

A journey with Bill Kuperman from Ocean Acoustics to Structural Health Monitoring

Sandrine T. Rakotonarivo

Aix Marseille Univ, IUT Aix, LMA UMR 7031, France

188th ASA meeting, New Orleans, USA

Friday May 23th, 2025

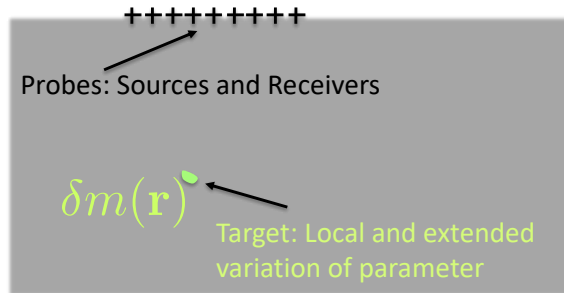
How would you conduct research with Bill ?

- Work on hard and useful problems!
- “There is no magic”, “Don’t let the mystery linger”
- “Pick the low hanging fruit”
- ”Do more with less”
- Data & Experiments !
- Don’t work alone, collaborate !

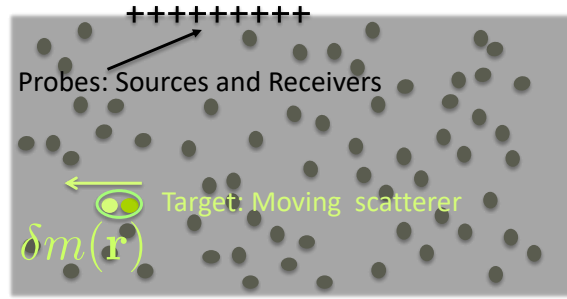
Bill's contributions to fields other than Ocean Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

Active set-up



[Roux et al., 2013; Yildiz et al., JASA 2013]

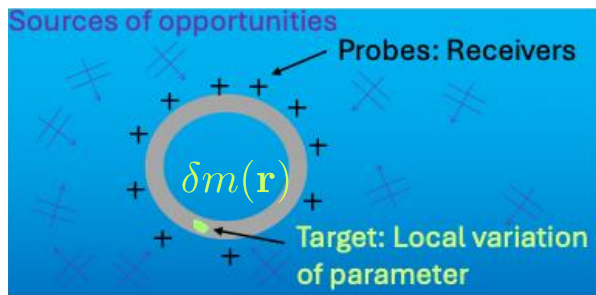


[Rakotonarivo et al., JASA 2011]

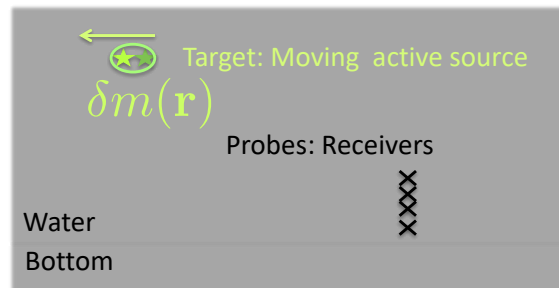
CONSTRAINTS

- ➔ Low SNR
- ➔ Limited data
- ➔ Limited *a priori* information

Passive set-up



[Lubeigt et al., JASA 2019;
Tippmann et al., Phil.Trans.R.Soc.A 2015]



[Rakotonarivo and Kuperman, JASA 2012]

OVERALL APPROACH

- ➔ Exploit multiple interactions of the waves with the environment
- ➔ Small perturbation approach (Sensitivity Kernel, Fréchet derivative)
- ➔ Time reversal, Matched Field processing, Interferometry (Noise correlation)
- ➔ Forward modeling:
 - Simplified modeling & Filtering
 - Data based modeling

