New Method Determines Optimized Reference SDM for MIMO Testing

Presented by:

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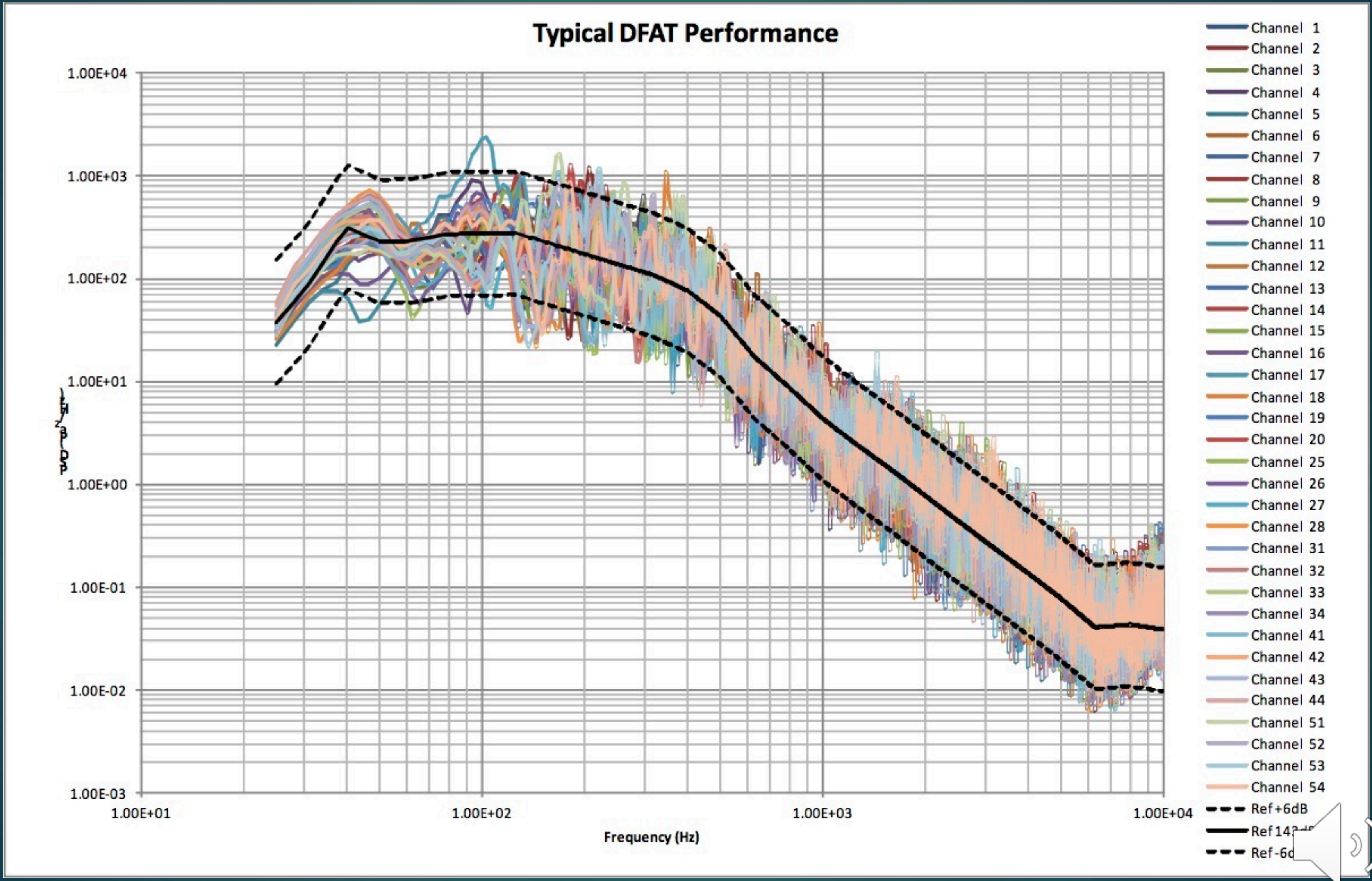
Introduction

- New Method Generates P.D. Reference SDM Approximating Pre-specified Reference SDM with the Least Drive Power & Approximation Error
- Modifies Off-Diagonal Elements of Pre-specified SDM, but keeps its Diagonal Elements Fixed
- Takes into Account Limitations that may Exist in Testing System and/or Facility as a Constraint
- Typically, a More Uniform and Diffuse Acoustic Field Results for a MIMO DFAT™ Test
- Reduced Control Errors for MIMO Random Testing, with More Linear Responses for Both
- Synthesized by Jaguar's Underlying Adaptive Optimal MIMO Control Optimization Capability

Previous MIMO DFAT™ Results

- Narrow-band, Digital MIMO control
- 20 Hz – 10kHz, Δf=3.125Hz
- 15 Drives, 15 Control Mic.'s, & 15 Speaker Stacks
- More Drives and Controls Were Possible
- Additional Monitor and Array Microphones Used to Verify Achieved Acoustic Field Uniformity
- Advanced Optimal Adaptive Control and Randomized Microphone Placement Reduce Magnitude of Standing Waves to Reduce Structural "Hot Spots" due to Response Enhancement
- MIMO Limit Control on Test Article Possible

