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Finite element techniques for modeling the effect on circuit board dynamic response of mechanical coupling at electrical board-to-board connectors

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Stanford University
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Presentation Outline

- Design of electronics packaging
- Case study
- Literature
- Experimental test setup
- Preliminary FE analyses
- Comparison of results
- Preliminary conclusions
- Proposed future work
- Questions

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- Design of electronics packaging
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  - Analysis of single circuit board design
  - Research motivation: designs with multiple circuit boards
- Literature
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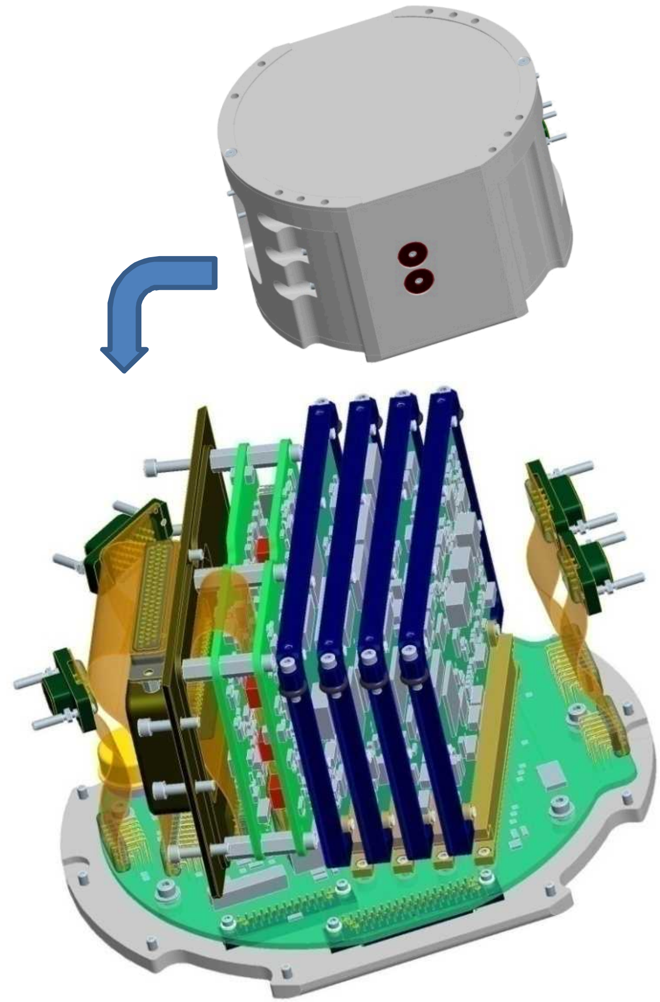
Electronics packaging designs

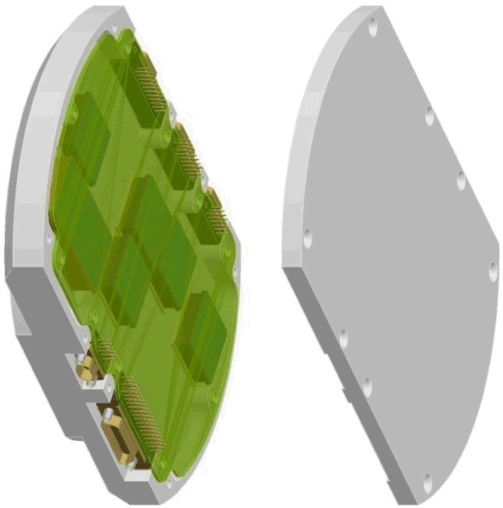
- Typical requirements
  - Volume constraint
  - Interface
    - Mounting features
    - Electrical connectors
  - Circuit board area
  - Mass properties
    - Weight, c.g.
    - Inertia tensor
  - Design-for
    - Manufacture
    - (Dis-)Assembly
    - Environment
  - Ruggedness
    - Vibration, shock
    - Thermal

Trade space:
- *size, geometry*
- *quantity*
- *interconnect scheme*
- *mounting method*

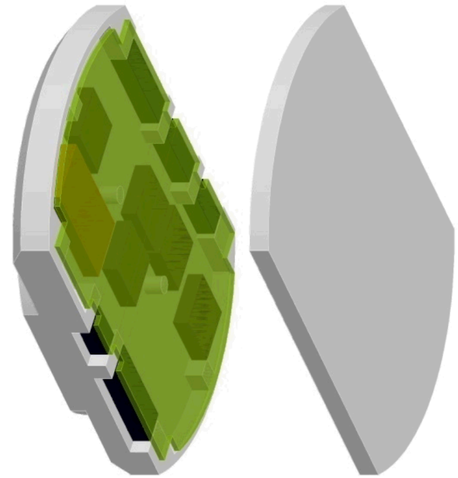


Case study: single circuit board design

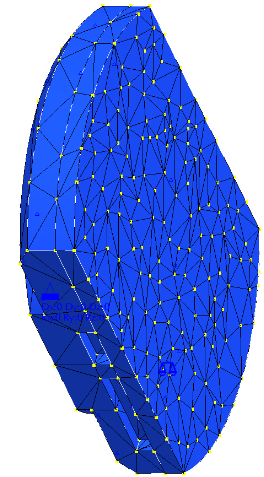
- Early design concept



Conceptual design in Pro/Engineer



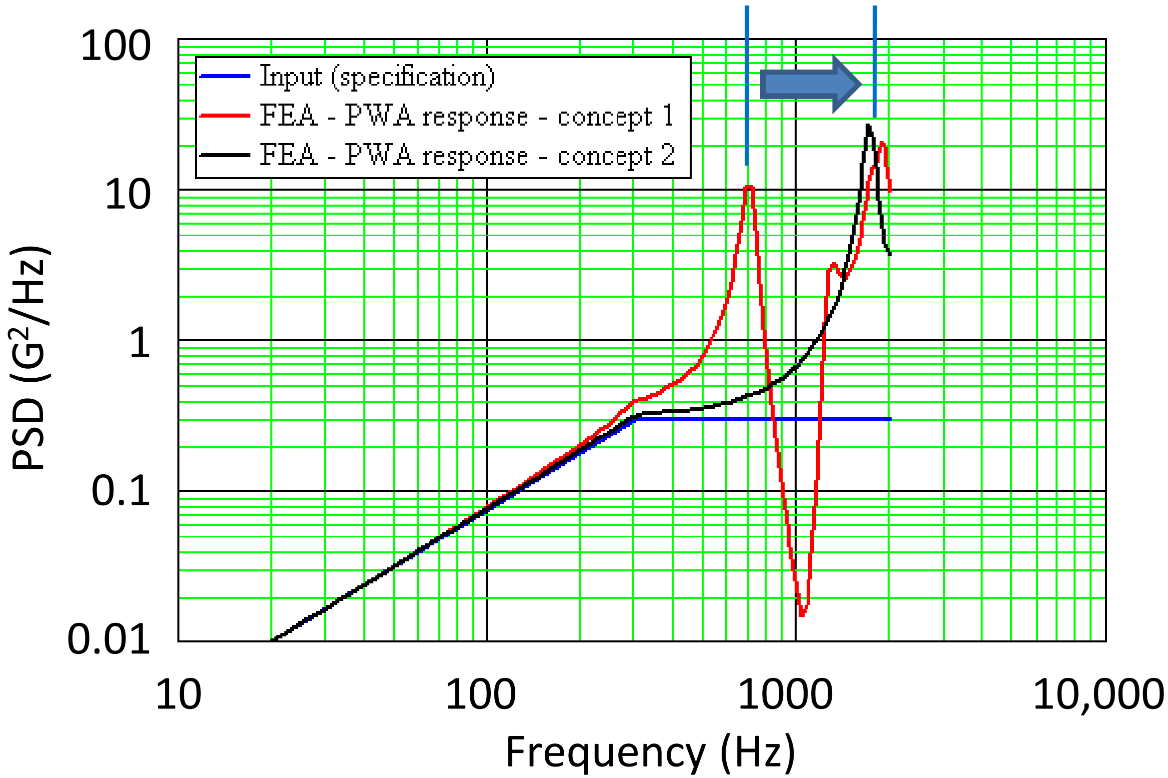
Simplified for finite-element analysis



Meshed finite-element model

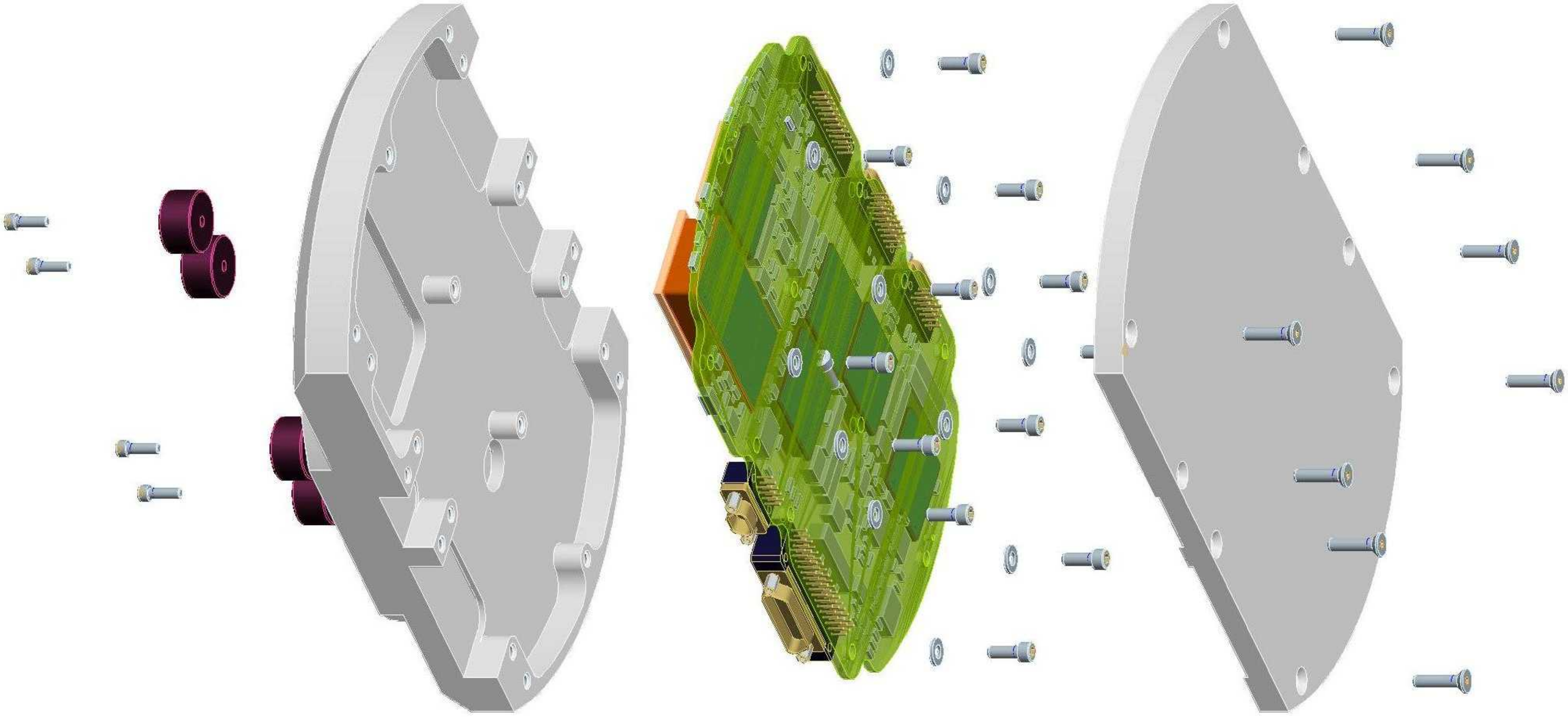
Case study: single circuit board design

- Early analysis of design concept in vibration environment
  - Circuit board material properties from literature
  - Result: desire to increase 1st natural frequency
  - Modify design concept based on result



