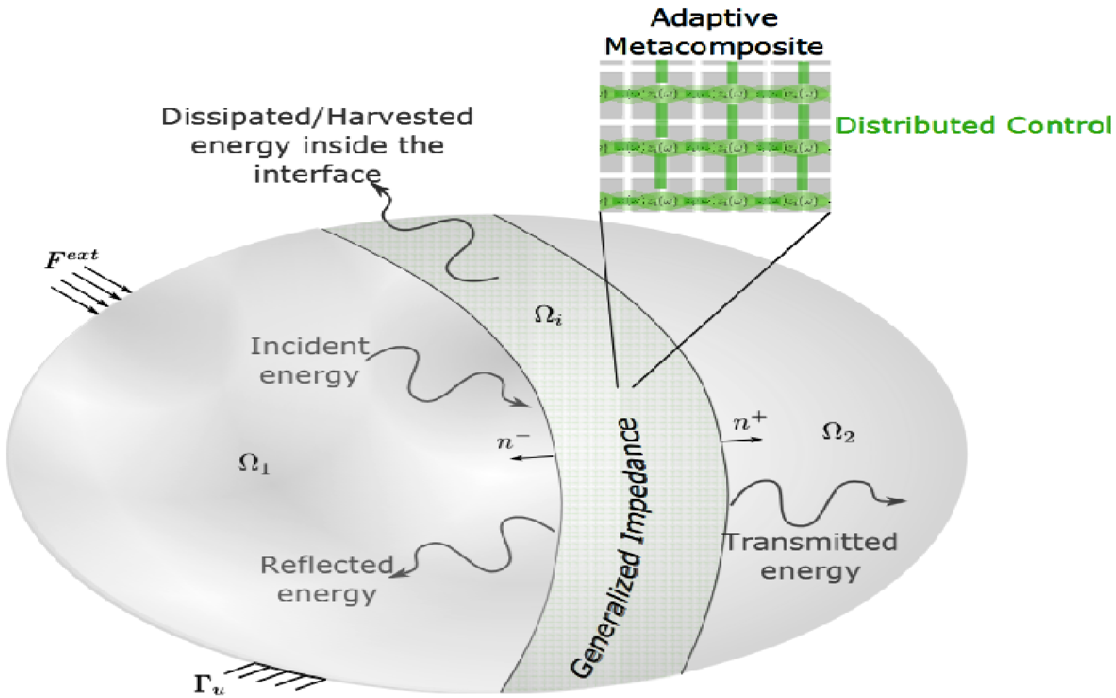
# Structural Optimization by architected Material

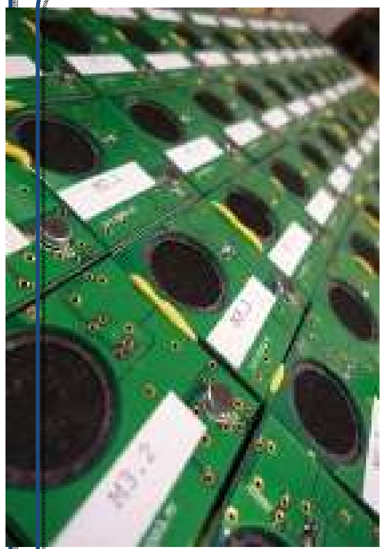
Classical approaches of **ANC or AVC** is difficult to apply into real fully distributed applications :

- Technological and Numerical **complexity**
- Difficulties for integrating such technology into the **Design Process** (**Robustness**/Performances)
- **Energy Cost**

**Necessity to propose a new approach ….**

**Synthesis** of **generalized Impedance operator** using **distributed** (low cost, low energy) **individual** (communicating) **cells**



**Metacomposites:**

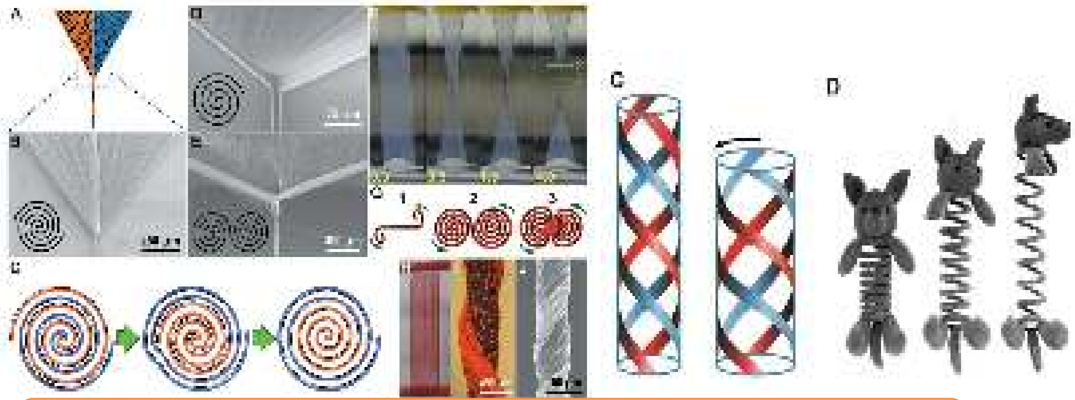
**Synthesis of functional constitutive laws** inside **hybrid composite material** by using **distributed sets of smart cells**

**Scale of interest:**

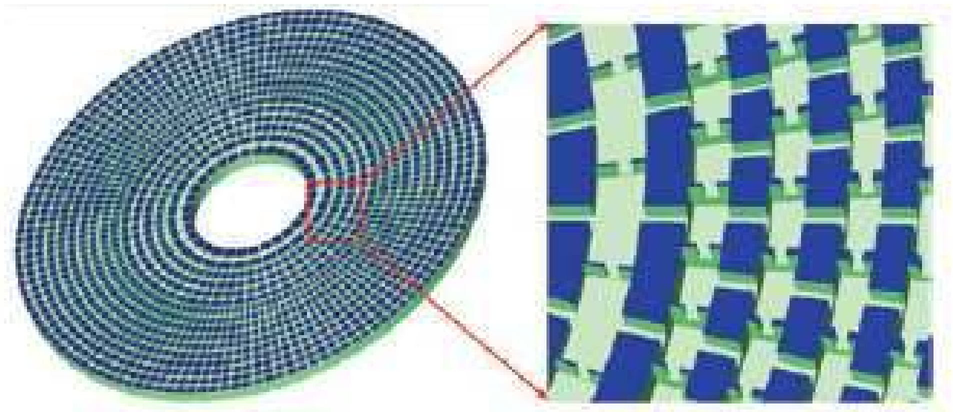
**mm -> few cm**

# Structural Optimization by architected Material

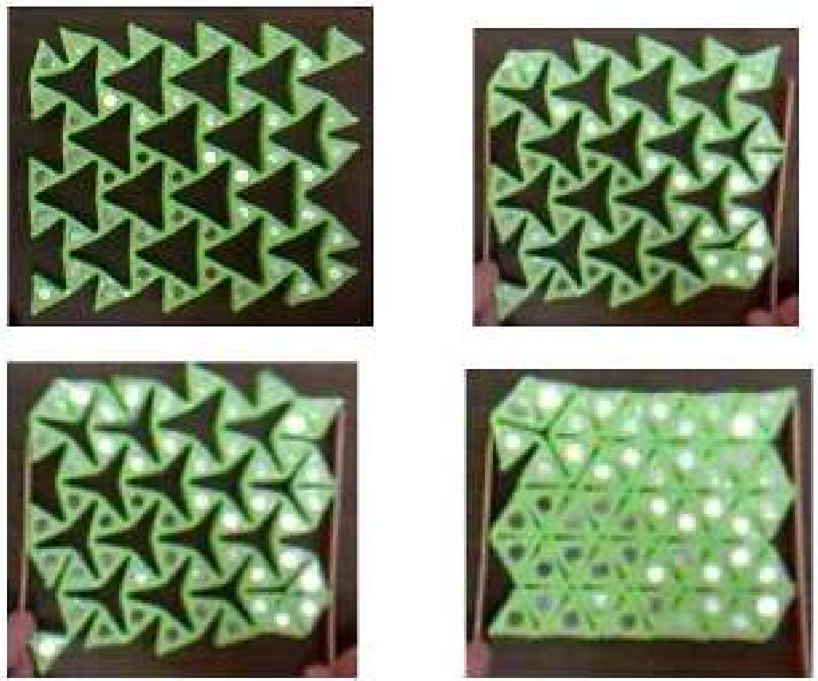
A sequence of images demonstrating the self-folding of a 4D printed multi-material single strand into the world of MIT



