Comparisons of the Structural Response of a Test Article Excited by DFAT™ Diffuse and Non-Diffuse Acoustic Fields

by

Marcos A. Underwood, Ph.D.

Tu'tuli Enterprises and

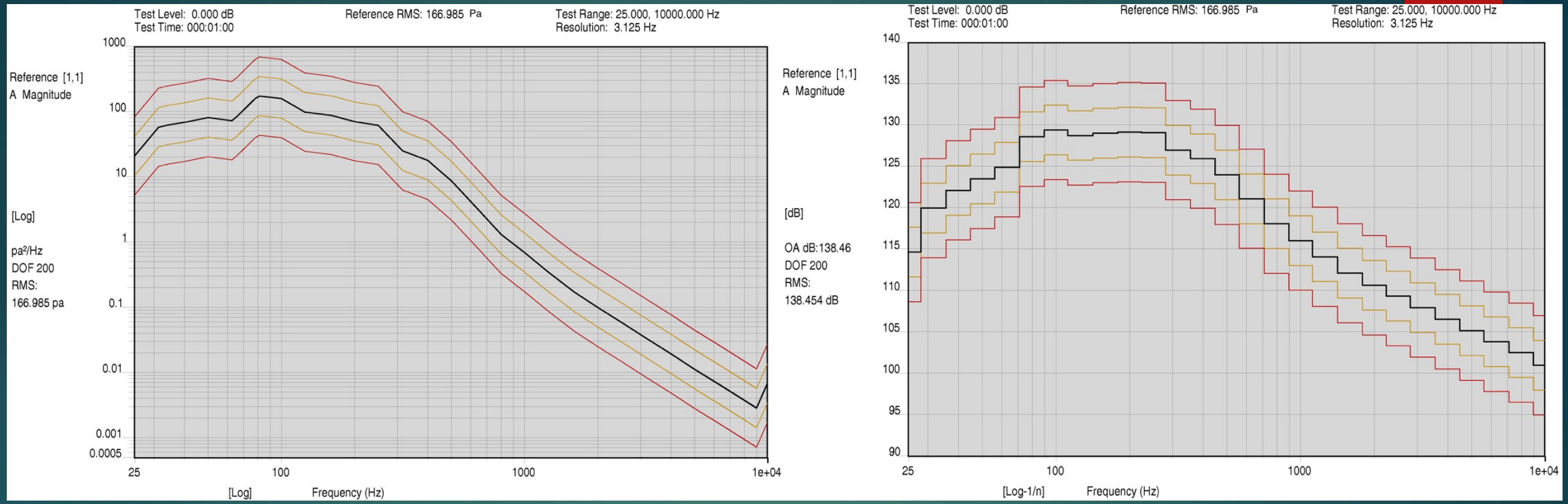
MSI DFAT Chief Scientist

m.underwood@msidfat.com

Introduction

- This Paper Discusses the Use of Direct Field Acoustic Tests (DFAT™) to Excite an Aluminum Honeycombed 4'x8' Test Panel (Panel) Using Four Types of Acoustic Fields
- The Testing Goal was to Assess How Effectively: Nearly Diffuse (Low Coherence); Non-Diffuse Uniform Coherent and Directed Coherent; and MISO Generated Acoustic Fields Excite the Test Panel's Structural Resonances
- The Analysis of the Results from the Testing Are Presented that Demonstrate the Dependence of the Test Panel's PSD Resonance Response Characteristics on Each of the Four Types of Acoustic Fields Used to Excite the Test Panel
- The Study Found that When Using the Same Acoustic OASPL and Reference Spectrum Profile, the Reference SDM Coherence and Phase Settings for the First 3 Tests Have a Fundamental Effect on the Nature of the Test Panel's Response
- The 3 Non-Diffuse Tests Consistently Missed Properly Exciting Significant Resonances. Their Panel Responses Exhibited Enhancement/Cancellation and "Phantom Resonance" Effects
- Only the Diffuse Acoustic Field Properly Excited and Identified the Panel's Structural Resonances, With no such Effects, Matching Those Found by a Separate Modal Analysis.
- The Paper Further Found that the MISO Non-Diffuse Test Performed the Poorest, While Only Saving 1.3 dB of Power as Compared to What the MIMO Diffuse Field Test Required.

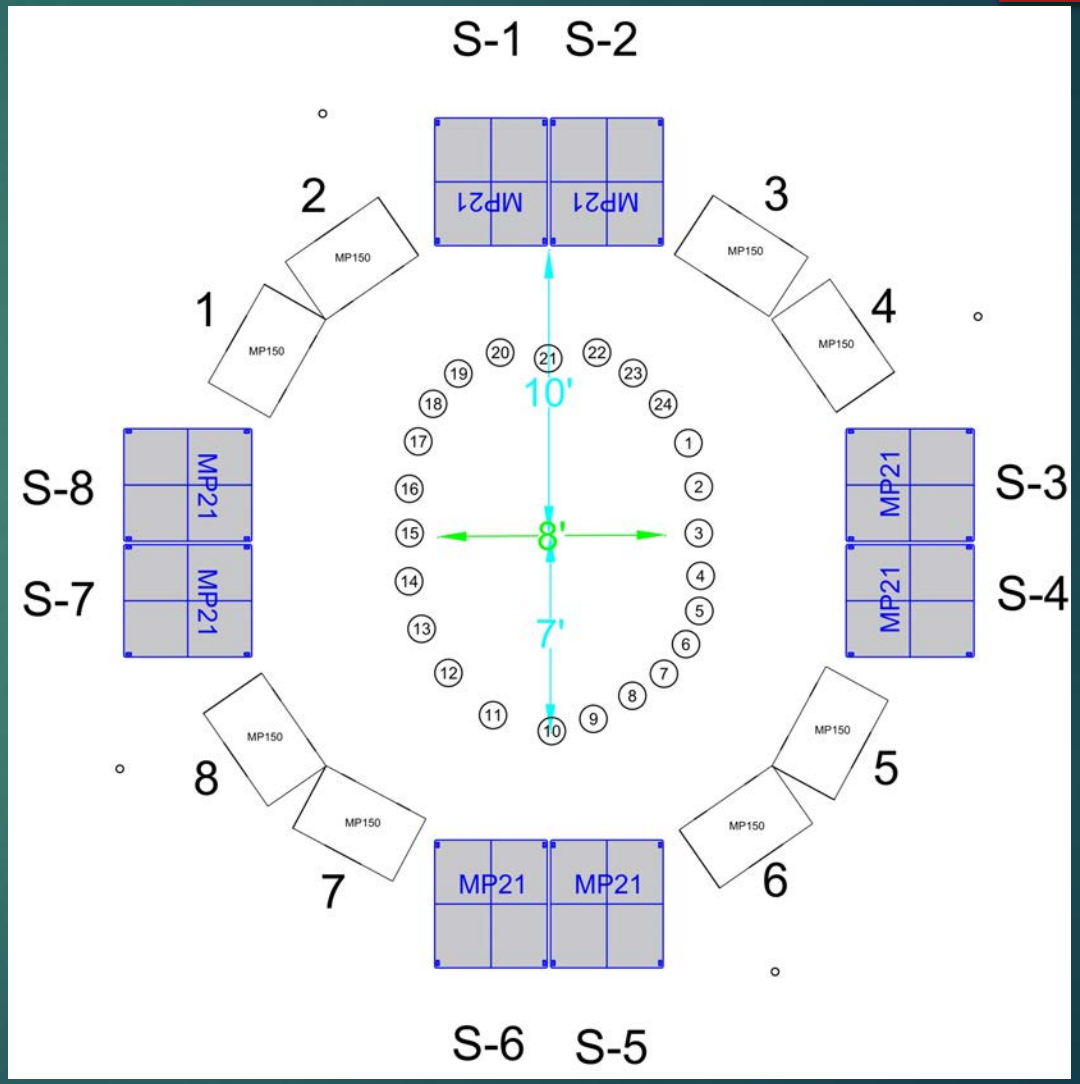
Test Profiles and Control Methods Used



- MIMO Rectangular Adaptive Control Was Used for First 3 and MISO Control Used for Last of 4 Tests
- For the 4 Tests, Control Was Narrow Band and Used The Above PSD Reference, Using 24 Control Mic's
- MIMO Tests Used Reference SDM with Different Coherence & Phase Settings for Each Test
- MISO Used Single Reference, Drive, & Average Control and Measured Resultant Phase and Coherence
- MIMO Used the Same Reference PSD for 24 Diagonal Elements of Reference SDM for the 24 Control Microphones Using 8x24 MIMO Control.