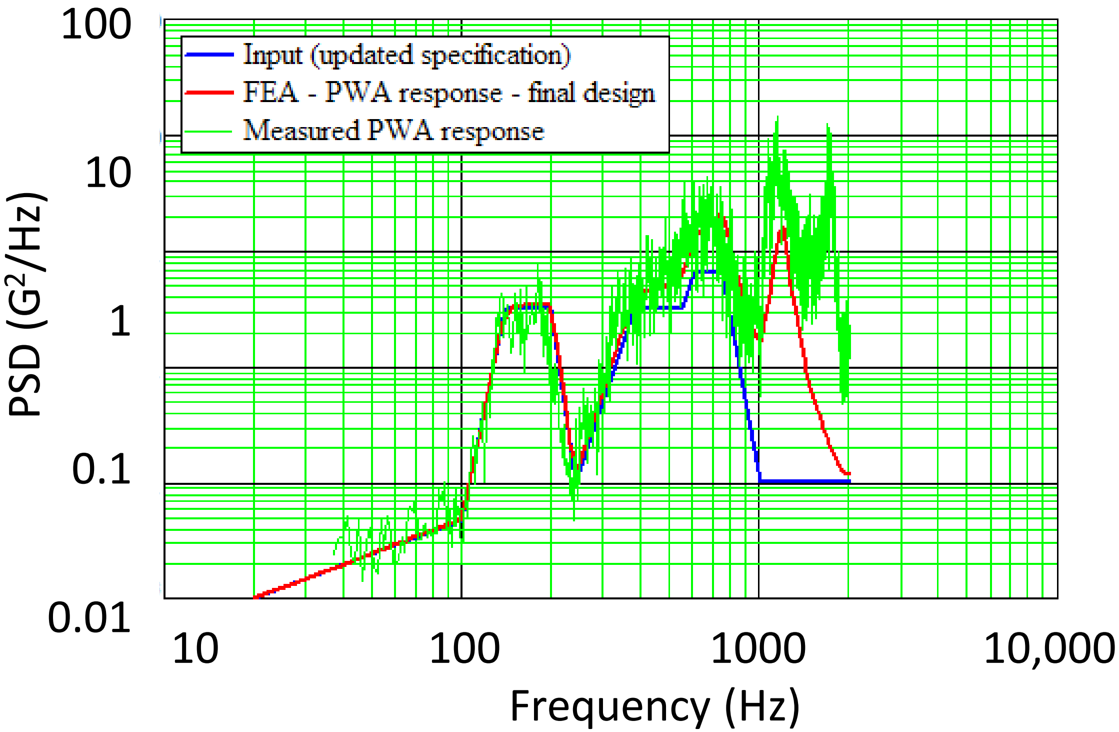
Case study:
single circuit board design

- Final design

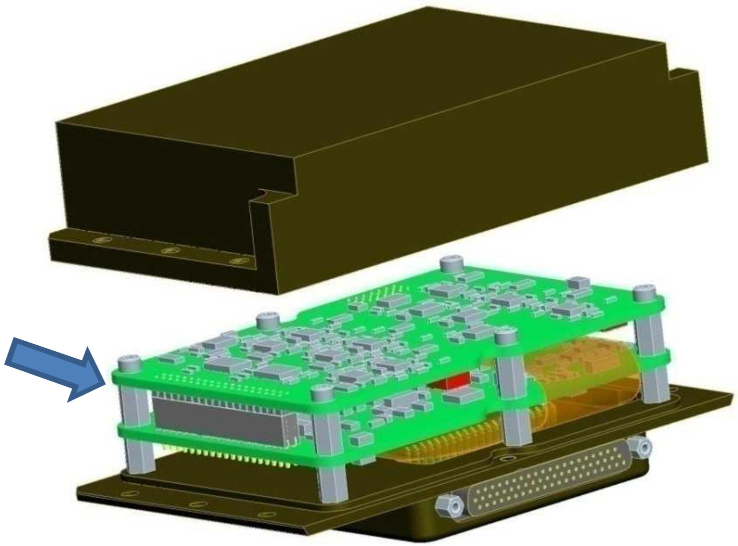


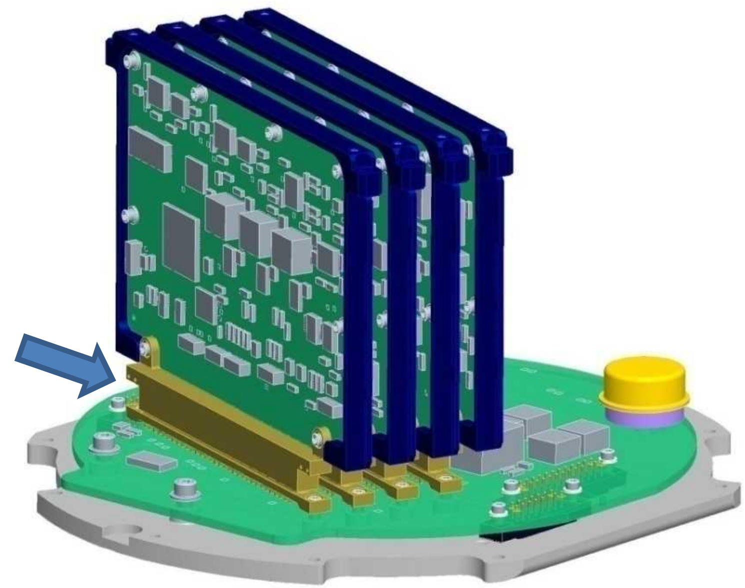
Case study: single circuit board design

- Repeat analysis for final design
  - Updated environmental specification
  - Circuit board material properties from literature
  - Good agreement with laboratory results



Multiple circuit board designs





- Circuit board response affected by mechanical coupling at electrical board-to-board connectors
- Research goals
  - Characterize this effect and develop modeling techniques
  - Enable efficient FEA modeling for conceptual design studies

Literature

FEA of individual circuit boards in vibration and shock

- *Park et al. (2007)[1]*
- *Pitarresi et al. (2004)[2]*
- *Wu et al. (2002)[3]*

Simplified FEA models for optimizing conceptual designs in vibration

- *Donders et al. (2009)[5]*
- *Mundo et al. (2009)[6]*
- *Pitarresi et al. (2004)[2]*

FEA techniques for mechanical coupling at electrical board-to-board connectors

FEA methods for circuit board boundary conditions in vibration and shock

- *Lee et al. (2008)[4]*
- *Park et al. (2007)[1]*

Electrical connector fretting due to vibration

- *Flowers et al. (2004)[7]*
- *Van Dijk et al. (1996)[8]*

- Effect on circuit board response is not well-characterized in literature
- Suitable finite-element modeling techniques are not presented in literature

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- Design of electronics packaging
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- Experimental test setup
  - Goal: collect response data using 2 circuit boards with connector for FE model validation
- Preliminary FE analyses
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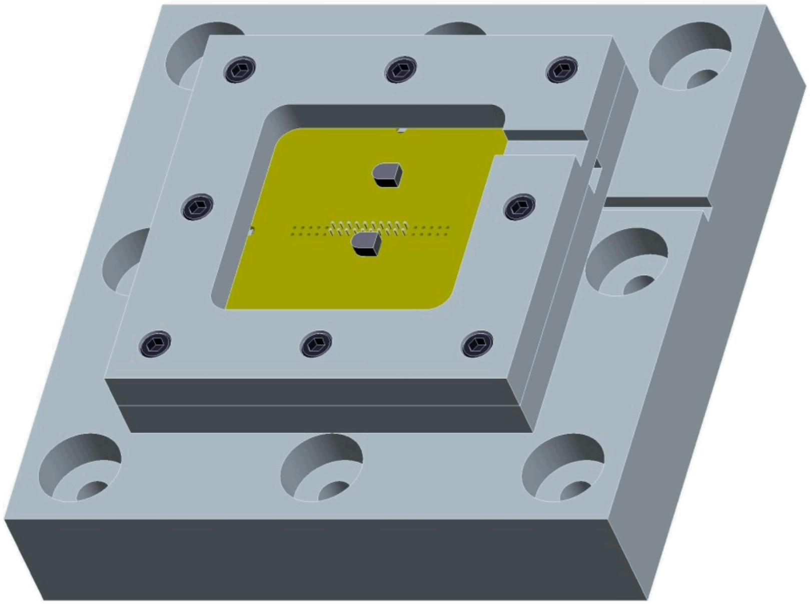
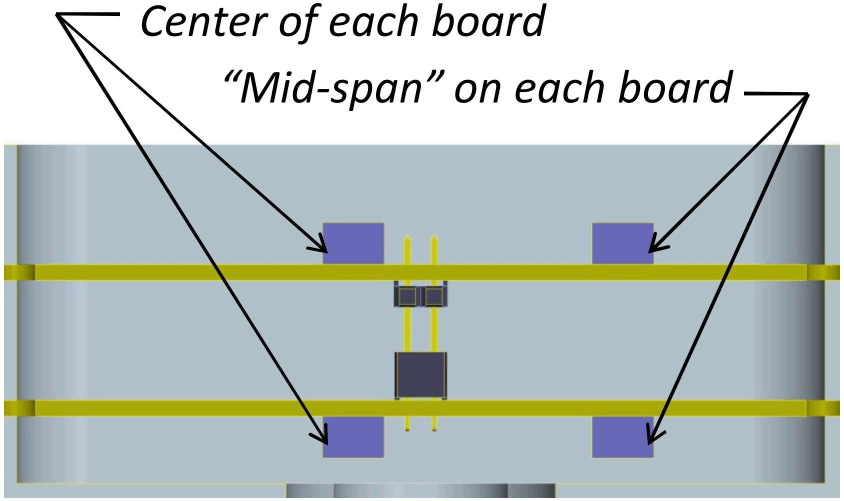
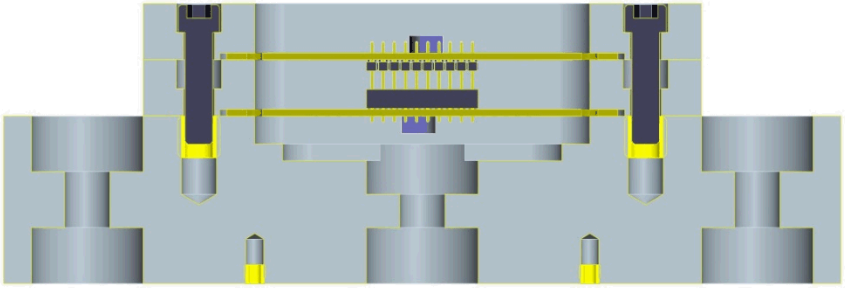
Overview of test setup

- 2 circuit boards
  - 3.5 inches square, 1/16th inch thick
  - FR4 Tg 140 epoxy laminate
  - Electrical connector located at center of boards
- Response measured using 4 uni-axial accelerometers

