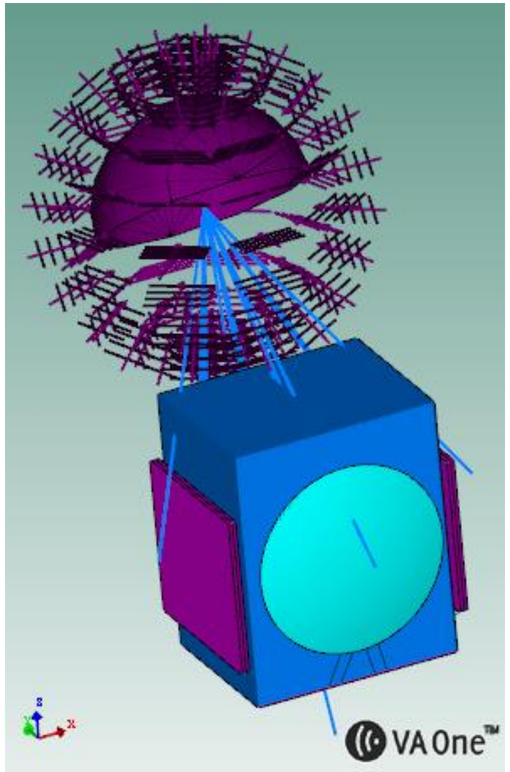
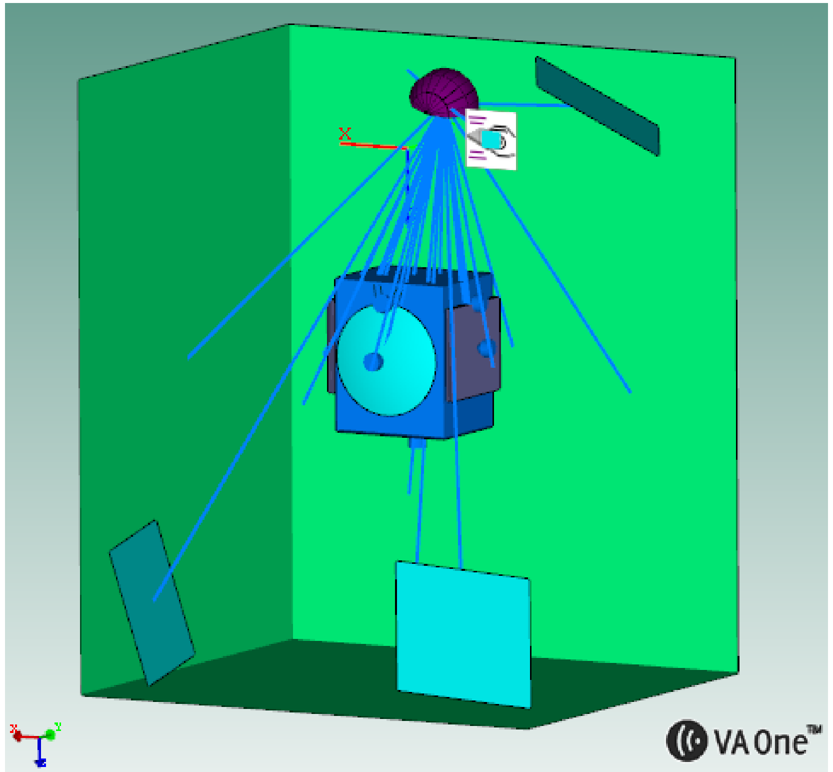
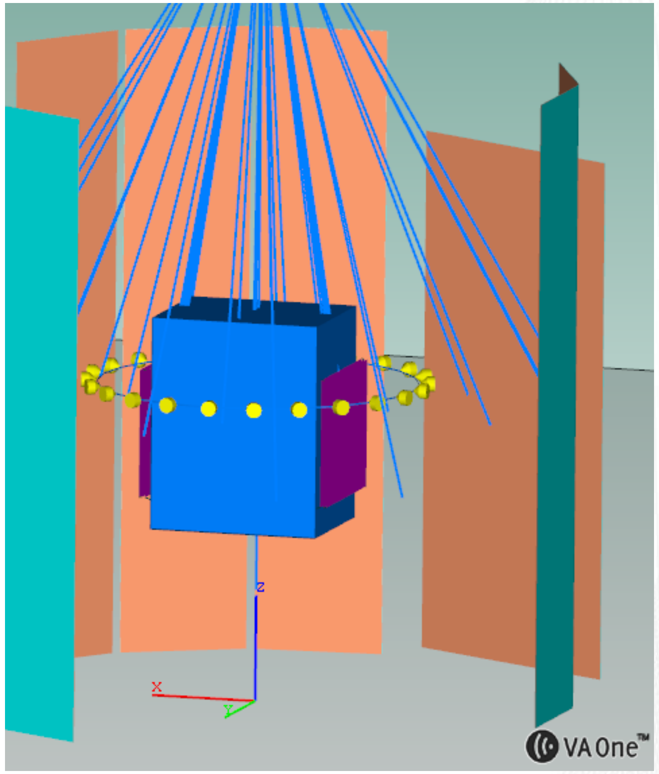
Virtual comparison of a reverberant room, Direct Field Acoustic Test and analytical Diffuse Acoustic Field







