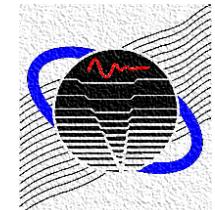


March 3, 2022

Notes on the Inverse Boundary Element Method

David Herrin
University of Kentucky

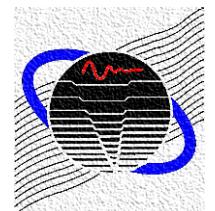
Vibro-Acoustics Consortium



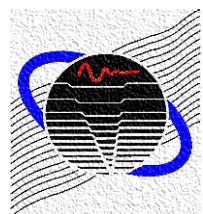
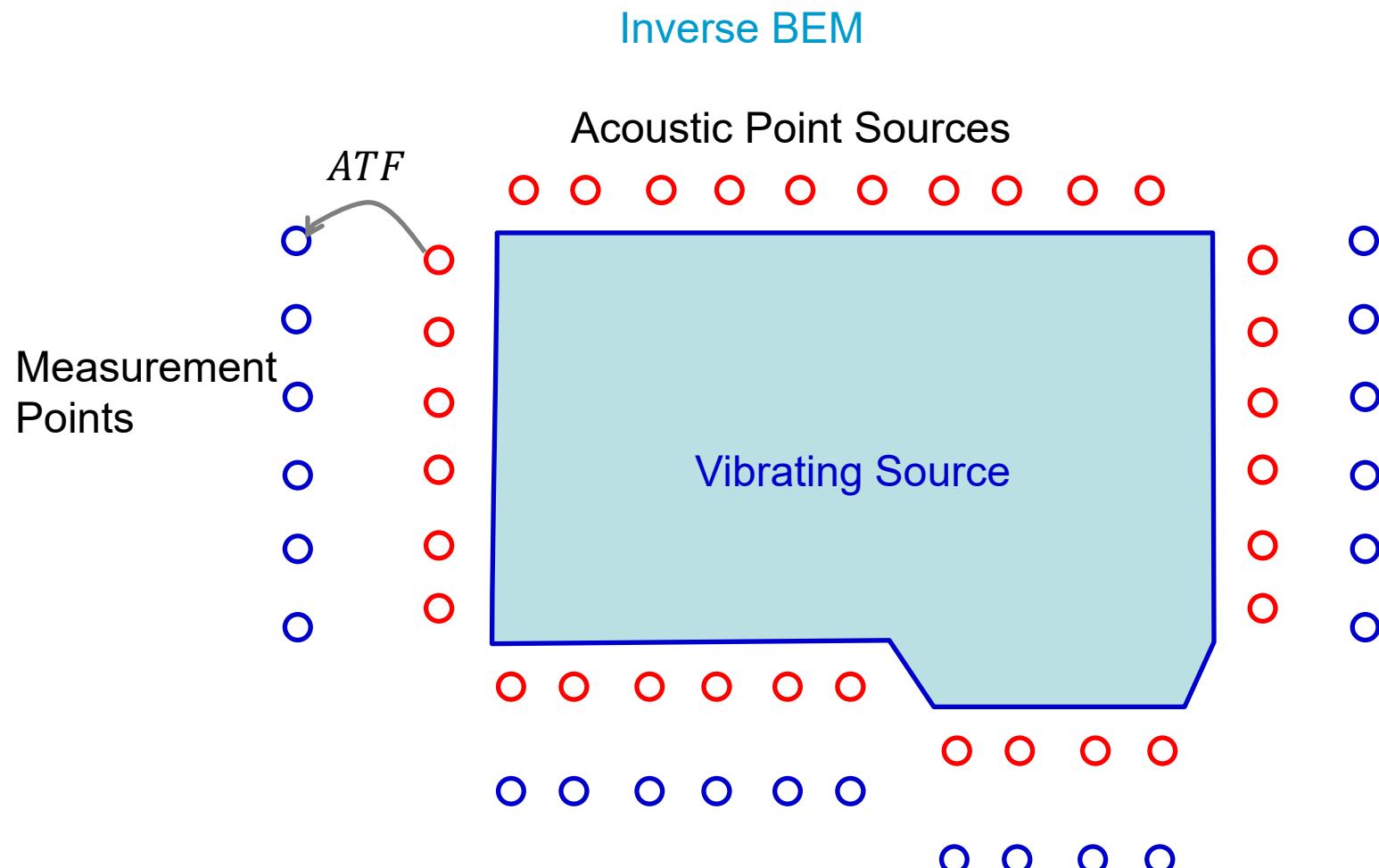
Overview

Inverse BEM

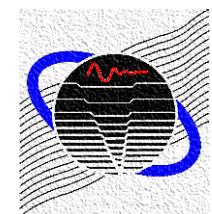
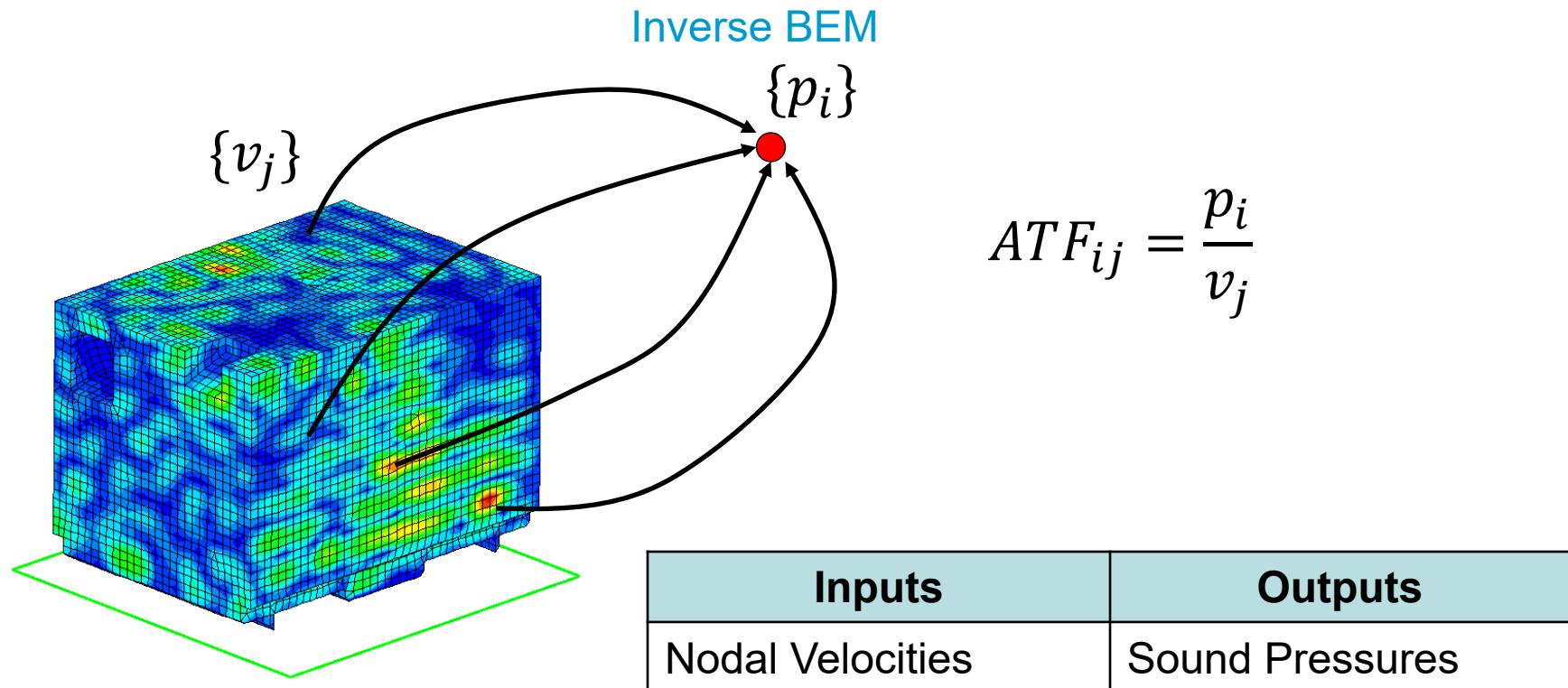
- Theory
- Case 1 – Diesel Engine
- Case 2 – Generator Set
- Case 3 – Aeroacoustic Source



Acoustic Transfer Functions



Inverse BEM

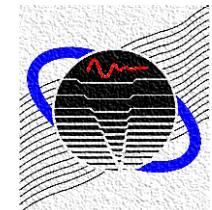


Inverse BEM

Inverse BEM

$$\{p_i\} = [ATM]\{\nu_j\}$$

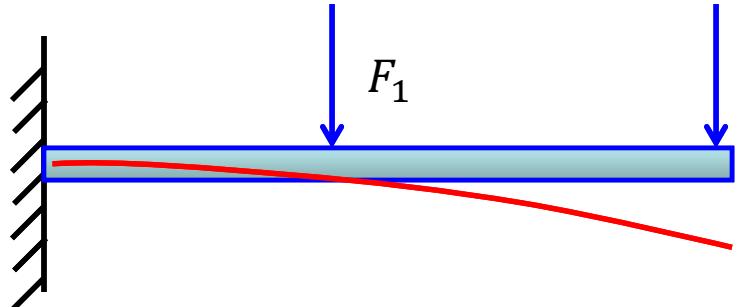
- Step 1 Measure the sound pressure $\{p_i\}$ in the field.
- Step 2 Determine the transfer matrix $[ATM]$ via BEM.
- Step 3 Invert the matrix to find unknown inputs $\{\nu_j\}$.



An Observation

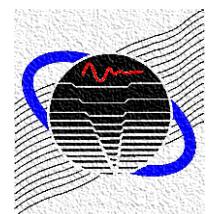
Inverse BEM

- Inverse solutions are not unique.



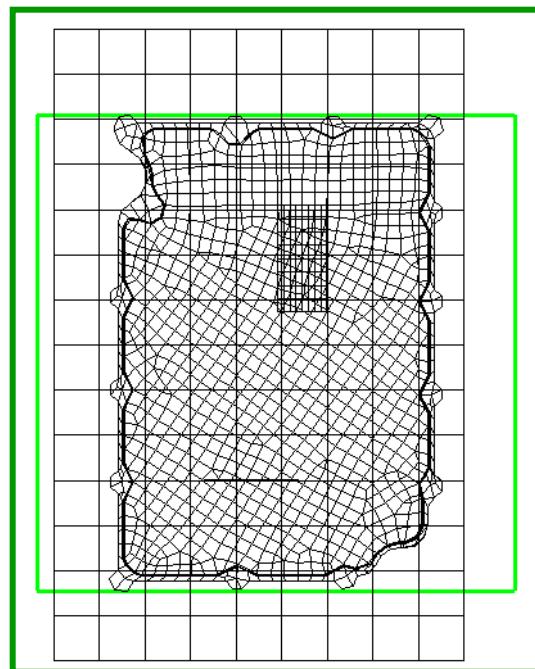
If both forces are in phase, any combination of the two forces will produce the first mode.

- Inverse solutions are often ill conditioned (i.e., a small change in the measurement can greatly impact the inverse solution).

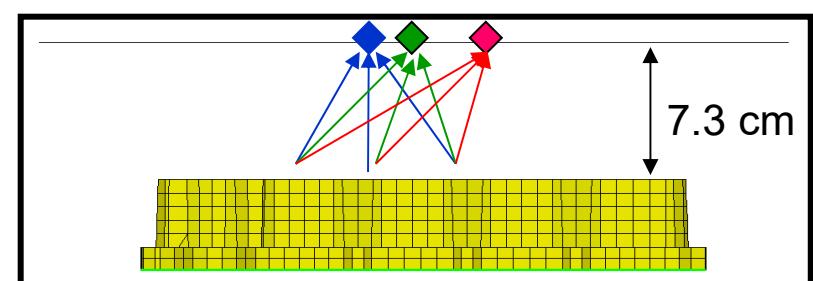


Acoustic Transfer Vectors

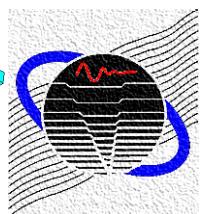
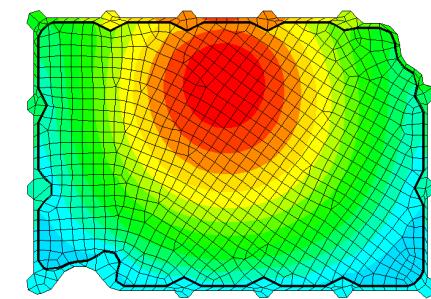
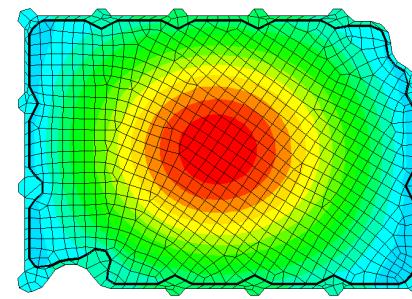
Inverse BEM



ATV



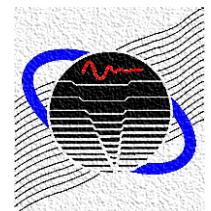
$$\begin{Bmatrix} p_1 \\ p_2 \\ p_3 \\ \vdots \\ \vdots \end{Bmatrix} = \begin{Bmatrix} \text{blue line} \\ \text{green line} \\ \text{red line} \\ \text{empty box} \\ \vdots \\ \vdots \end{Bmatrix} \begin{Bmatrix} v_1 \\ v_2 \\ v_3 \\ \vdots \\ \vdots \end{Bmatrix}$$