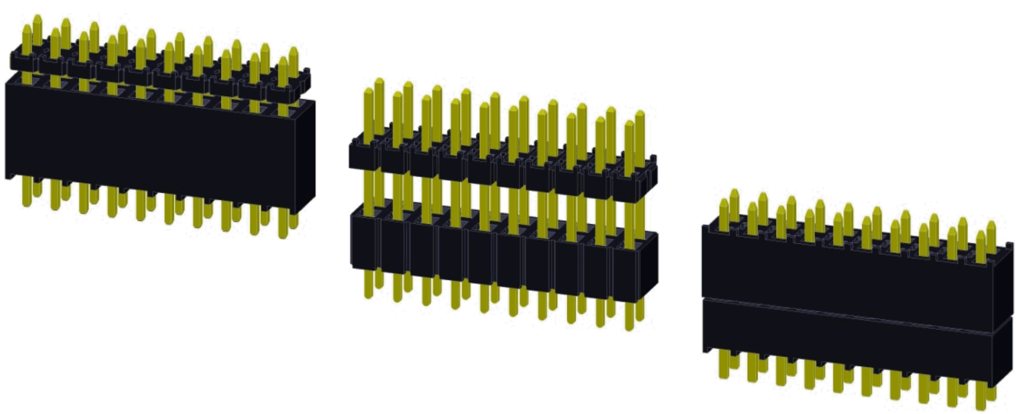


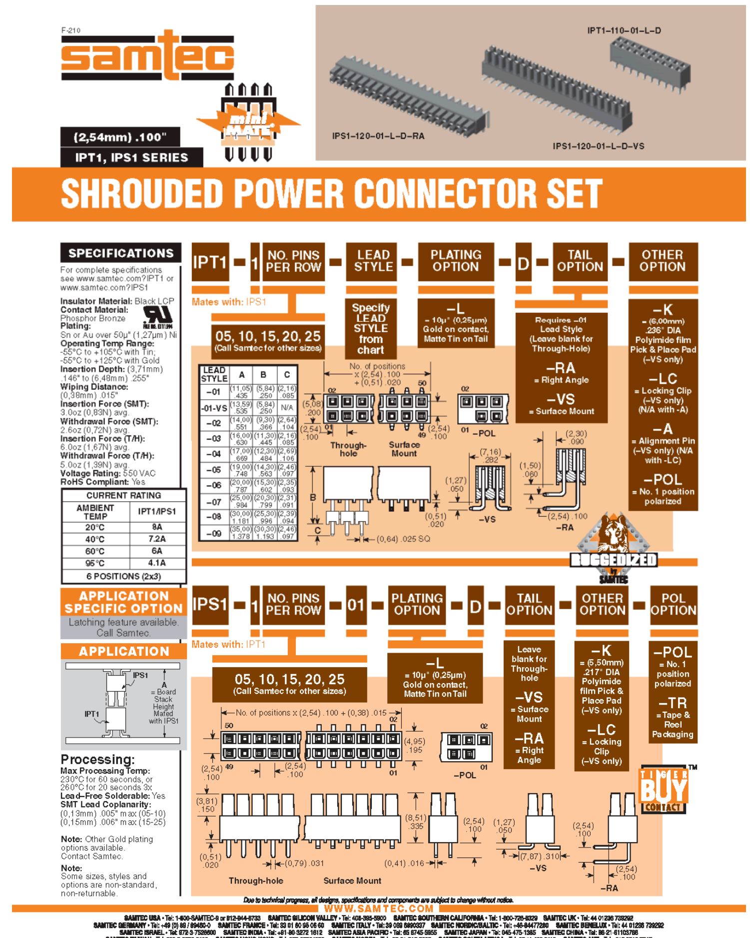




Electrical connectors: 9 types

- 3 unique styles
  - Engagement/pull-out force
  - Bending stiffness
  - Mass
- 3 sizes of each style
  - 20, 30, and 40 pin





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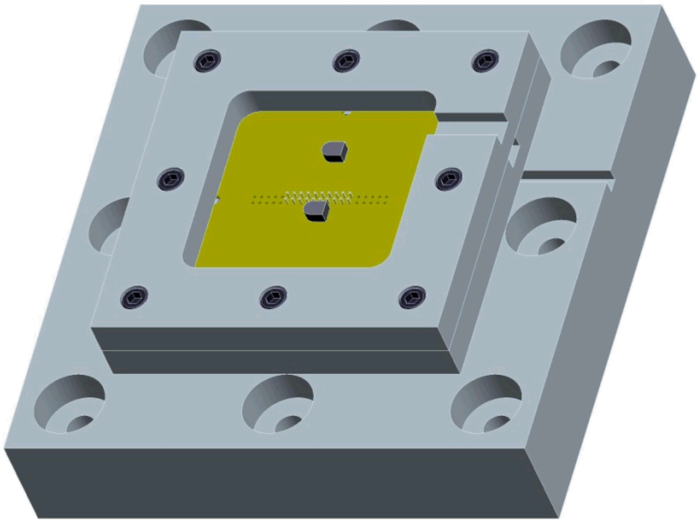
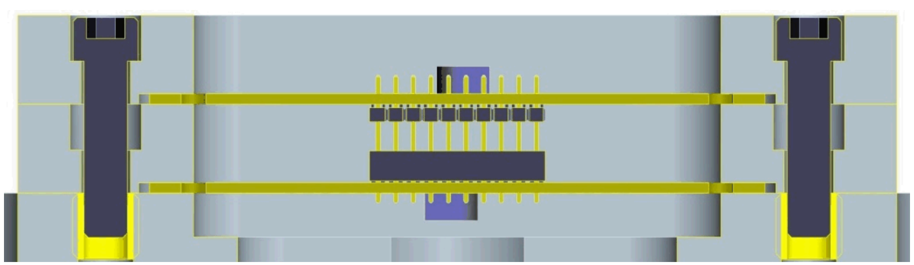
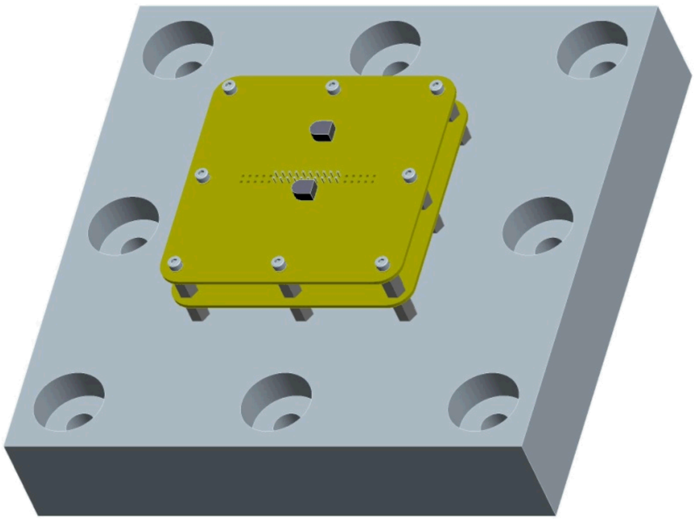
Edge constraint: 2 types