M.D Limaet al Biscrolling Nanotube Sheets and Functional Guests into Yarns, Science 331, 51, 2011

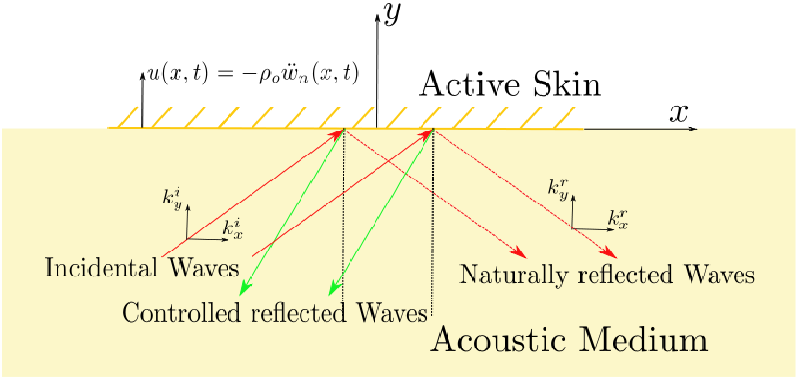


S. Zhang, C. Xia and N. Fang,
“Broadband acoustic cloak for ultrasound waves”, PRL, 106,2,2 4301, 2011



M. D. Schaeffer; M. Ruzzene, “Wave propagation in 2D magneto-elastic kagome lattices”, Proc. SPIE 9064, SMS 2014

# Generalized Impedance operator for breaking reciprocity



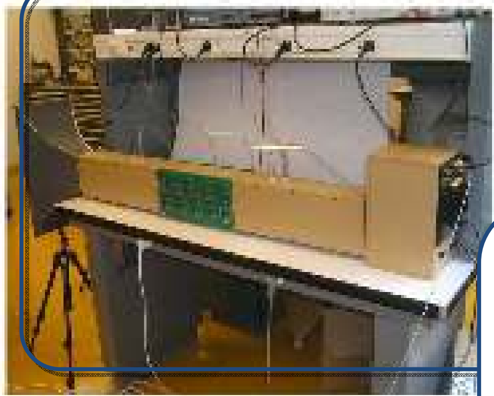

$$\begin{cases} \frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2} - \Delta p = 0 & \text{on } \Re_y^{-*} \times \Re_x \times \Re_t^{*+} \\ \frac{\partial p(x,0,t)}{\partial y} = u(x,t) & \\ y(x,t) = p(x,0,t) & \end{cases}$$

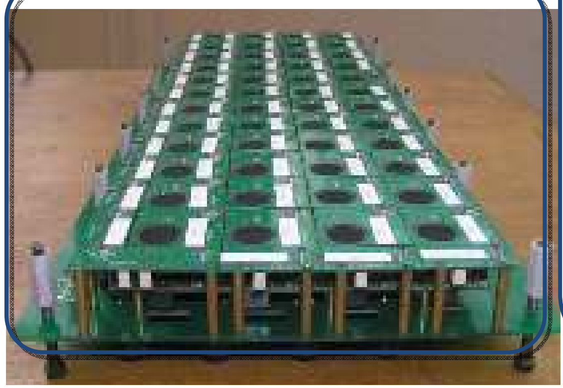
The physics

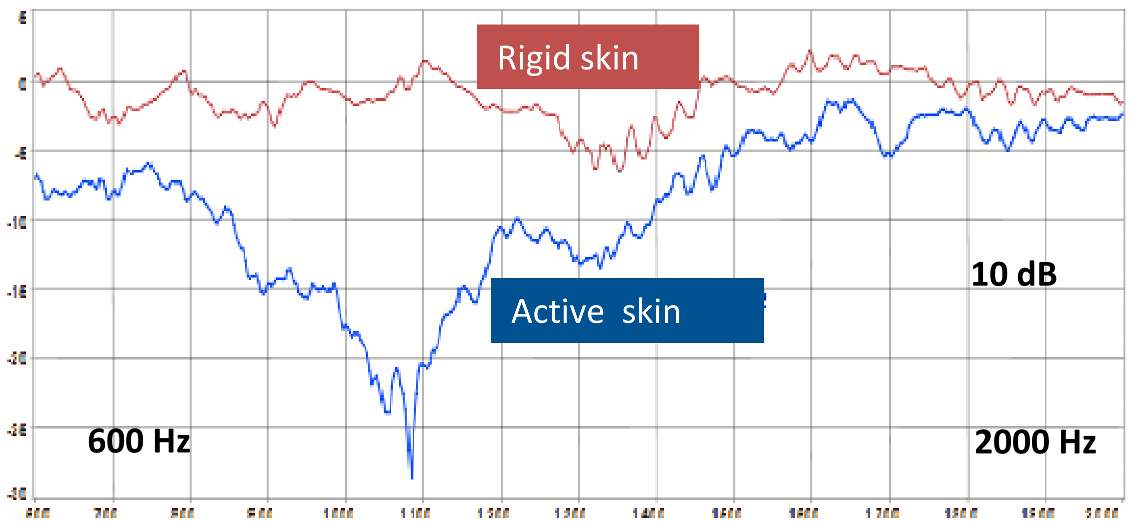
Control law that guarantees **kx<0**:

$$u(x,t) = -\left(\frac{1}{c_0}\frac{\partial p(x,0,t)}{\partial t} - \frac{\partial p(x,0,t)}{\partial x}\right)$$