Overview

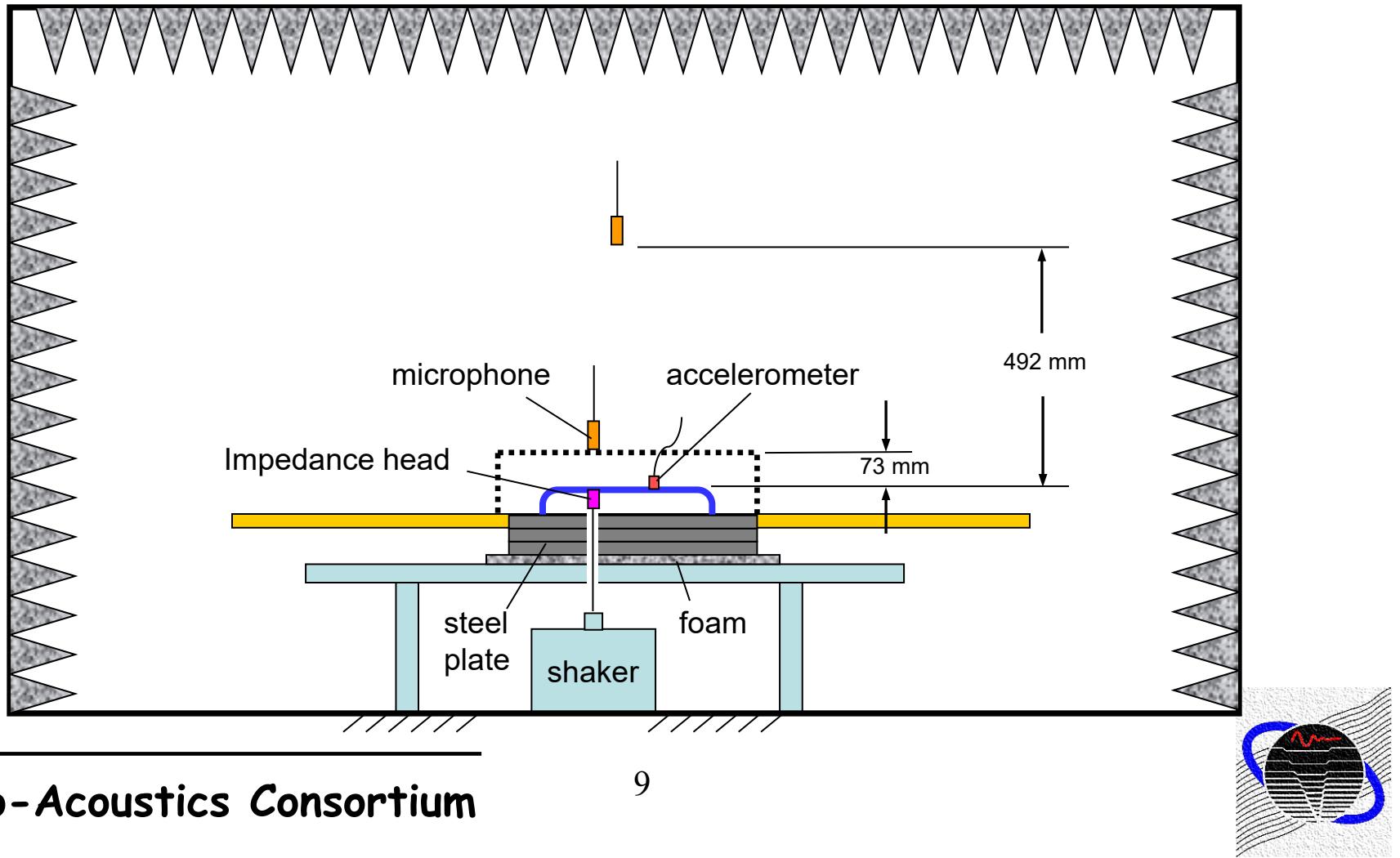
Inverse BEM

- Theory
- Case 1 – Engine Cover
- Case 2 – Generator Set
- Case 3 – Aeroacoustic Source



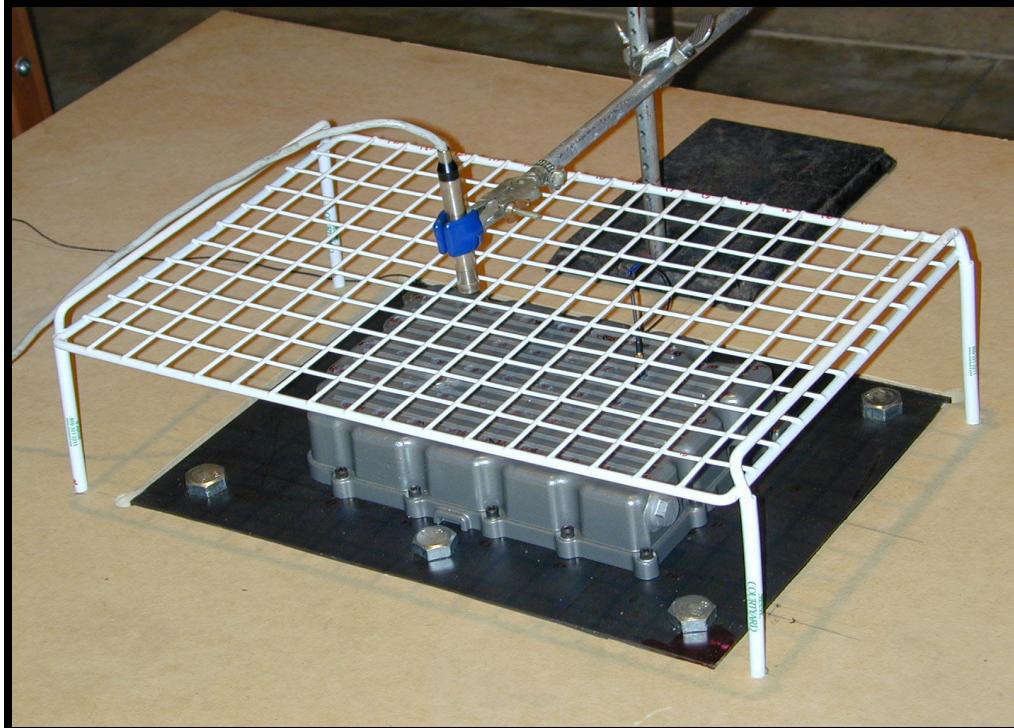
Experimental Setup

Inverse BEM

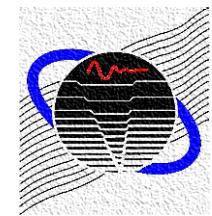
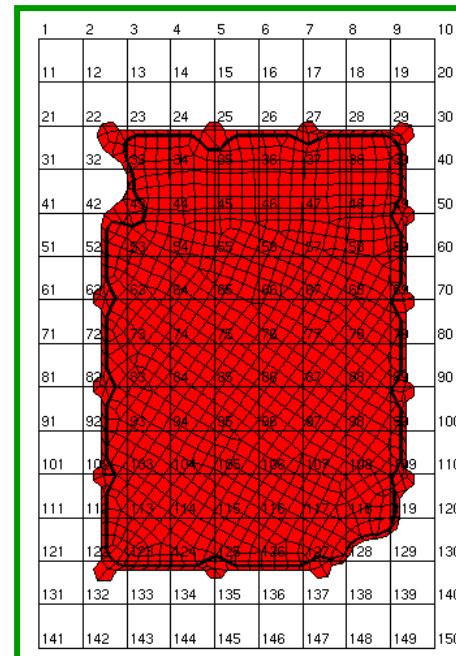
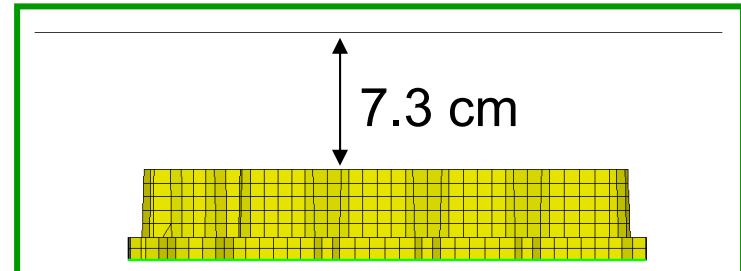


Sound Pressure Measurements

Inverse BEM

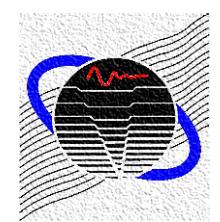
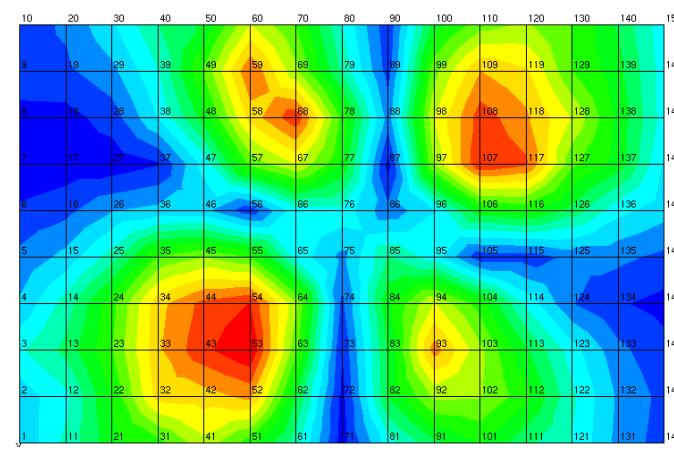
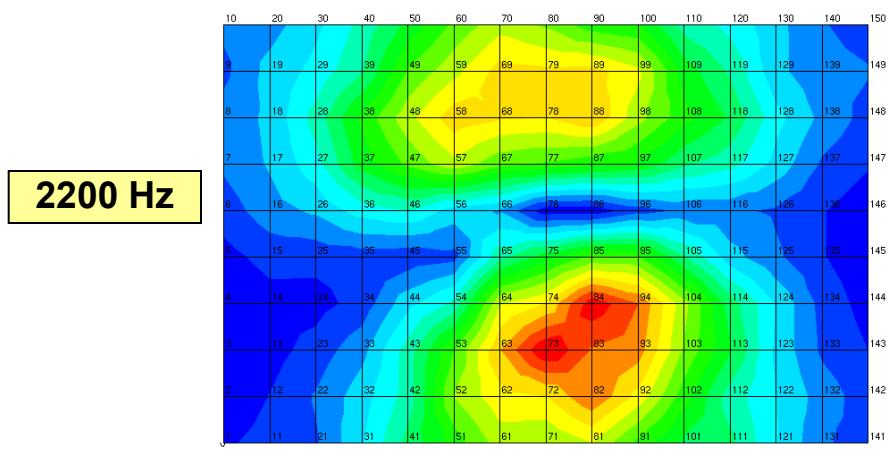
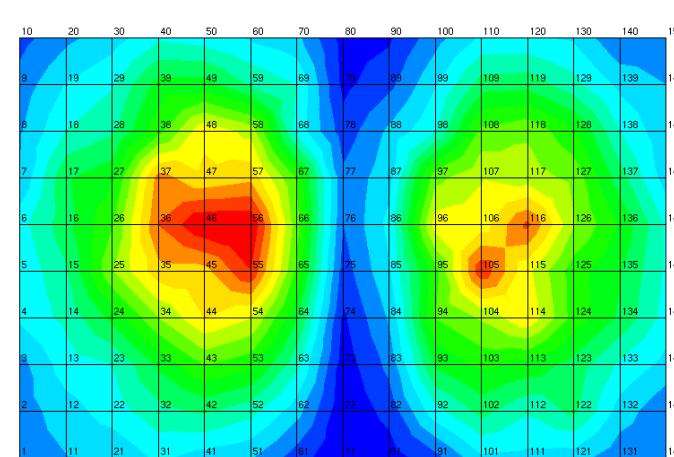
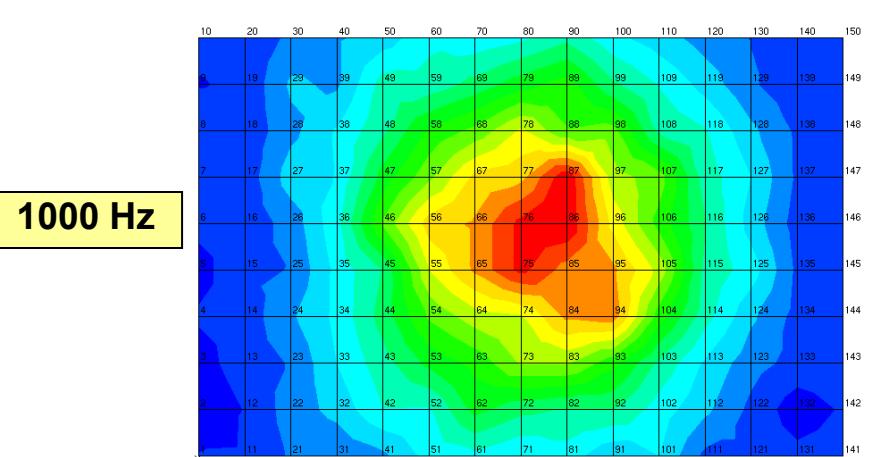