Forward modeling

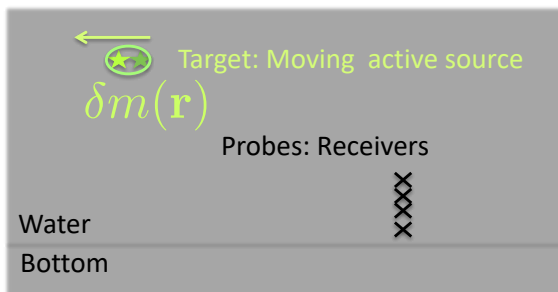
$$\Delta\Psi(\mathbf{r}_r) = \Psi_{i+1}(\mathbf{r}_r) - \Psi_i(\mathbf{r}_r)$$

$$\Delta\Psi(\mathbf{r}_r) = \mathcal{M}[\delta m(\mathbf{r})] \longrightarrow \propto \delta m(\mathbf{r}) \begin{cases} \neq 0 & \text{at } \mathbf{r} = \mathbf{r}_{change} \\ = 0 & \text{elsewhere} \end{cases}$$

An example of Bill's contributions to Ocean Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

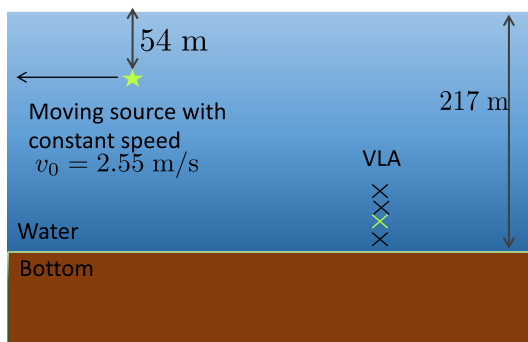
Passive set-up



- Variation of pressure field between 2 positions of the sources: Interferometry or Differencing on a single sensor
- No modeling of the waveguide: average phase speed of the modes

Active moving source localization in a shallow water waveguide with a single sensor

Swell-Ex 96 Experiment:

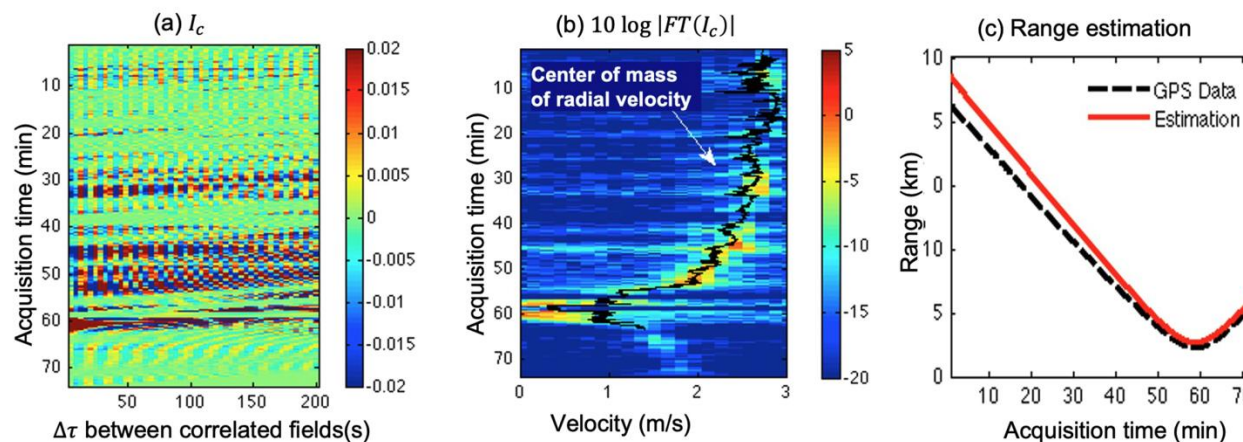


The frequency interference spacing for a particular $\Delta\tau$

$$d_f = \frac{\overline{V_p}}{v_s(\tau)\Delta\tau} \quad \text{Broadband process}$$

The $\Delta\tau$ interference spacing for a particular frequency

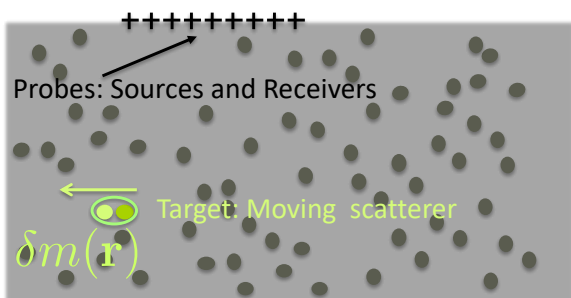
$$d_t = \frac{\overline{V_p}}{v_s(\tau)f} \quad \text{Narrowband process}$$



