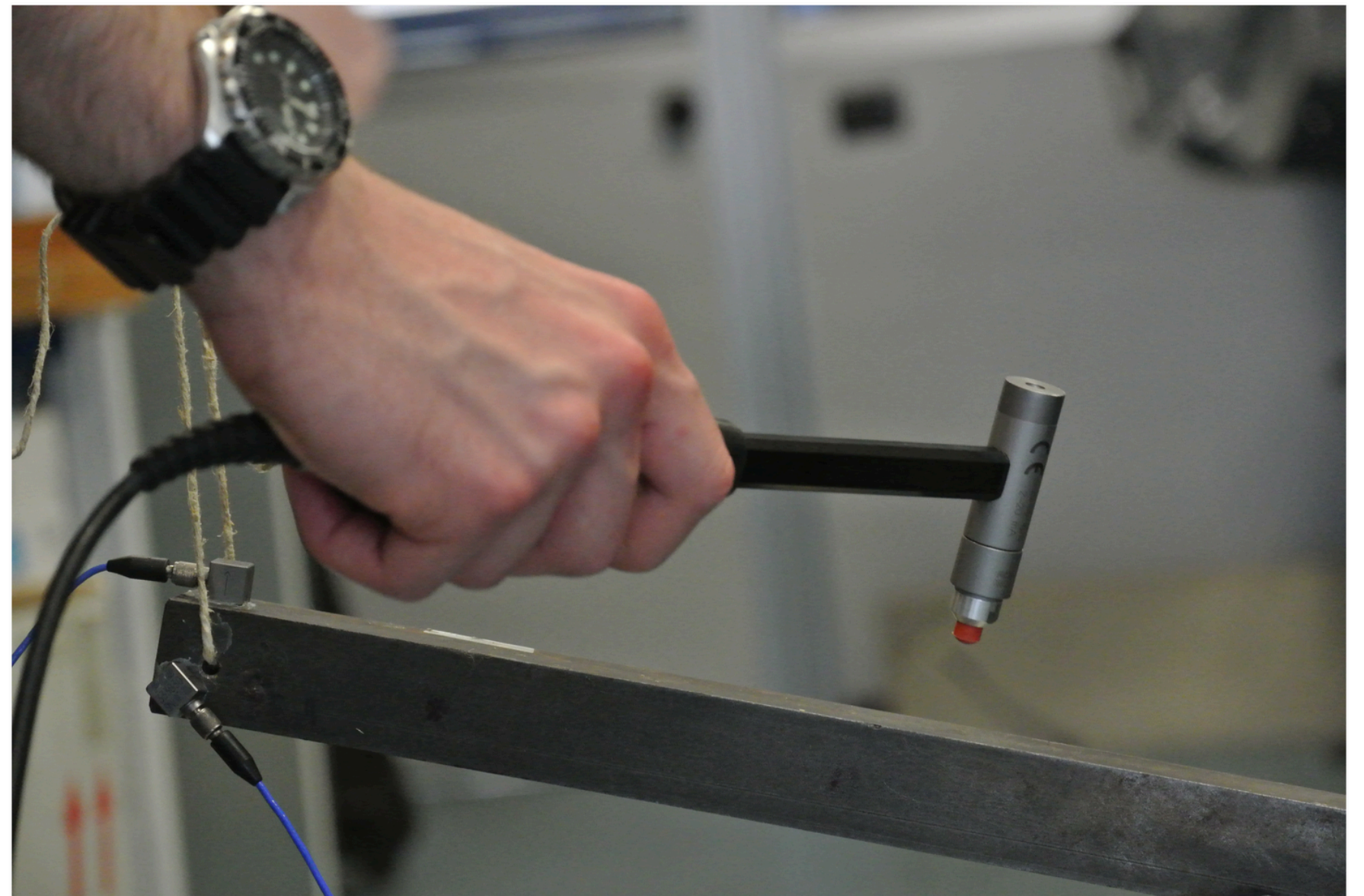




A.A.2025/2026

EXPERIMENTAL DYNAMICS AND DATA PROCESSING

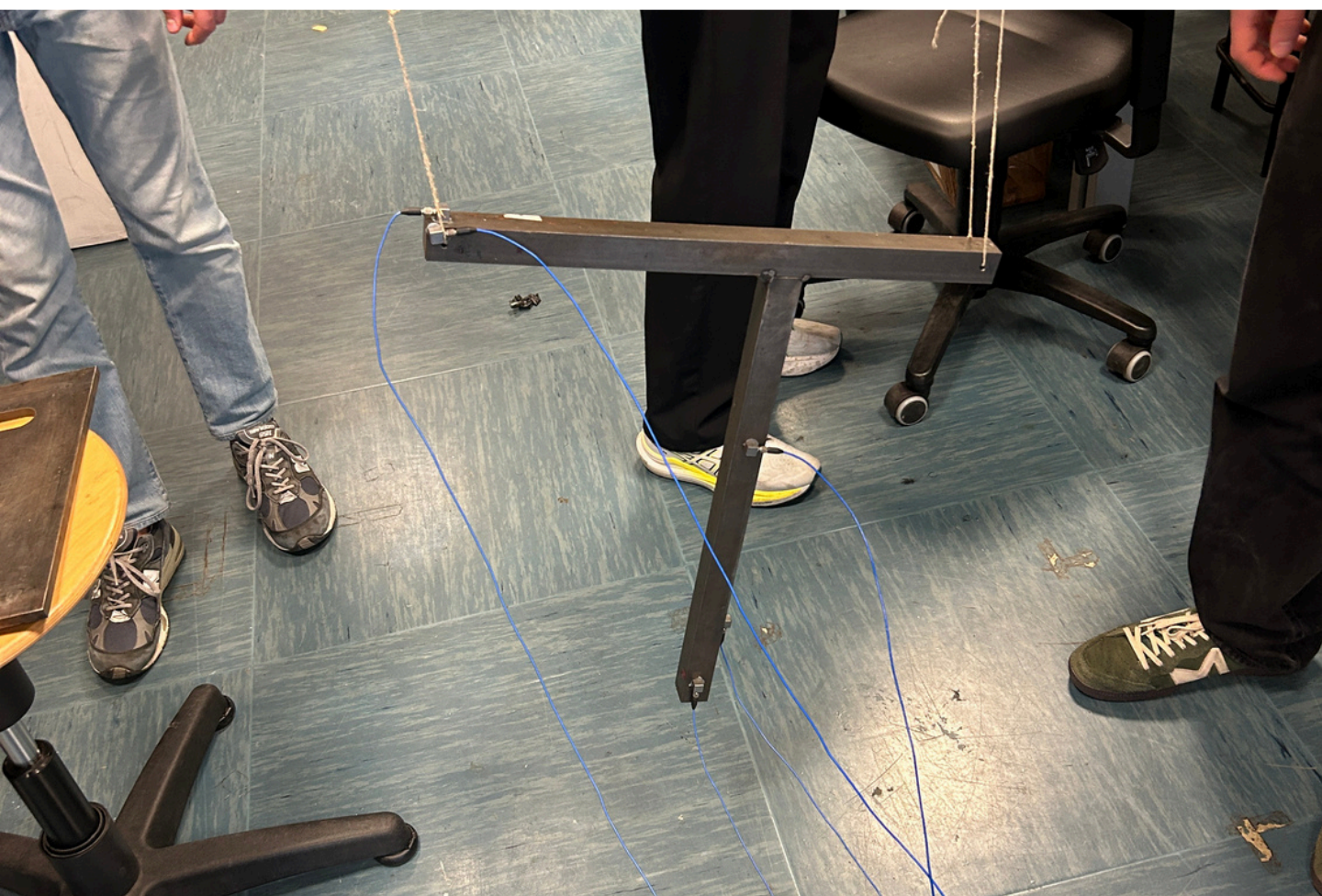
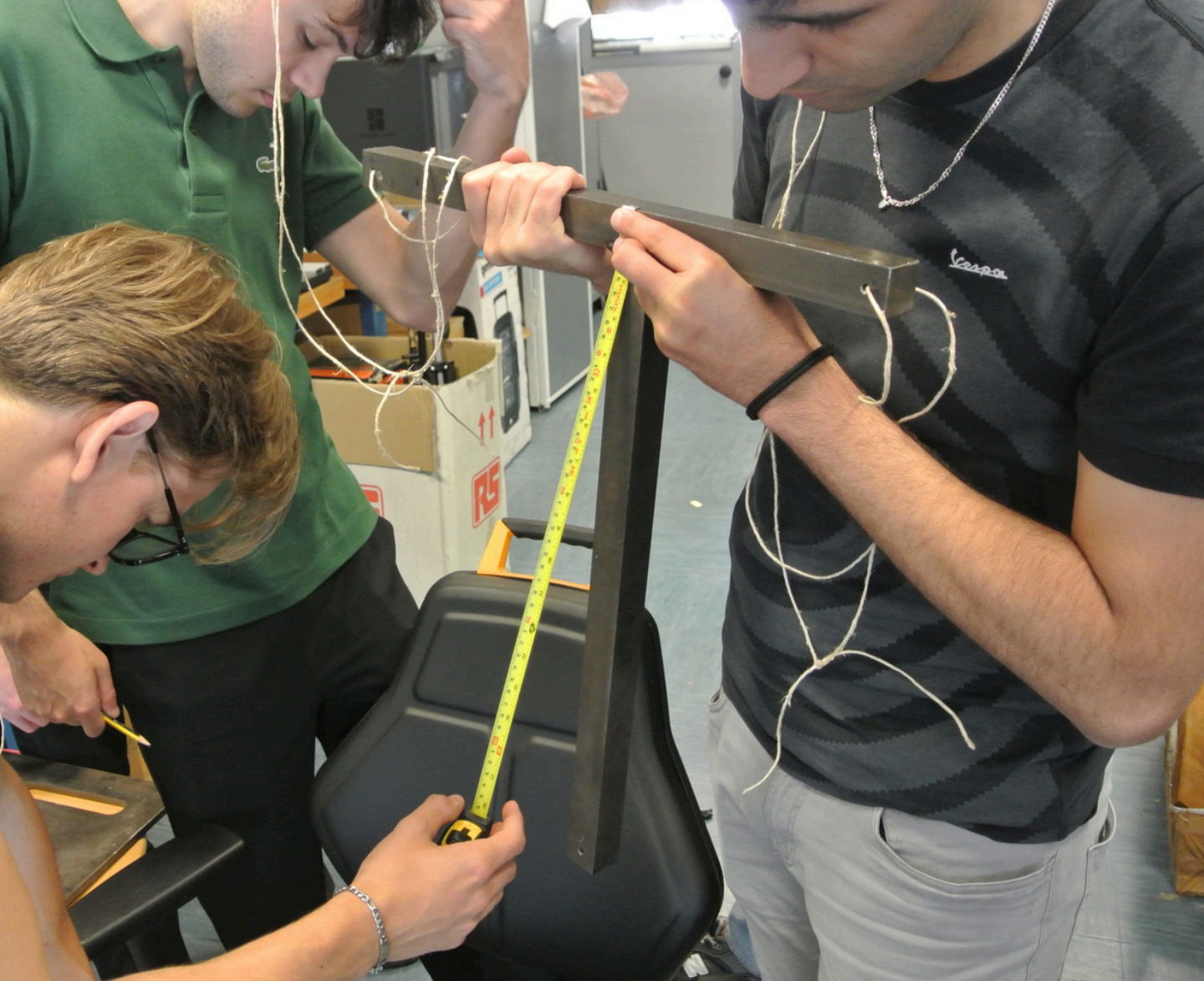
Alici Giovanni
Cecchini Alessia
De Vuono Marco
El Kajjyouy Tareq
Mariani Domenico
Rizzi Luca
Turina Davide



OBJECTIVE

**Modal analysis of a
steel specimen**





STEPS

1. INTRODUCTION

2. FINITE ELEMENT MODEL ANALYSIS

3. AUTOMAC

4. TESTS

5. MODAL EXTRACTION

6. COMPARISON BETWEEN PARAMETERS

7. COMPARISON BETWEEN FRFs



01. INTRODUCTION

Definition of the problem

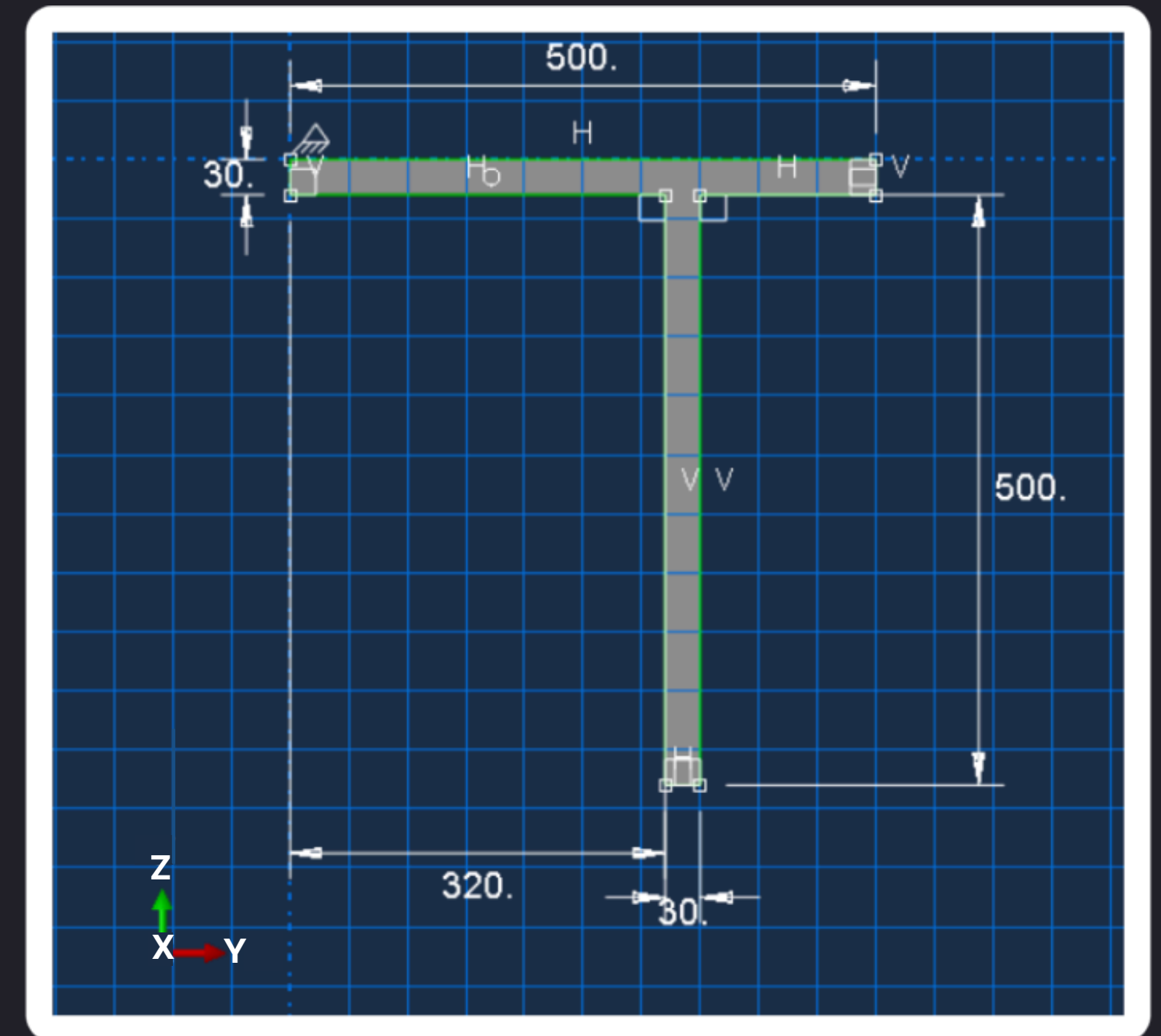
THE STRUCTURE

T-shaped steel structure:

- **Mass:** 7007 g
- **Cross-Section:** 30x30 mm²
- **Constraints:** Free-Free condition

Experimental tools:

- Impact hammer
- 5 mono-directional accelerometers
- Acquisition system



IMPACT HAMMER

IMPULSE FORCE HAMMER (PCB Piezotronics):
plastic tip, 2.361 mV/N sensitivity.

Advantages:

- No load effect
- Cheap and easy to move
- Quick to set up
- Large excitation in frequency

Drawbacks:

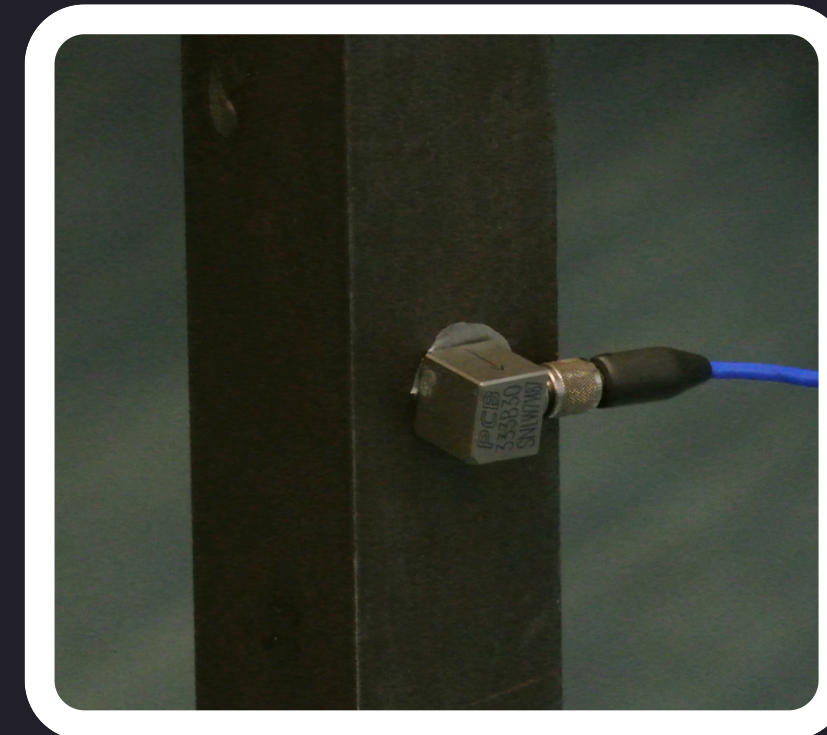
- Low input control
- Limited energetic content
- Data requires processing



ACCELEROMETERS

ICP ACCELEROMETER (PCB Piezotronics)

- Sensitivity: 10.2 mV / (m/s²)
- Size: 10.2 mm x 16 mm x 10.2 mm (HeightxLengthxWidth)
- Weight: 4 g
- Frequency Range: 0.5 - 3000 Hz
- Mounting: Petro Wax, suitable for temperature <70° C, mass <40g and frequency < 3000 Hz



Source:

<https://www.modalshop.com/rental/products/accelerometers/accessories/mounting-adhesives>



02. FINITE ELEMENT MODEL ANALYSIS

Mode Shapes and Eigenfrequencies



WHY PERFORM FEA?

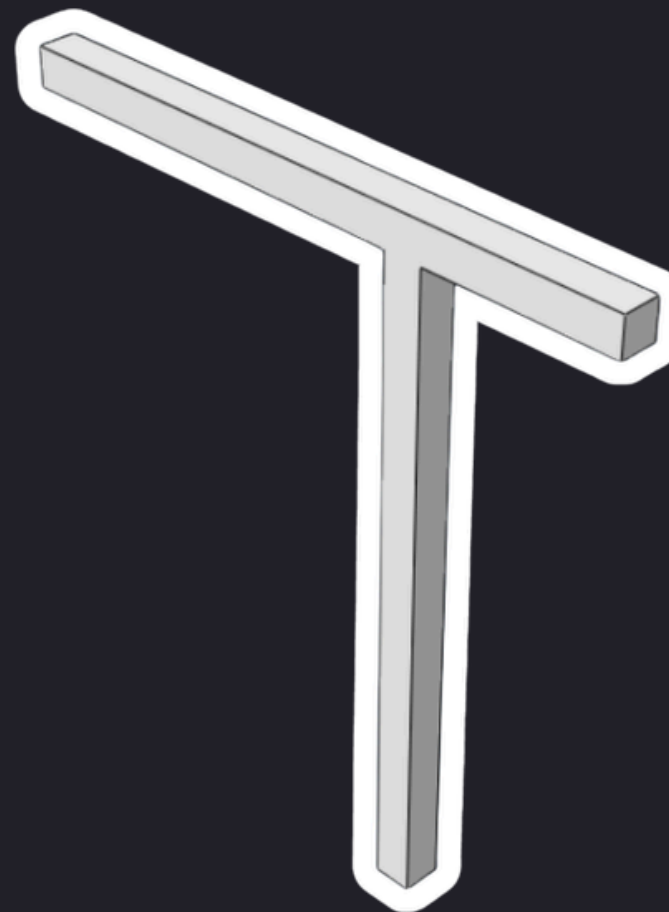
- To understand in advance the **frequency range** to be studied
- To have a first guess of the structure's **natural frequencies**
- To derive numerical **modeshapes** in order to perform the autoMAC
- To choose where to put the **input**

FINITE ELEMENTS MODEL

FEM Parameters

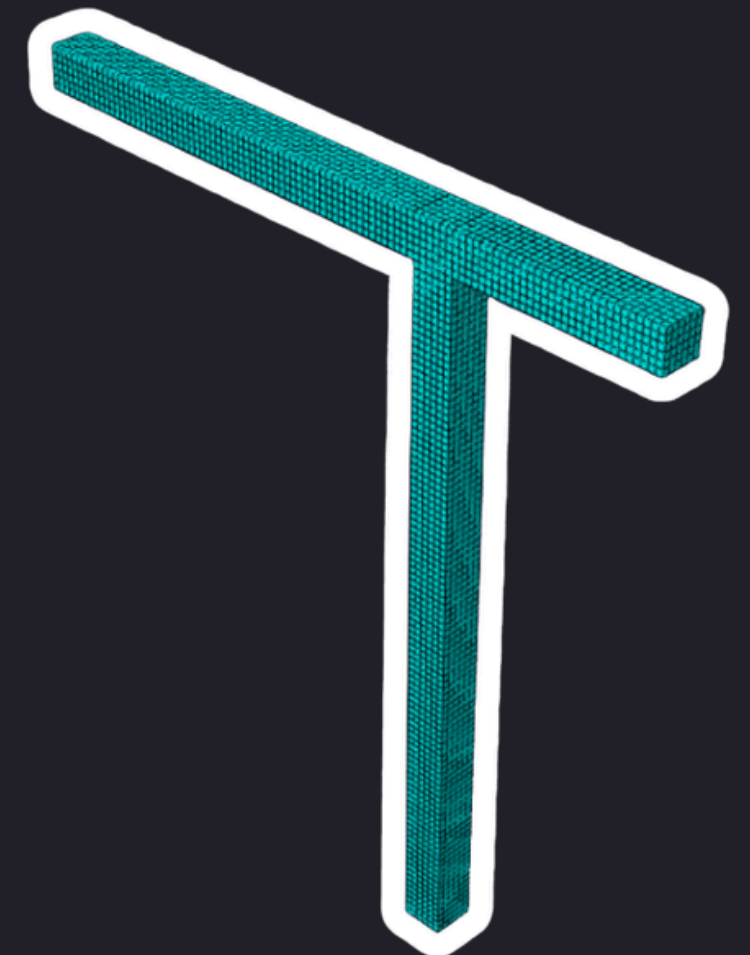
Mechanical Properties

- **Material Density:**
7850 kg/m³
- **Young's Modulus:**
210 GPa



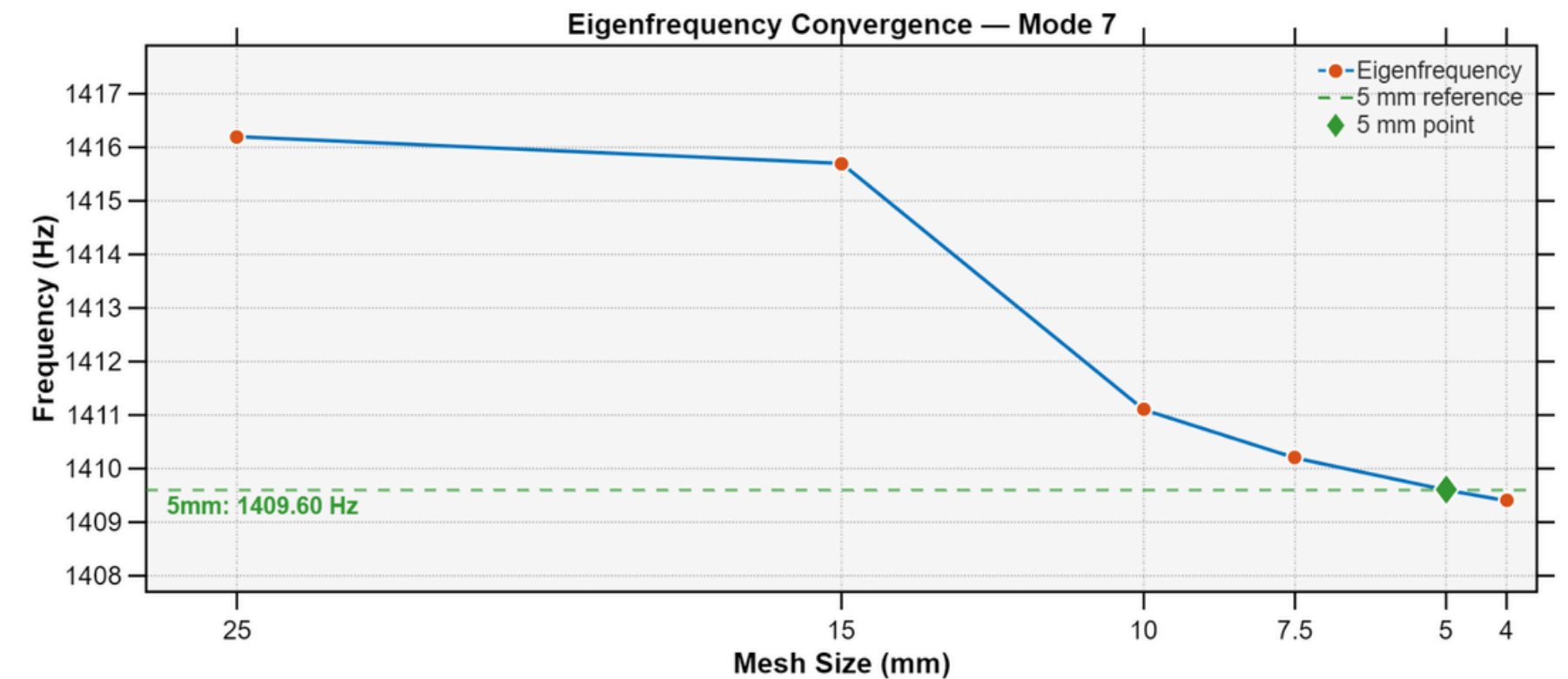
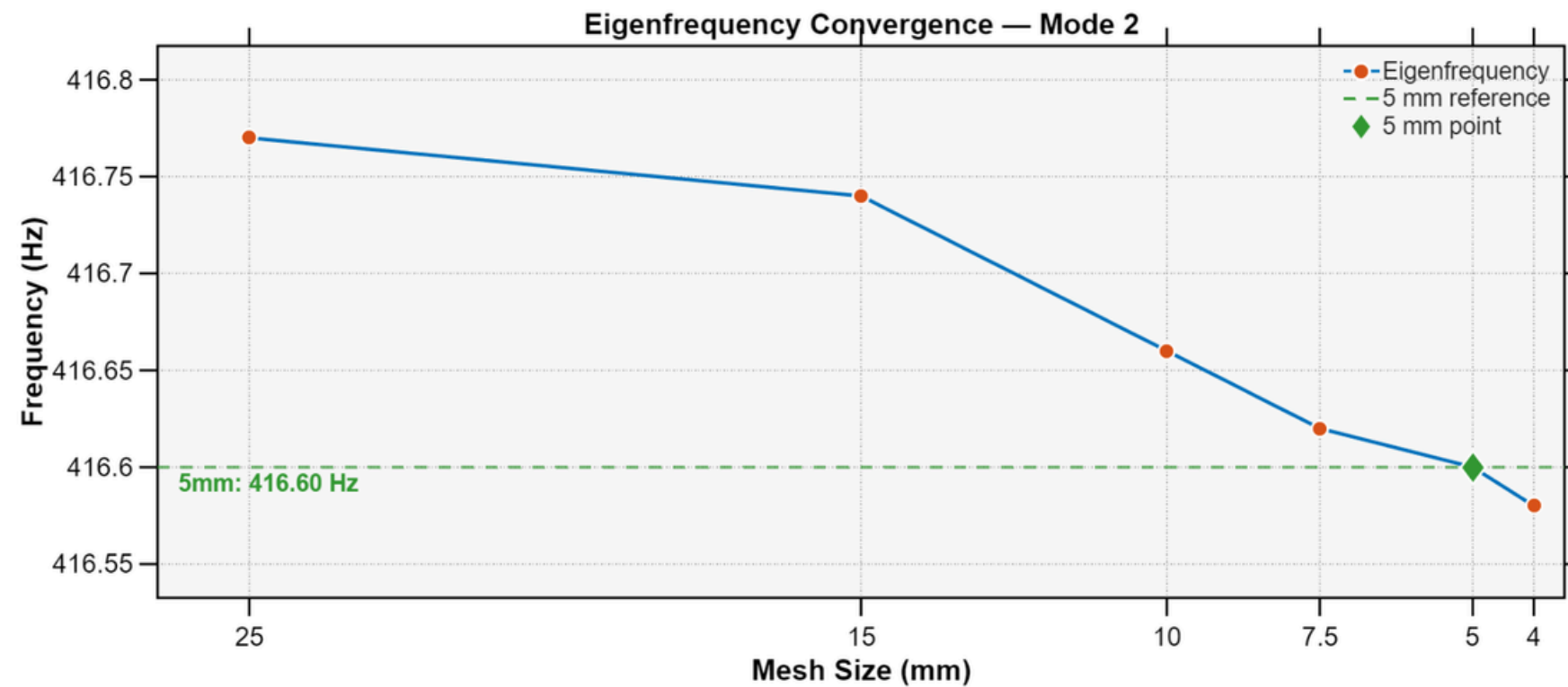
Mesh Properties

- **Element Size:**
5mm
- **Number of Elements:**
7200



MESH INDEPENDENCE ANALYSIS

Which is the right **mesh size**?



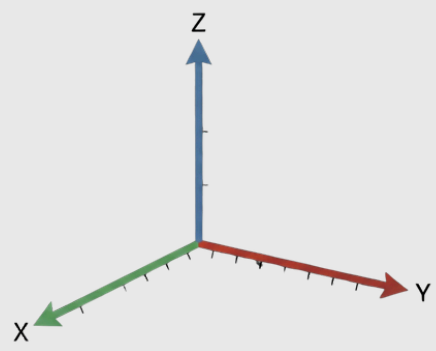
Chosen size: **5 mm**

NATURAL FREQUENCIES

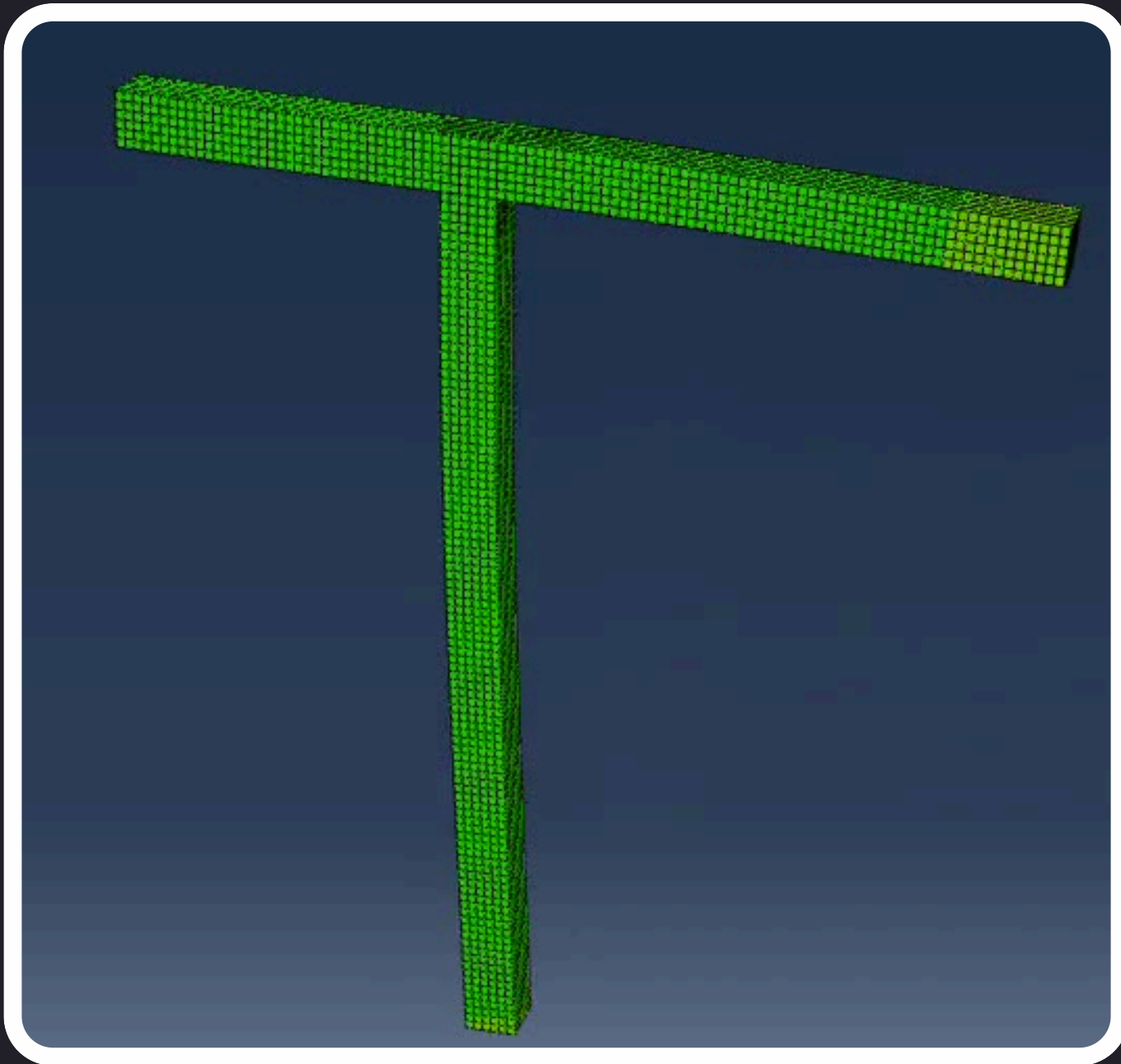
The first **10 natural frequencies** are estimated with the FE model:

Mode	1	2	3	4	5	6	7	8	9	10
Natural Frequency	184.2 Hz	416.6 Hz	500.6 Hz	627.4 Hz	675.9 Hz	1280.2 Hz	1409.6 Hz	1427.0 Hz	1703.7 Hz	1705.8 Hz

