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Paper #14349

Actual Field Response Simulation Using Modified Laboratory Loading Conditions

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University of Massachusetts Lowell

IMAC XLI

(Troy Skousen - presenter)
Structural Dynamics and Acoustic Systems Laboratory
University of Massachusetts Lowell

Outline

Motivation | History | Model | Cases | Conclusions

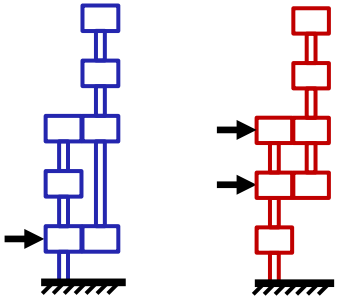
Motivation

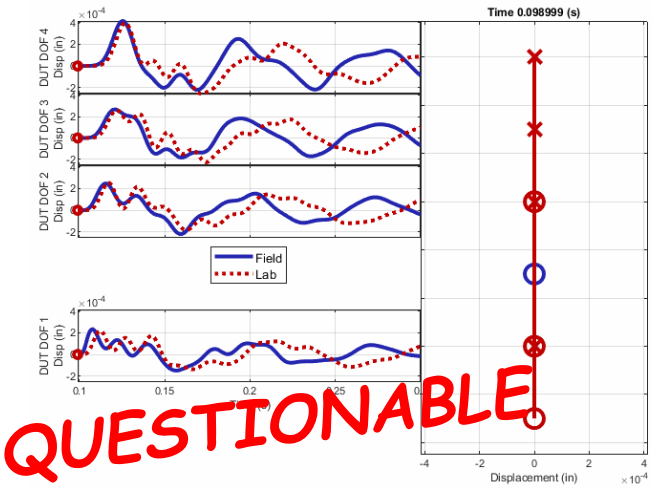
Brief history of test specifications

Analytical Model Description

Case Studies

Conclusions





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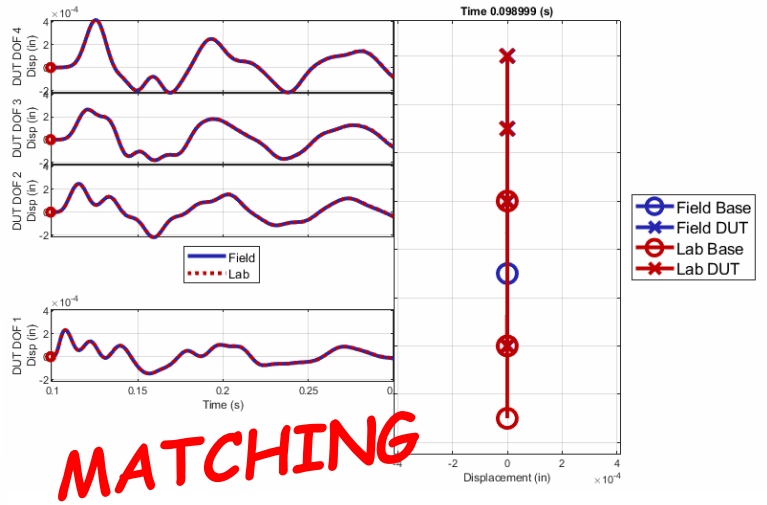


MATCHING

Motivation

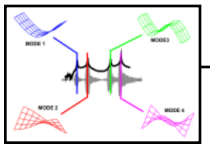
Vibration tests are used to qualify designs

Lab responses don't match the field

- Boundary condition discrepancies
- Load discrepancies
- Unnecessary test failures

Techniques are driving toward faithfully reproducing field responses

Ultimate goal is to simulate realistic damage mechanism in laboratory testing



Early Days

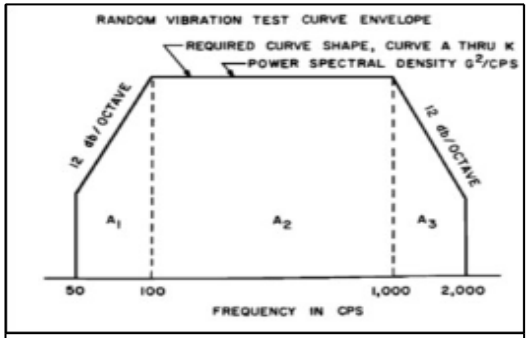
Institutions developed (1940s)

- *Independent test methods*
- *Independent test specifications*

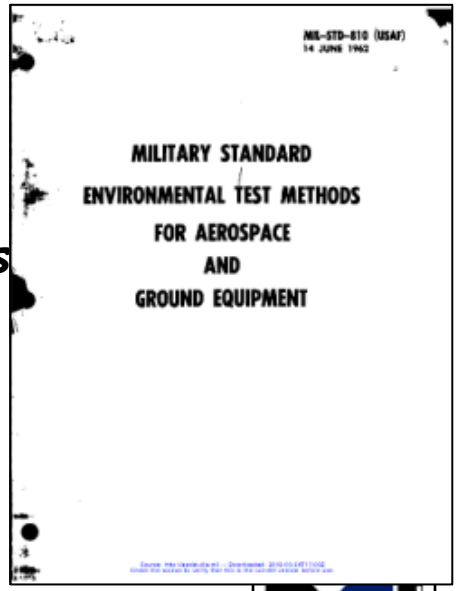
Concerns with broad flat specifications (1950s)

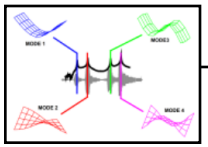
Community called for a standard MIL-STD-810 (1962)

- *Reduce cost: Simple and repeatable*
- *Single axis input covering multiple environments*
- *Rigid fixture, control at interface*
- *Incorrectly assumed rigid systems*
- *De-emphasize correlation of lab to field (seen as advanced solutions)*
- *Intended as starting point*



MIL-STD-810 Figure 514-4





Please understand:

We tried to make testing simple and repeatable with the same inputs, but the exciters and fixtures were different from lab to lab so the responses might never be the same. This is fine for some test articles, but more is needed for high consequence designs.

Simple 1DOF Inputs Need Improvement

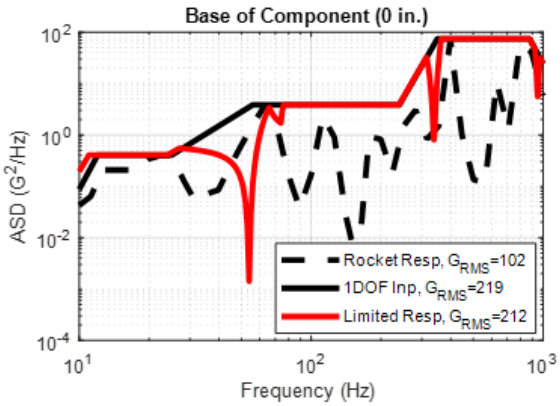
Inappropriate single axis test failures

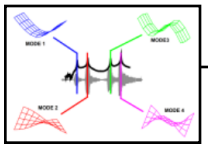
- OK in field
- Very high lab test responses common
- Possibly miss design flaws
- Hesitant to publish failures

Limiting single axis vibration tests

- In the field, input valleys are natural
- Straight line enveloping fills in valleys
- Shaker can impart too much force
- Results in extremely high responses

- Force input and/or response limit
- Added to standards





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Please understand:

We had to do force limiting because we were overtesting hardware, but that doesn't address that the inputs are wrong. This is a band aid for the symptoms of bad inputs rather than fixing the real problem. For high consequence testing, we need to do better.

Multiple Input testing

Can reduce test time and cost

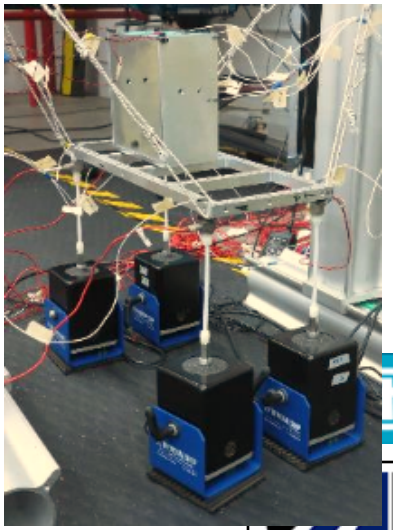
Photo from Aerospace Testing International

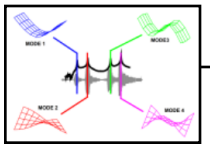
Base excitation (input at single location)

- 3-axis: 3 translations
- 6-axis: 3 translations, 3 rotations

Multiple input testing

- Modal shakers, base shakers, others
- Impedance Matched, Multi-Axis Testing (IMMAT)
- Direct loads on connections with multiple DOFs



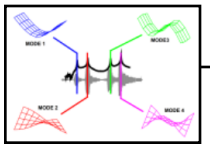


Fixture Neutralization (FINE) Methods

One dynamic boundary condition in the field, different boundary condition in the laboratory

Applying the same inputs will result in undesired responses

Determine new laboratory inputs to replicate the field responses in the laboratory



Fixture Neutralization (FINE) Methods

Impedance Based FINE – only connection DOFS

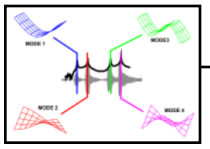
$$\left\{ X_c^{(L_2)} \right\} = \left(H_{cc}^{(D)} + H_{cc}^{(L_2)} \right) \left(H_{cc}^{(D)} + H_{cc}^{(L_1)} \right)^g \left\{ X_c^{(L_1)} \right\}$$