150 measurement points



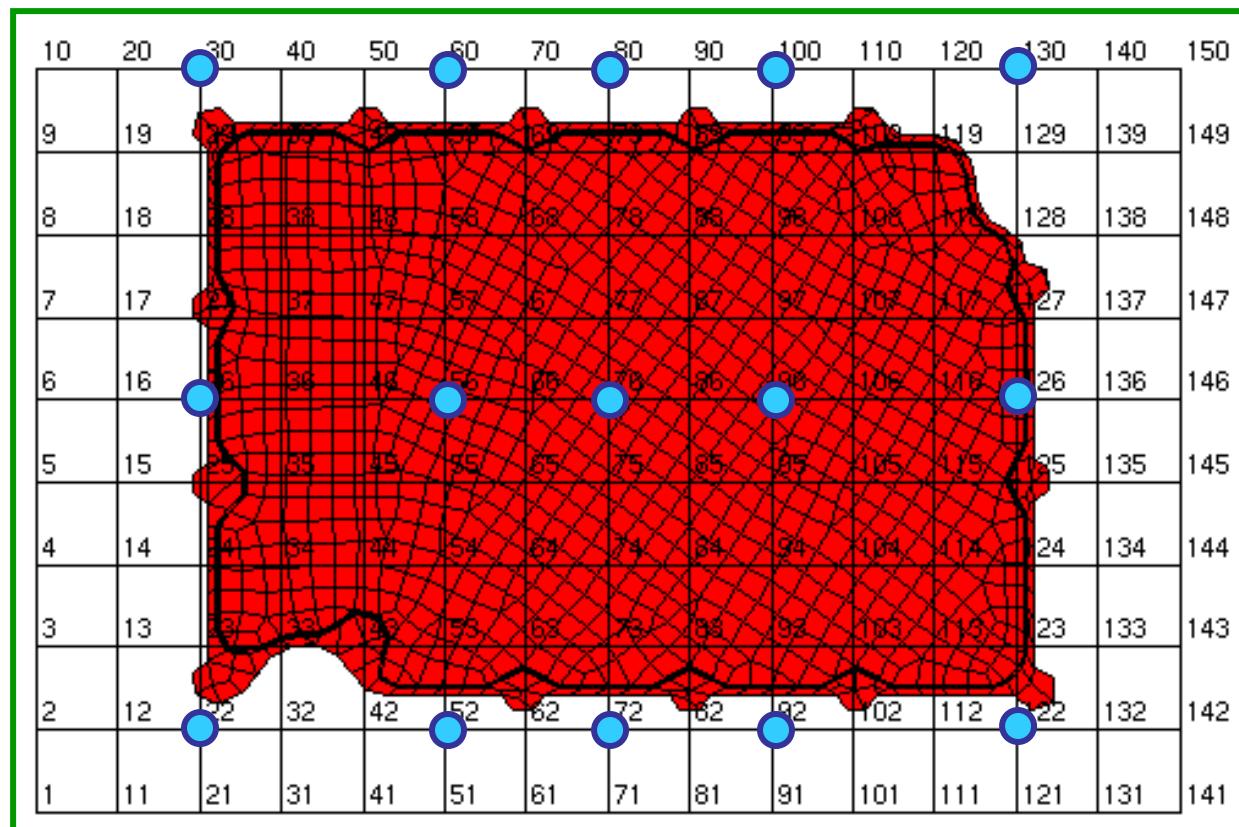
Measured Sound Pressure

Inverse BEM

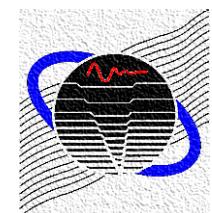


Measurement Points Used

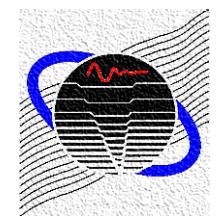
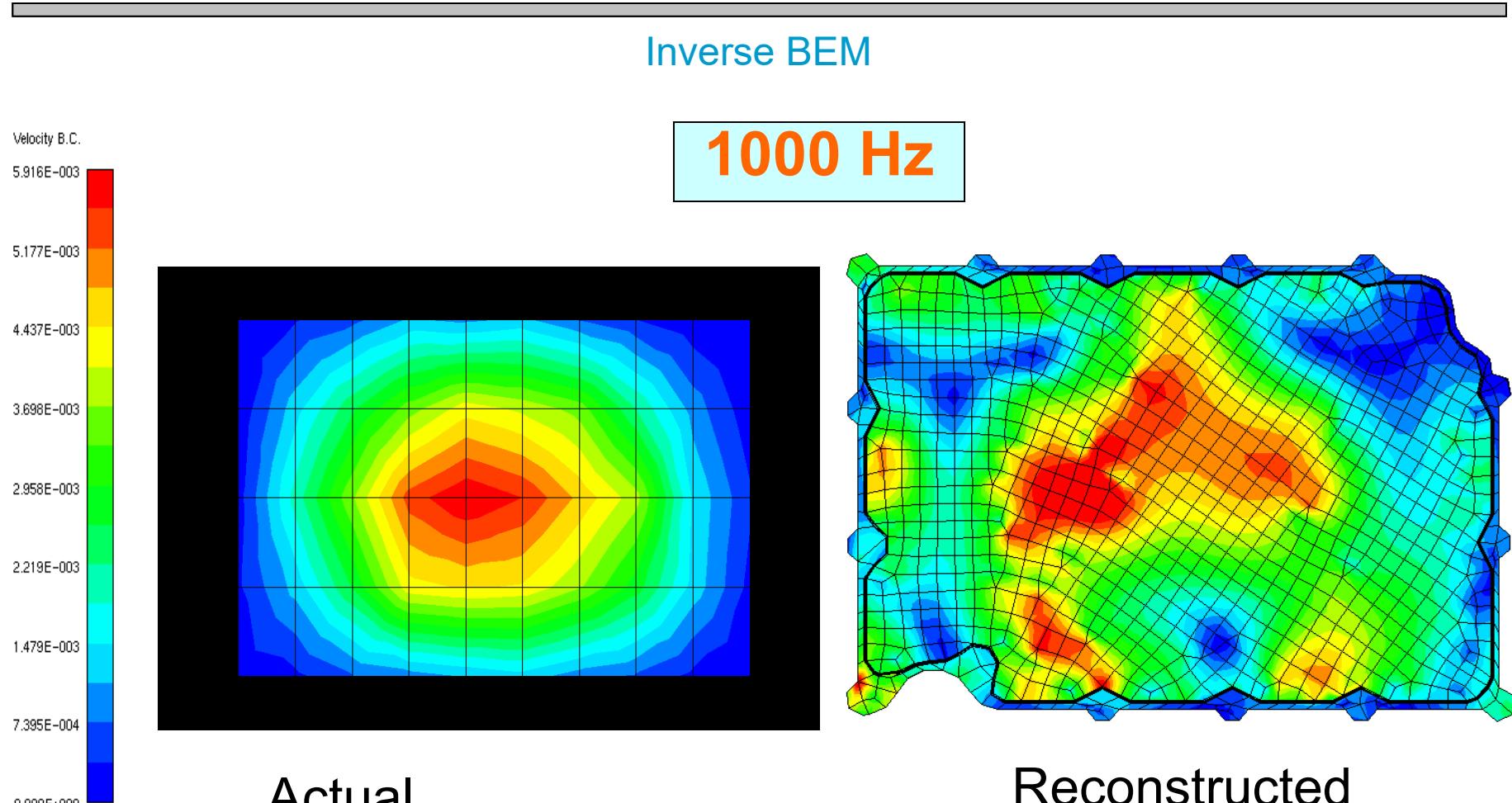
Inverse BEM



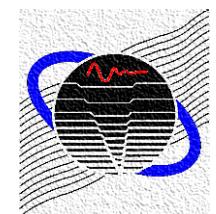
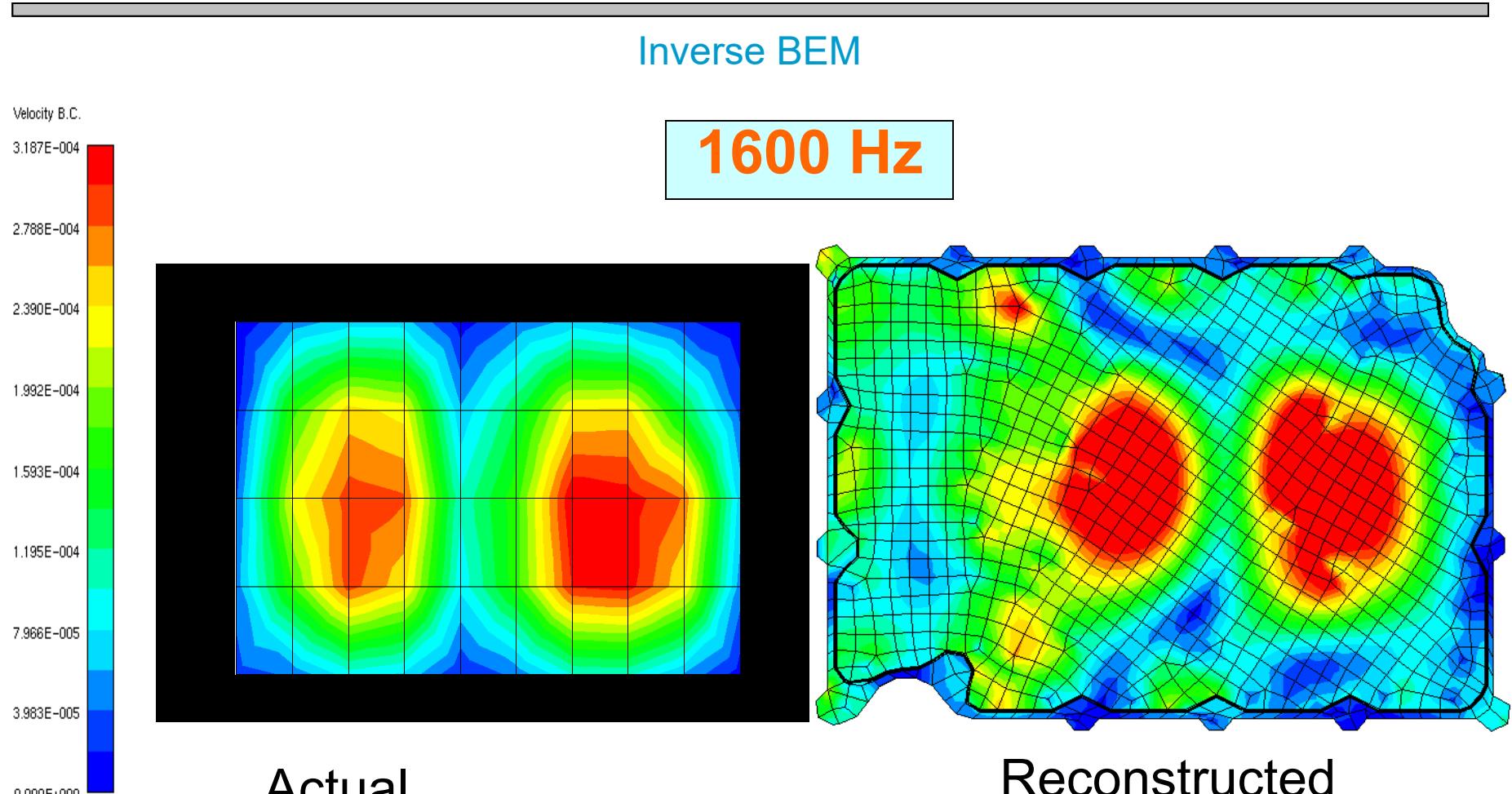
15 measurement points used for inverse BEM



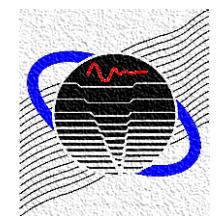
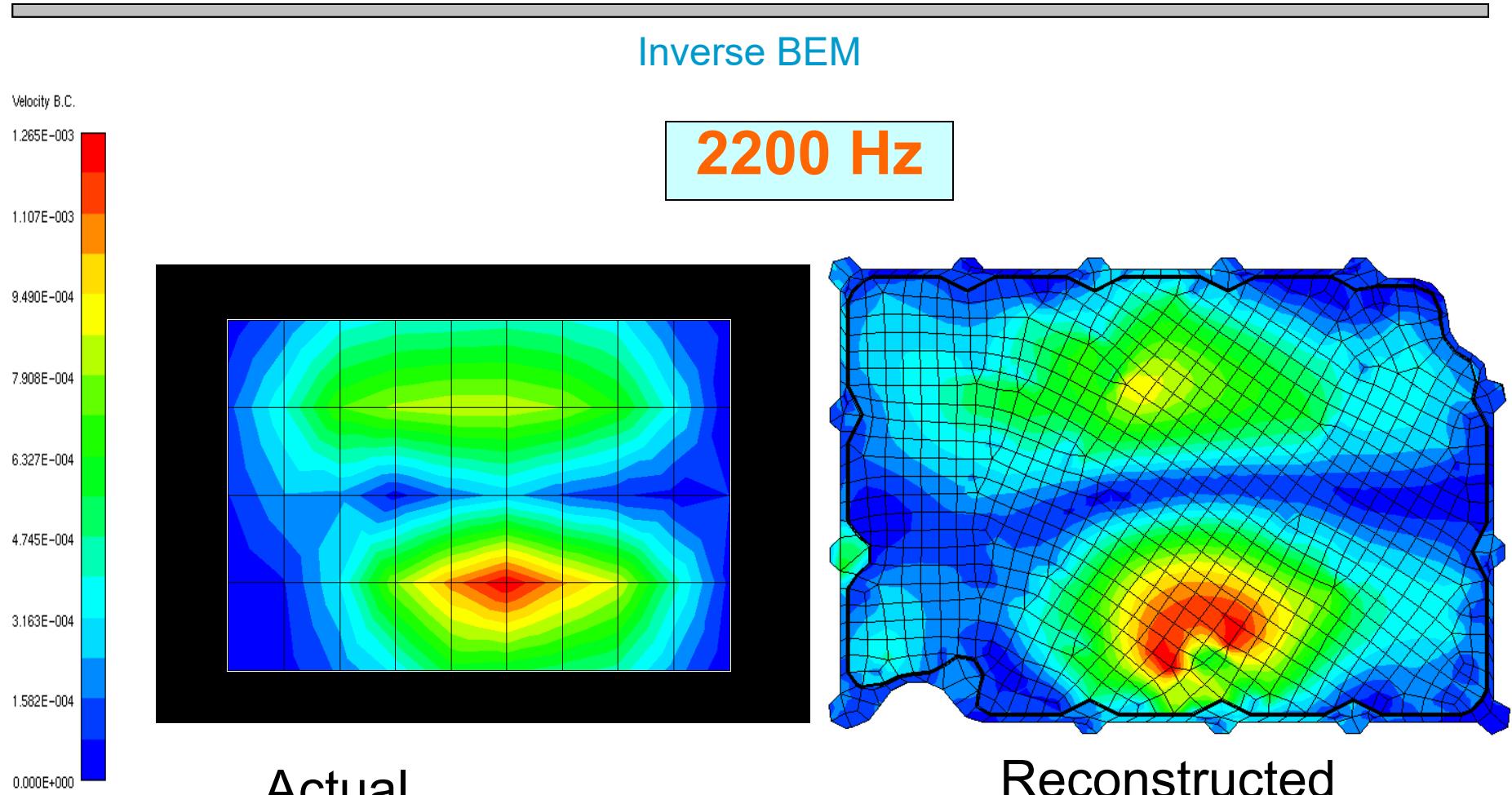
Reconstructed Surface Vibration