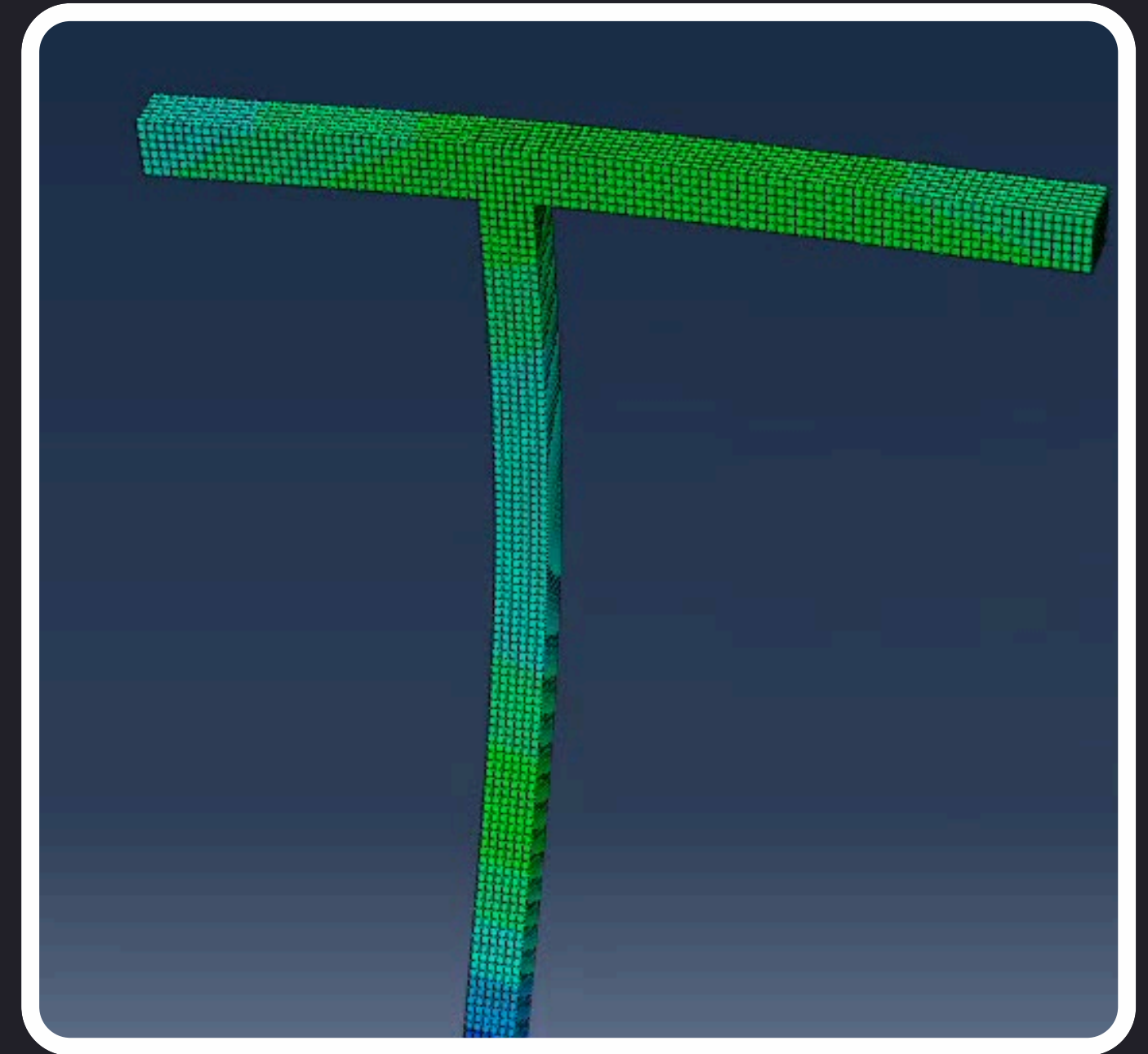
Frequency range: 0 - 1800 Hz



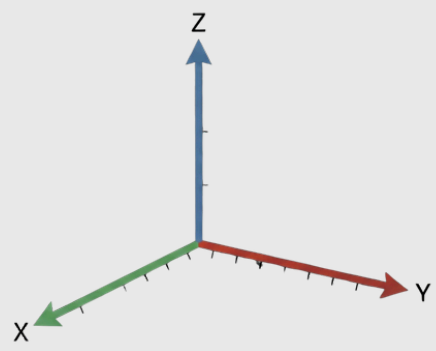
MODE SHAPES



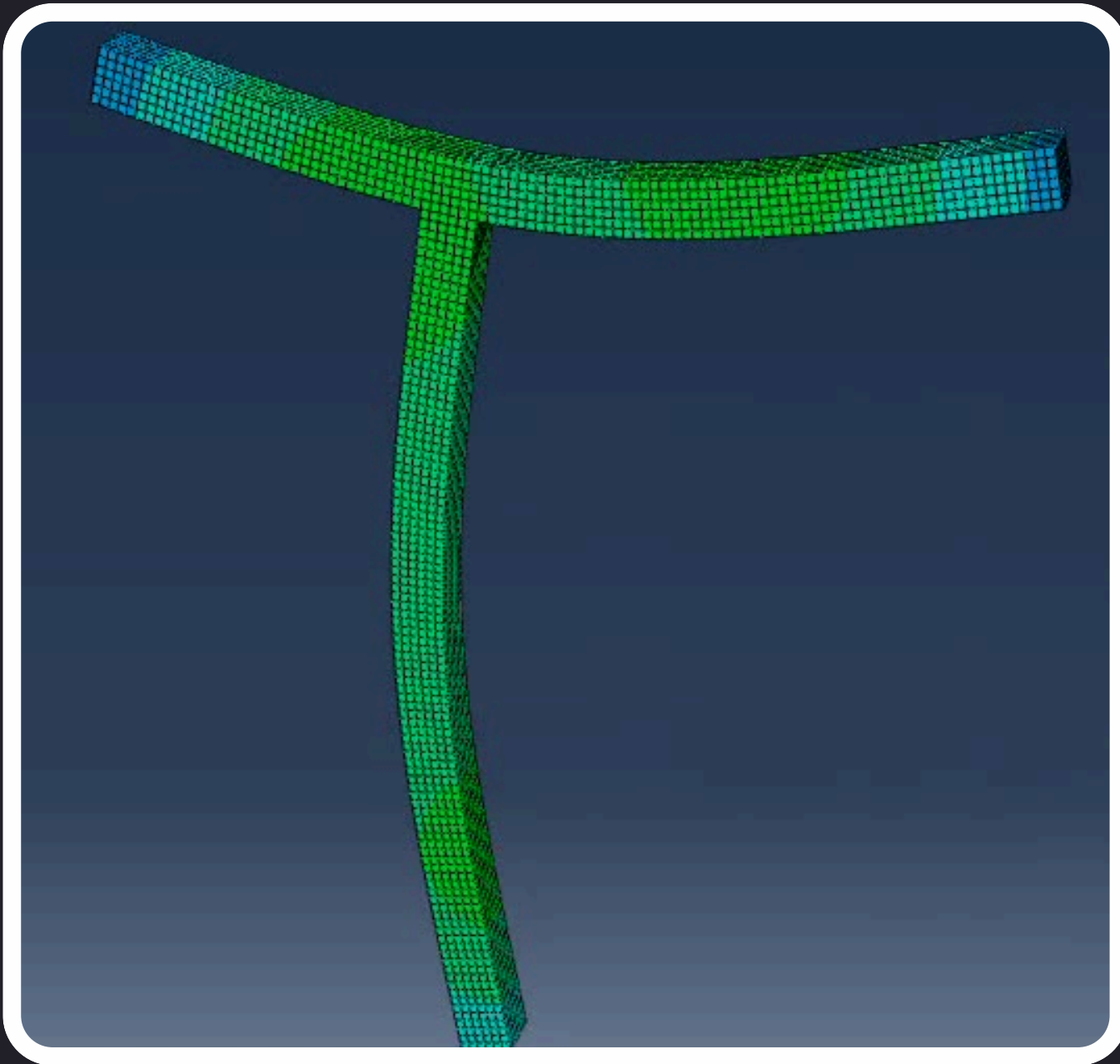
Mode 1 - 184.2 Hz



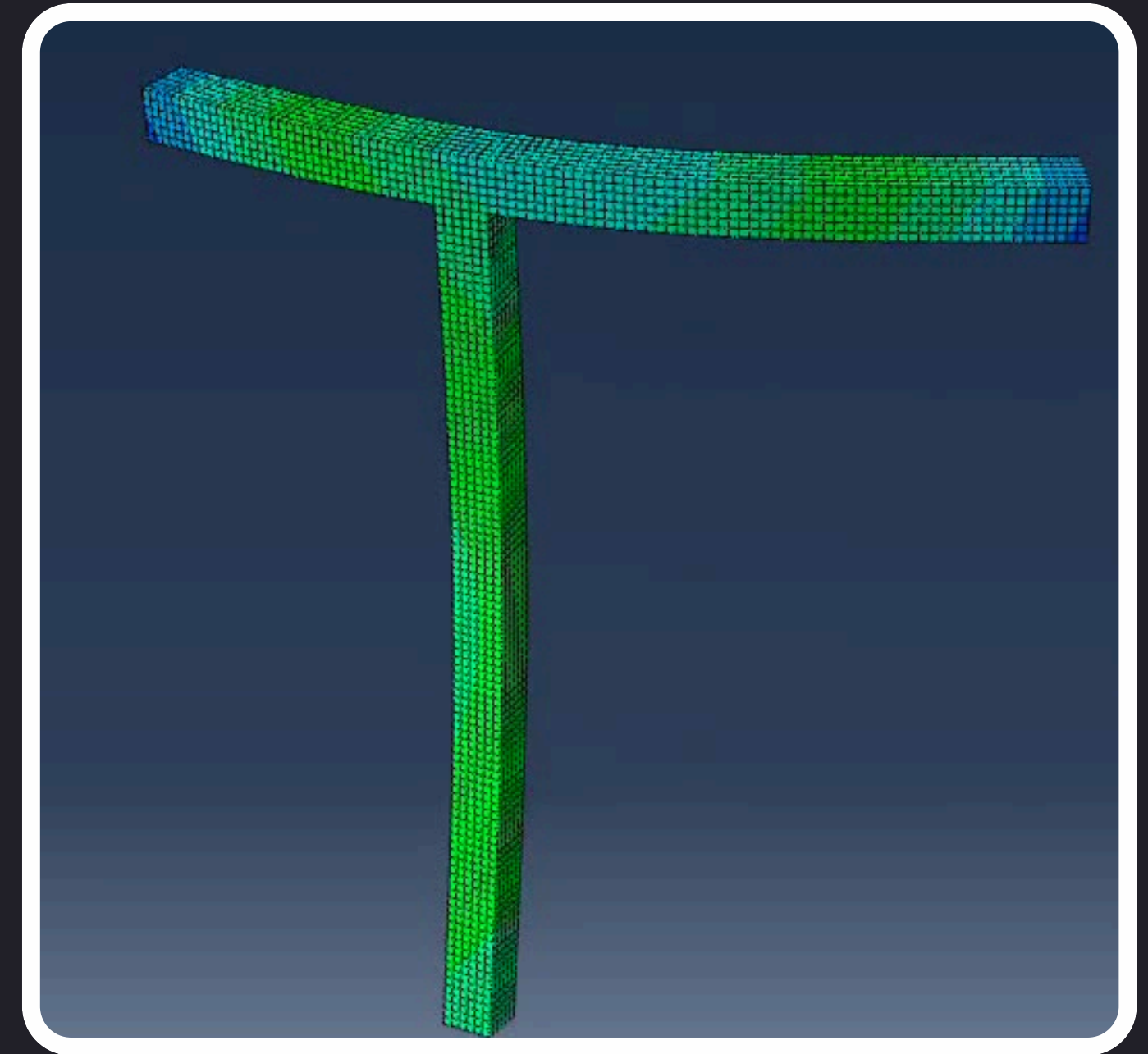
Mode 2 - 416.6 Hz



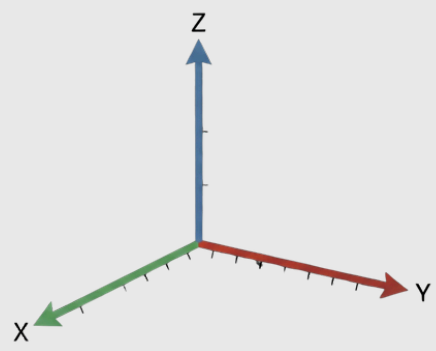
MODE SHAPES



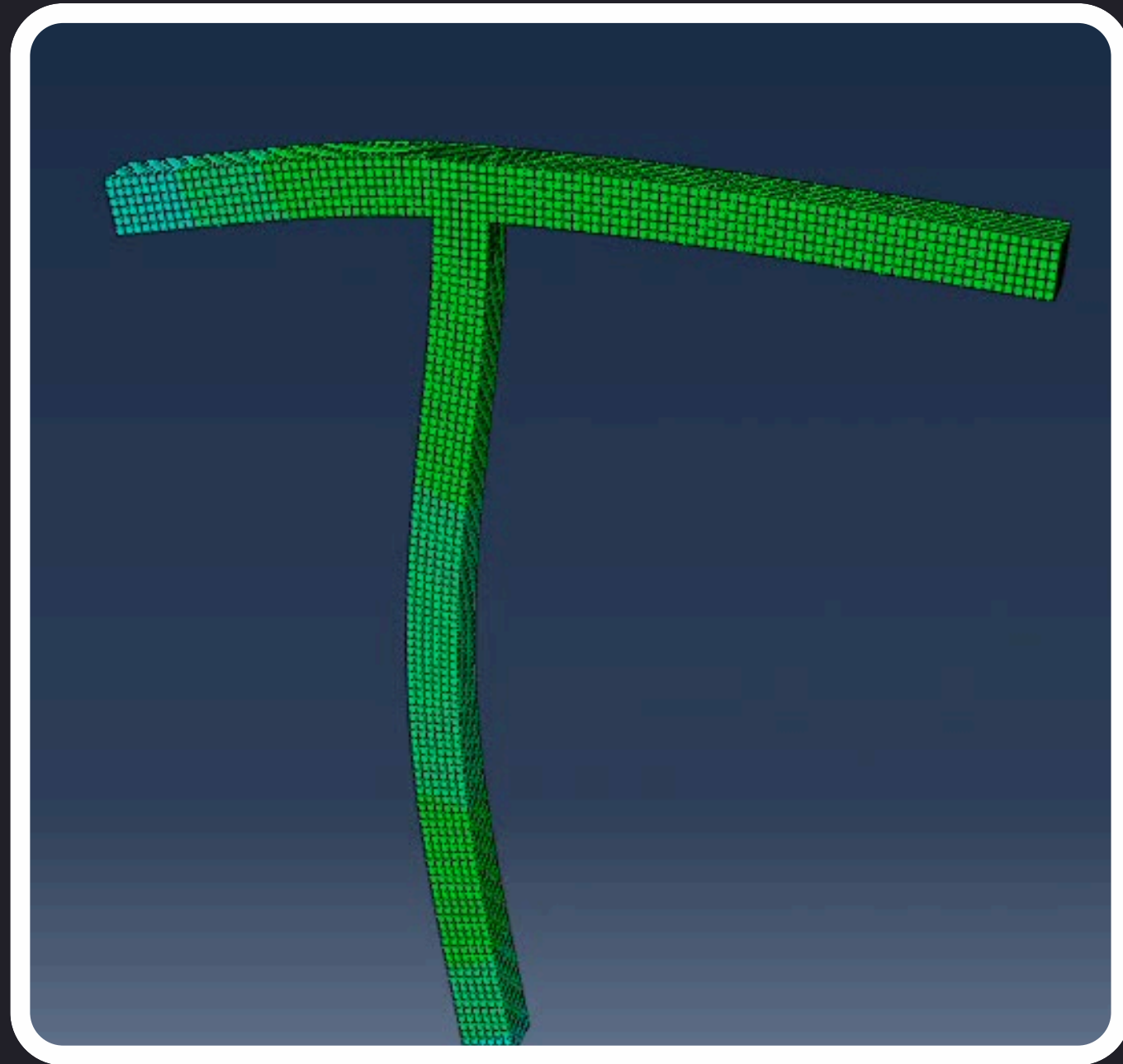
Mode 3 - 500.6 Hz



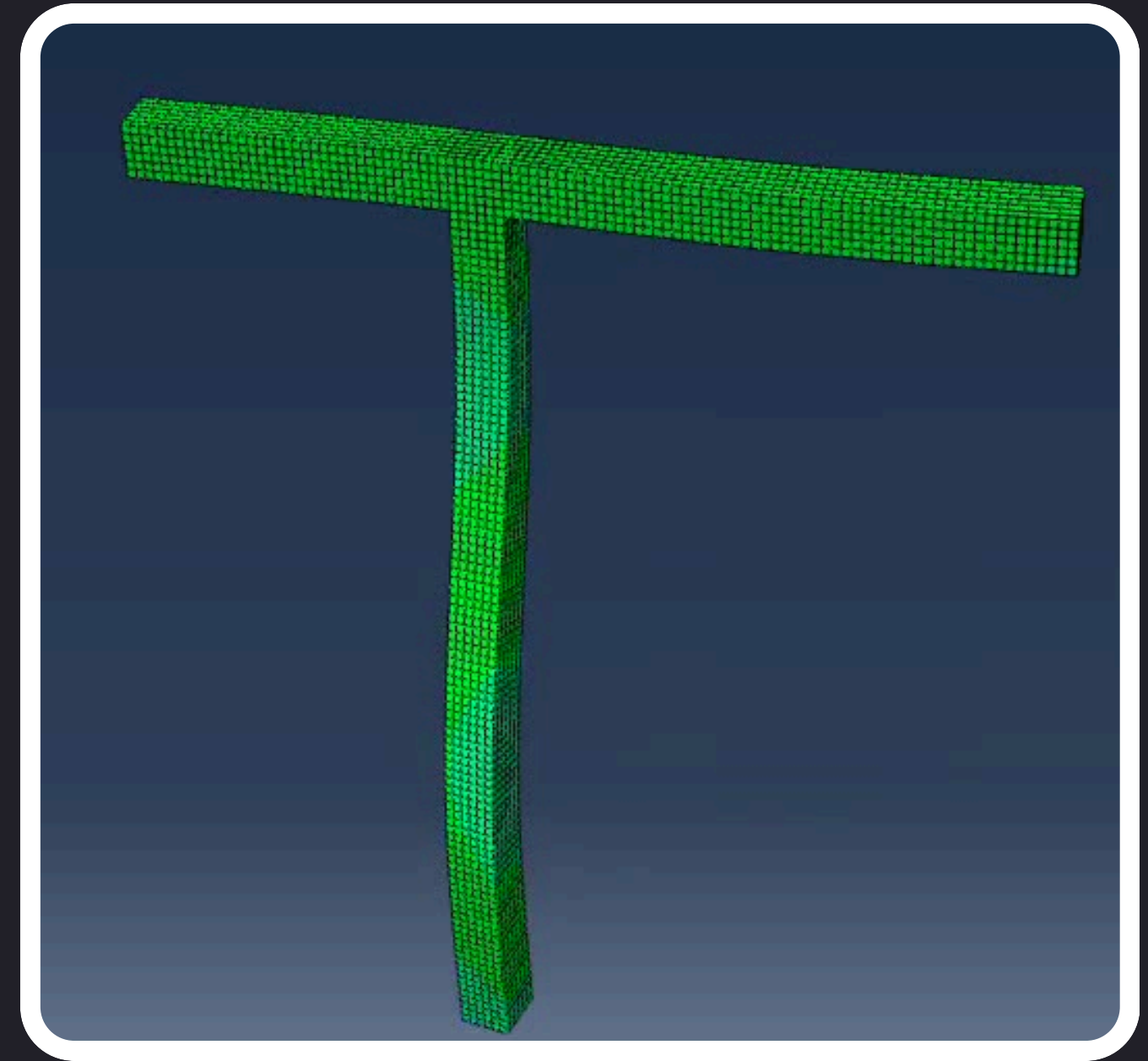
Mode 4 - 627.4 Hz



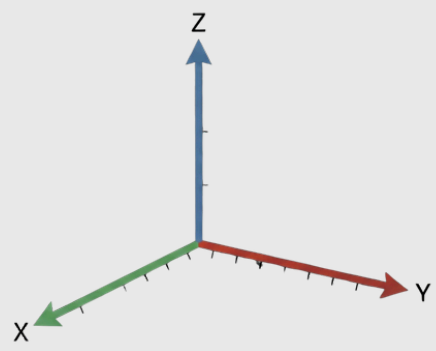
MODE SHAPES



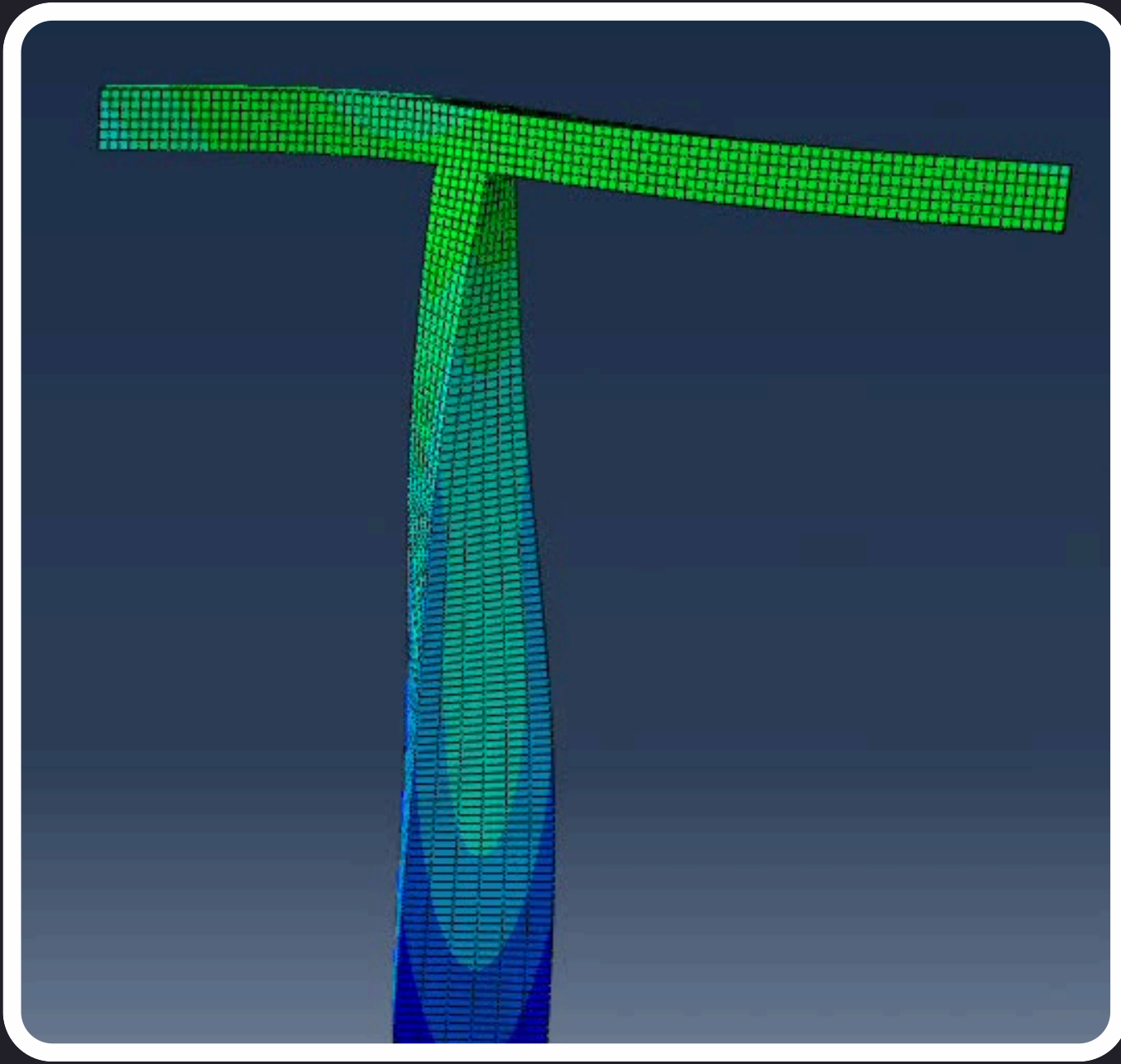
Mode 5 - 675.9



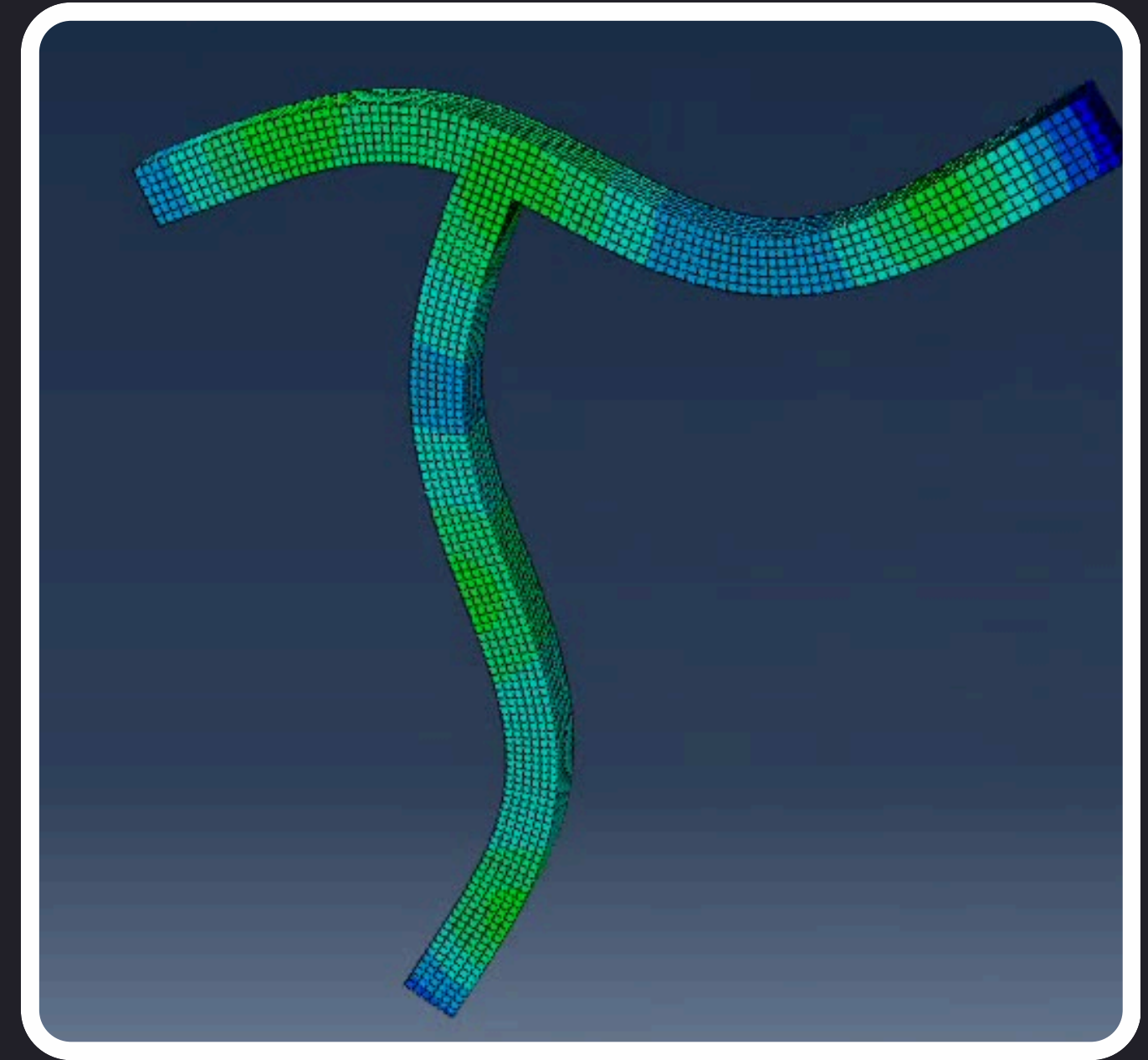
Mode 6 - 1280.2 Hz



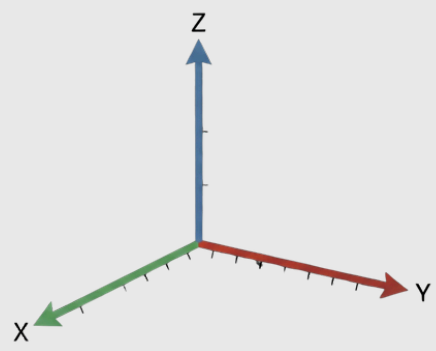
MODE SHAPES



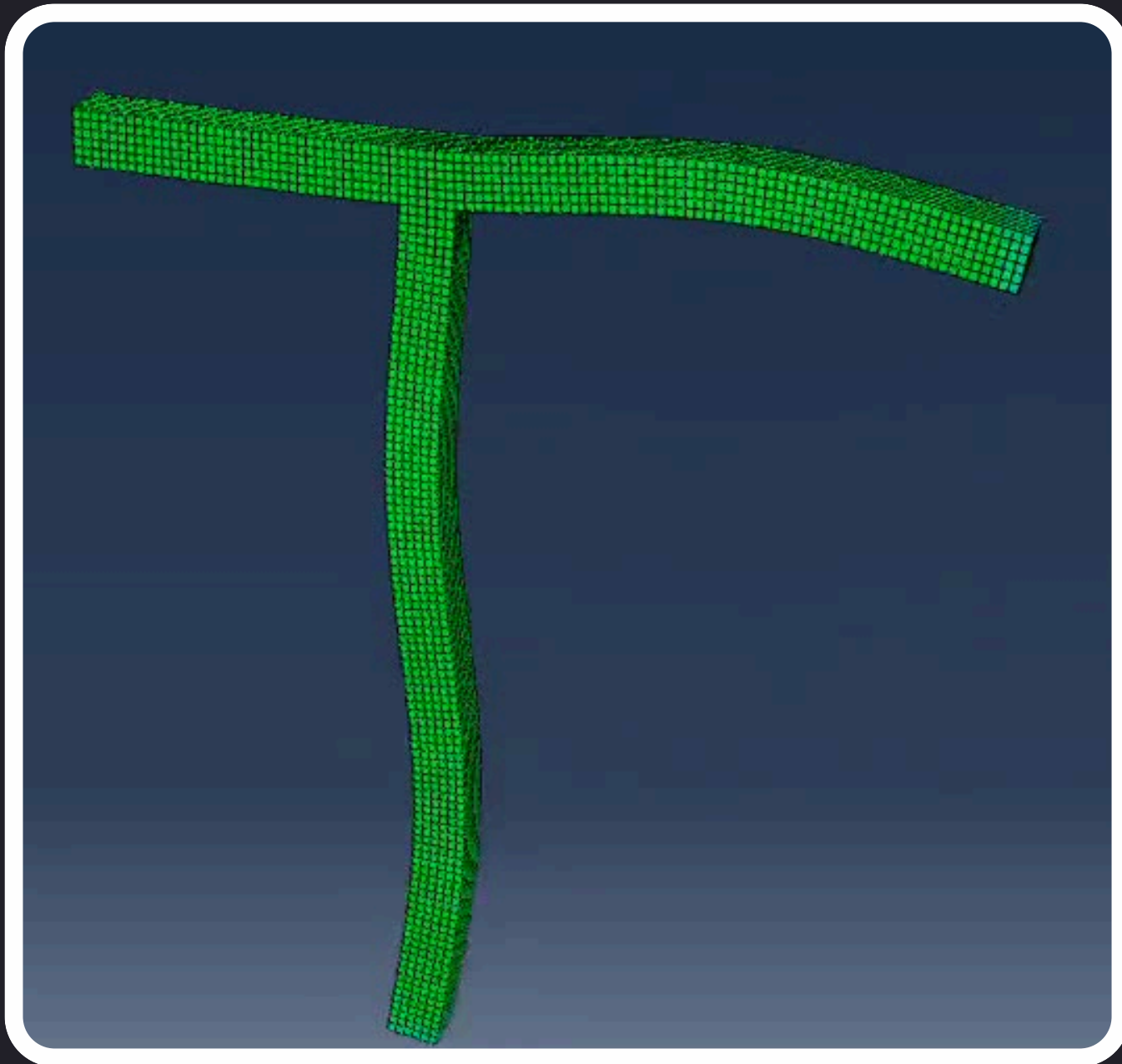
Mode 7 - 1409.6 Hz



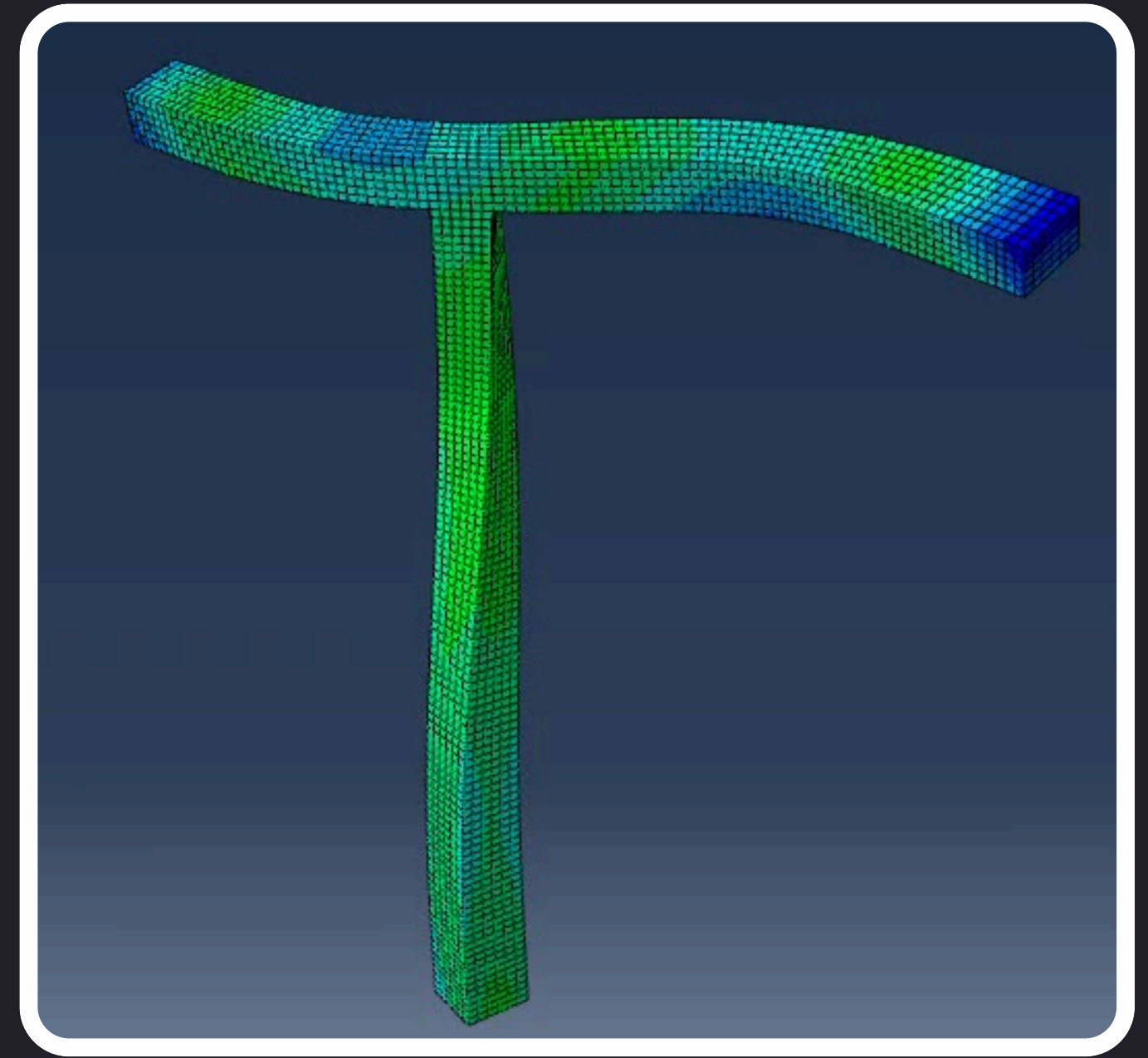
Mode 8 - 1427.0 Hz



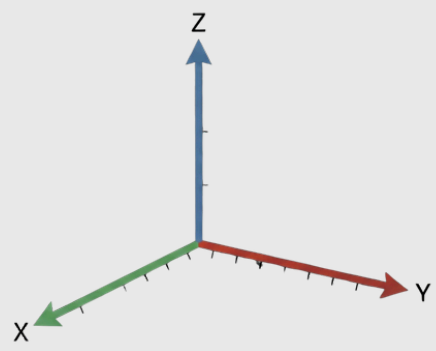
MODE SHAPES



Mode 9 - 1703.7 Hz



Mode 10 - 1705.8 Hz



MODE SHAPES

Analysis of the first 10 mode shapes

- Modes **1, 3, 5, 8, 9** are flexural on the Y-Z plane
- Modes **2, 4, 6** are flexural on the X-Z plane for the lower part and on the X-Y one for the upper one
- Modes **7** and **10** are torsional, around the Z axis for the lower part and around the Y axis for the upper part
- Modes **4** and **6** show a small torsional vibration around the Z axis in the lower part



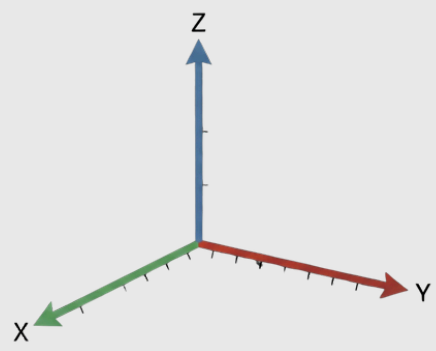
03. AUTOMAC

Choice of the accelerometers' position

THEORETICAL DEFINITION

$$\text{AutoMAC}(A_i, A_j) = \frac{|\{\psi_{A,i}\}^T \{\psi_{A,j}\}|^2}{(\{\psi_{A,i}\}^T \{\psi_{A,i}\}) \cdot (\{\psi_{A,j}\}^T \{\psi_{A,j}\})}$$

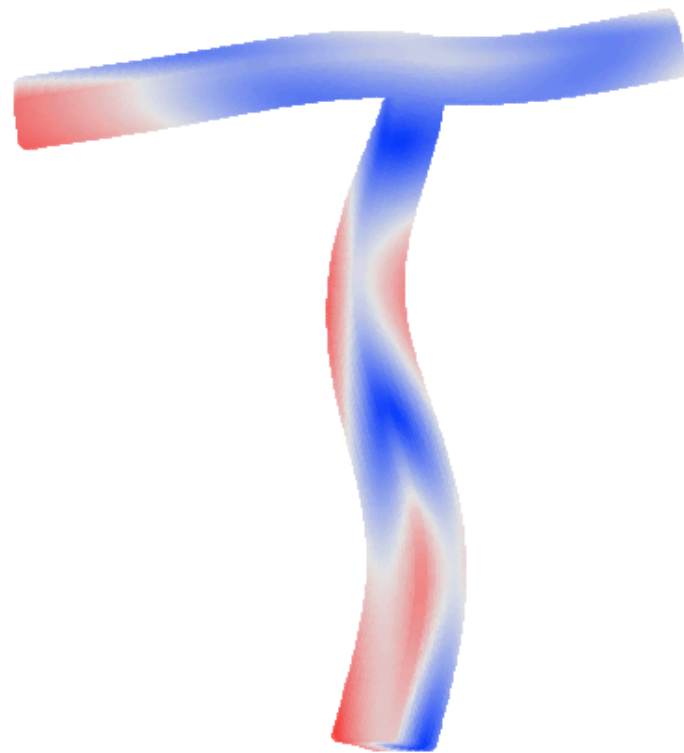
- Automac verifies if the sensors' configuration clearly distinguishes all modes without introducing spatial aliasing.
- 5 available accelerometers $\longrightarrow$ 5 nodes to analyze



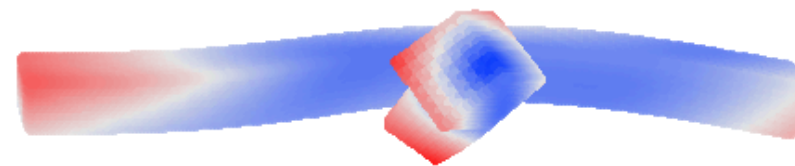
NODES SELECTION

Superposition of the normalized displacement of the different modes

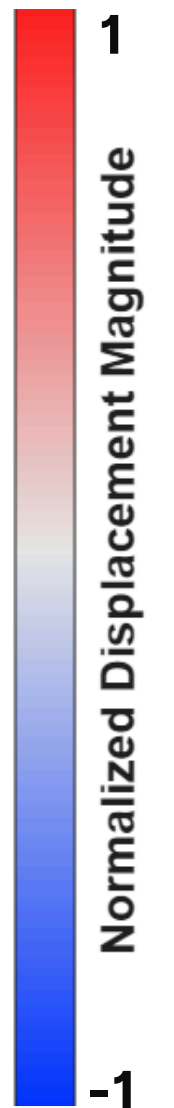
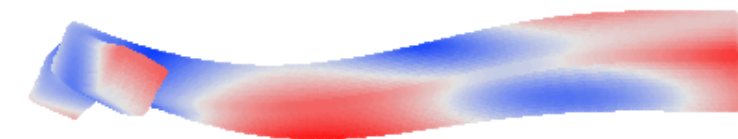
Plane Y-Z



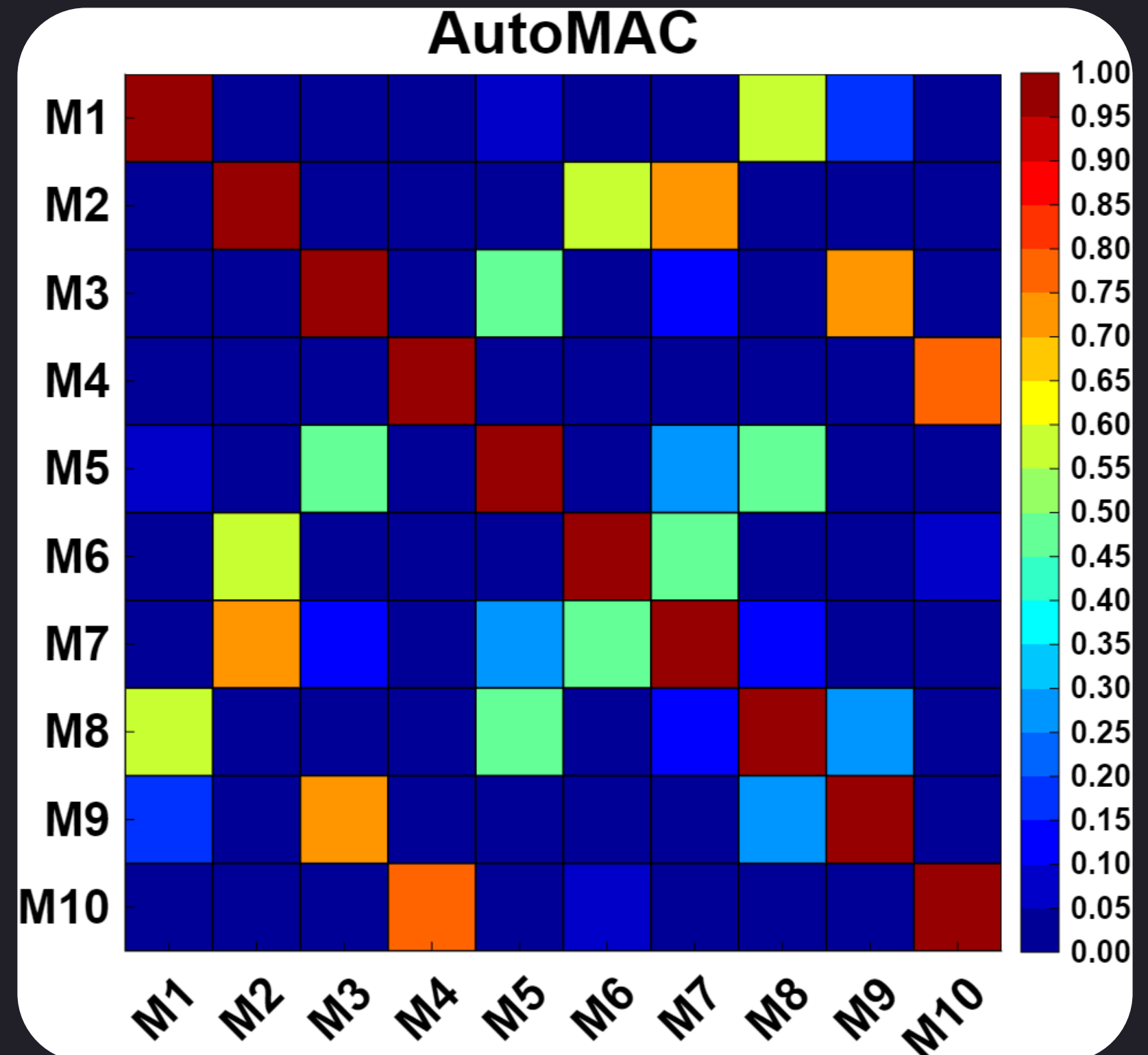
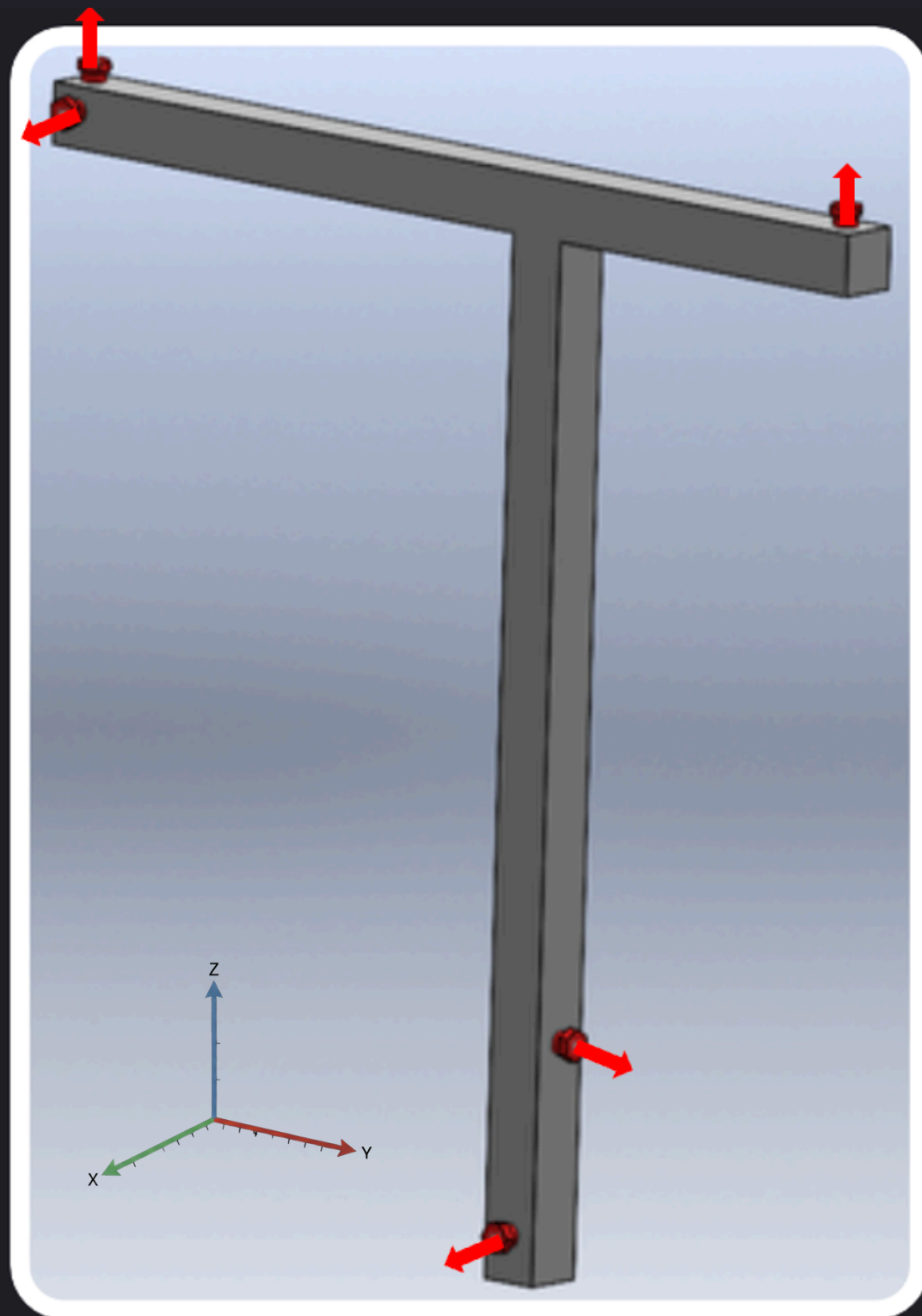
Plane X-Y