Finite difference estimation of 1st-order derivatives

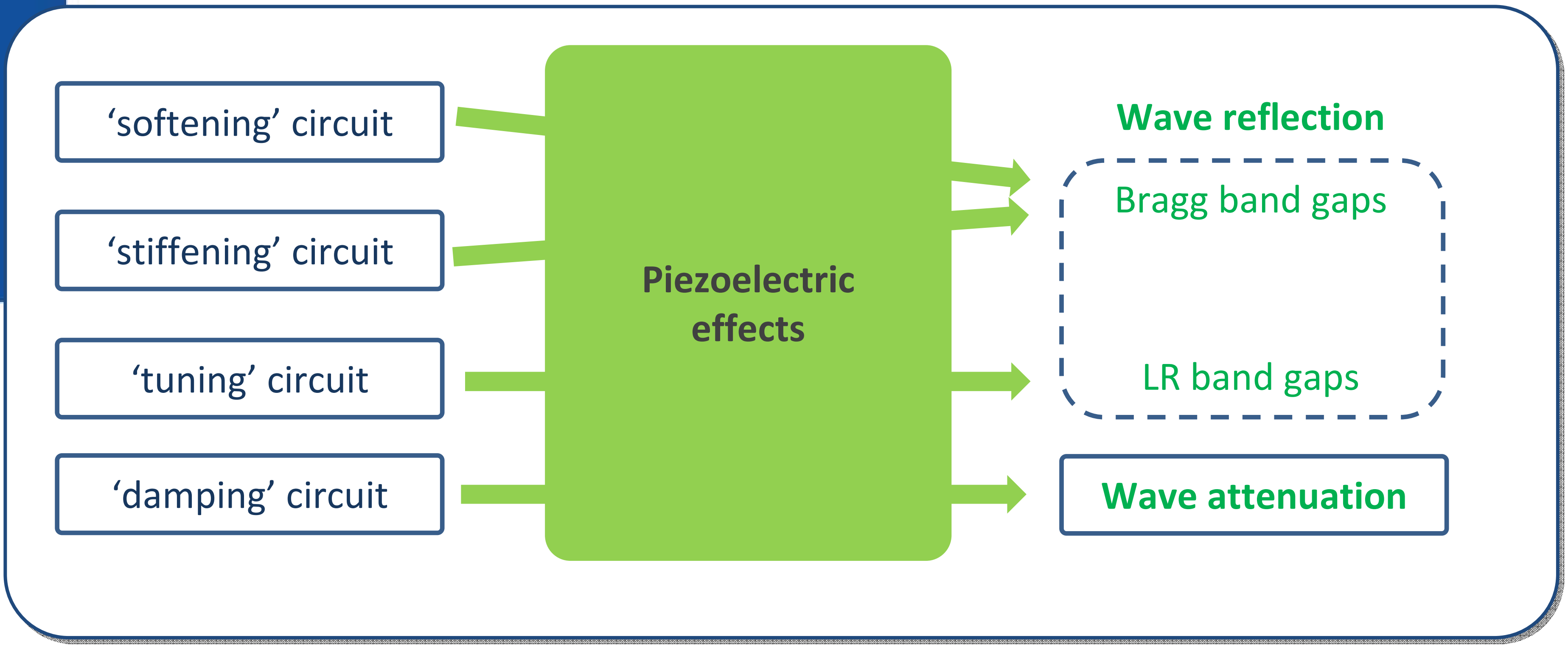


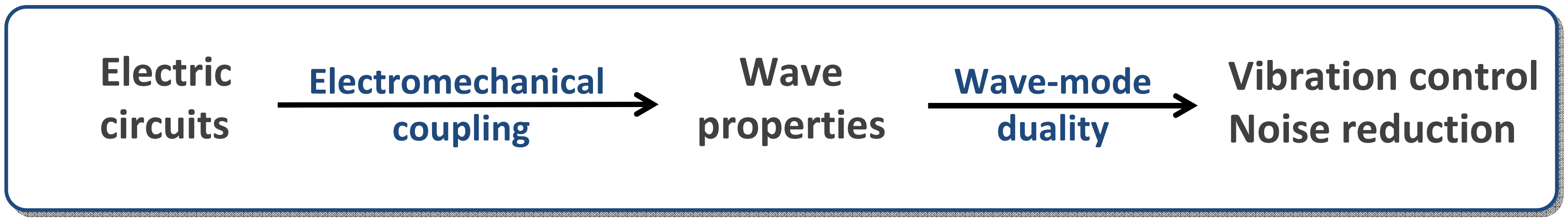





P. David, M Collet et al., SMS, 19(3), 2012

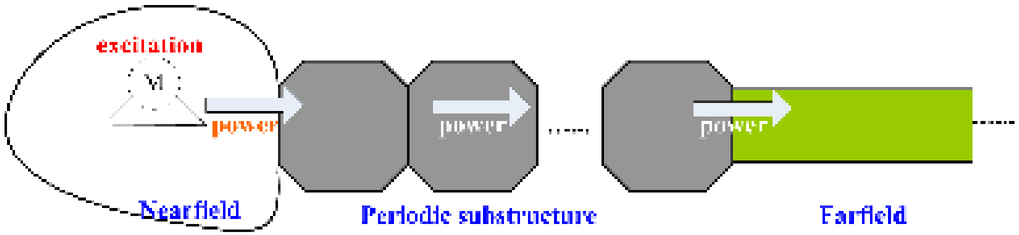
# How piezo composite can be optimized to control waves?