Modal Based FINE – Includes modal insight

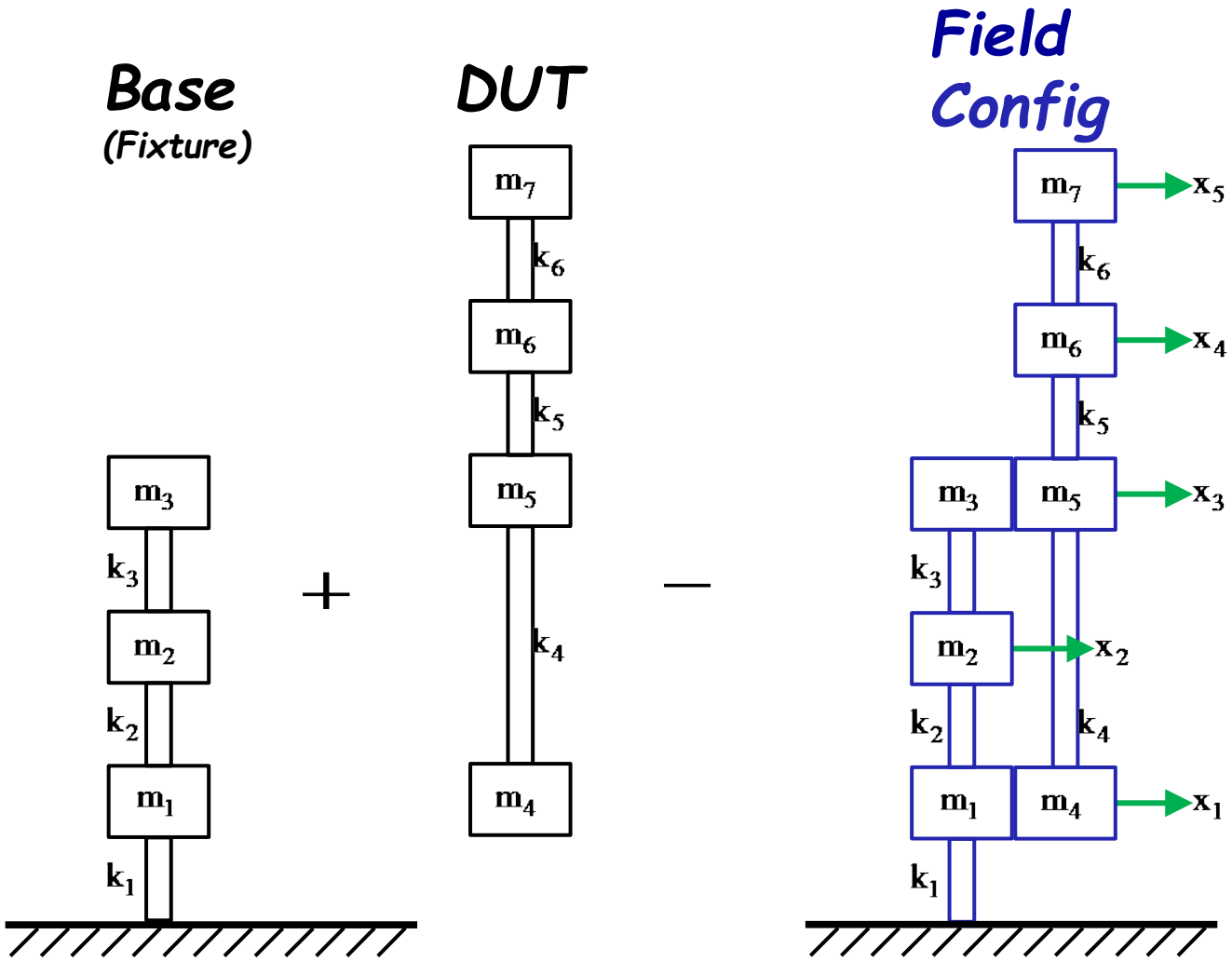
$$\left\{ F_j^{(DL_2)} \right\} = \left[H_{ij}^{(DL_2)} \right]^g \left\{ X_i^{(DL_1)} \right\}$$

Modal Amplitude Contribution Map (MACM) Equation – Lab modal acceleration to match field modal accelerations

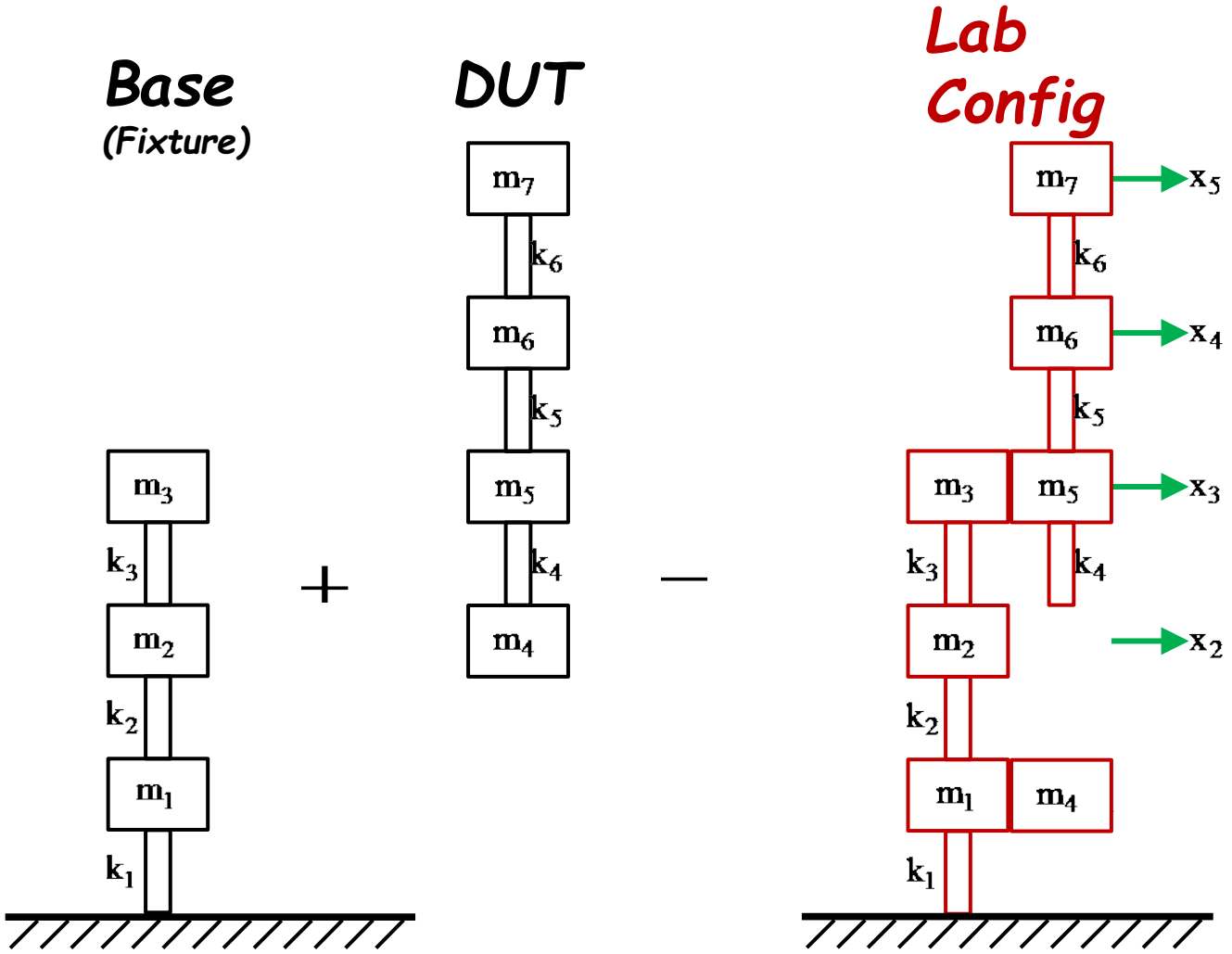
$$\left[\ddot{H}^{(DL_2)} \right] \left[U_j^{(DL_2)} \right]^T \left[\left[U_i^{(DL_2)} \right] \left[\ddot{H}^{(DL_2)} \right] \left[U_j^{(DL_2)} \right]^T \right]^g \left[U_i^{(DL_1)} \right] \bullet \left\{ \ddot{F}^{(DL_1)} \right\}^T$$