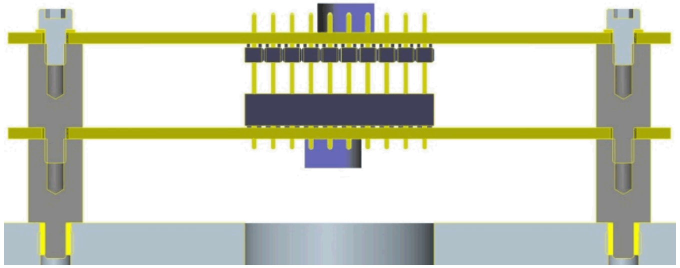
Clamp rings





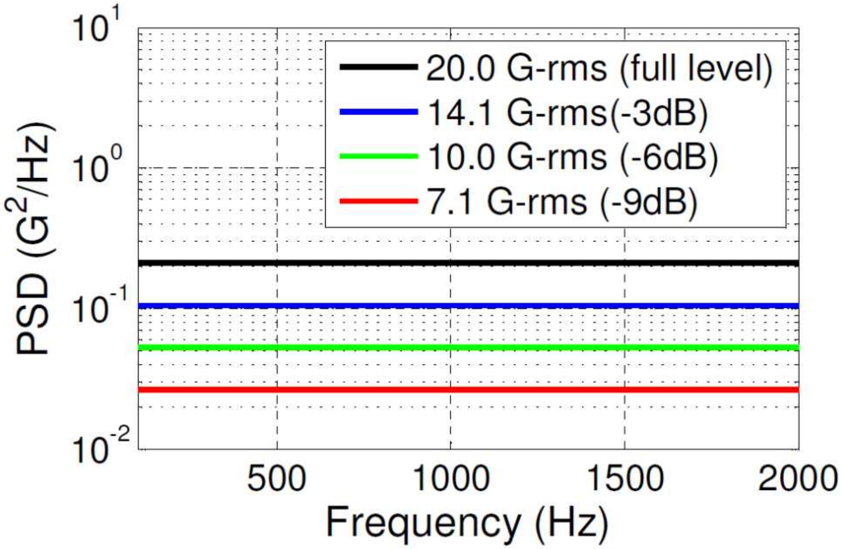
Hex standoffs & fasteners



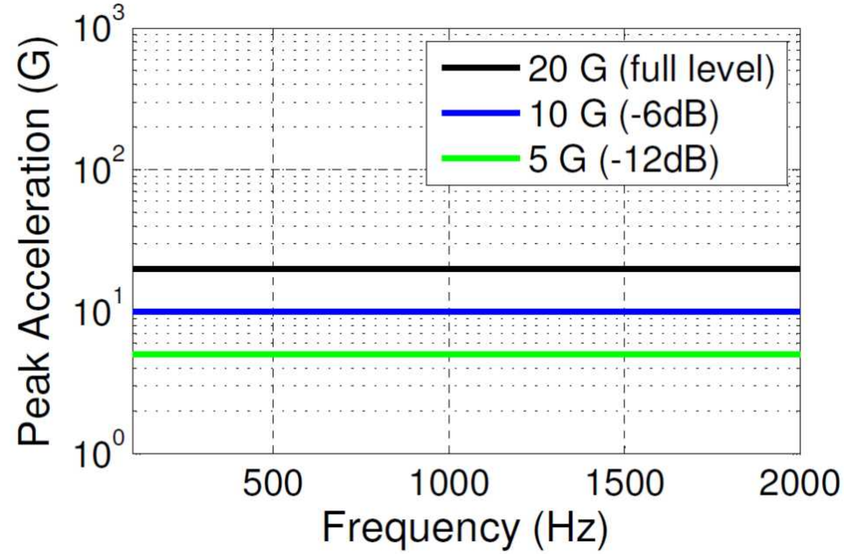


Dynamic loading

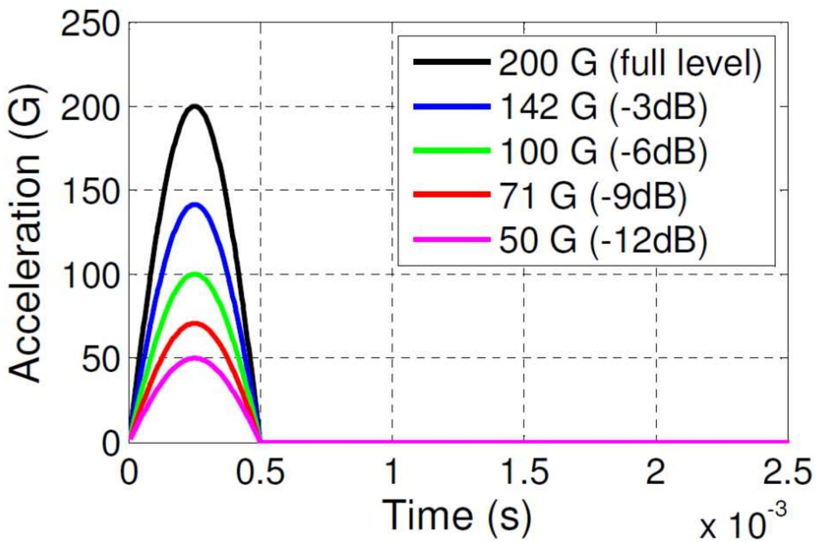
Random vibration – flat spectrum



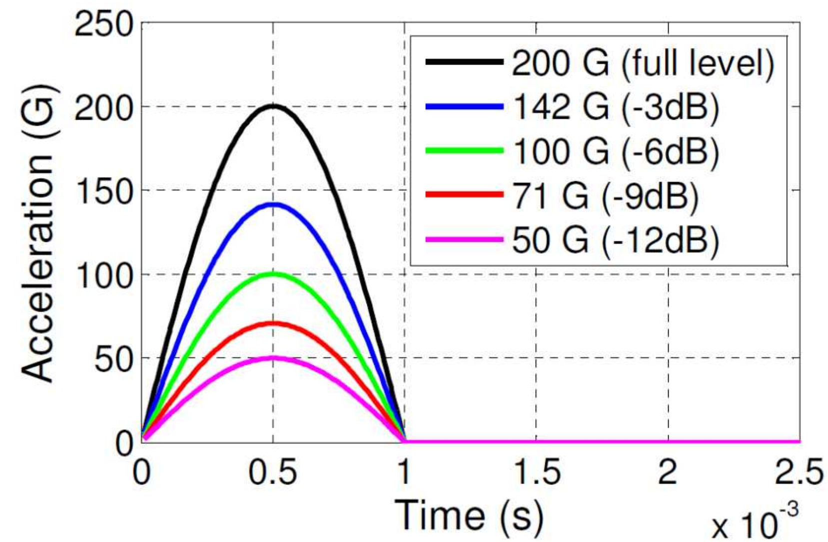
Sinusoidal vibration – frequency sweep



0.5 ms half-sine shock



1.0 ms half-sine shock



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- Preliminary FE analyses
  - Goal: predict response with 'bounding' estimates of 1st natural frequency
- Comparison of results
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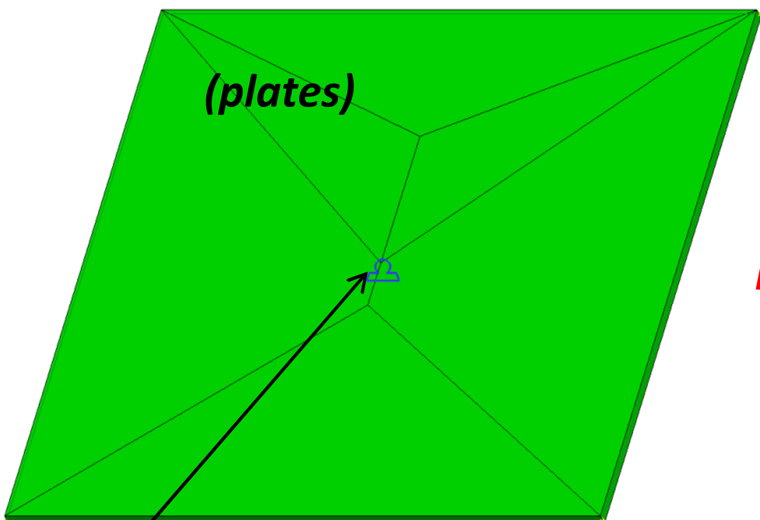
Preliminary FE analyses

- Software
  - Mechanica (Pro/Engineer)
  - P-element code
  - Semi-automated meshing
- Model parameters
  - Estimates for FR4 material properties (from literature)
  - Estimate 5% damping
- Typical model size
  - No. elements:
  - No. nodes:
  - Run time: 1 to 45 minutes

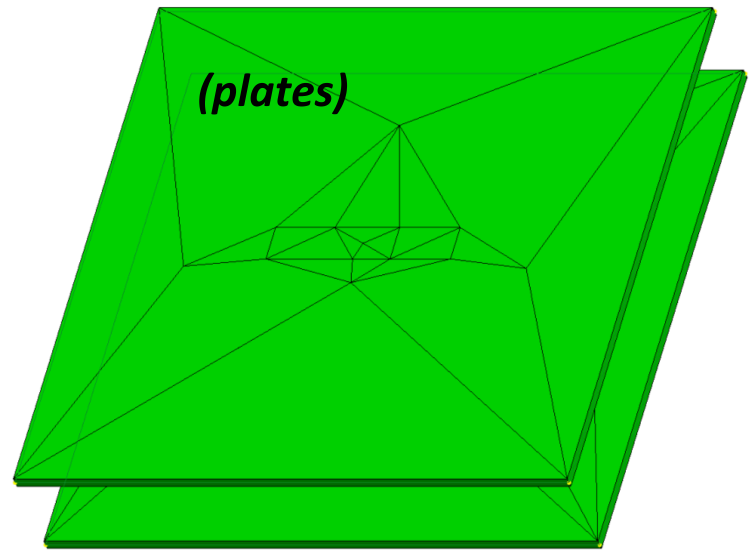
Parameter	Details
Connector size & style	Mass
	Stiffness
	Size
Edge constraint type	Clamped
	Standoffs
Dynamic loading type & level	Random vibration
	Swept sine
	Half-shock

Preliminary models: clamped

Lower bound: "Compliant" model (ignores connector)



Upper bound: "Rigid" model (connector stiffness = 10 x 10^6 psi)

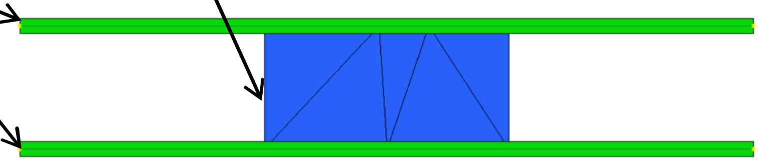


NOTE: P-element code!

Connector (point mass)

6 DOFs fixed along edges

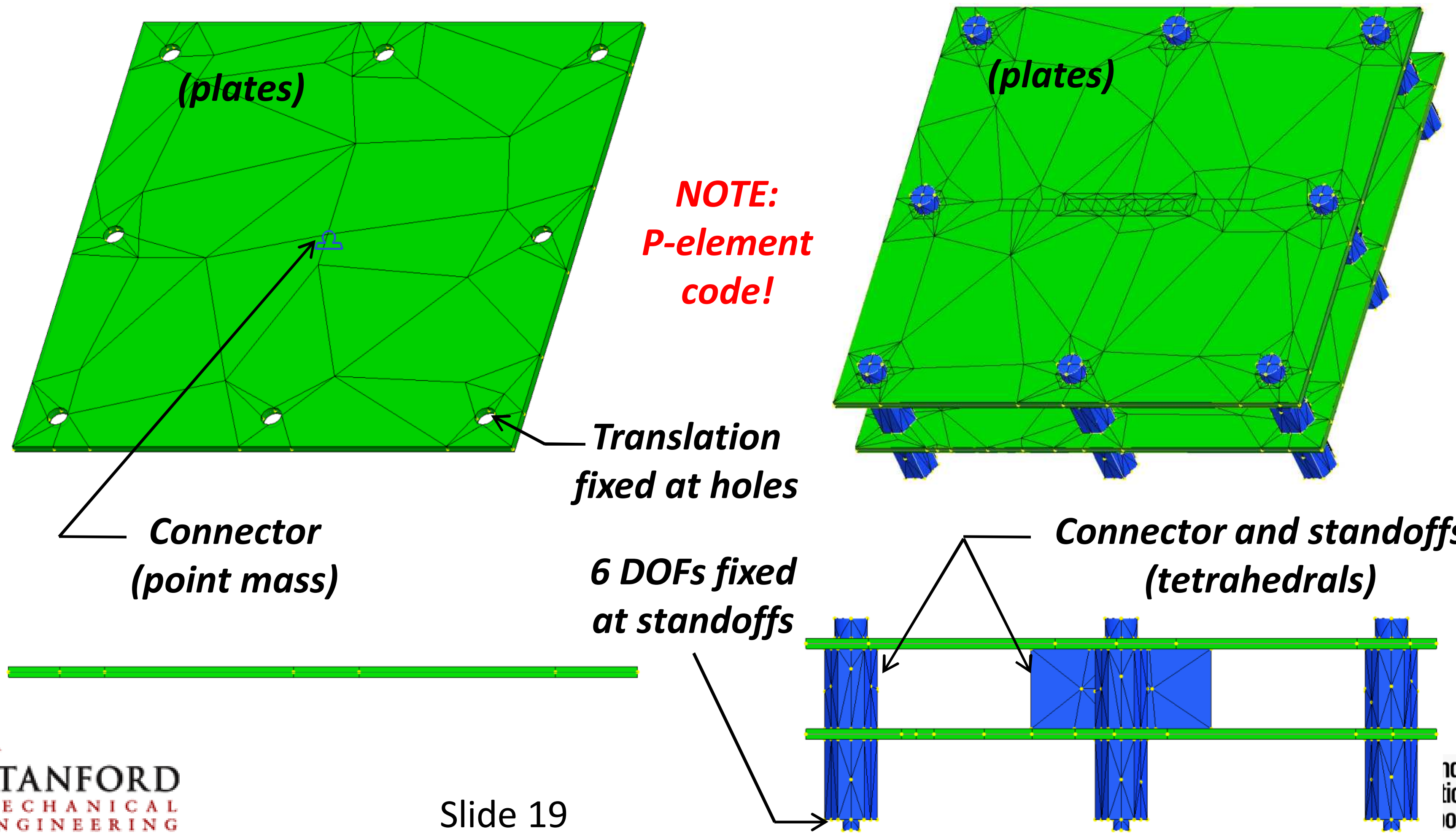
Connector (tetrahedrals)



Preliminary models: standoffs

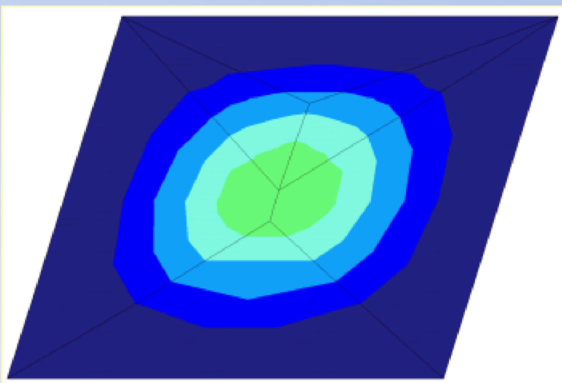
Lower bound: "Compliant" model (ignores connector)

Upper bound: "Rigid" model (connector stiffness = 10 x 10^6 psi)