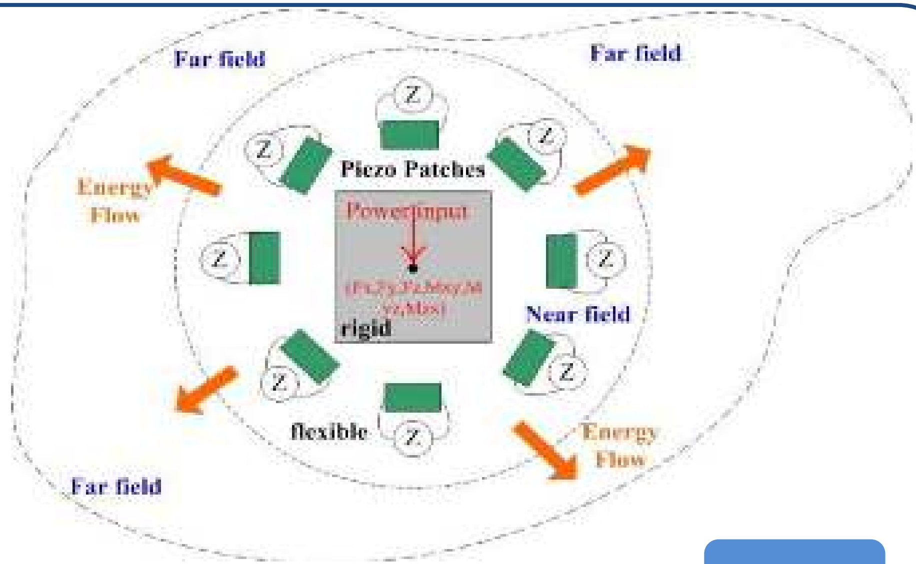


# Is Band Gap the optimal solution for controlling transmission ?

1D



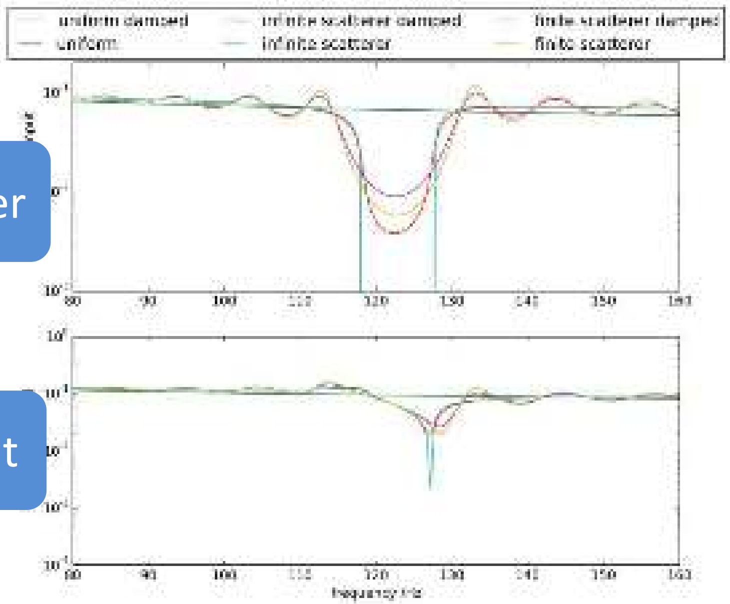




2D

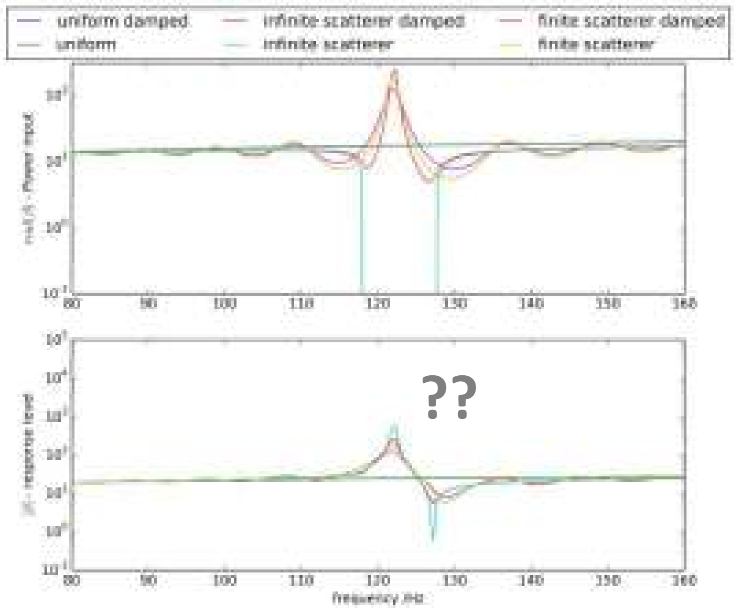
Output Power

Displacement

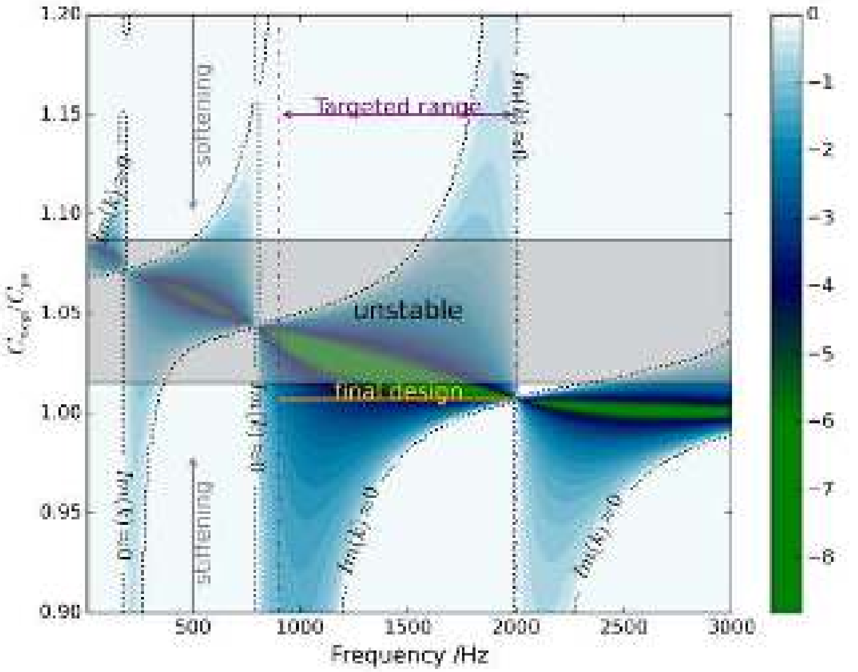
## Local modes not excited

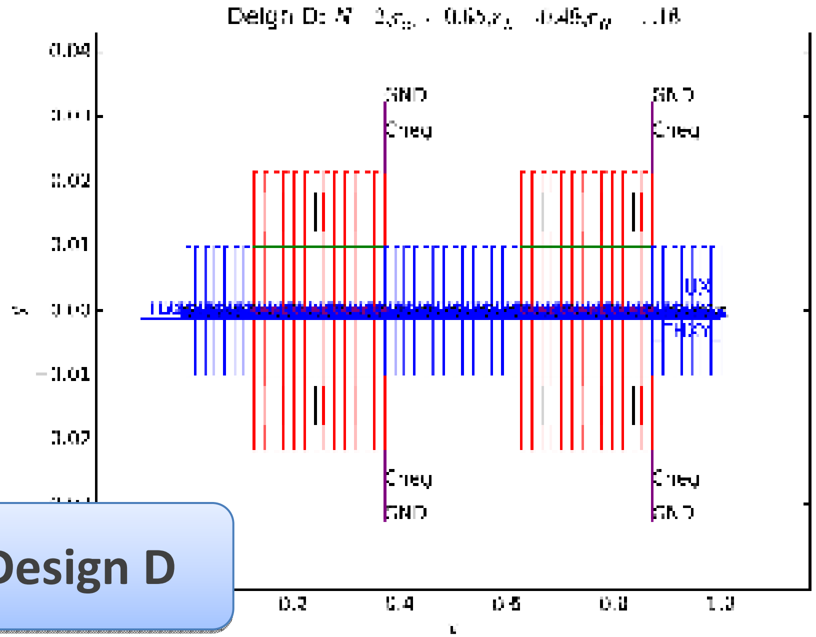



## Local modes excited

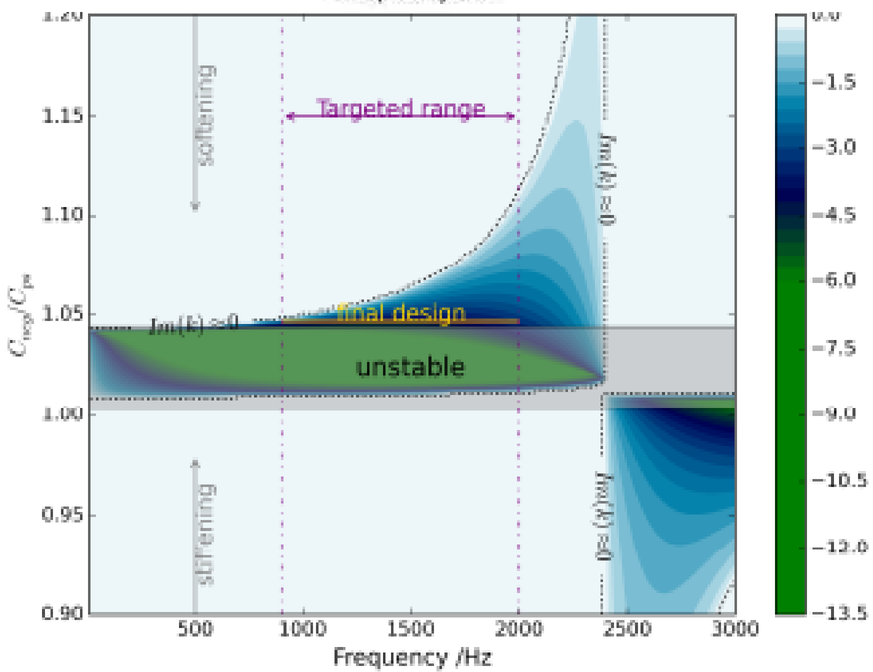


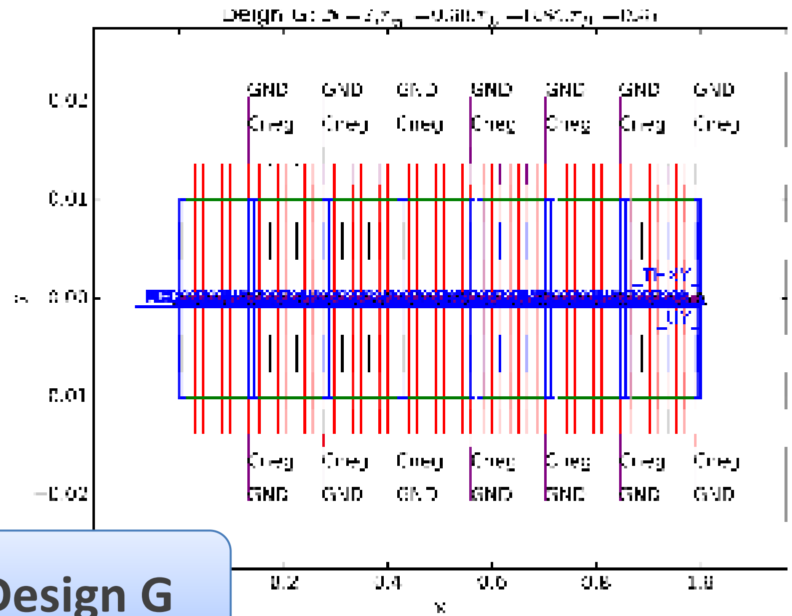
# How piezo composite can be optimized to control waves?