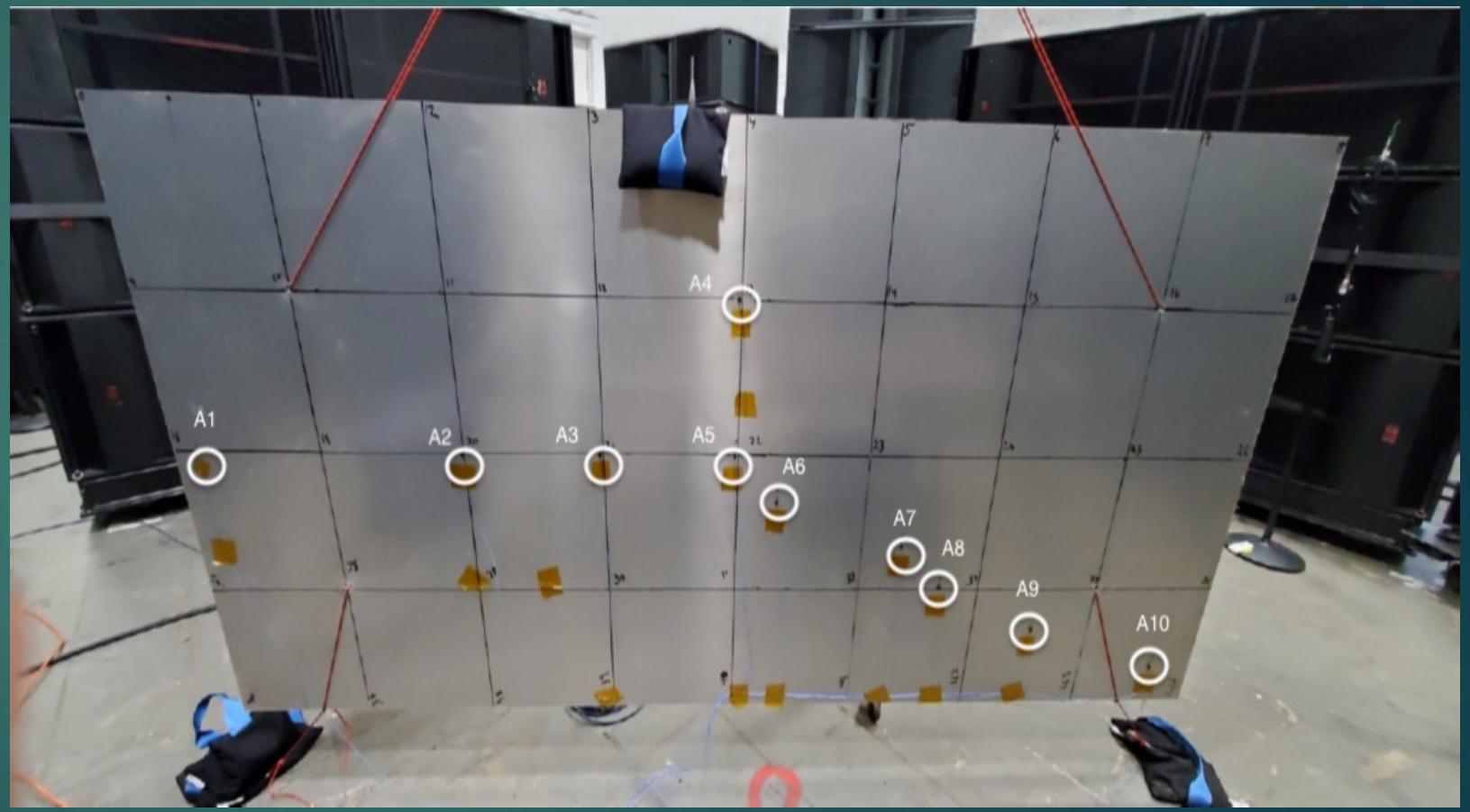
Overall Testing Configuration

- 8x8 stack configuration with 8-drives and 24 Control Microphones
- Consists of 8 MP-150 Mid/High & 8 MP-21 Subwoofers Speaker Stacks
- 14'x 12' Elliptic Microphone Configuration Used Around Panel
- Panel Suspended from Ceiling and Anchored to Floor with Bungee Cords at Center of Microphones



Instrumentation of Test Panel

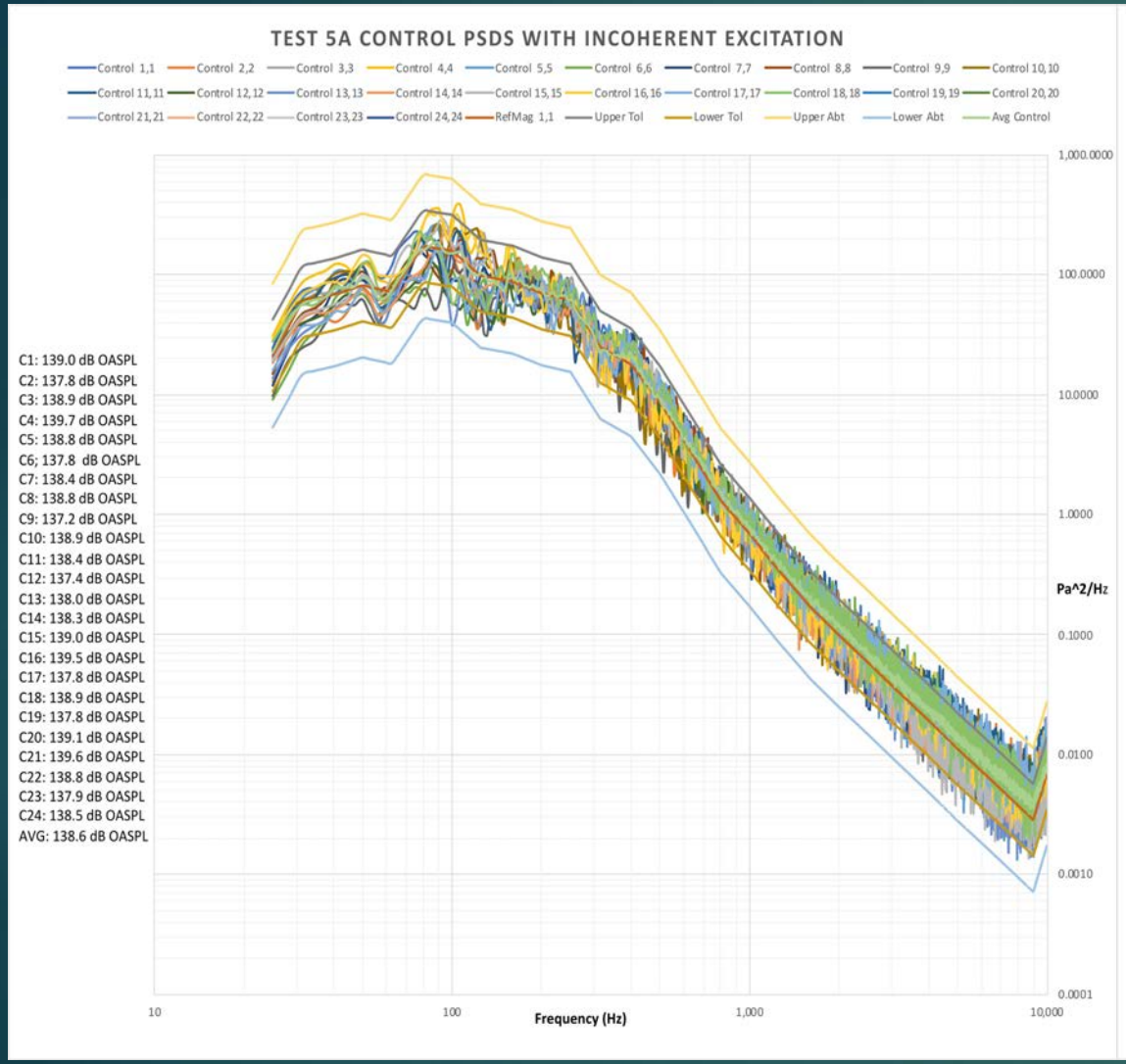
- 10 Response Accelerometers Mounted on Panel.
- Accel Placement Shown By Labeled Circles on Panel.
- Suspending and Anchoring Bungee Cords Shown
- Damping Point Mass on Top
- Modal Test and Analysis Was Used to Identify the first 16 Resonances for Comparison
- The Damped Resonances Used to Compare to Peaks Found in PSDs During Tests

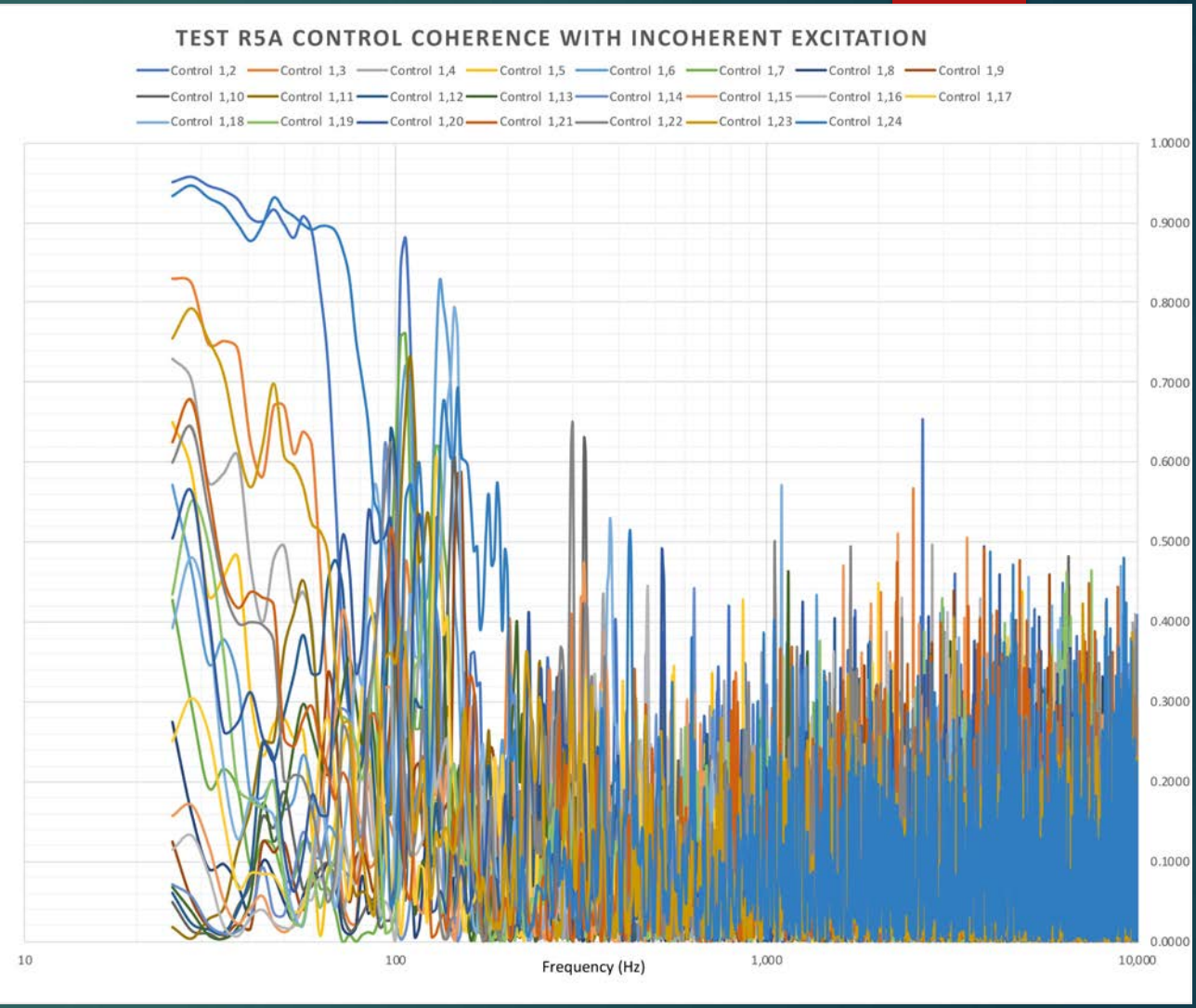


Description of the Four Tests Performed

- First 3 Tests Configured to Use 8x24 Rectangular MIMO Adaptive Control.
- All Used Initial Coherence and Phase Settings that a Subsequent Characterization Low-Level Test Used to Determine an Optimized Reference SDM and Impedance Matrix to Use for Actual Test As Described by Recent Paper at 32nd ATS Conference
- Diffuse Test R5A Used Initial Settings of 0.0 and 0.0° for Coherence and Phase to Approximate a Diffuse Acoustic Field in the Least Mean Squared Error Sense
- Non-Diffuse Test R5B Used Initial Settings of 0.6 and 0.0° for Coherence and Phase to Approximate Uniform Non-Diffuse Acoustic Field
- Non-Diffuse Test R4A Used Initial Setting of 0.7 for Coherence and Variable Phase Settings to Approximate Non-Diffuse Directed Uniform Acoustic Field
- Non-Diffuse MISO Test R5E Controlled its Drive to Cause the Average of the 24 control microphone Responses to Match the Reference PSD. The Coherence and Phase Responses Depend on the Test Article, Acoustic Modes, and Standing Waves Present