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06/2018

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Agenda

- What are we comparing?

- What can we compare?
  - Diffusivity
  - Uniformity

- Who wins the diffusivity competition?
  - Open field case

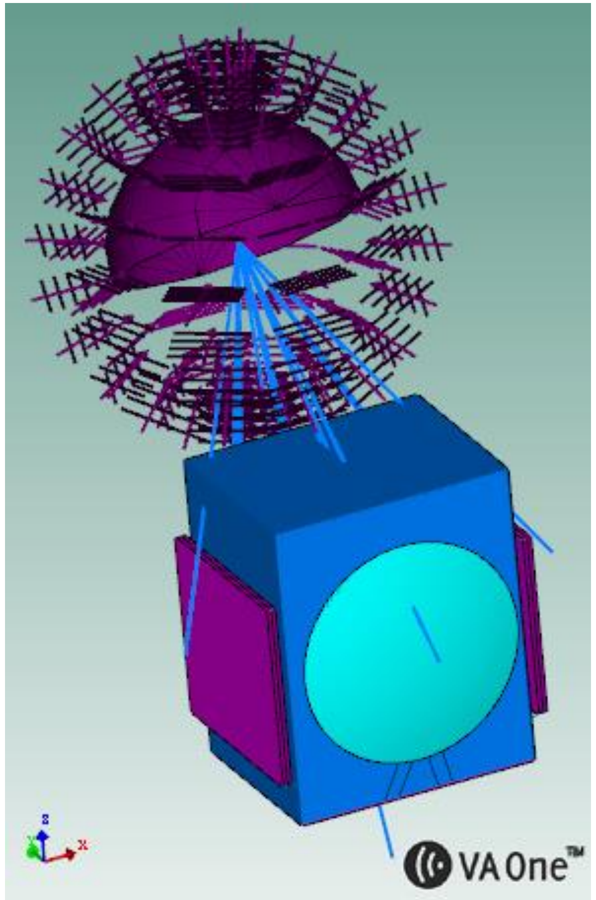
- How about uniformity?

- In the end, is it all the same?
  - Comparing the test article response

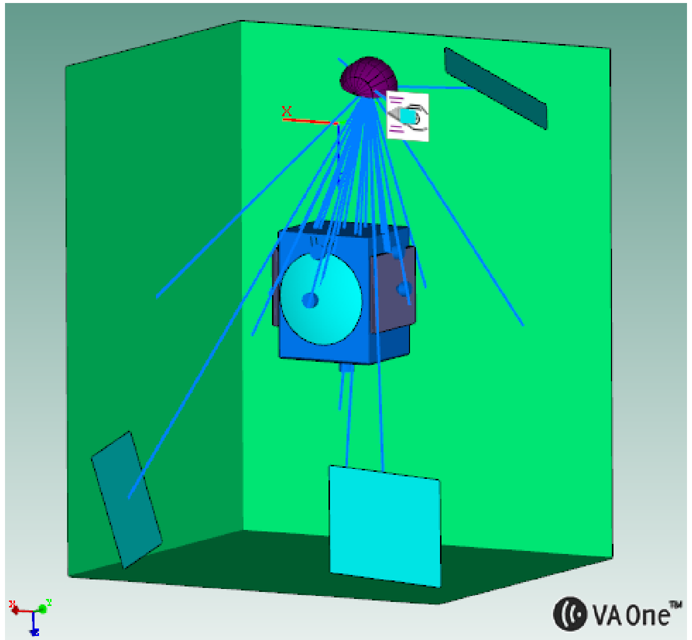
- Conclusions

What are we comparing?