An example of Bill's contributions to Physical Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

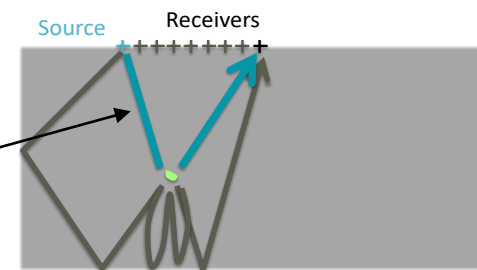
Active set-up



Few a priori information \rightarrow Simplified description of the environment

$$\Delta\Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})]$$

$$\mathcal{L} = \mathcal{L}_{0,model} \leftarrow \text{Only direct path}$$



Moving target tracking in a multiple scattering medium

Delay-And-Sum with **incoherent**

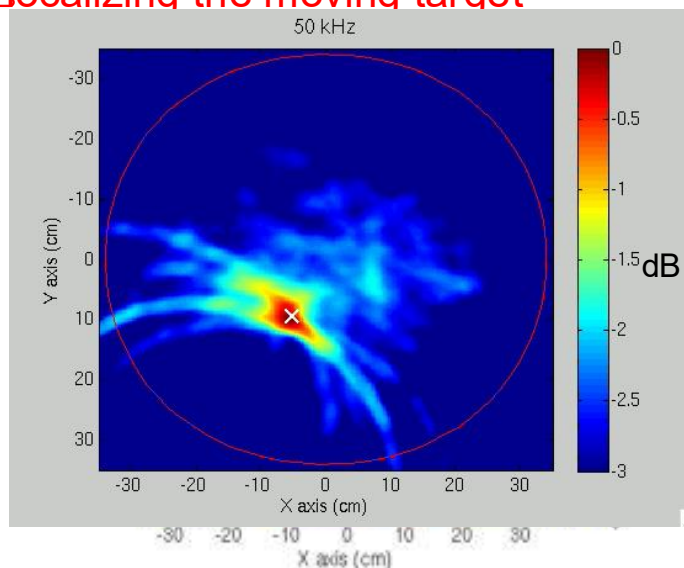
Summation Over Sources method fails at localizing the moving target

l^* transport mean free path

$$d_{sr} = 340 \text{ mm} \approx 3.2l^*$$



Receiver 15 rec x 15 src Source



✓ Robust localization in a multiple scattering environment

➤ Valid in a specific regime

Single scattering regime

Multiple scattering regime

Diffuse regime

An example of Bill's contributions to Structural Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

Previous application of Matched Field Processing on structural acoustics

Applications of matched-field processing to structural vibration problems

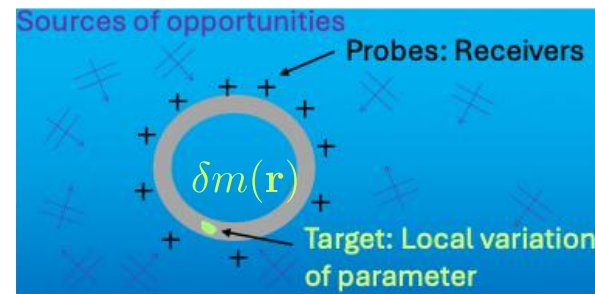
G. Turek and W. A. Kuperman
*Marine Physical Laboratory of the Scripps Institution of Oceanography, University of California,
San Diego, La Jolla, California 92093-0701*

(Received 15 March 1996; accepted for publication 23 October 1996)

- Target: Active source
- Numerical forward model (beam):
$$\Delta \Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{f,model}$$
- Numerical demonstration

Data-based adjoint matched field processing for target localization in a noise field

Passive
set-up



- Target: change of stiffness
- Data-based model:
$$\Delta \Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{data}$$
- Numerical demonstration