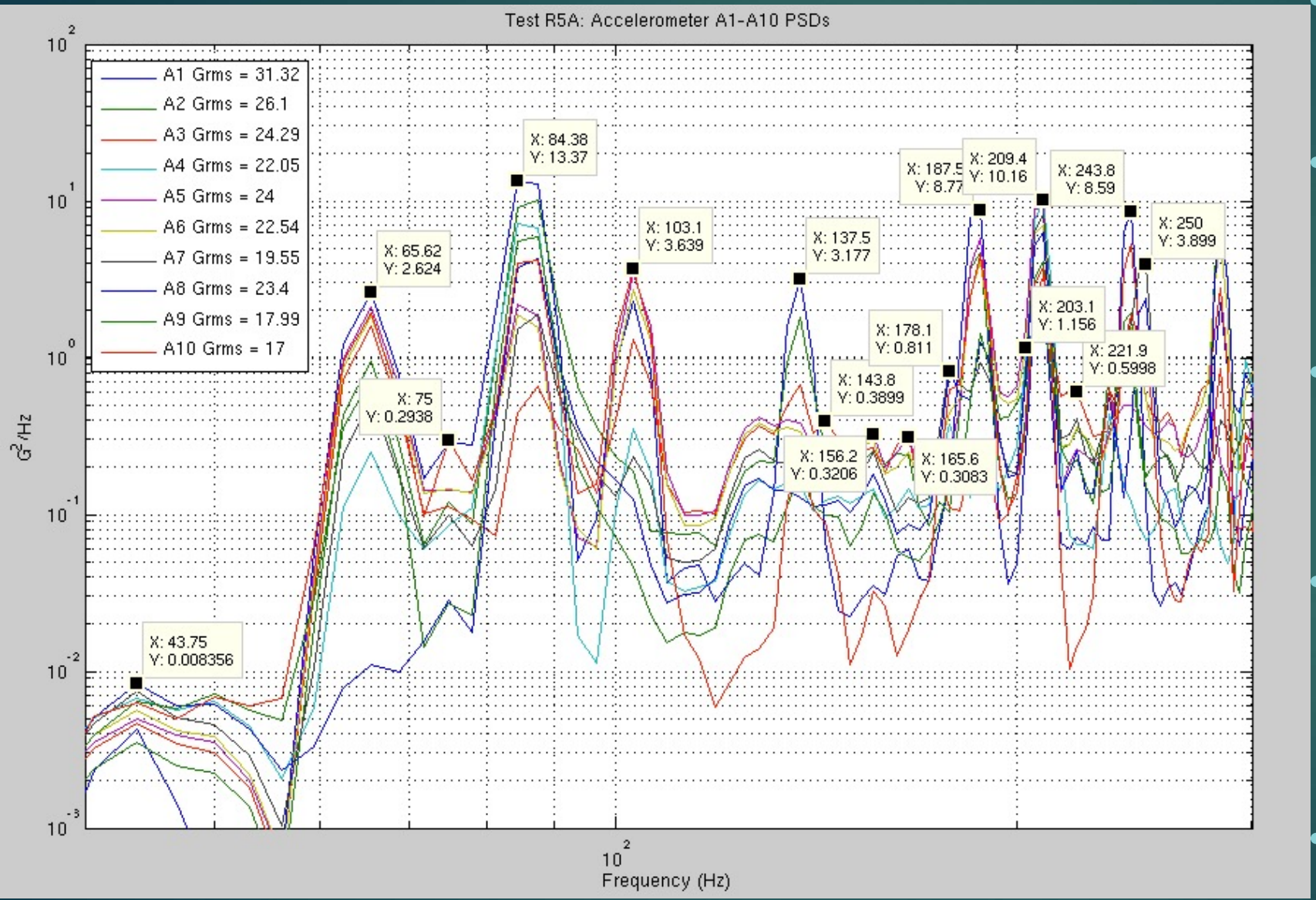
Acoustic Test Results for Test R5A





- Control PSD and Coherence Results, which Account for Mic. Spacing, Match What is Expected From a Uniform Diffuse Acoustic Field. Test Excites All Expected Test Panel Resonances Properly.

R5A Test Panel Response PSDs

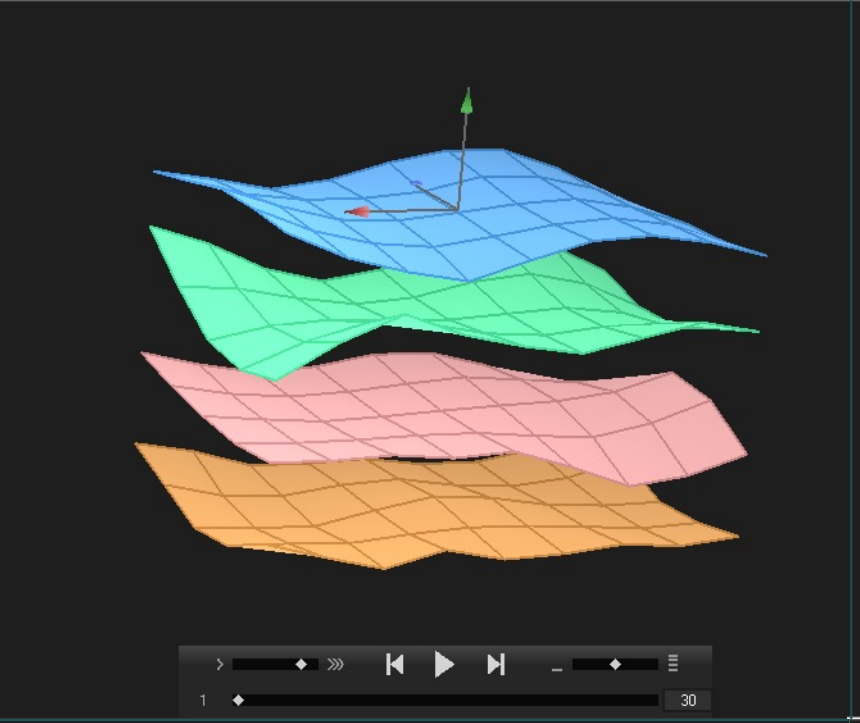


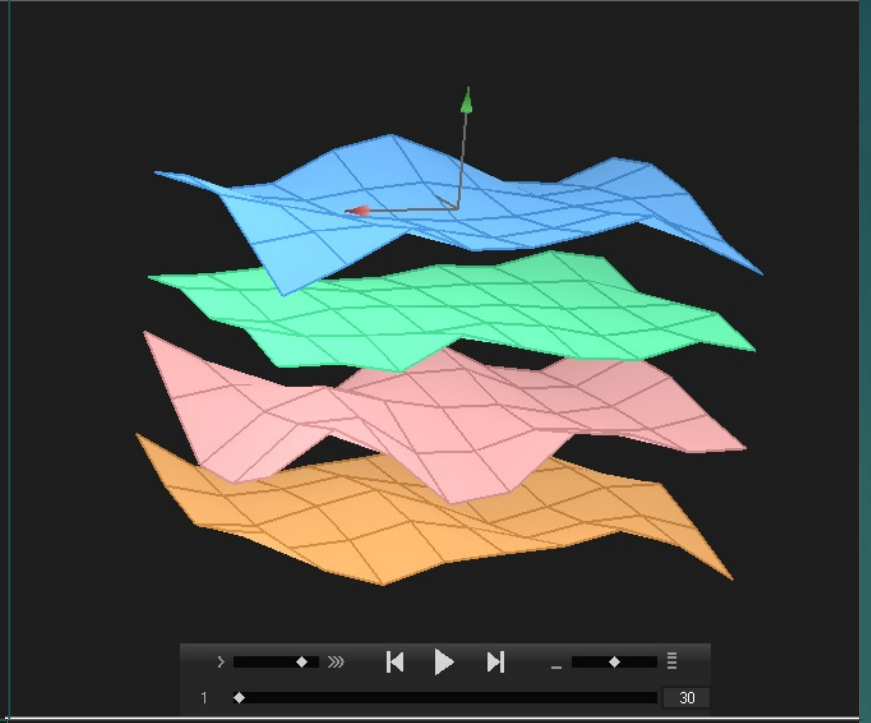
- Objective of Study is to Identify which Acoustic Field is Best for Testing
- Zoomed Plot Shows the PSDs of the 10 Accelerometers Mounted on Test Panel
- Plot Identifies all 16 Resonances Found During Test R5A via Tagged Cursors
- These Correlate well with the16 Damped Resonances Found by Modal Test and Analysis, as Shown by Next Slide
- Test R5A Results Support Objective of Study