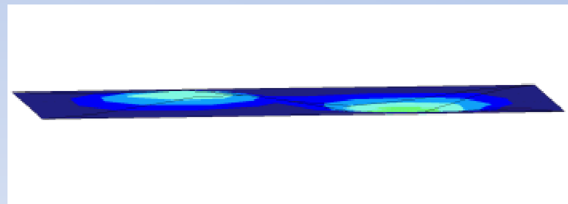


Mode shapes

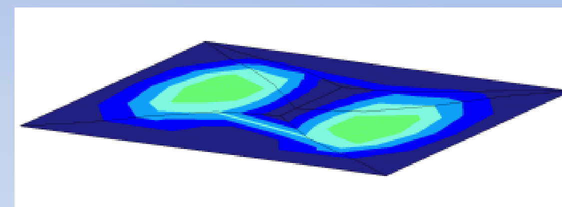
Bound 1: No mechanical coupling



Mode 1

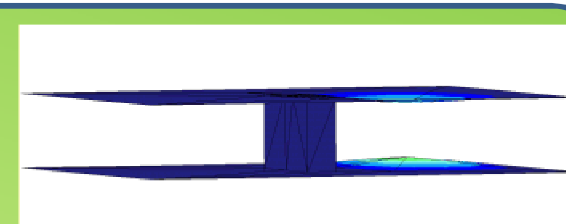


Mode 2

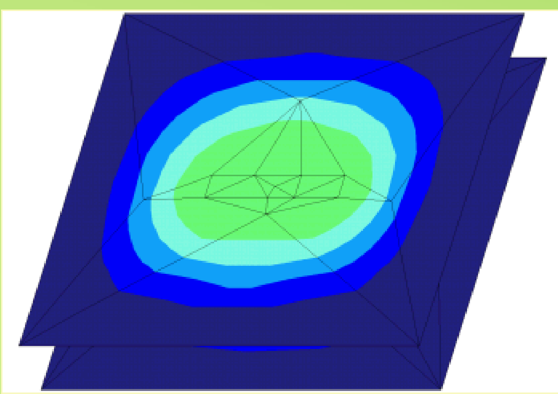


Mode 3

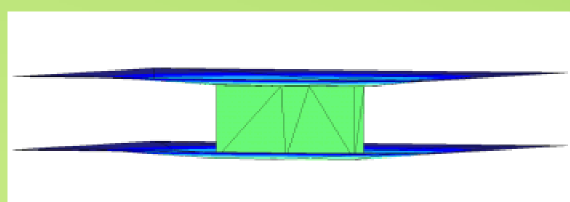
Bound 2: Rigid mechanical coupling



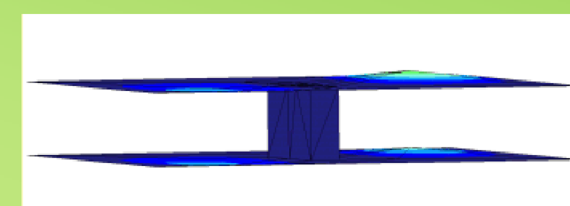
Mode 2



Mode 1



Mode 1 (side view)



Mode 3

Modal frequencies

Boundary condition	No. pins	Mechanical coupling	Mode		
			1st	2nd	3rd
Clamped	20	None	1015	2483	2725
		Rigid	1217	3312	3443
	40	None	878	2477	2719
		Rigid	1845	3341	3497
Standoffs	20	None	810	1771	1849
		Rigid	1142	2754	2785
	40	None	718	1771	1849
		Rigid	1737	2910	2961

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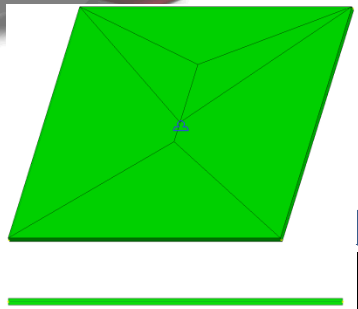
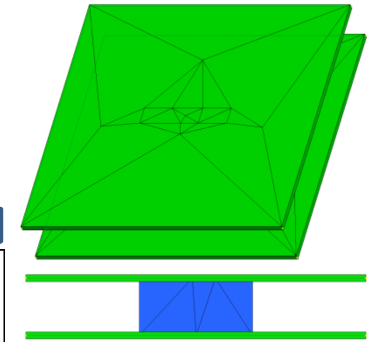
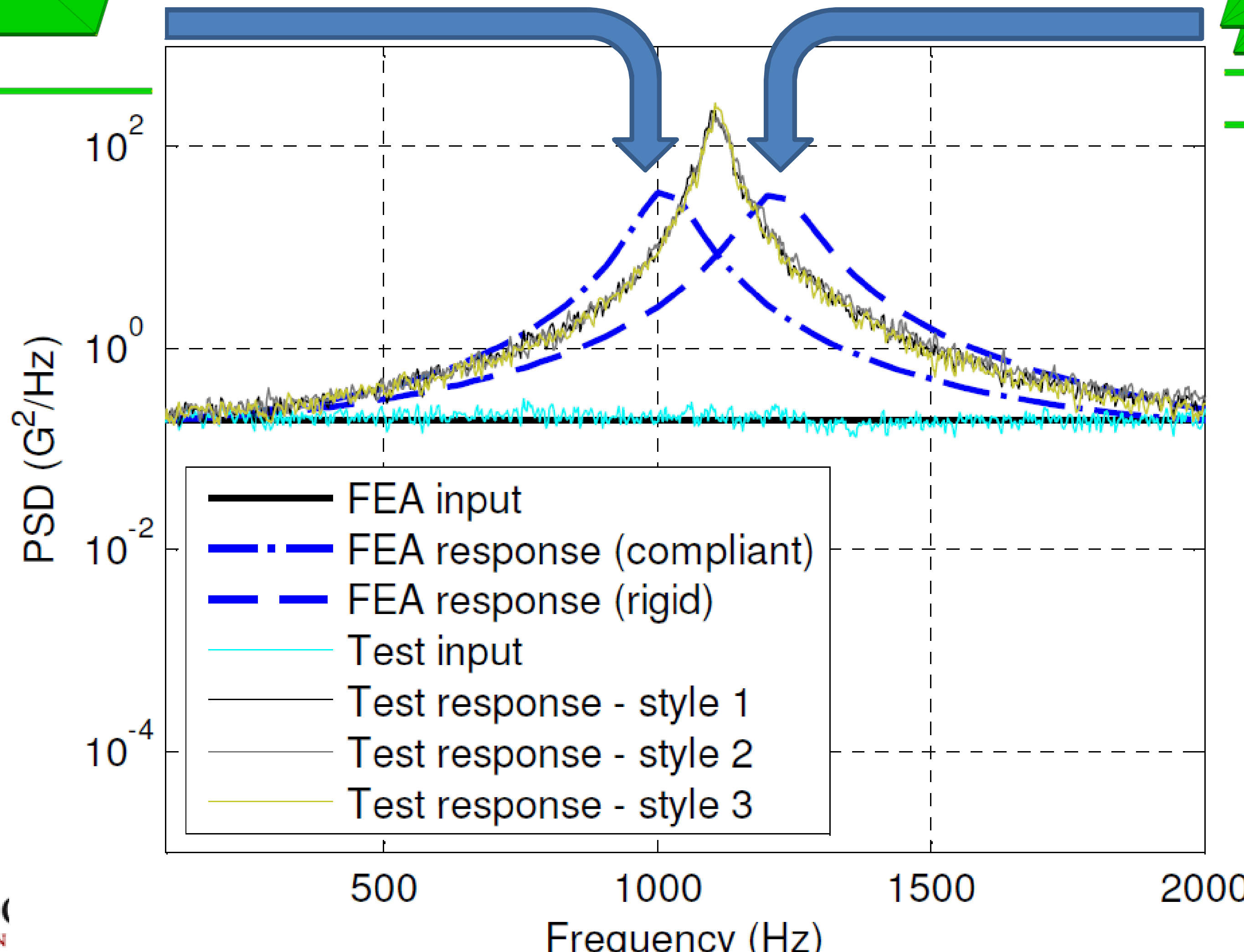
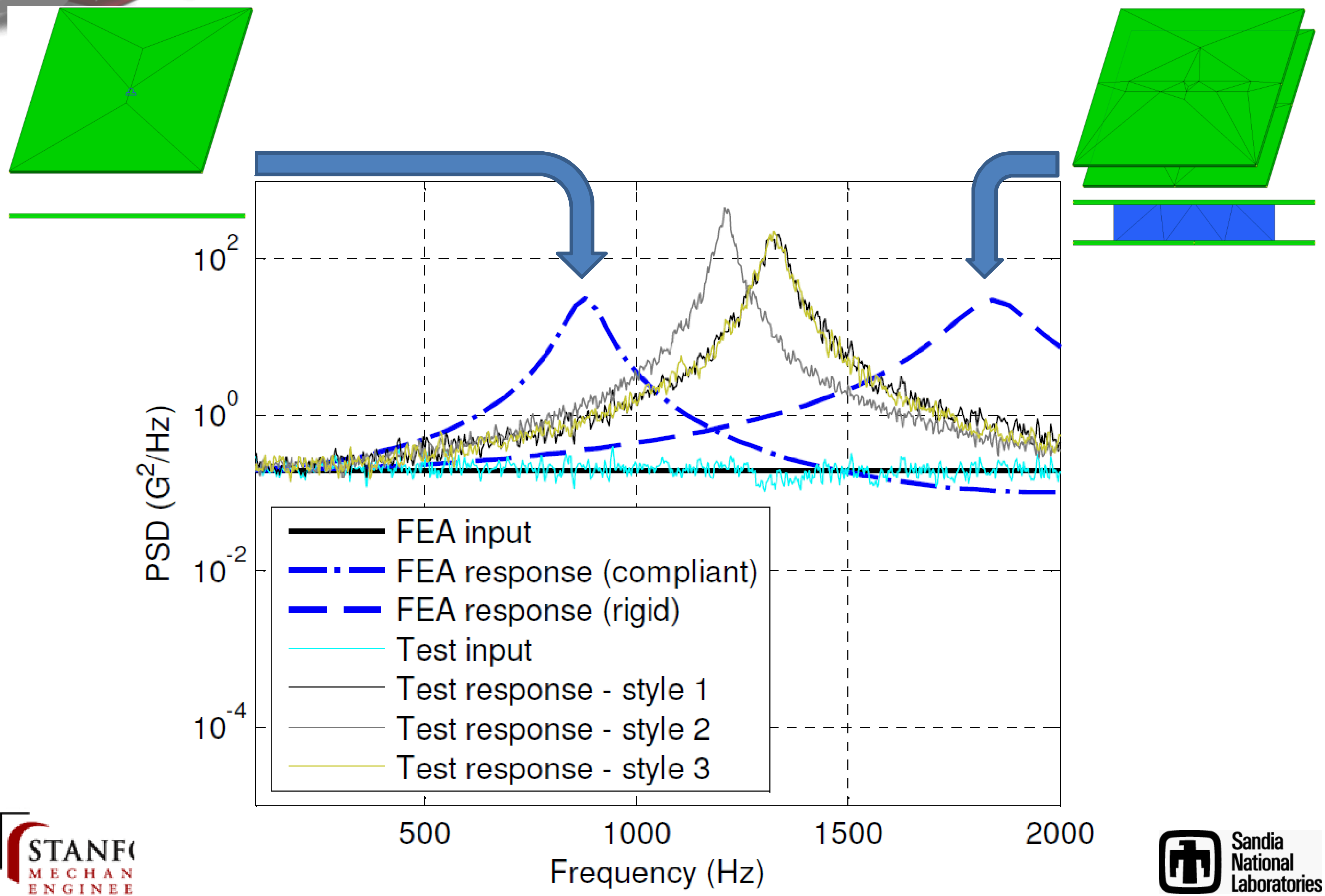
Clamped, 20 pin, top board, center