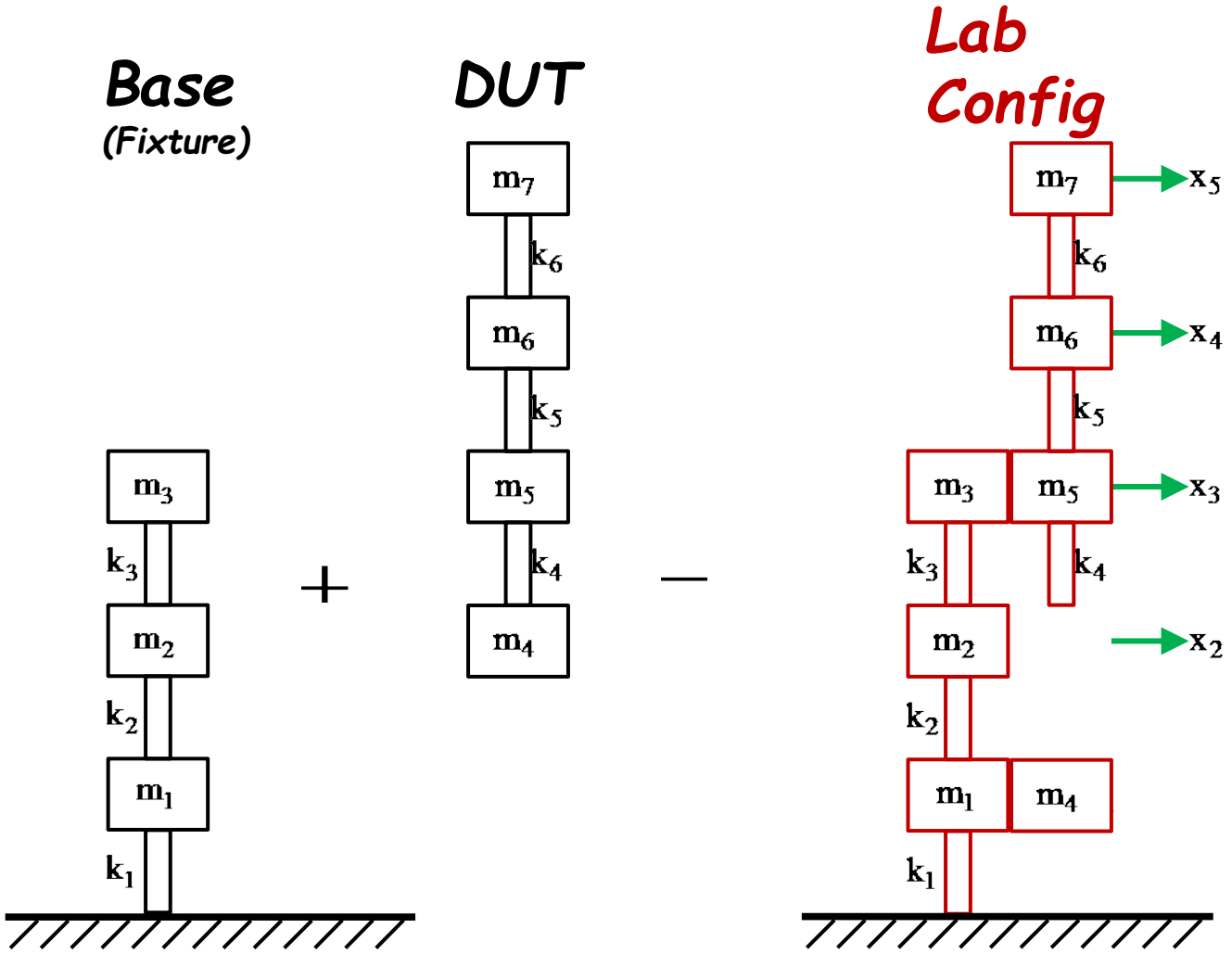
Field Configuration



Laboratory Configuration



Laboratory Configuration



Laboratory Configuration

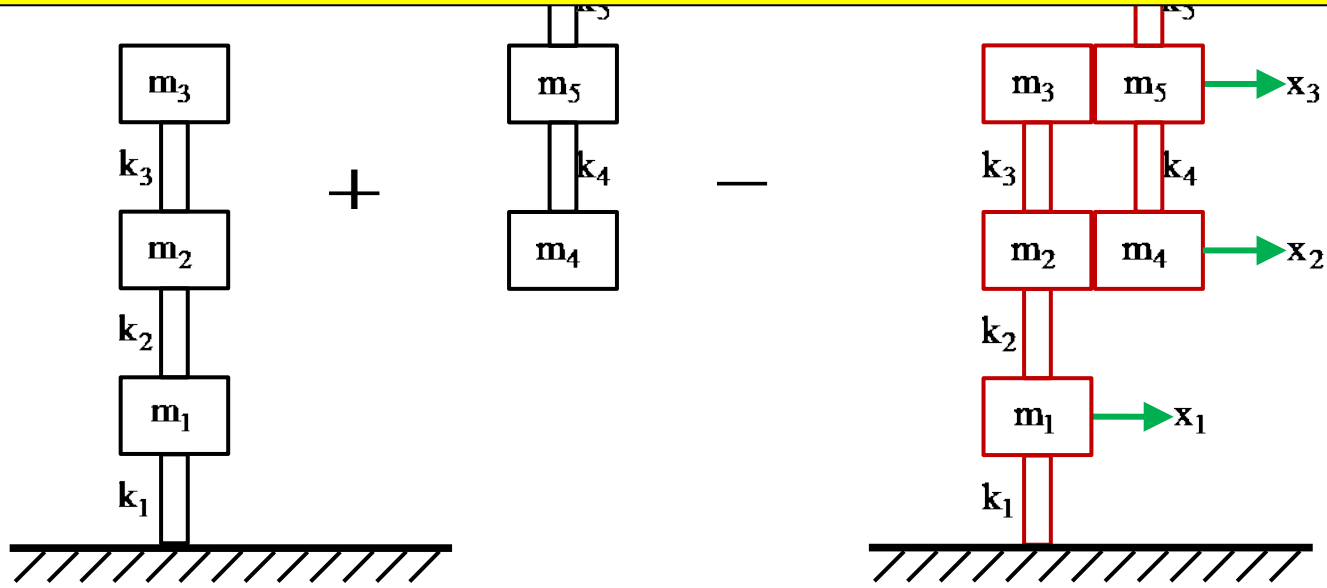
Base
(Fixture)

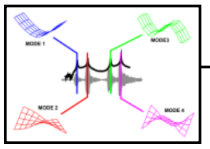
DUT

Lab Config

To change the boundary condition from the field to the lab,

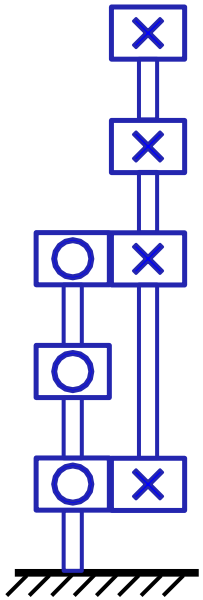
I'm only changing one connection location for the DUT to the Fixture

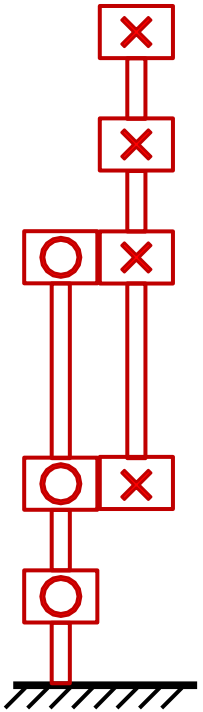




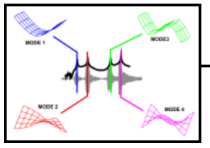
Models Side by Side

Two models will be used to show the difference between the field and lab

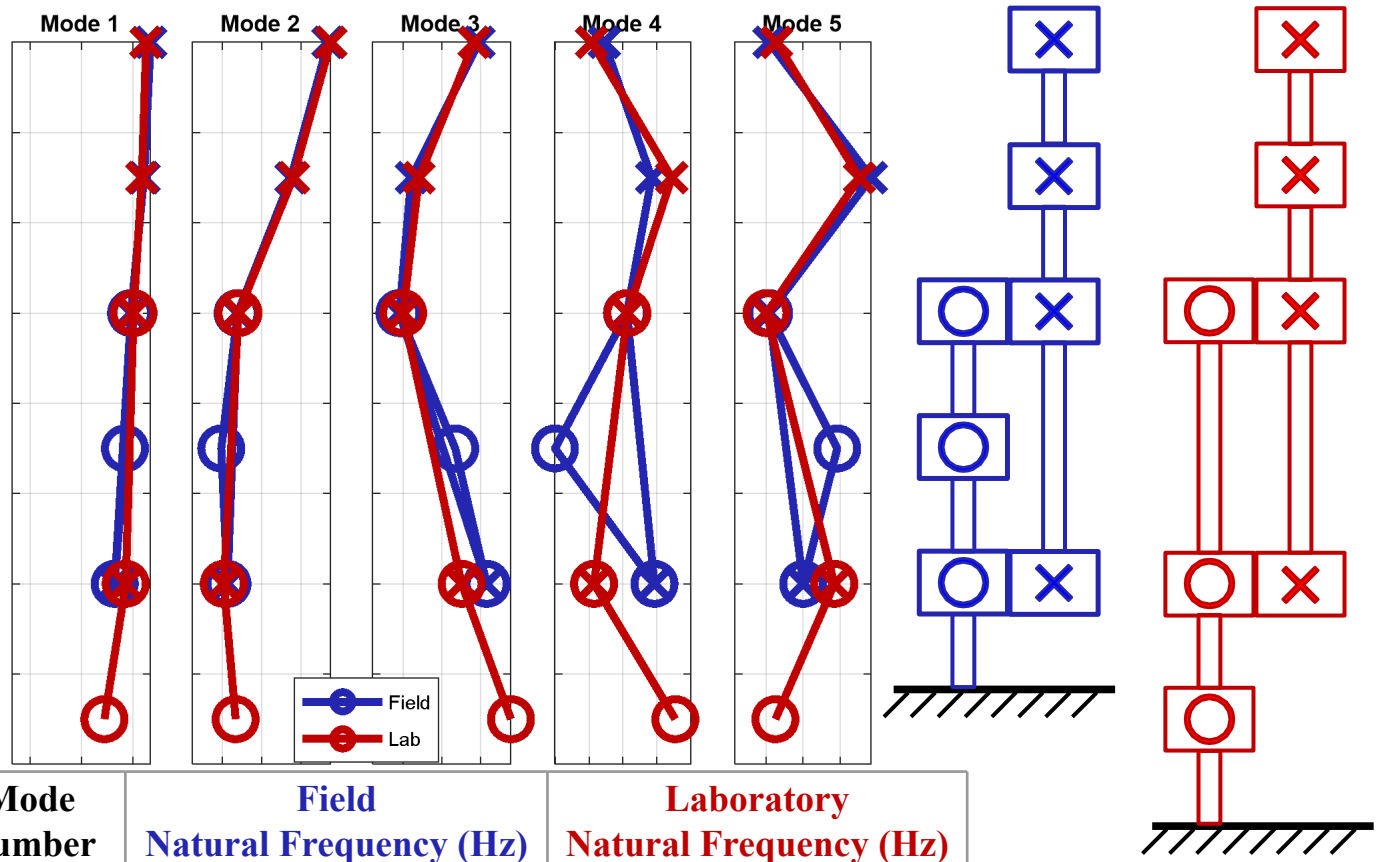




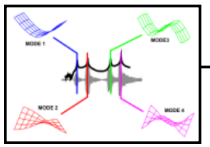
Impedance and Modal FINE have same solutions