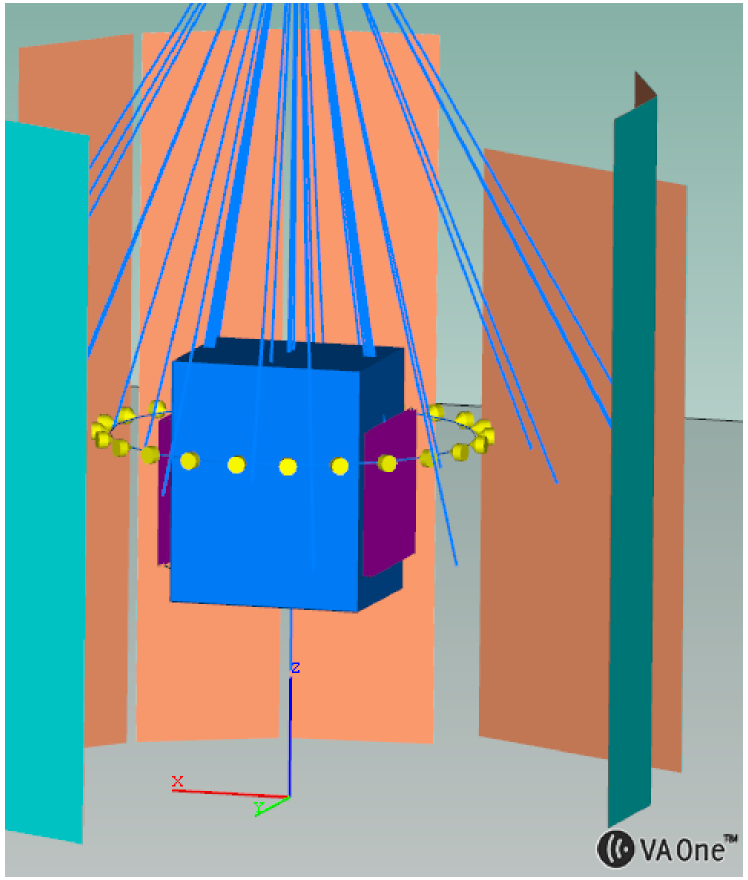
Virtual DAF



Reverberant room



DFAT setup



Virtual DAF

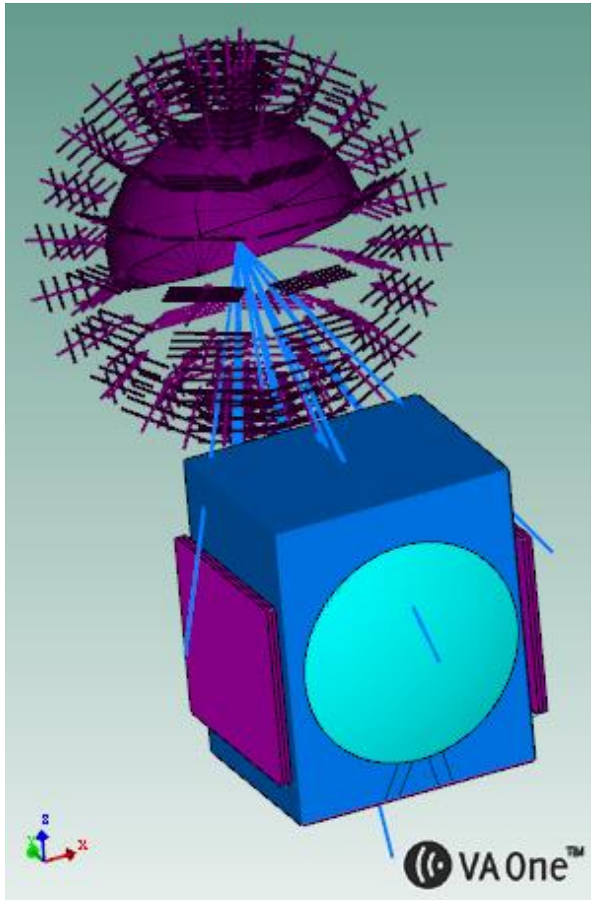
Sum of incoherent plane waves

Cross Spectral Pressure response → $$[S_{pp}] = [H_{pw}][S_{ww}][H_{pw}]^H$$

Cross Spectral Modal structural response → $$[S_{qq}] = [H_{qw}][S_{ww}][H_{qw}]^H$$