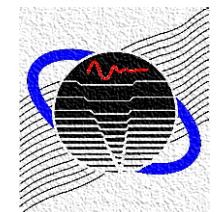
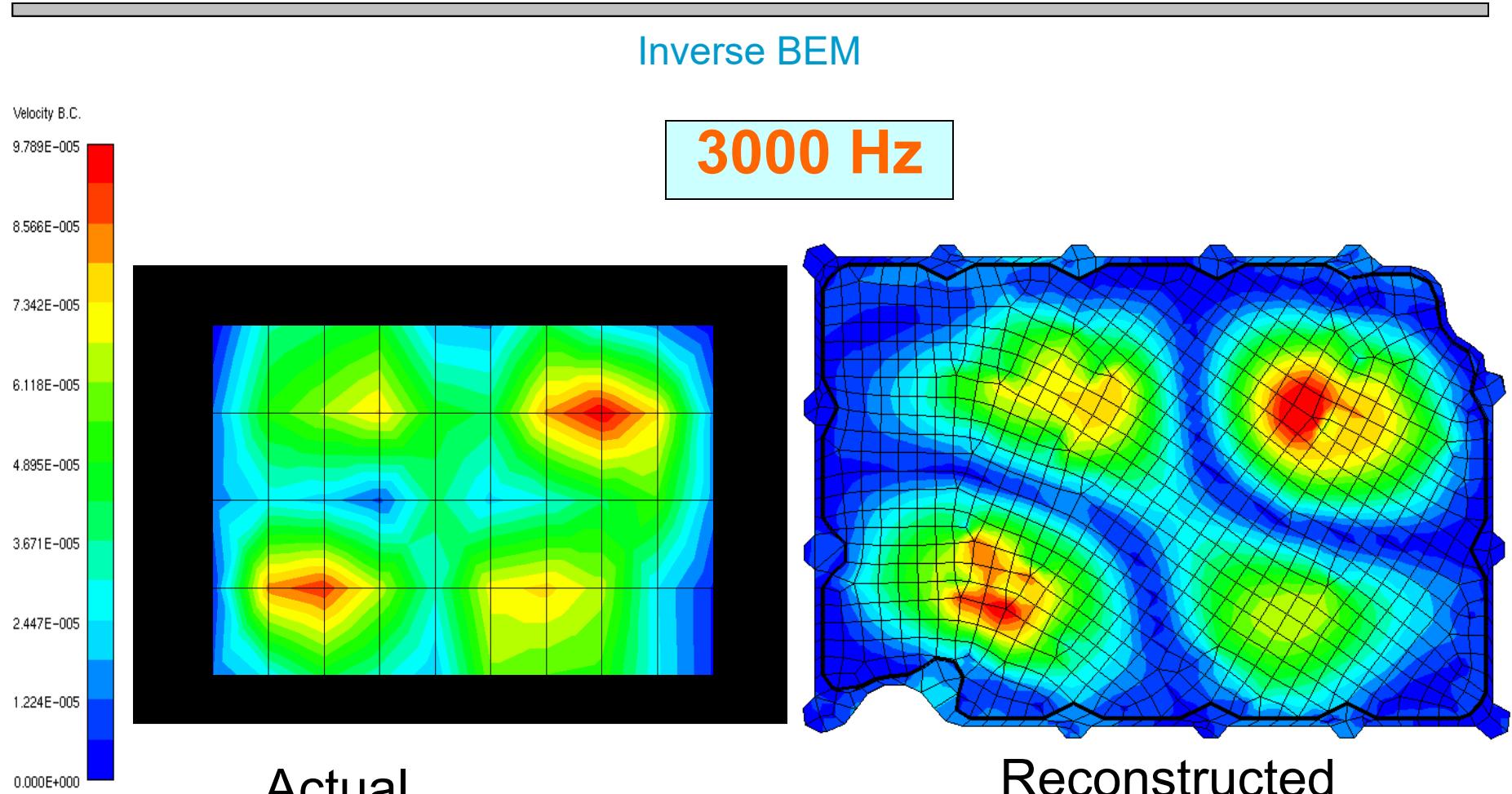
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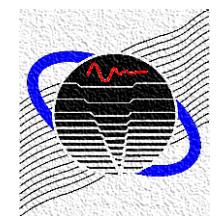
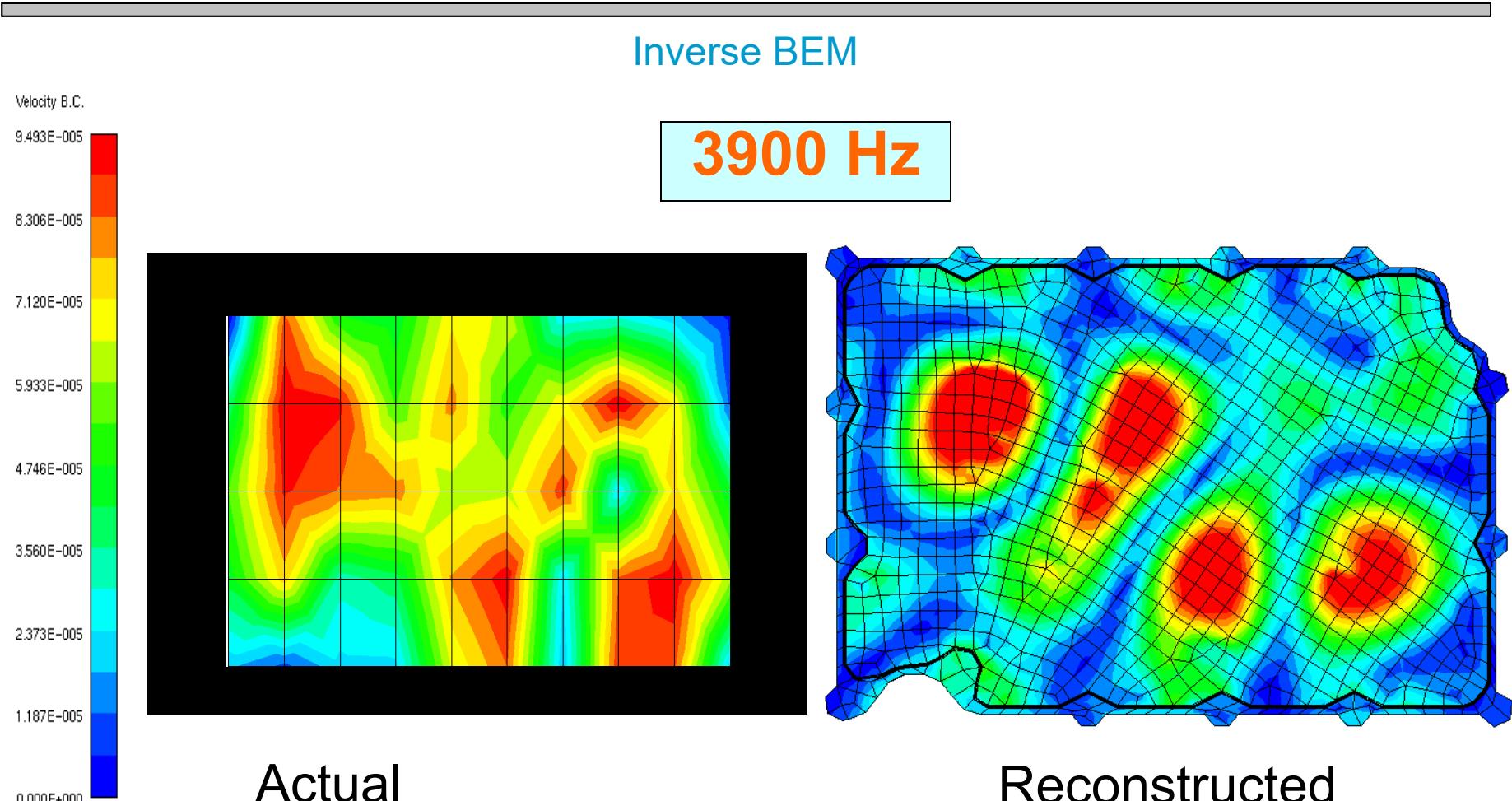
Reconstructed Surface Vibration



Reconstructed Surface Vibration

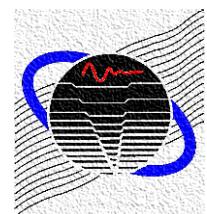
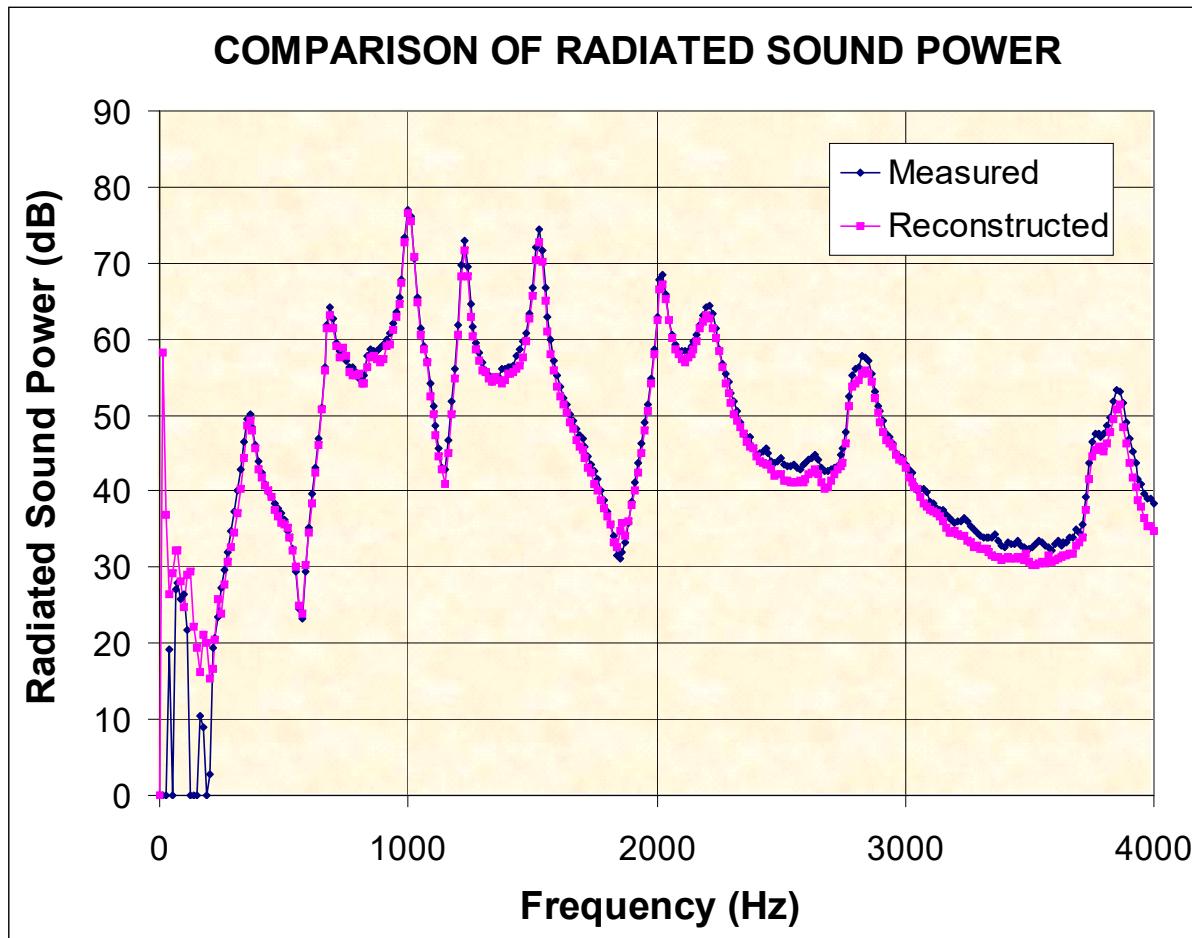