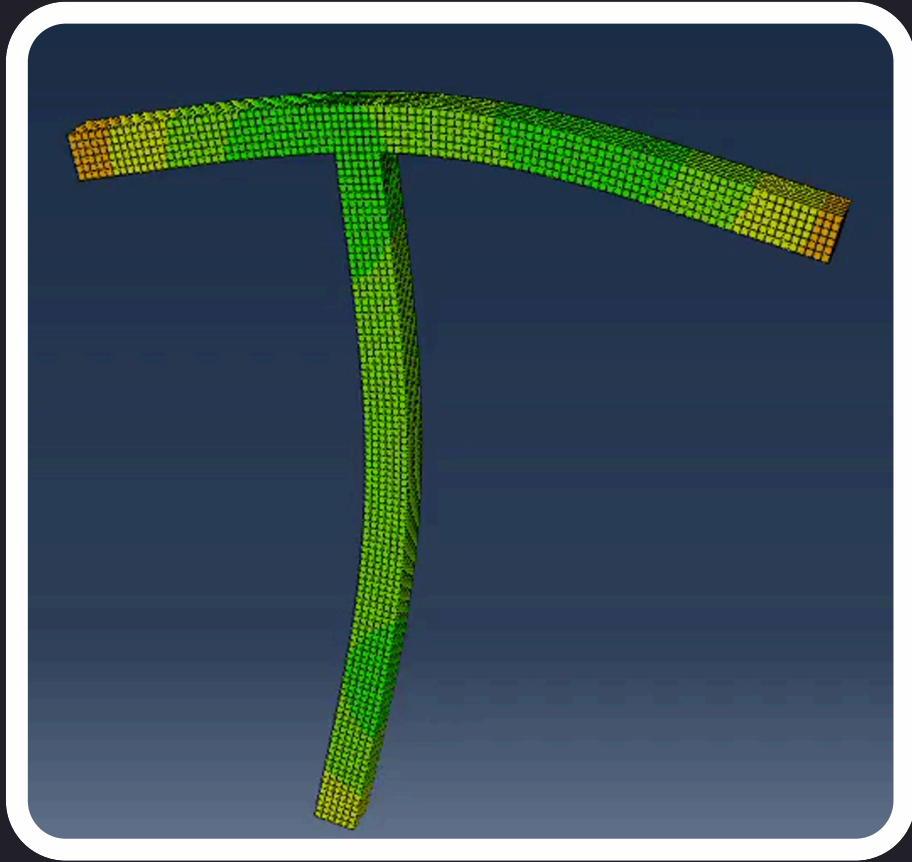


Plane X-Z

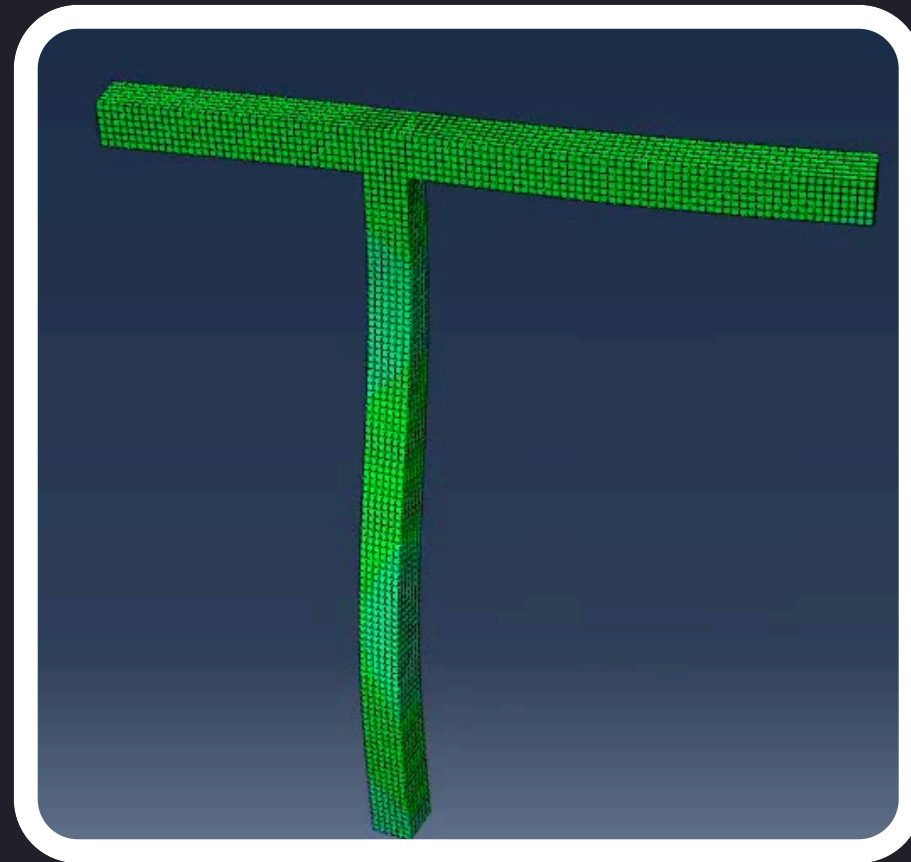


AUTOMAC - 1st Configuration

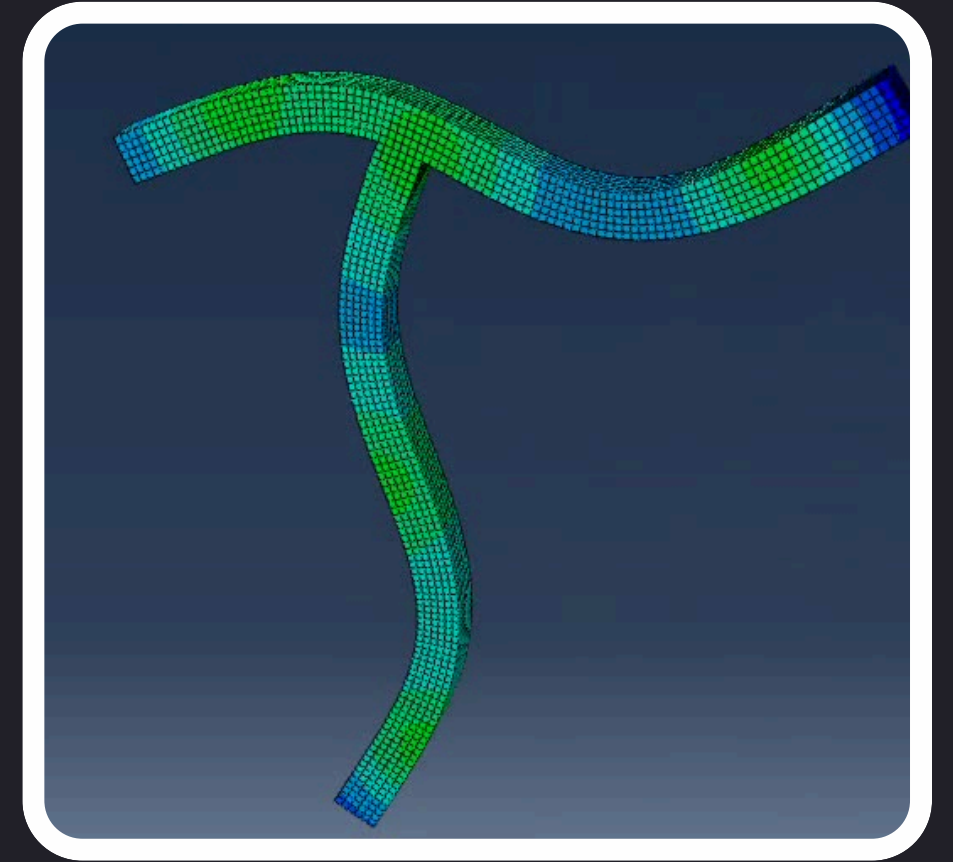




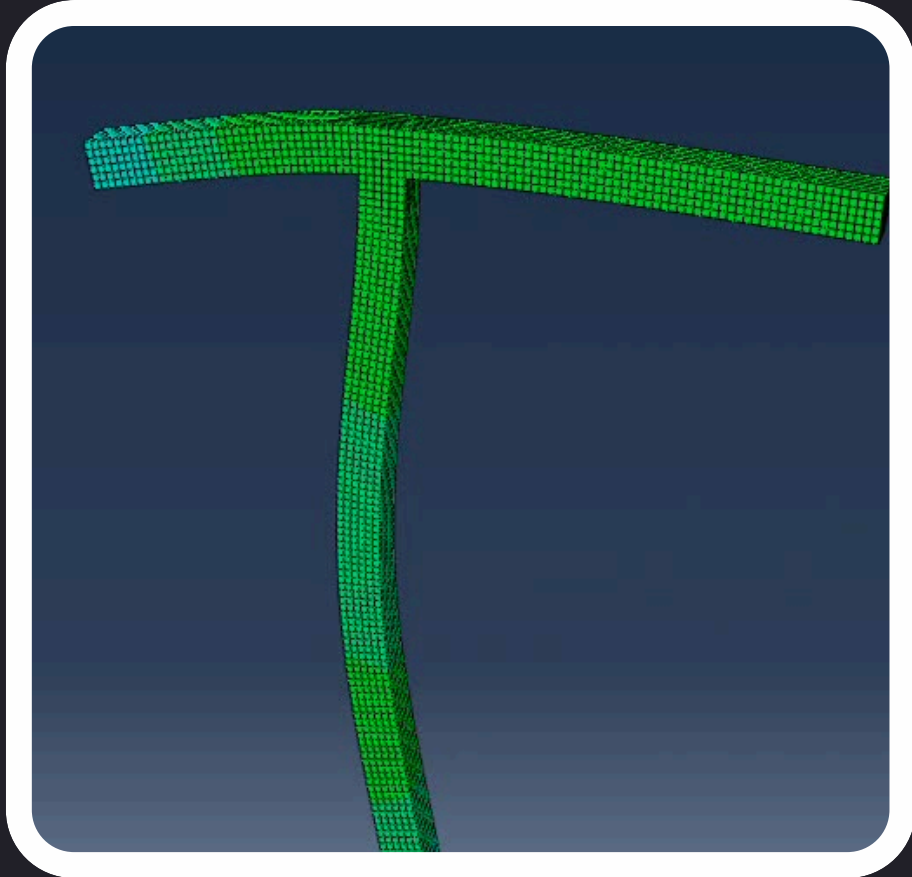
Mode 3



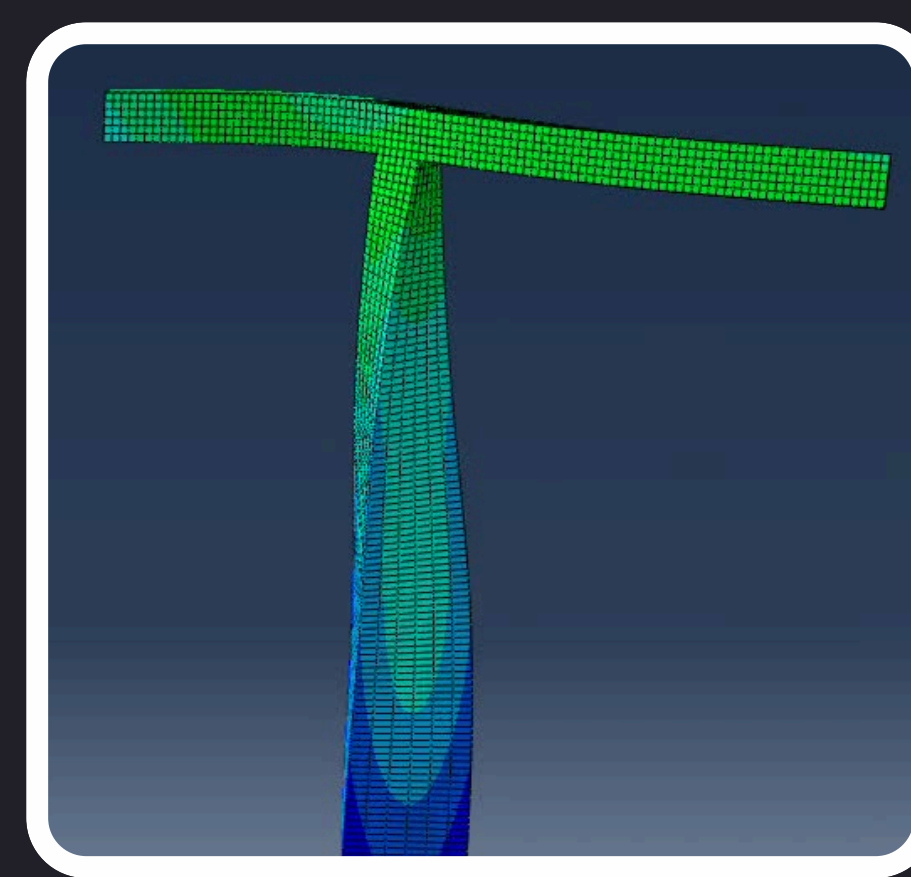
Mode 6



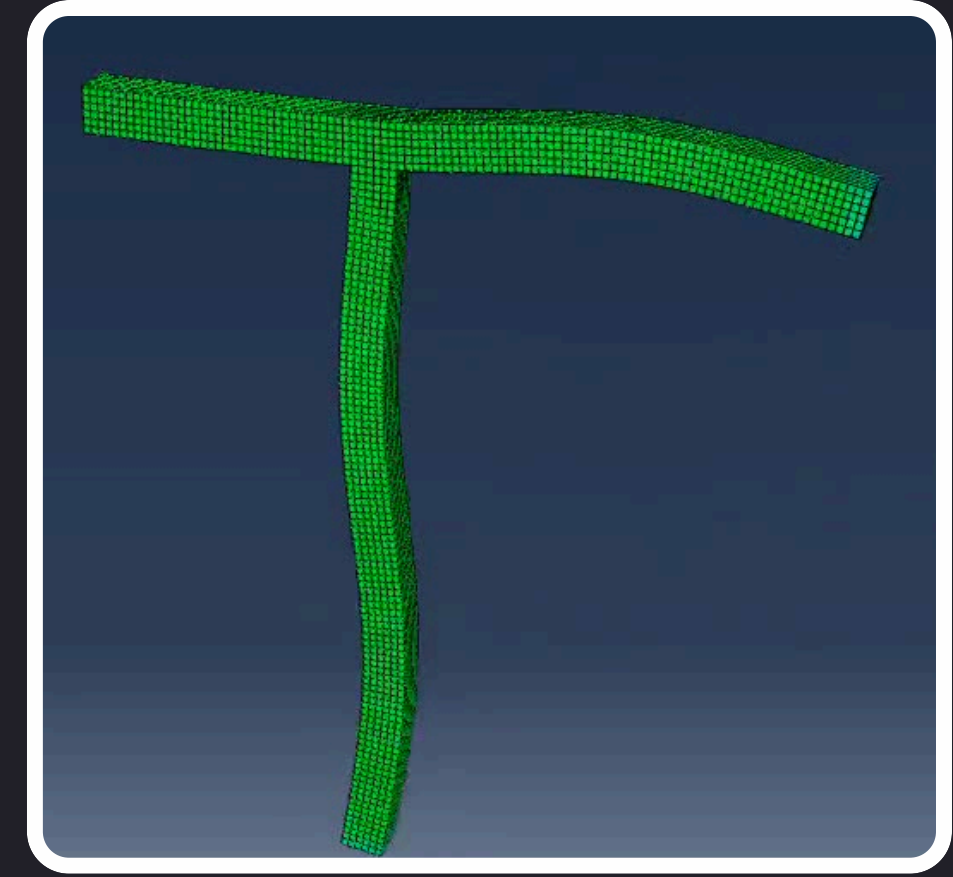
Mode 8



Mode 5

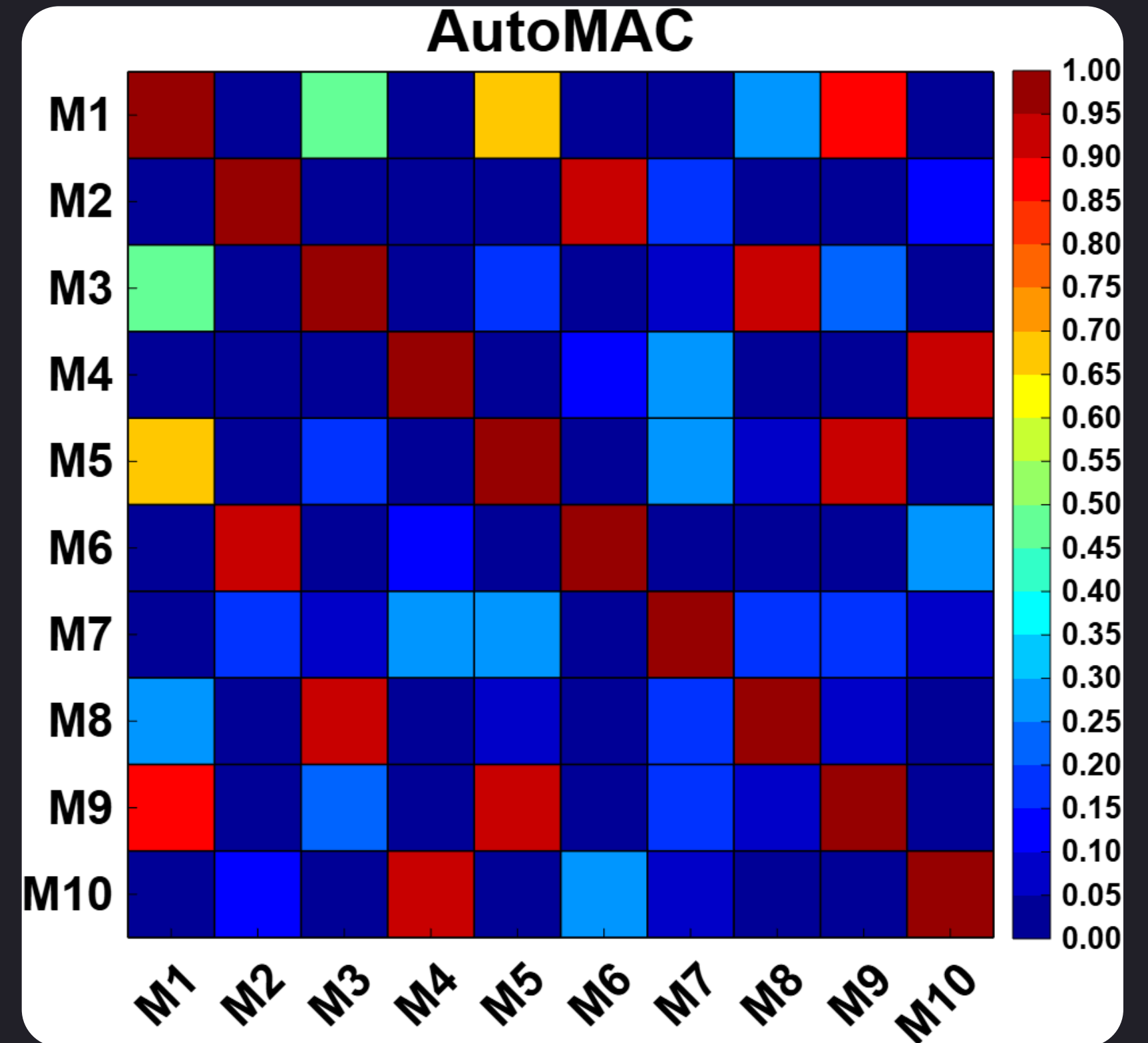
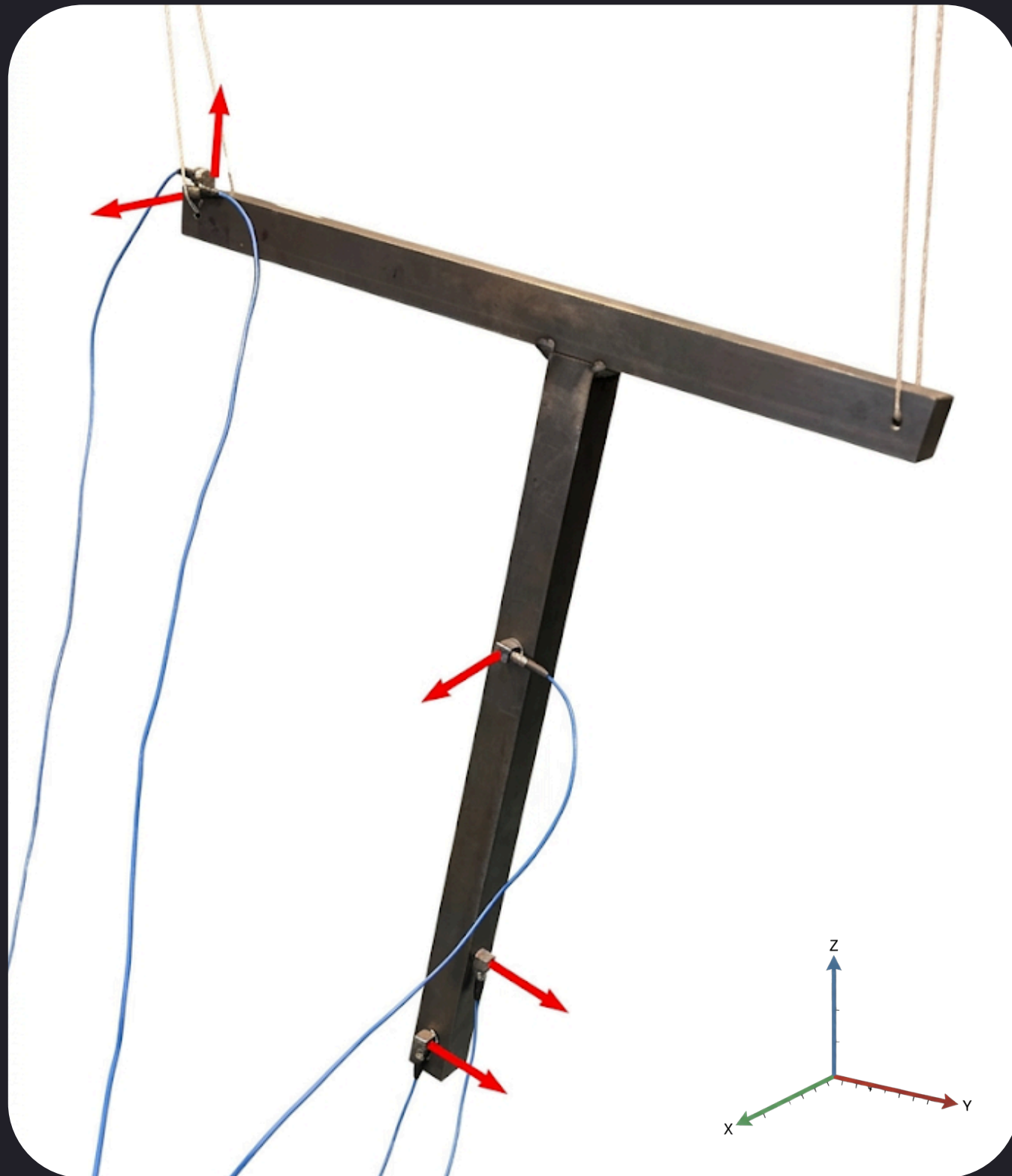


Mode 7



Mode 9

AUTOMAC - 2nd Configuration



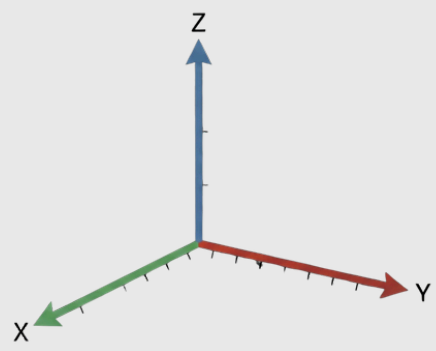
SYNTHESIS

- The **frequency range** to be studied is **0 - 1800 Hz**, till 10th mode



Sampling frequency: 5000 Hz

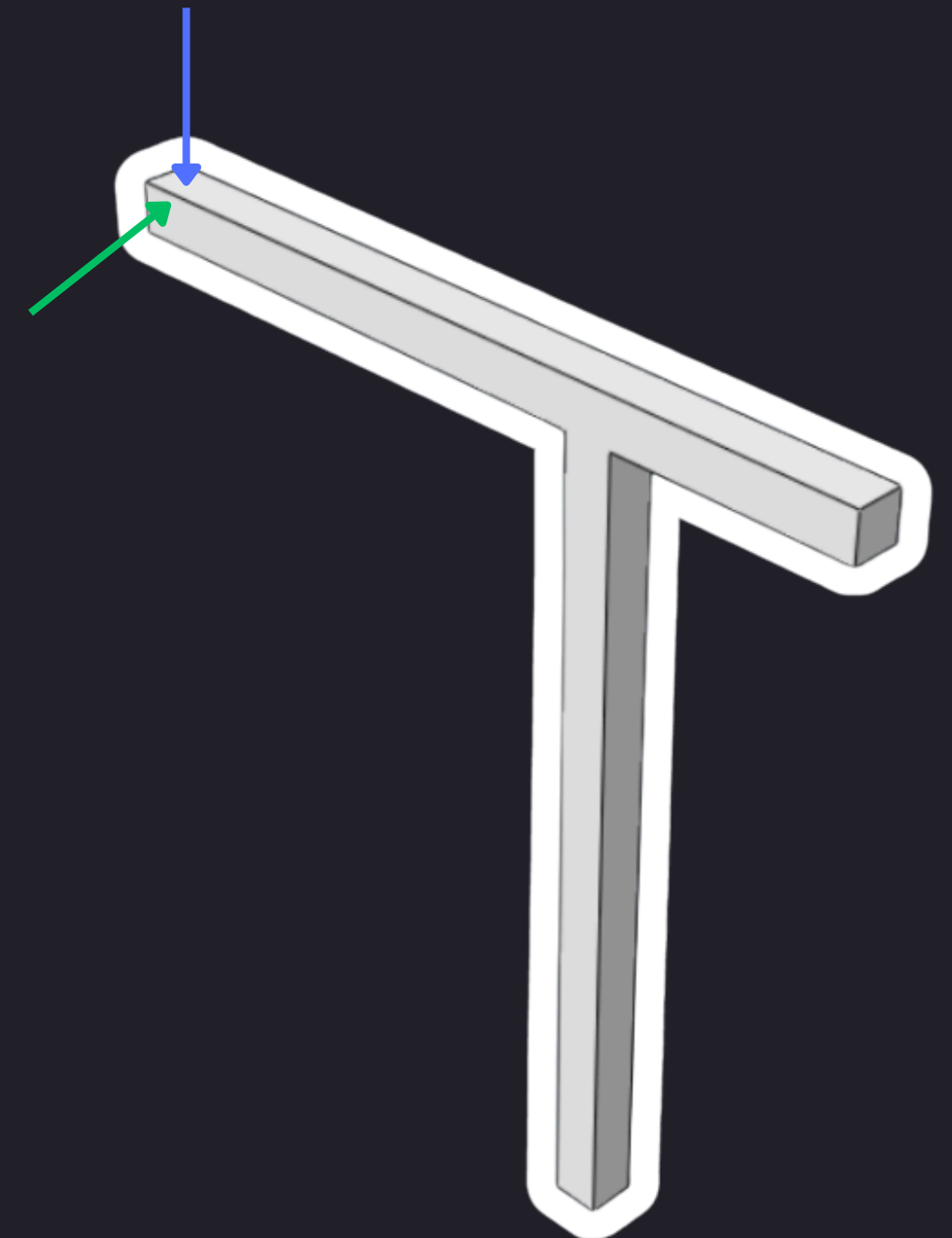
- The natural frequencies to pay attention to are **7-8** and **9-10**
- **Accelerometers' positions** have been selected
- Where can we put the **input**?



INPUT LOCATION

To derive the eigenvector components, **at least one co-located FRF is needed**

- **Z axis:** co-located, in order to trigger flexural modes in the Y-Z plane
- **X axis:** co-located, in order to trigger the other flexural modes (along different planes) and torsional modes along the Z axis





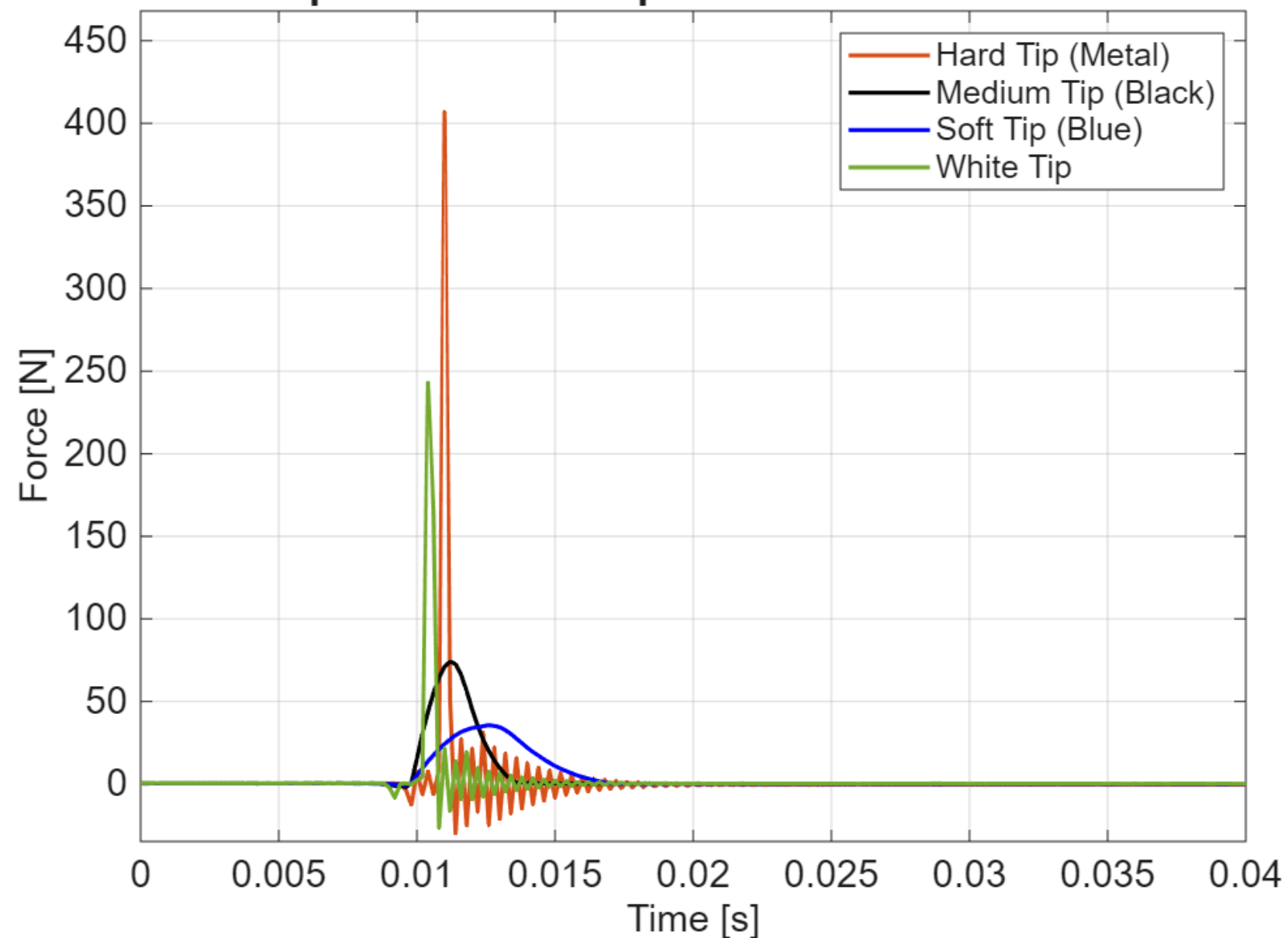
04. TESTING

Setup, experimental tests and data processing

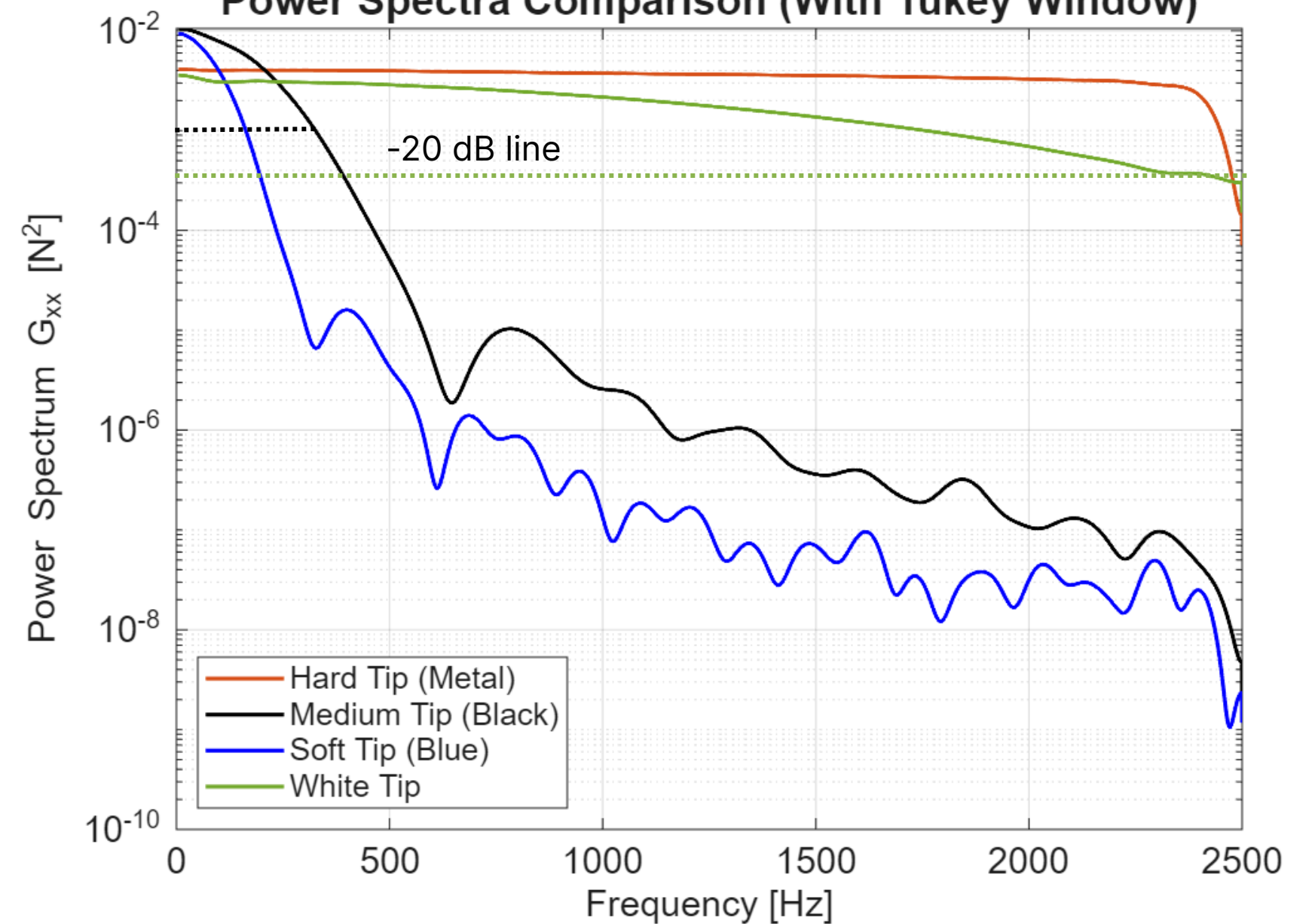
TIP

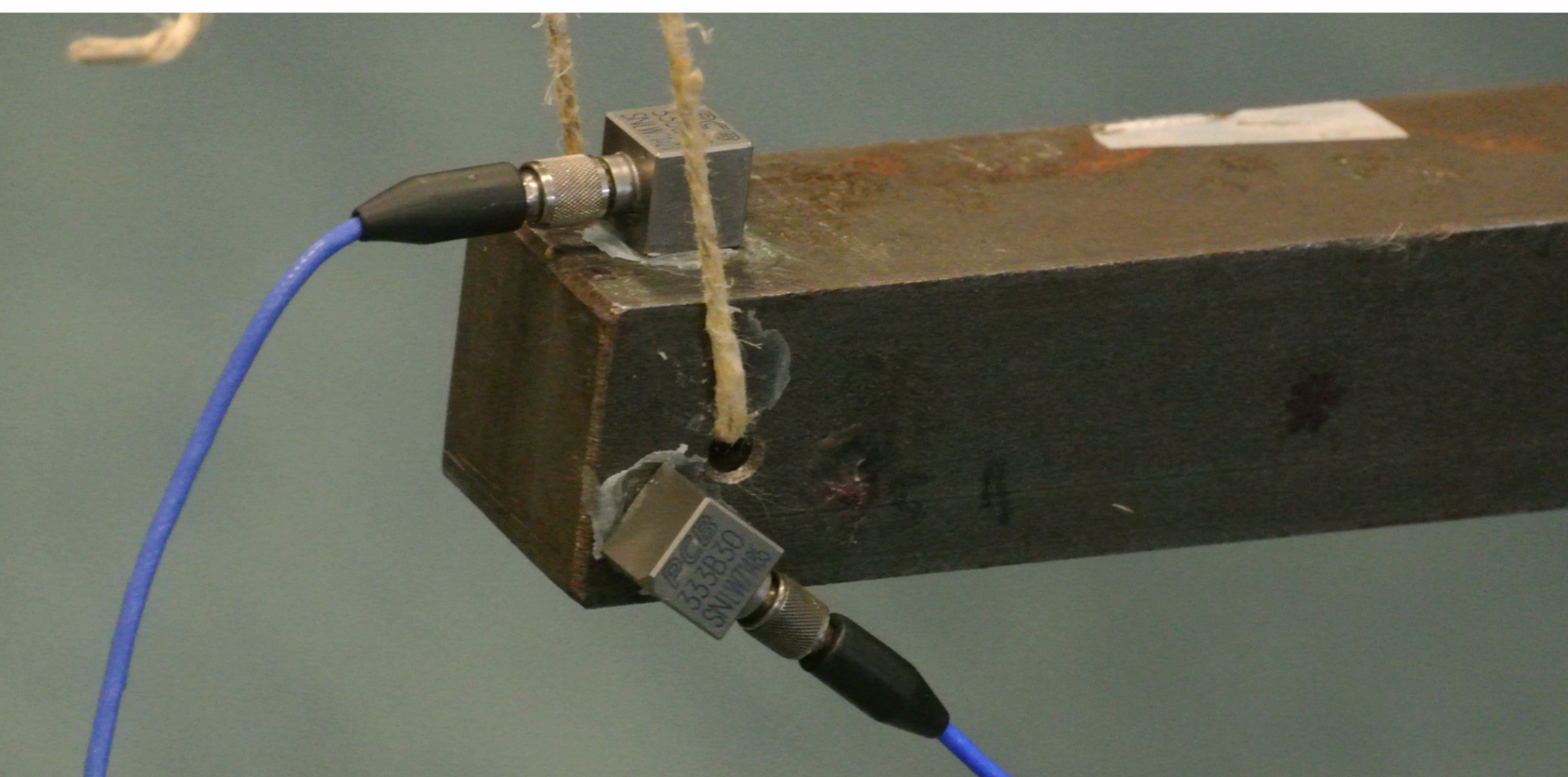
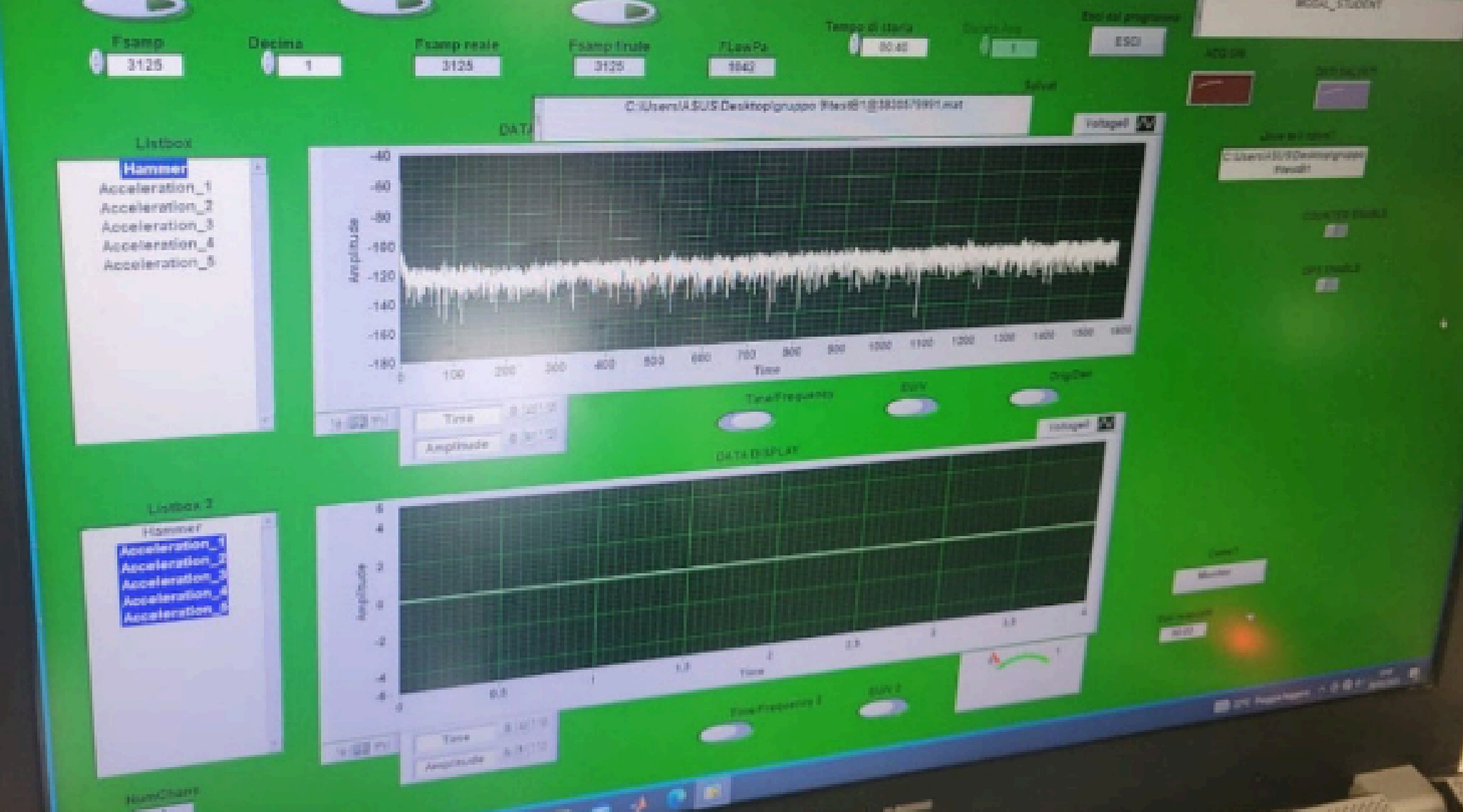
Frequency range to excite: **0 - 1800 Hz**

Impact Force Comparison in Time Domain

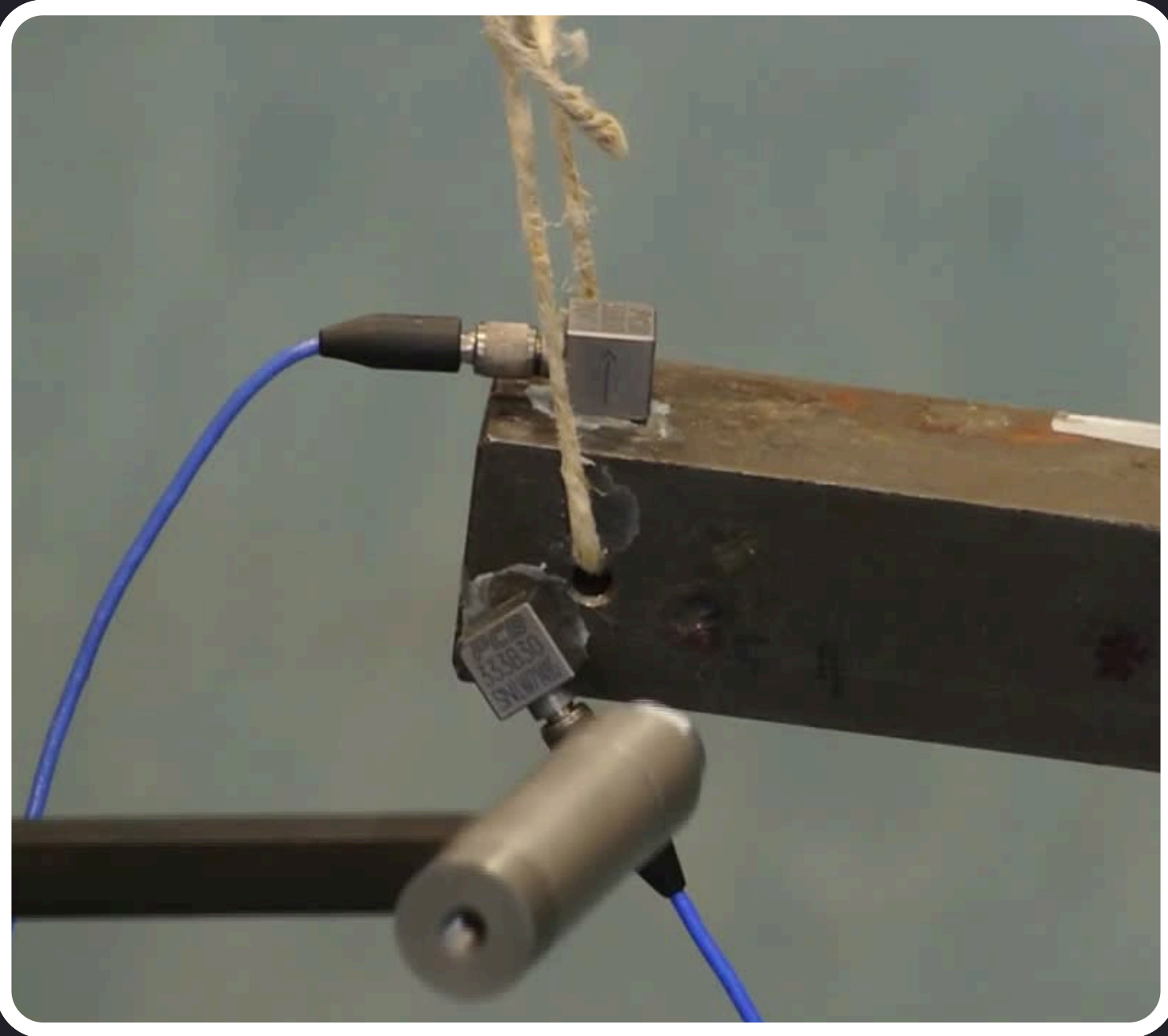


Power Spectra Comparison (With Tukey Window)





EXPERIMENTAL CAMPAIGN



- 10 hammer impacts for each input location.

→ Spectra average

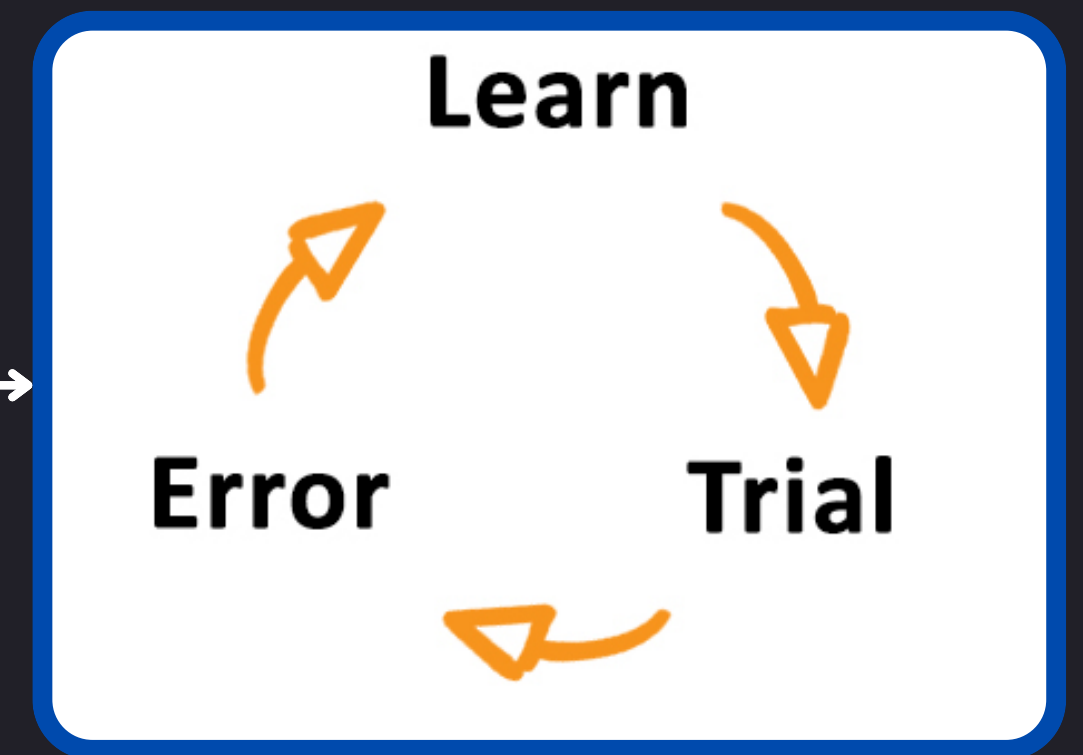
- Time window of 25 seconds.

→ Frequency resolution: 0.04 Hz

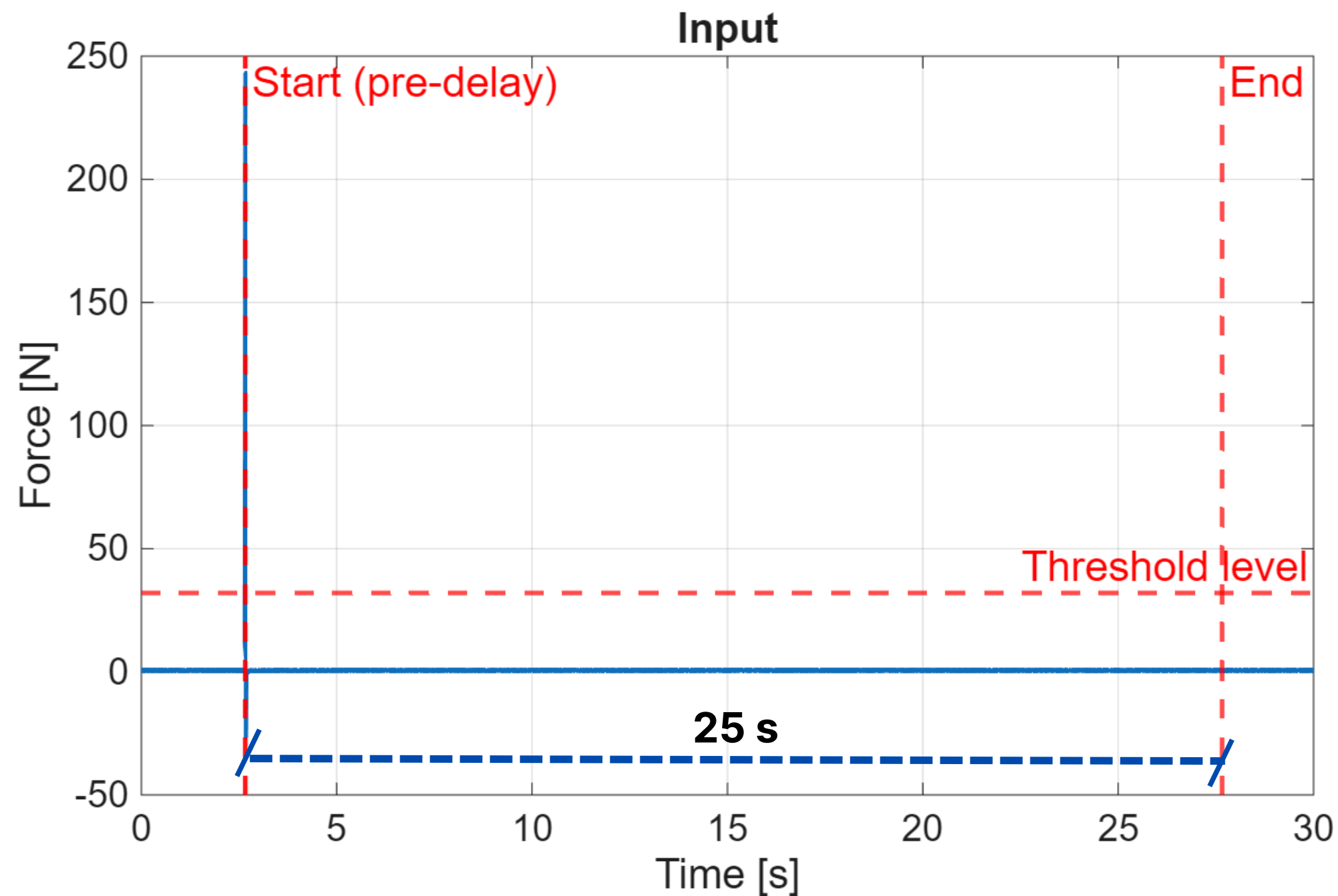
→ Leakage

PROBLEMS

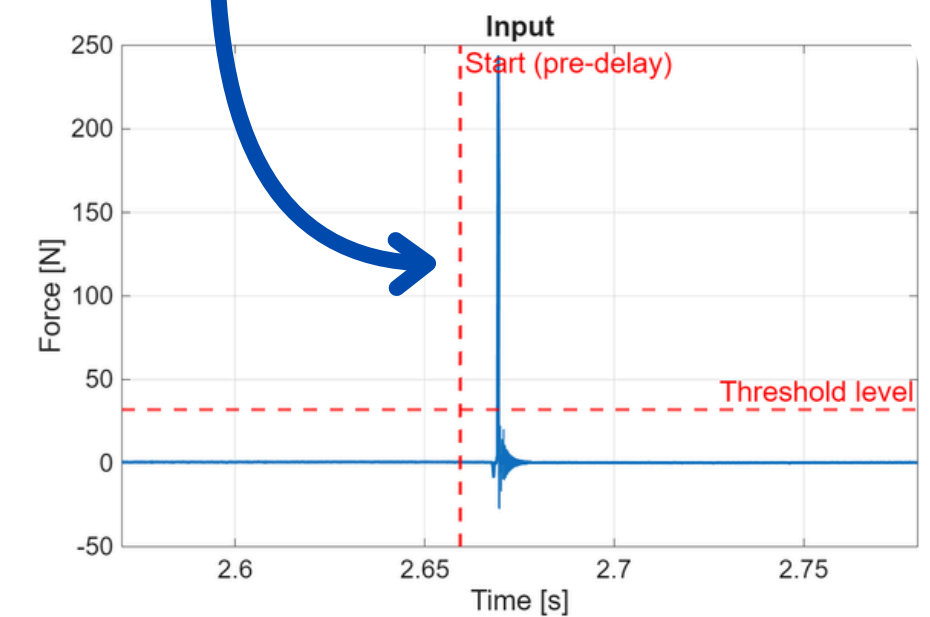
- Hammer double hits
- Co-located hits
- Saturation of accelerometers



TRIGGER AND PRE-TRIGGER



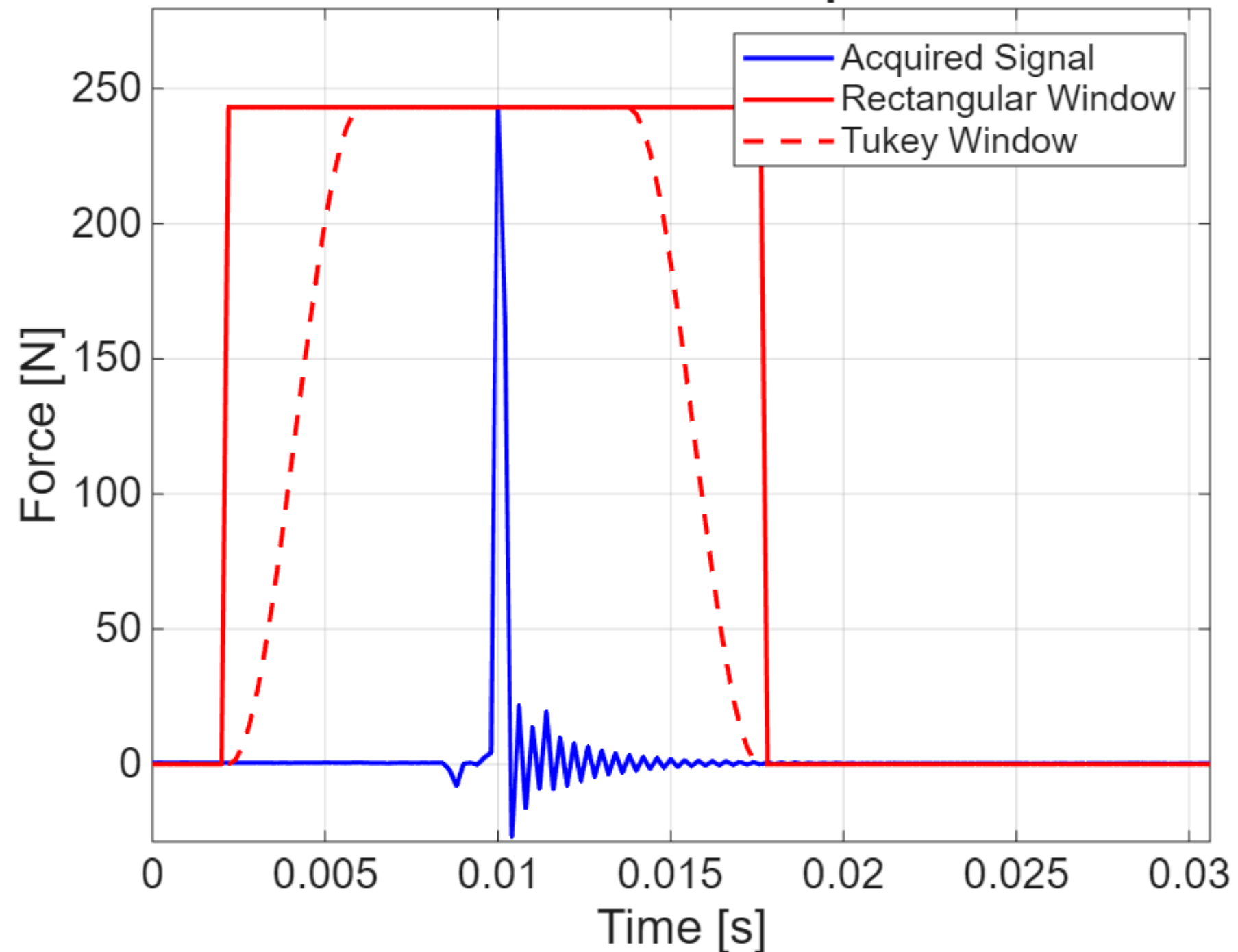
- Pre-trigger time: 0.01 s



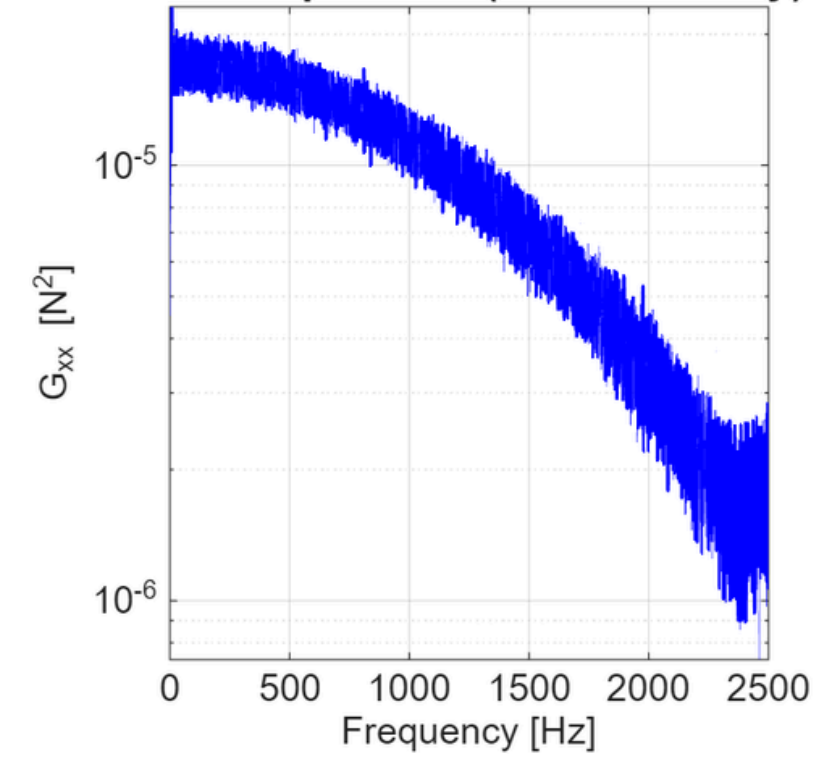
- Time window: 25 s

TUKEY WINDOW

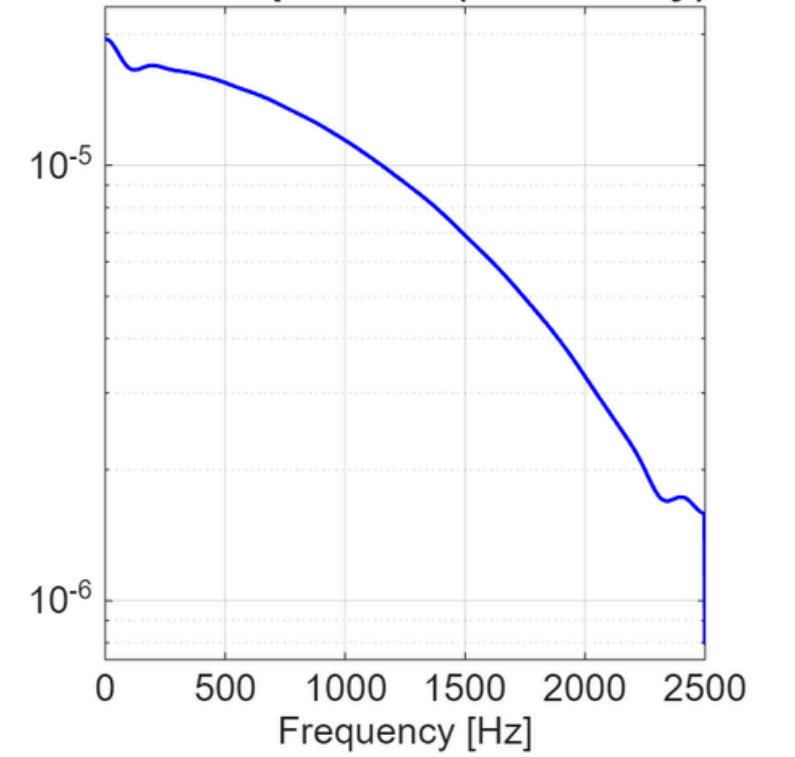
Time Windows Comparison



Power Spectrum (Without Tukey)