An example of Bill's contributions to Structural Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

Previous application of Matched Field Processing on structural acoustics

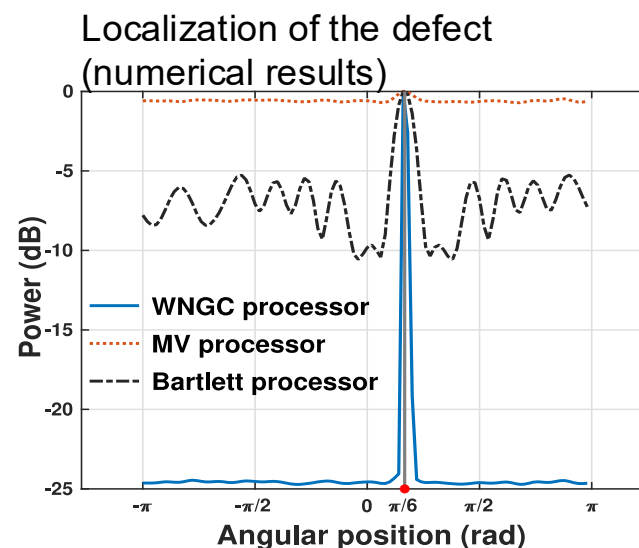
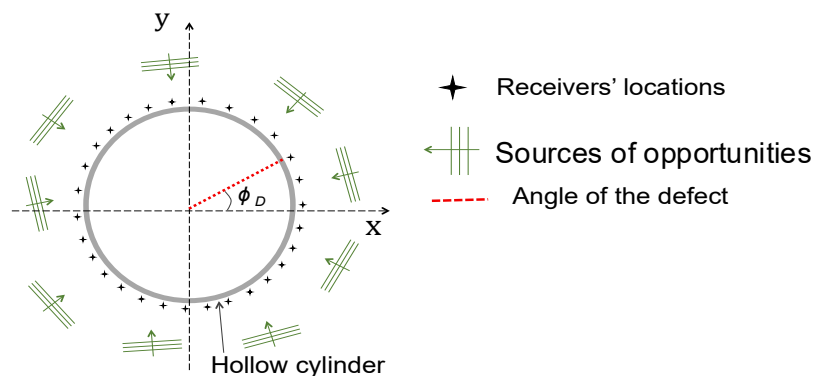
Applications of matched-field processing to structural vibration problems

G. Turek and W. A. Kuperman
Marine Physical Laboratory of the Scripps Institution of Oceanography, University of California,
San Diego, La Jolla, California 92093-0701

(Received 15 March 1996; accepted for publication 23 October 1996)

- Target: Active source
- Numerical forward model (beam):
$$\Delta \Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{f,model}$$
- Numerical demonstration

Data-based adjoint matched field processing for target localization in a noise field



An example of Bill's contributions to Structural Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

Previous application of Matched Field Processing on structural acoustics

Applications of matched-field processing to structural vibration problems

G. Turek and W. A. Kuperman
Marine Physical Laboratory of the Scripps Institution of Oceanography, University of California,
San Diego, La Jolla, California 92093-0701

(Received 15 March 1996; accepted for publication 23 October 1996)

- Target: Active source
- Numerical forward model (beam):
$$\Delta\Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{f,model}$$
- Numerical demonstration

Data-based adjoint matched field processing for target localization in a noise field

NEXT

- Target: change of stiffness ← Low SNR but small perturbation
- Data-based model: ← No *a priori* information but involving experiment ← Less sensors
$$\Delta\Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{data}$$
- Numerical demonstration ← Experimental demonstration ? ← Experiments

An example of Bill's contributions to Structural Acoustics

1 - Source (change) localization in a complex environment (Reverberation/Multiple scattering)