System Mode Shape Comparisons

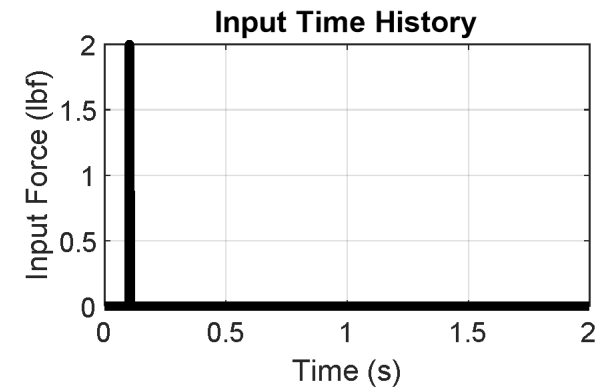


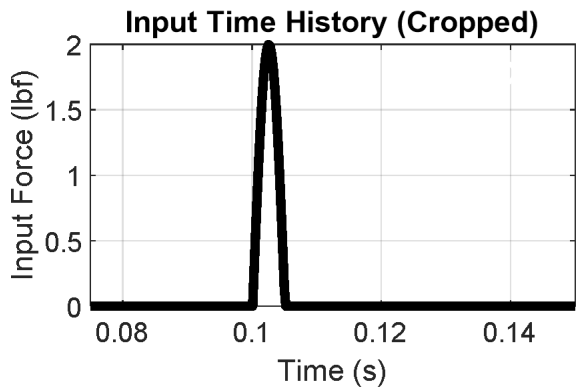
Mode Number	Field Natural Frequency (Hz)	Laboratory Natural Frequency (Hz)
1	13.1	10.9
2	31.3	30.9
3	56.6	54.8
4	66.5	66.9
5	72.5	74.0

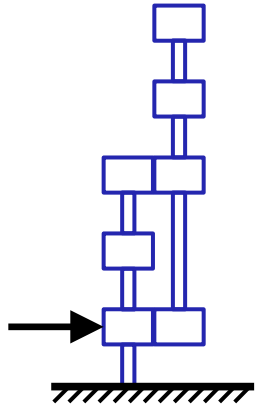


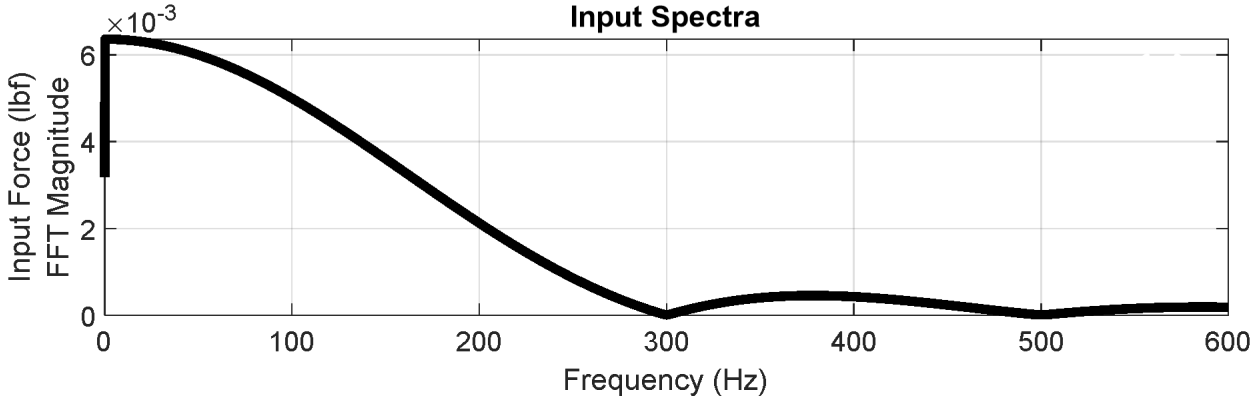
Impulse Load

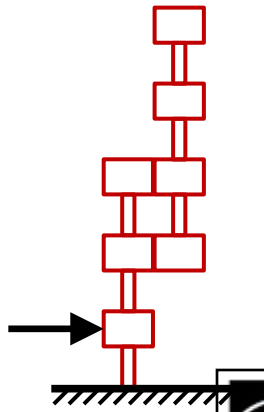
Using the same load for both field and lab produces the wrong DUT response

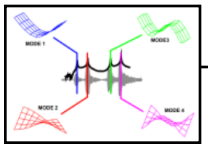




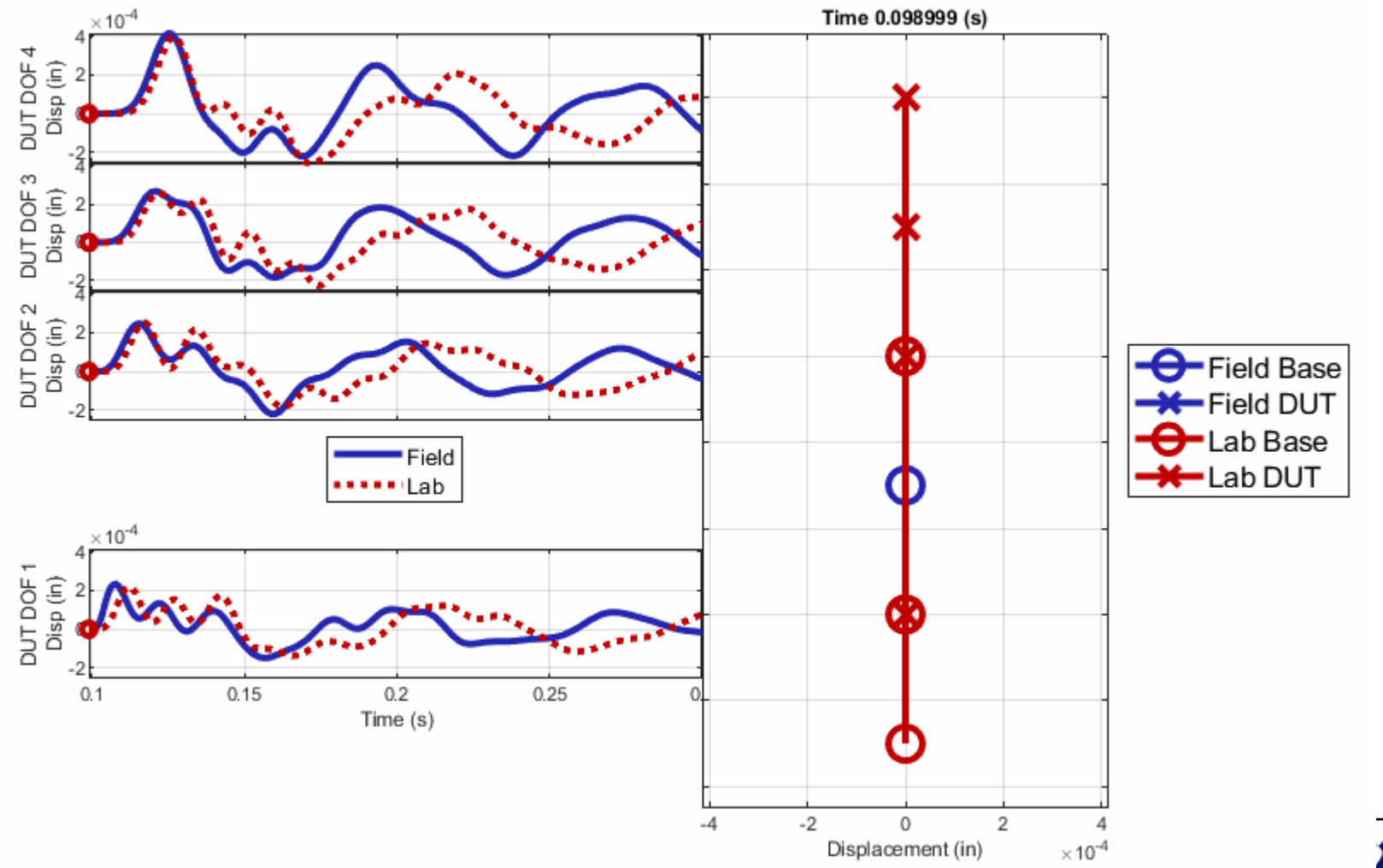








Same Load to Field and Laboratory



Need Modified Laboratory Loads

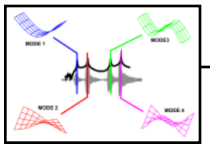
Modified forces are necessary for the DUT response to be the same in the lab as they are in the field