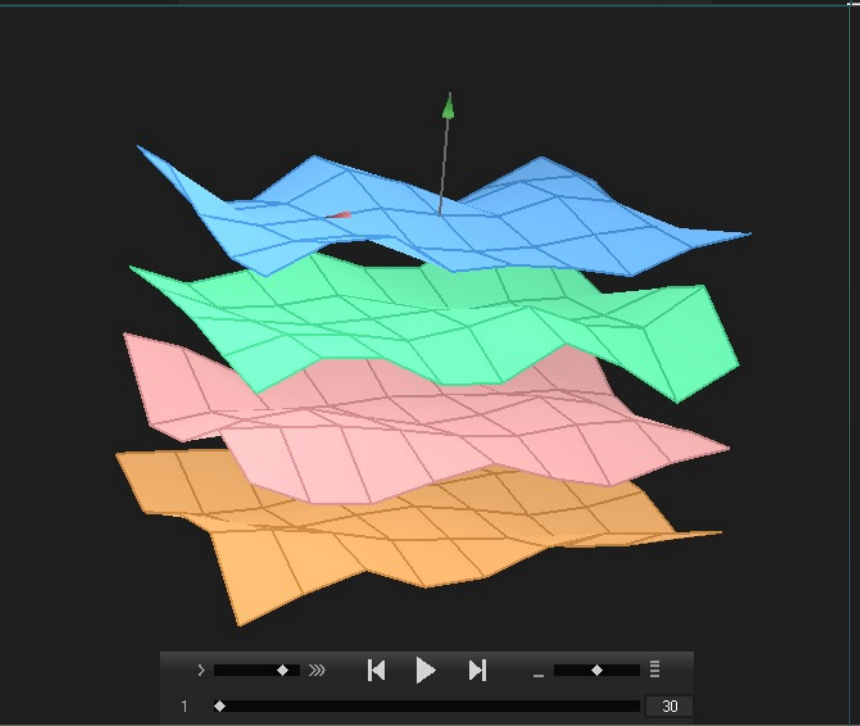
Modal vs. Acoustic Test R5A Results

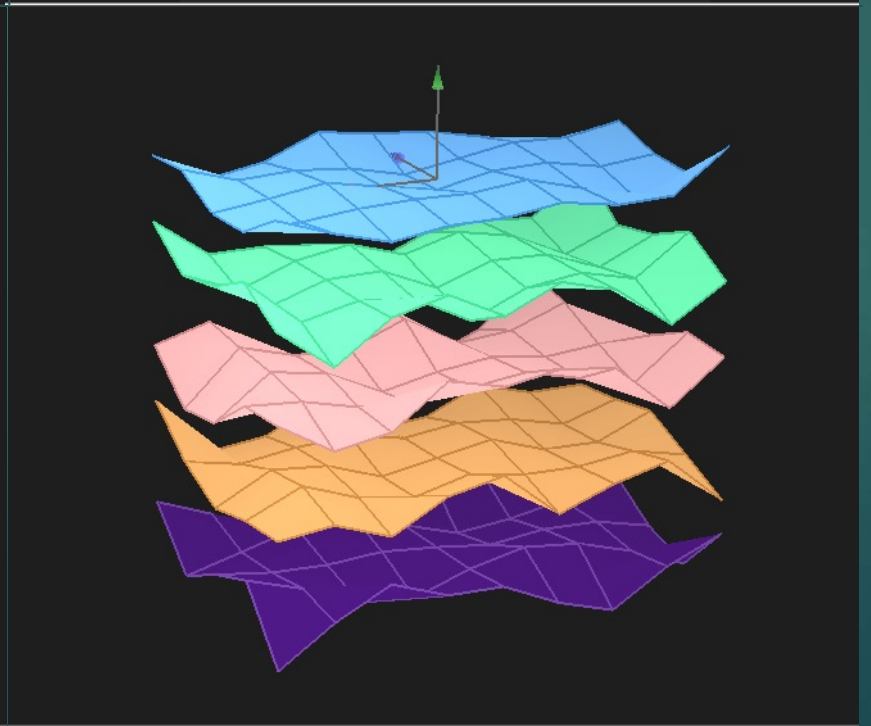
Mode	Natural Frequency (Hz)	Damping Ratio (Hz)	Damping Ratio (%)	Damped Resonant Frequency (Hz)	Observed Resonant Frequency (Hz)	Observation Discrepancy (%)
1	43.77	2.46	5.62	43.70	43.8	0.23
2	69.32	0.18	0.26	69.32	65.6	-5.37
3	77.72	1.02	1.31	77.71	75.0	-3.49
4	85.65	20.04	22.78	83.40	84.4	1.20
5	103.43	7.39	7.13	103.17	103.1	-0.06
6	131.13	1.31	1	131.12	137.5	4.86
7	143.71	0.08	0.05	143.71	143.8	0.06
8	153.59	2.17	1.41	153.57	156.2	1.71
9	172.76	1.07	0.62	172.76	165.6	-4.14
10	181.35	0.51	0.28	181.35	178.1	-1.79
11	187.51	0.58	0.31	187.51	187.5	-0.00
12	202.42	1.3	0.64	202.42	203.1	0.34
13	208.97	0.61	0.29	208.97	209.4	0.21
14	222.36	1.84	0.83	222.35	221.9	-0.20
15	240.07	1.1	0.46	240.07	243.8	1.55
16	247.94	0.64	0.26	247.94	250	0.83

- Modal Test and Analysis Used to Identify the first 16 Damped Resonant Frequencies
- The Damped Resonances Used to Compare to Frequencies of PSD Peaks Found During Tests
- 16 Damped Resonant Resonances, Observed Resonances, and their Discrepancies Shown
- Match Between Them in Last Column is Within a few %, With One at 5%, Which is Quite Good
- All 16 Resonances Identified by Test R5A
- Only Test R5A Able to Do So, as will be Shown
- This and Later Results Show that Diffuse Acoustic Tests are Best for Significant Structures