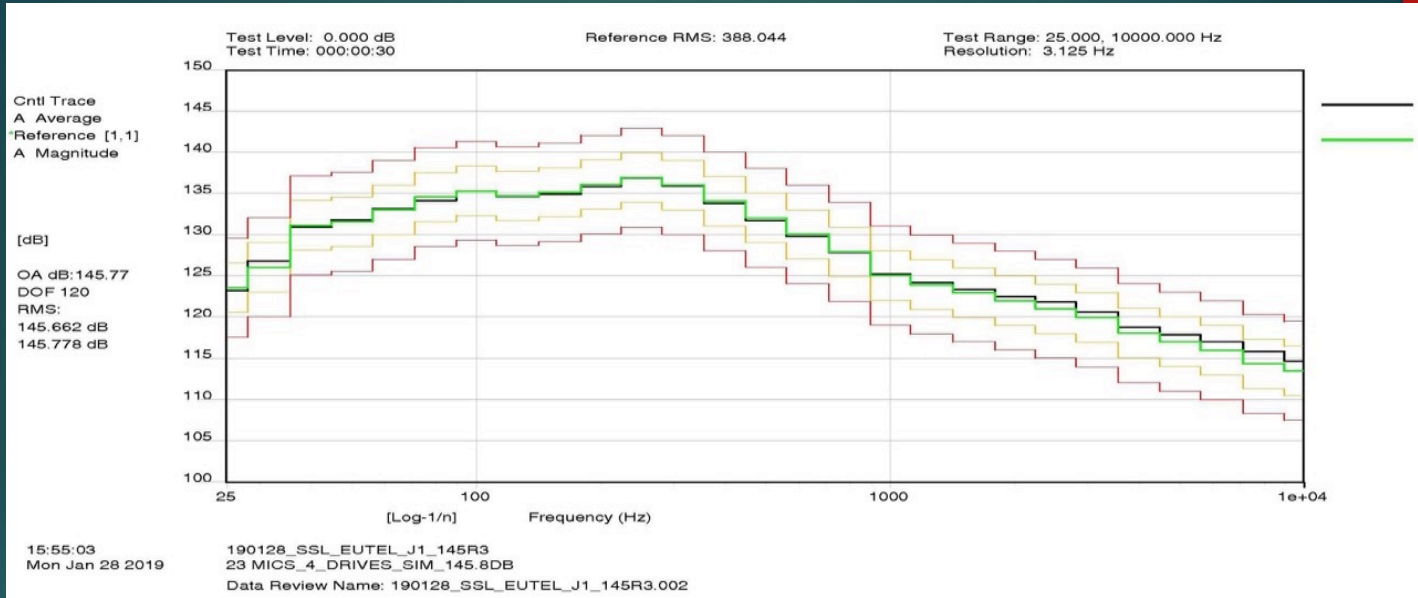
Example of Previous Results: 15 control and 21 monitor Mic.'s