Reconstructed Surface Vibration



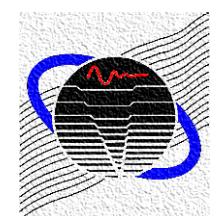
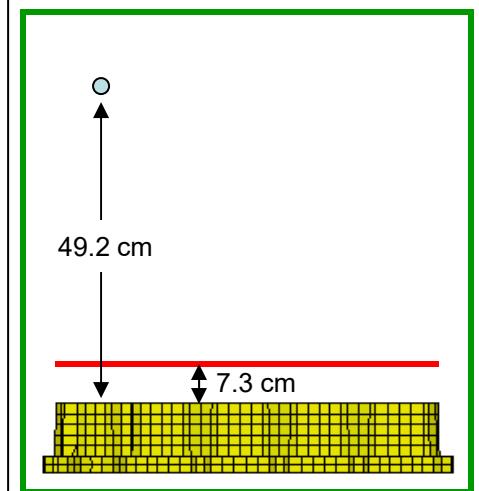
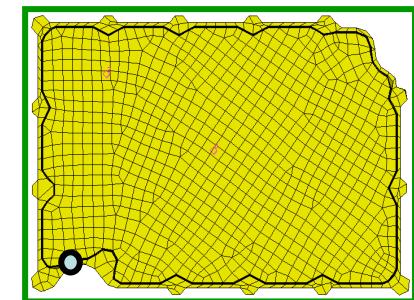
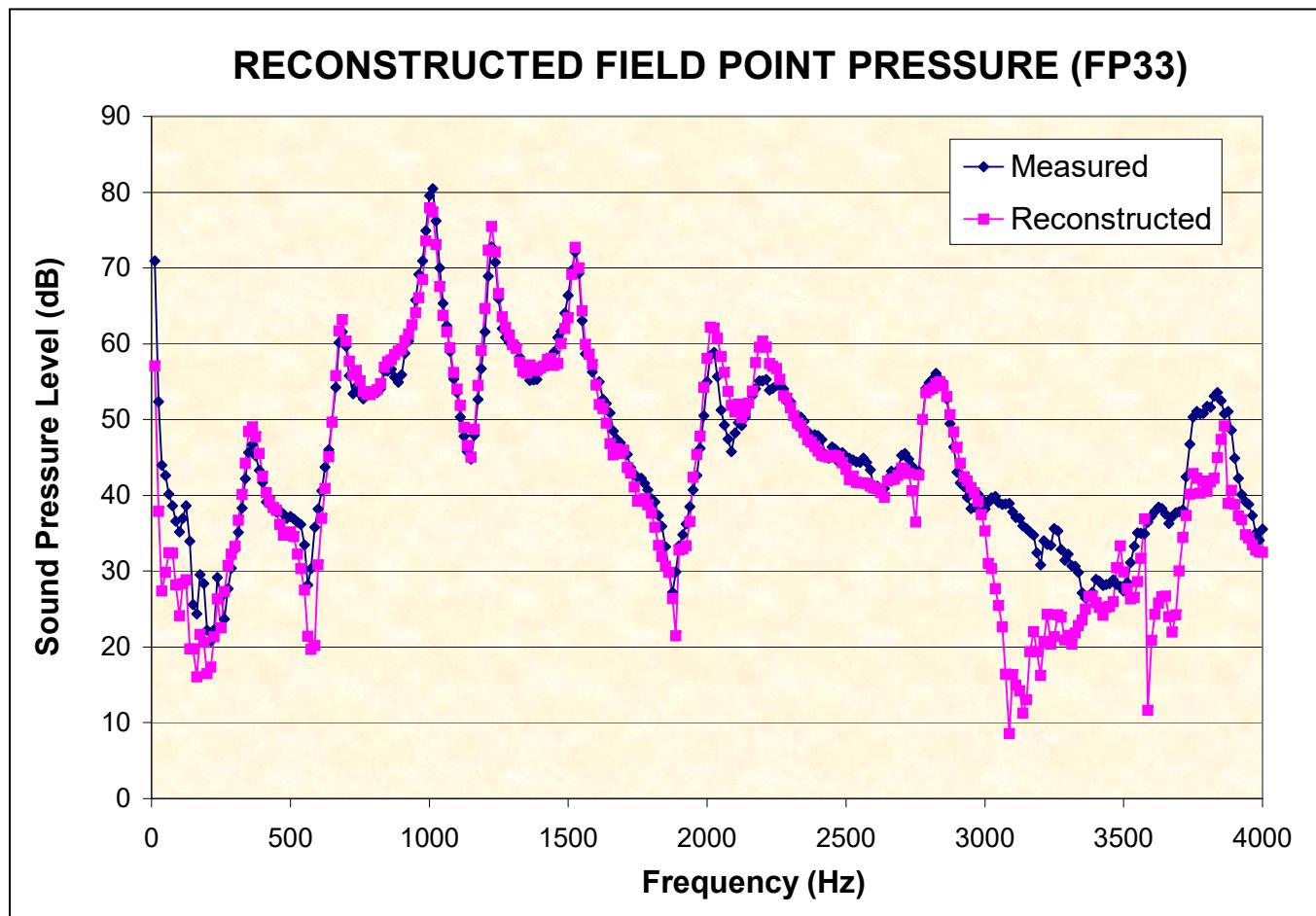
Radiated Sound Power

Inverse BEM



Field Point Pressure

Inverse BEM

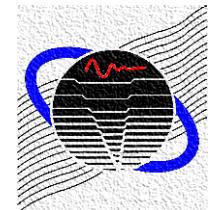


Some Rough Guidelines

Inverse BEM

Measurement points should be:

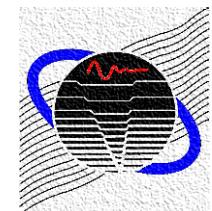
- ✓ Spaced 1/2 acoustic wavelength apart
- ✓ Spaced 1/3 acoustic wavelength from the surface



Overview

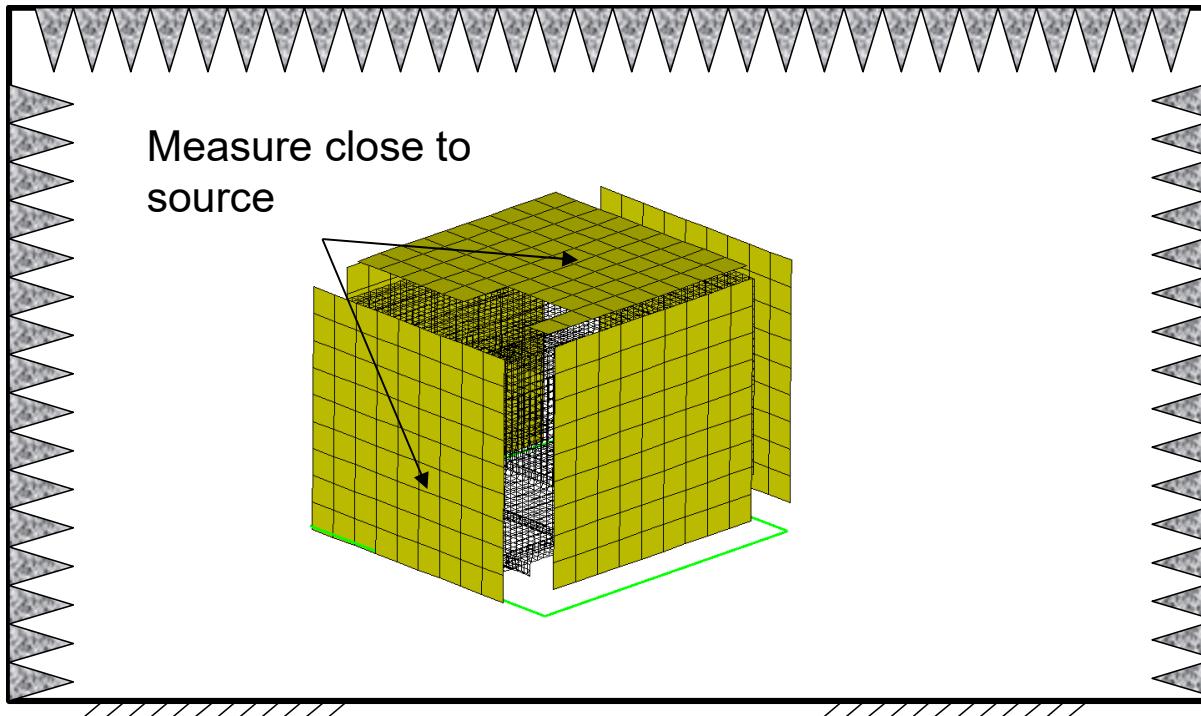
Inverse BEM

- Theory
- Case 1 – Engine Cover
- Case 2 – Generator Set
- Case 3 – Aeroacoustic Source

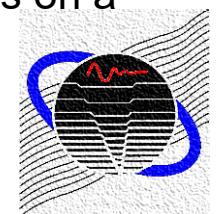


Objective

Inverse BEM



- Many standards call for measurements to be made 7 m away from equipment.
- Measurements must be made in a voluminous anechoic environment (outdoors on a test pad or in a chamber).



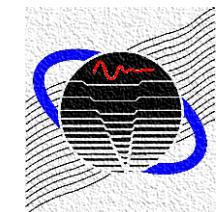
Generator Set

Inverse BEM

Inverse BEM Measurements



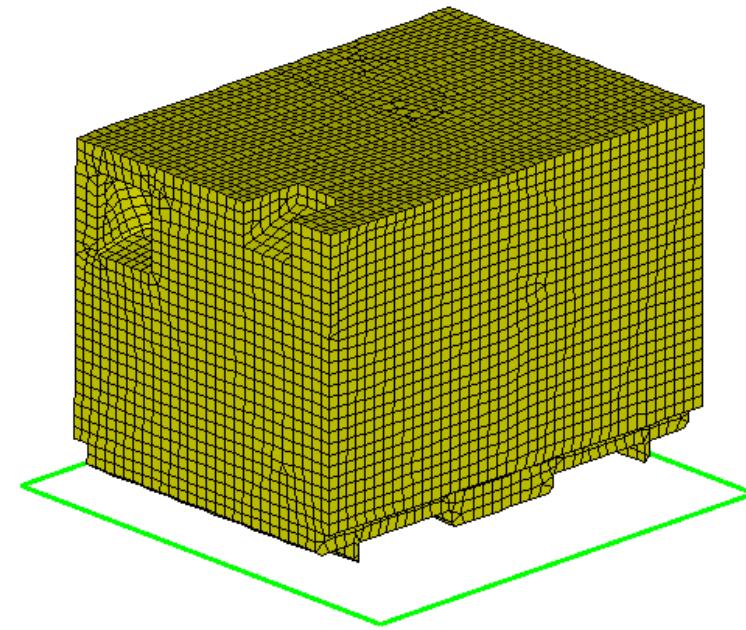
SPL Prediction (7 m)



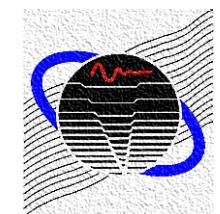
Boundary Element Model

Inverse BEM

Generator Set



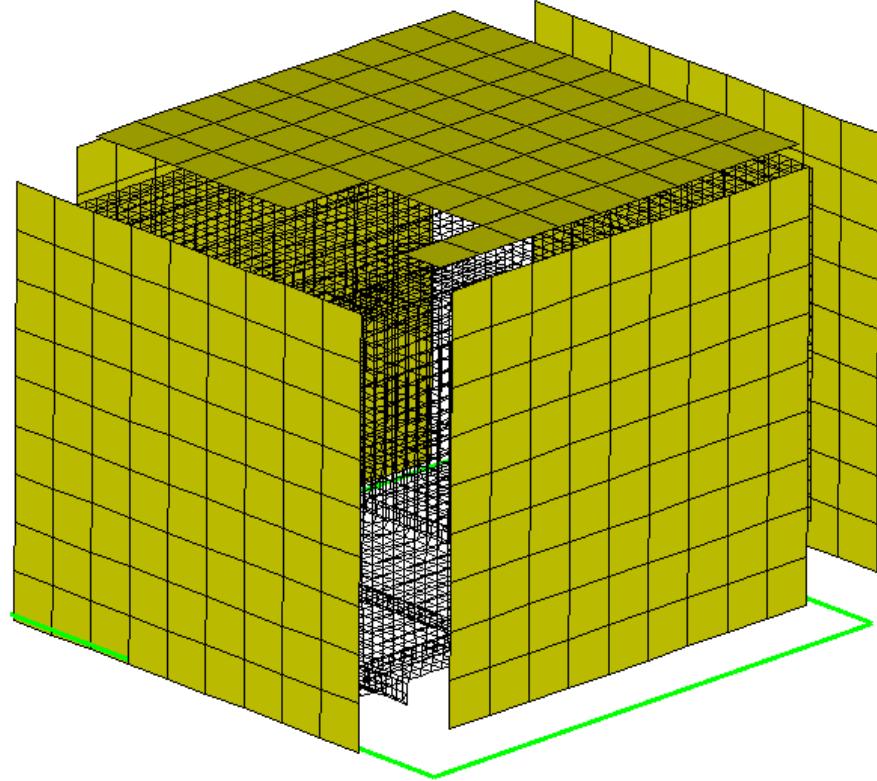
Boundary Element Model



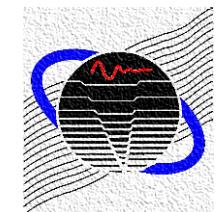
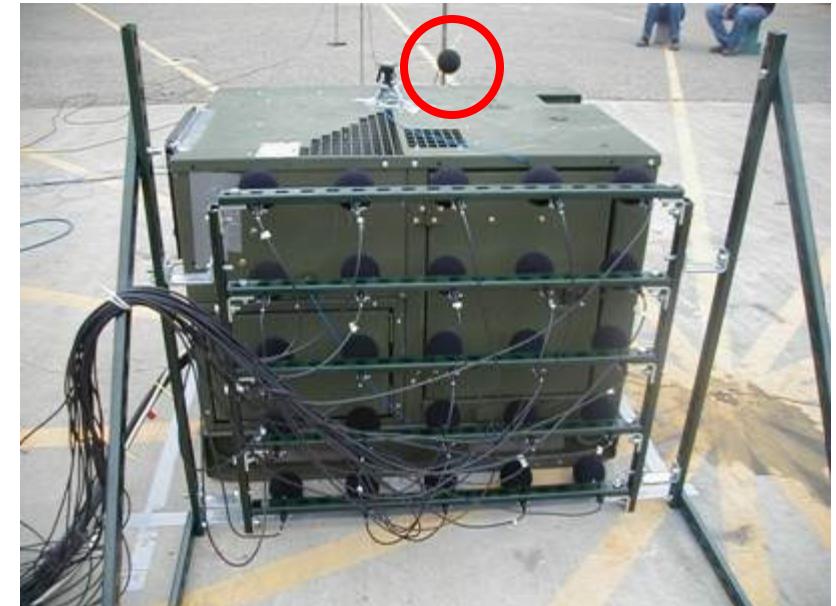
Near Field Measurements