Design D




Design G

# How piezo composite can be optimized to control waves?

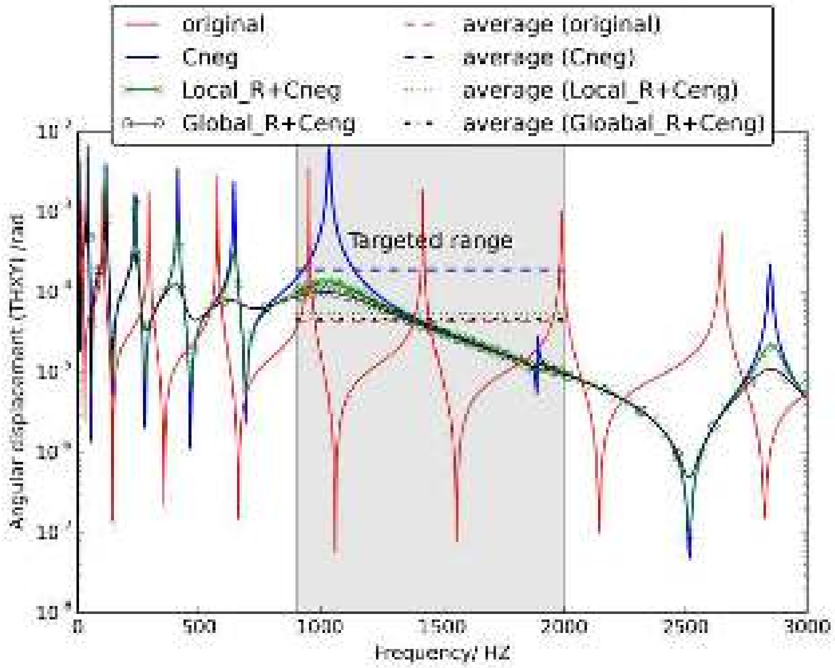



Figure 13: FRF of the rotation DOF at the excitation point ($x = 0.0$ m) of des

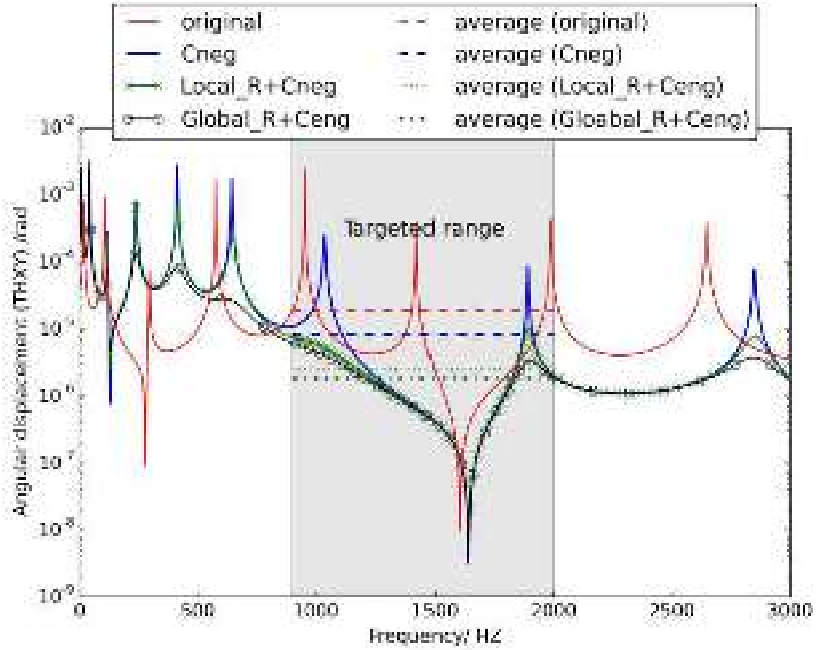
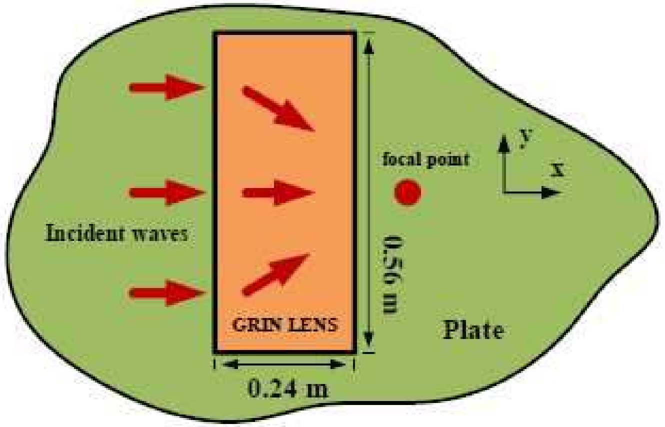
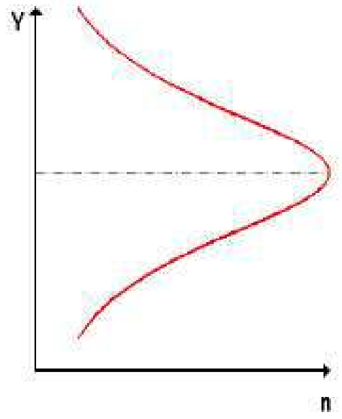



Figure 14: FRF of the rotation DOF away from the excitation point ($x = 0.7$ m) of design G