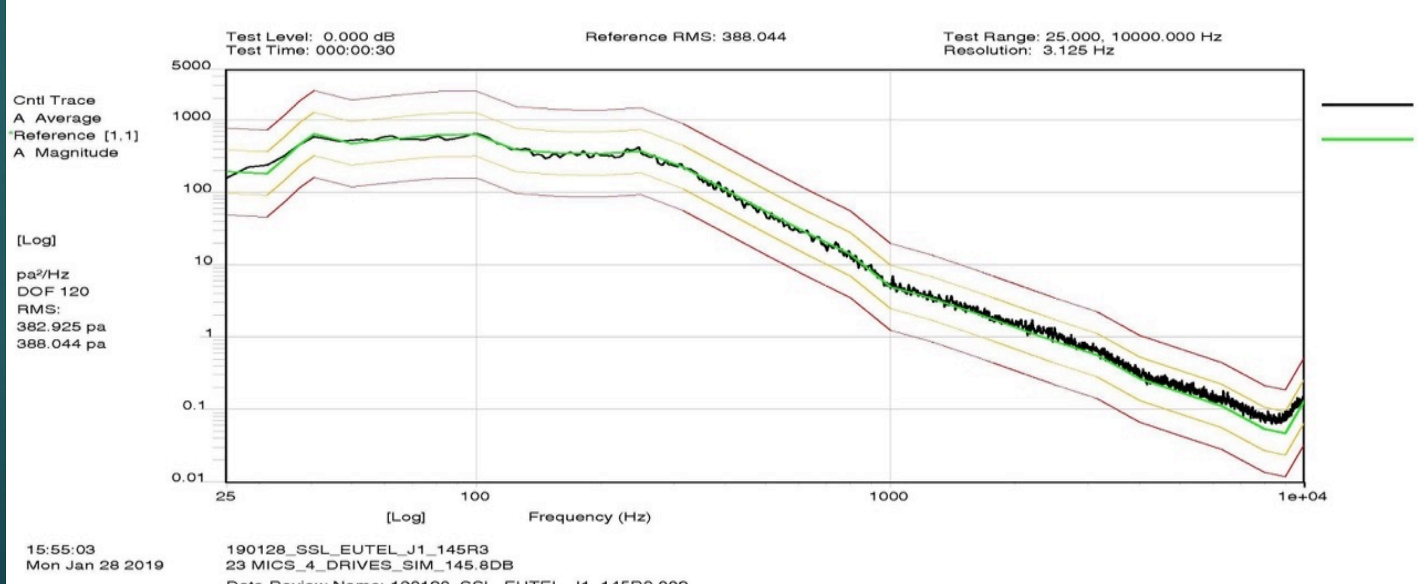


New Research & Testing Results

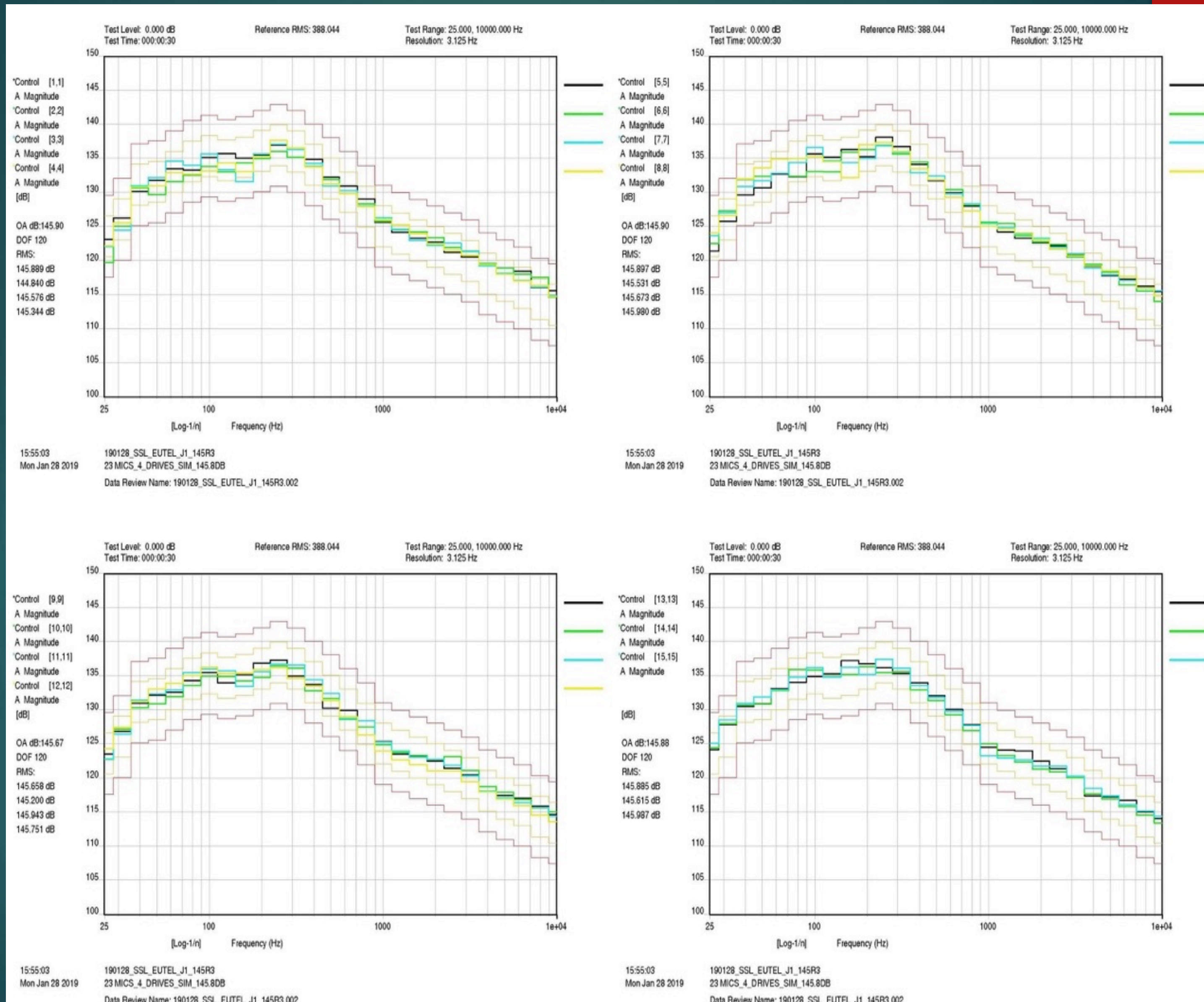
- New Control Reference SDM Synthesis Developed that Approximates Pre-Specified Control-Reference SDMs with Least Mean-Square Error & Least Drive Power
- Requires Least Drive SDM Power for Least Approximating Error due to Advanced Adaptive Optimal Control Methods
- Provides Uniform and Diffuse Acoustic Field, as well as Other Types of Acoustic Fields for DFAT™
- Better Control of both Levels, Coherence, and Phase
- Control Optimization Performed Each Control Loop Iteration Using Advanced MIMO Adaptive Optimal Control Methods
- Results in More Linear Response Characteristics

Average of 15 Controls with 4 Drives & 15 Speaker Stacks: Using Optimal Reference - SPL & PSD