Inverse BEM

100 Measurement Points on Each Side

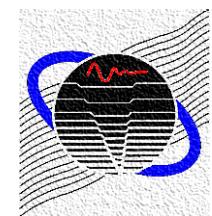
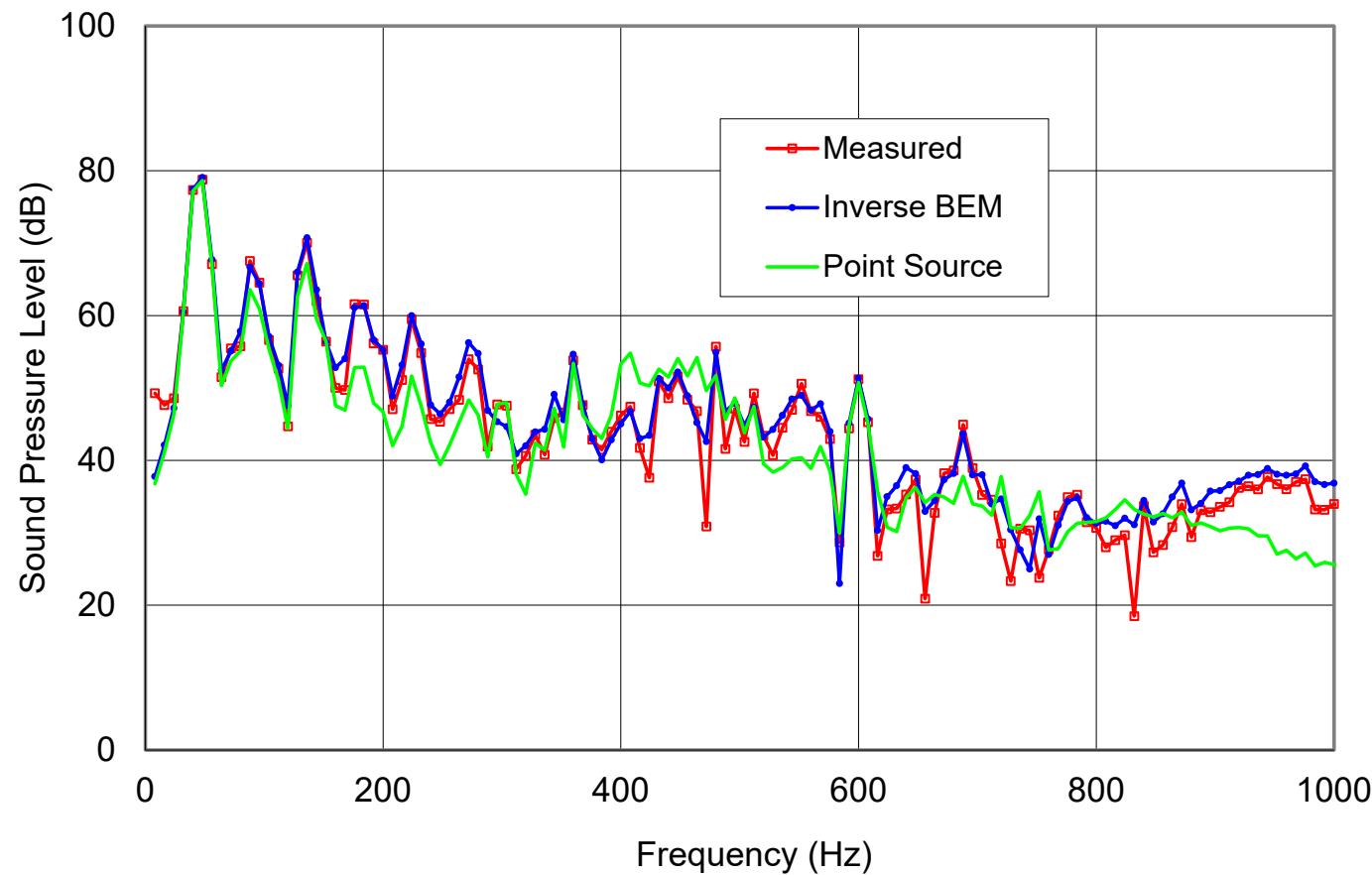


Reference Microphone



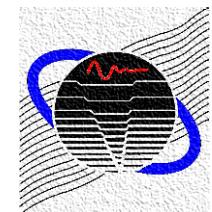
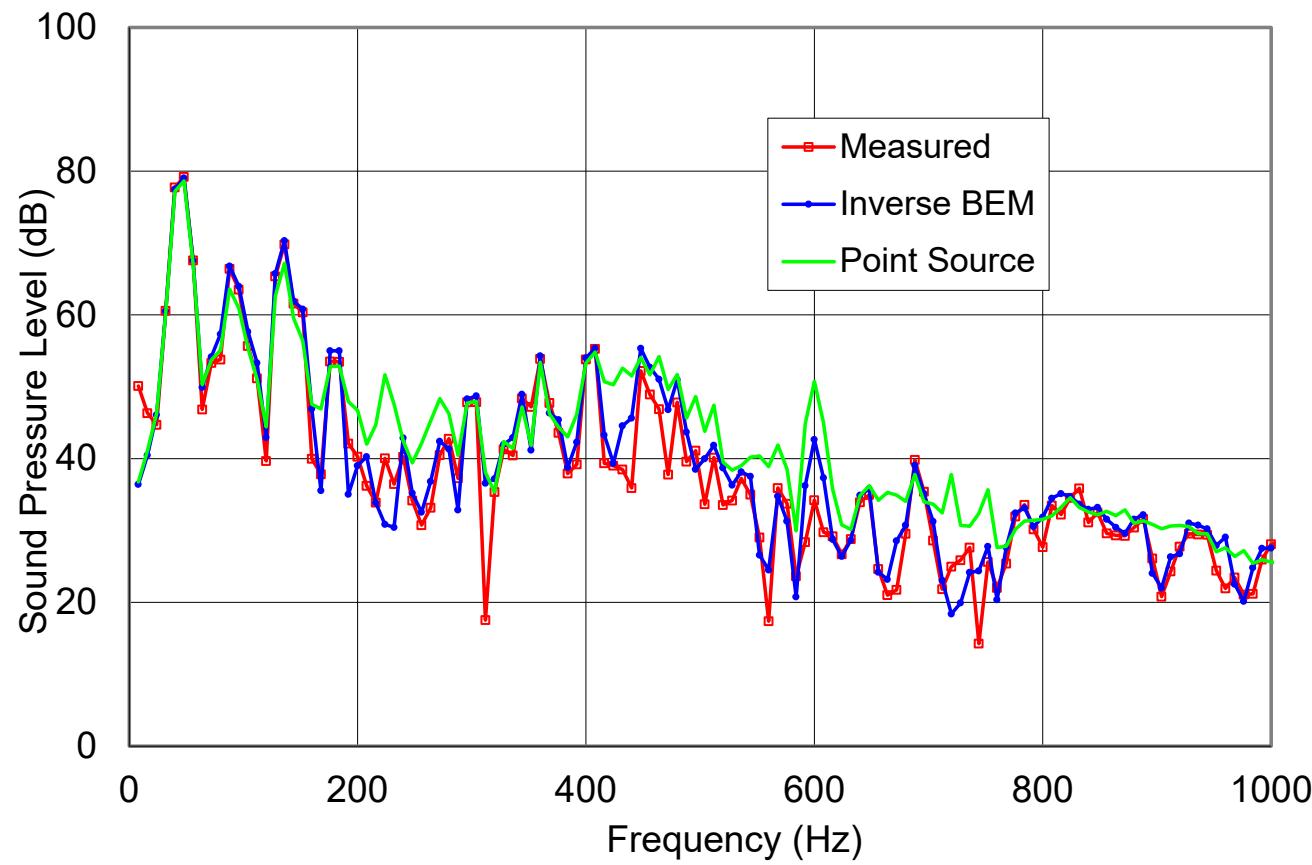
SPL (7.0 m from Left Side)

Inverse BEM



SPL (7.0 m from Front)

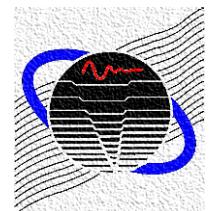
Inverse BEM



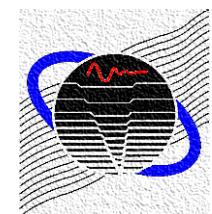
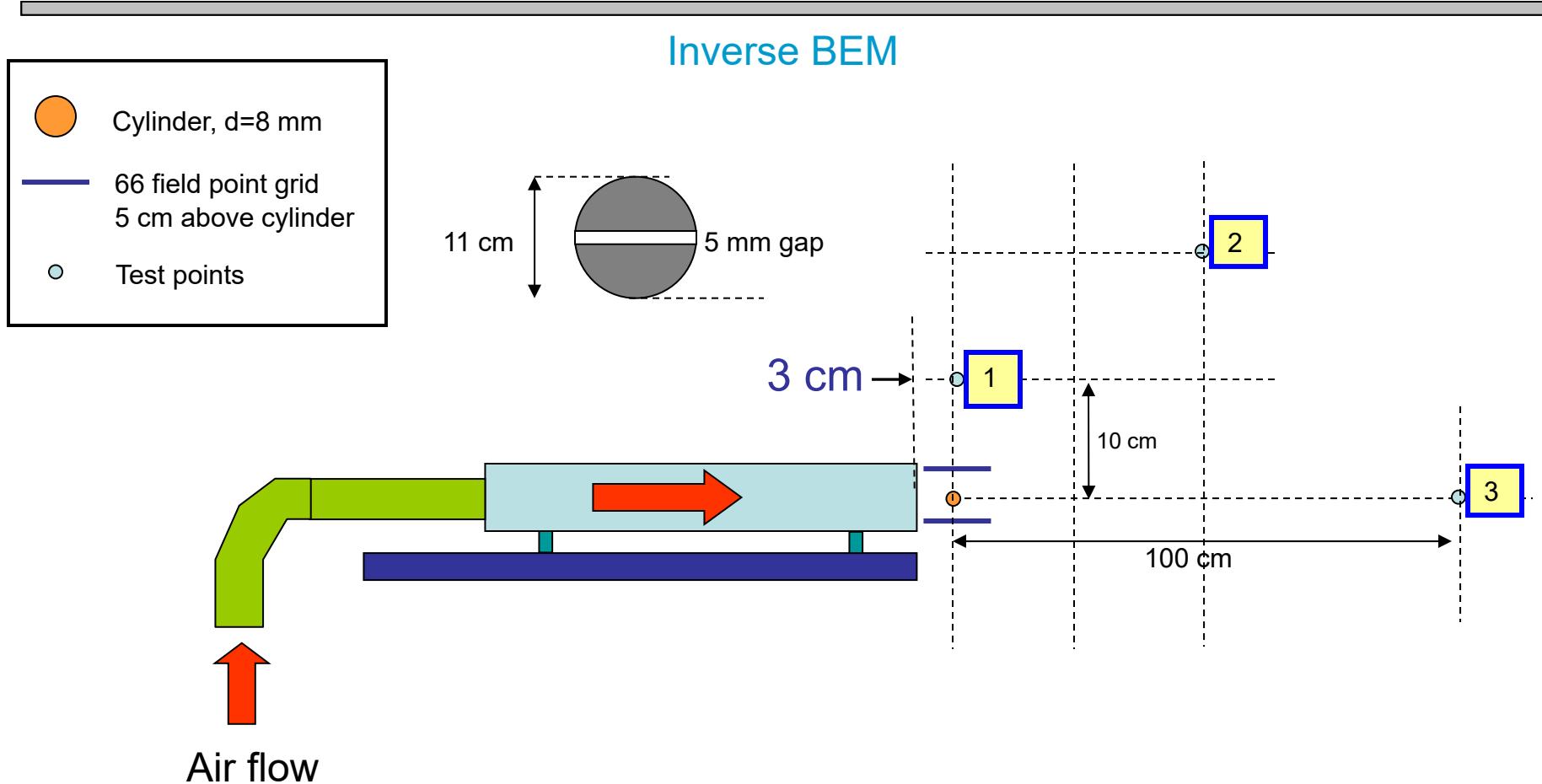
Overview

Inverse BEM

- Theory
- Case 1 – Engine Cover
- Case 2 – Generator Set
- Case 3 – Aeroacoustic Source