Previous application of Matched Field Processing on structural acoustics

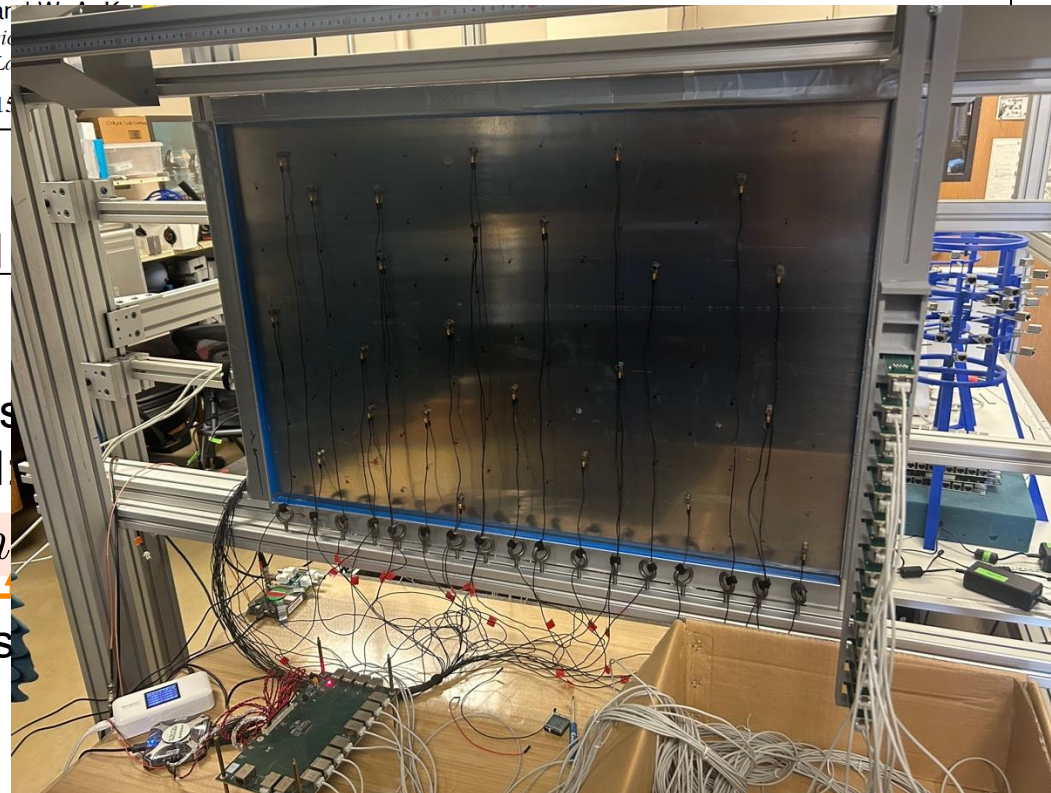
Applications of matched-field processing to structural vibration problems

G. Turek and Bill D. O'Neil
Marine Physics
San Diego, CA
(Received 15...)

- Target: Active source
- Numerical forward model (beam):
$$\Delta \Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m(\mathbf{r})] \quad \mathcal{L} = \mathcal{L}_{f,model}$$
- Numerical demonstration

Data-based

- Target: change of s
- Data-based model
$$\Delta \Psi(\mathbf{r}_r) \approx \mathcal{L}[\delta m]$$
- Numerical demons



Localization in a noise field

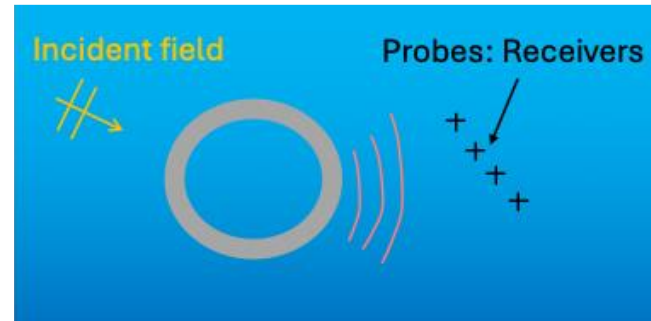
NEXT

on
olving experiment ← Less sensors

← Experiments

An example of Bill's contributions to Structural Acoustics

2 - Passive characterization of elastic structures radiation & scattering



Scattering/Radiation in any environment

A new impedance-based approach to analysis and control of sound scattering

Yu.I. Bobrovnikii*

Vibroacoustic Department, Mechanical Engineering Research Institute of Russian Academy of Sciences, Moscow 101990, Russia