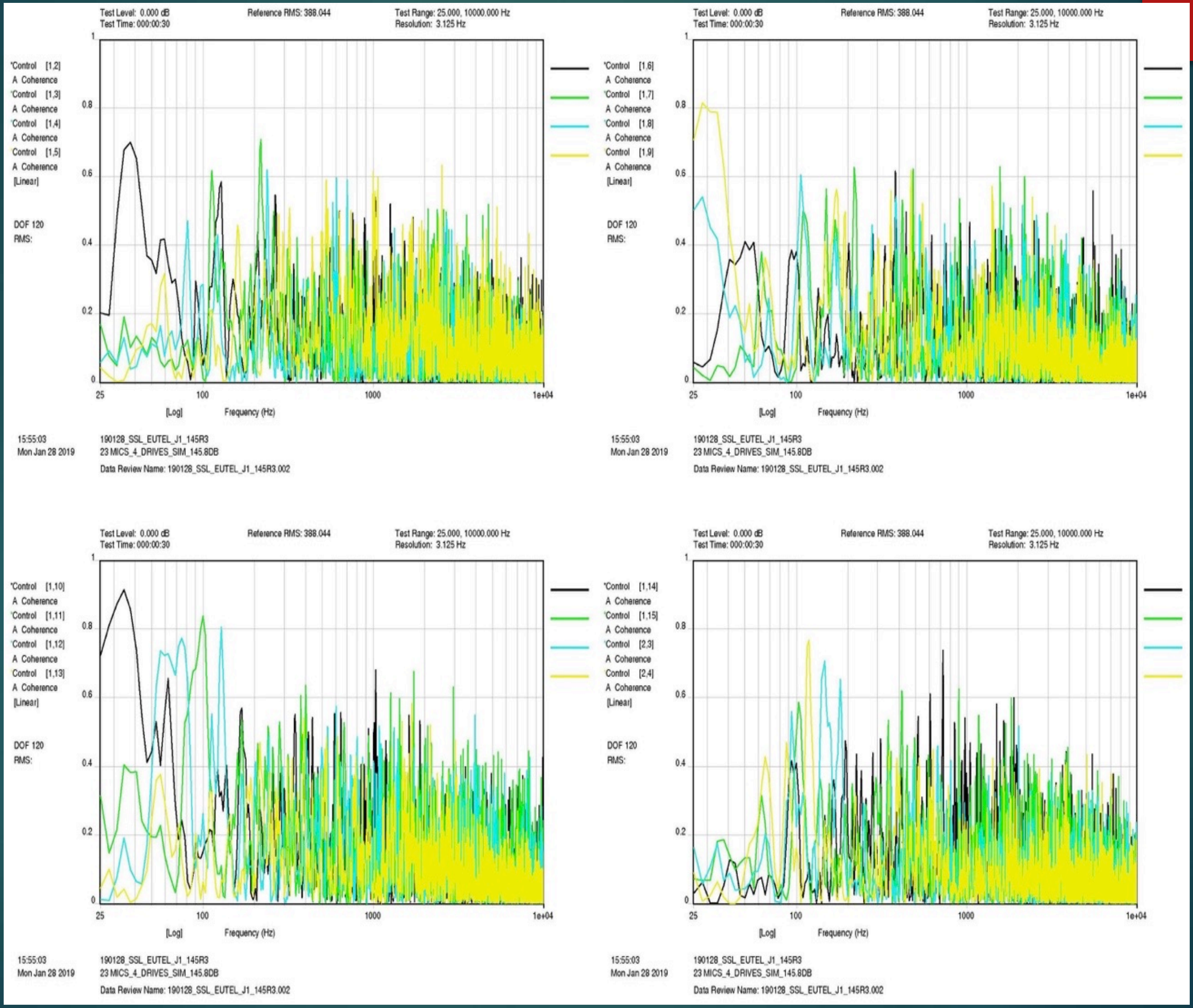




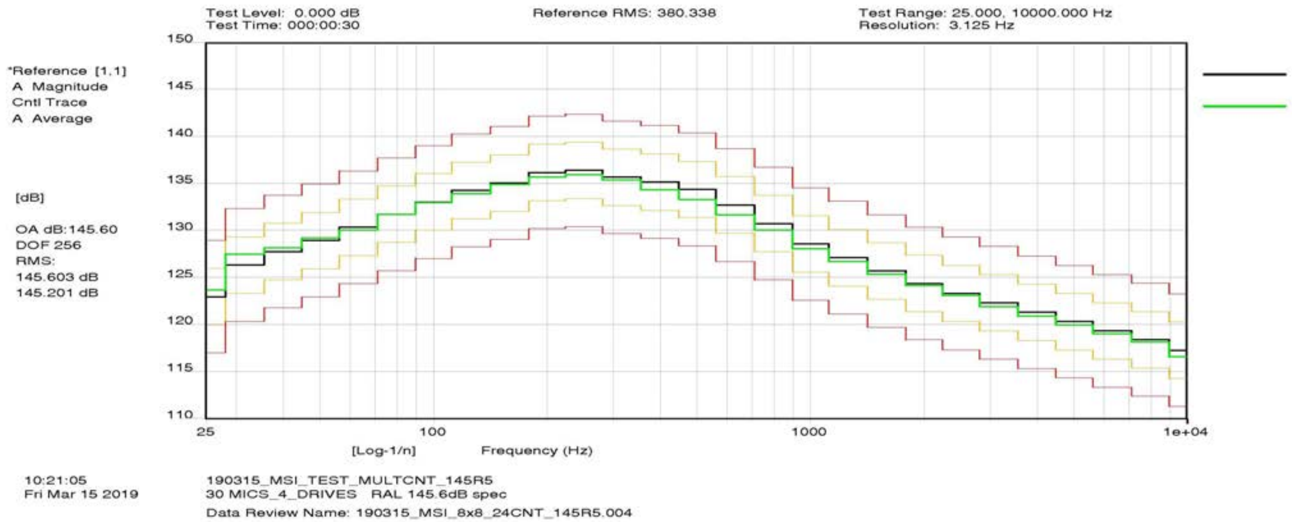
Individual Controls - 1 Through 15

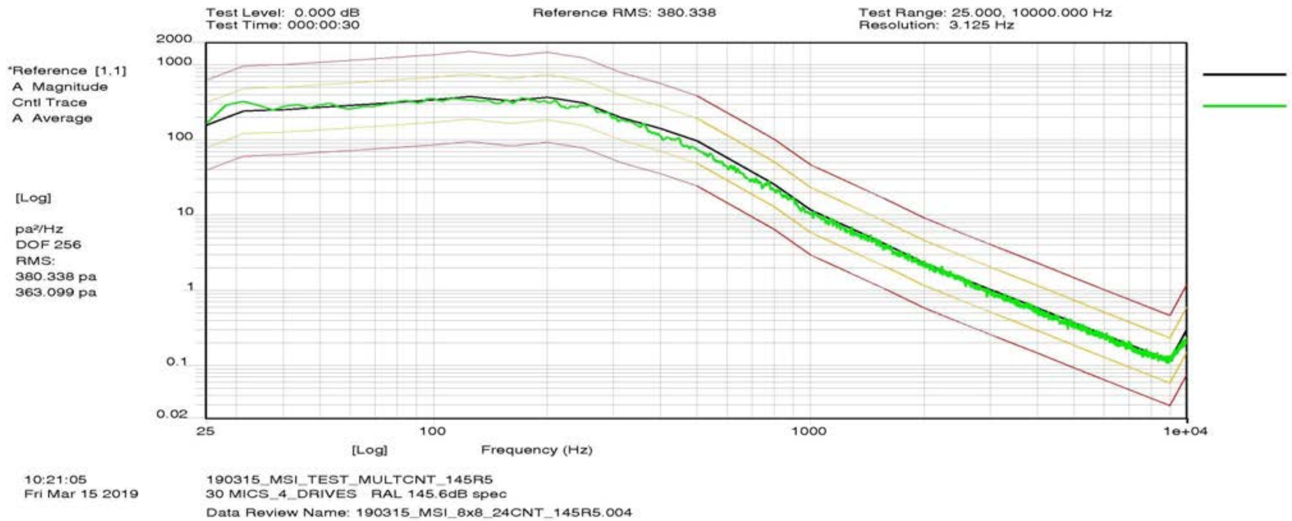


Coherence Results – Mic 1 Vs. 2 To 15

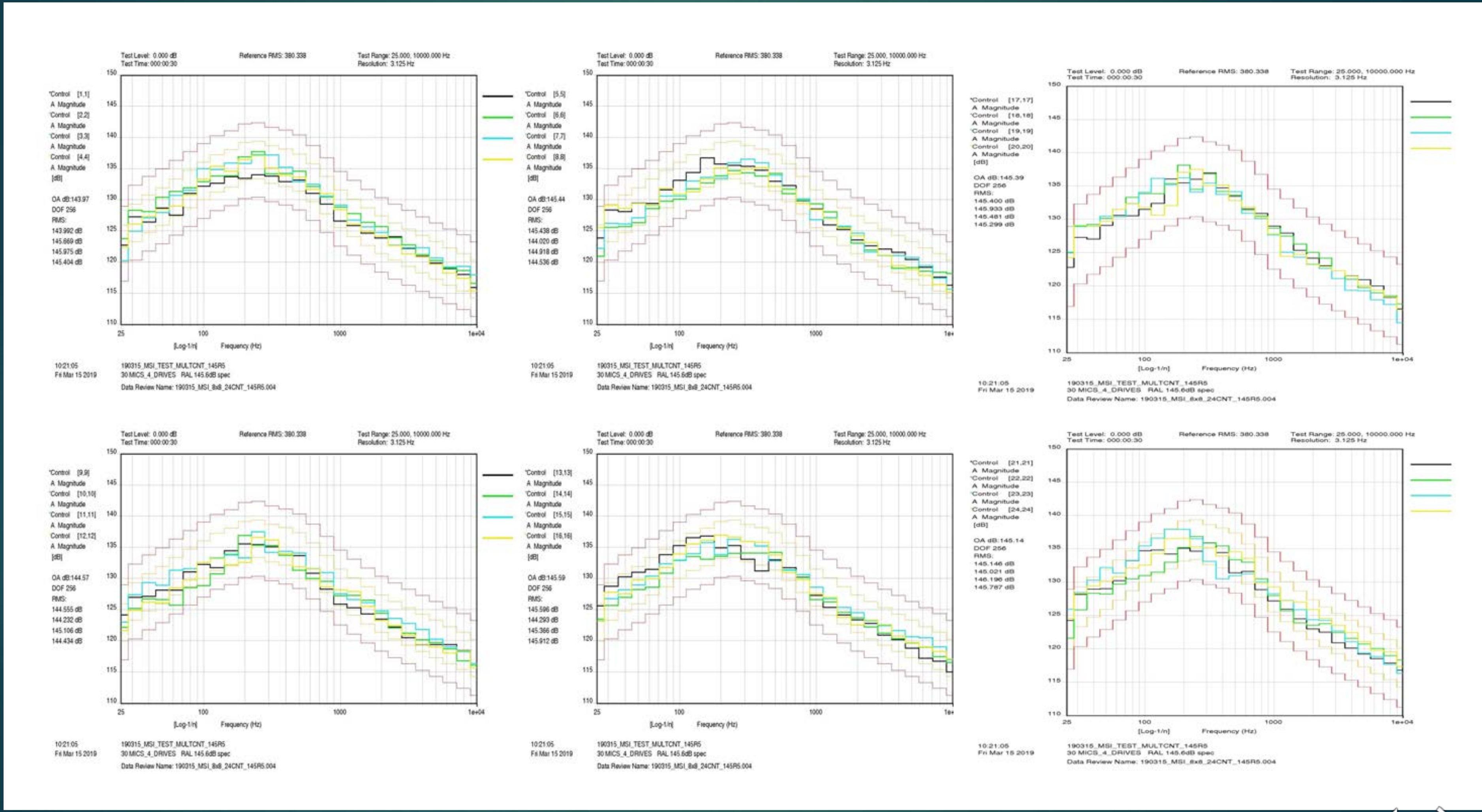


Most Recent Results: 24 Controls, 4 Drives, and 8 Speaker Stacks – Control Avg.





Most Recent Results: 24 Controls, 4 Drives, and 8 Speaker Stacks – 24 Controls



New DFAT™ Performance

- Optimal Adaptive Control and Optimal Reference SDM Reduce Control Error to the Least Mean Squared Error (LMSE)
- Reduces Power Needed to Drive Multiple Speakers
- Most Recently, Achieved Same OA SPL with Fewer Speakers
- New Synthesis Matches Initial Reference in LMSE Sense
- Improved Uniformity & Lower Coherence Between Control Microphones Compared to Previous DFAT™ Results
- Better Uniformity of Control and Monitor Microphones.
- Better Approximation of Uniform Diffuse Acoustic Field
- Recent Test Panel Response Studies Show Achieved Field Excites Structural Resonances Better than Response from Non-Diffuse and Fields Obtained from MISO Acoustic Testing.
- Better Rectangular Control Uniformity and Coherence between Control Microphones over Control Frequency Range