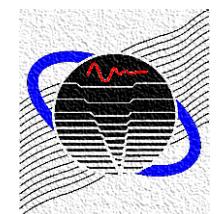
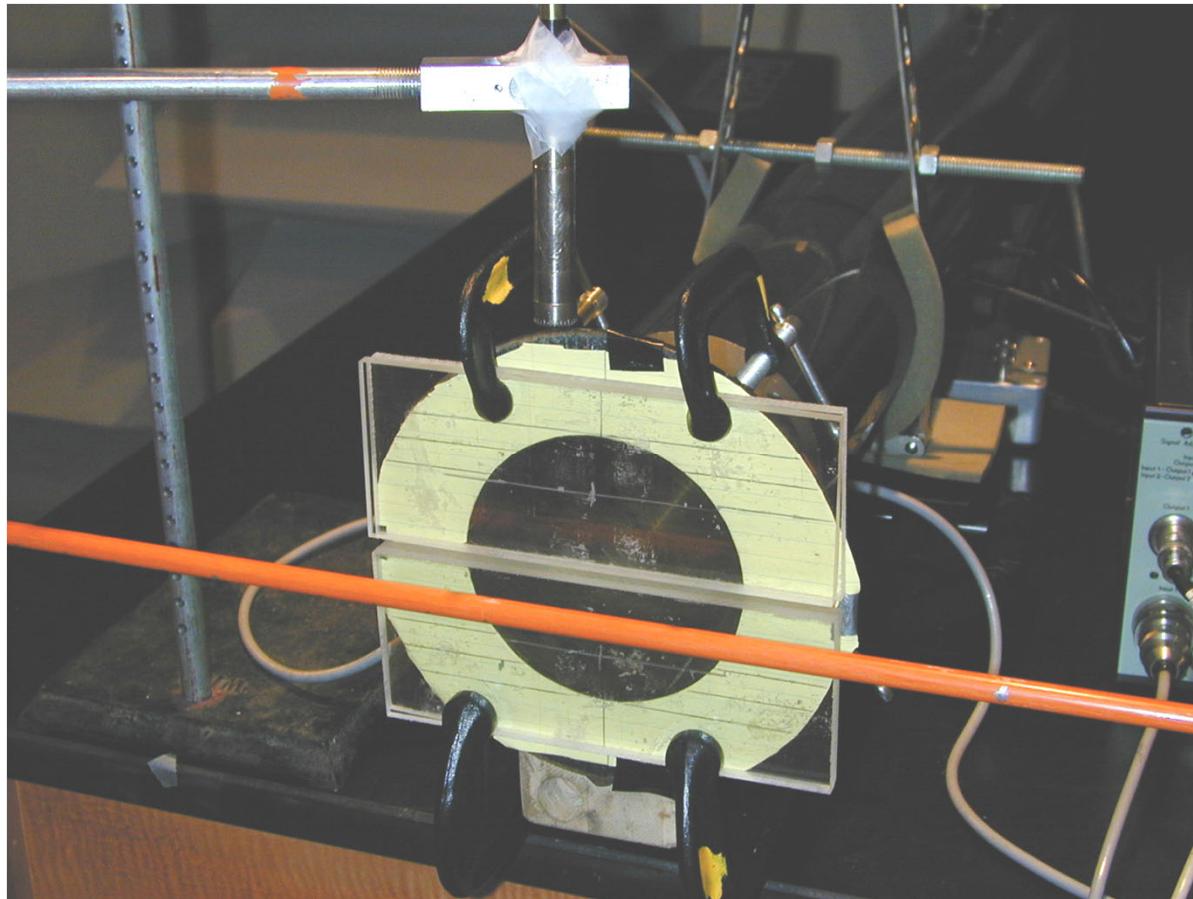


Experimental Setup



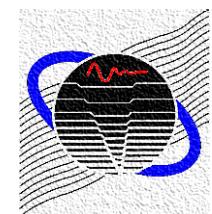
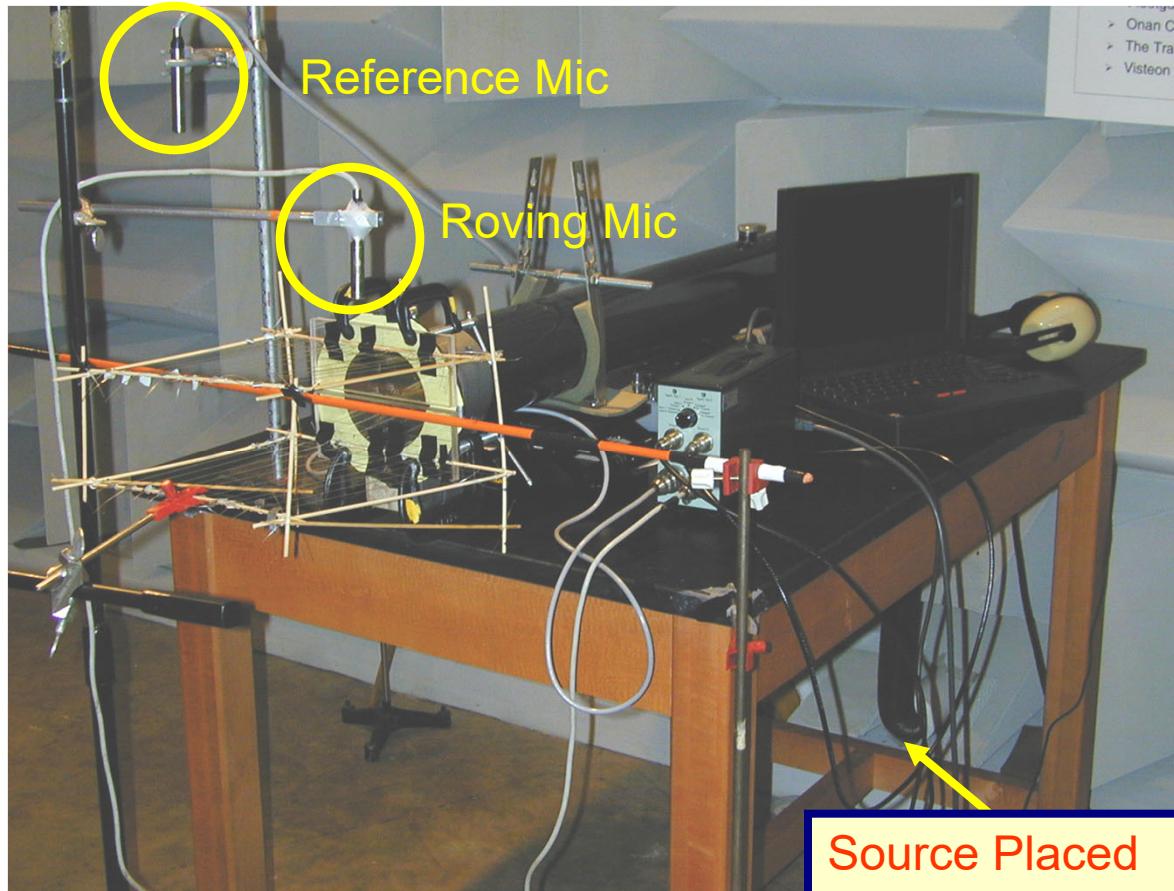
Experimental Setup

Inverse BEM



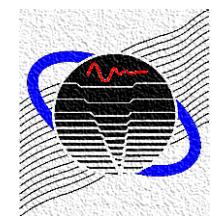
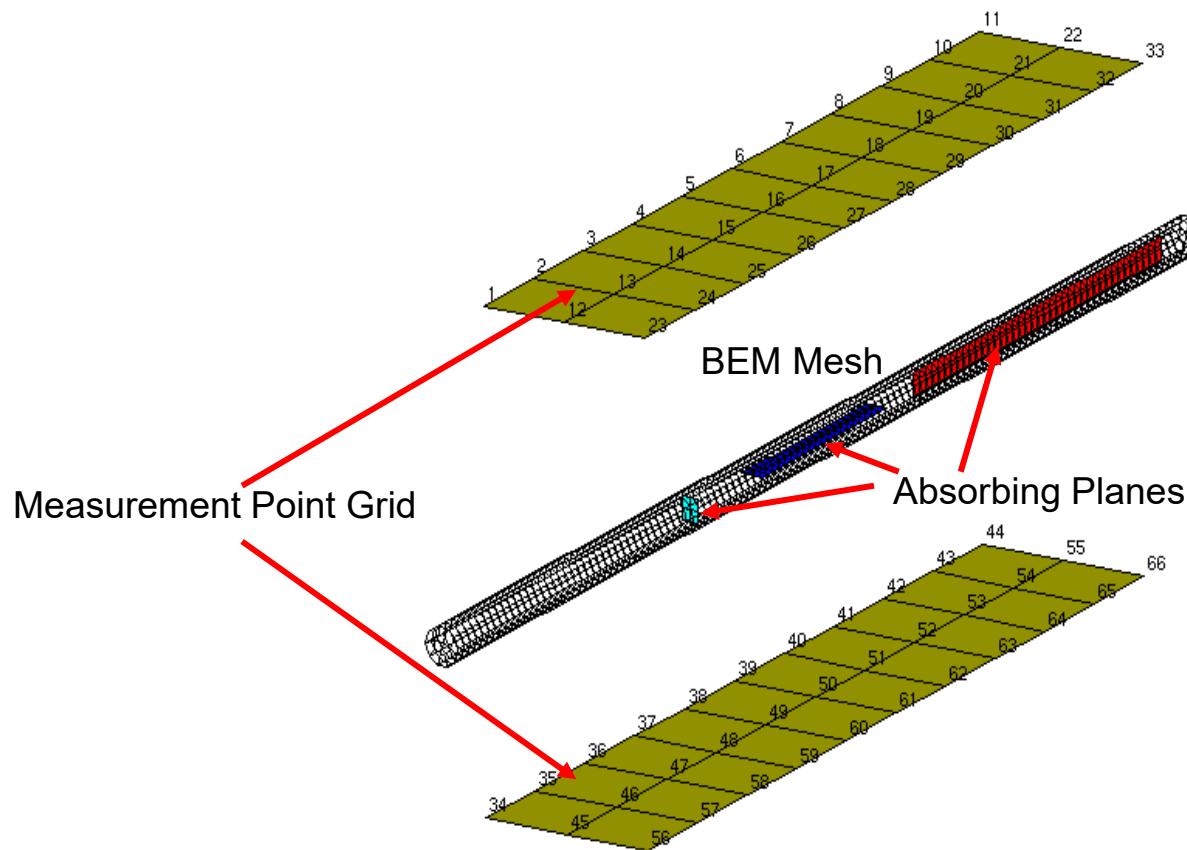
Experimental Setup

Inverse BEM

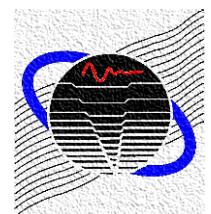
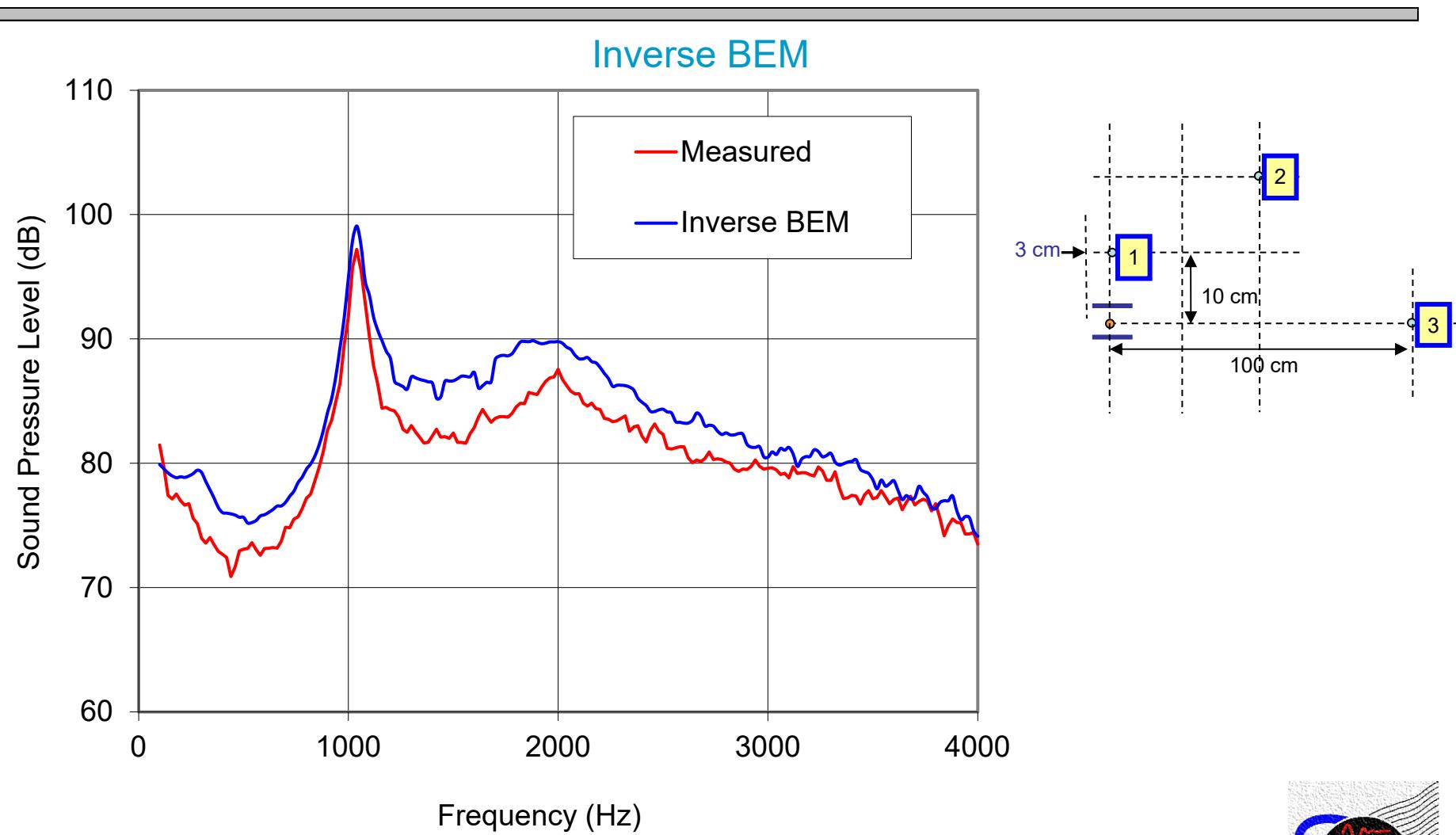