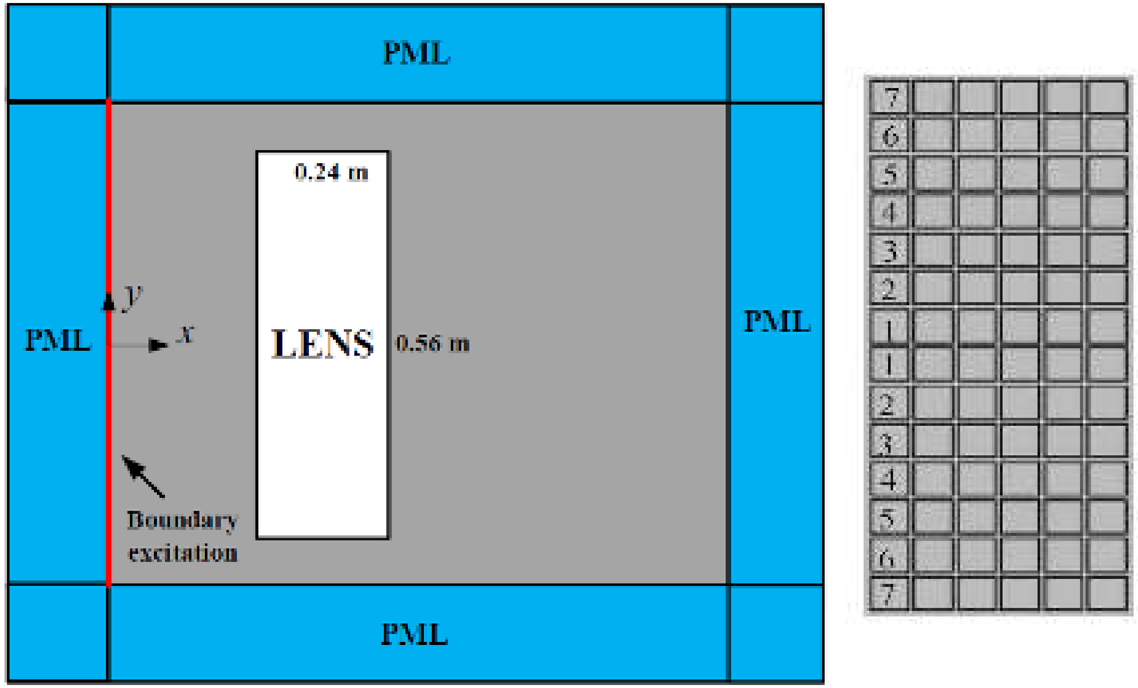
**Design G**

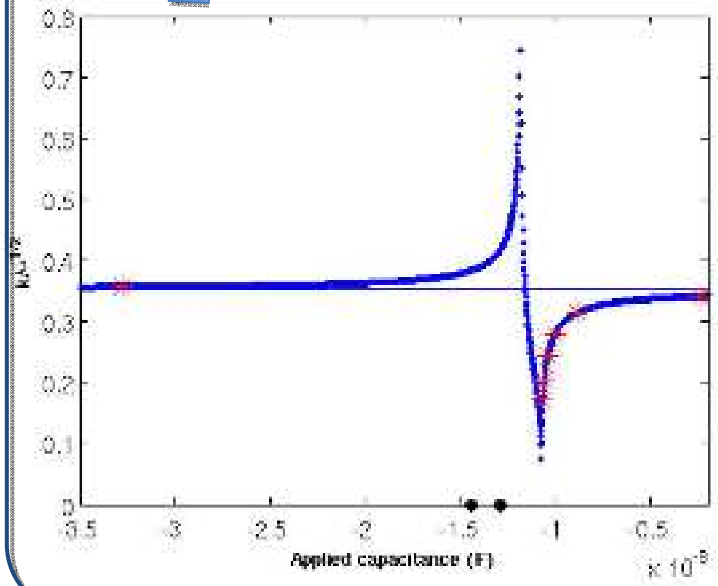


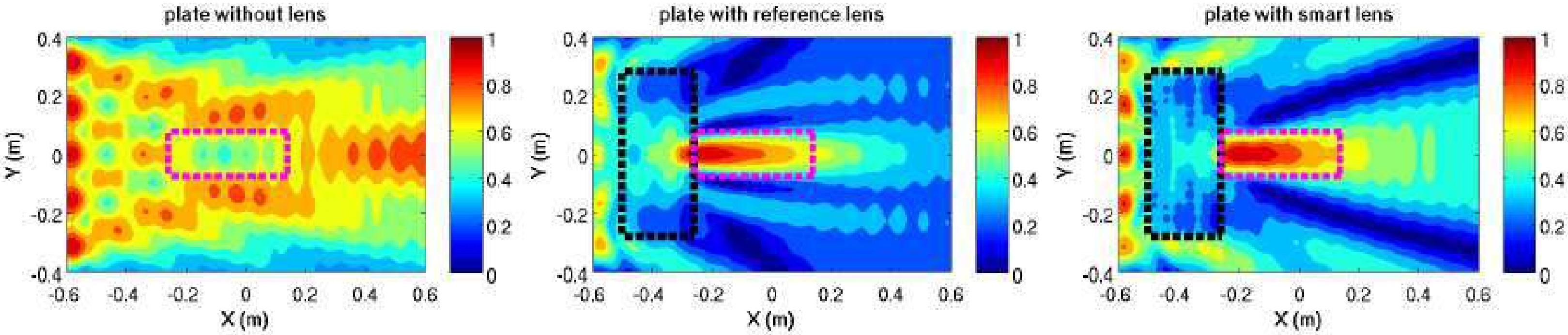

Refractive index

$$n(y) = \text{sech}[\alpha(y - y_0)]$$

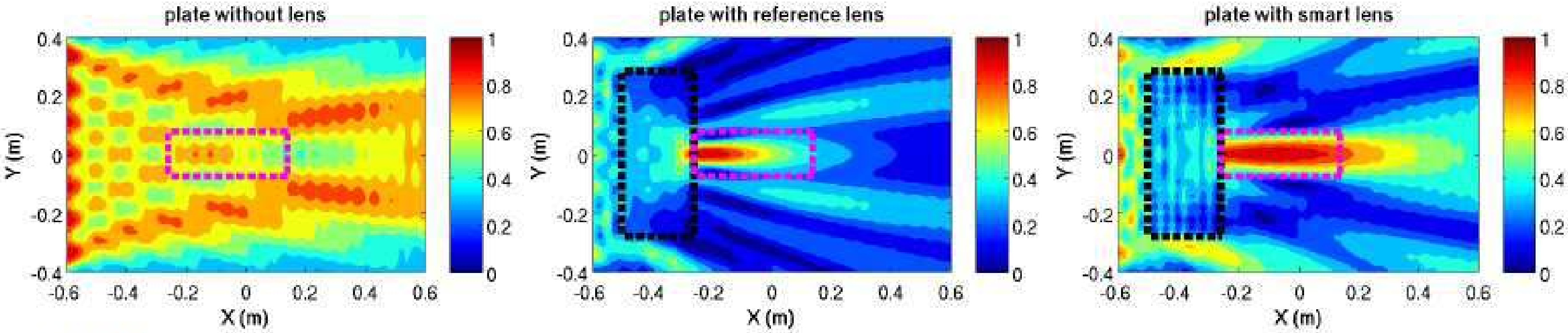


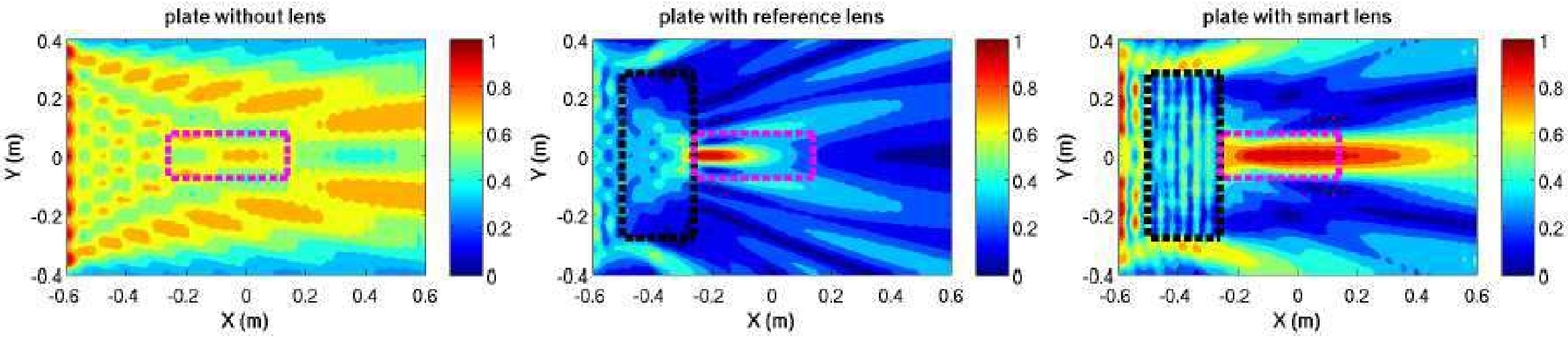
## 2000 Hz:




## 4000 Hz:



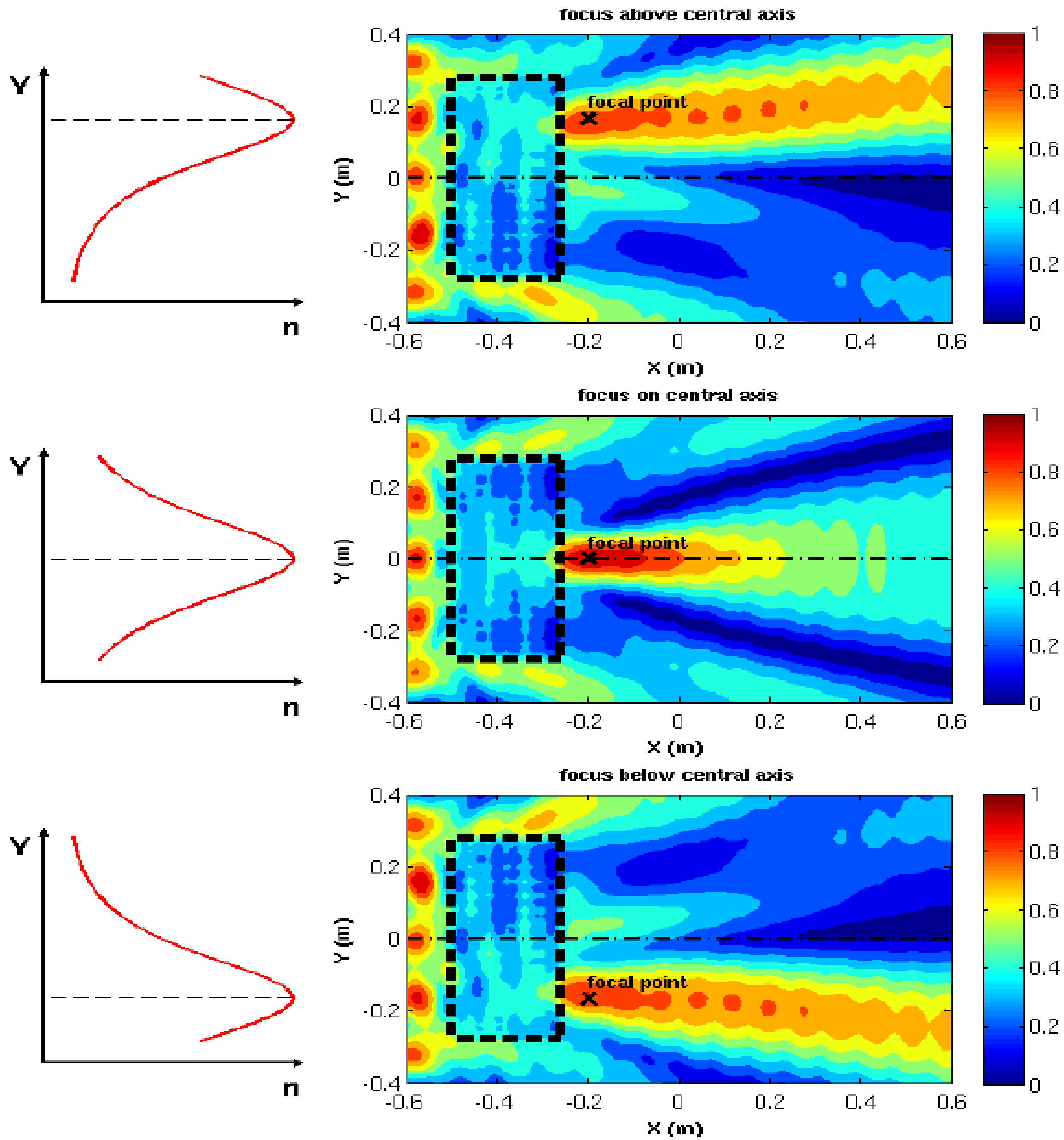

## 6000 Hz:



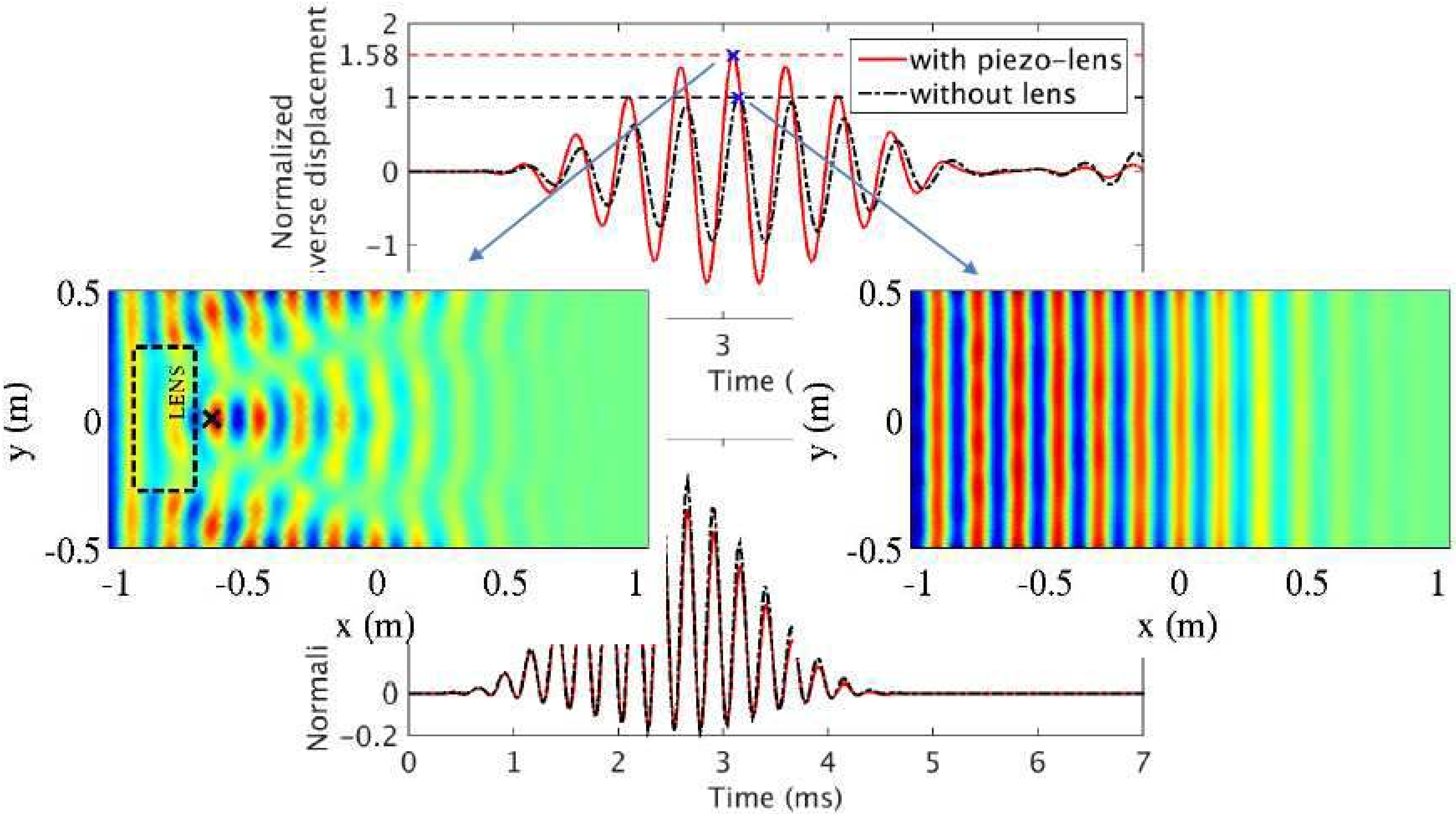
# Gradient Index : Adaptive Lens

## Tunability of the focal point

At 2000 Hz

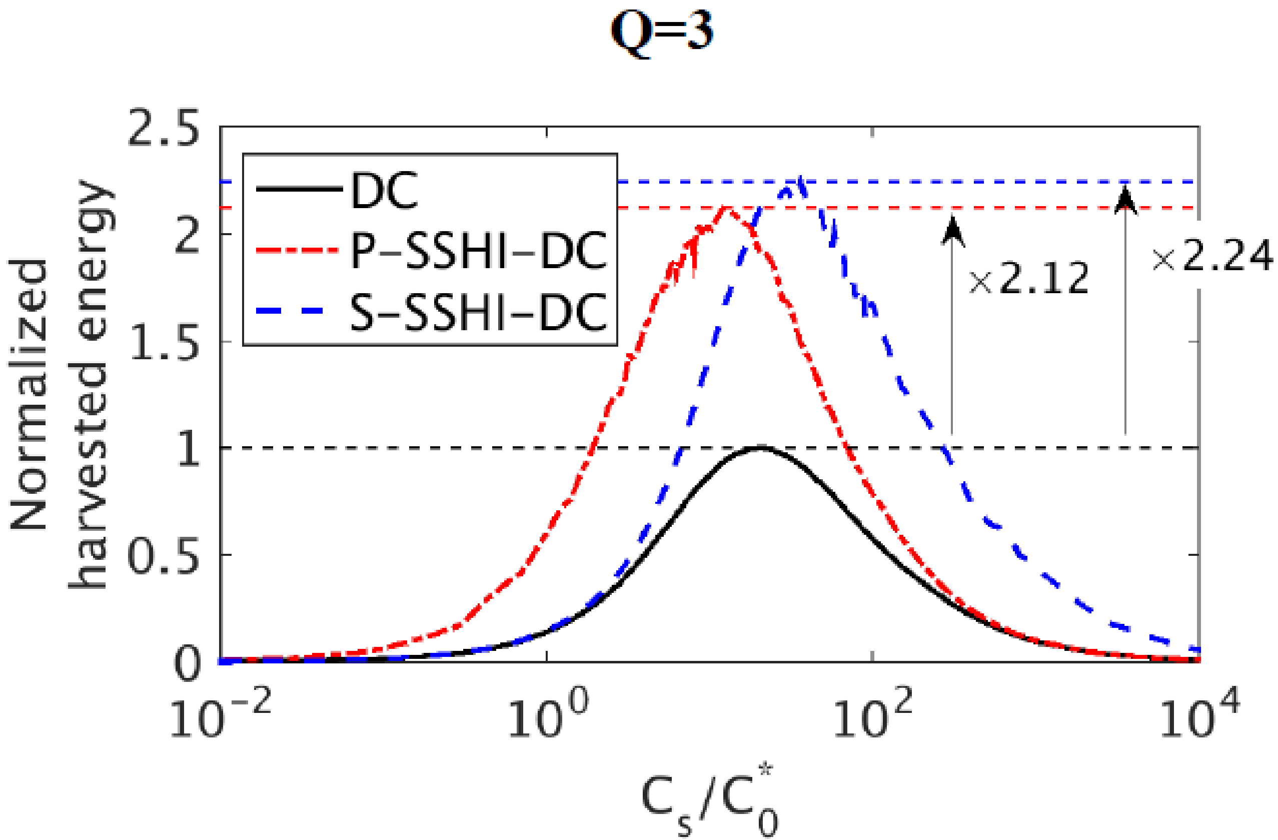


- Transverse response at focal point and input power:



Metric 1: harvested energy

$$E_{har}(C_s) = \frac{1}{2} C_s \cdot \max(V_{C_s}(t))^2$$



# Conclusions

## Concepts

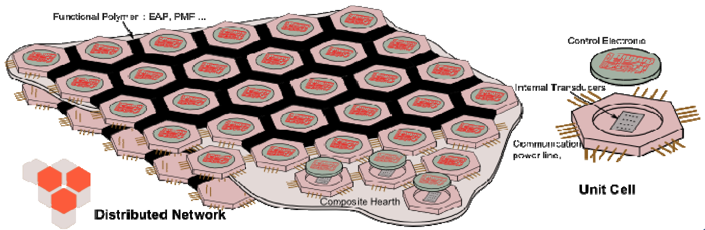
- **Periodic** systems
- **Smart** individual cells (multifunctionnal, reconfigurable, adaptive…)
- **Integrated** systems
- **Finite Elements** Approach / multiphysics
- **Global design strategy**

## Results

- **Whole 2D space** computation with **frequency dependent** physical behavior
- **Impedance** optimization
- **Reconfigurable** concept
- Validation of the **smart interface** on finite structure
- **Practical** implementation
- **Experimental** validation

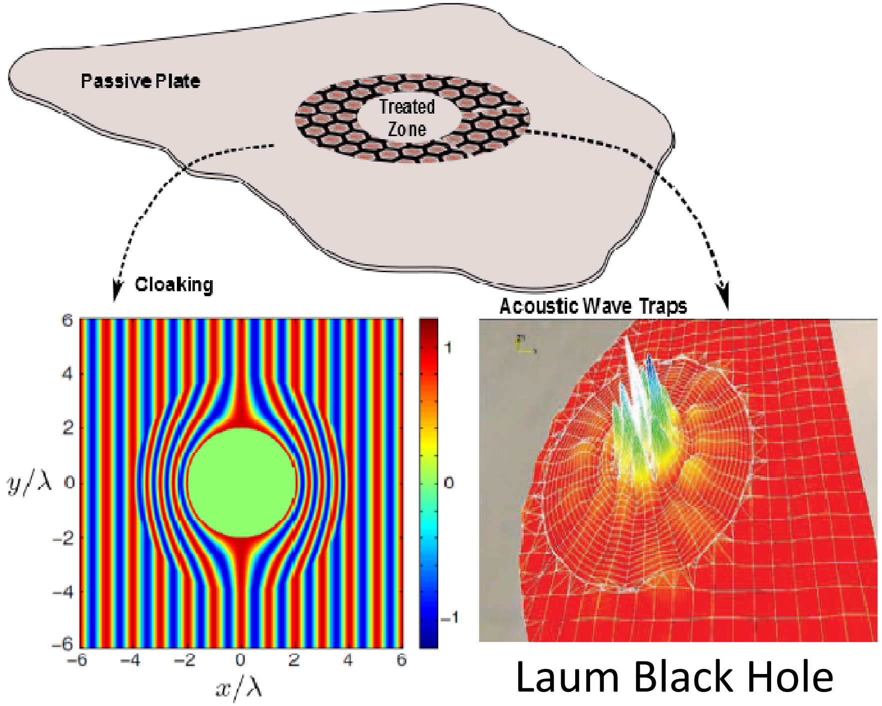
## Future steps for the metacomposites

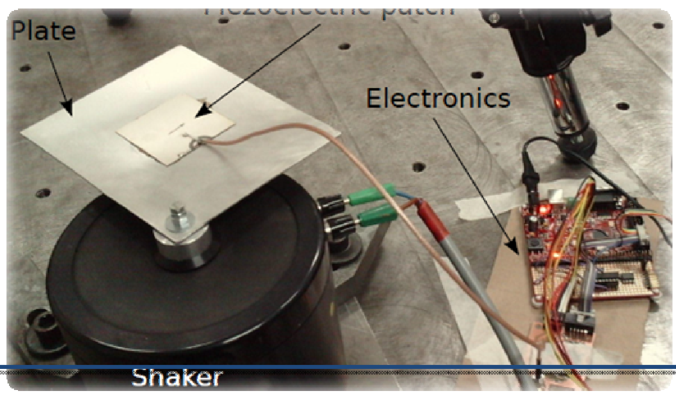
- Toward **fully integrated metacomposites**
- Combination of the concept with **DSP**:
  - Achieve **new functionnalities**
  - **Self reconfiguration**



## Future functions for the metacomposites

- Multiscale Network modeling and optimization for **Focusing, Cloaking** and **Wave traps**
- **Reciprocity breaking**
- Material programming network Robust design tools
- Toward innovative, integrated and autonomous smart metacomposite for Vibroacoustics…




- **Integrated programmable circuit**
- Design for distributed implementation
- Programming interface

**need more details?**

M. Collet, M. Ouisse, F. Tateo
*Adaptive Metacomposites for Vibroacoustic Control Applications*
Cover of IEEE Sensors Journal 14(7), 2014
http://dx.doi.org/10.1109/JSEN.2014.2300052


F. Tateo, M. Collet, M. Ouisse, M. Ichchou, K.A. Cunefare, P. Abbe
*Experimental characterization of a bi-dimensional array of negative capacitance piezo-patches for vibroacoustic control*
Journal of Intelligent Material Systems and Structures, 2014
http://dx.doi.org/10.1177/1045389X14536006

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