Doesn't matter if you use

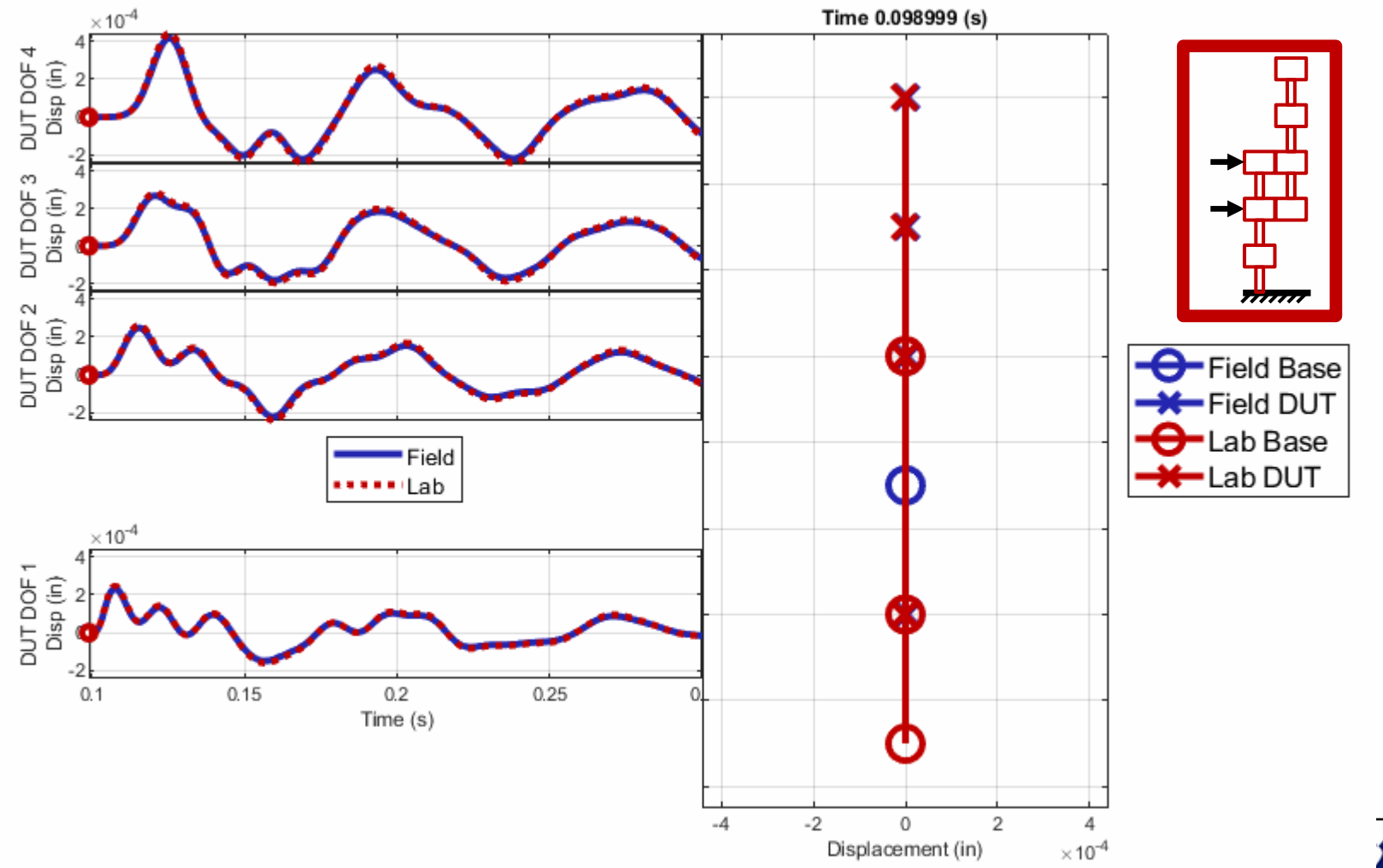
Impedance FINE

or

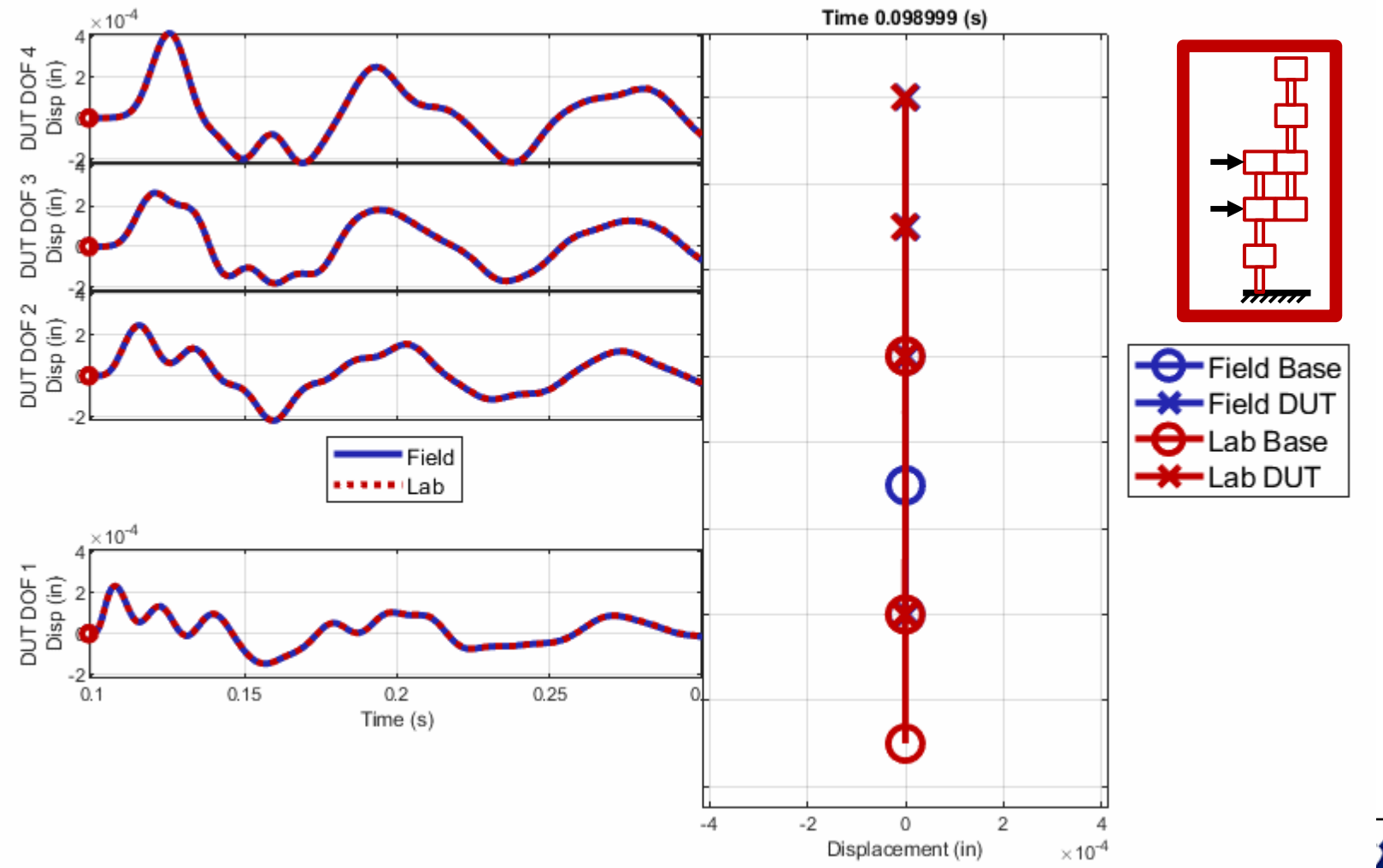
Modal FINE



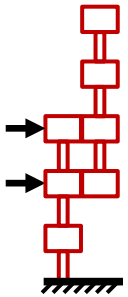
Impedance Based FINE

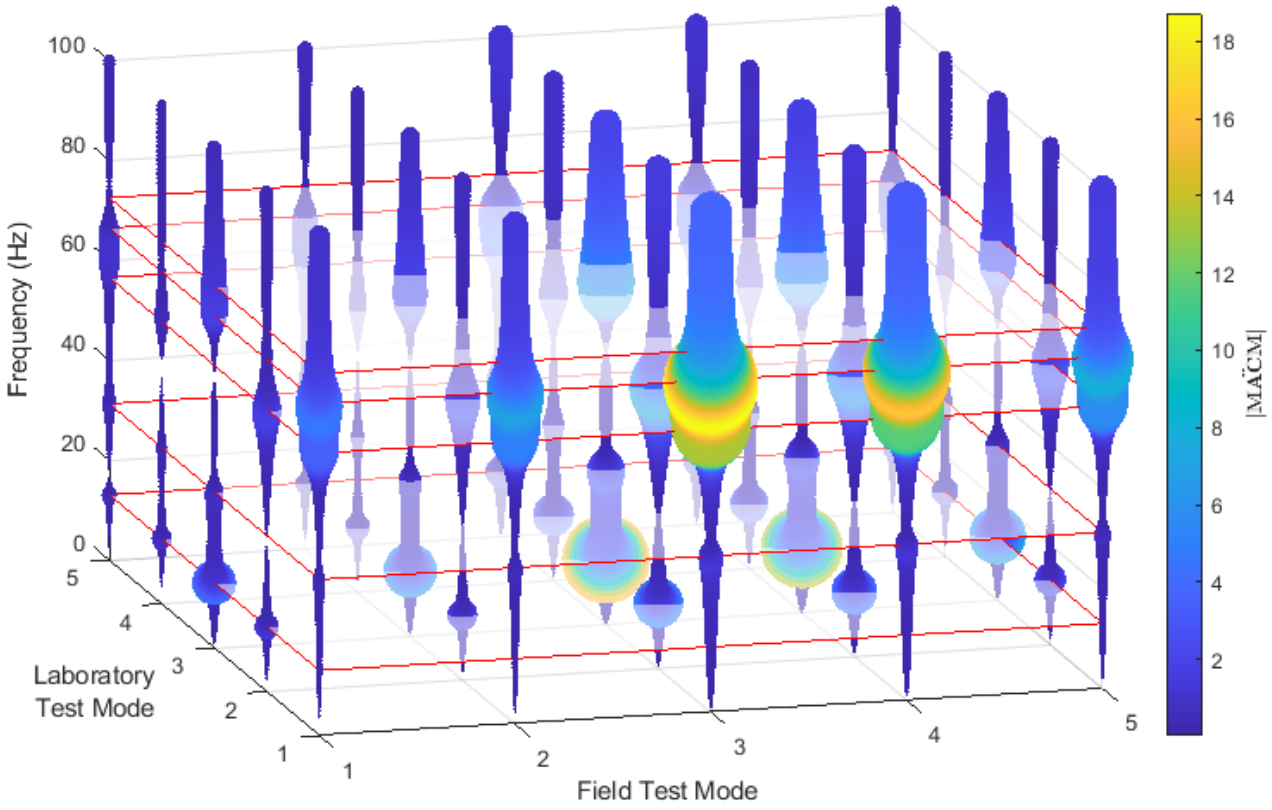


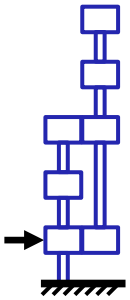
Modal Based FINE



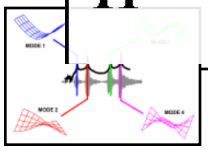
MACM







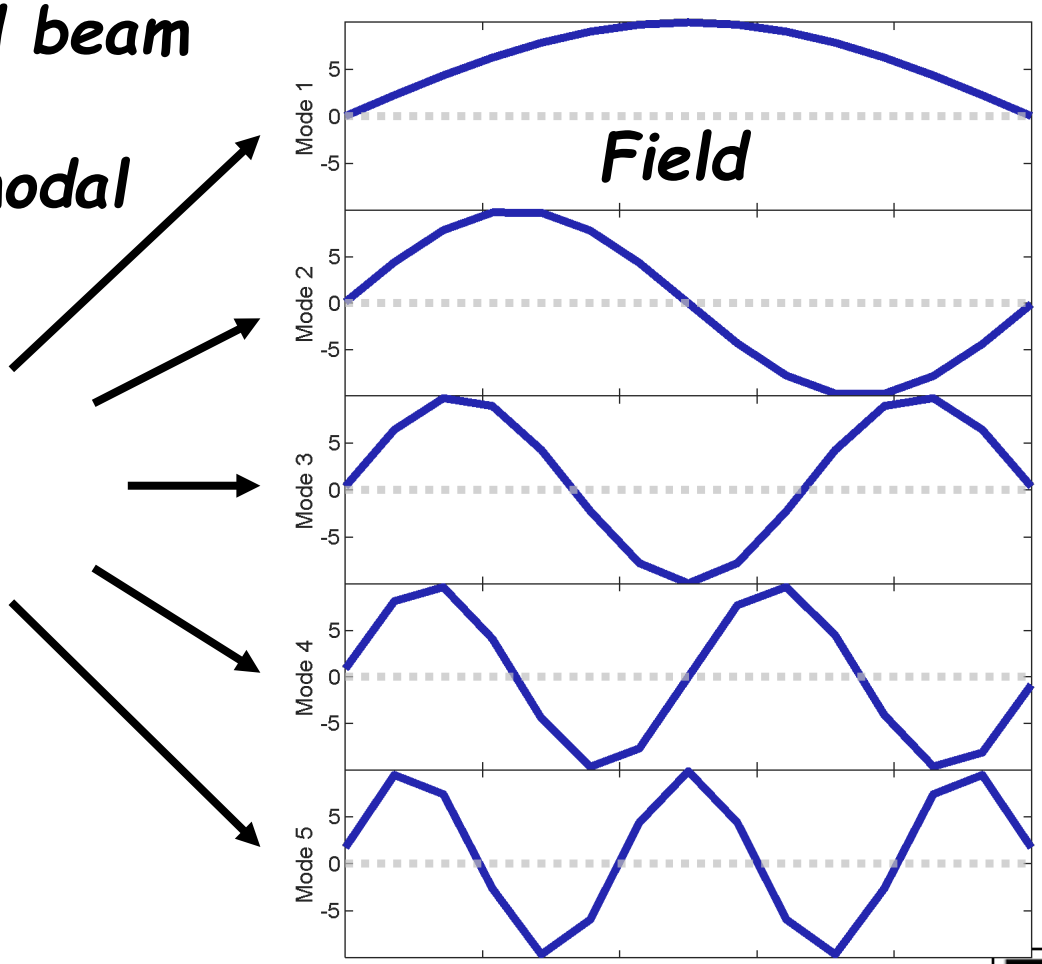