SYSNOISE Model

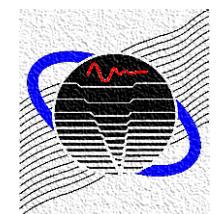
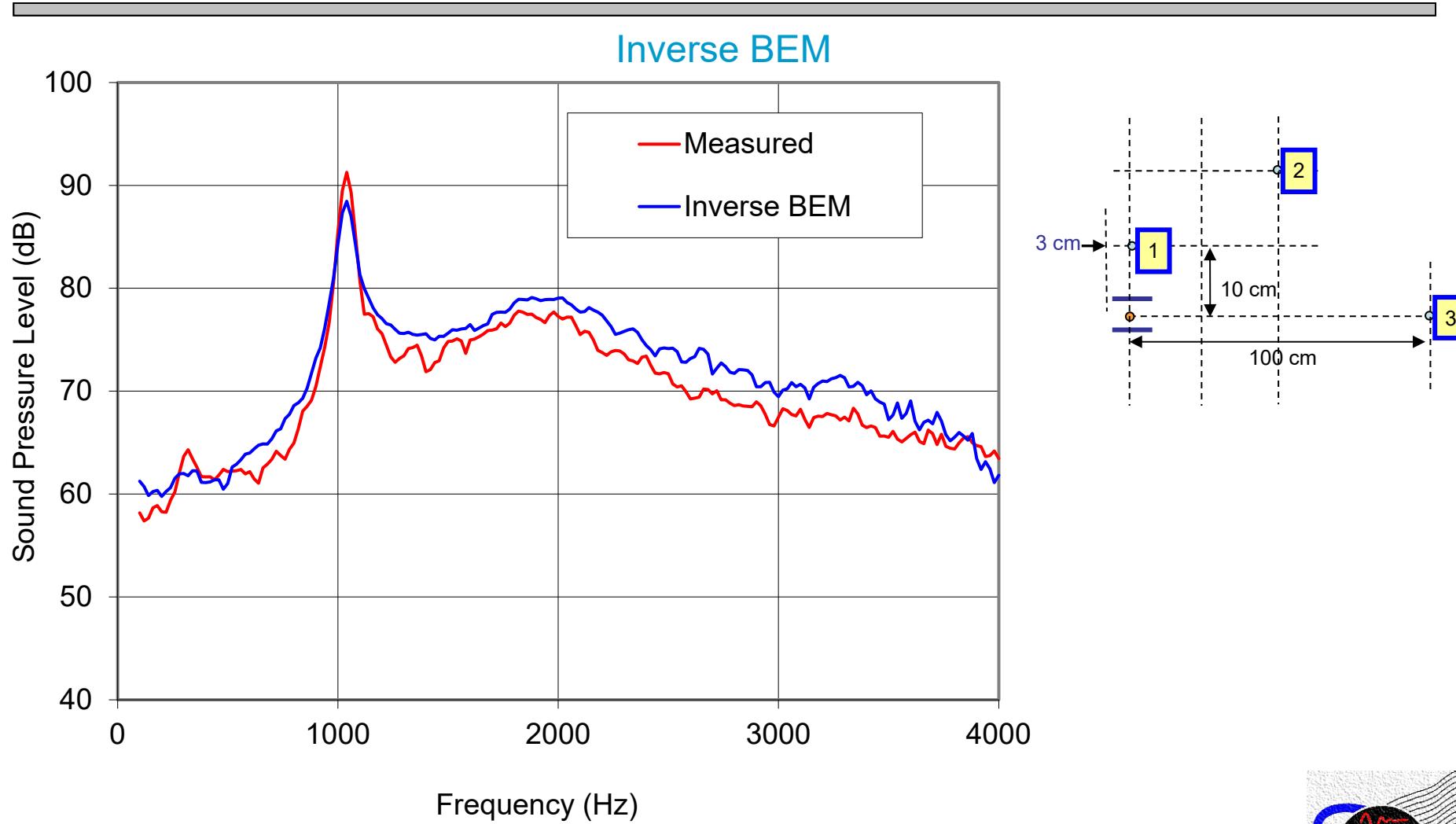
Inverse BEM



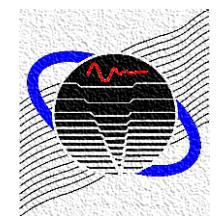
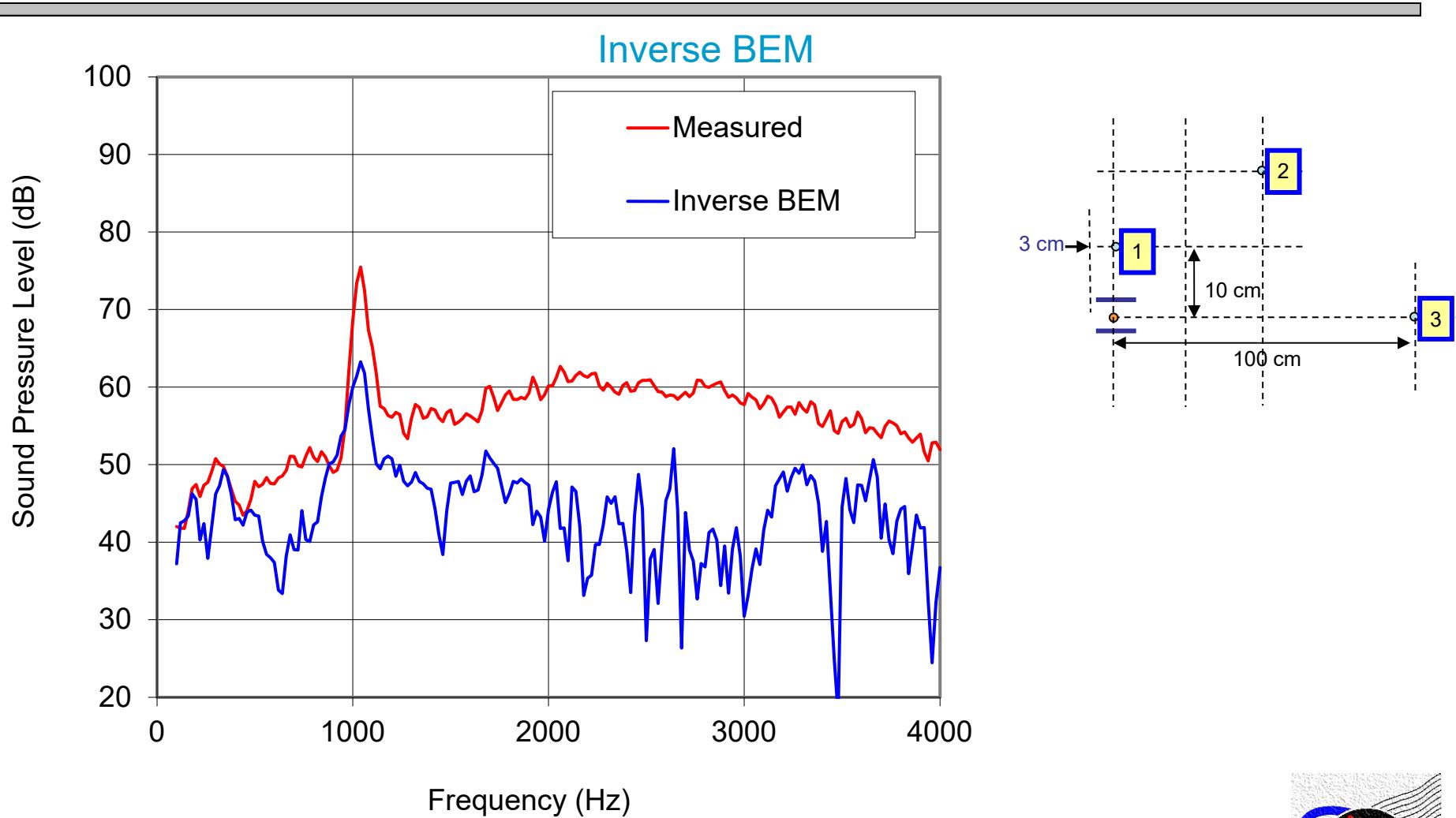
Position 1



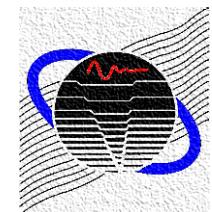
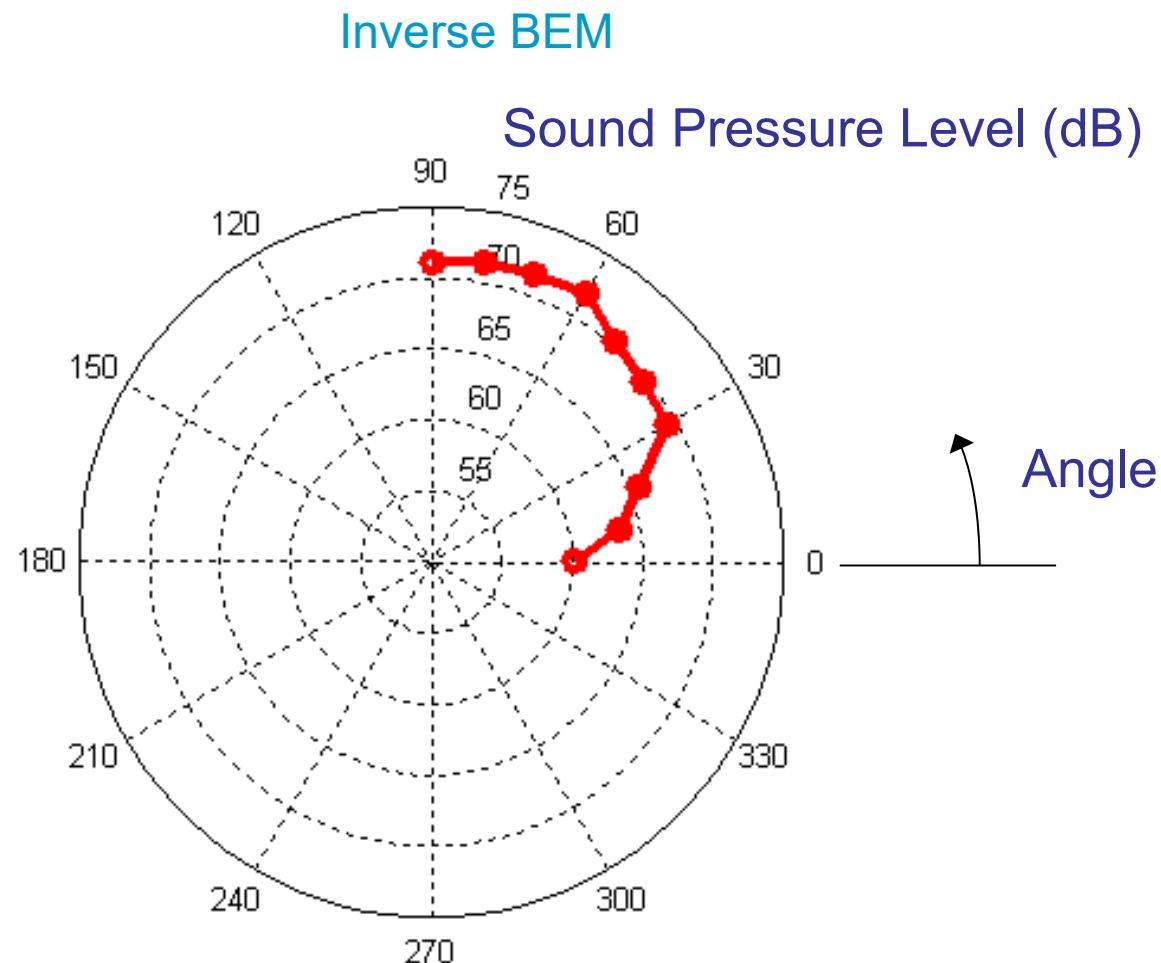
Position 2



Position 3

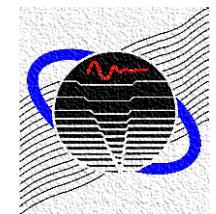
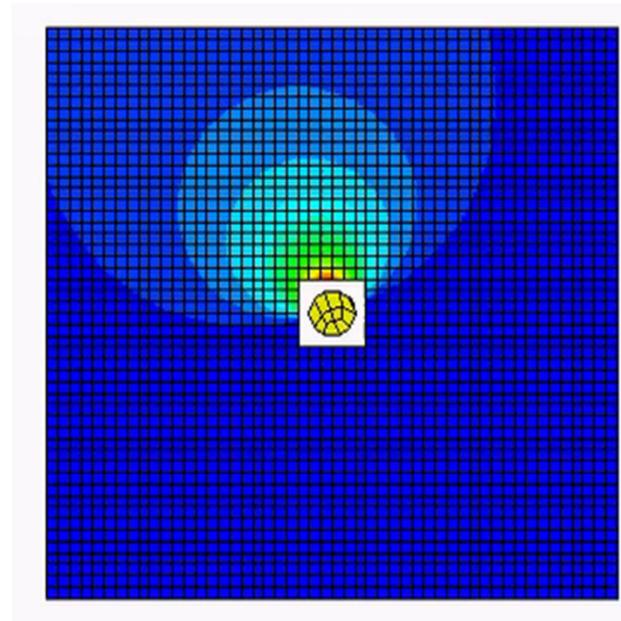
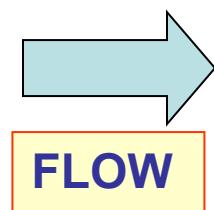


Sound Pressure Directivity at 1 m



Sound Pressure (1040 Hz)

Inverse BEM



References

Inverse BEM

- F. Martinus, D. W. Herrin, and A. F. Seybert, “Selecting Measurement Locations to Minimize Reconstruction Error Using the Inverse Boundary Element Method,” Journal of Computational Acoustics, Vol. 15, No. 4, (2007).
- D. W. Herrin, J. Liu, F. Martinus, D. J. Kato, and S. Cheah, “Prediction of Sound Pressure in the Far Field using the Inverse Boundary Element Method,” Noise Control Engineering Journal, Vol. 58, No.1, pp. 74-82 (2010).
- F. Martinus, D. W. Herrin, and J. Han, “Identification of an Aeroacoustic Source using the Inverse Boundary Element Method,” Noise Control Engineering Journal, Vol. 58, No.1, pp. 83-92 (2010).