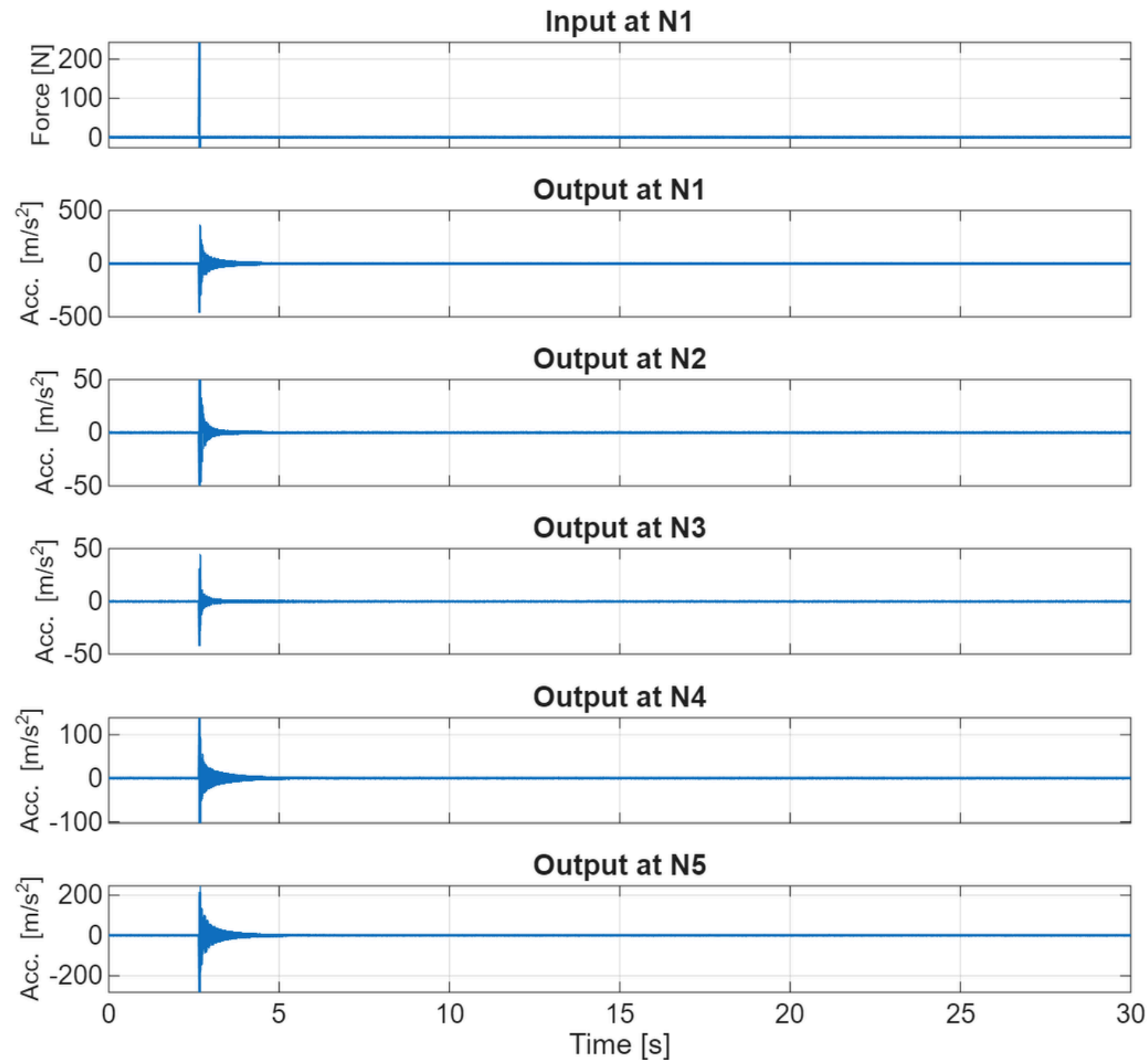


Power Spectrum (With Tukey)



- Noise removed
- Visible ringing effect

SIGNALS IN TIME: EXAMPLE



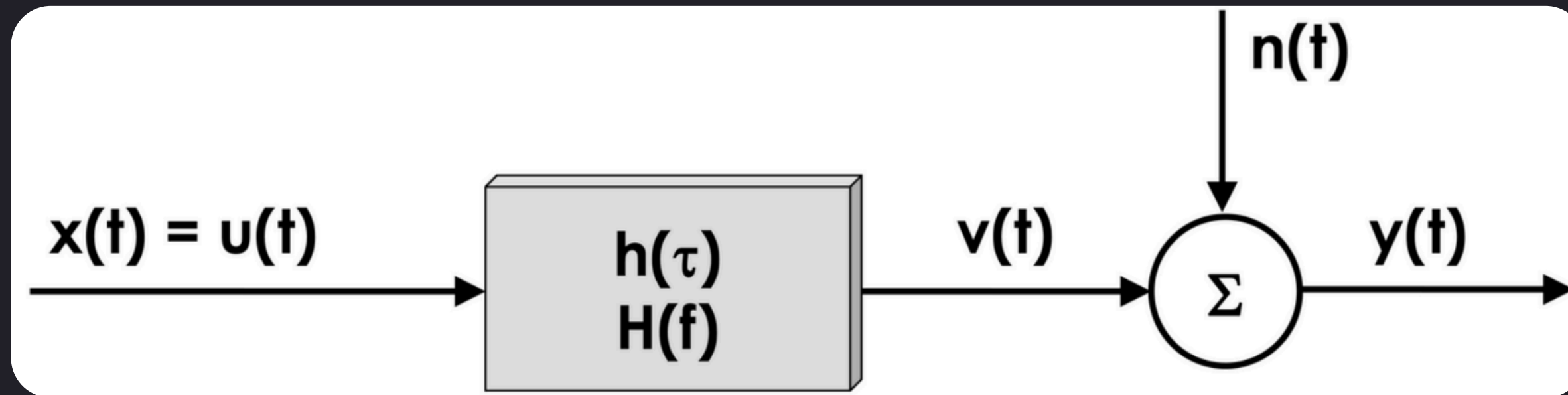
Clearly visible decay in the considered window



No need of **exponential window** on the output

ESTIMATOR'S CHOICE

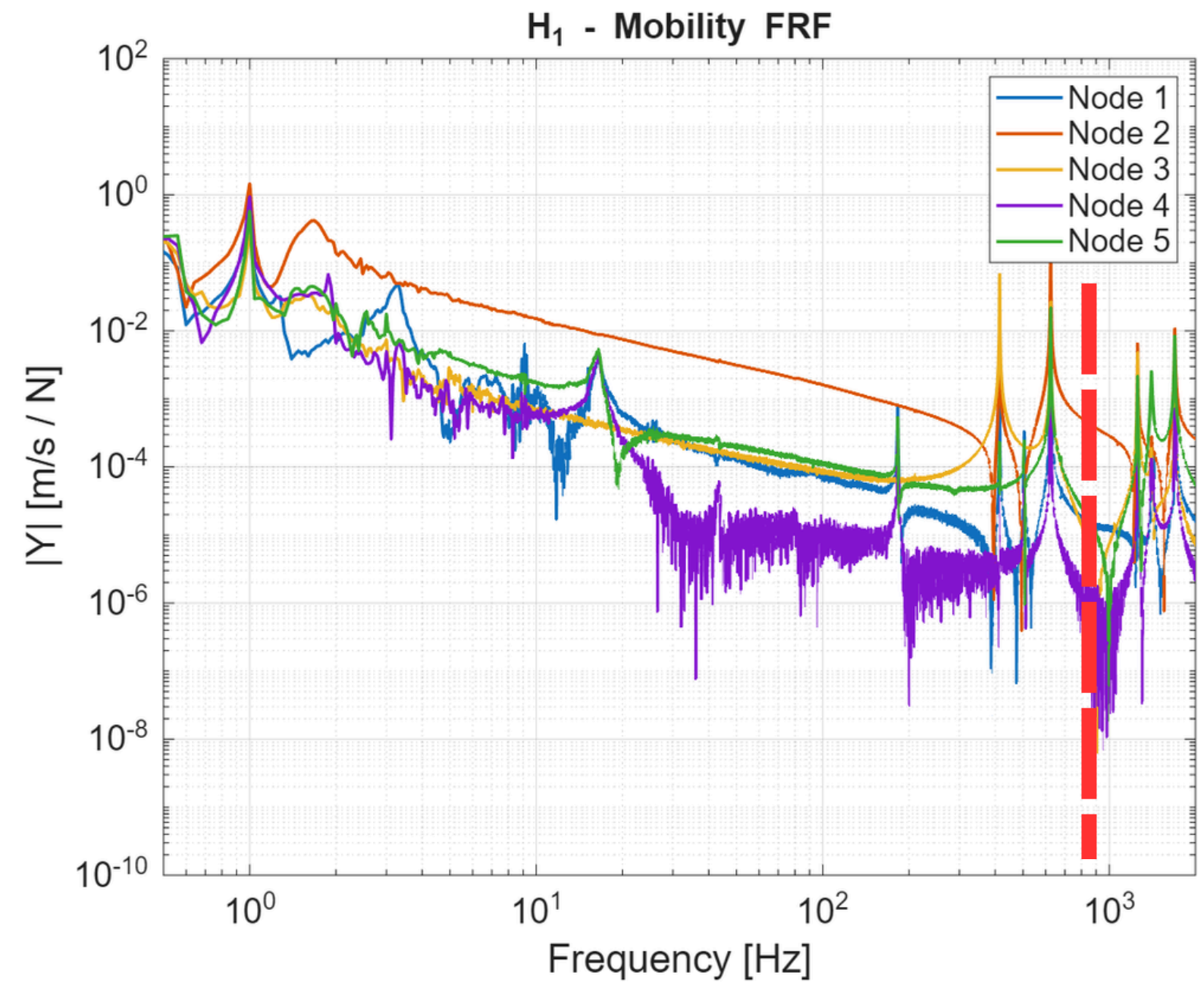
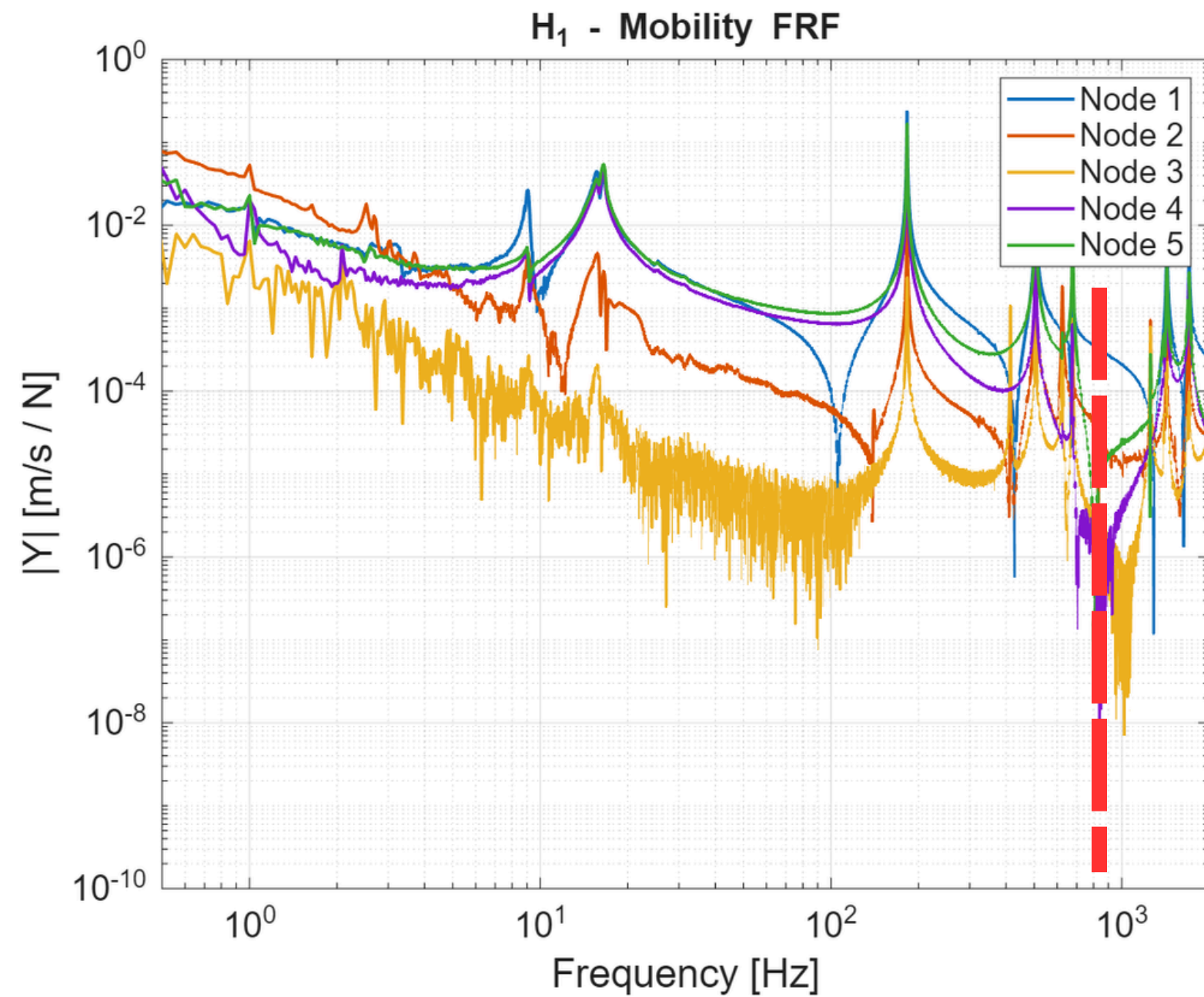
HP: noise on the output much bigger than noise in the input



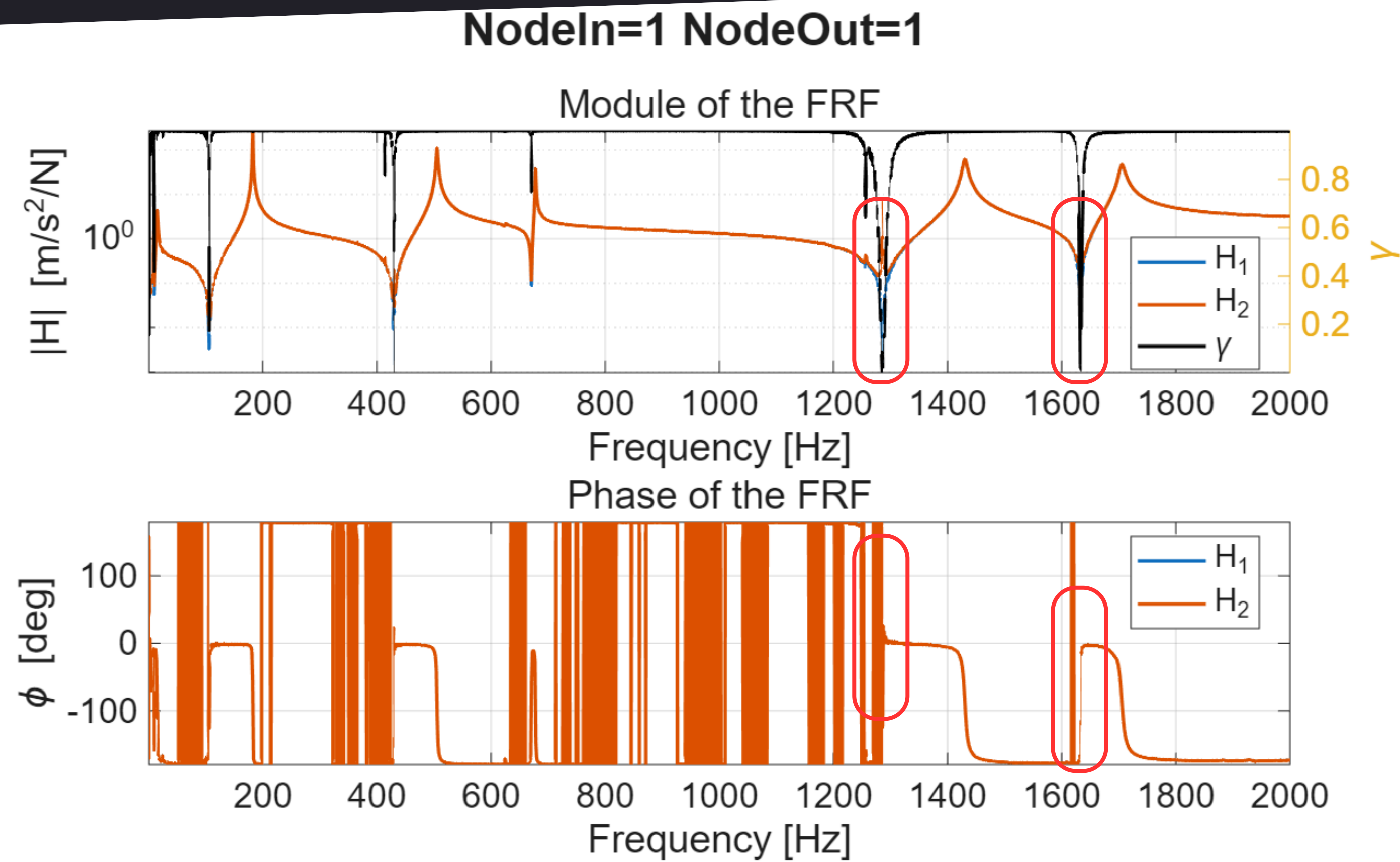
The chosen estimator was H1

VISUAL CHECK: MOBILITY

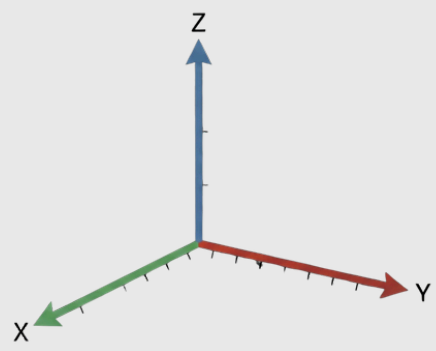
Decreasing trend at low frequency: **mass dominated**



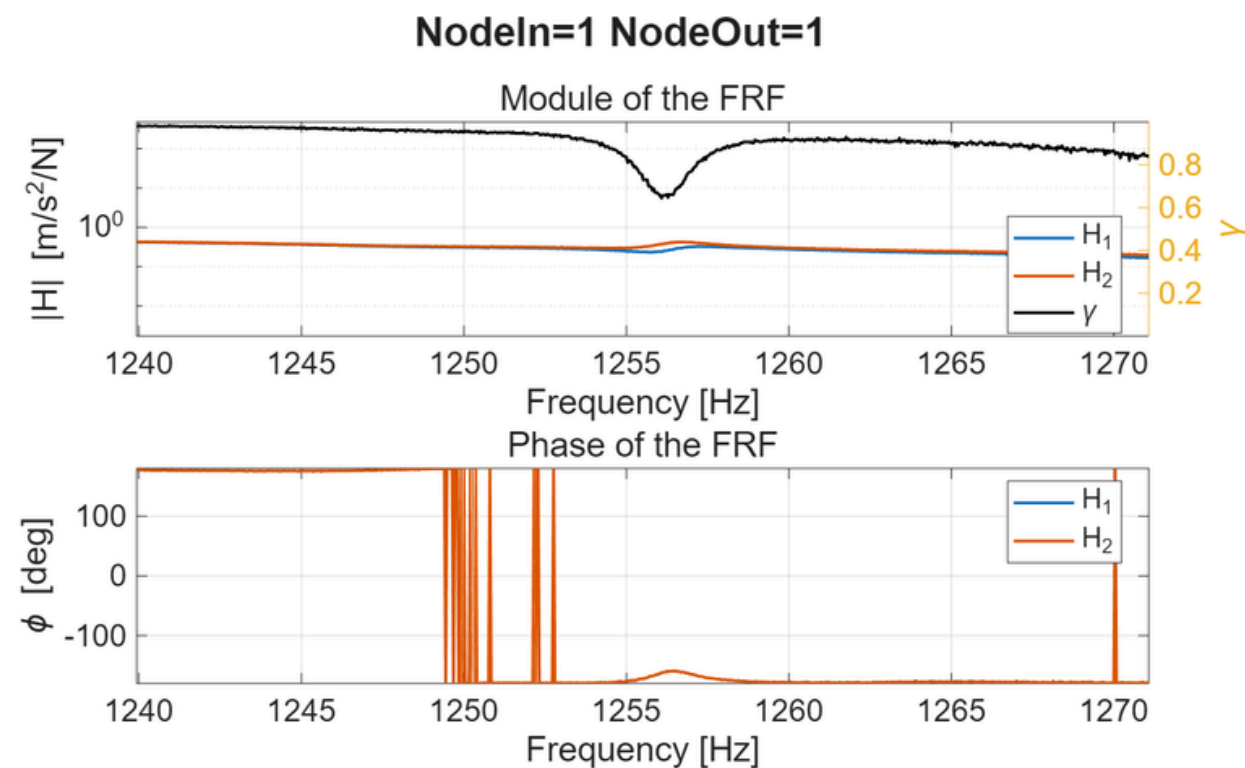
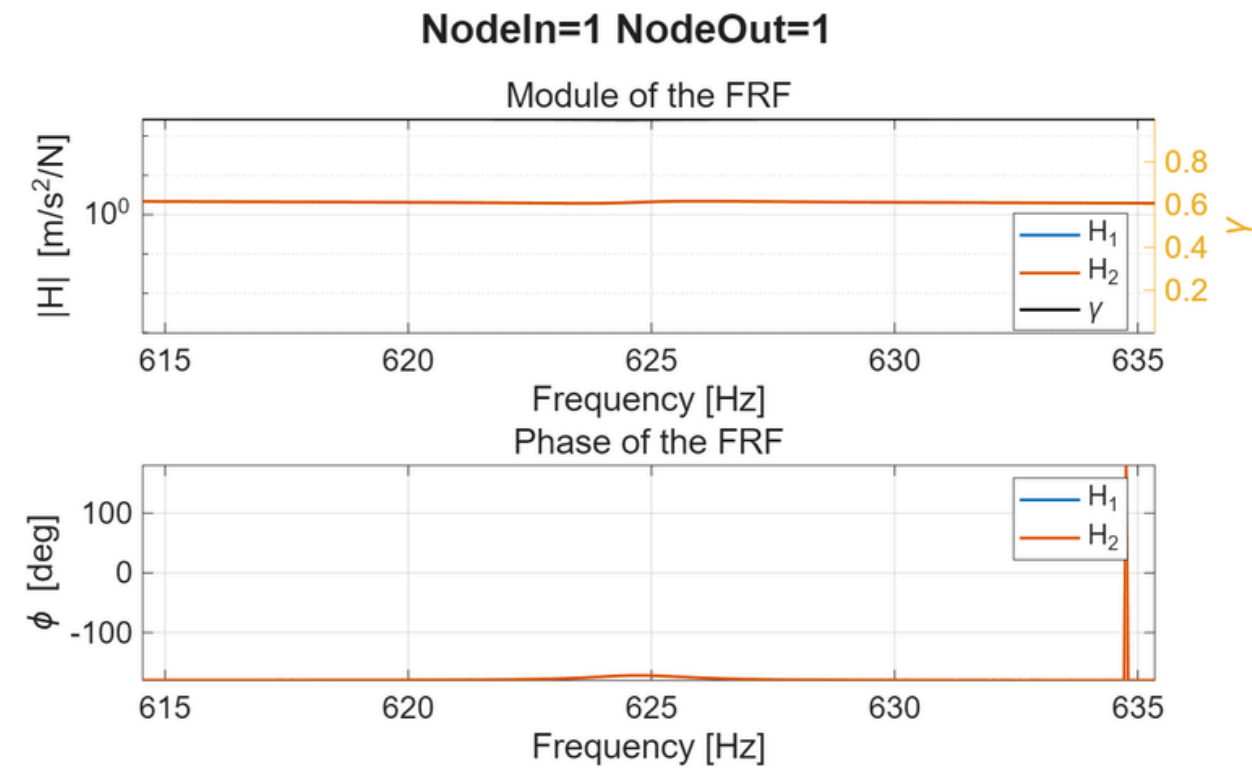
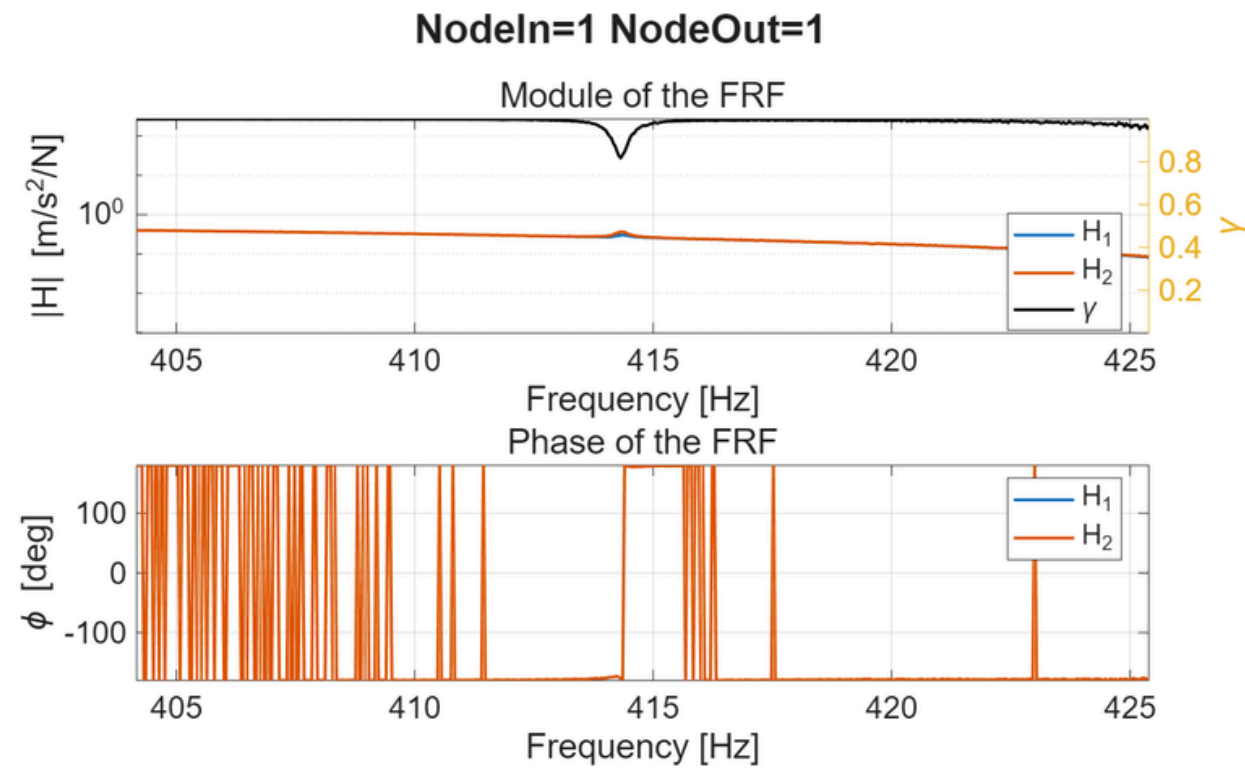
INPUT 1: CO-LOCATED FRF



1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz

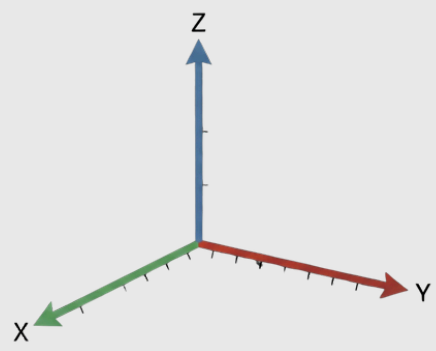


ANALYSIS

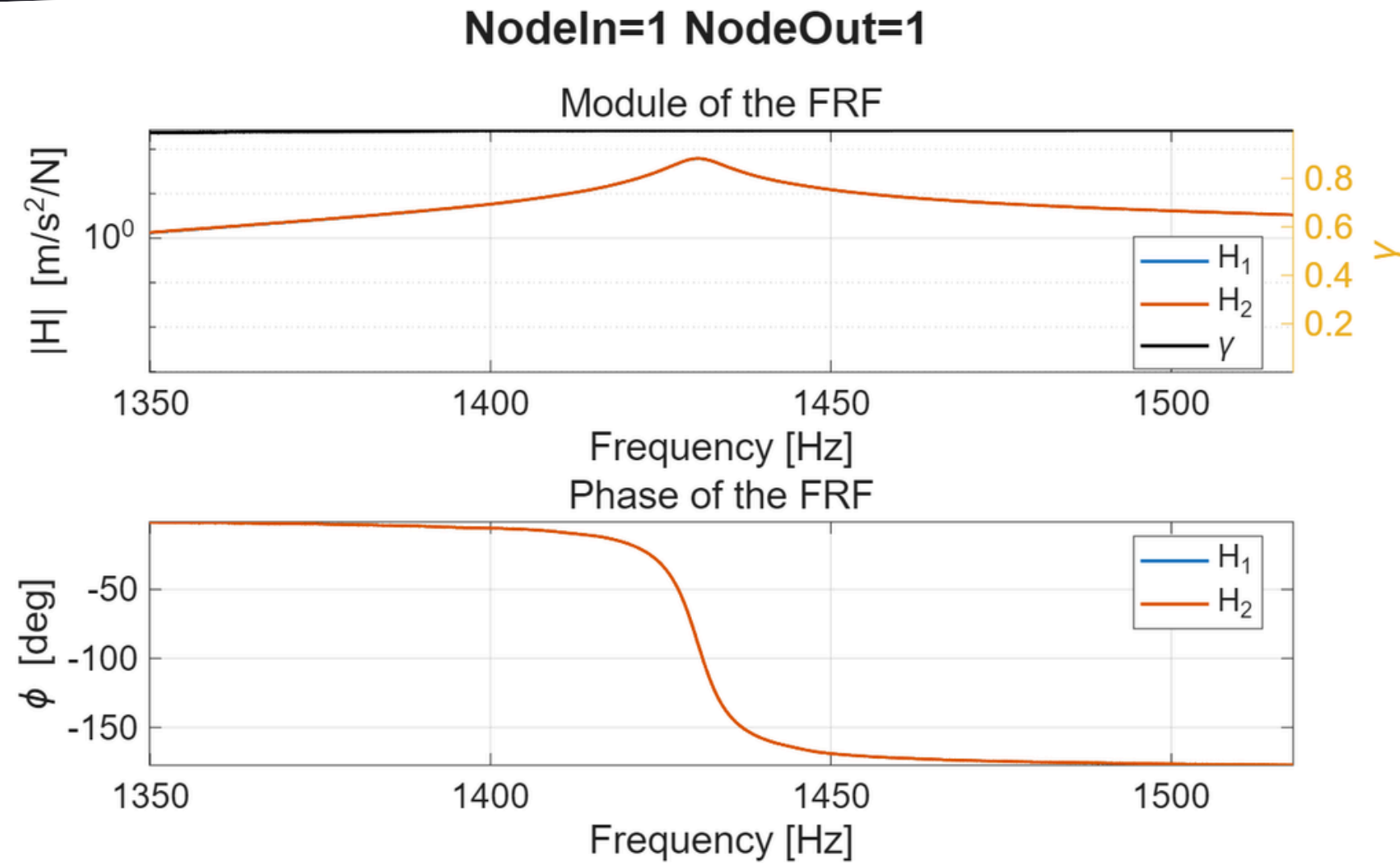


- They are “**nodes**”
- Structure excited on Y-Z plane

2	416.6 Hz
4	627.4 Hz
6	1280.2 Hz

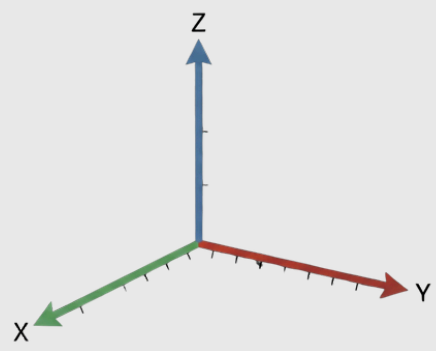


ANALYSIS

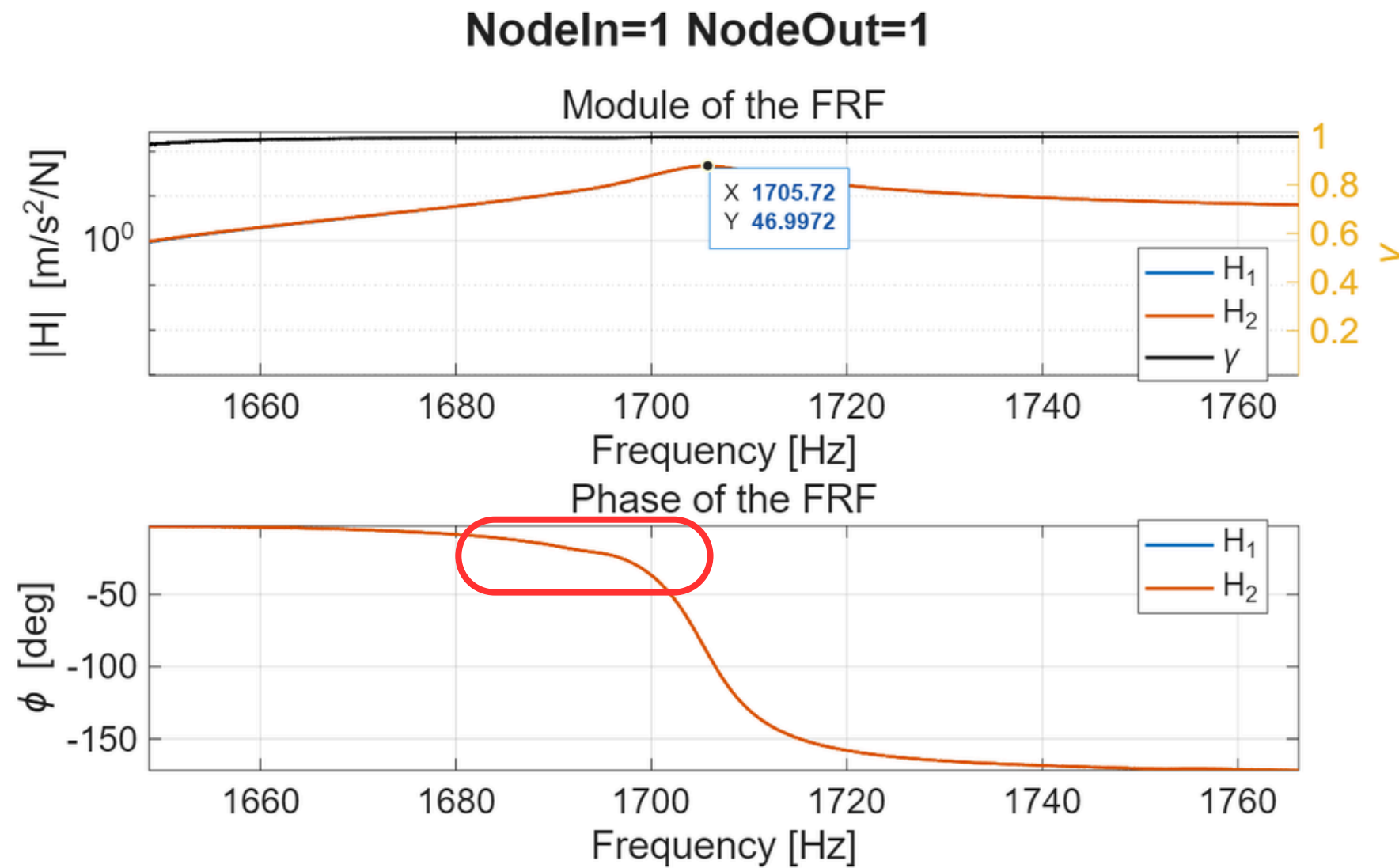


- **Mode 7** (torsional) clearly **not measured**
- **Mode 8** (Y-Z plane) **well visible**

7	1409.6 Hz
8	1427.0 Hz



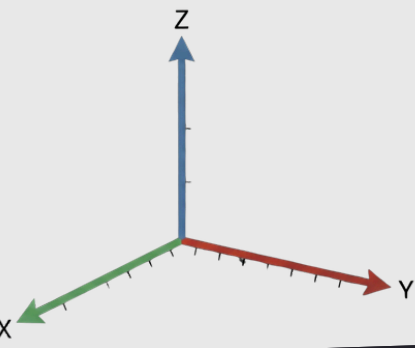
ANALYSIS



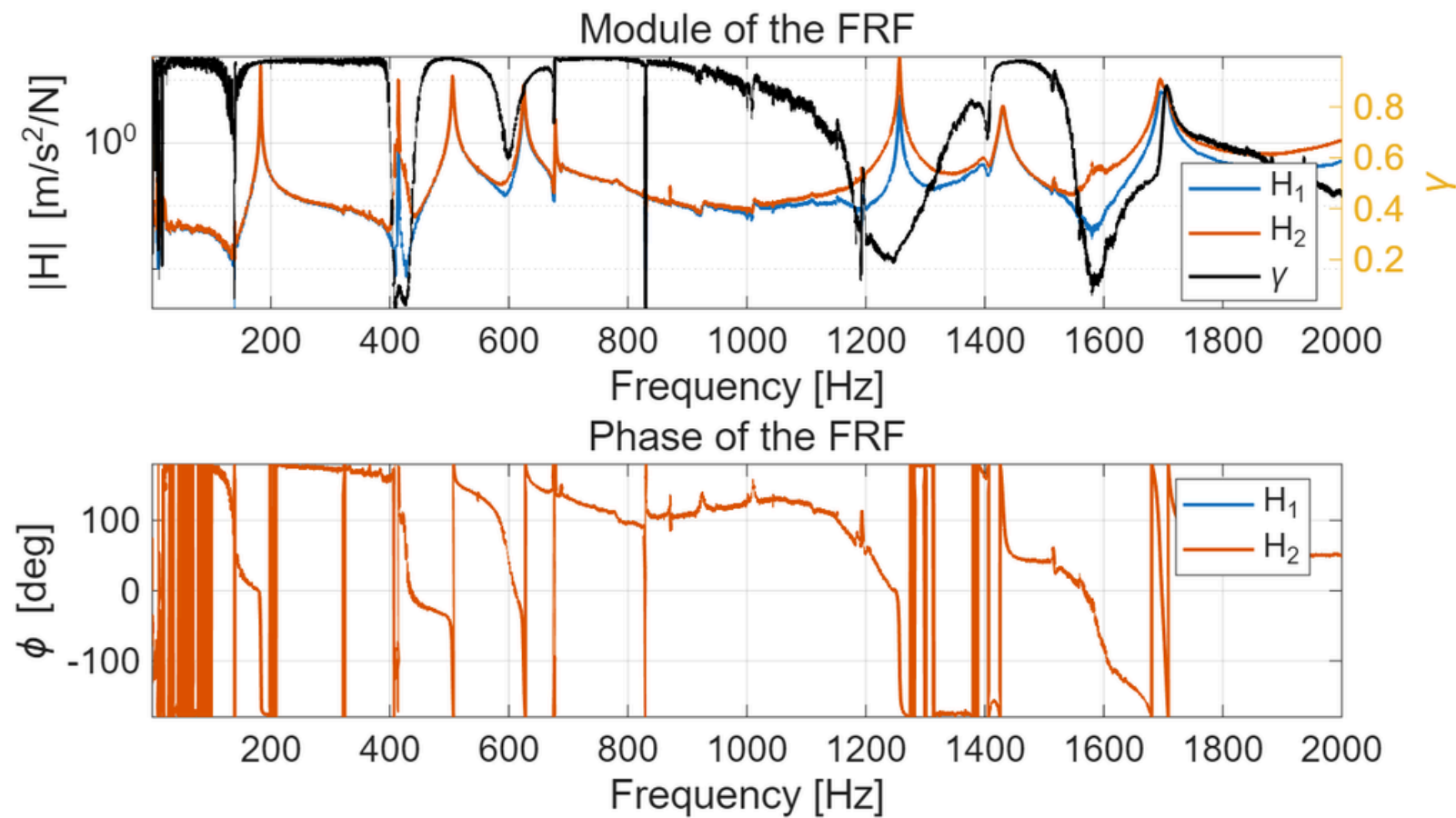
- Is it **mode 9 or 10**? It seems the 10th
- The 2 modes are very **influenced** by each other

9	1703.7 Hz
10	1705.8 Hz

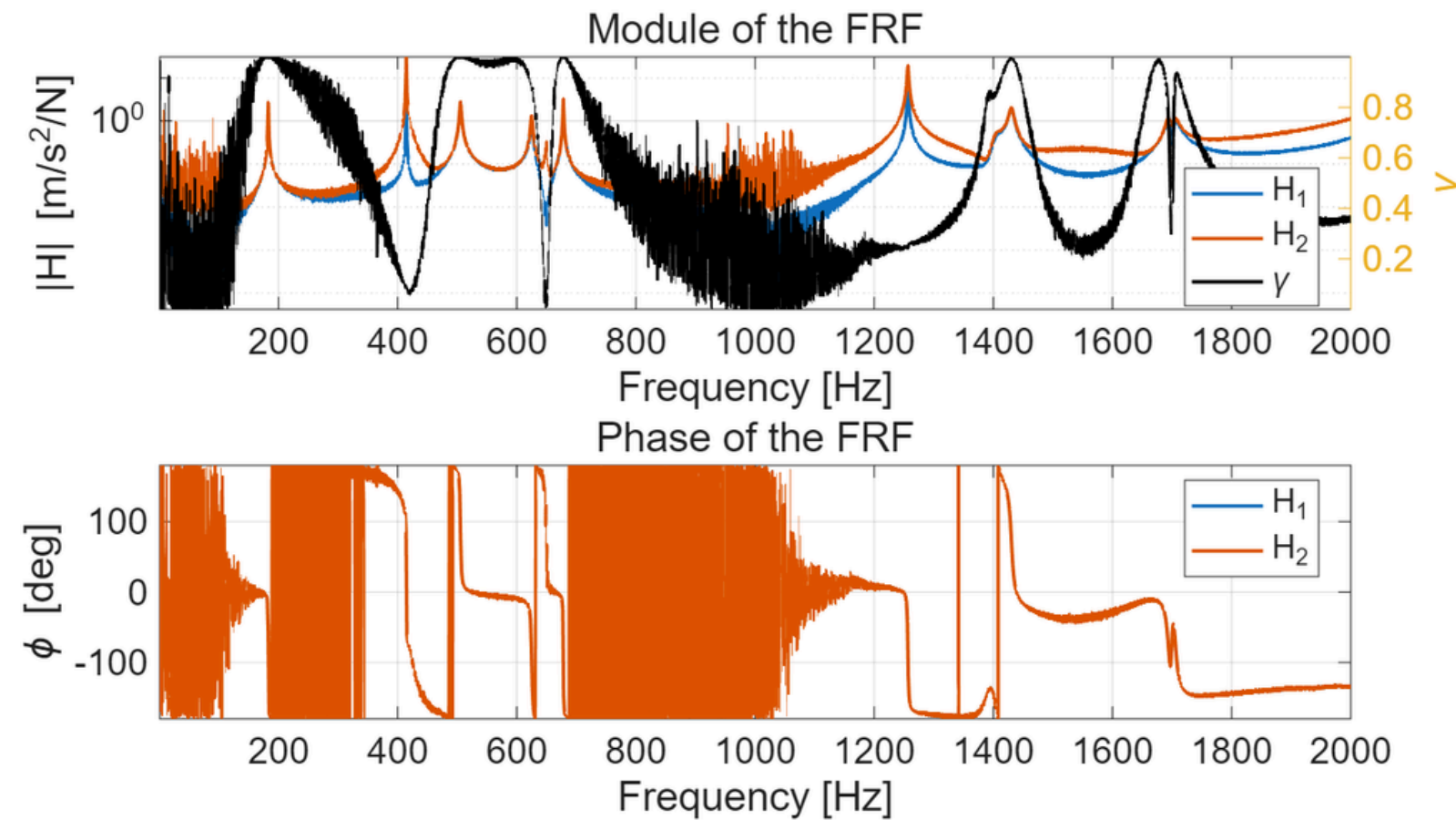
INPUT 1: TRANSFER FRF



NodeIn=1 NodeOut=2

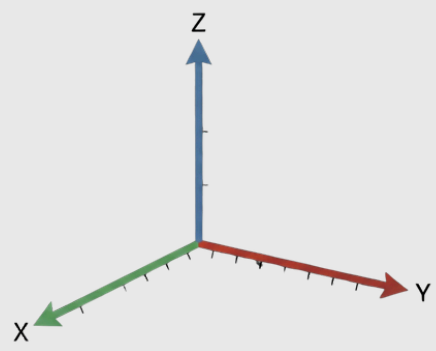


NodeIn=1 NodeOut=3

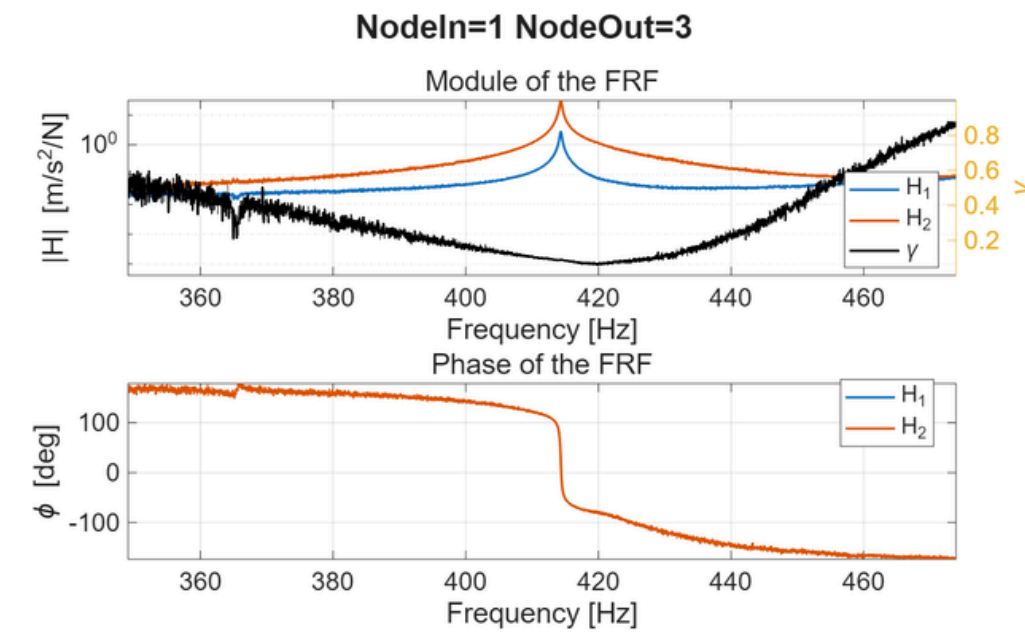
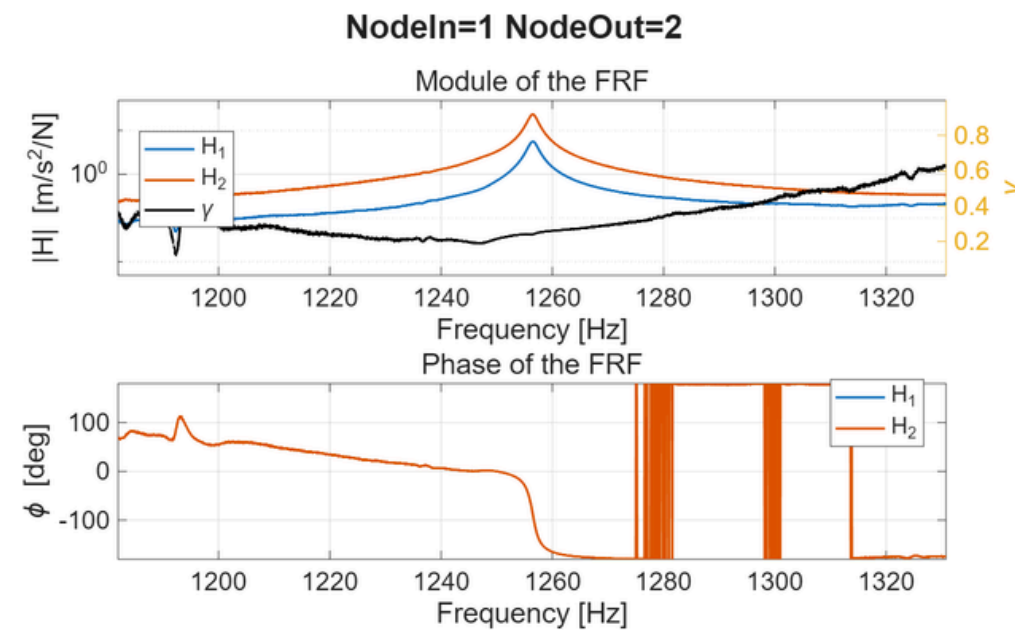
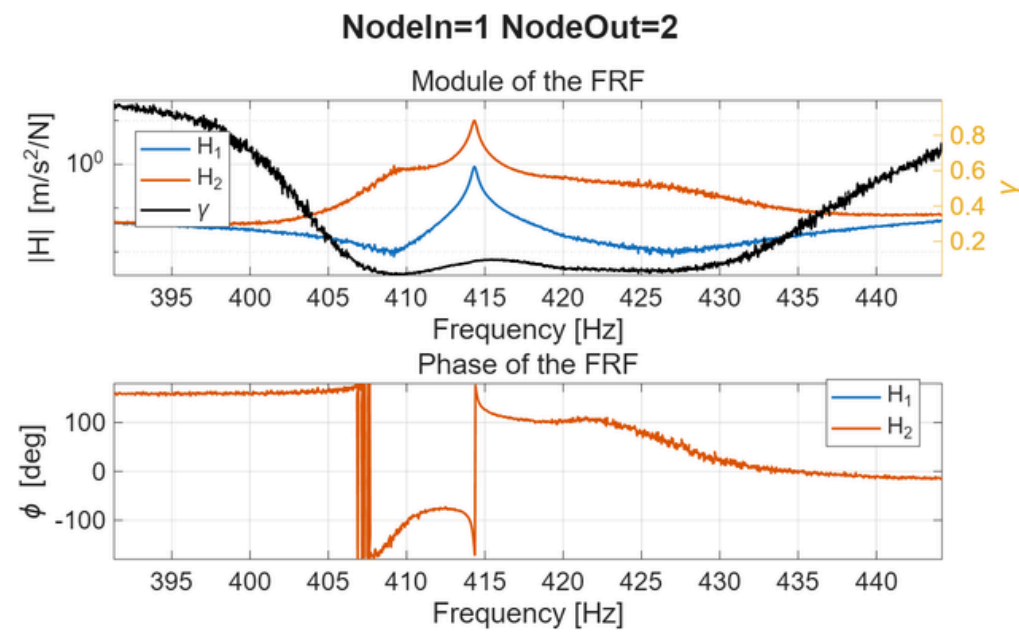


- Accelerometers 2 and 3 measure along the X axis (not excited)