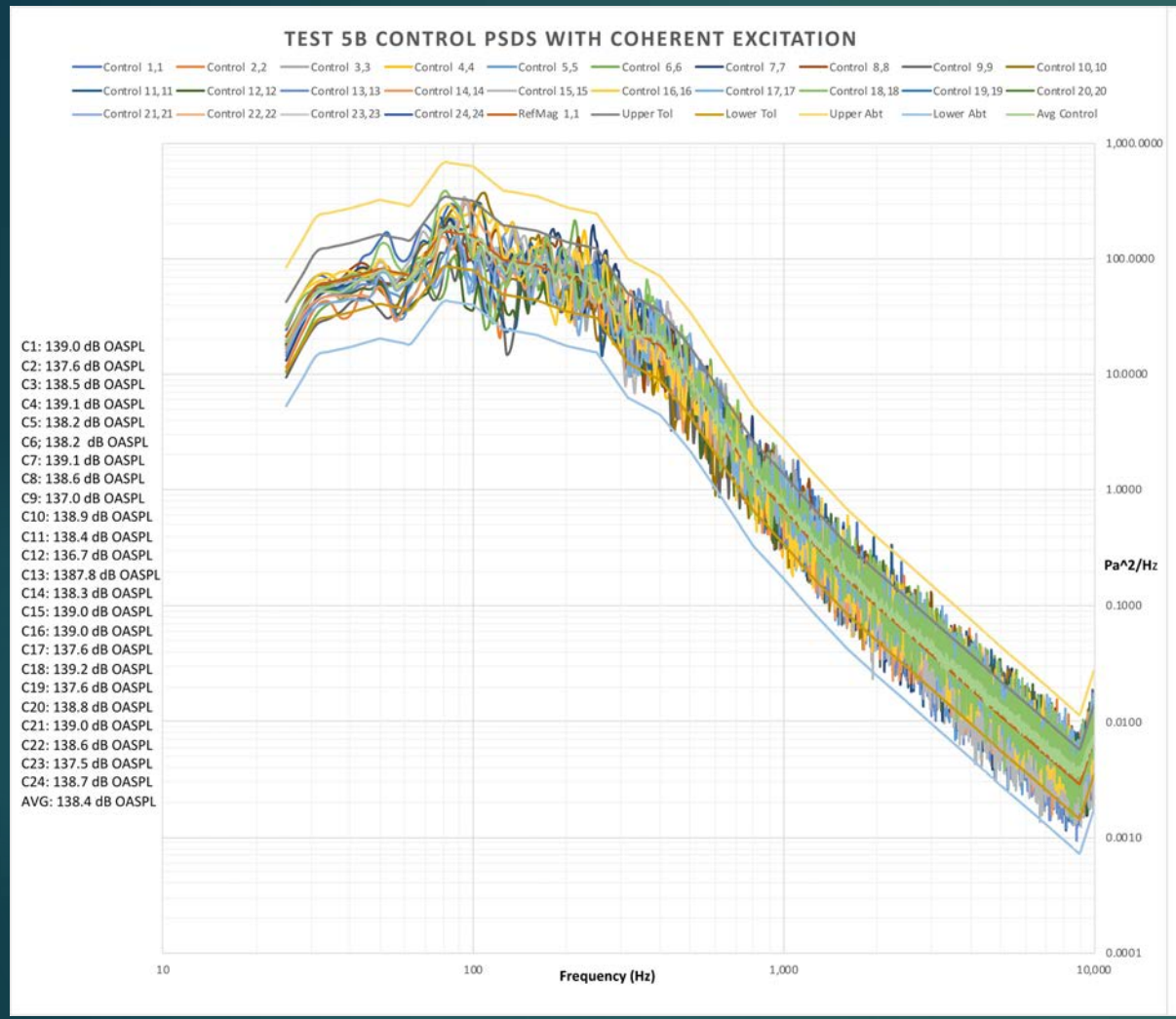


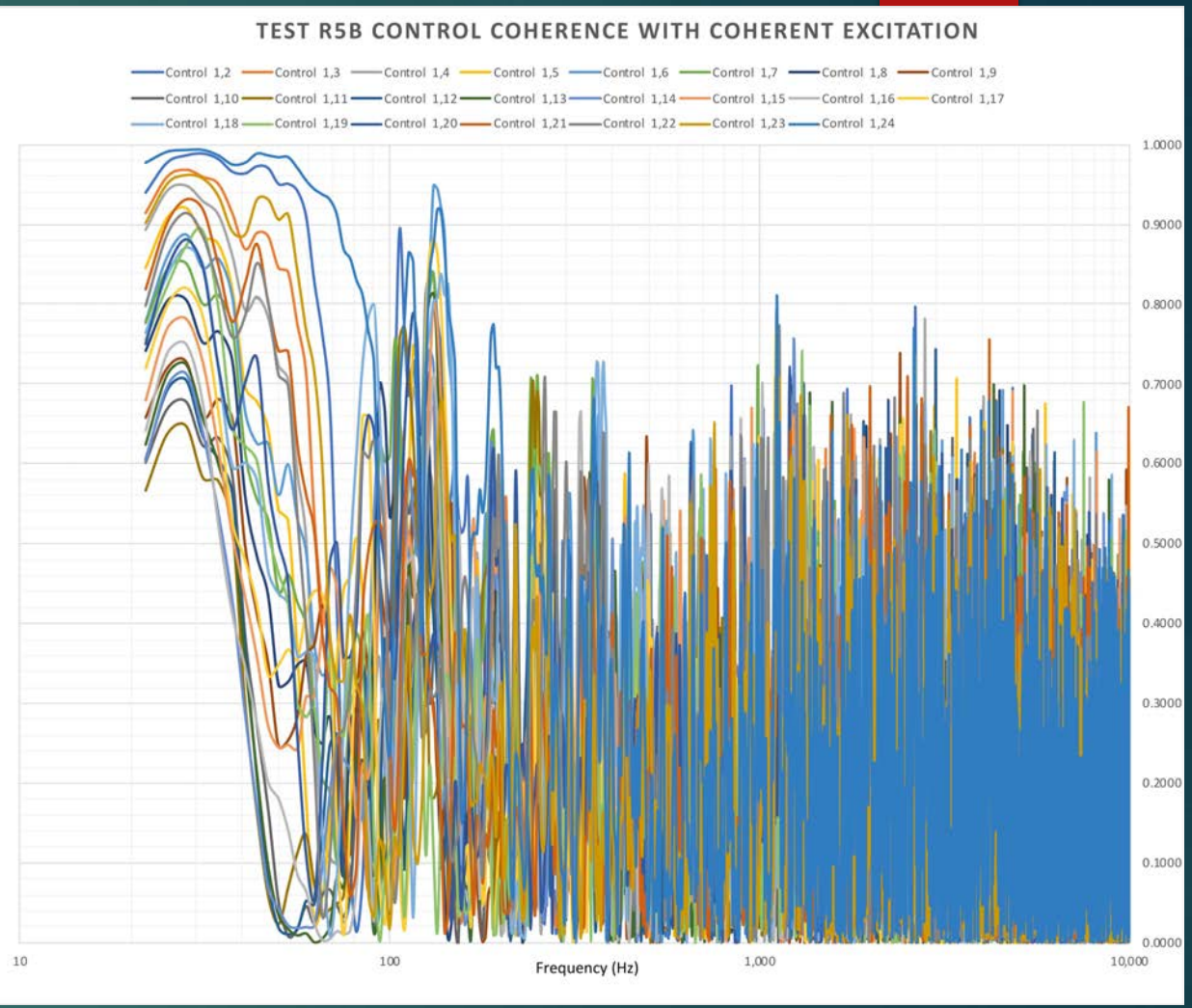


Identified Panel Mode Shapes

- Upper Left Block Contains Modes 1-4
- Upper Right Block Contains Modes 5-8
- Lower Left Block Contains Modes 9-12
- Lower Right Block Contains Modes 13-16
- Non-Diffuse Results Follow

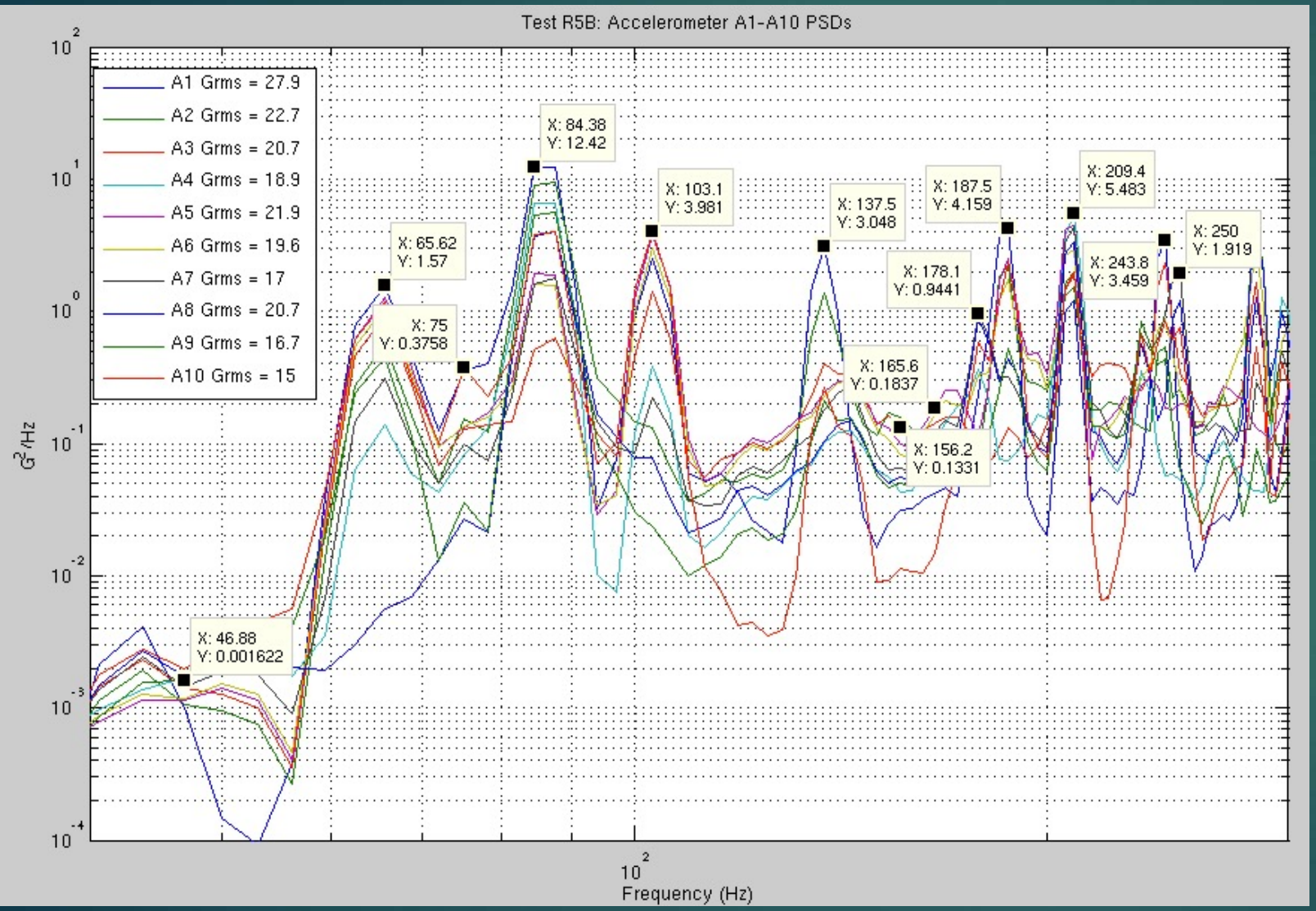
Test R5B Acoustic Control Results





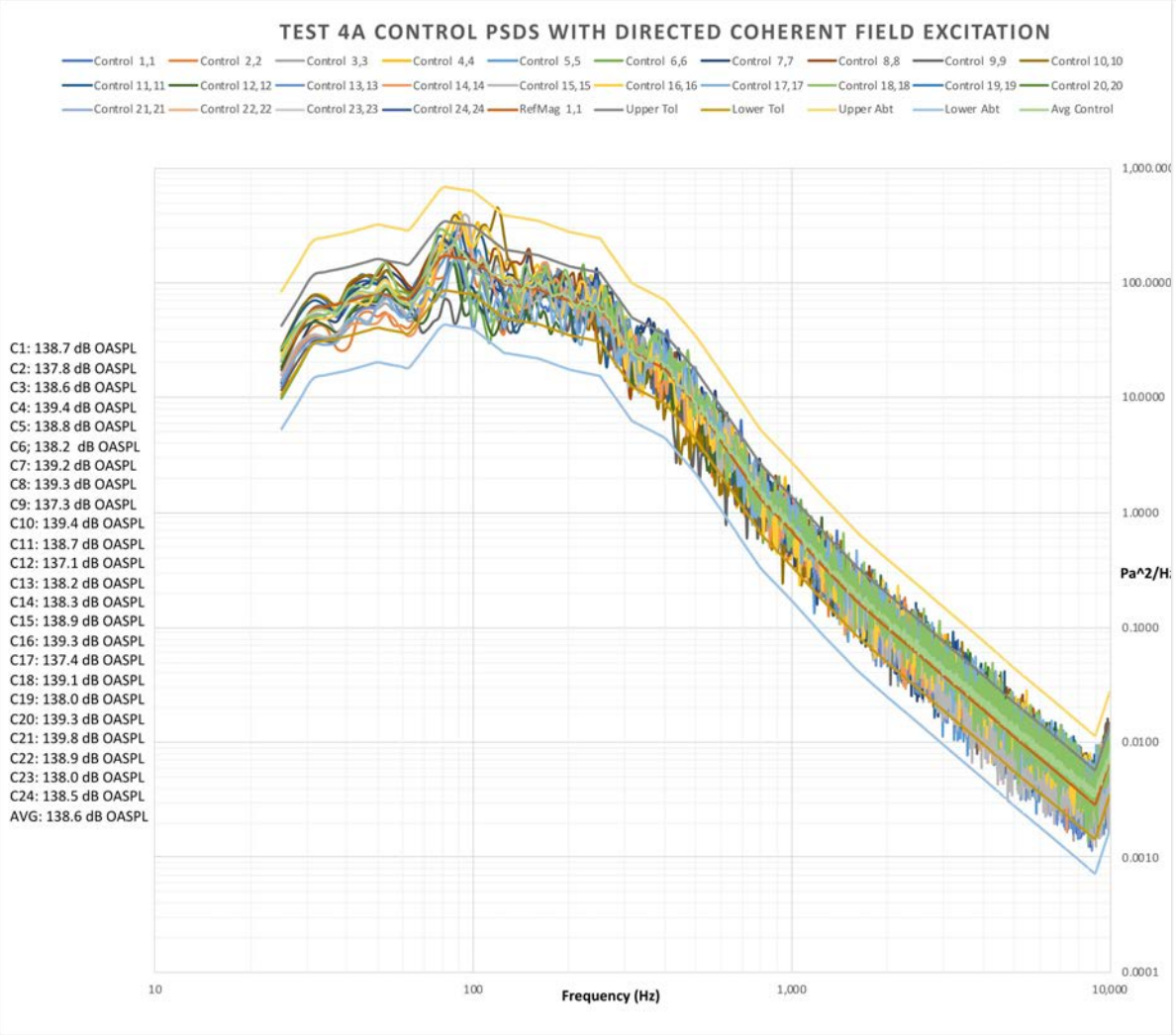
- Control PSD and Coherence Results Match What is Expected From a Non-Diffuse Acoustic Field. Does not Excite All Expected Test Panel Resonances Properly. Phase Nearly Zero Below 140 Hz, Which is Probable Cause of Response Cancellation/Enhancement Effects, as Paper Explains