Received 22 June 2005; received in revised form 6 April 2006; accepted 21 April 2006
Available online 7 July 2006

Structural impedance/admittance formalism

Virtual source approach to scattering from partially buried elastic targets

Henrik Schmidt

Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

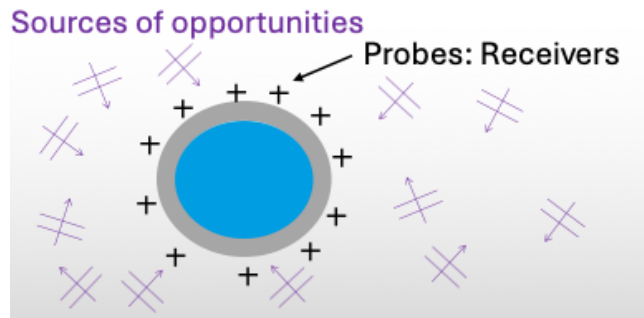
Equivalent source method

[Koopmann et al., 1989; Bi et al., 2008]

An example of Bill's contributions to Structural Acoustics

2 - Passive characterization of elastic structures radiation & scattering

1 - Elastic structure characterization (structural impedance/admittance) in a diffuse field



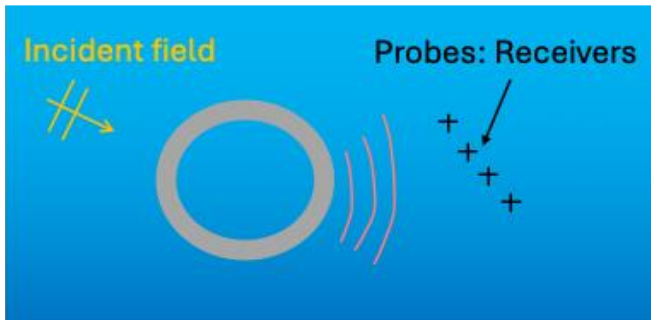
$$\mathbf{p} = -\mathbf{Z}_s \mathbf{v}$$

\mathbf{p} : Total pressure field and total normal velocity at the object surface
 \mathbf{v} : Total pressure field and total normal velocity at the object surface

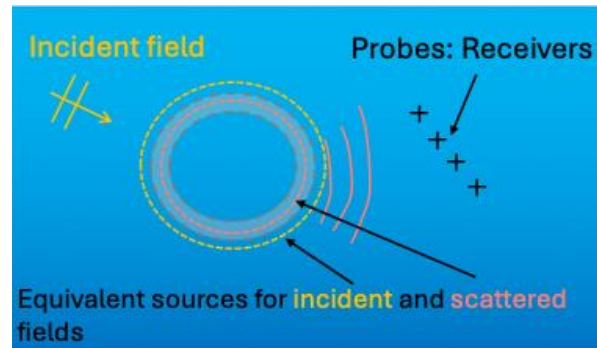
CONSTRAINTS

- ➔ No *a priori* information about the inner structure
- ➔ Limited data

2 - Elastic structure scattering in any external medium



≈



$$\mathbf{p} = \mathbf{H} \left(\frac{1}{\mathbf{z}_a} + \frac{1}{\mathbf{z}_s} \right)^{-1} \left(\frac{1}{\mathbf{z}_i} - \frac{1}{\mathbf{z}_s} \right) \mathbf{p}_i$$

OVERALL APPROACH

- ➔ Data based method for structure characterization in a diffuse field
- ➔ Admittance/Impedance formalism
- ➔ Near field holography
- ➔ Equivalent source methods