1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz



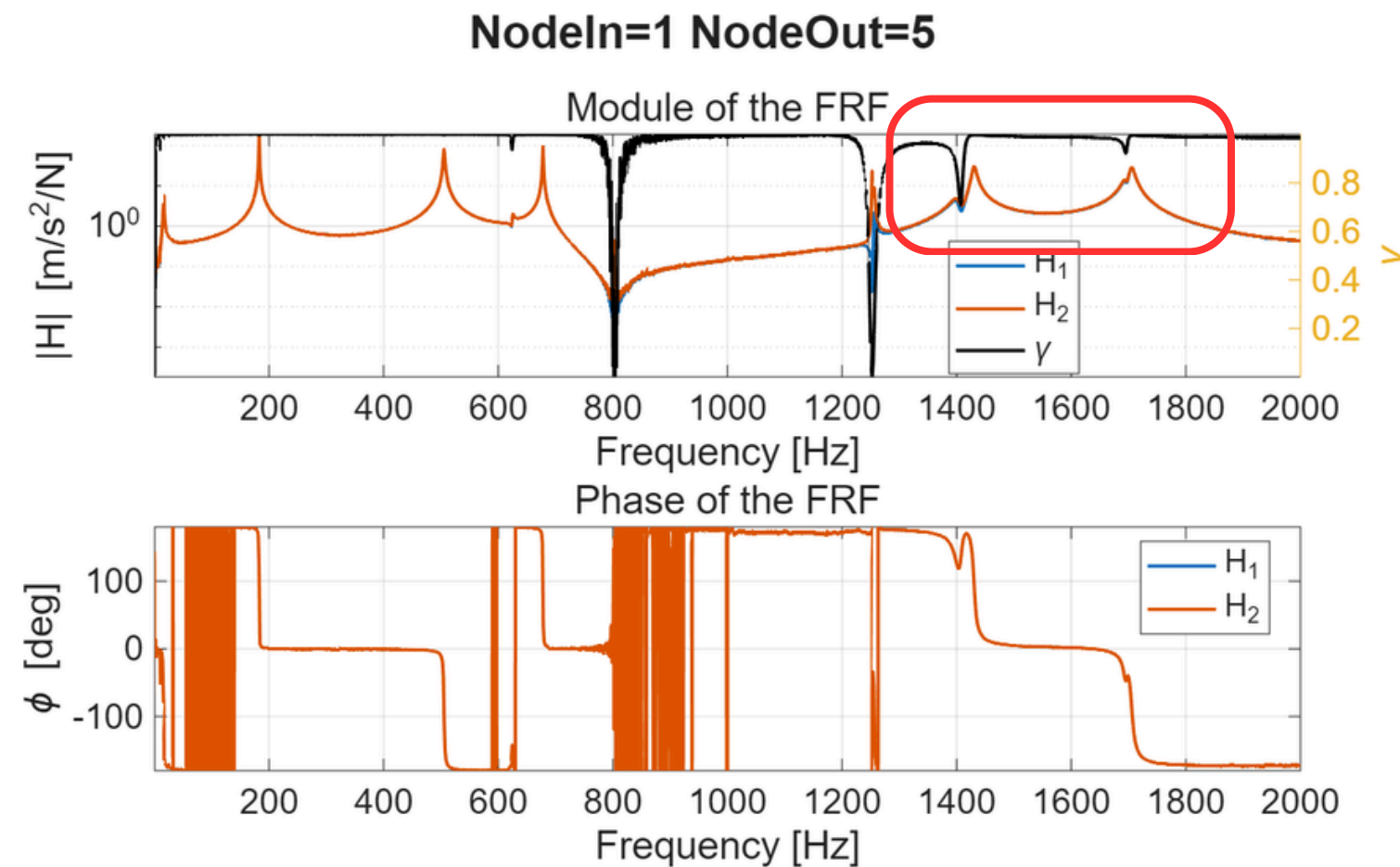
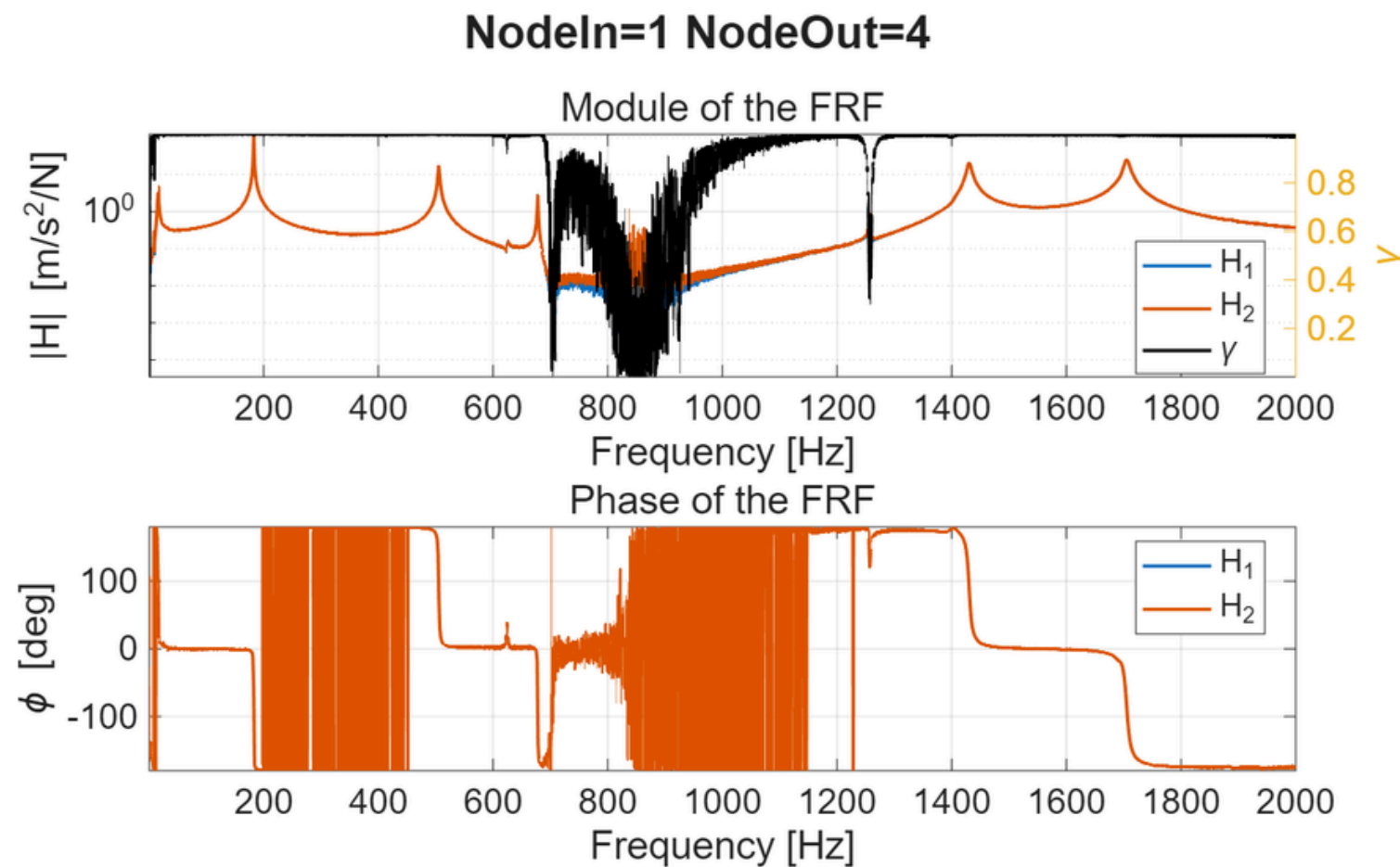
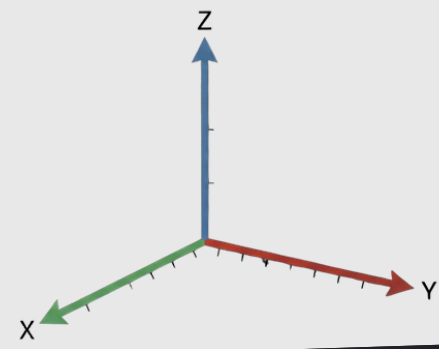
ANALYSIS



- **Bad signal to noise ratio**, because we are measuring in a nodal plane
- FRF 1-2 and 1-3 **not reliable**

2	416.6 Hz
6	1280.2 Hz

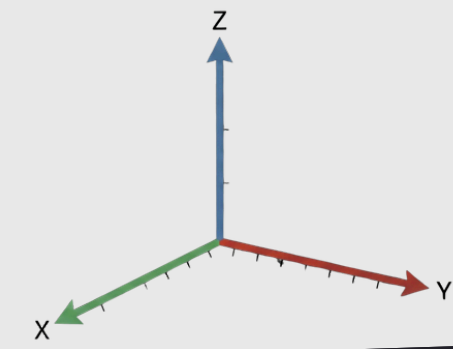
INPUT 1: TRANSFER FRF



- Accelerometers 4 and 5 measure along the **Y axis** (excited)
- FRF 1-5 shows both the **double peaks**

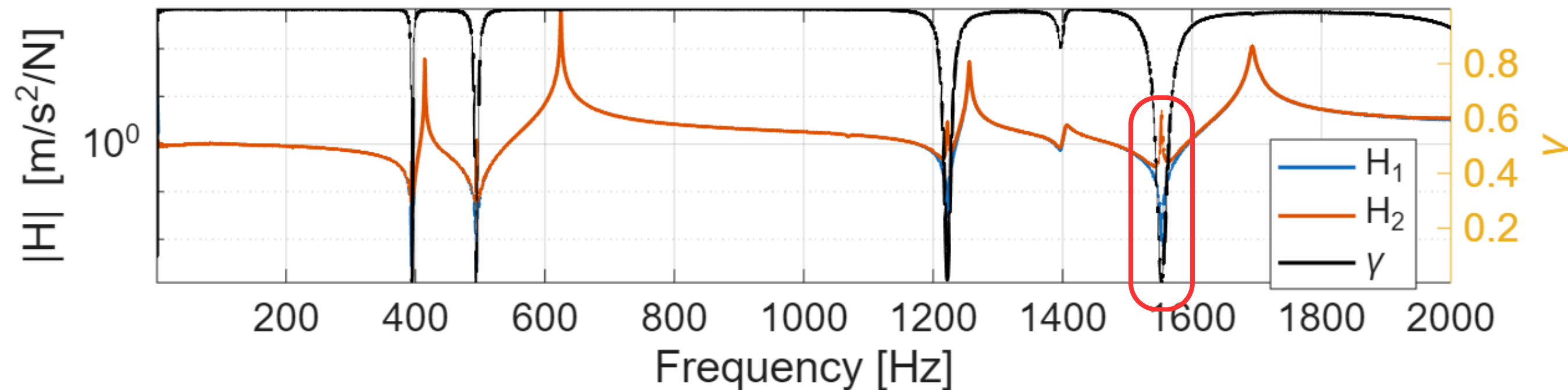
1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz

INPUT 2: CO-LOCATED FRF

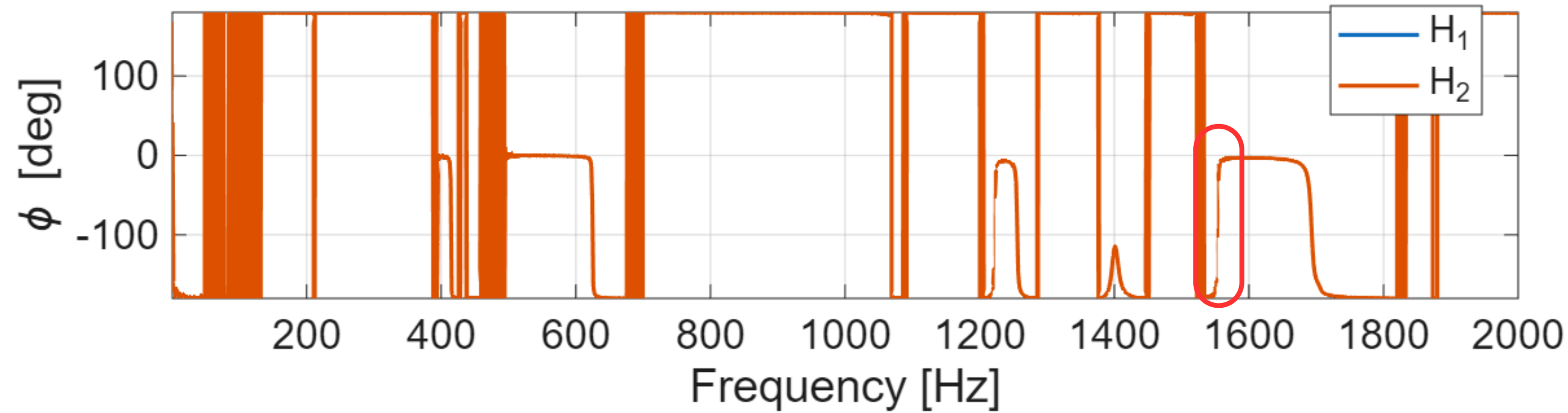


NodeIn=2 NodeOut=2

Module of the FRF

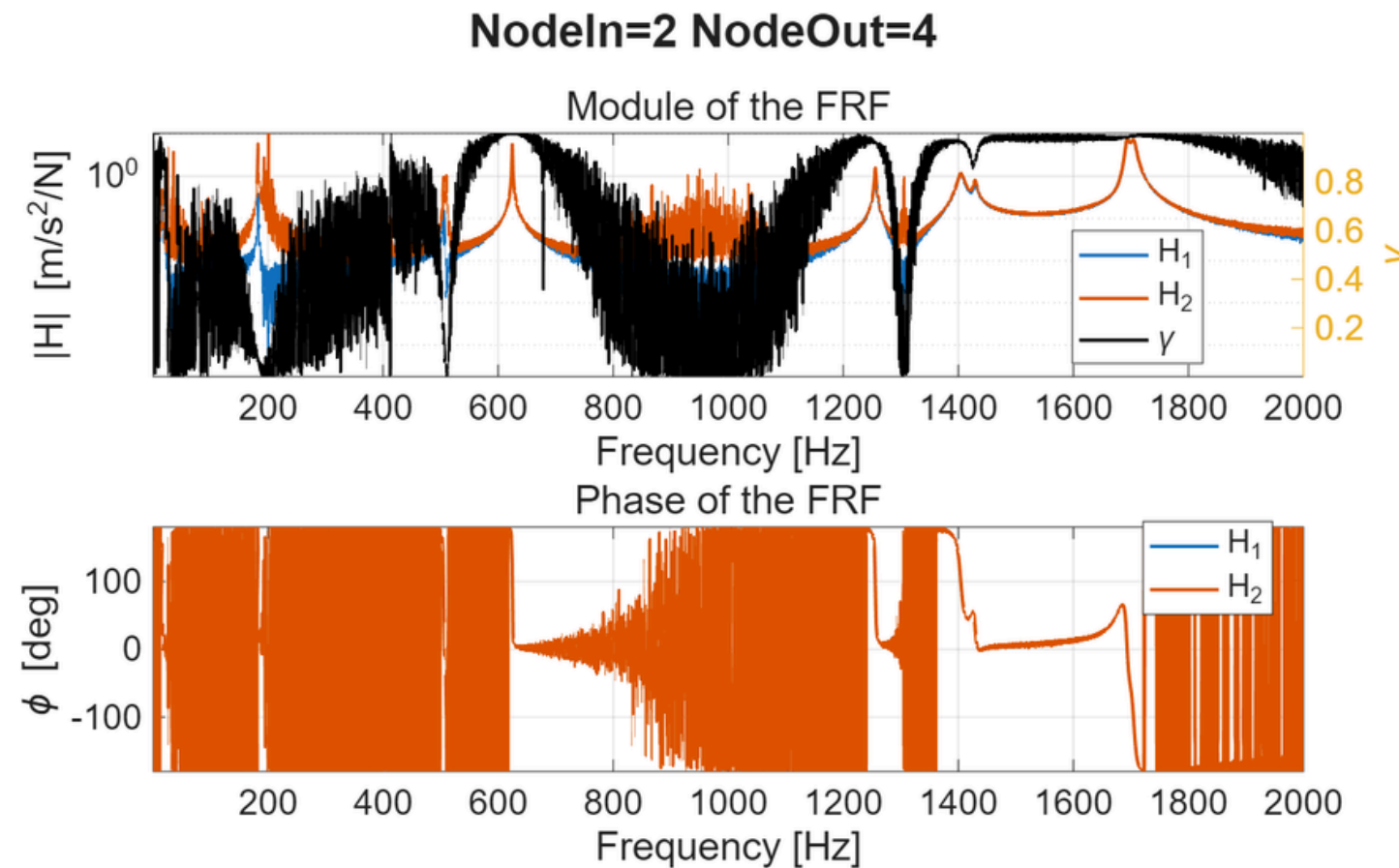
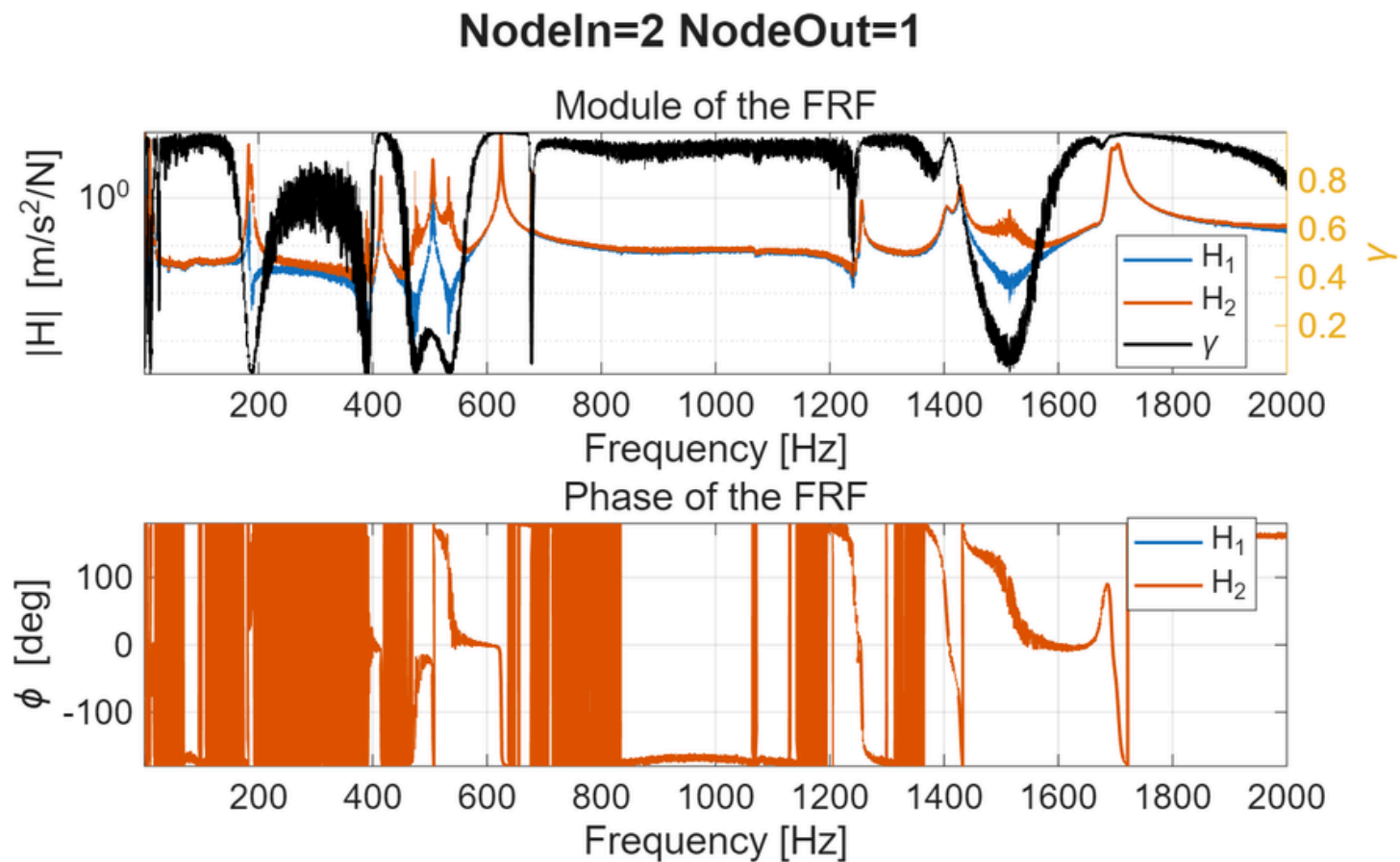


Phase of the FRF



1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz

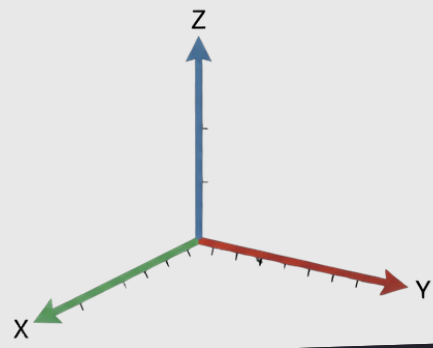
INPUT 2: TRANSFER FRF



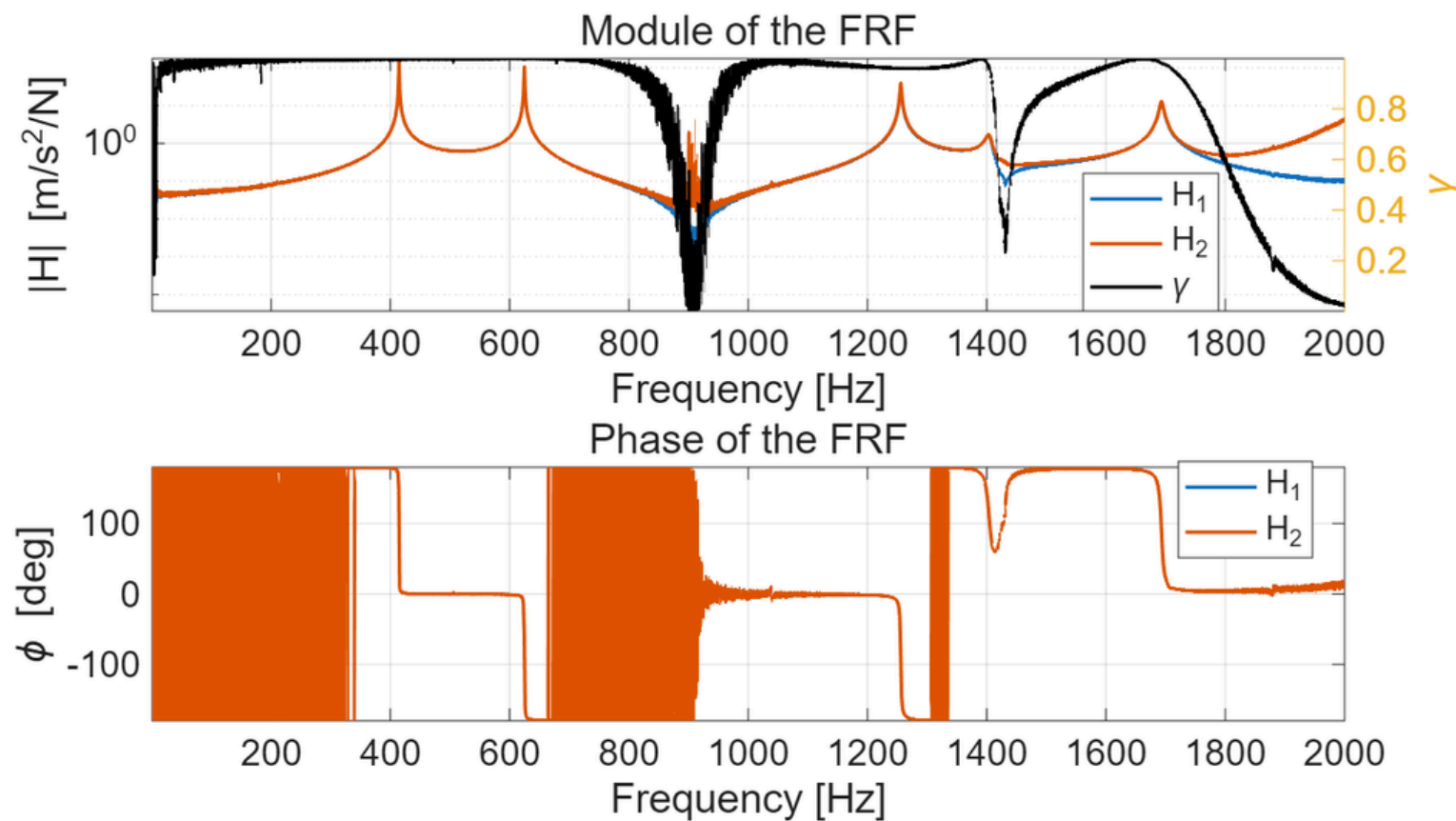
- Accelerometer 1 measures along the Z axis (not excited)
- Accelerometer 4 measures along the X axis

1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz

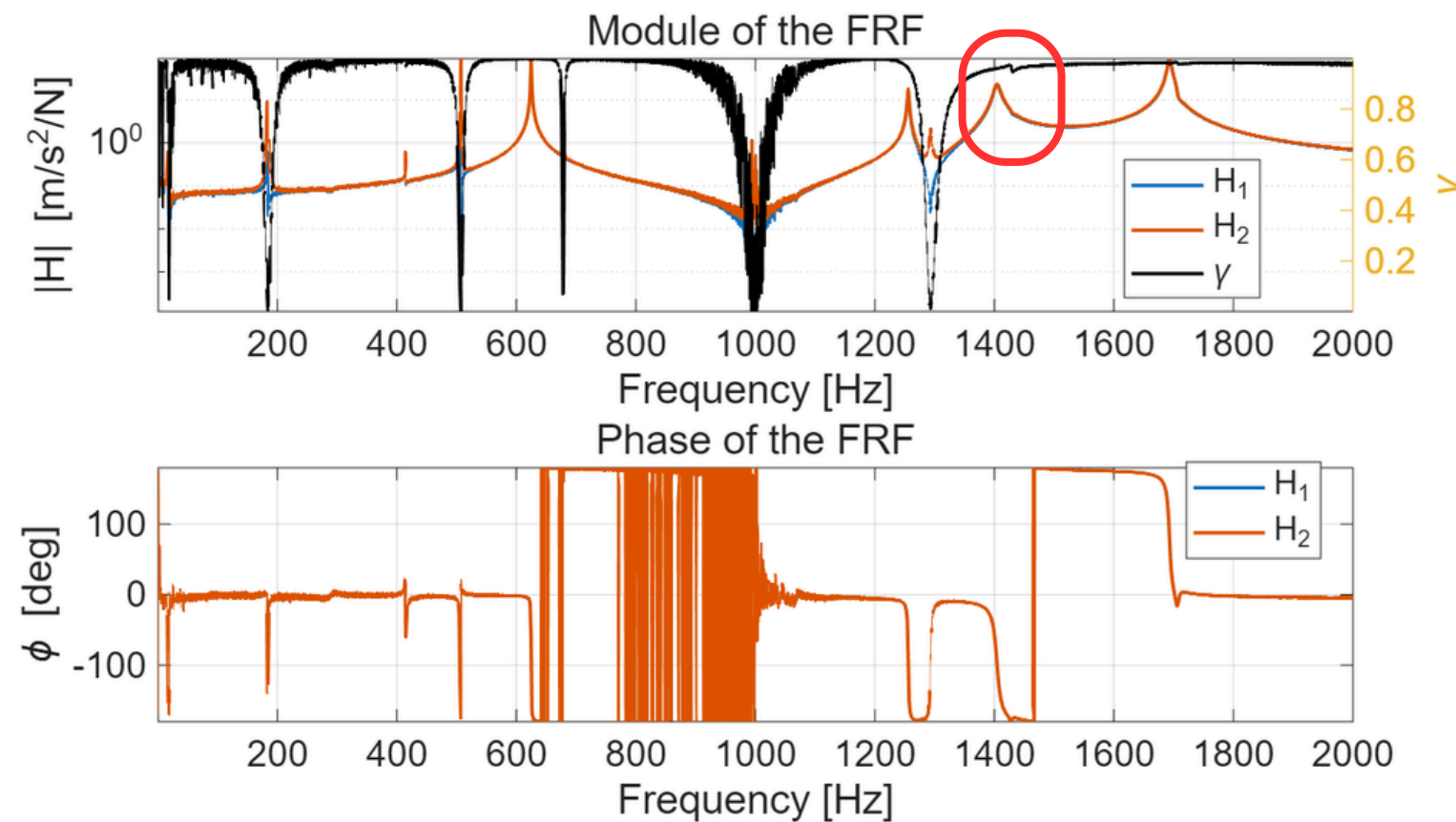
INPUT 2: TRANSFER FRF



NodeIn=2 NodeOut=3



NodeIn=2 NodeOut=5



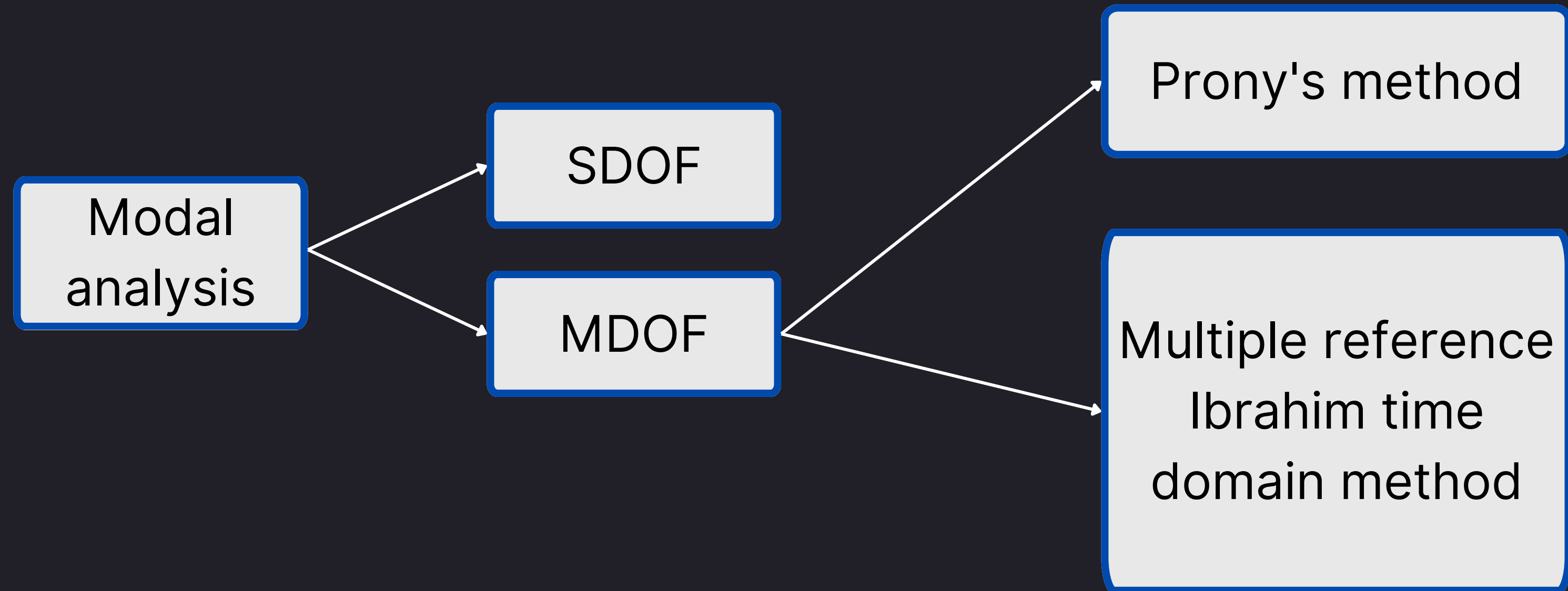
- Accelerometer 3 measures along the Y axis (excited)
- Accelerometer 5 measures along the X axis

1	184.2 Hz
2	416.6 Hz
3	500.6 Hz
4	627.4 Hz
5	675.9 Hz
6	1280.2 Hz
7	1409.6 Hz
8	1427.0 Hz
9	1703.7 Hz
10	1705.8 Hz

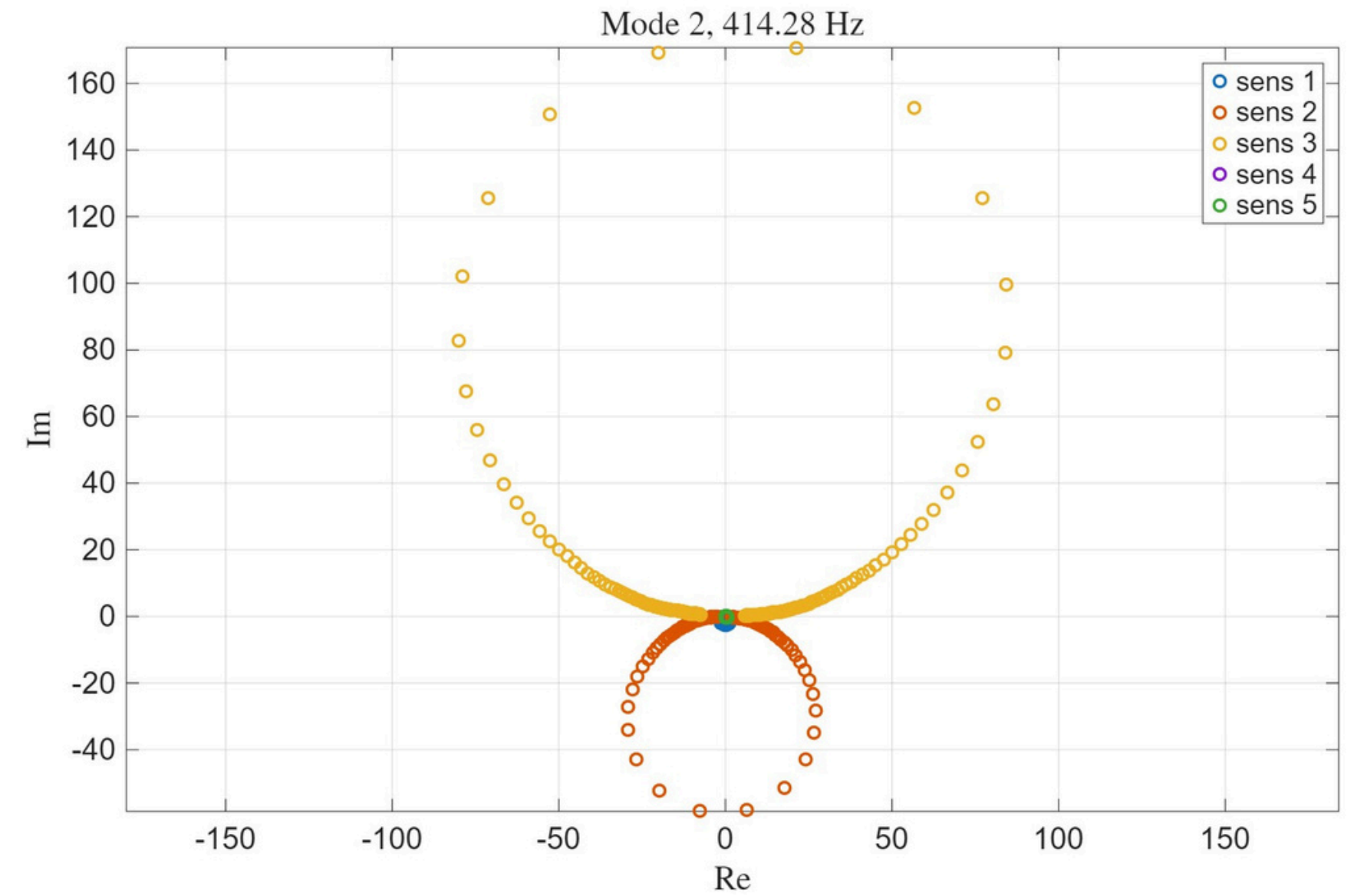
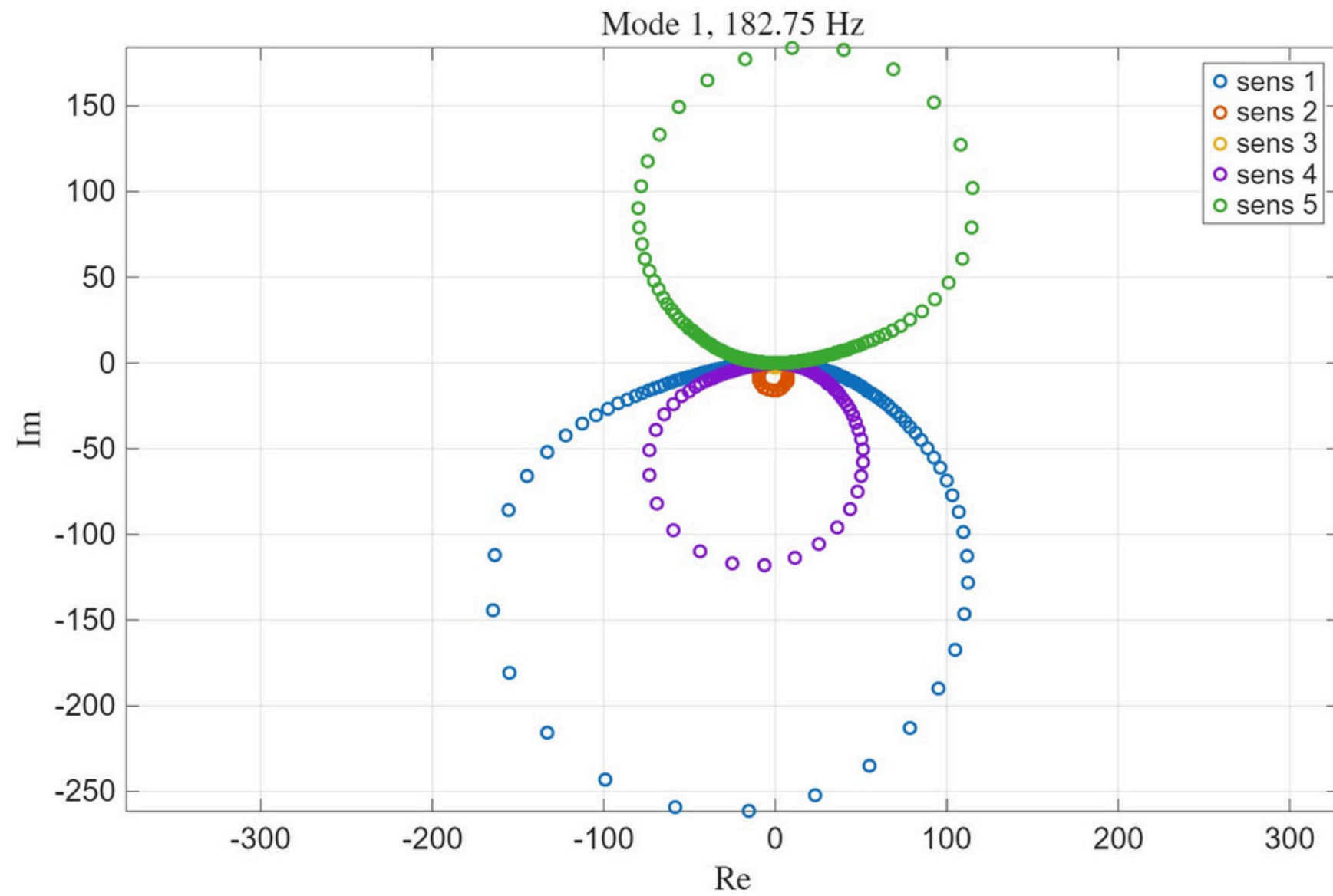


05. MODAL IDENTIFICATION

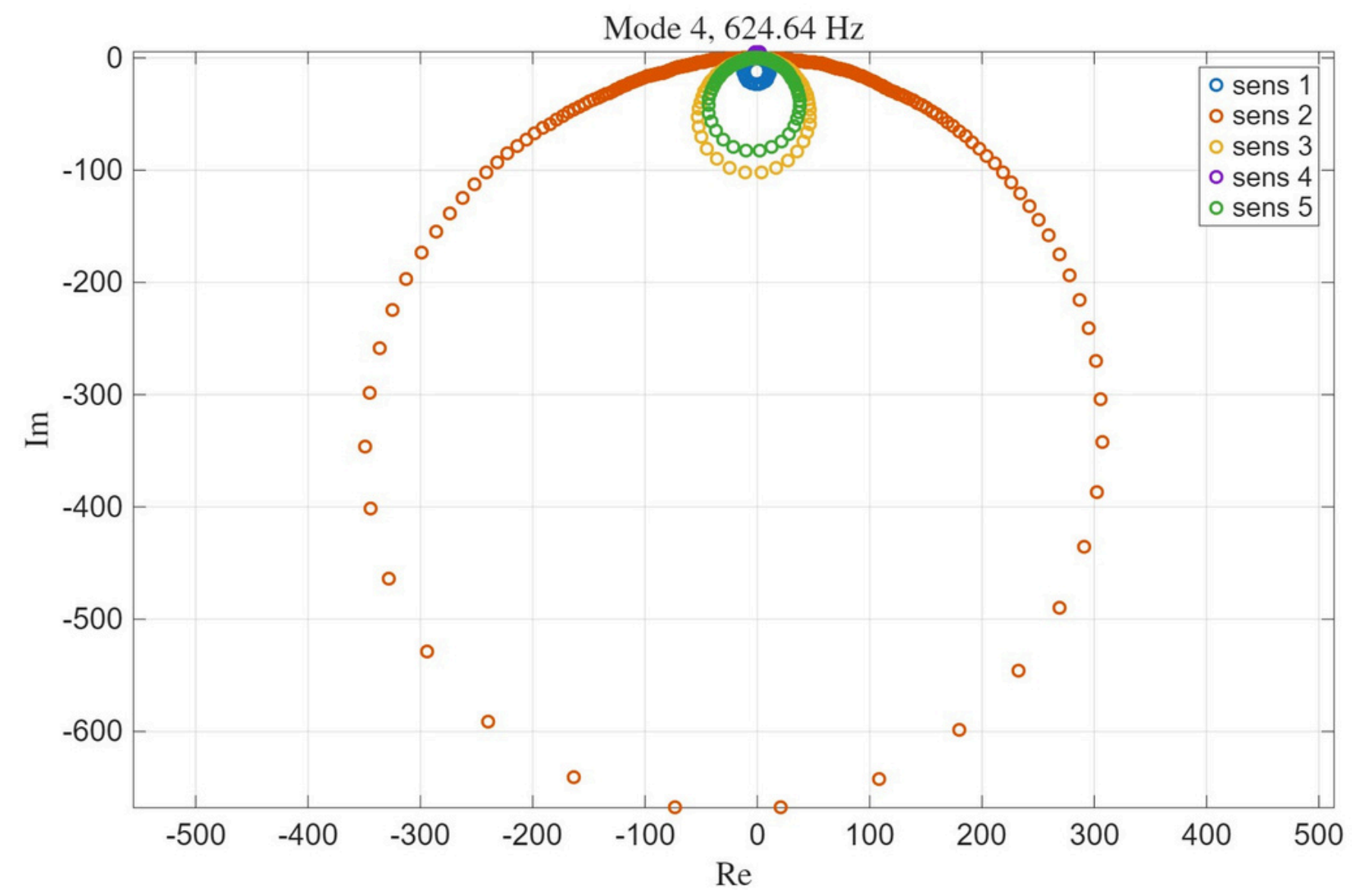
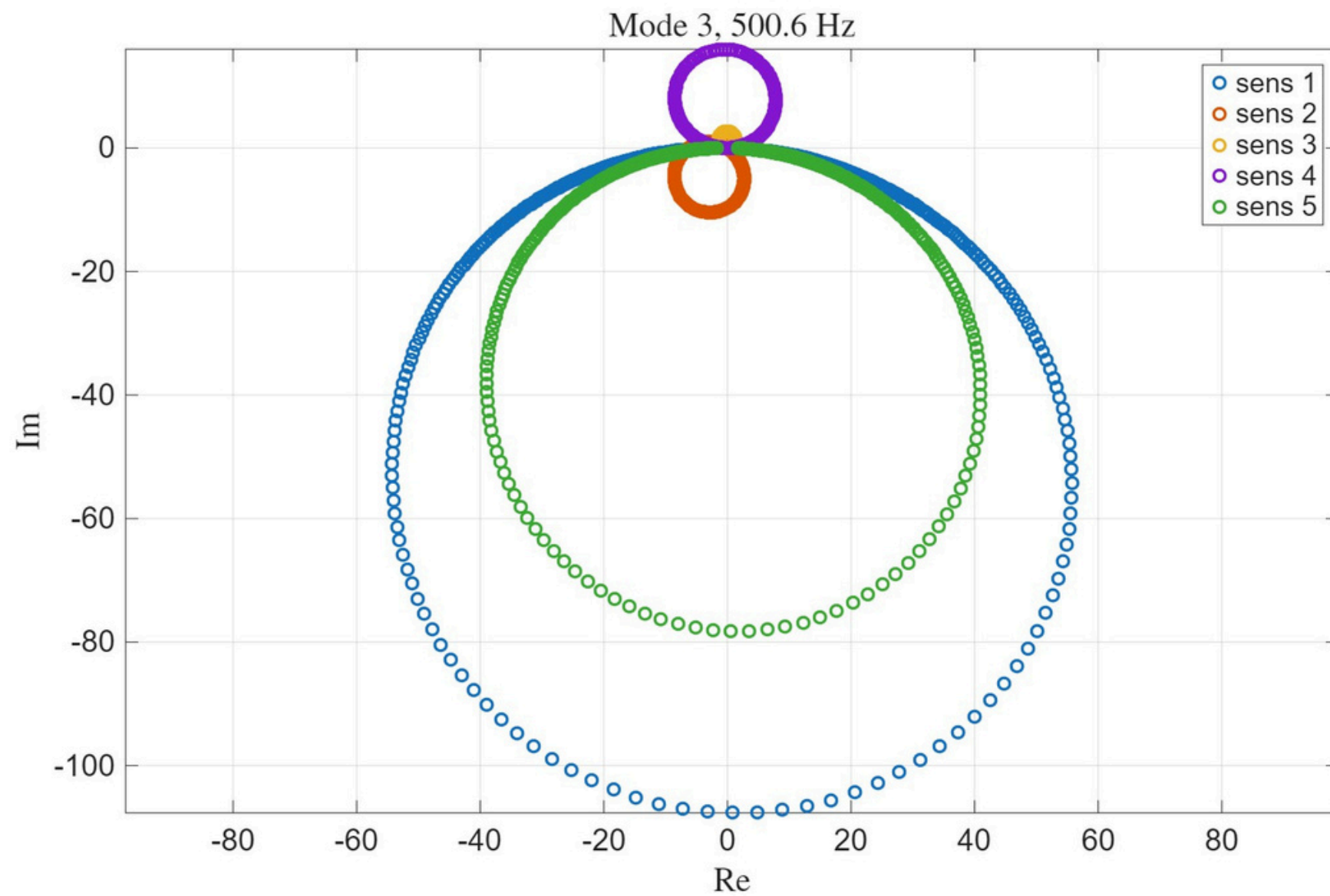
WHICH METHOD?