Clamped, 40 pin, top board, center

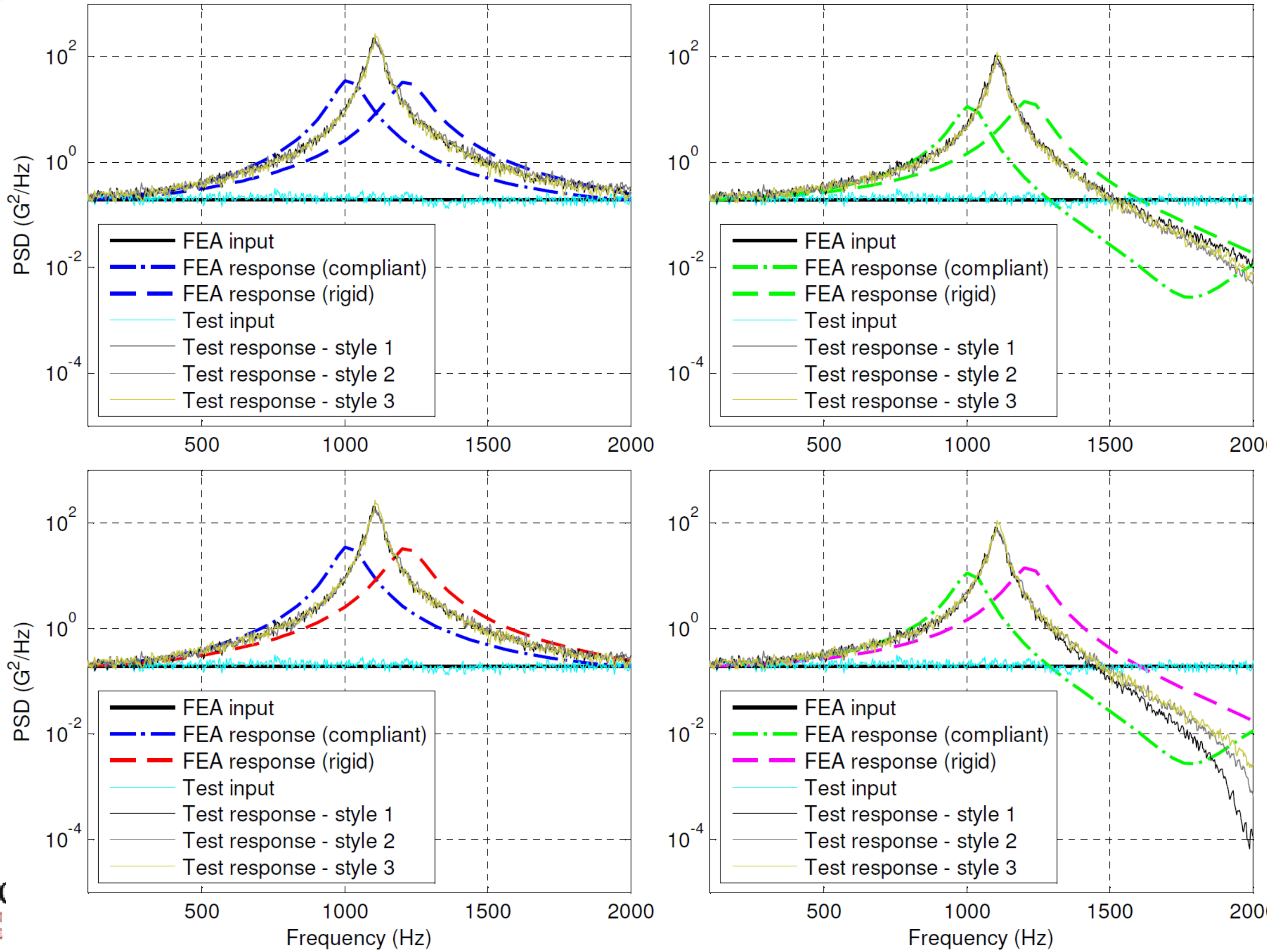


Clamped, 20 pin

Center location | *Midspan location*

Top circuit board

Bottom circuit board

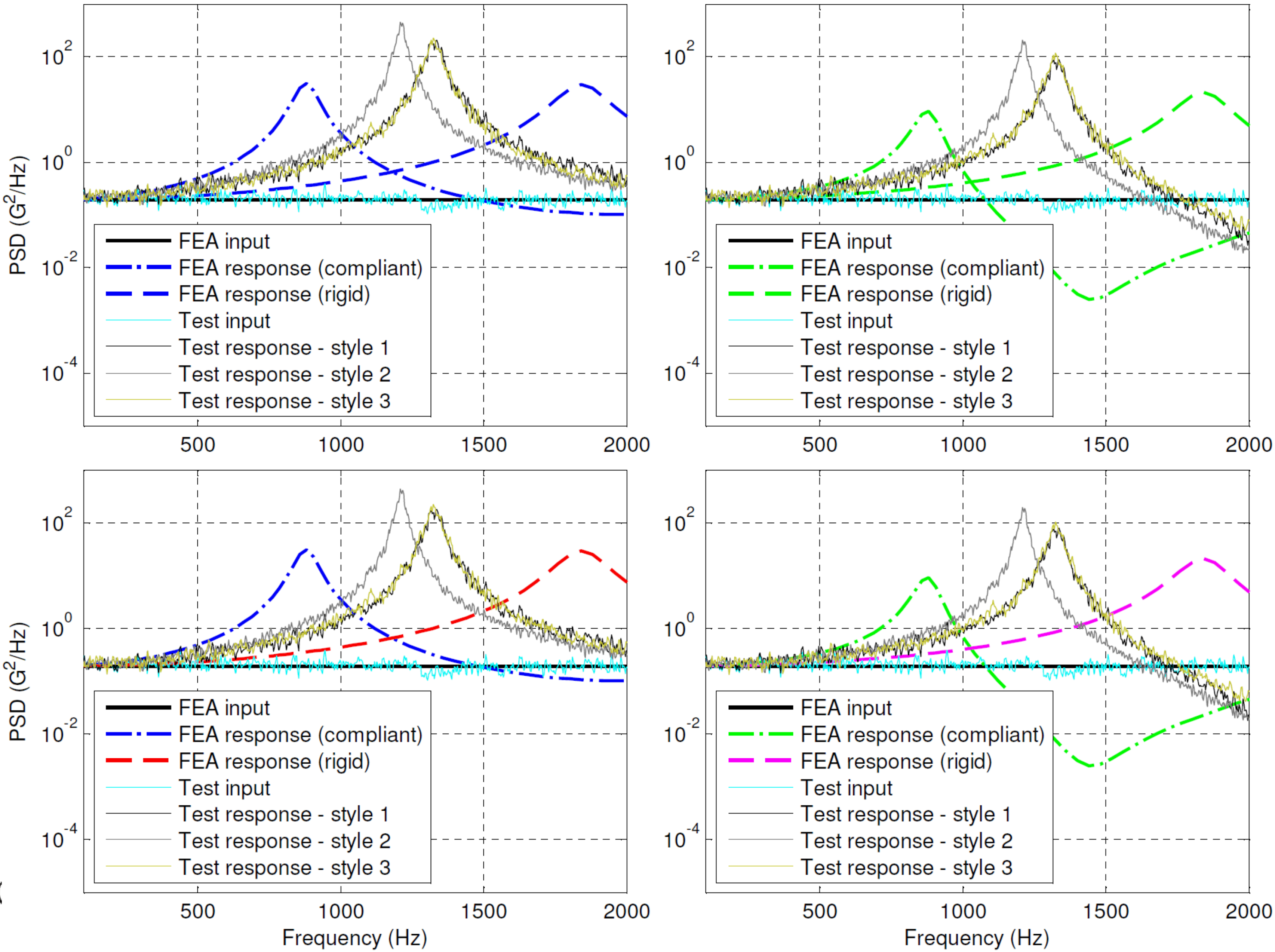


Clamped, 40 pin

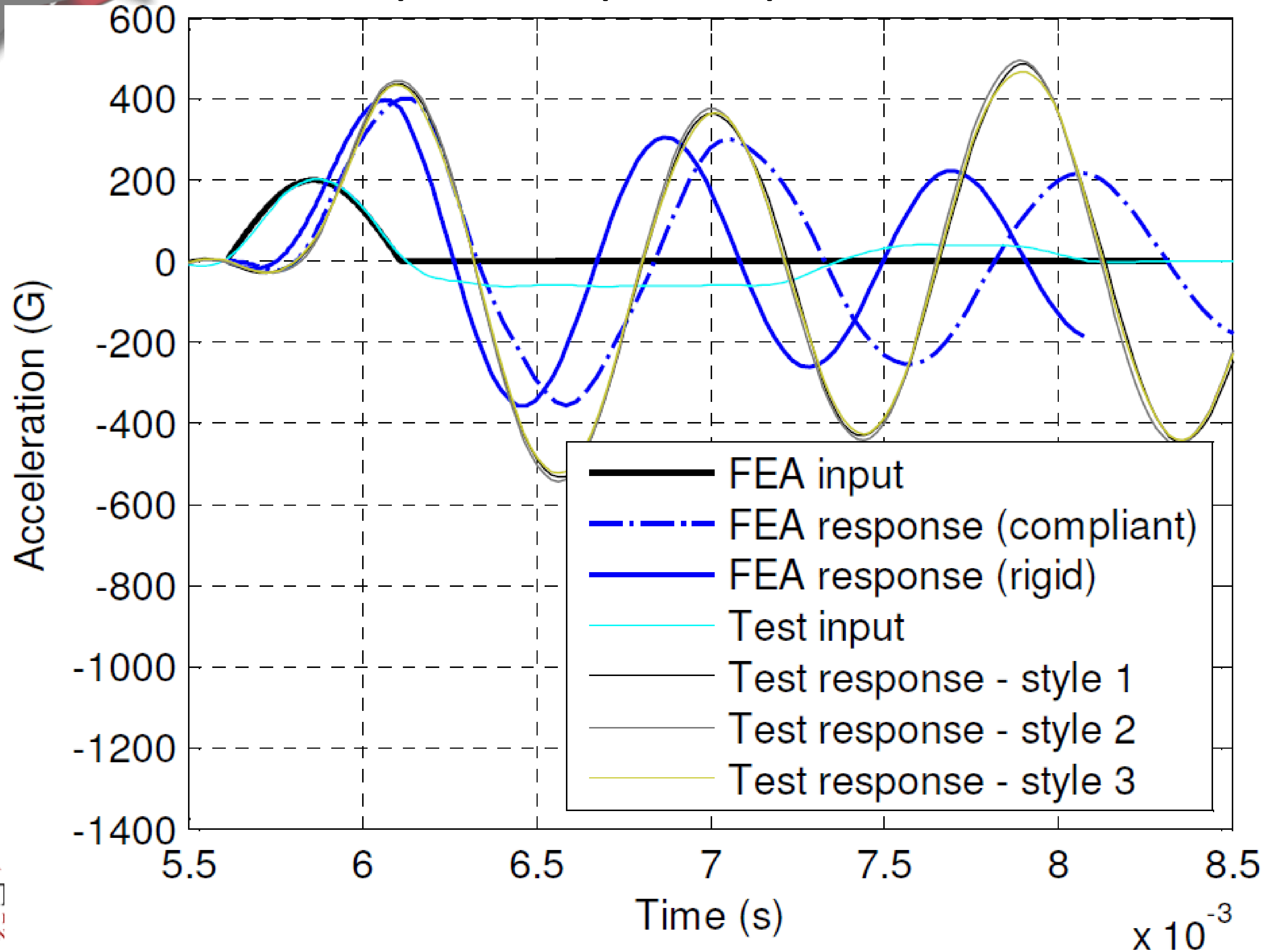
Center location | *Midspan location*

Top circuit board

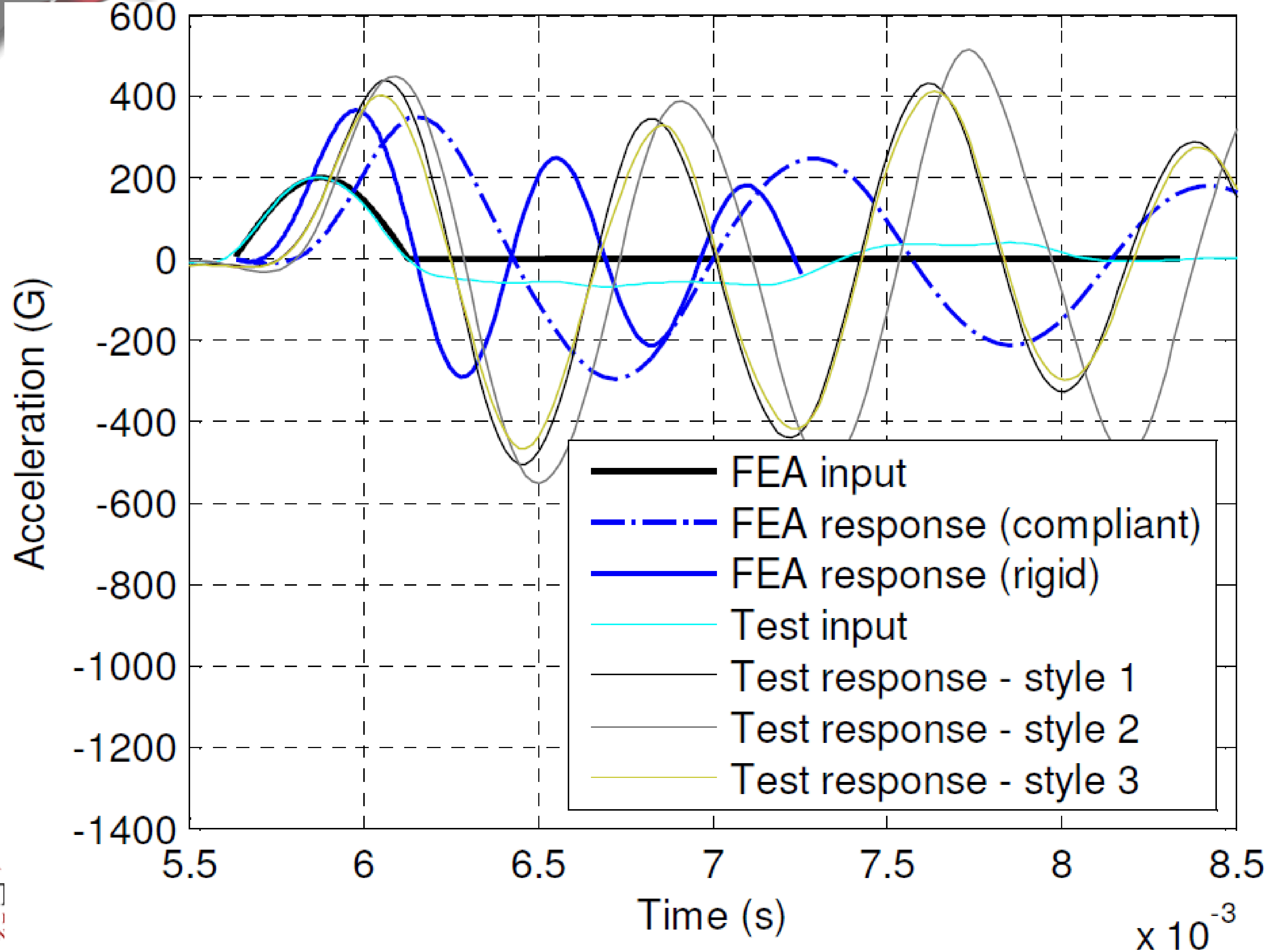
Bottom circuit board



Clamped, 20 pin, top board, center



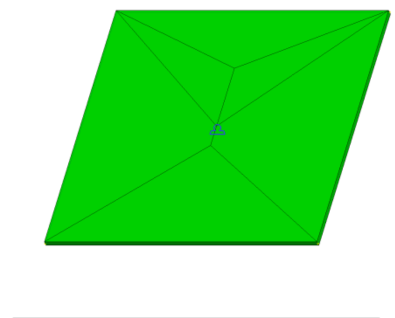
Clamped, 40 pin, top board, center



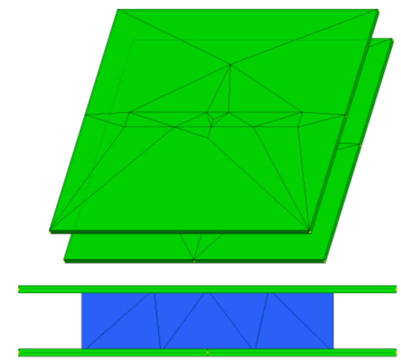
Preliminary conclusions

- Shape of predicted responses
  - Qualitatively correct
- 1st natural frequency
  - Well-bounded for 20 pin connectors
  - FEA predictions varied significantly for 30 and 40 pin connectors
- Response amplitude
  - Too low in all cases
  - Decrease damping to ~ 3%

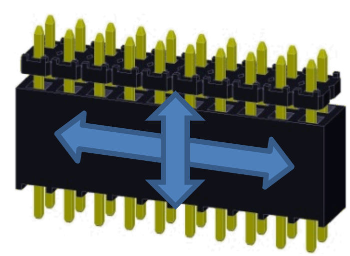
- Connector ‘stiffness’
  - Did not distinguish between bending stiffness and engagement ‘stiffness’



(Zero)



10×10^6 psi



Proposed future work

- Bending vs. engagement stiffness
  - FEA models of connectors and/or 3-point bend tests
  - Validate with test data
- Explore other element types
  - Link, linear spring, or linear spring-damper (engagement 'stiffness')
  - Beam (bending stiffness)
  - Non-linear spring elements
  - Contact elements
- Abaqus (H-element code)
- Expand study to include 2nd and 3rd natural frequencies

- Possible outcomes
  - Validated modeling techniques
  - Implementation in model of multi-board telemetry system
  - Generalized recommendations based on key design parameters, e.g. board size, connector size, estimated material properties