An example of Bill's contributions to Structural Acoustics

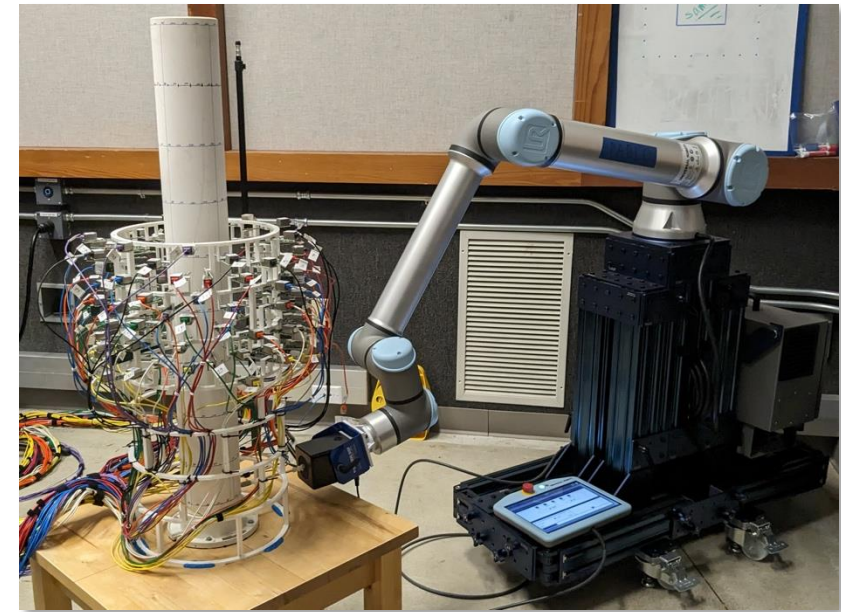
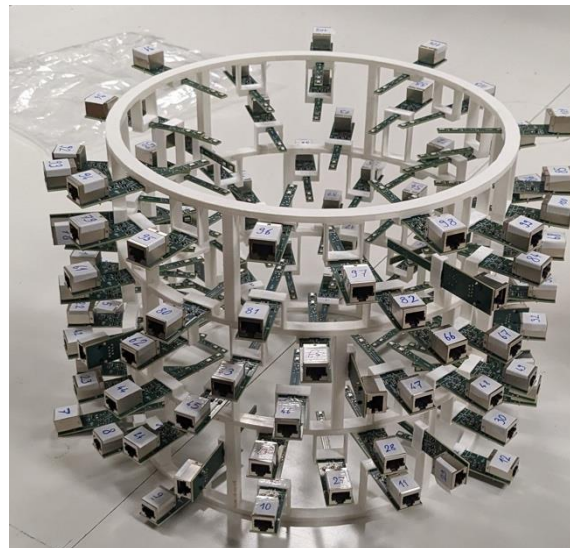
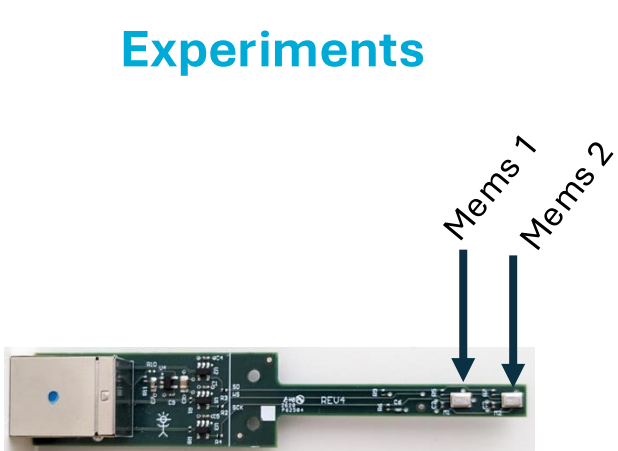
2 - Passive characterization of elastic structures radiation & scattering

- 1 - Elastic structure characterization (structural impedance/admittance) in a diffuse field
- 2 - Elastic structure scattering in any external medium

NEXT

Adaptation of the formalism to sharp objects [Roggerone et al., JSV 2024 & ASA 2025]

Experiments



Master Bill = An amazing mentor and the best boss ever

GENEROUS

INCLUSIVE

SUPPORTIVE

HUMBLE

GIFTED

ENTHOUSIASTIC

UNDERSTANDING

ENQUIRING MIND

TOUGH

A MAN OF INTEGRITY

ENERGETIC

VISIONARY

The art of delivering mind

A journey with Bill Kuperman from Ocean Acoustics to Structural Health Monitoring (2009-2024)....

THANK YOU !