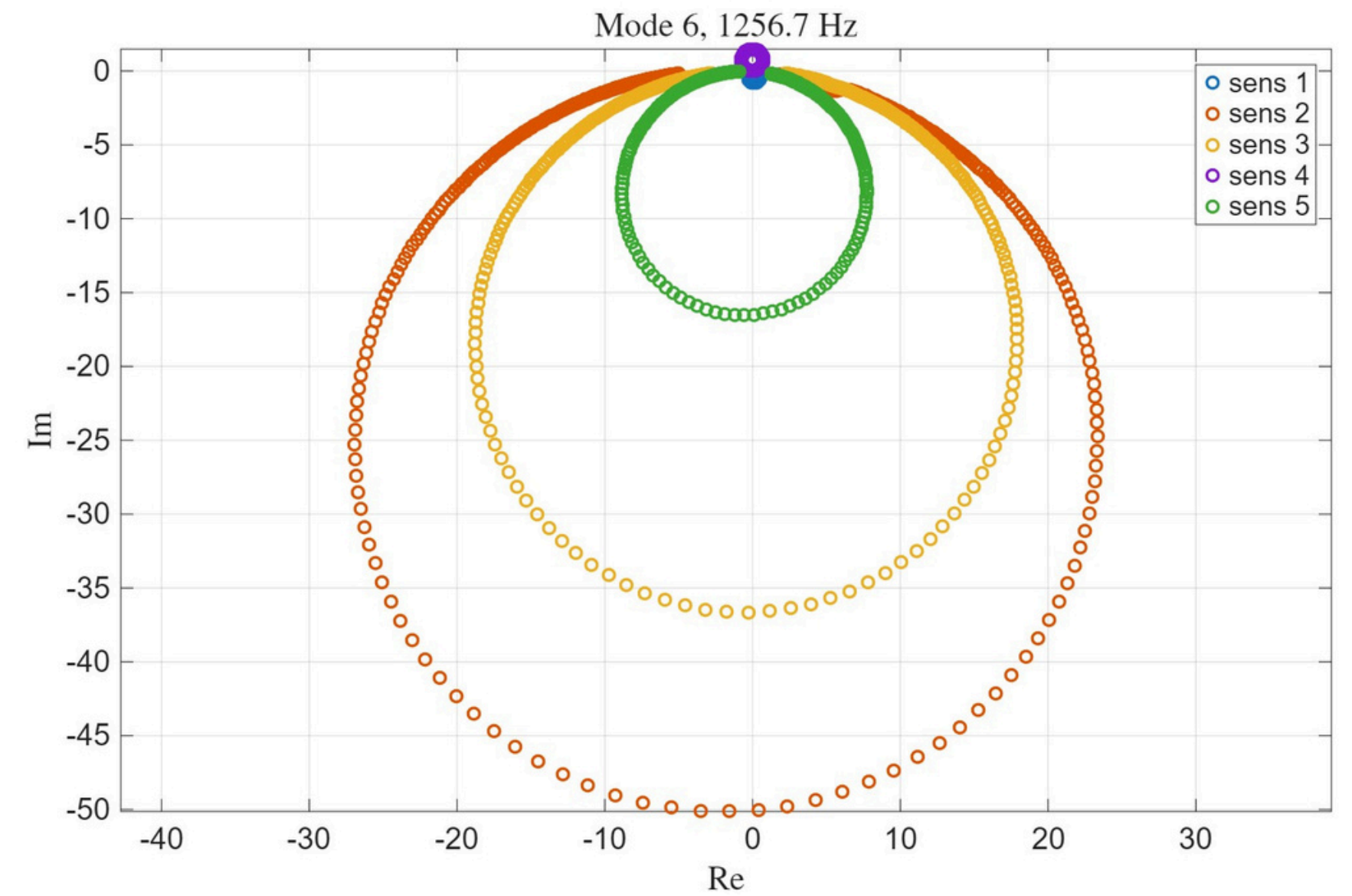
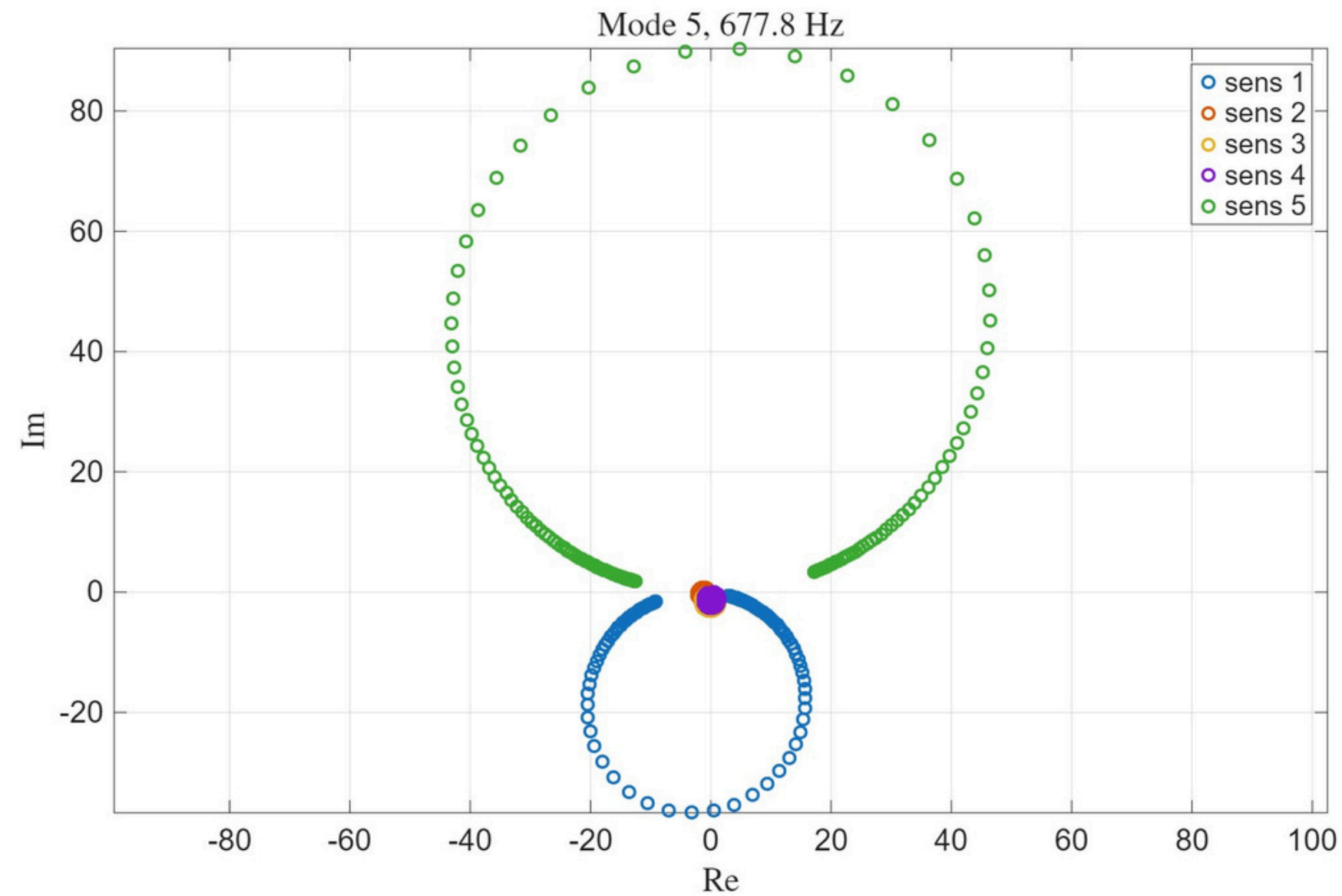
SDOF - NYQUIST CIRCLES



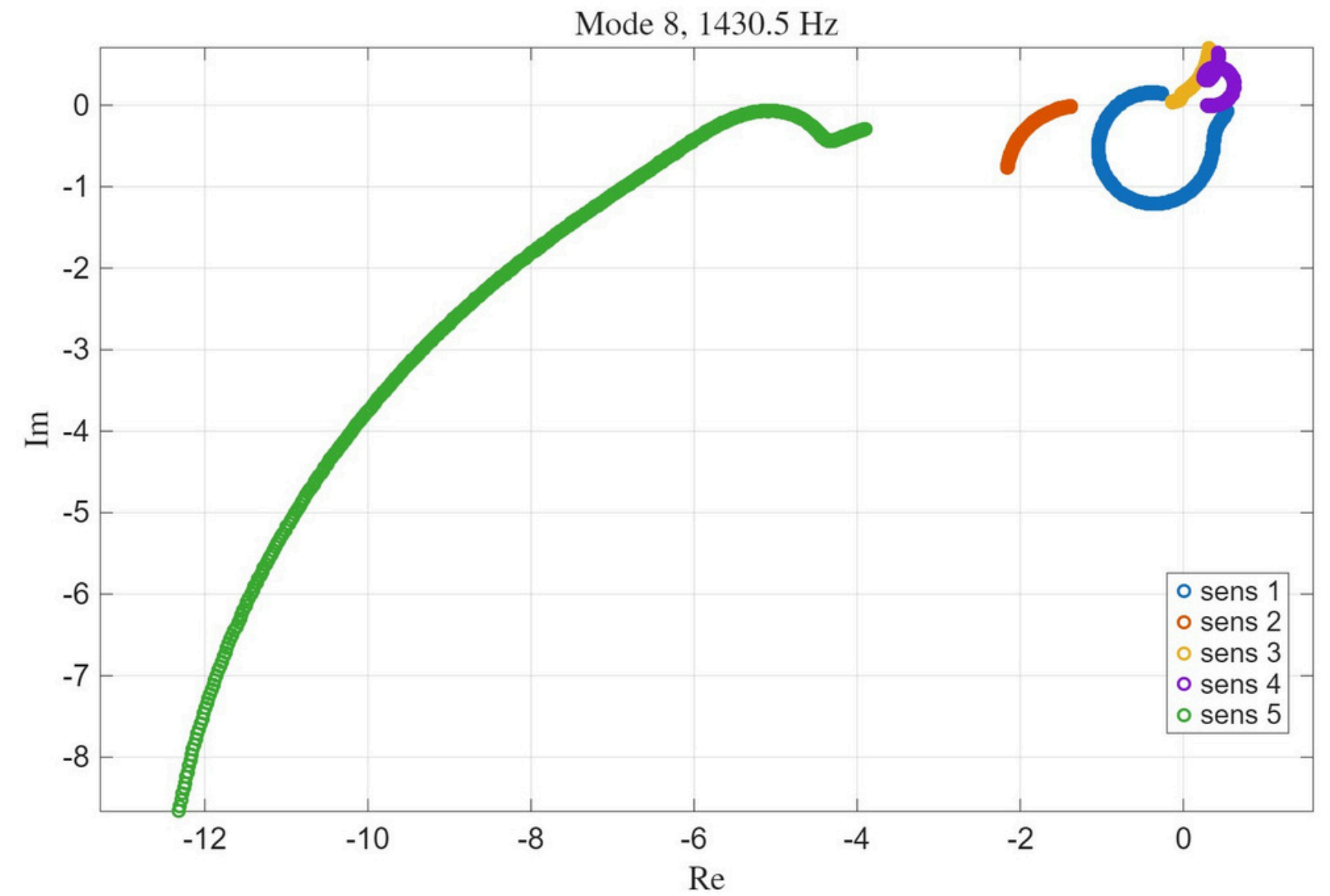
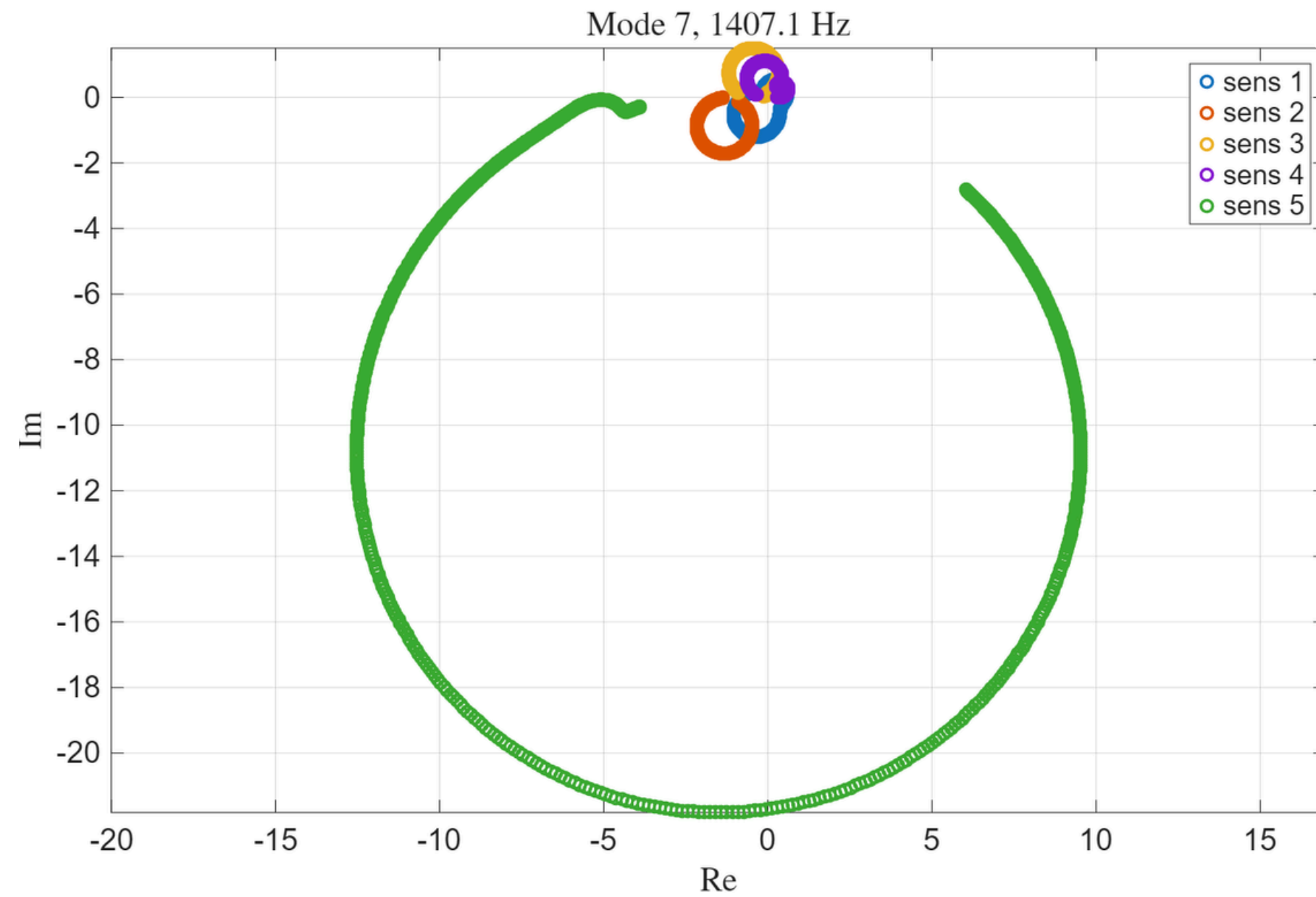
SDOF - NYQUIST CIRCLES



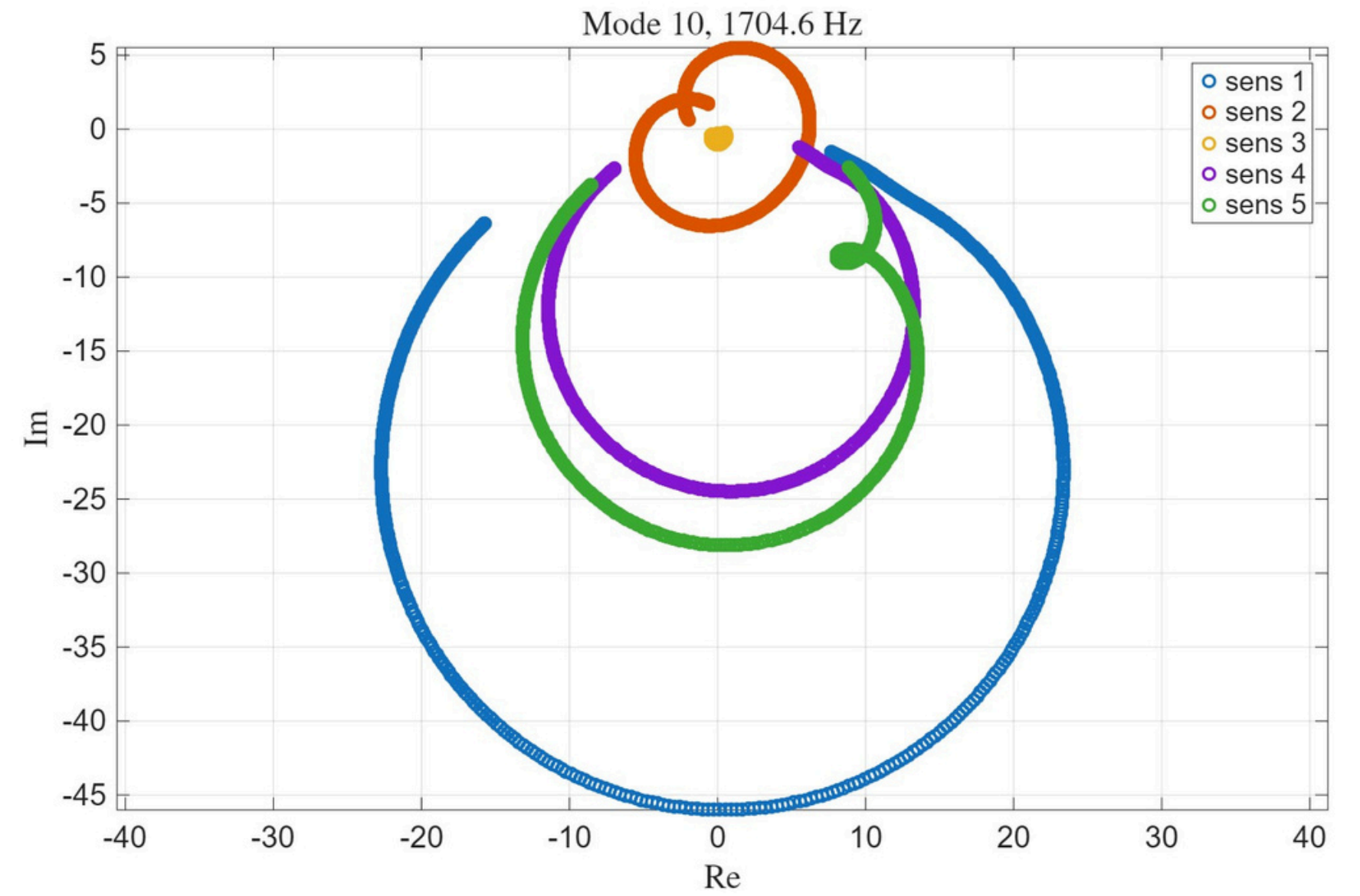
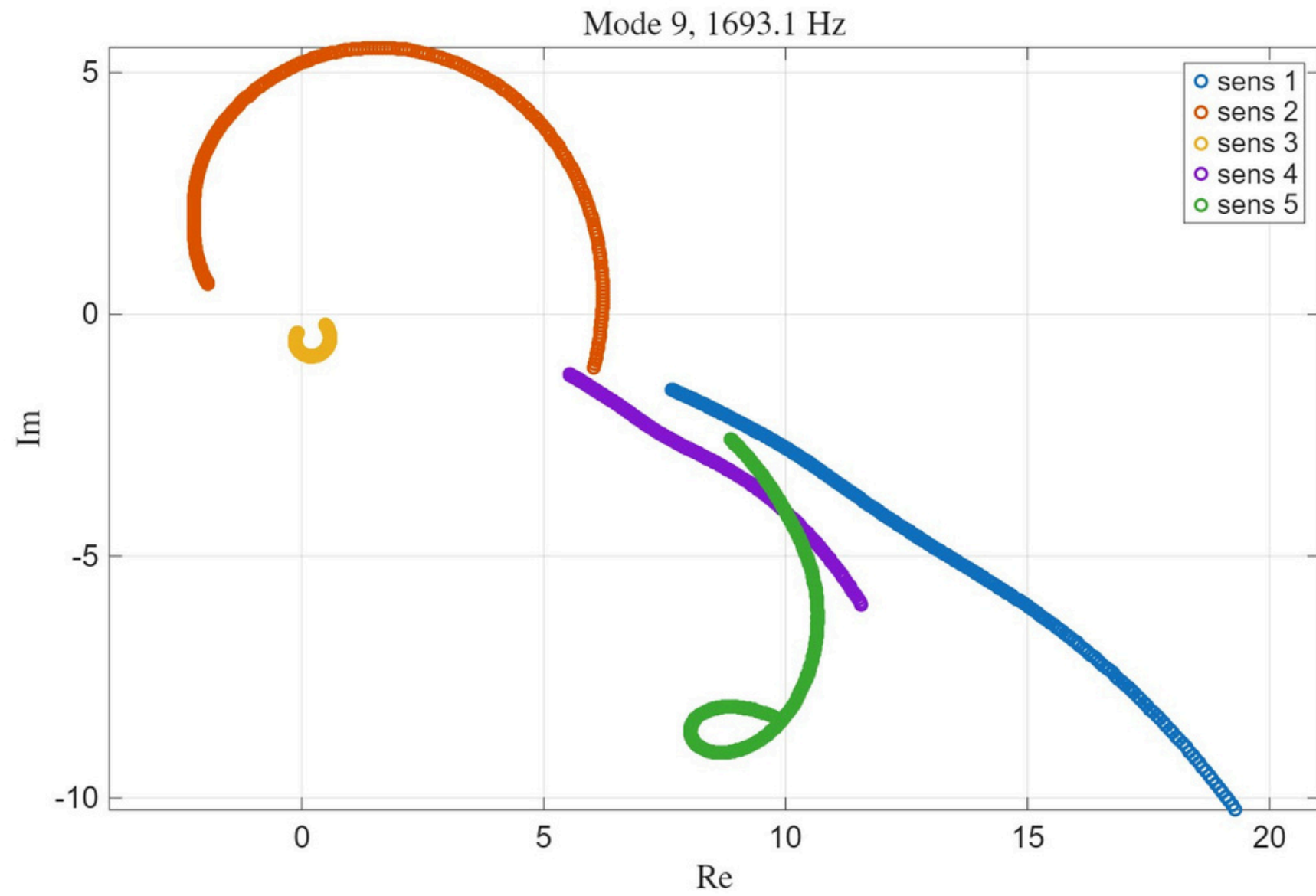
SDOF - NYQUIST CIRCLES



SDOF - NYQUIST CIRCLES



SDOF - NYQUIST CIRCLES



IBRAHIM METHOD

2 inputs - 5 outputs $\longrightarrow$ 10 FRFs $\longrightarrow$ 10 IRFs



$[h(t)]$ can be evaluated
at each time instant

$$[h(t)] = \begin{bmatrix} h_{11}(t) & h_{12}(t) \\ h_{21}(t) & h_{22}(t) \\ \vdots & \vdots \\ h_{51}(t) & h_{52}(t) \end{bmatrix}_{5 \times 2} = [\Psi] [e^{st}] [L]^T$$

IBRAHIM METHOD

By assembling the **Hankel's matrix**:

$$[H_{mn}(t)] = \begin{bmatrix} h(t) & h(t + \Delta t) & \dots & h(t + (n - 1)\Delta t) \\ h(t + \Delta t) & h(t + 2\Delta t) & \dots & h(t + n\Delta t) \\ \vdots & \vdots & \ddots & \vdots \\ h(t + (m - 1)\Delta t) & h(t + m\Delta t) & \dots & h(t + (m + n - 2)\Delta t) \end{bmatrix}$$

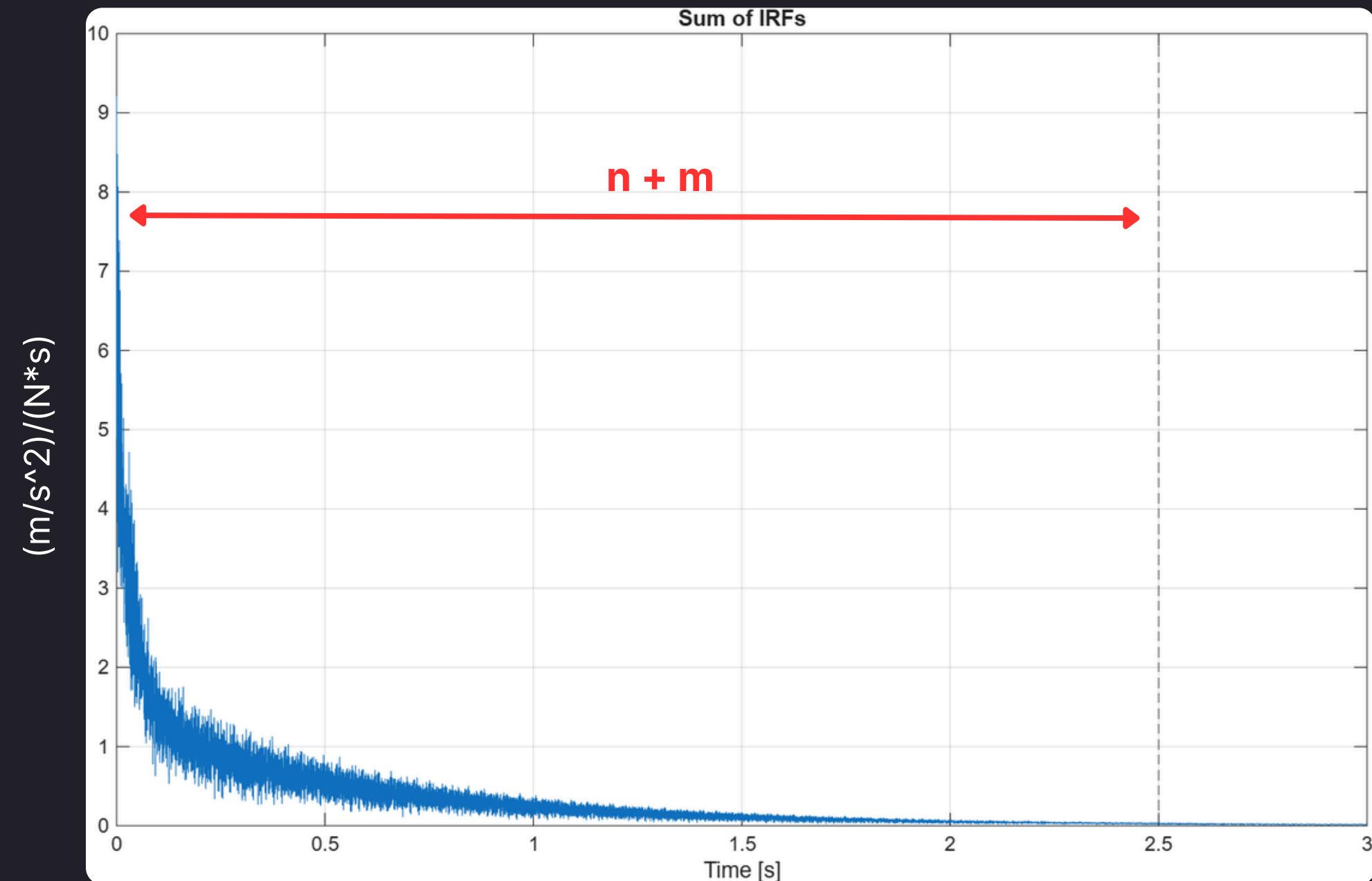
Where m and n are Hankel's parameters.

$$[H_{mn}(t)] = [\tilde{\Psi}][e^{s_r t}][\tilde{L}]^T$$

HANKEL PARAMETERS

$$[H_{mn}(t)] = \begin{bmatrix} h(t) & h(t + \Delta t) & \dots & h(t + (n-1)\Delta t) \\ h(t + \Delta t) & h(t + 2\Delta t) & \dots & h(t + n\Delta t) \\ \vdots & \vdots & \ddots & \vdots \\ h(t + (m-1)\Delta t) & h(t + m\Delta t) & \dots & h(t + (m+n-2)\Delta t) \end{bmatrix}$$

$n + m$ is limited to discard samples dominated by noise.



MATHEMATICAL PROCEDURE

Pseudo Inverse

$$[H_{mn}(t)] = [\tilde{\Psi}][e^{st}][\tilde{L}]^T$$

Shifted in time

$$[\tilde{\Psi}]^+[H_{mn}(t)] = [e^{st}][\tilde{L}]^T$$

$$[H_{mn}(t + \Delta t)] = [\tilde{\Psi}][e^{s\Delta t}][e^{st}][\tilde{L}]^T$$

MATHEMATICAL PROCEDURE

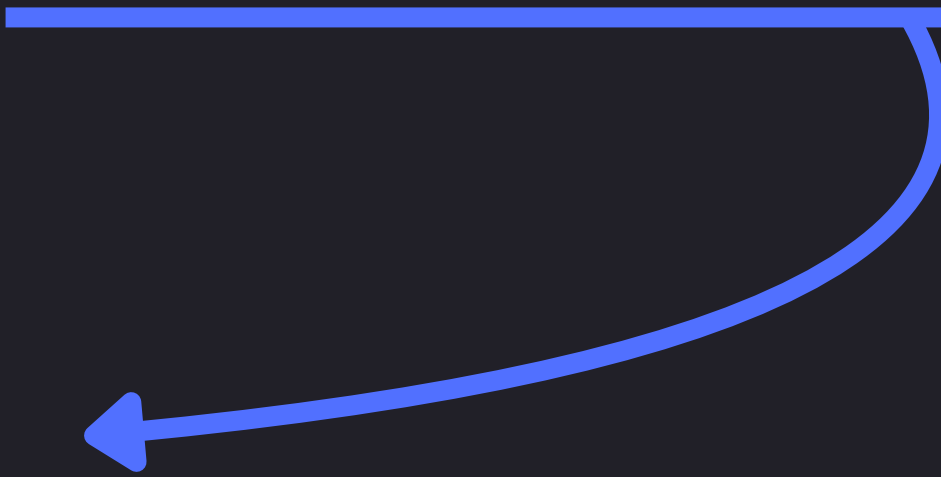
Substituting

$$[H_{mn}(t + \Delta t)] = [\tilde{\Psi}] [e^{s\Delta t}] [\tilde{\Psi}]^+ [H_{mn}(t)]$$

Again, Pseudo inverse

$$[A] = [H_{mn}(t + \Delta t)] [H_{mn}(t)]^+$$

Fully known product



MATHEMATICAL PROCEDURE

$$[A] = [\tilde{\psi}] [e^{s\Delta t}] [\tilde{\psi}]^+$$

By solving an
eigenvalue/eigenvector problem

Eigenvalues $\lambda_r = e^{s_r \Delta t} \Rightarrow s_r = \frac{\ln \lambda_r}{\Delta t} \Rightarrow$

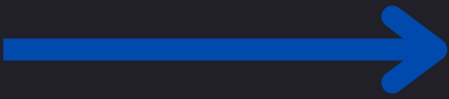
**Natural frequencies
Dampings**

Eigenvectors $\Rightarrow$

Modeshapes

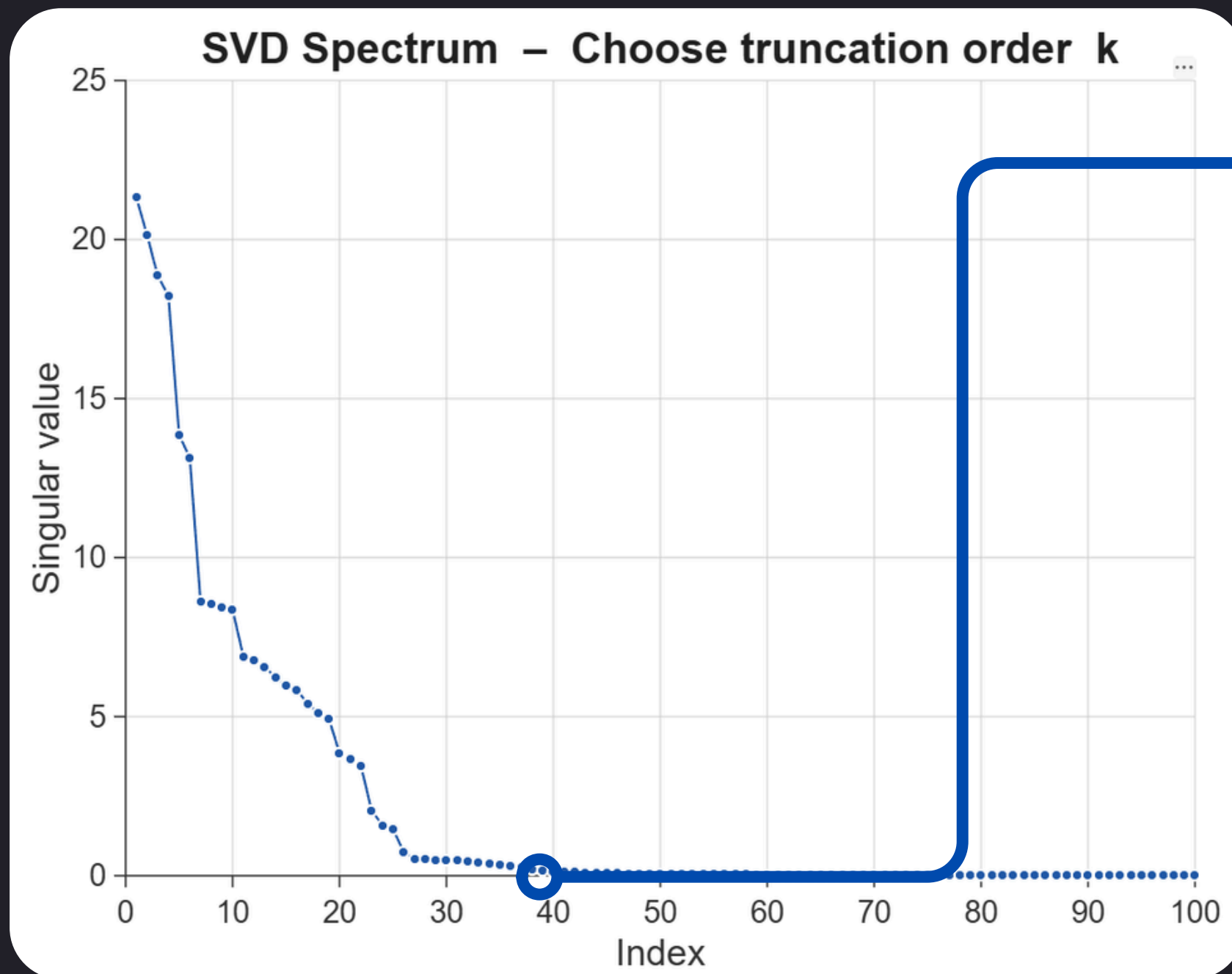
SVD IMPLEMENTATION

From a computational point of view,

H_{mn} is noisy and expensive to pseudo-invert. Solution?  **Singular value decomposition**

$$[H_{mn}(t)] = [U][S][V]^T$$

SVD IMPLEMENTATION



The first **K = 40** singular values are kept

Reduced Hankel matrix is then
computed as

$$[H'_{mn}(t)] = [U']^T [H_{mn}(t)]$$

U' contains the first K columns of [U]

STABILIZATION DIAGRAM

The stabilization diagram is built by repeating the following steps by changing m_k :

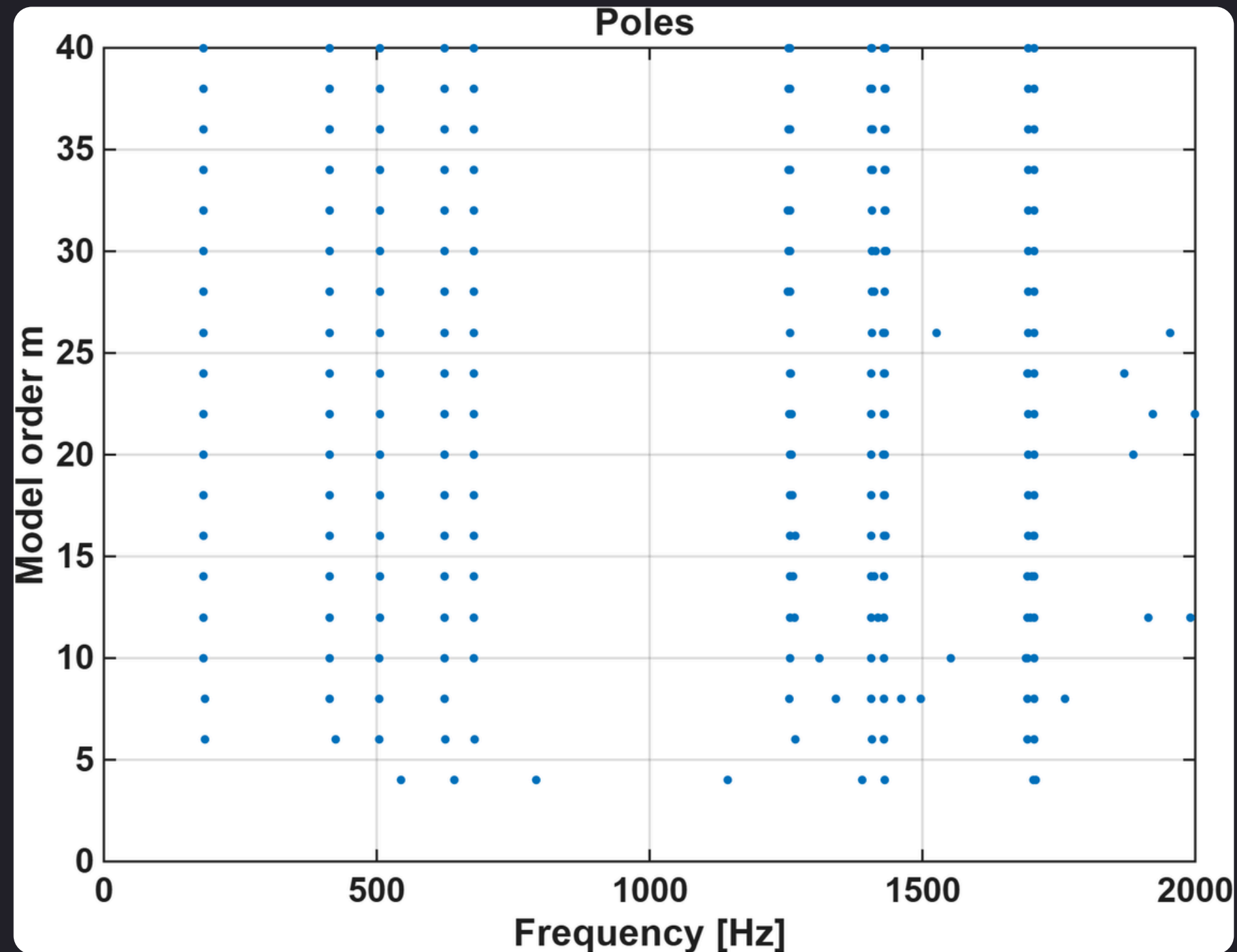
1. Extract sub-Hankel matrix with $m_k \cdot n_l$ rows
2. Apply SVD: $U_k \in \mathbb{R}^{(m_k n_l) \times (m_k n_l)}$
3. Truncate to $k_{use} = \min(k_{svd}, m_k n_l)$
4. Project: $H_{red,k} \in \mathbb{R}^{k_{use} \times (n n_s)}$
5. Compute system matrix: $[A]_k \in \mathbb{R}^{k_{use} \times k_{use}}$
6. Solve eigenvalue problem $\rightarrow k_{use}$ poles for this m_k

$$[H_{mn}(t)] = \begin{bmatrix} h(t) & h(t + \Delta t) & \dots & h(t + (n-1)\Delta t) \\ h(t + \Delta t) & h(t + 2\Delta t) & \dots & h(t + n\Delta t) \\ \vdots & \vdots & \ddots & \vdots \\ h(t + (m-1)\Delta t) & h(t + m\Delta t) & \dots & h(t + (m+n-2)\Delta t) \end{bmatrix}$$

$$[H_{mn}(t)] = [U][S][V]^T \quad [H'_{mn}(t)] = [U']^T [H_{mn}(t)]$$

$$[A] = [H_{mn}(t + \Delta t)] [H_{mn}(t)]^+ \quad \textbf{Eigenvalues} \quad \lambda_r = e^{s_r \Delta t}$$

STABILIZATION DIAGRAM



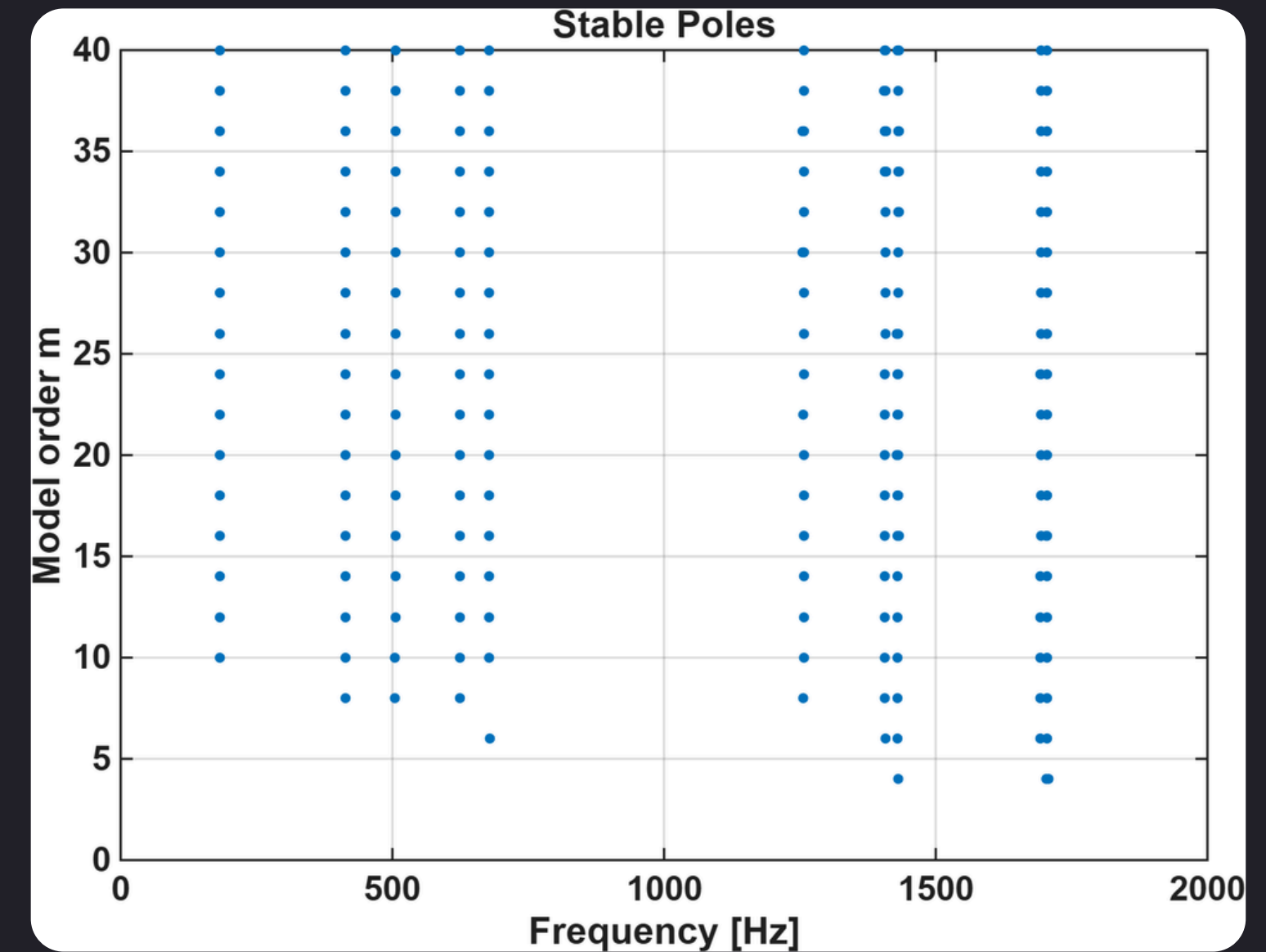
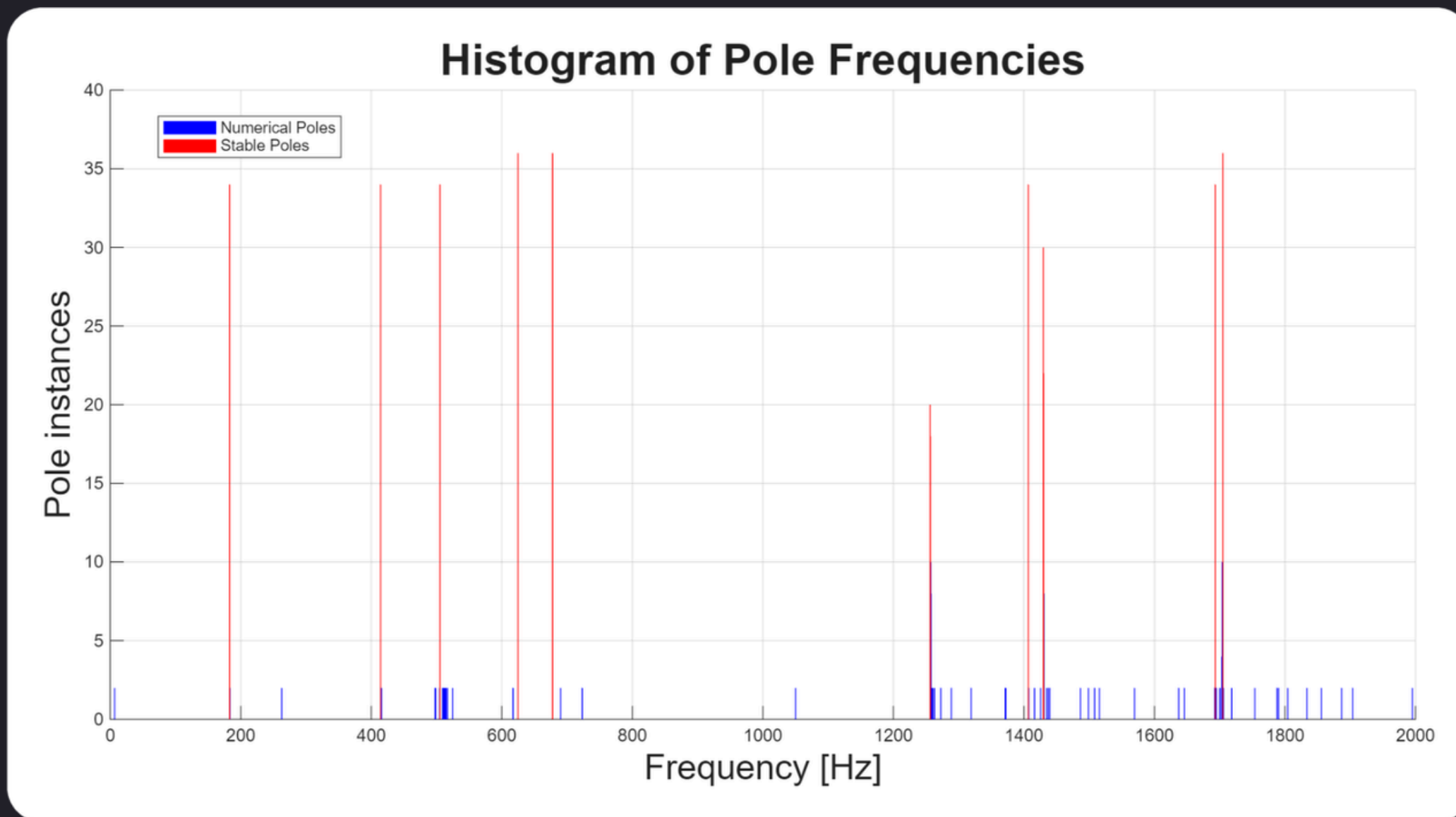
Both **physical** and **numerical** poles are found.