- Goals
  - 1st natural freq.: ± 5%
  - Peak response: ± 10%
  - Total run time: ≤ ~ 3 hours
  - Enable efficient FEA modeling for conceptual design studies

Summary

- Design of electronics packaging
  - Circuit board geometry ↔ dynamic response
- Case study (single board)
  - Research motivation: designs with multiple circuit boards
- Literature
  - Mechanical coupling at circuit board connectors not addressed
- Experimental test setup
  - Collected response data using 2 circuit boards with connector under a variety of conditions for FE model validation
- Preliminary FE analyses
  - Bounded estimate of response using 'compliant' and 'rigid' models
- Comparison of results
  - Good agreement between FEA and experimental results
- Preliminary conclusions
  - Effect of engagement 'stiffness' vs. bending stiffness remains unclear
- Proposed future work
  - Develop improved models to better match data
  - Develop guidelines for implementation in analyses of conceptual designs
- Questions

Backups

References

1. Park, S., Shah, C., Kwak, J., Jang, C., Pitarresi, J., Park, T., and Jang, S., 2007, "Transient dynamic simulation and full-field test validation for a slim-PCB of mobile phone under drop / impact," *Proc. 57th Electronic Components and Technology Conference (ECTC)*, IEEE, New York.
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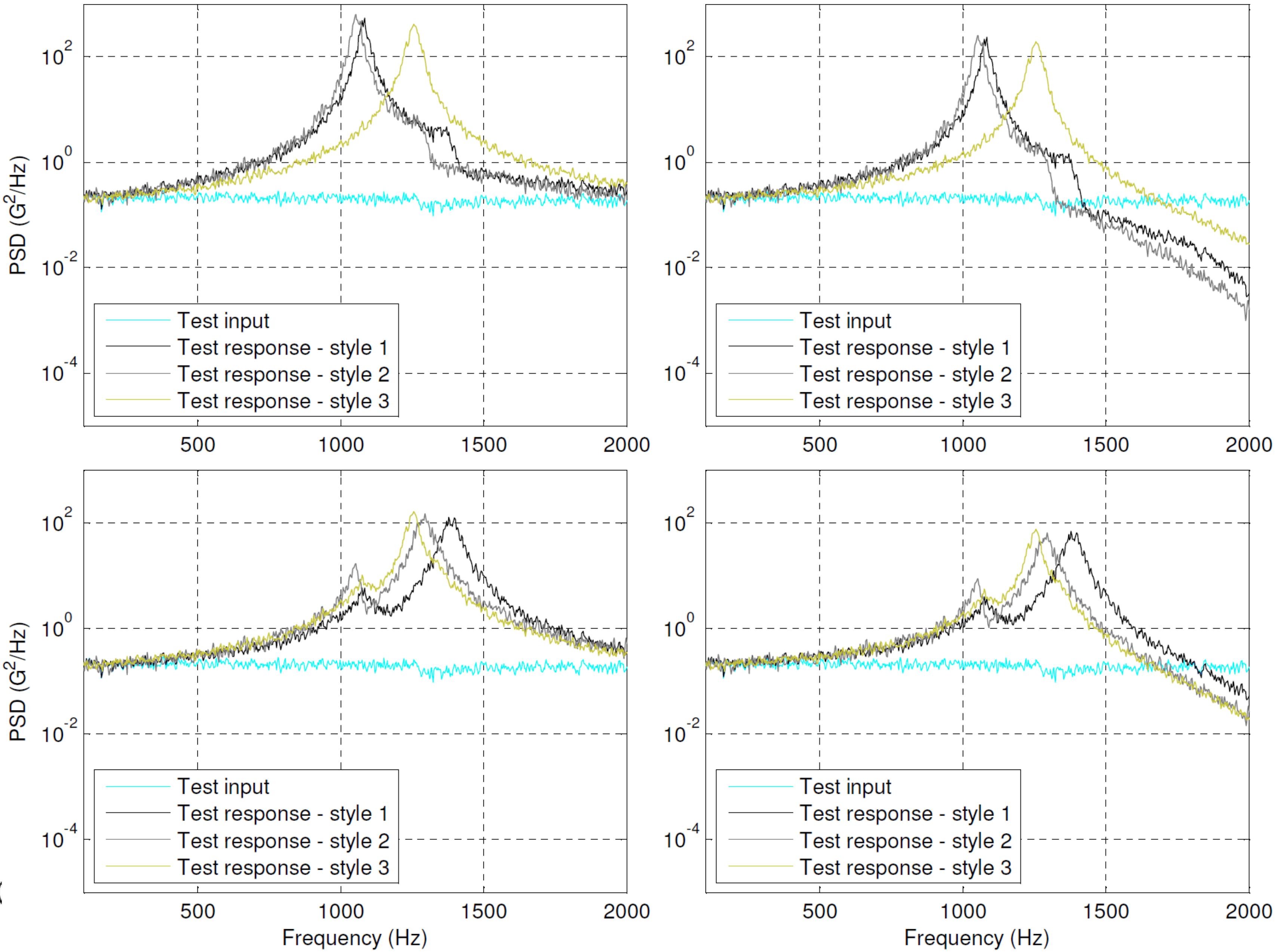
8. Van Dijk, P., and Van Meijl, F., 1996, "Contact problems due to fretting and their solutions," *AMP J. of Technology*, **5**, pp. 14-18.