$$\left[\bar{\Phi}^{(DL_2)}\right]\left[U_j^{(DL_2)}\right]^T\left[\left[U_i^{(DL_2)}\right]\left[\bar{\Phi}^{(DL_2)}\right]\left[U_j^{(DL_2)}\right]^T\right]^g\left[U_i^{(DL_1)}\right]\bullet\left\{\bar{\Phi}^{(DL_1)}\right\}^T$$

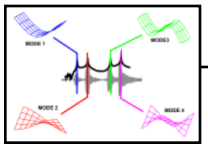


Simply Supported Beam (Field Example)

Simply supported beam motion = linear combination of modal motion

$$\ddot{x} = U\ddot{\bar{x}}$$

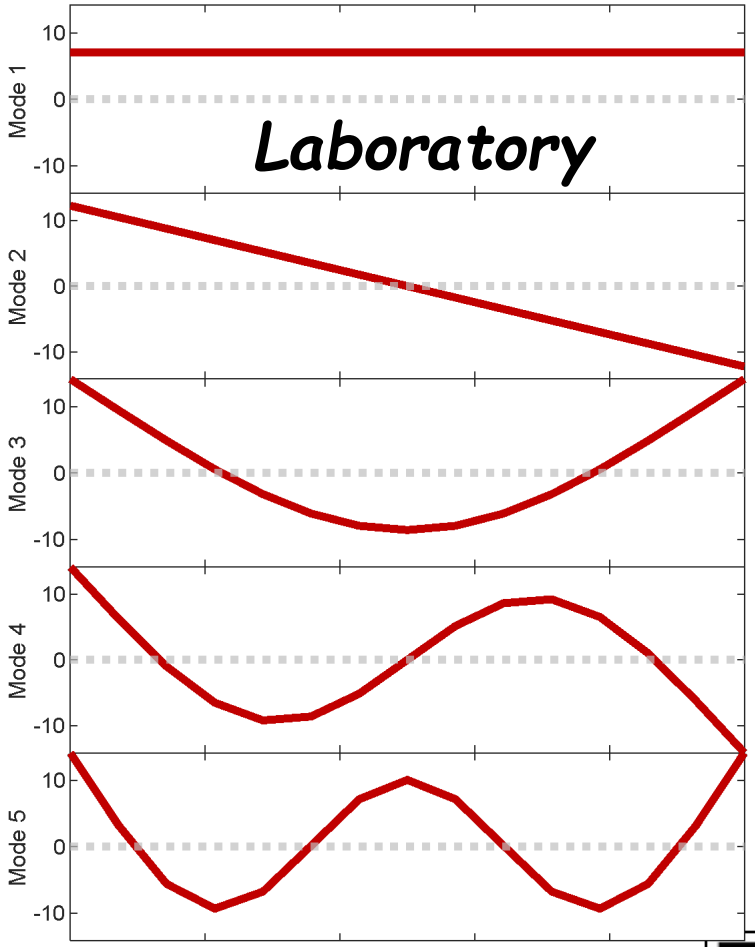




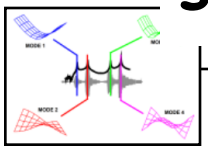
Free – Free Beam (Lab Example)