3-steps **filtering procedure** are needed:

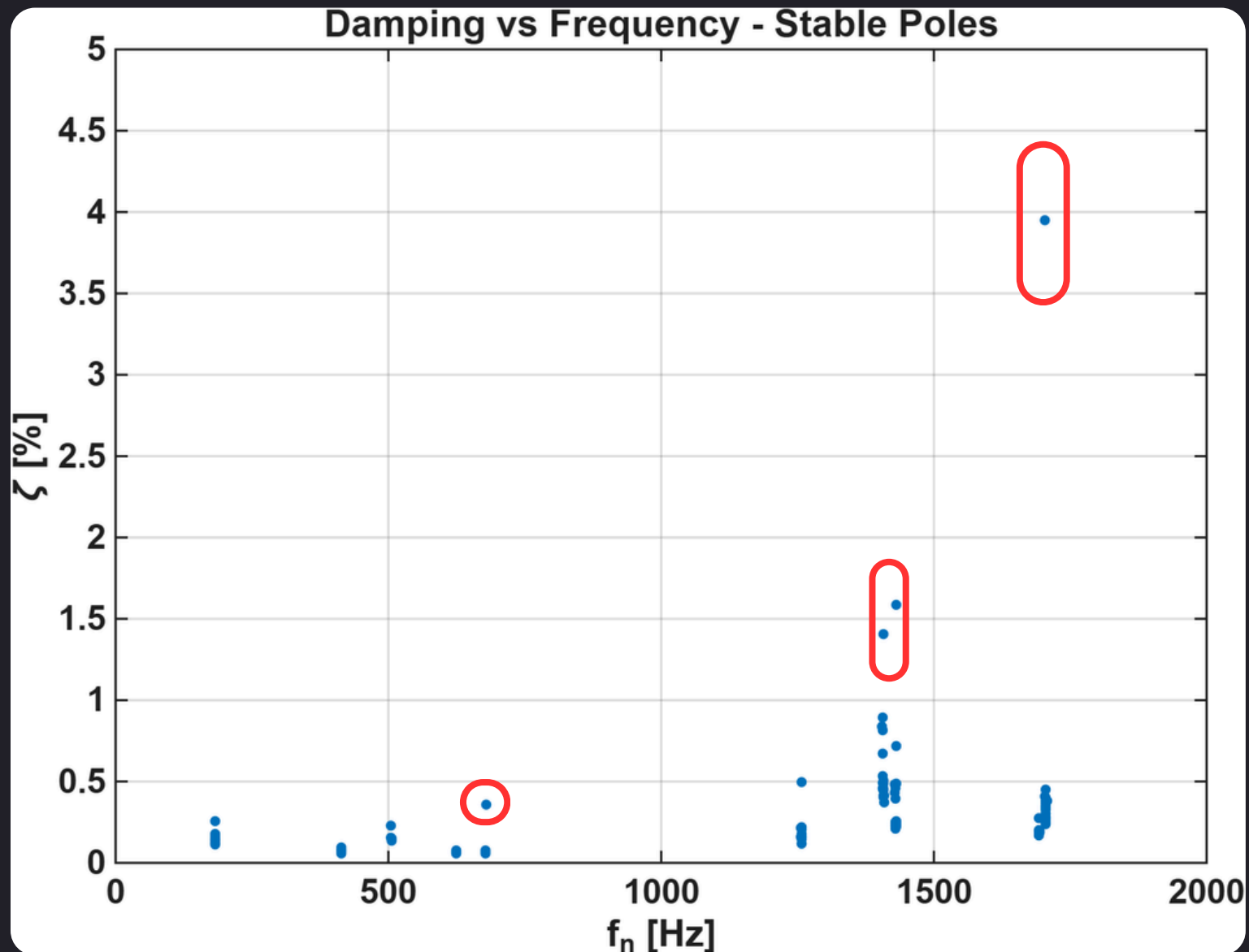
- **Frequency** stability check
- **Damping** stability check
- **Eigenmodes** stability check

FREQUENCY FILTER

Stable pole → It falls at least **50%** within the same sub-range $f = 0.1\% * f_{nom}$



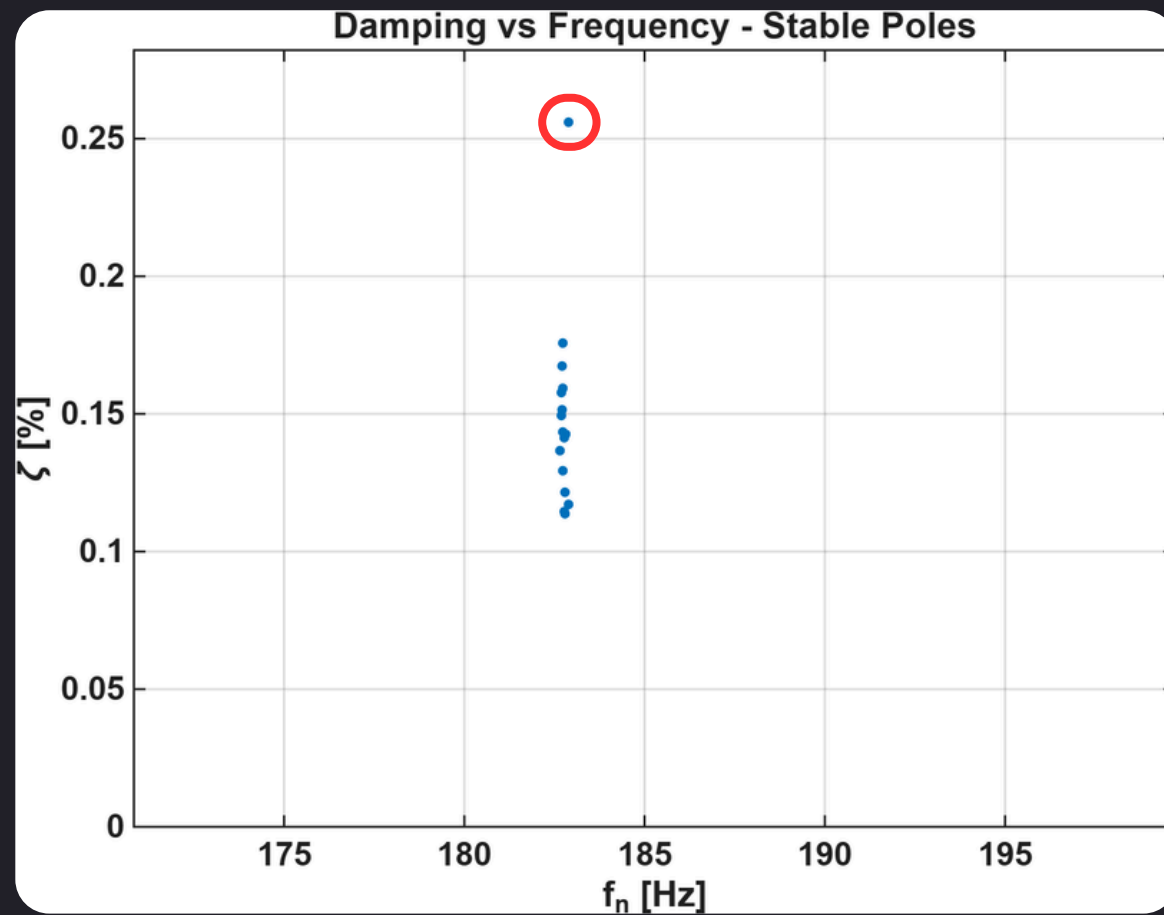
DAMPING FILTER



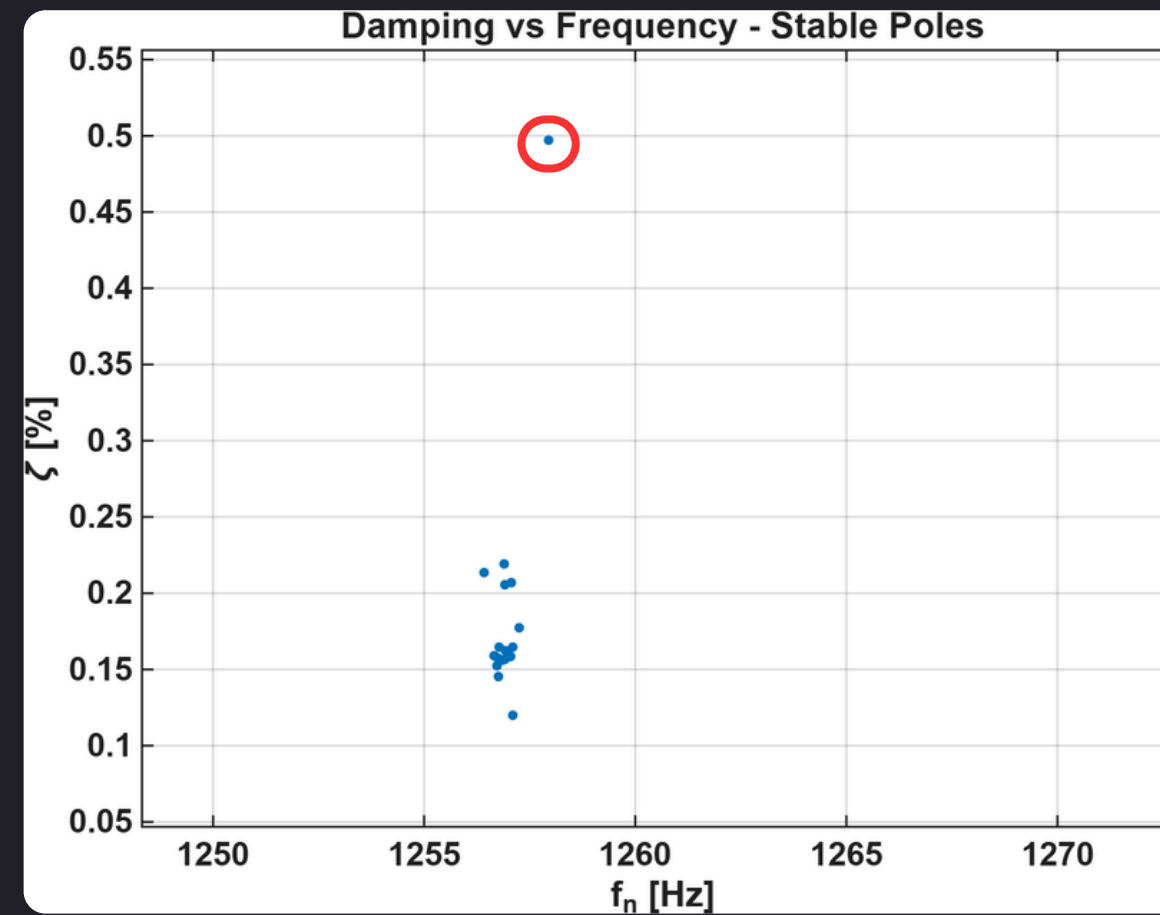
- Poles far from clusters are neglected.
- The median of each group is used as reference.

DAMPING FILTER

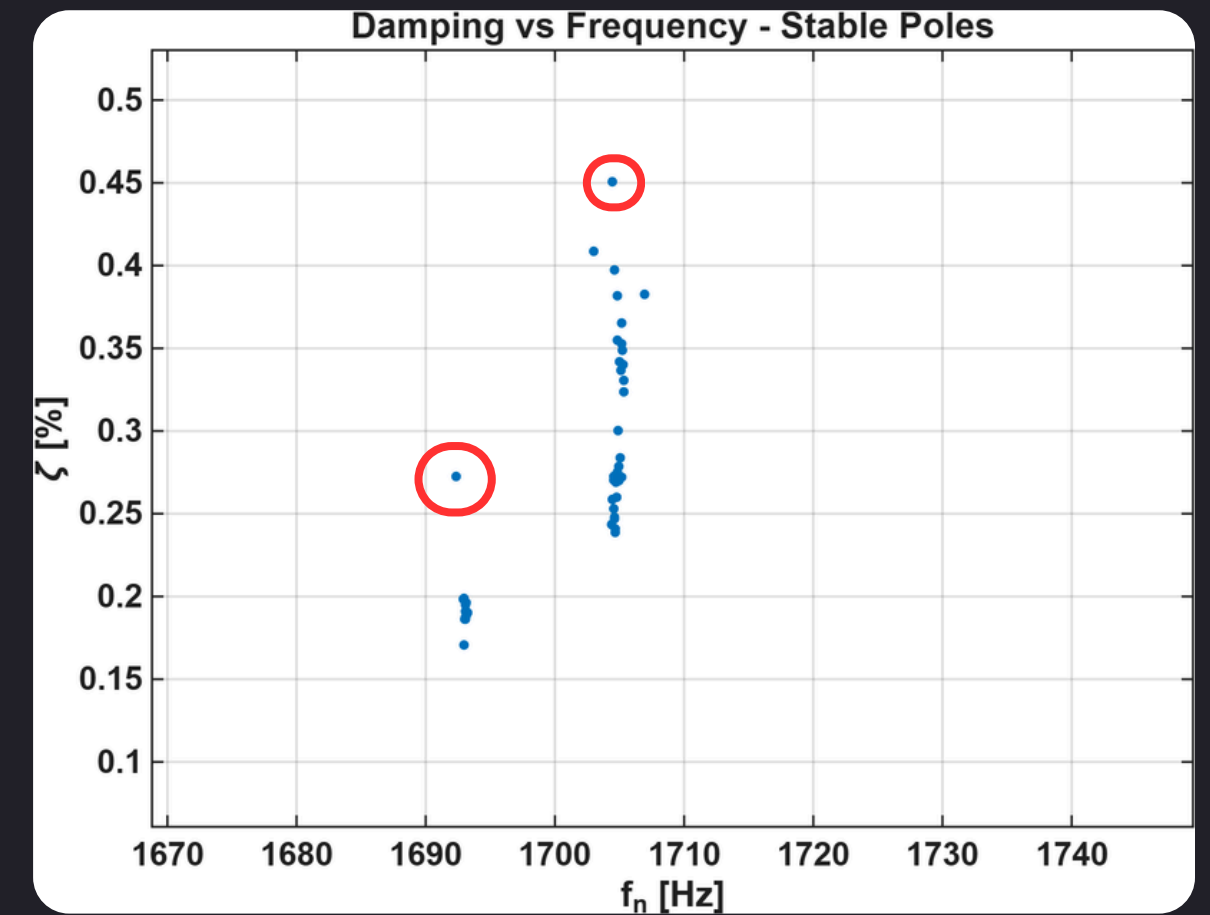
Mode 1



Mode 6

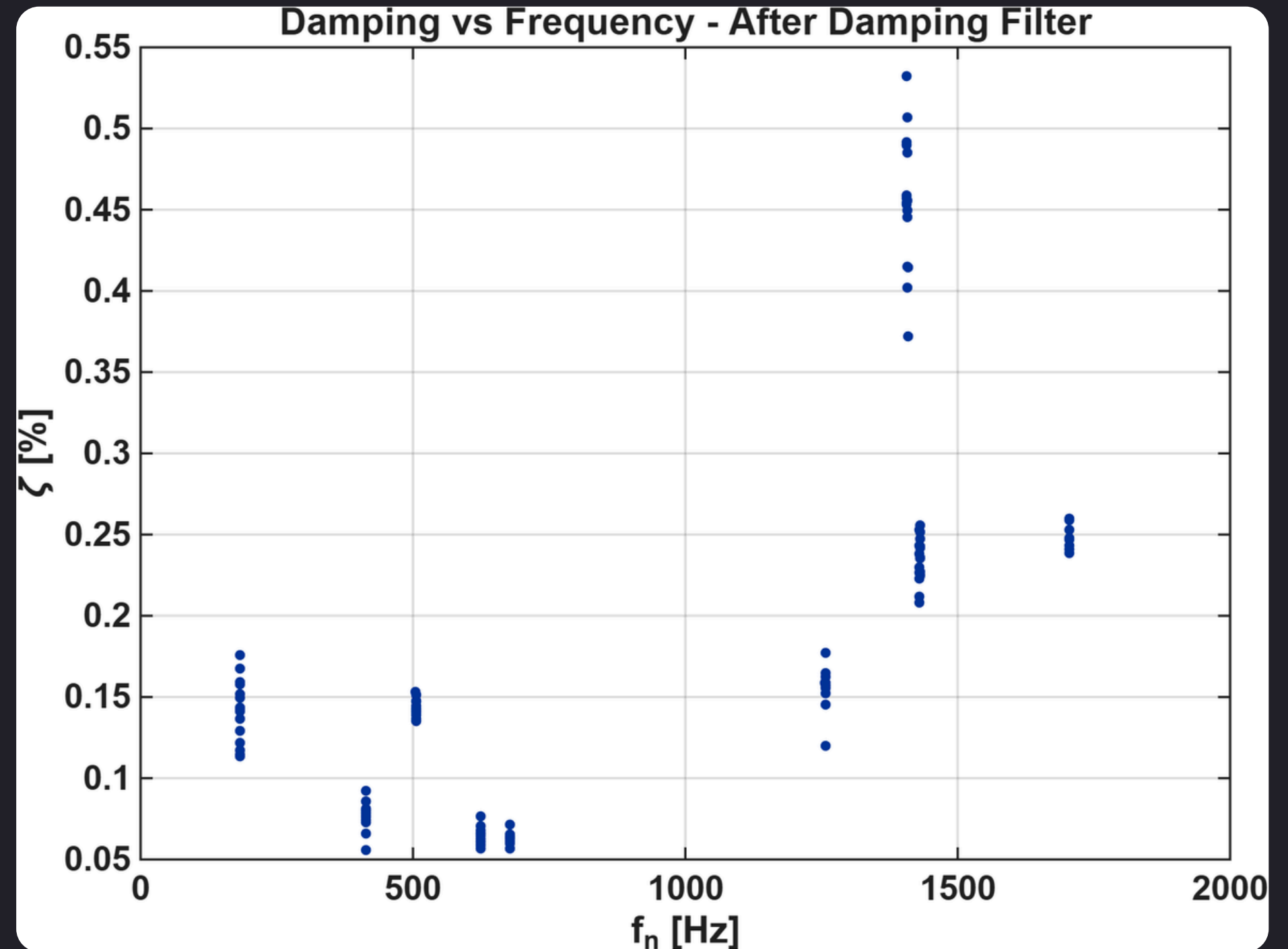


Mode 9-10



DAMPING FILTER

Stable poles in
**damping and
frequency.**



EIGENMODES FILTER

So far, the **clusters** of poles show:

Frequency [Hz]	182	414	505	624	677	1257	1407	1430	1693	1704
N of poles around that f	18	34	32	34	32	26	36	36	34	52

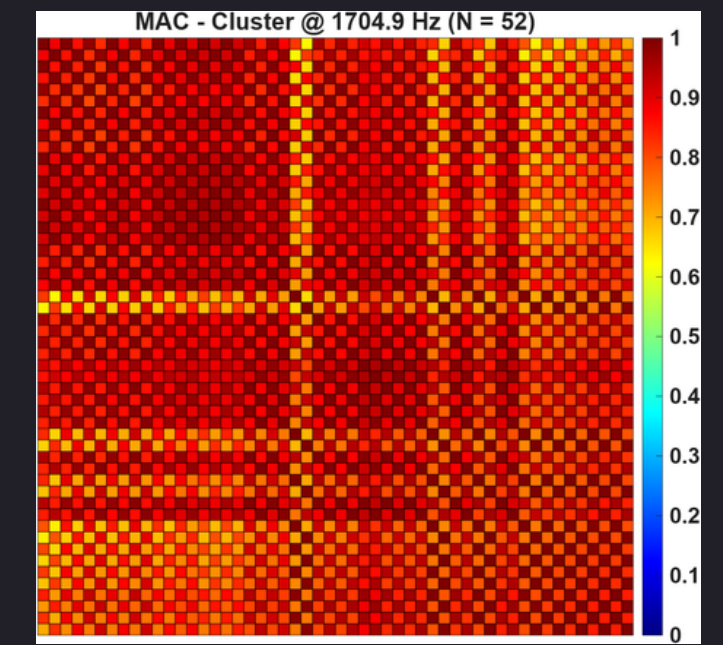
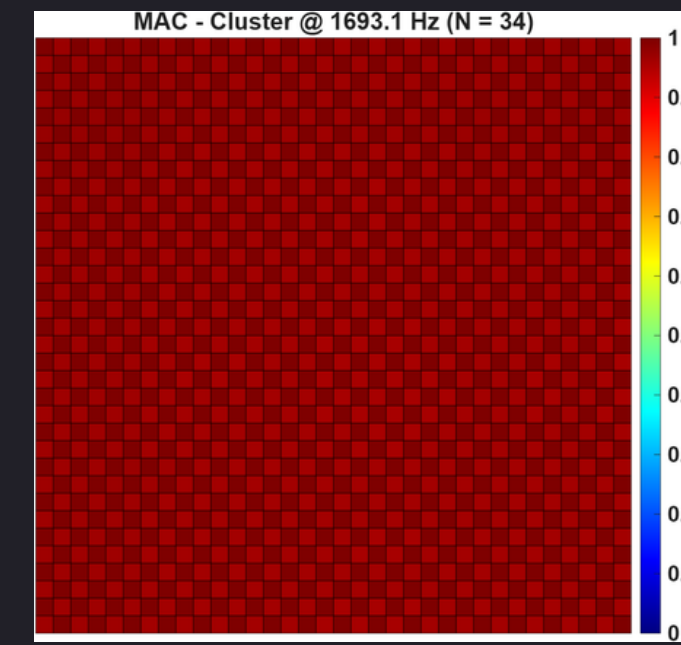
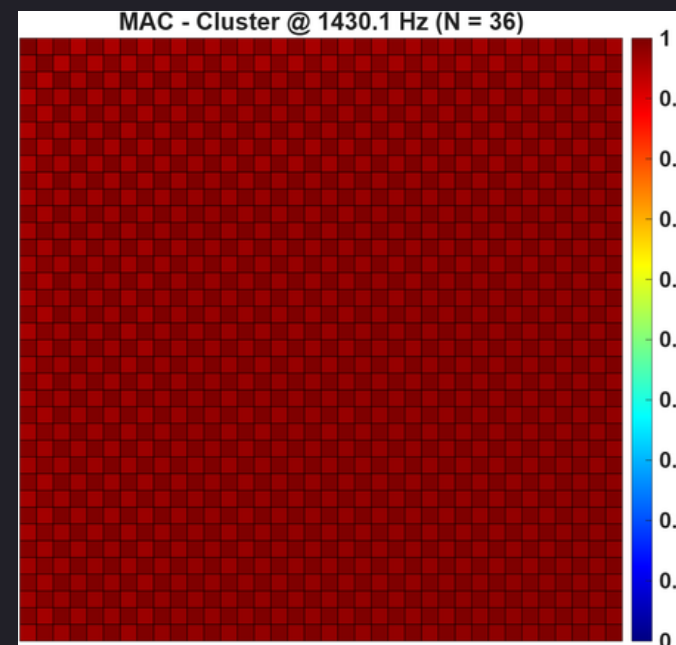
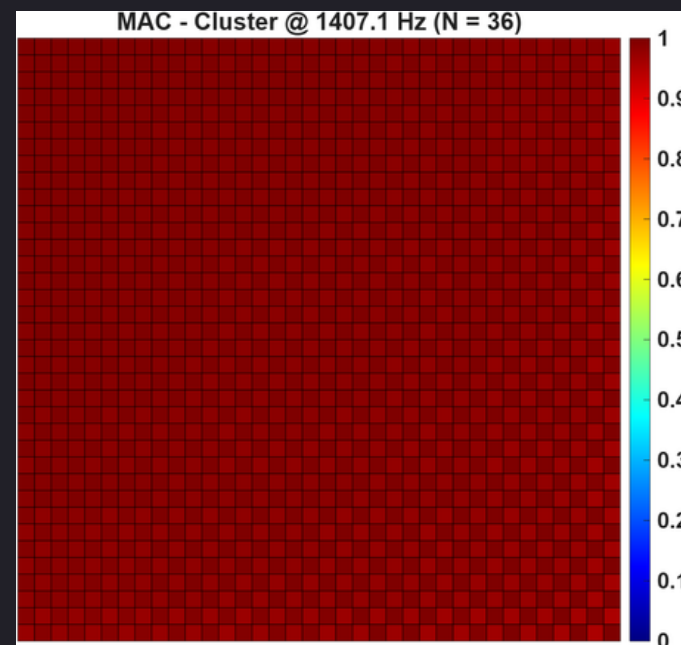
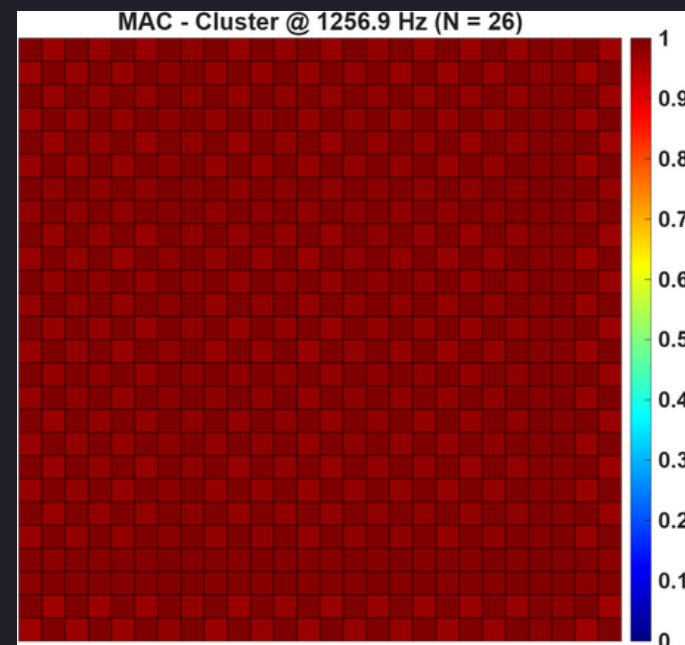
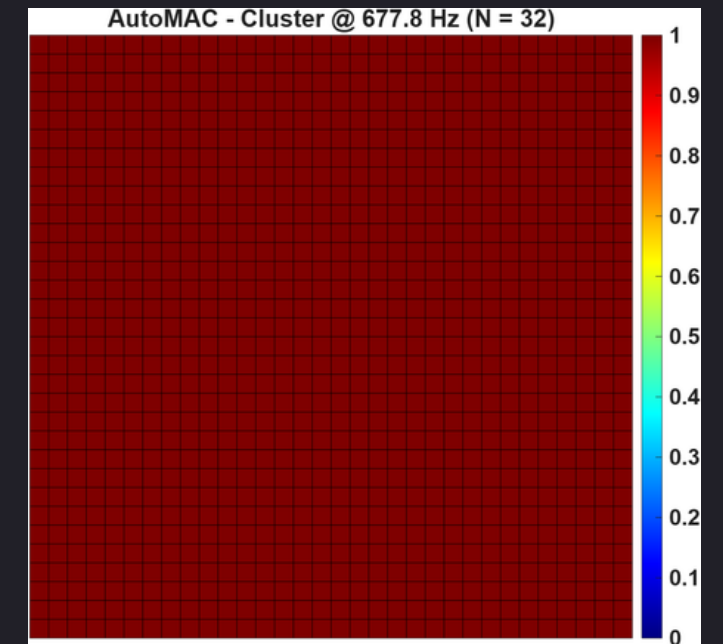
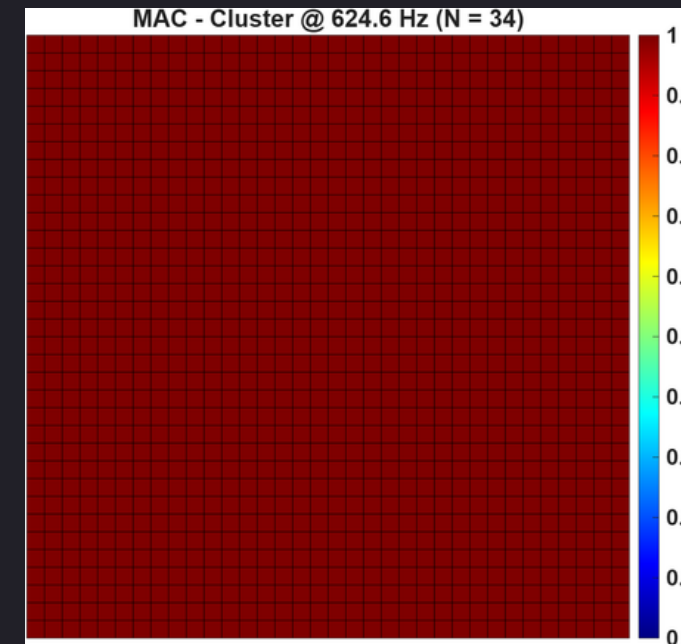
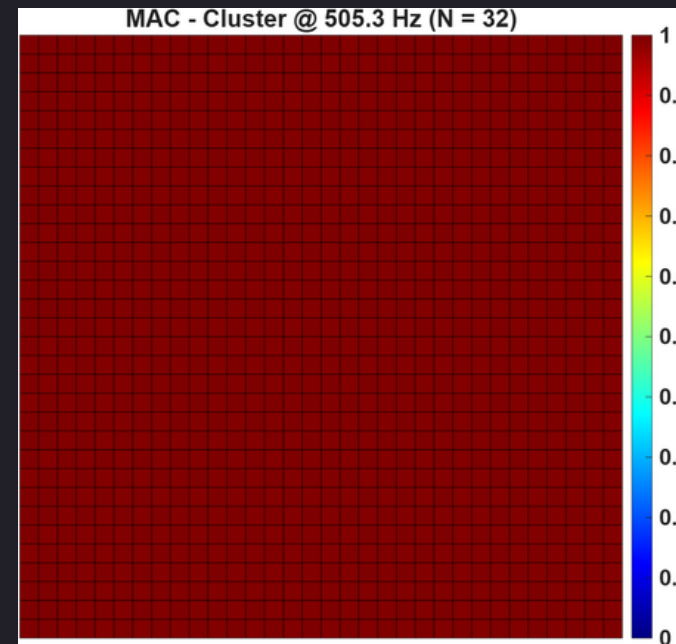
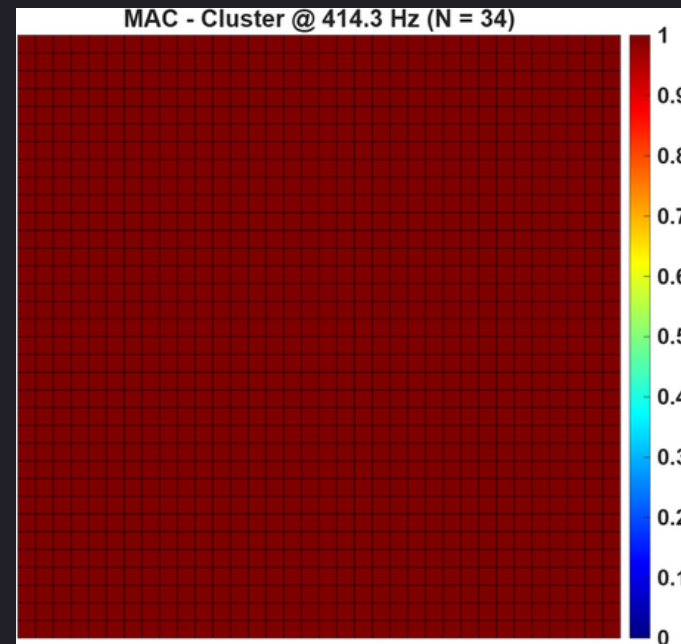
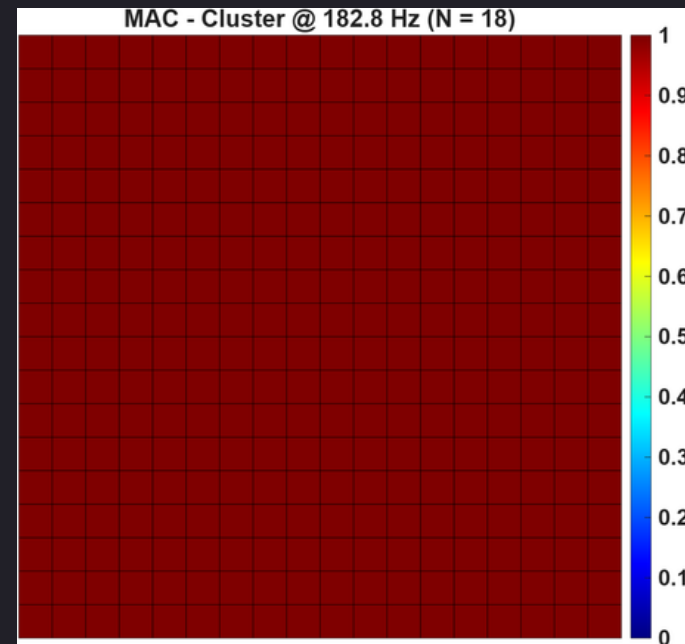
EIGENMODES FILTER

MAC between the modes of each cluster has been computed

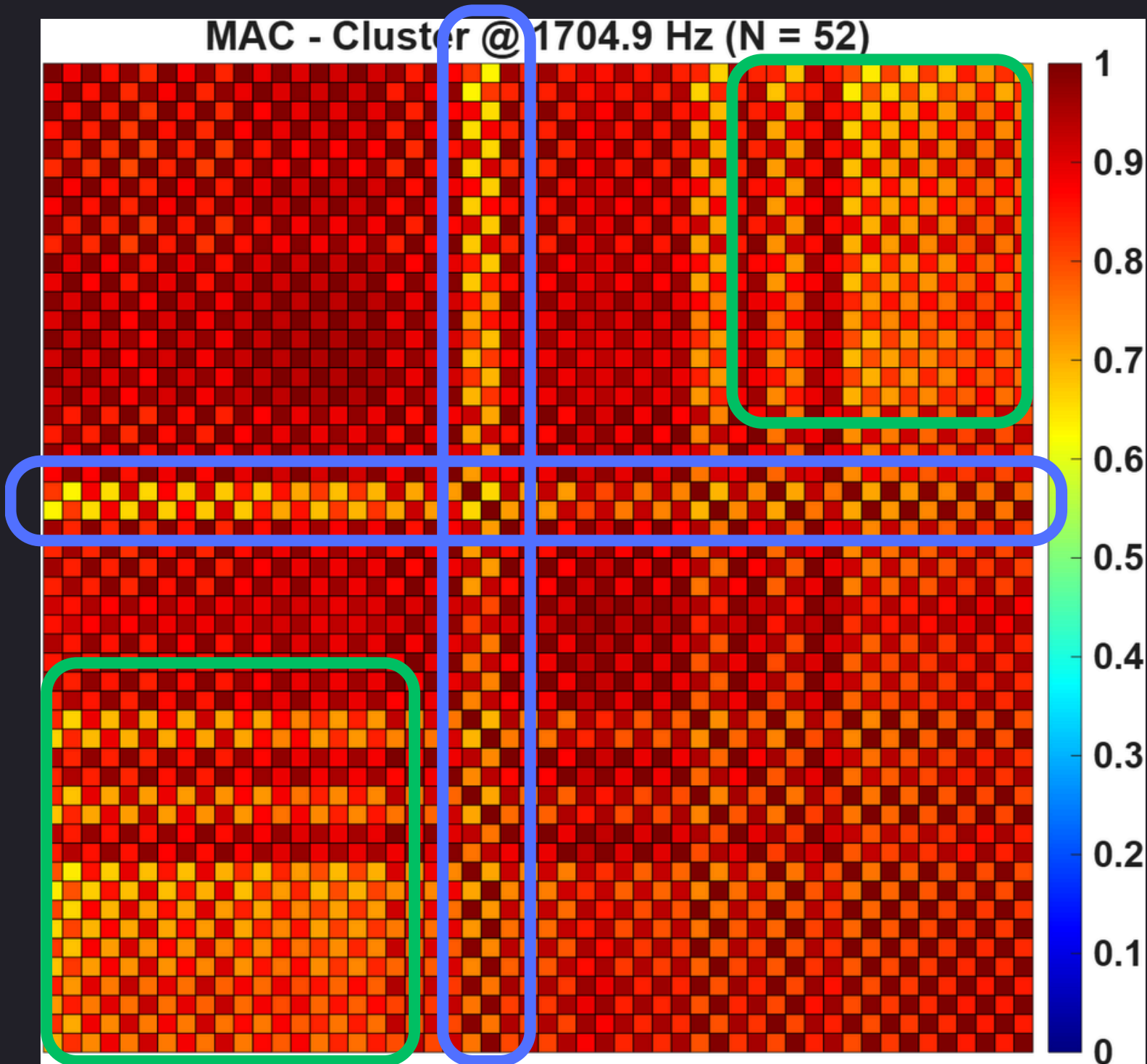
$$\text{MAC}(A_i, A_j) = \frac{|\{\psi_{A,i}\}^T \{\psi_{A,j}\}|^2}{(\{\psi_{A,i}\}^T \{\psi_{A,i}\}) \cdot (\{\psi_{A,j}\}^T \{\psi_{A,j}\})}$$

Poles with **MAC** < 0.8 are discharged

EIGENMODES FILTER



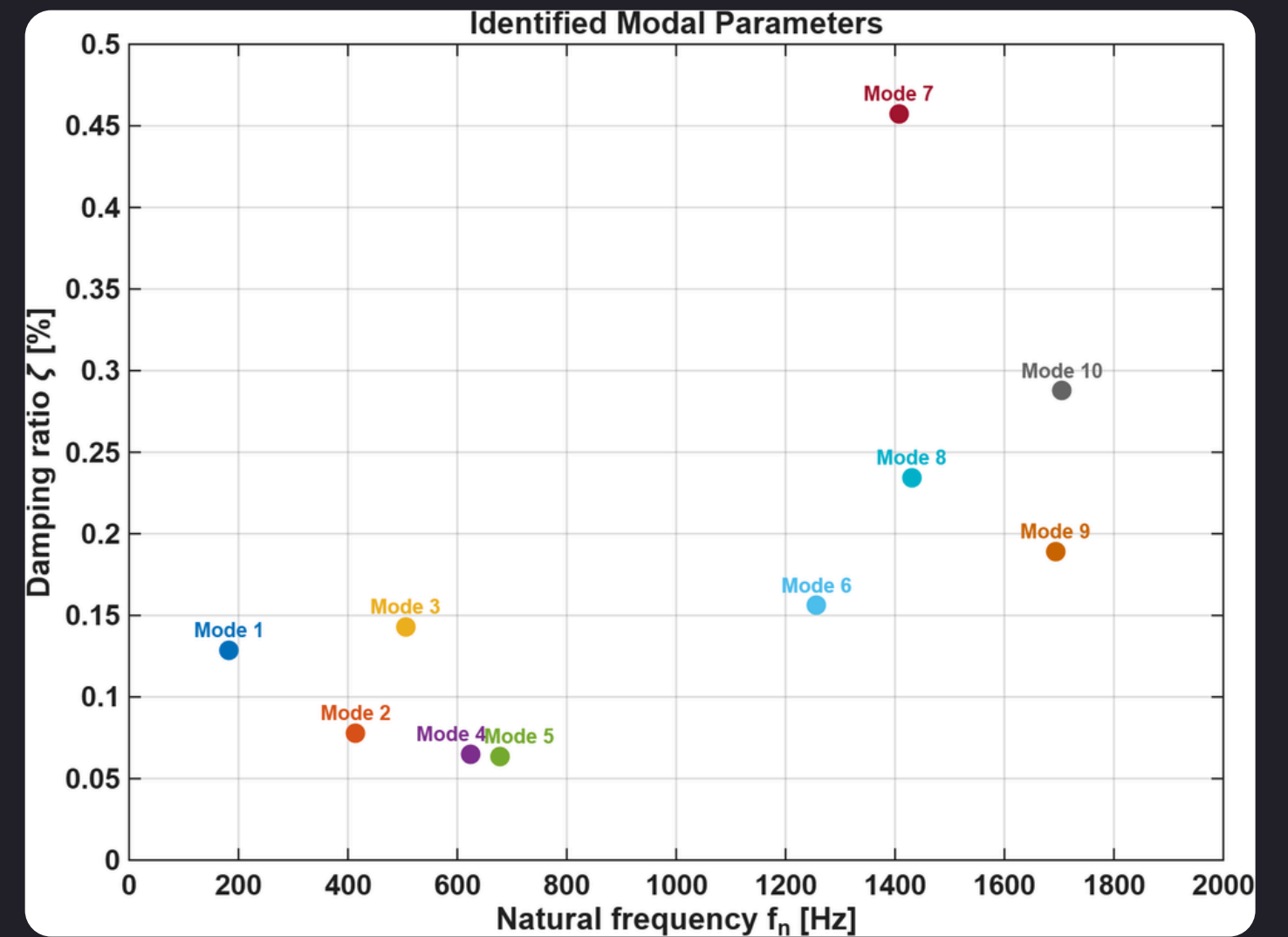
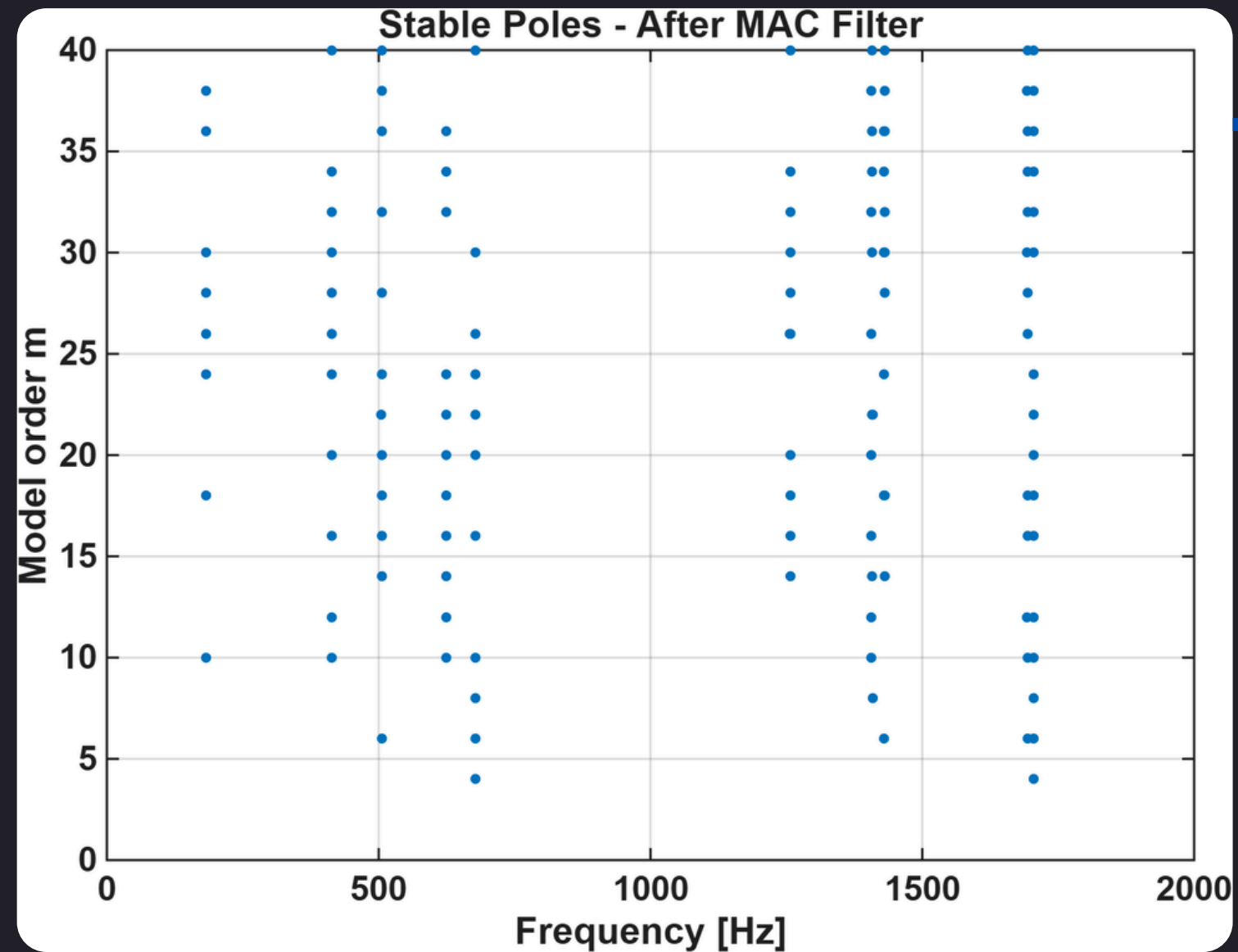
EIGENMODES FILTER



$$\text{MAC}(A_i, A_j) = \frac{|\{\psi_{A,i}\}^T \{\psi_{A,j}\}|^2}{(\{\psi_{A,i}\}^T \{\psi_{A,i}\}) \cdot (\{\psi_{A,j}\}^T \{\psi_{A,j}\})}$$

STABLE POLES

By averaging
eigenfrequency,
eigenmodes and **damping.**



RESULTS

Mode	Frequency (Hz)	Damping (%)
1	182.75	0.1288
2	414.28	0.0778
3	505.23	0.1429
4	624.57	0.0650
5	677.83	0.0637

Mode	Frequency (Hz)	Damping (%)
6	1256.70	0.1561
7	1407.10	0.4574
8	1430.53	0.2345
9	1693.10	0.1892
10	1704.90	0.2878



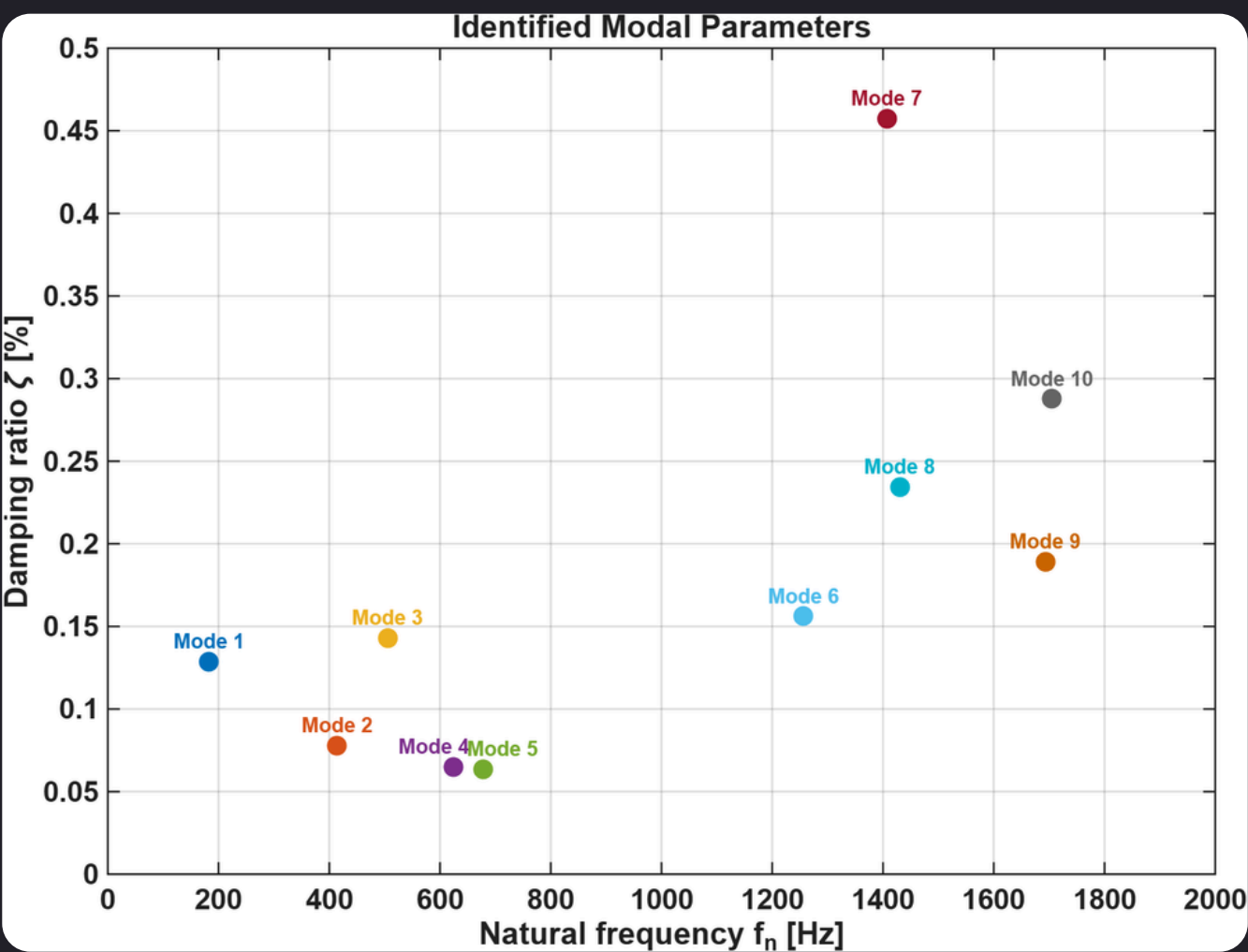
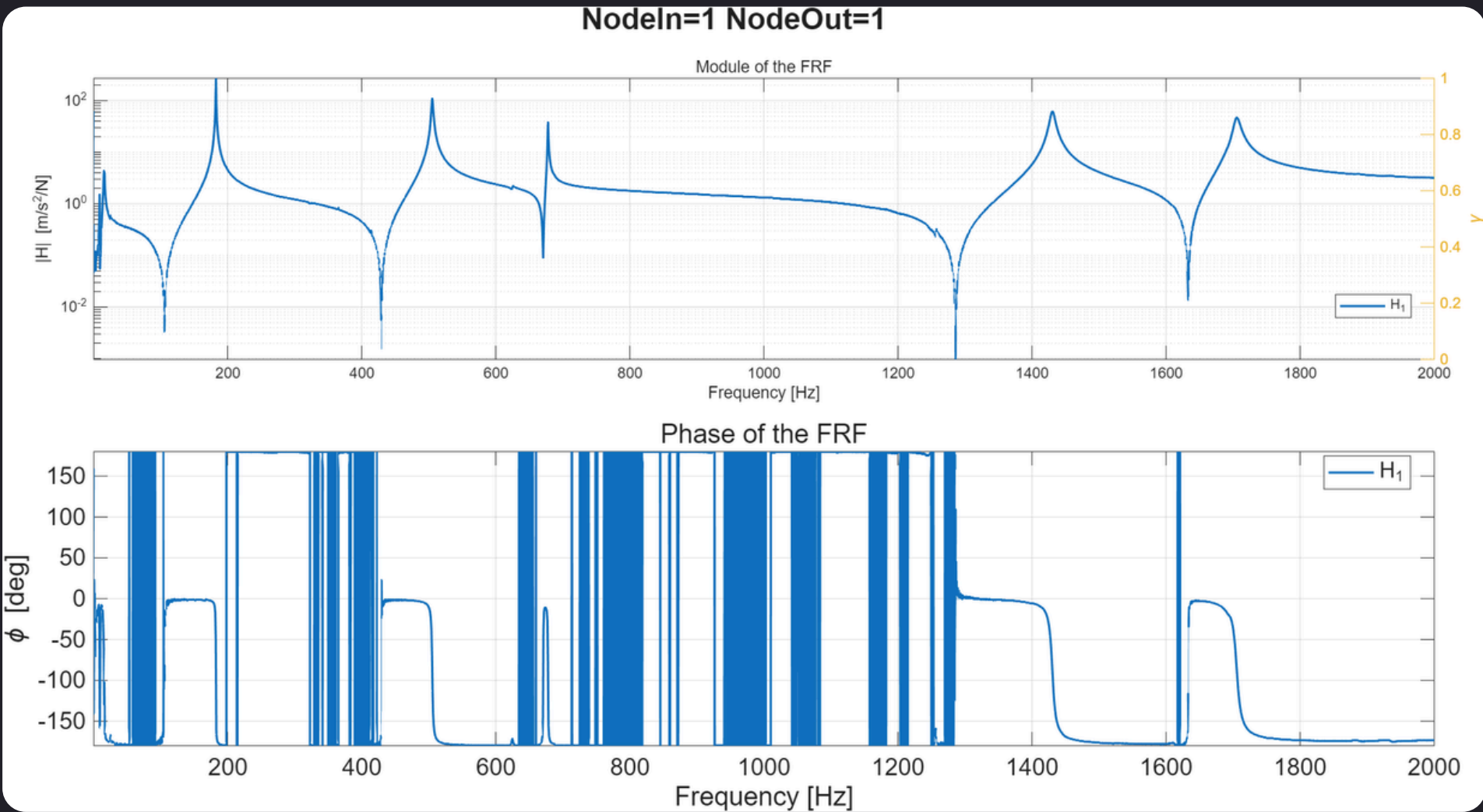
06. COMPARISON OF PARAMETERS

EIGENFREQUENCIES COMPARISON

Mode	1	2	3	4	5	6	7	8	9	10
MITD	182.75	414.28	505.23	624.57	677.83	1256.70	1407.10	1430.53	1693.10	1704.90
FEM	184.2	416.6	500.6	627.4	675.9	1280.2	1409.6	1427.0	1703.7	1705.8
Error %	0.79	0.56	0.93	0.45	0.29	1.84	0.18	0.25	0.62	0.05

DAMPINGS COMPARISON

Reasonable values compared to the Experim. FRFs
(sharpness of peaks - slope of phase)