Clamped, 40 pin, disengaged

Center location | *Midspan location*

Top circuit board

Bottom circuit board

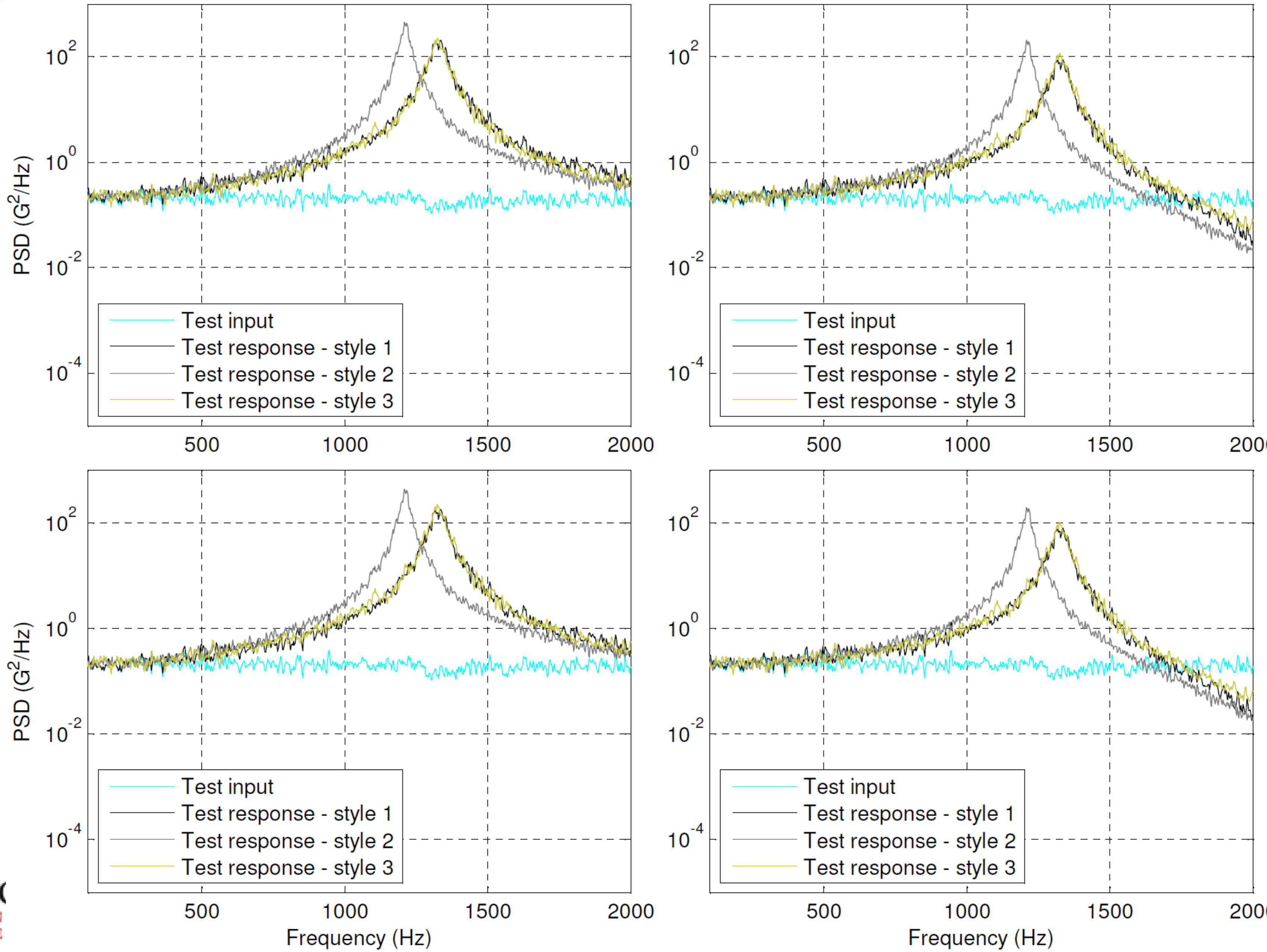


Clamped, 40 pin, engaged

Center location | *Midspan location*

Top circuit board

Bottom circuit board



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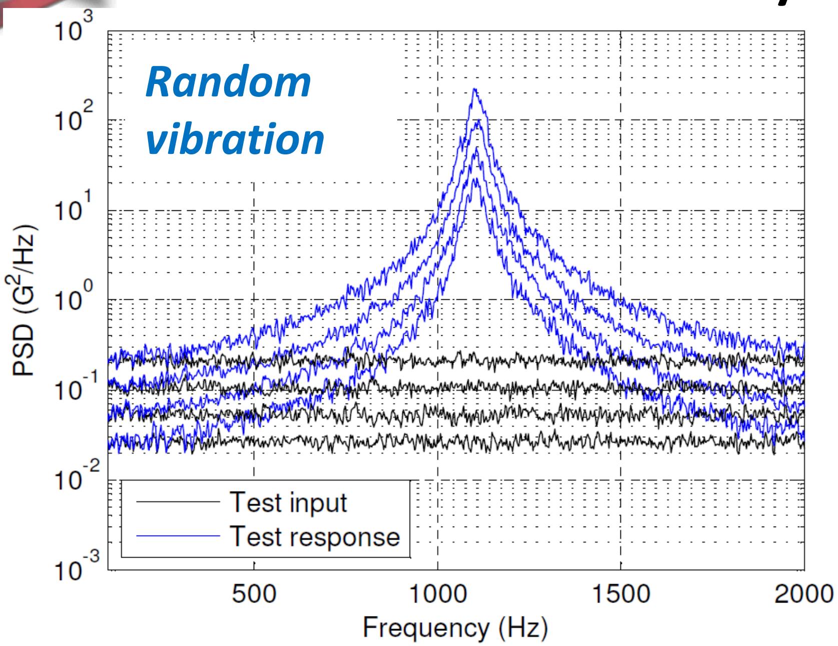
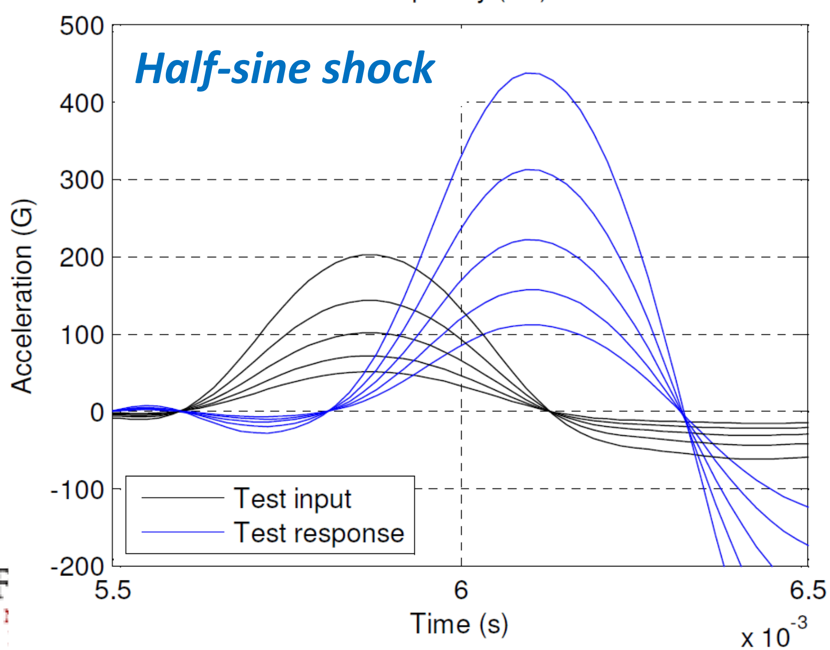
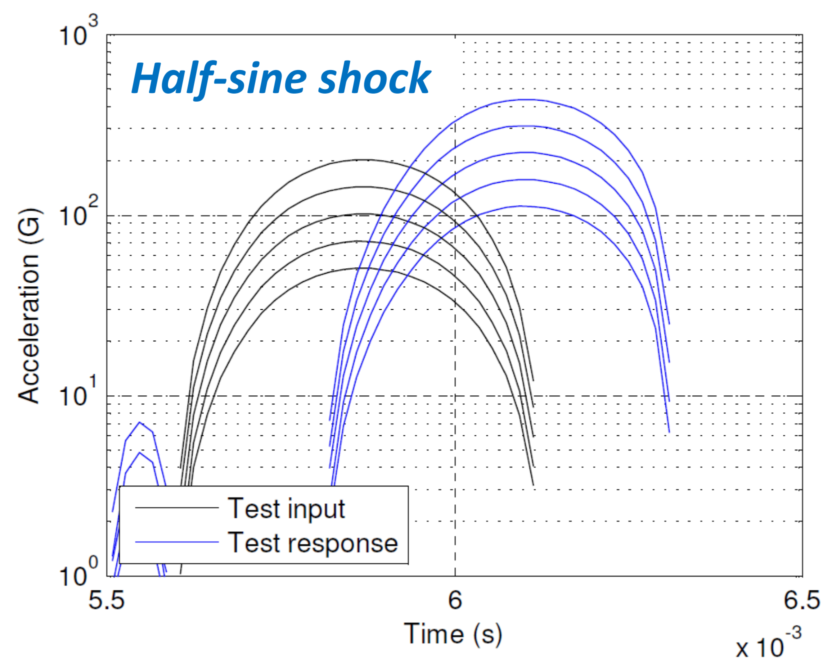
Linearity of response







STANF MECHA ENGINE

Modal frequencies

Boundary condition	No. pins	Mechanical coupling	Mode 1st	Mode 2nd	Mode 3rd
Clamped	20	None	1015	2483	2725
		Rigid	1217	3312	3443
	40	None	878	2477	2719
		Rigid	1845	3341	3497
Standoffs	20	None	810	1771	1849
		Rigid	1142	2754	2785
	40	None	718	1771	1849
		Rigid	1737	2910	2961

Material properties of FR4

- Approximate values (taken from literature) are often adequate for typical design studies
  - $E = 2.0$ to 3.3×10^6 psi
  - $\nu = 0.12$ to 0.25
- Used for preliminary analyses
  - $E = 2.7 \times 10^6$ psi
  - $\nu = 0.12$
- Higher accuracy required for developing board-to-board connector modeling techniques
- Tensile tests presently being performed to determine E, ν
  - E =
  - ν =