Free – free beam motion = linear combination of modal motion

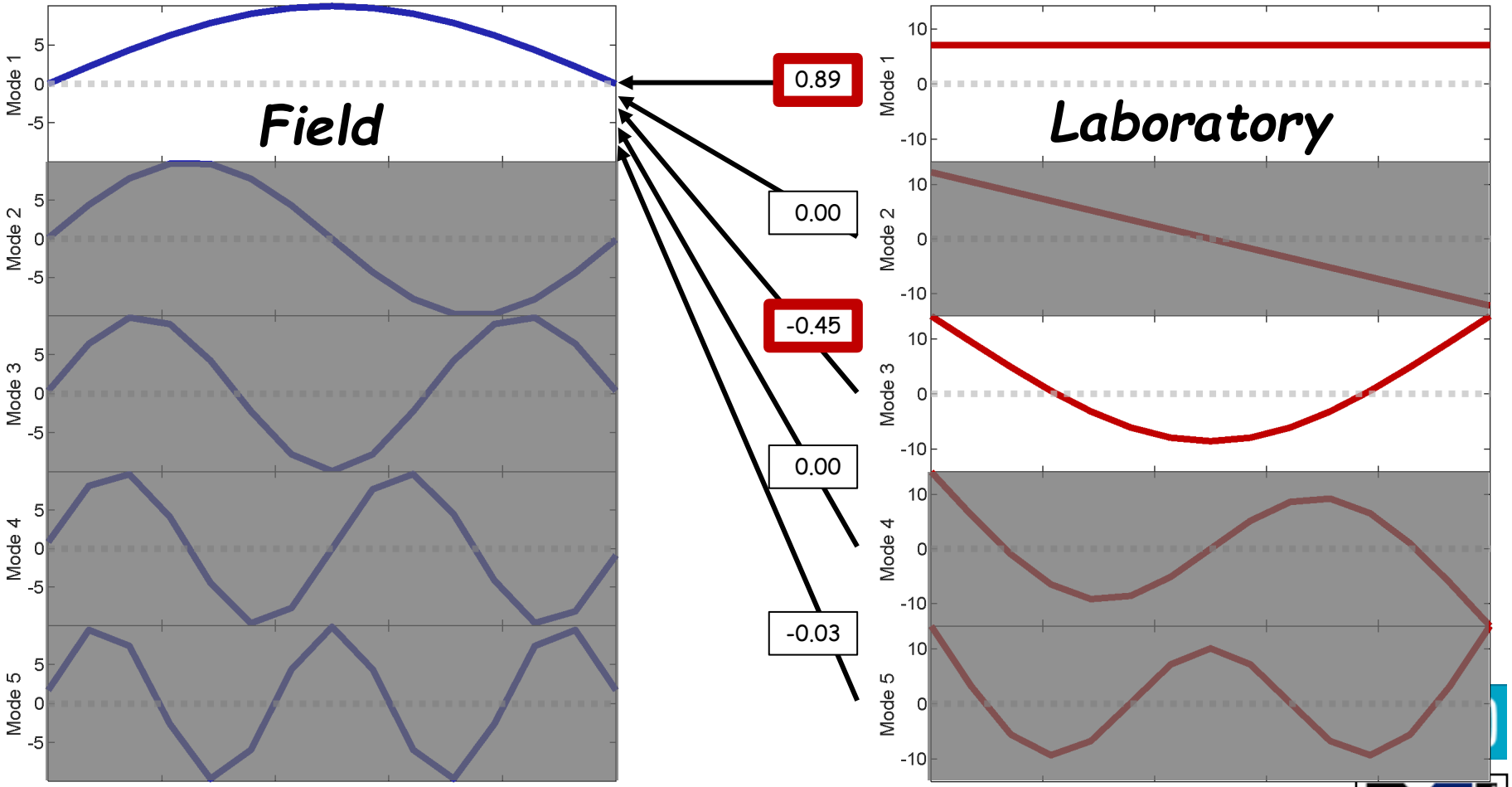
$$\{X\} = U\{\overline{X}\}$$



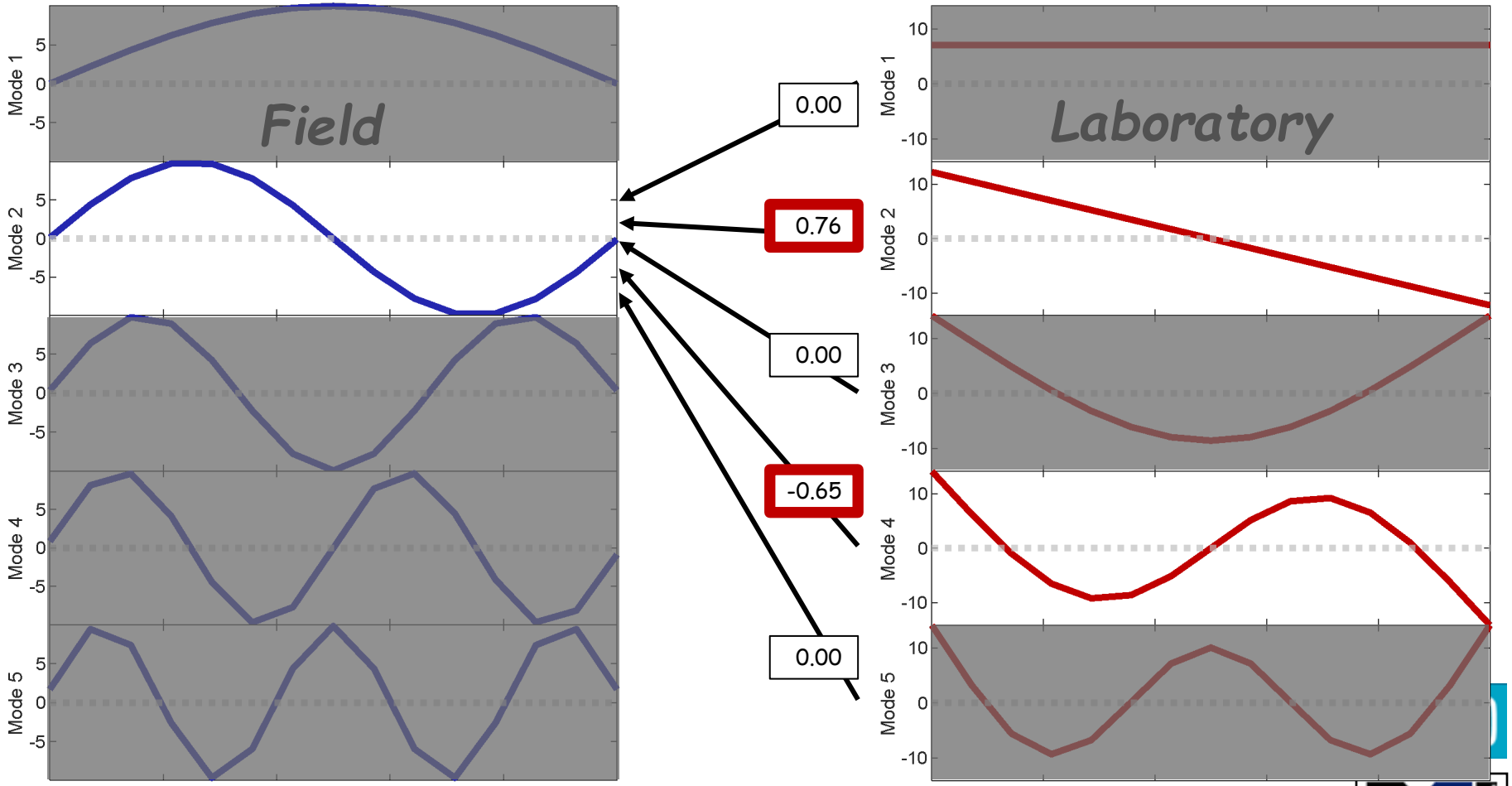
What combination of these modes adds up to each of the simply supported beam modes?



Simply Supported Beam Mode 1 from Free - Free



Simply Supported Beam Mode 2 from Free - Free



MACM Provides More Information

Mode mixing found in U_{12} transformation matrix

$$U_{12} = U_1^g U_2$$

U_{12}		Lab Modes				
		1	2	3	4	5
Field Modes	1	0.89	0.00	-0.45	0.00	-0.03
	2	0.00	0.76	0.00	-0.65	0.00
	3	0.28	0.00	0.61	0.00	-0.73
	4	0.00	0.37	0.00	0.51	0.00
	5	0.18	0.00	0.35	0.00	0.48

MACM

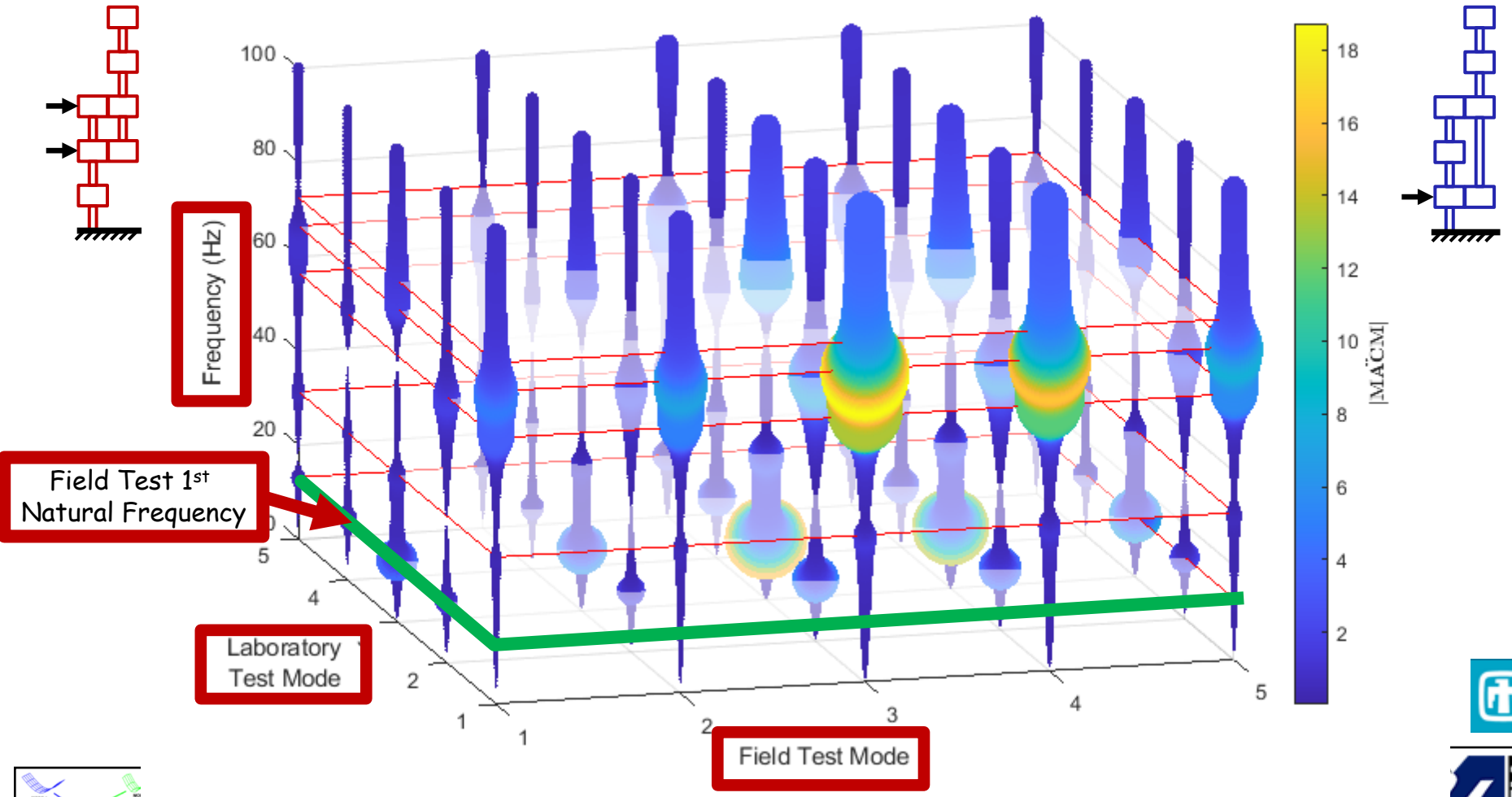
- Field modal response
- Laboratory mode mixing for each Field Mode
- By frequency

$$\left[\bar{H}^{(DL_2)}\right]\left[U_j^{(DL_2)}\right]^T\left[U_i^{(DL_2)}\right]\left[\bar{H}^{(DL_2)}\right]\left[U_j^{(DL_2)}\right]^T\Big]^g\left[U_i^{(DL_1)}\right]\bullet\left\{\bar{X}^{(DL_1)}\right\}$$