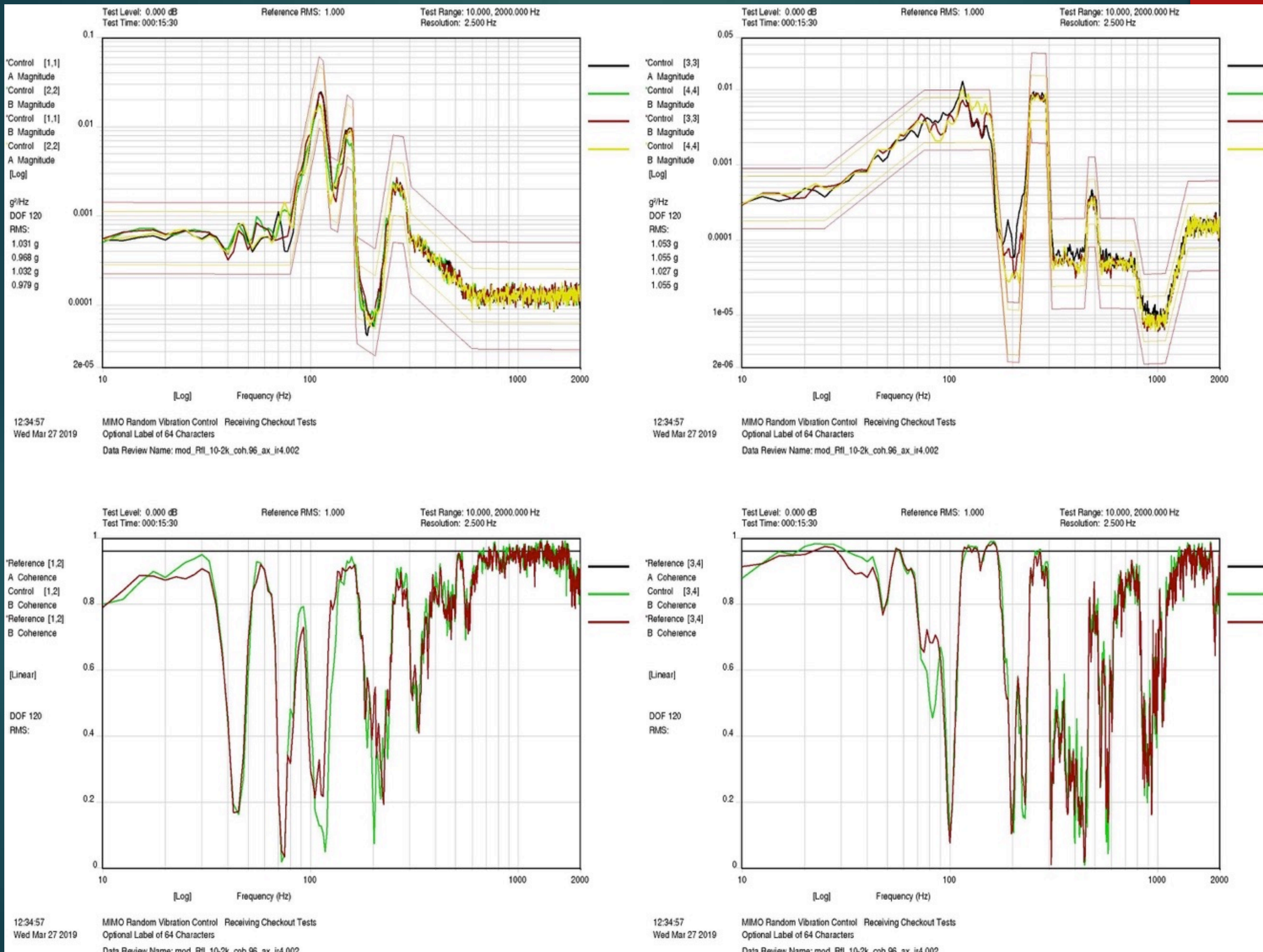
MIMO Random Test Article

- 5 Shakers for 5 Rigid Body DOFs:
- 1-X, 2-Y, 2-Z, 2-R_z, & 2-R_y
- Stingers Used to Create Independent DOFs by Decoupling Shakers
- Stinger Bending Stiffness much Lower than Axial for Independent Axes
- Non-Linear with Rattling
- Control of PSD & Coherence Difficult and Low Partial Coherence between drives & controls at Many Frequencies Prior to Use of New Optimized Reference SDM