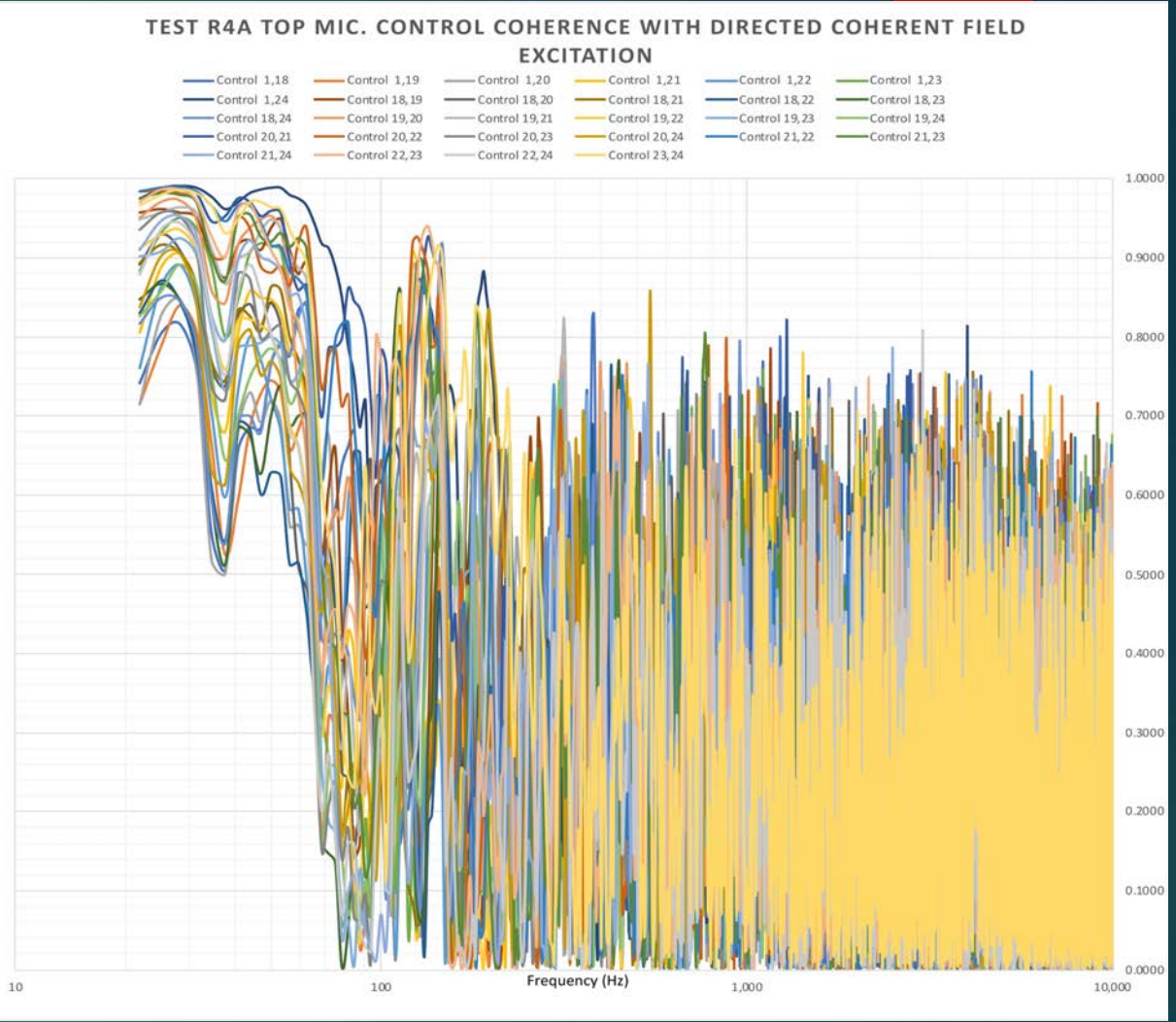
R5B Test Panel Response PSDs



- PSD Responses of Same 10 Accelerometers Mounted on Test Panel are Shown by Plot
- Test R5B Excites Panel with a Non-Diffuse Acoustic Field, but with Same OASPL & Reference Spectra
- Many Notable Differences in the Responses are Seen
- Resonances Seen for Test R5A are not as well Defined or Excited by Test R5B. Some are Missed
- "Phantom" Resonances are Seen that are not in Modal Analysis
- Particularly around 43.8 Hz, 75 Hz, 137.5 Hz, 165.6 Hz, and 156.2 Hz
- Evidence of Resonance Response Enhancement & Cancellation