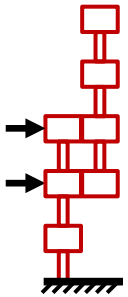
Lab: Separated Modal Response

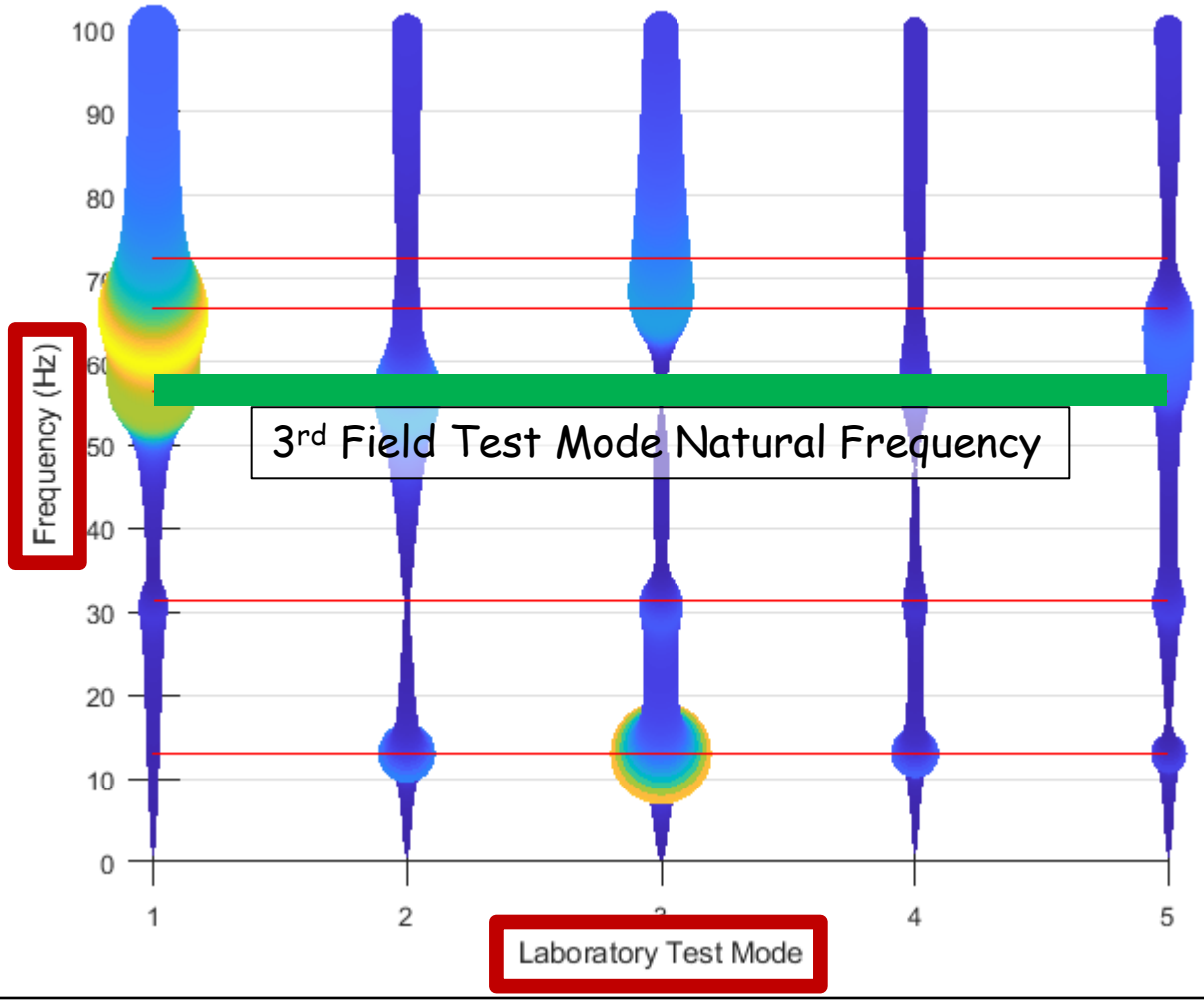
Field: Separated Modal Response

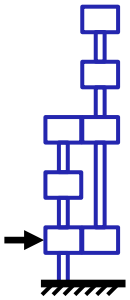
MACM

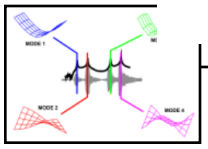

Frequency (Hz)
100
80
60
40
20
0
Field Test 1st Natural Frequency
Laboratory Test Mode
5
4
3
2
1
Field Test Mode
1
2
3
4
5
|MAC|
18
16
14
12
10
8
6
4
2

Focus on MACM for 3rd Field Test Mode

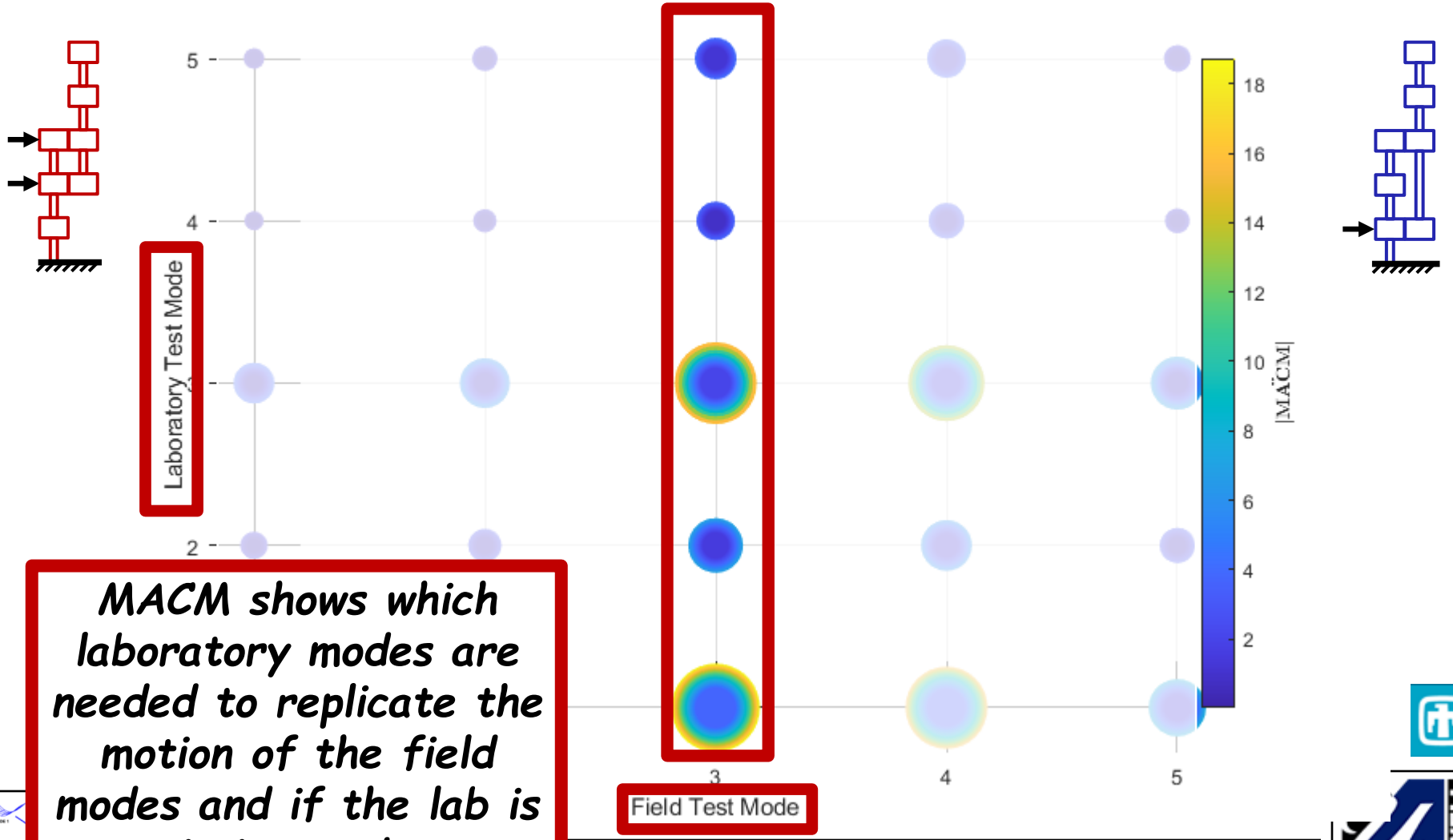








Top Down View of MACM



MACM shows which laboratory modes are needed to replicate the motion of the field modes and if the lab is missing modes.

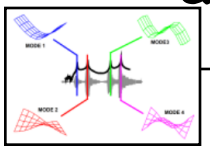
Observations and Future Direction

When the boundary condition changes,
(i.e., field to lab) new inputs required
to obtain proper field response in the lab

Impedance and Modal Fixture Neutralization methods can generate new inputs to cause response to match

Modal/MACM information shows if needed modes are missing in the lab

Developing a method that blends the capabilities and information from the two FINE techniques

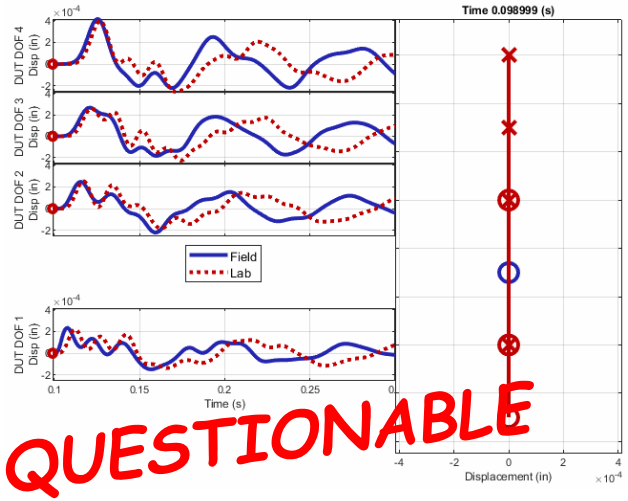


Summary

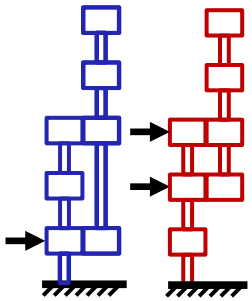
Brief history of qualification testing discussed

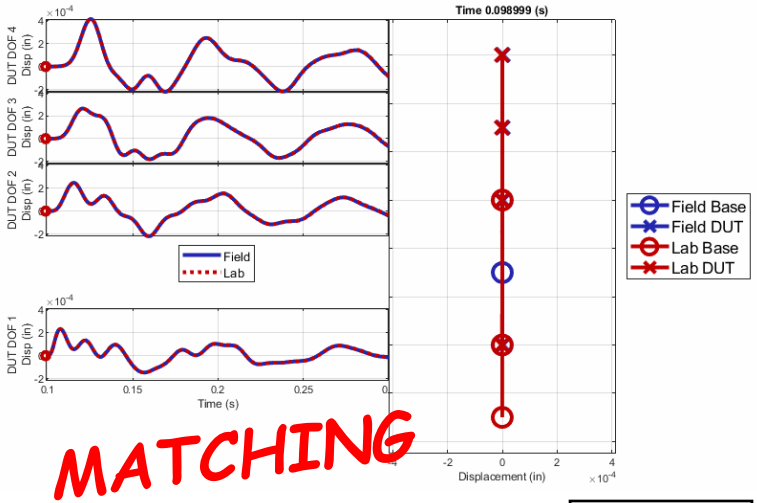
Impedance and Modal FINE models presented

Viable path to address field to lab differences



QUESTIONABLE





MATCHING