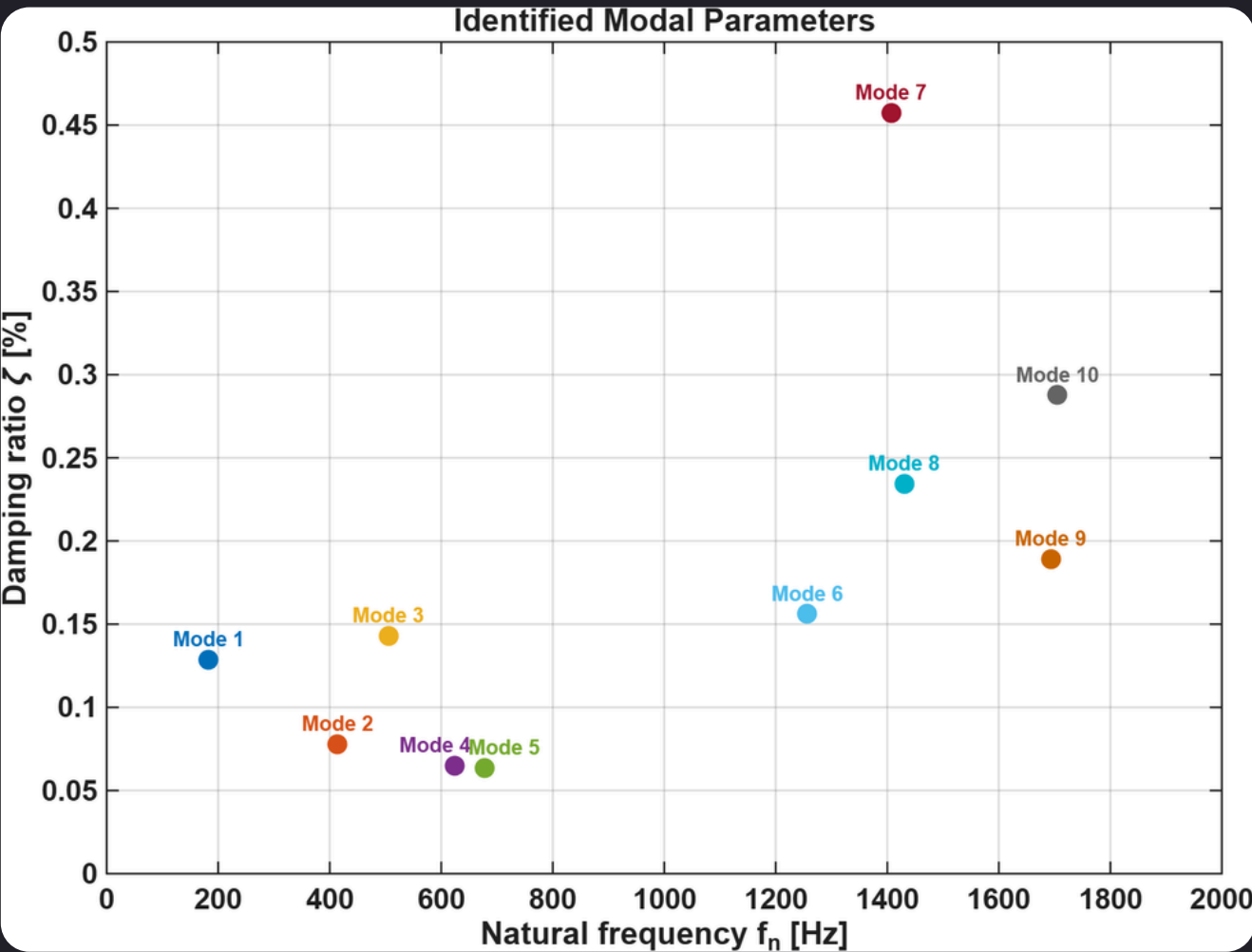
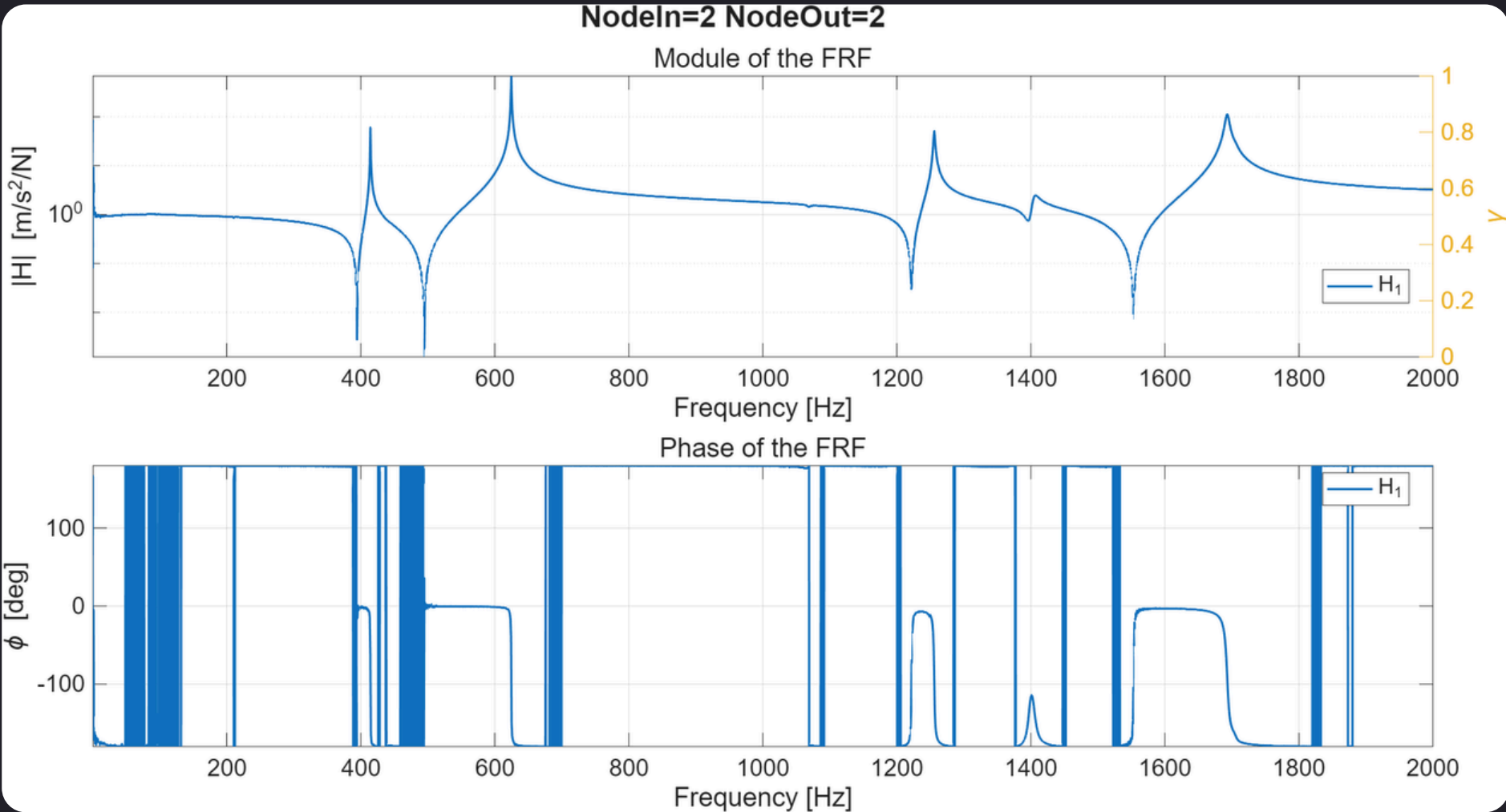


Very low dampings on modes 1, 3, 5
Higher for modes 8 and 10

1	182.75
2	414.28
3	505.23
4	624.57
5	677.83
6	1256.7
7	1407.10
8	1430.53
9	1693.1
10	1704.9

DAMPINGS COMPARISON

Reasonable values compared to the Experim. FRFs
(sharpness of peaks - slope of phase)

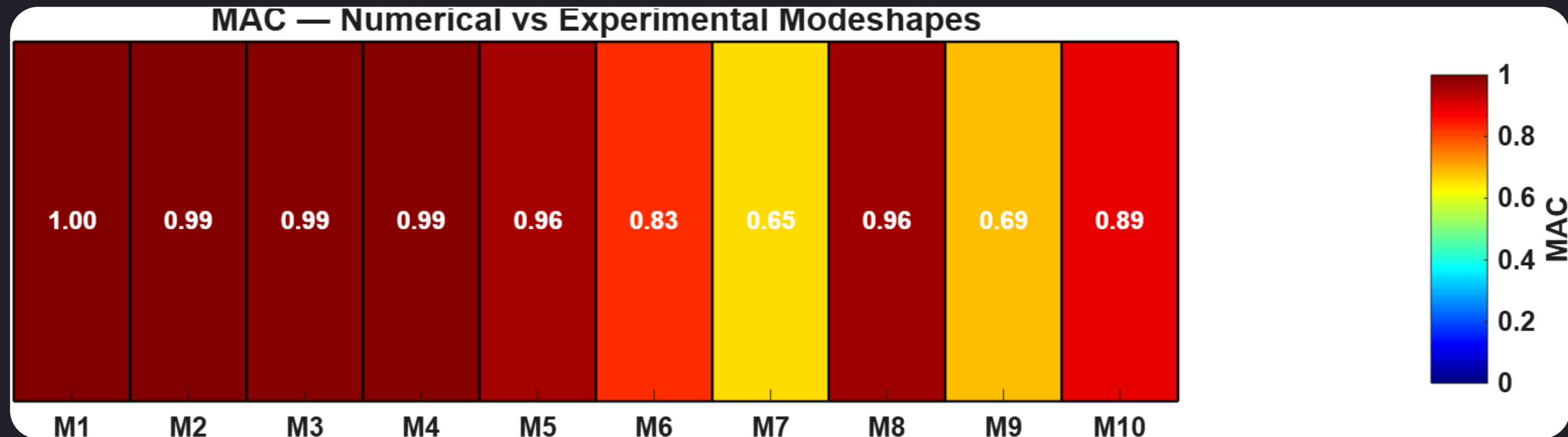


Very low dampings on modes 2, 4, 6
Higher for modes 7 and 9

1	182.75
2	414.28
3	505.23
4	624.57
5	677.83
6	1256.7
7	1407.10
8	1430.53
9	1693.1
10	1704.9

EIGENVECTORS COMPARISON

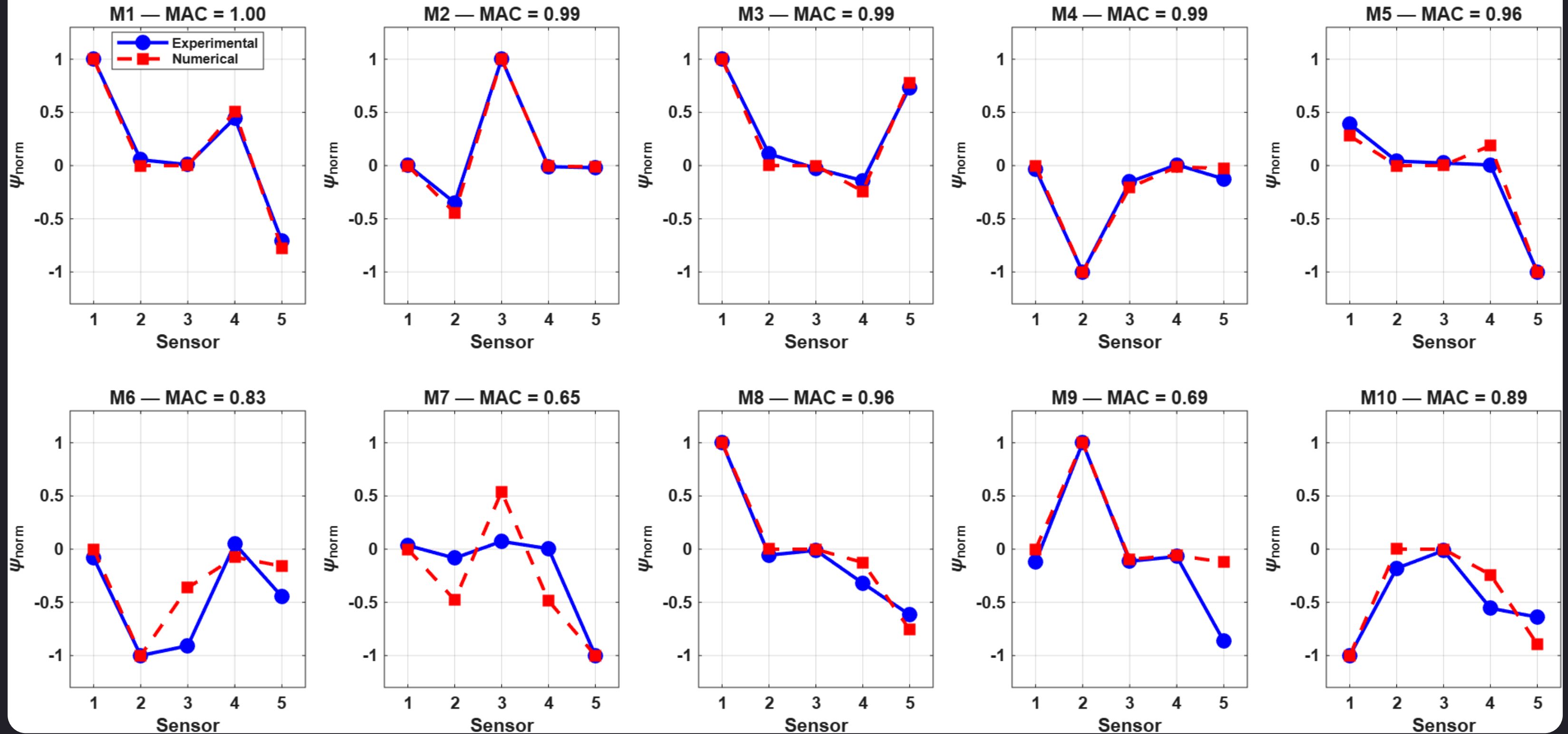
MAC for Numerical - Experimental mode shapes



- Poor matching for 7th and 9th

EIGENVECTORS COMPARISON

Numerical vs Experimental Modeshapes





07. COMPARISON BETWEEN FRFS

FRFs RECONSTRUCTION

$$\begin{Bmatrix} H_{pq}(\omega_1) \\ H_{pq}(\omega_2) \\ \vdots \\ H_{pq}(\omega_{N_f}) \end{Bmatrix} = \begin{bmatrix} \frac{\psi_{p1}\psi_{p1}}{j\omega_1-s_1} & \frac{\psi_{p2}\psi_{p2}}{j\omega_1-s_2} & \cdots & \frac{\psi_{p2N}\psi_{p2N}}{j\omega_1-s_{2N}} & 1 & \frac{1}{\omega_1^2} \\ \frac{\psi_{p1}\psi_{p1}}{j\omega_2-s_1} & \frac{\psi_{p2}\psi_{p2}}{j\omega_2-s_2} & \cdots & \frac{\psi_{p2N}\psi_{p2N}}{j\omega_2-s_{2N}} & 1 & \frac{1}{\omega_2^2} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ \frac{\psi_{p1}\psi_{p1}}{j\omega_M-s_1} & \frac{\psi_{p2}\psi_{p2}}{j\omega_M-s_2} & \cdots & \frac{\psi_{p2N}\psi_{p2N}}{j\omega_M-s_{2N}} & 1 & \frac{1}{\omega_M^2} \end{bmatrix} \begin{Bmatrix} Q_1 \\ Q_2 \\ \vdots \\ Q_{2N} \\ R_U \\ R_L \end{Bmatrix}$$

By solving in a **least square** sense, we find: **Qr**, **Ru** and **RL**.

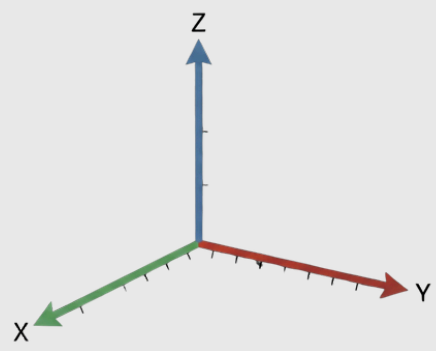
FRFs RECONSTRUCTION

Reconstructed (**scaled**) FRFs:

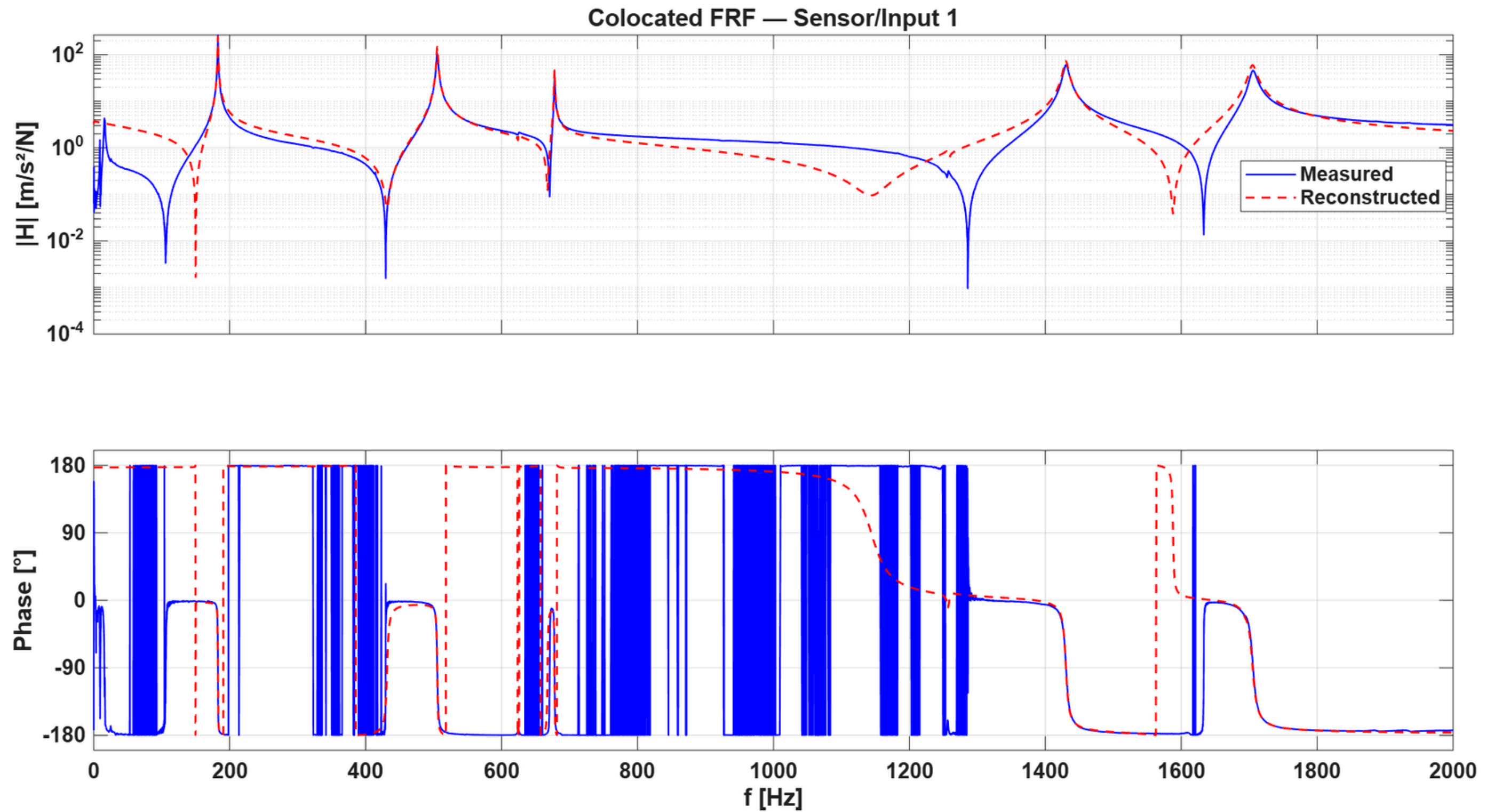
$$H_{pq}(\omega) = \sum_{r=1}^{2N} \frac{\psi_{pr}\psi_{qr}}{j\omega - s_r} Q_r + R_U + \frac{R_L}{\omega^2}$$

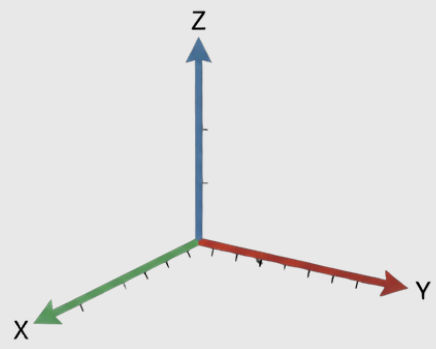
Modal mass' extraction:

$$m_r = \frac{-\omega^2}{2j Q_r \omega_r \sqrt{1-\xi_r^2}}$$

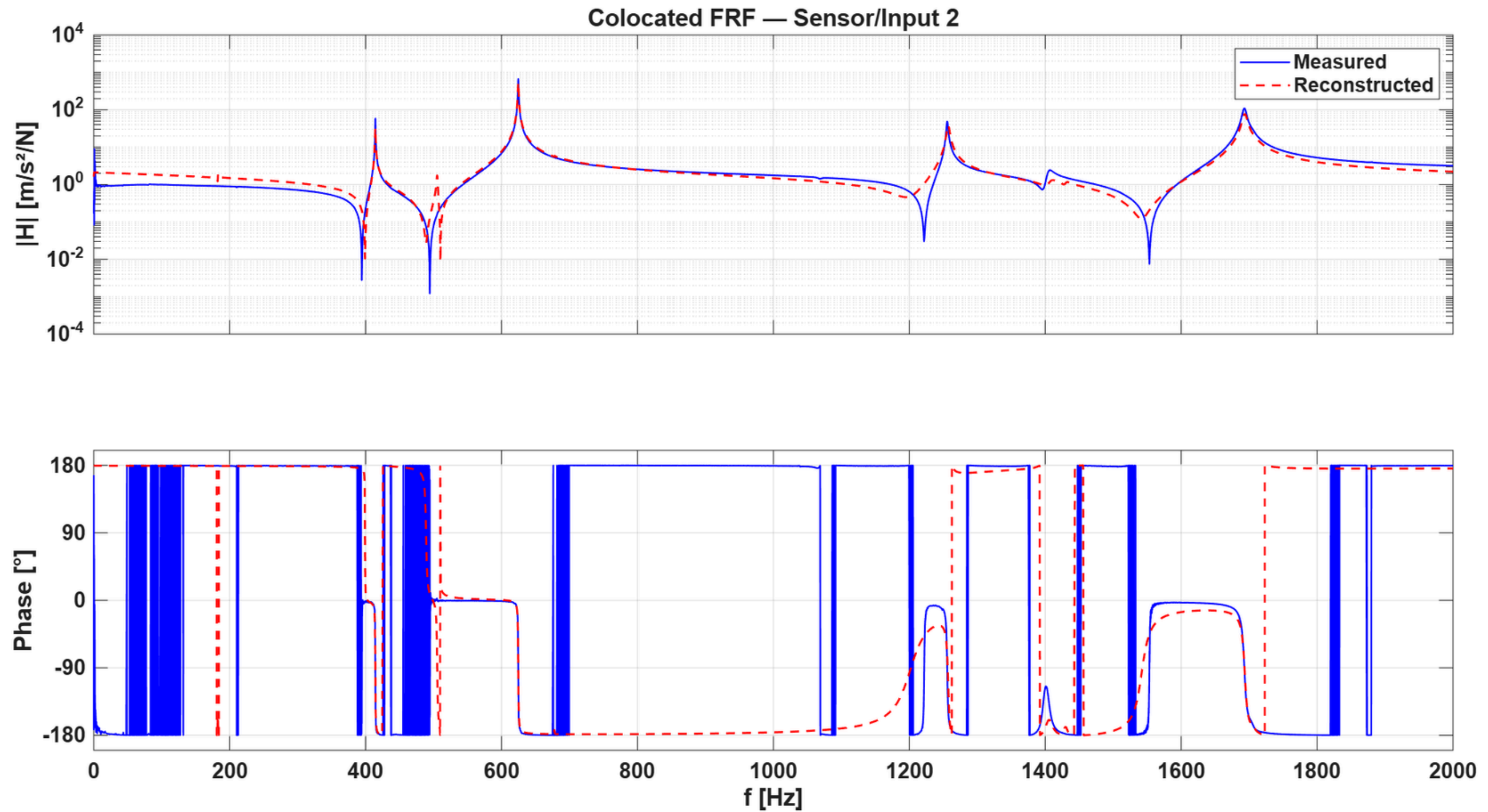


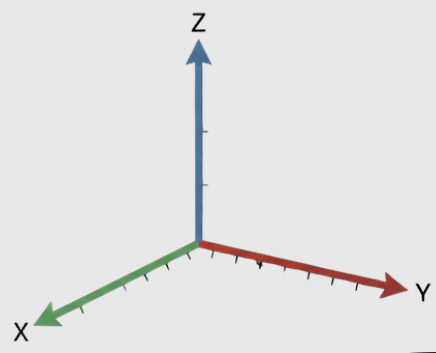
CO-LOCATED FRF





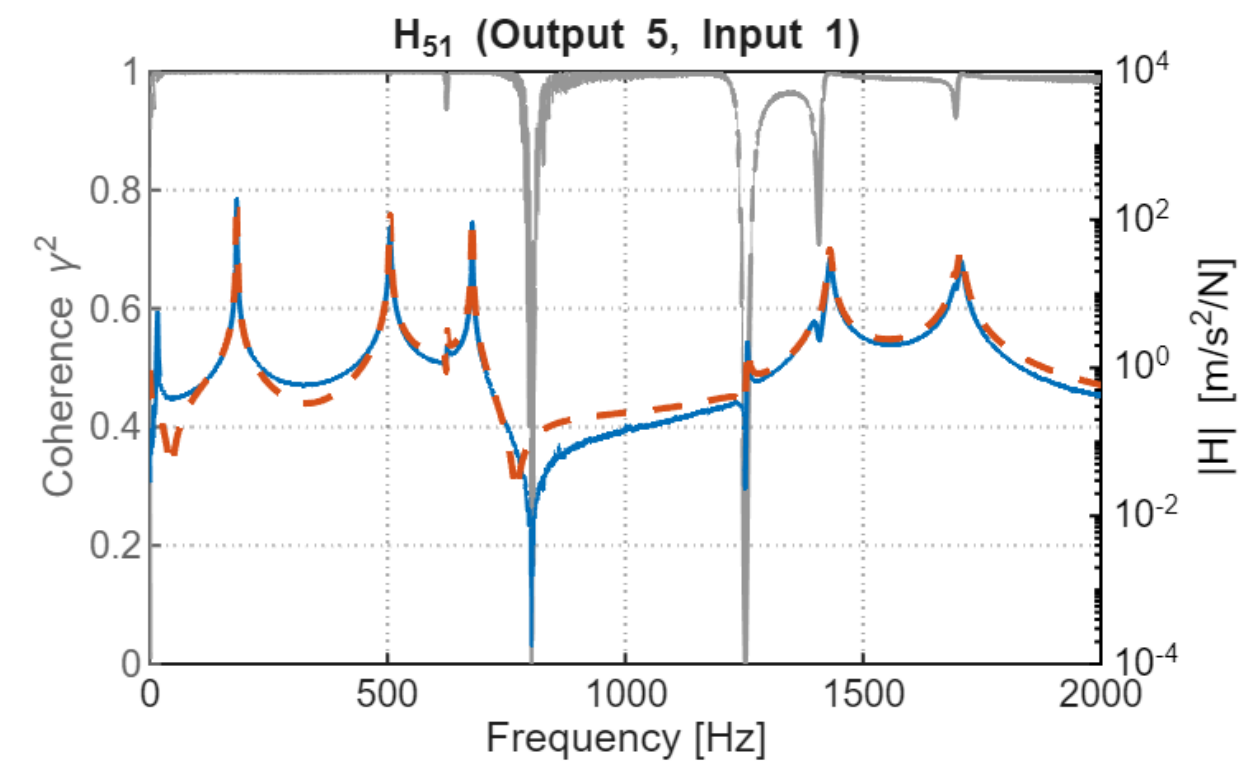
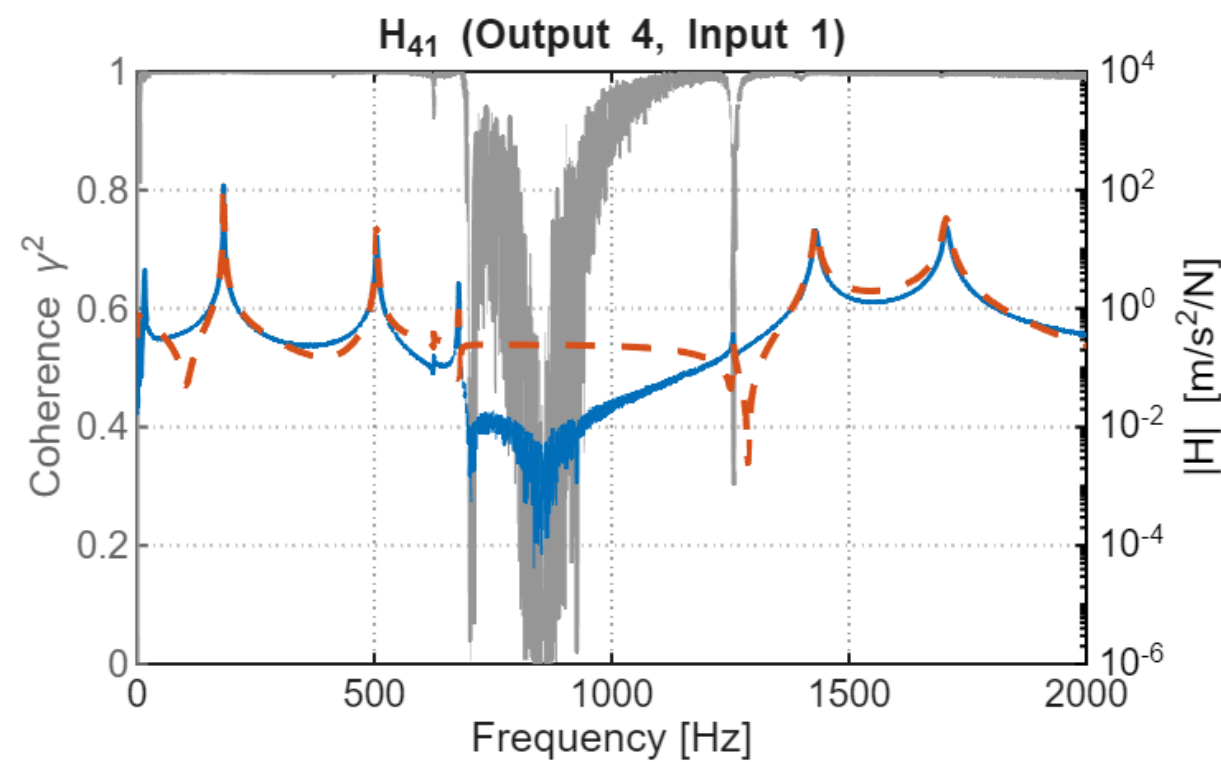
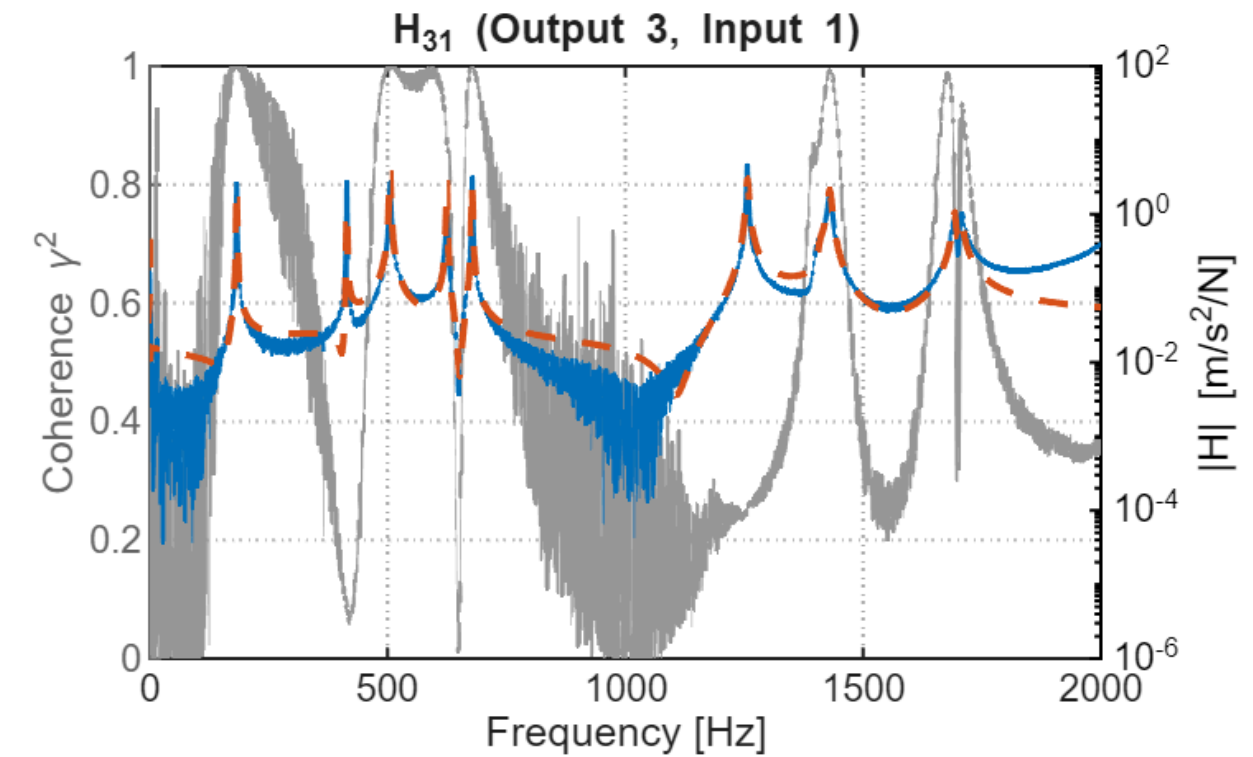
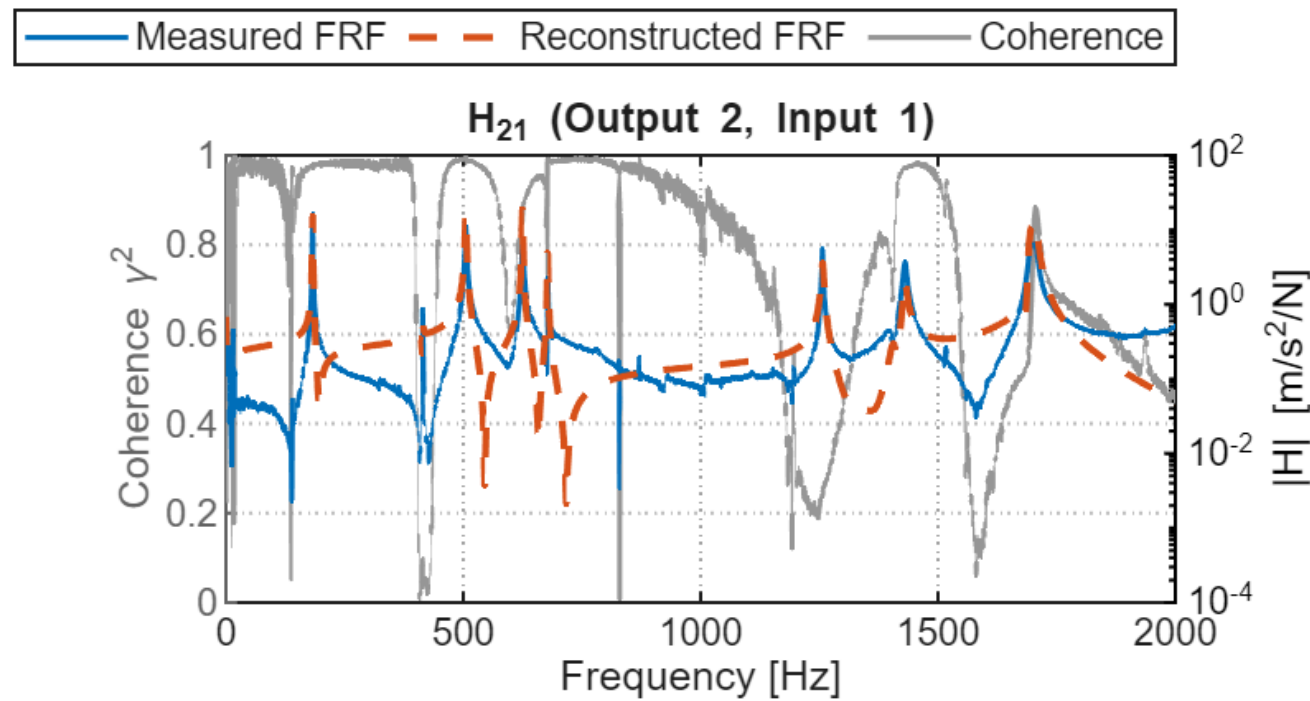
CO-LOCATED FRF

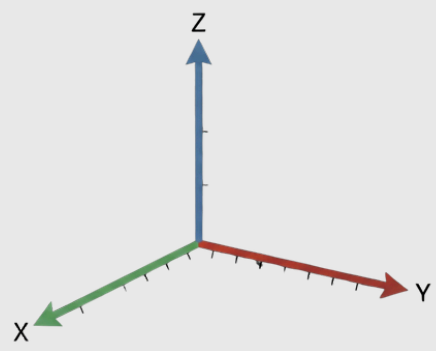




TRANSFER FRFs

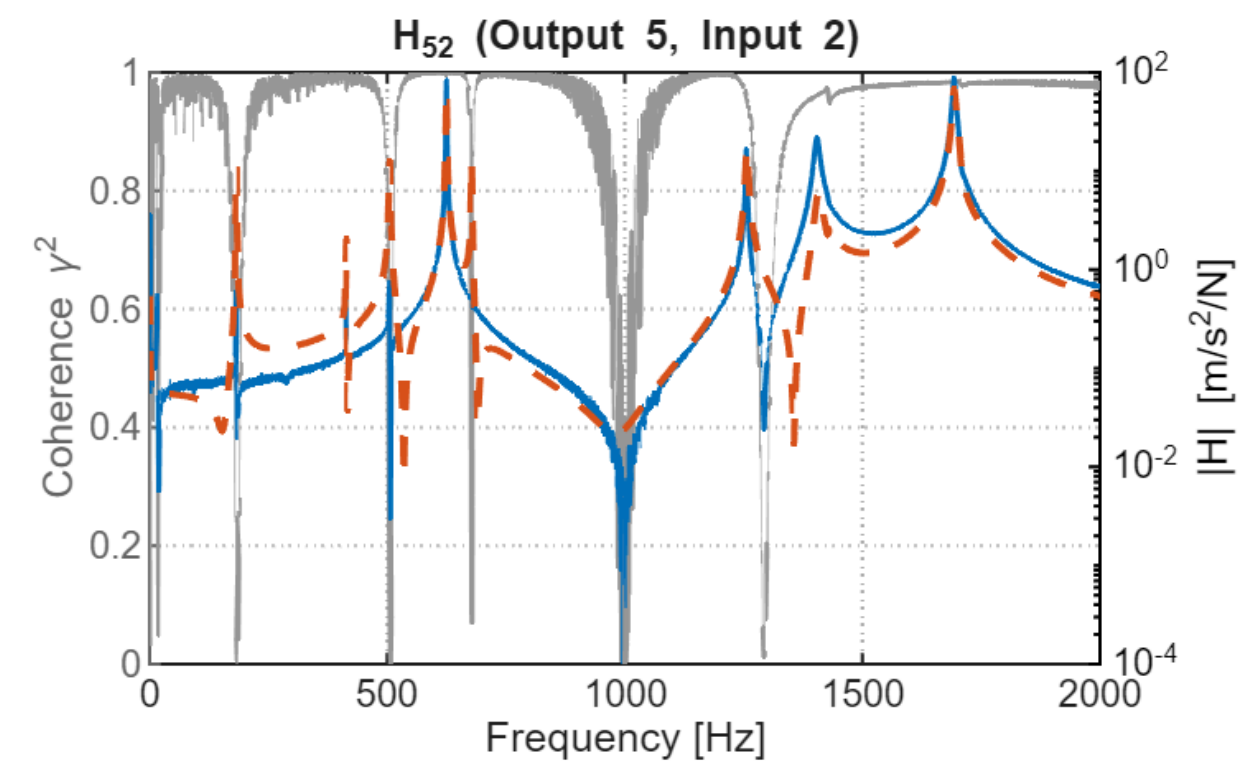
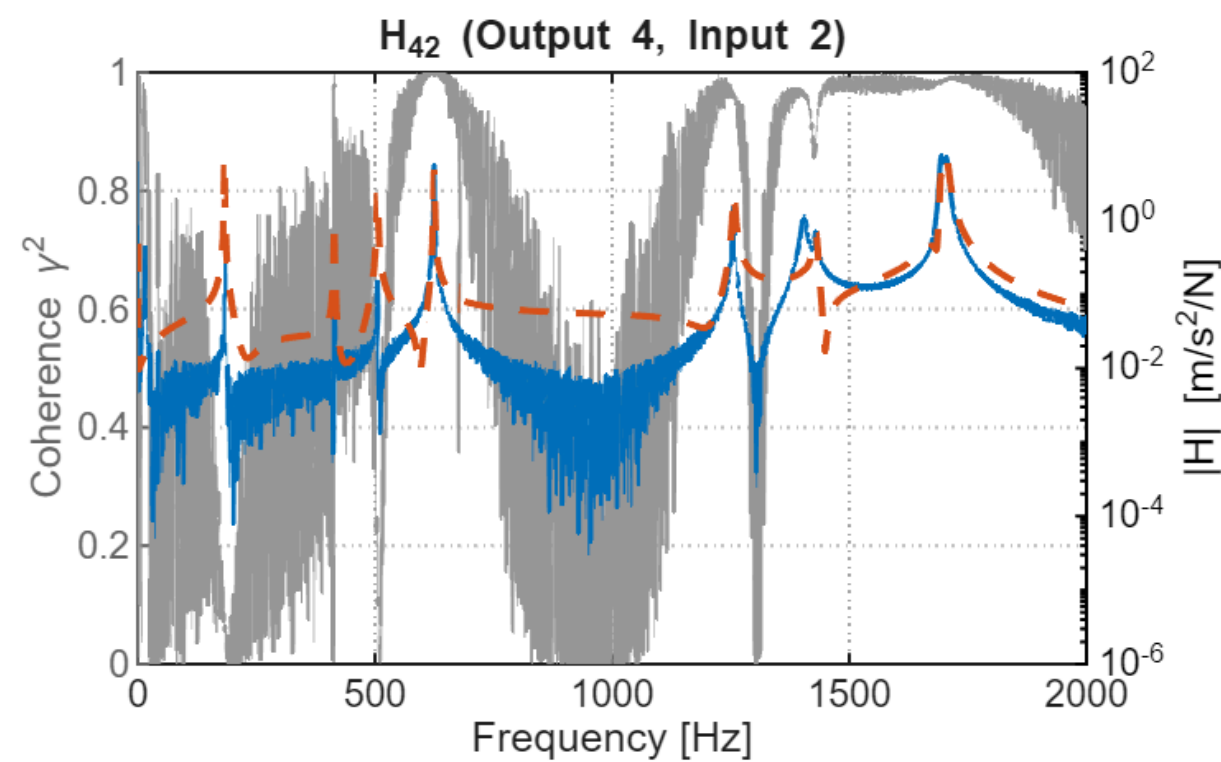
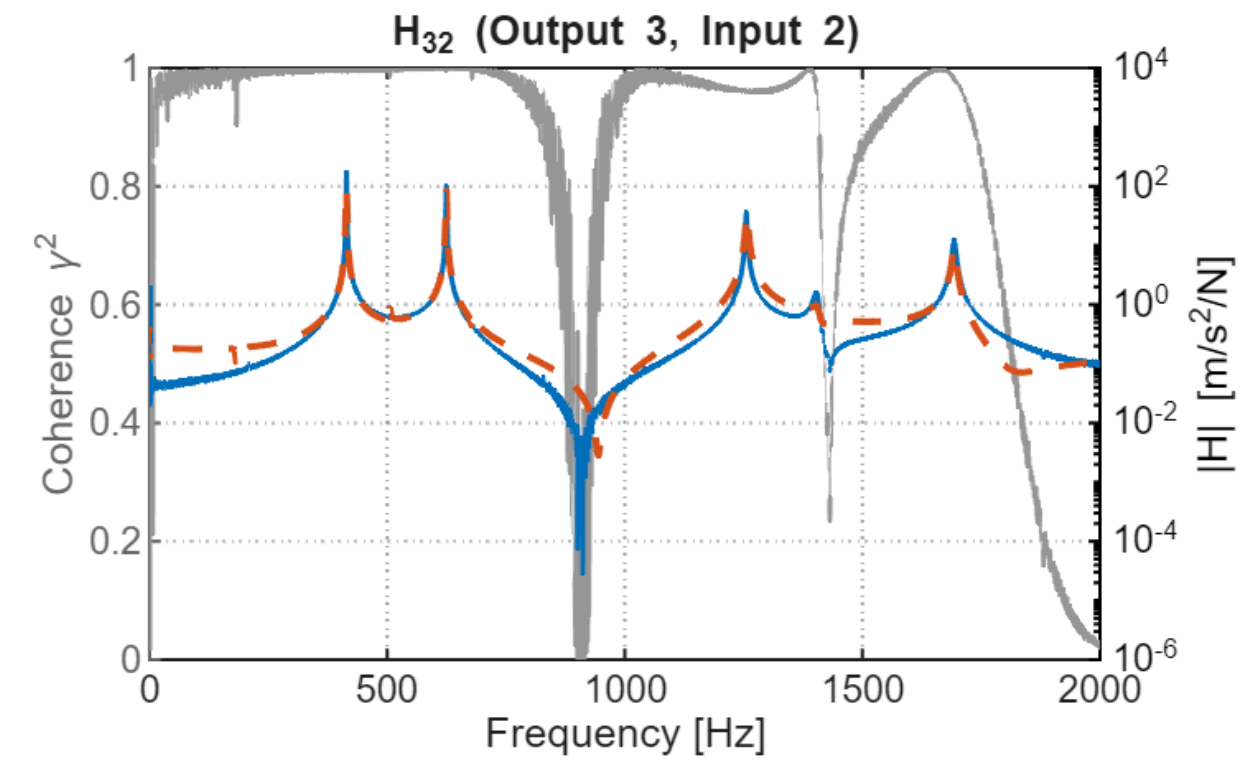
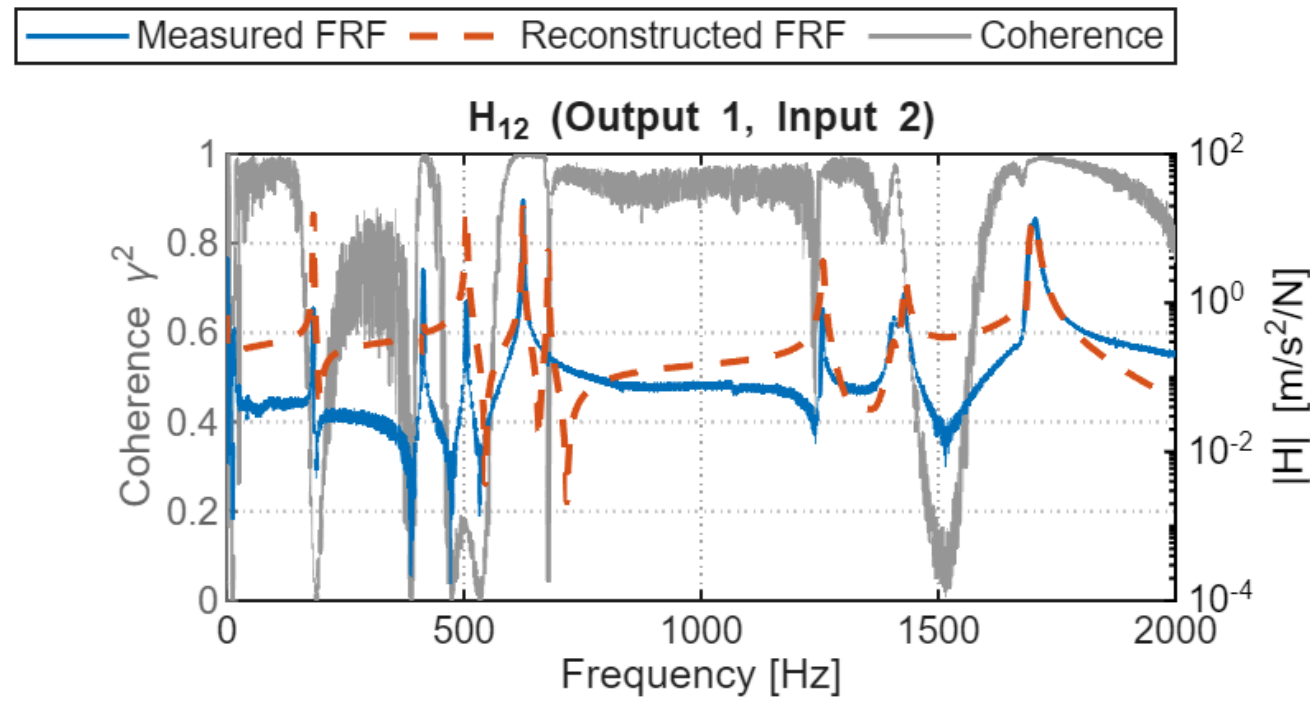
FRFs and Coherence: Input 1 $\rightarrow$ Outputs 2, 3, 4, 5





TRANSFER FRFs

FRFs and Coherence: Input 2 $\rightarrow$ Outputs 1, 3, 4, 5



POSSIBLE IMPROVEMENTS

- Focus on **fewer modes**, while maintaining the same configuration
- Improve **Spatial Resolution** - increase number of accelerometers
- **Repeat** the measurements to **decrease noise**
- Tailoring **position** of **accelerometers** based also on the real testing



EXPERIMENTAL DYNAMICS AND DATA PROCESSING
A.Y.2025/2026

THANK YOU

FOR YOUR ATTENTION