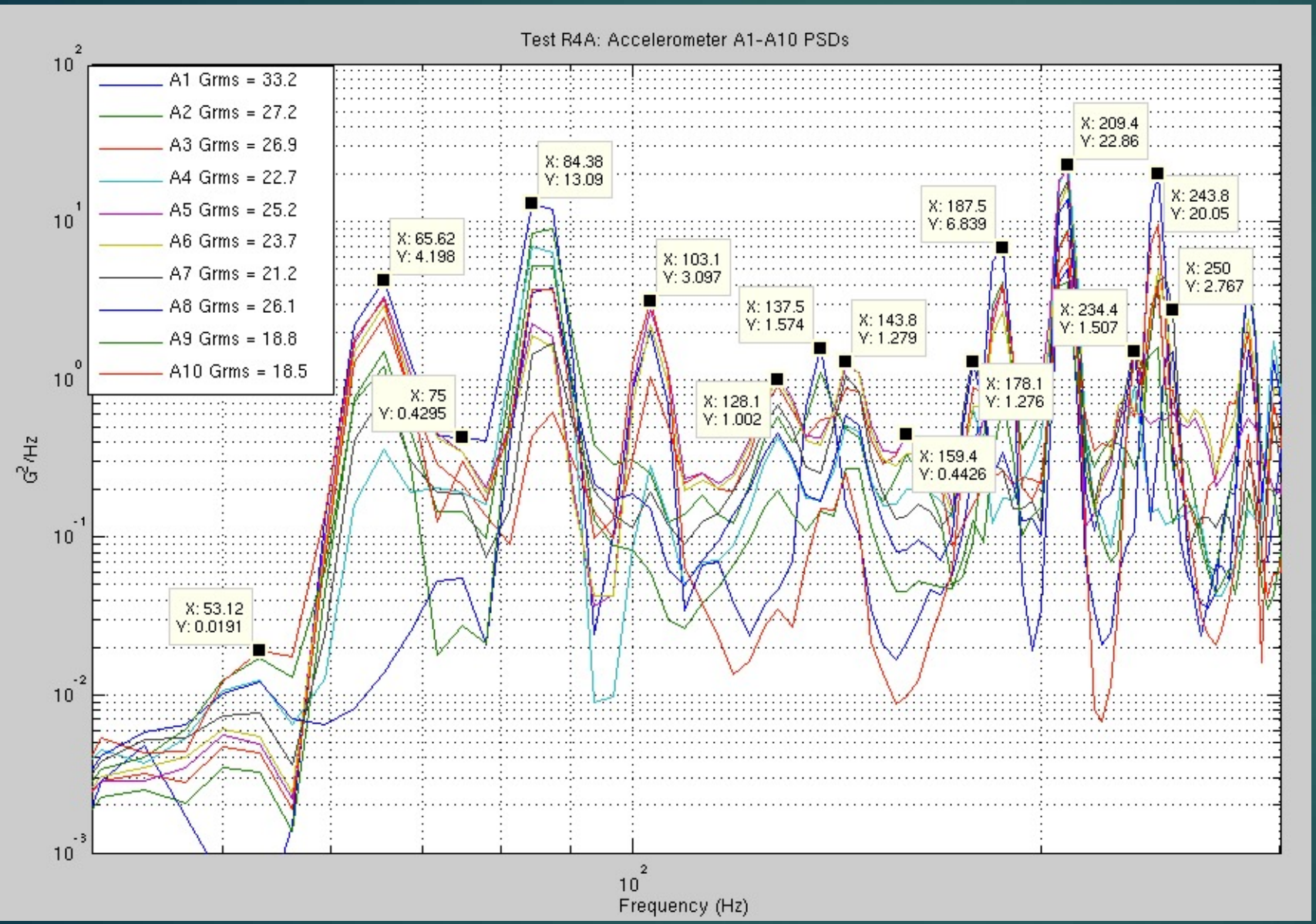
Test R4A Acoustic Control Results





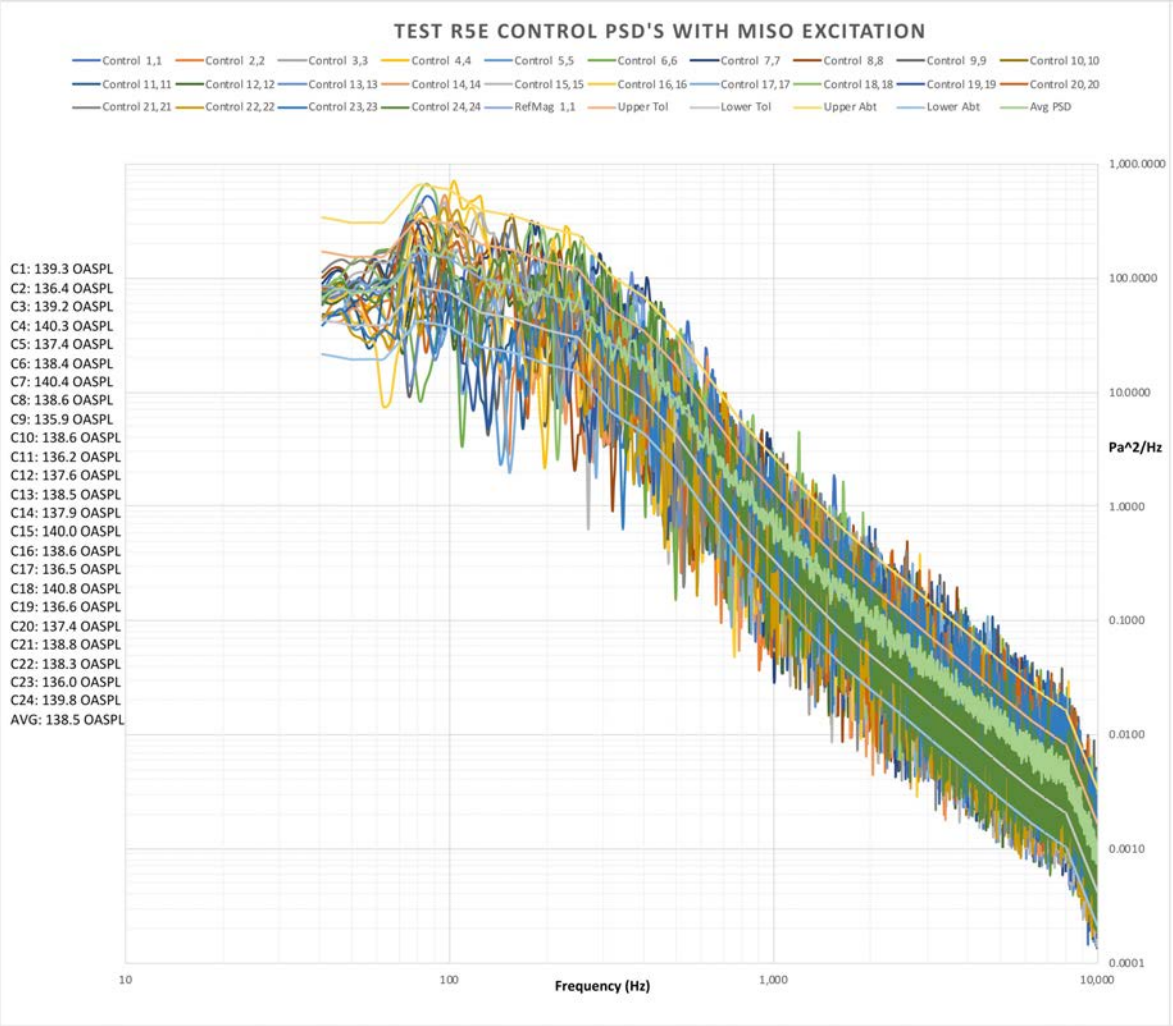
- Control PSD, Coherence, and Phase Results Match What is Expected From a Directed Coherent Acoustic Field. Does not Excite All Expected Test Panel Resonances Properly. Shows Many Examples of "Phantom" Resonances & Response Enhancement/Cancellation.

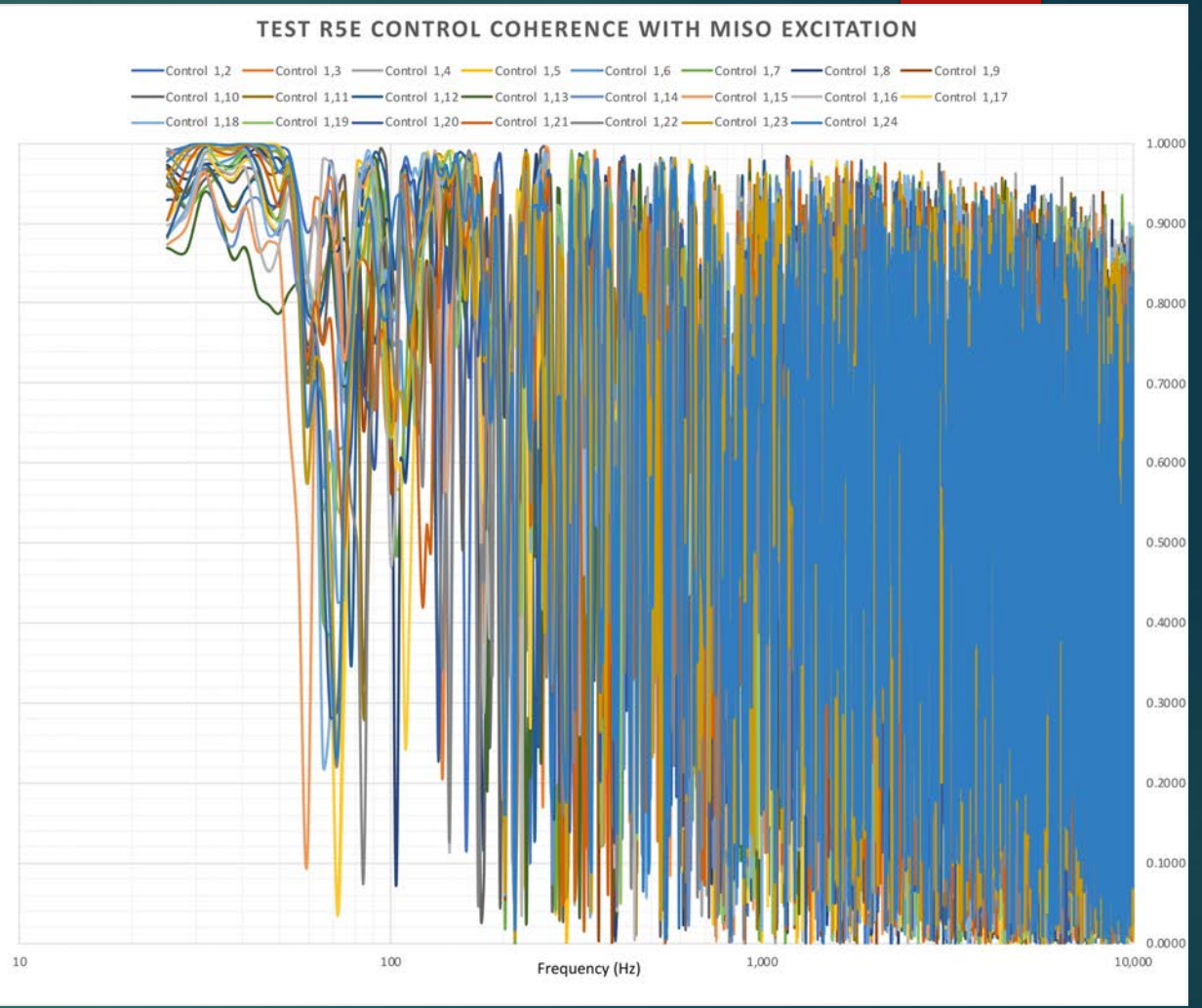
R4A Test Panel Response PSDs



- PSD Responses of Same 10 Accelerometers Mounted on Test Panel Shown by Plot
- Test R4A Excites Panel with a Directed Uniform Coherent Acoustic Field with Same Spectra
- Shows More Notable Differences in PSD Responses
- Resonances Seen for Test R5A are not as well Defined or Excited by Test R4A. More are Missed
- "Phantom" Resonances are Seen that are not in Modal Analysis
- Particularly around 53.1 Hz, 75 Hz, 103.1 Hz, and 137.5 Hz
- More Evidence of Response Enhancement & Cancellation
- Significant Cancellation of Resonance around 137.5 Hz
- More Details in Paper