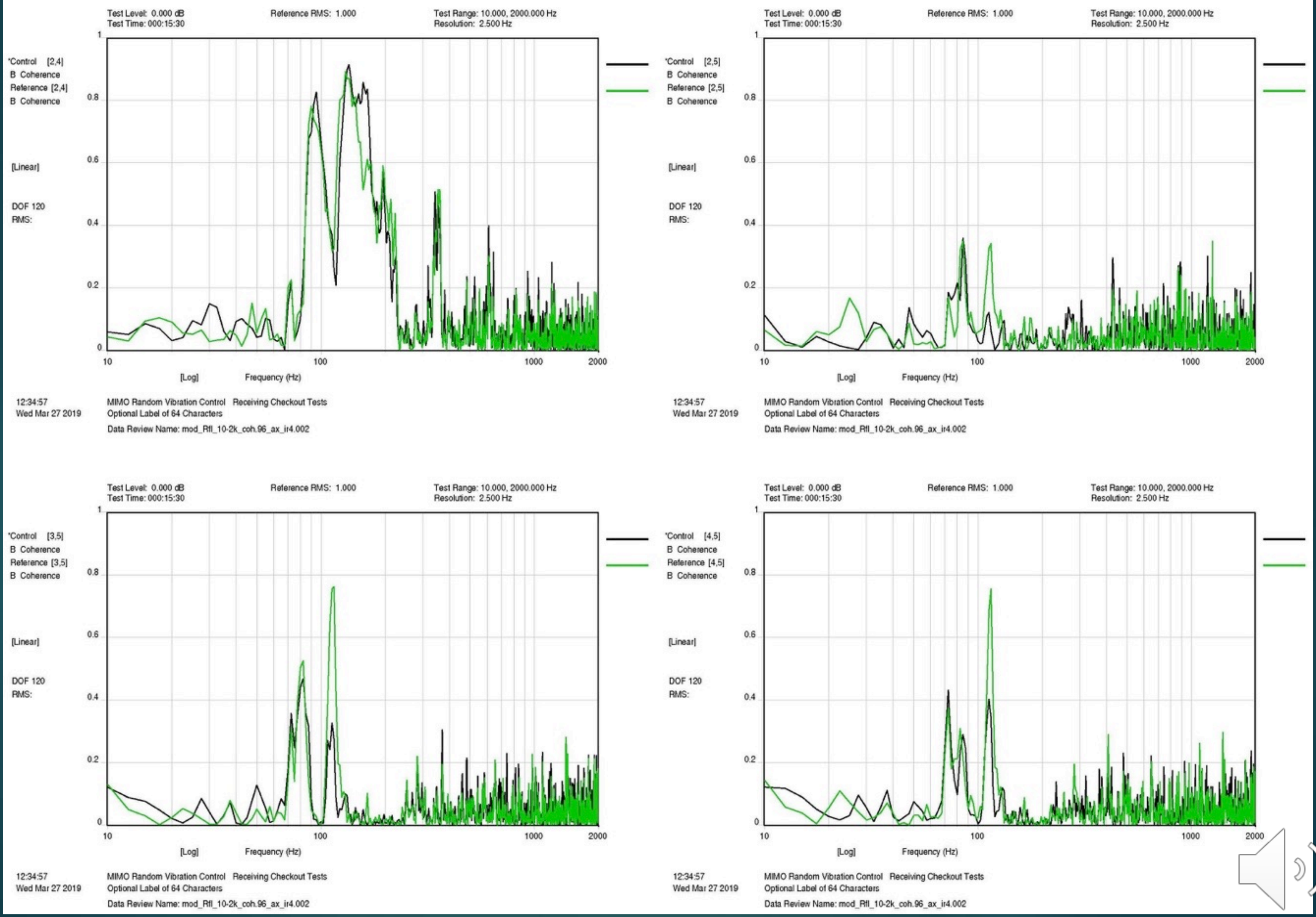
MIMO Random Tests

- Test Defined With Different PSDs for each axis at 1 Grms
- A Three-Axis (X, Y, and Z) Test, with all Three Axes Uncorrelated with Each Other and Suppressing the Two Rotations R_z and R_y
- Initial Coherence 0.9 Between Similar Axes, to Suppress Rotations, and Zero Between Dissimilar Axes, to Make them Uncorrelated
- Determine New Optimized Control-Reference SDM from Initial Test Using Pre-Specified Reference SDM
- Two Tests Run for 15 Minutes: Test A Used Pre-Specified SDM and Test B used Optimized SDM Obtained with New Method

PSD & Coherence Test Results



Zero Coherence Test Results



Ordinary & Partial I/O Coherence

- Measures the Degree to which Random Drives and Control-Response Vectors are Linearly Related
- Ordinary Coherence is Appropriate when there is Only One Drive Input and One or More Control-Responses (SISO and SIMO)
- Partial Coherence is Appropriate when there are Multiple Drive Inputs and One or More Control-Responses (MIMO) Outputs
- Partial Coherence Measures the Degree to which Any One Drive is Linearly Related to Any One Control, with the Linear Effects of All Other Drives Removed
- A Value of One Indicates Completely Linearly Dependent and a Value of Zero Indicates Completely Uncorrelated

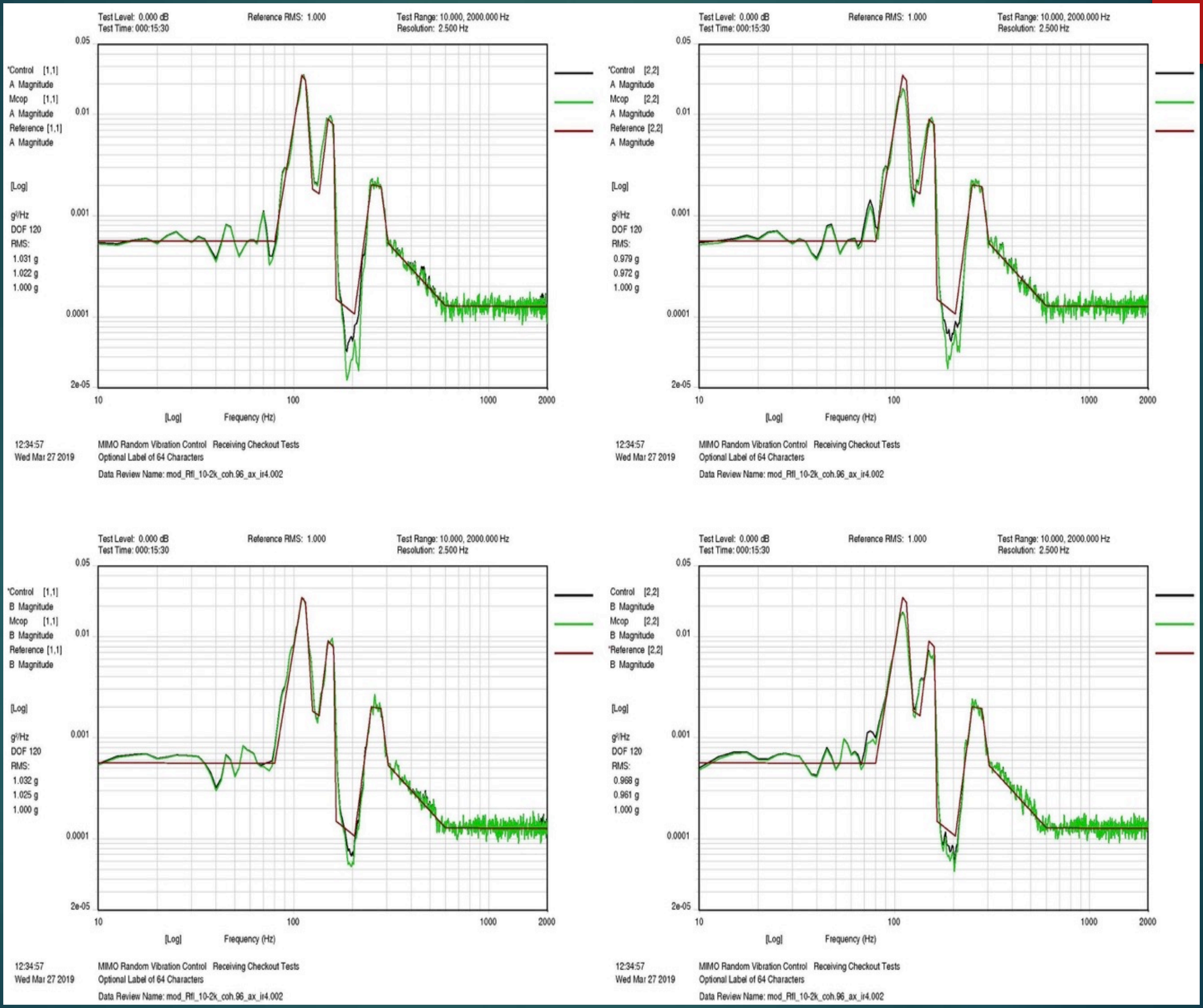
MIMO Coherent Output Power (MCOP)

- The SDM of the Coherent Response: $\{\hat{c}(t)\}$
- Can be Obtained as:

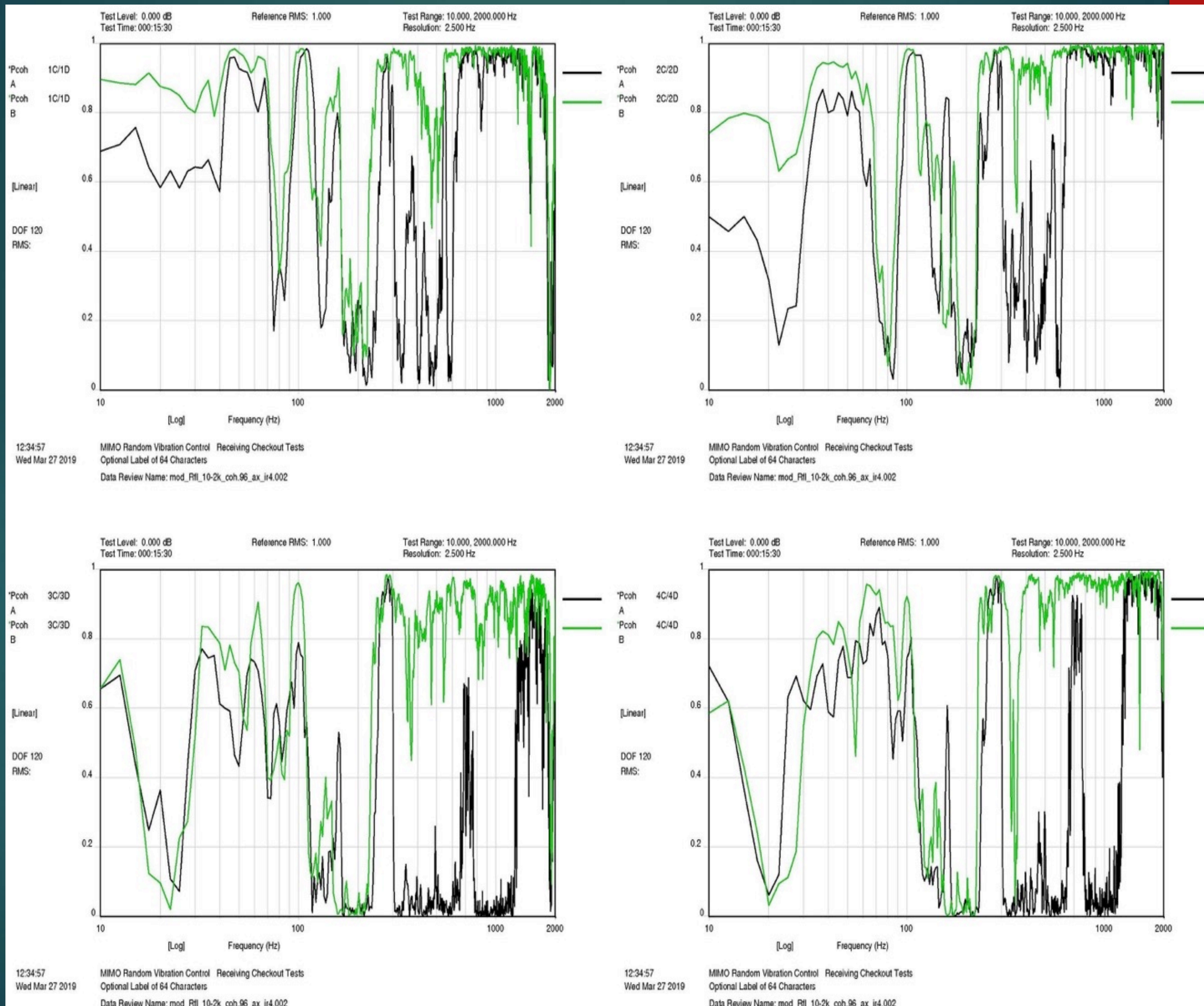
$$[G_{\hat{c}\hat{c}}(f)] = [\hat{H}_1(f)][G_{dc}(f)] = [G_{cd}(f)][G_{dd}(f)]^{-1}[G_{dc}(f)]$$

- It's Similar to COP, where: $g_{\hat{c}\hat{c}}(f) = |g_{cd}(f)|^2 / g_{dd}(f)$
- $[G_{\hat{c}\hat{c}}(f)]$ is Hermitian and Non-negative.
- It Represents the SDM of $\{\hat{c}(t)\}$, the Response that's Coherent with the Drive Vector {D(t)}, and $[G_{\hat{c}\hat{c}}(f)]$ is thus the System's MIMO Coherent Output Power, where: $[G_{cc}(f)] = [G_{\hat{c}\hat{c}}(f)] + [G_{nn}(f)]$
- Provides a Decomposition of $[G_{cc}(f)]$

PSD & MCOP Test Results



Partial Coherence Results



New MIMO Random Test Results

- Optimal Adaptive Control and New Optimized Reference SDM Reduce Control Errors in the LMSE sense
- Its use Reduces Power Needed to Drive Multiple Shakers
- New Synthesis Matches Initial Reference in LMSE Sense, Compensating for Test System & Facility Limitations
- Better Match of Controls to Pre-Specified PSDs
- Better Matching of Control Coherence to new Reference
- Better Uniformity of Controls with Rectangular Control
- Improves Linearity of Shaker System, Better Match Between Control Responses and Respective MCOPs
- Improves Partial Coherence Between Control Accelerometers and Respective Shakers

Overall Conclusions

- Advanced Adaptive Optimal MIMO Control Produces Closer Matching to Reference than Other Approaches by Optimizing each Control Loop
- New Synthesized P.D. Control-Reference SDM Further Improves Control and Avoids Trial-and-Error approach Used by Other Methods
- Optimized Reference Improves Uniformity via Rectangular Control by Using New Synthesized Control-Reference SDM, which Approximates a Pre-determined initial Control-Reference SDM in the LMSE sense.
- New Minimum Drive-Power Control-Reference SDM is Synthesized by the Adaptive Optimal Control System's Inherent Optimization and new Research Results, During an Initial Pre-Test.
- Use of New Control-Reference SDM Synthesis Method Further Reduces Needed Drive Power and Improves Control Accuracy and Linearity, by Accounting for Limitations in Test System and Facility as an Optimization Constraint