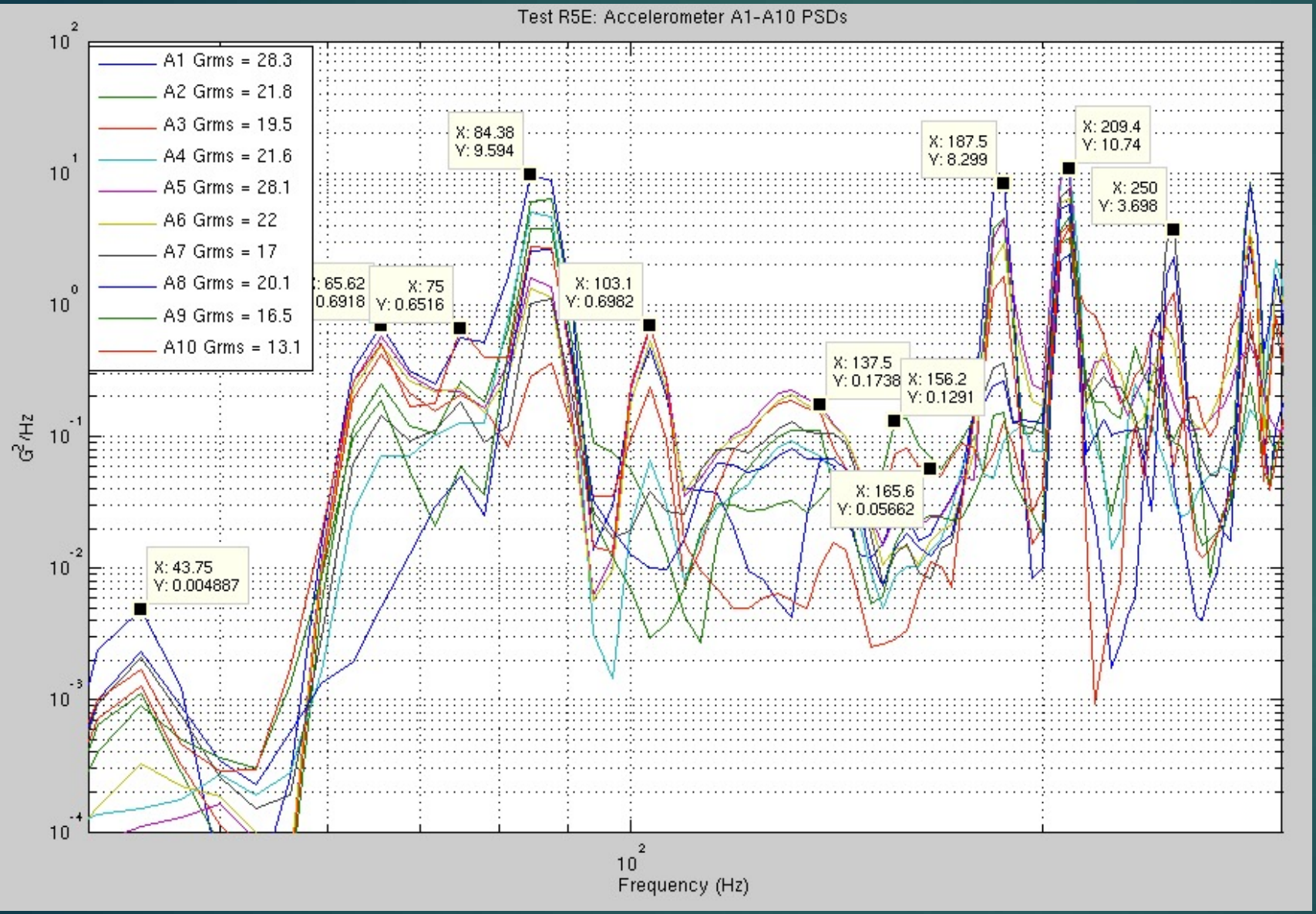
Test R5E Acoustic Control Results





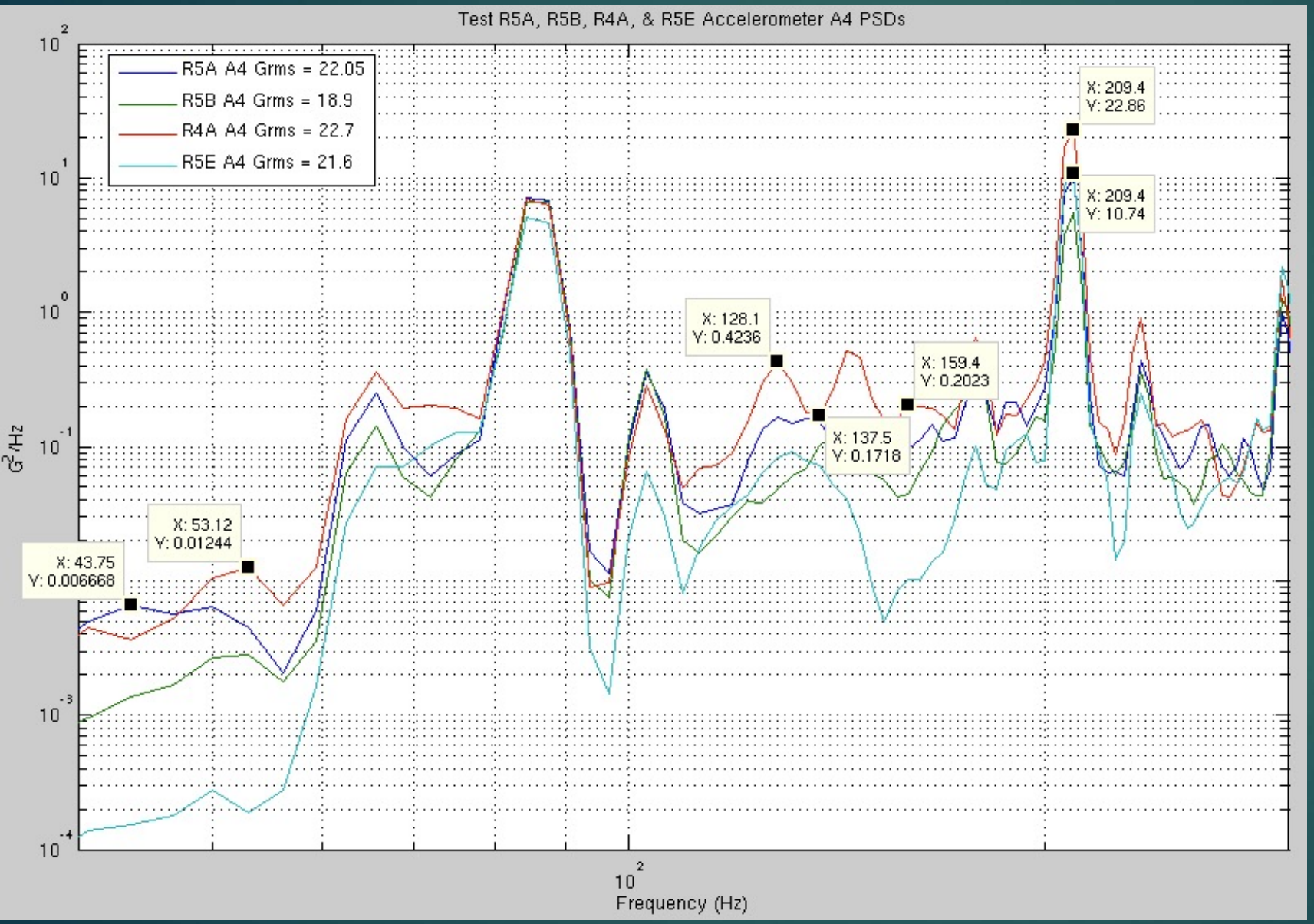
- Control PSD spread, & Coherence Results Match What is Expected From an Acoustic Field from MISO. Poorest Proper Excitation of Expected Test Panel Resonances. Shows Similar Examples of "Phantom" Resonances & Response Enhancement/Cancellation as in Tests R5B & R4A.

R5E Test Panel Response PSDs



- PSD Responses of Same 10 Accelerometers Mounted on Test Panel Shown by Plot
- Test R5E Excites Panel with an Acoustic Field from a MISO Test with Same OA SPL & Spectrum
- Shows More Significant Spread in PSD Responses, about 25 dB
- Resonances Seen for Test R5E are the Least Defined or Excited than Other Tests. Even More are Missed
- "Phantom" Resonances are also Seen, but not in Modal Analysis
- Around 43.8 Hz, 65.6 Hz, 75 Hz, 85.4, 103.1 Hz, and 137.5 Hz
- More Evidence of Response Enhancement & Cancellation
- Significantly more Cancellation of Resonance near 137.5 Hz, 156.2 Hz, and 165.6 Hz
- More Detailed Discussion in Paper

Detailed A4 Test R5A-R5B-R4A-R5E Comparison



- Graph Shows Comparison of Responses at A4 for All Tests.
- Plot shows Test R5B under excites structural resonances throughout.
- Misses 43.8 & 137.5 Resonances
- Plot Shows Similar Behavior for Test R4A, with Significant Response Cancellation around 43.8 and 137.8 Hz and more "Phantom" Resonances Surrounding Them. Response Enhancement Also Occurs.
- Shown by Cursors at 209.4 Hz.
- Test R5E is Again Shown to Under Excite Most of The Resonances, while R4A Over Excites Many of Them
- Test R5E is Poorest Performer.
- Test R5A Has No Such Problem for A3 and on other accel's

Response Enhancement and Cancellation

- Response Enhancement Occurs When the Sound Pressure Waves in an Acoustic Field are Coherent and In-Phase with Particular Structural Resonances, or at Intermediate Such Phase Relationships (Partial Enhancement)
- On the Other Hand, Response Cancellation Occurs When the Sound Pressure Waves in an Acoustic Field are Coherent and Out-of-Phase with Particular Structural Resonances, or at Intermediate Such Phase Relationships (Partial Cancellation)
- This Phenomena Can Also Occur when Standing Waves are Present in Acoustic Field (as Dr. Kolaini et. al. have shown), but also when The Acoustic Field Used for Testing is Highly Coherent (Non-Diffuse) As This Paper Discusses and Shows
- Exciting Structures with Non-Diffuse Fields can Either Reinforce Structural Responses at Non-Resonant Frequencies, which Causes "Phantom" Resonances, or Cancels/Reinforces the Response at bona fide resonances (Resonance Response Cancellation or Enhancement),
- Causes the Notch at 137.5 Hz and the Peaks at 53.8 Hz, 128.1 Hz, 143.8 Hz, 159.4 Hz, & 209 Hz seen in the Various Discussed Accelerometer Responses from Tests R5B, R4A, and R5E
- The Random Phase and Low Coherence of Diffuse Acoustic Fields Throughout the Frequency range, such as for Test R5A, Inhibit These Effects from Occurring, as Shown by Data in This Paper

Conclusions on Panel Response Comparisons

- Presented Analysis, and Detailed Discussion in Paper, Demonstrates that only test R5A Consistently Excites All Resonances, Particularly at 137.5 Hz and The First 6 Resonances
- Focus is on Lowest Frequency Resonances, Since These Exhibit Largest Stresses and Strains, Due to Largest Deflections
- Test R5A is Better than R5B, R4A and R5E, with MISO Test R5E Noticeably the Worst
- Results Underscores Importance of Relative Coherence and Phase Between Microphones in Determining the Structural Response of a Test Article During an Acoustic Test for Given Reference Spectra and OASPL

Overall General Conclusions

- The Presented Analysis Demonstrates that Only Diffuse Acoustic Fields, such as Test R5A, Effectively Excite and Identify the Structural Resonances of a given Test Article
- Non-Diffuse Tests, Like R5B, R4A, and R5E, Consistently Miss Exciting Significant Resonances Properly and Many Times Find "Phantom" Resonances and may be Subject to "Hot Spots" in Acoustic Field
- Achieved SDM Coherence and Phase Between Microphones of an Acoustic Field Used to Excite a Test Article are the Most Significant Parameters of an Acoustic Test, in Addition to the Test's OA SPL and Reference Spectrum Definition
- All of These Parameters Determine the Structural Response Induced by an Acoustic Test Using That Field, as Shown by This Response Study
- Additional Power Utilization Study in Paper Shows that MIMO Diffuse Acoustic Tests Require Only 1.3 dB More Power than Equivalent MISO Test

Questions?

- If You Have Any Questions, You May Send These by Email
- My Email Address is: m.underwood@msidfat.com