Cross Spectral Excitation matrix is diagonal

- Legacy method
- No Additional elements besides the structure
- Field is known to be diffuse
  - Diffusivity depends on the number of plane waves
- Represents an idealized test
  - For the actual test, it is often difficult to obtain a diffuse field in the low frequency



Reverberant room

Test article is placed in a reverberant room

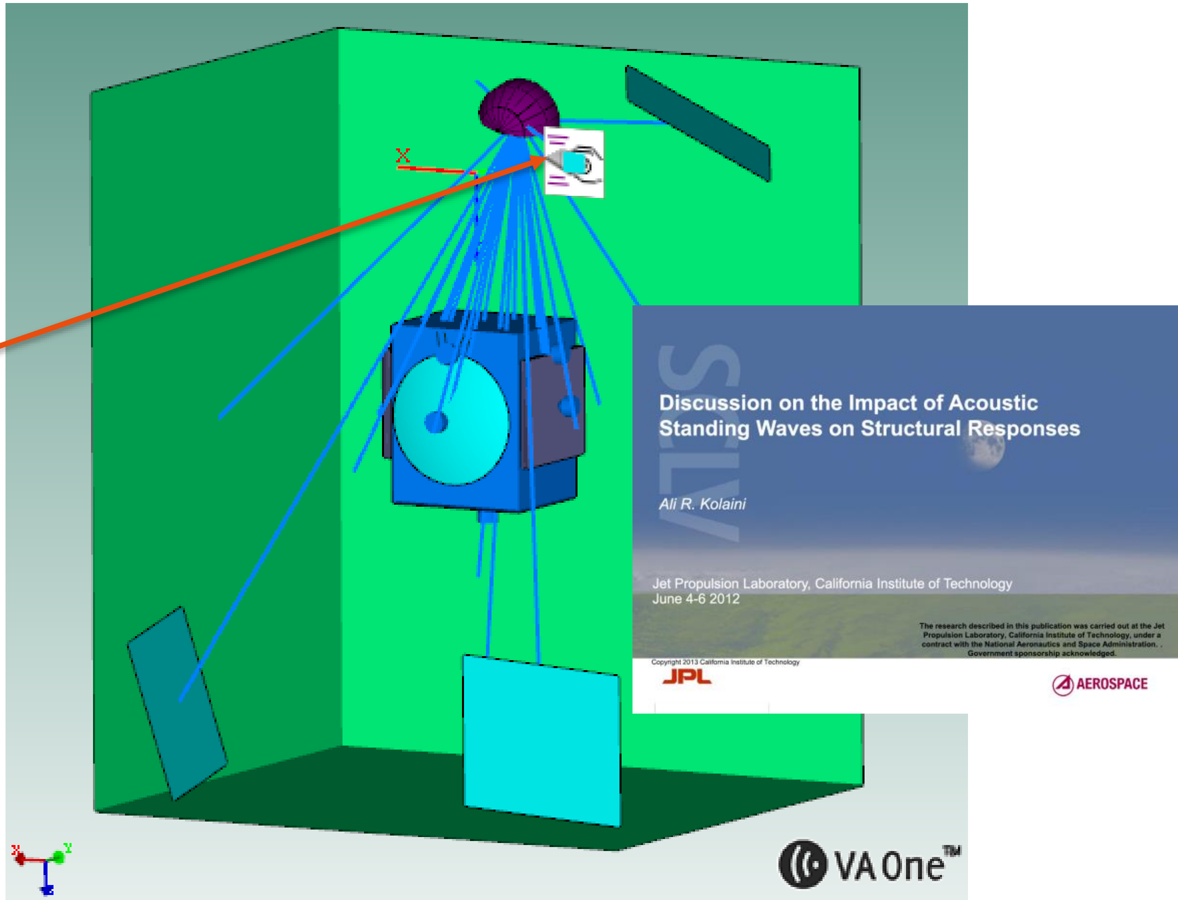
$$[S_{pp}] = [H_{pw}][S_{ww}][H_{pw}]^H$$

$$[S_{qq}] = [H_{qw}][S_{ww}][H_{qw}]^H$$

$[S_{ww}]$ is of size 1x1
(single horn example)

- Represents the traditional test
- One velocity constraint is representing a horn
- A few rigid panels are introduced to break the standing waves
- Here the diffusivity is introduced by the $[H]$ matrices as $[S_{ww}]$ is of size 1x1

Size matches JPL's room



DFAT setup

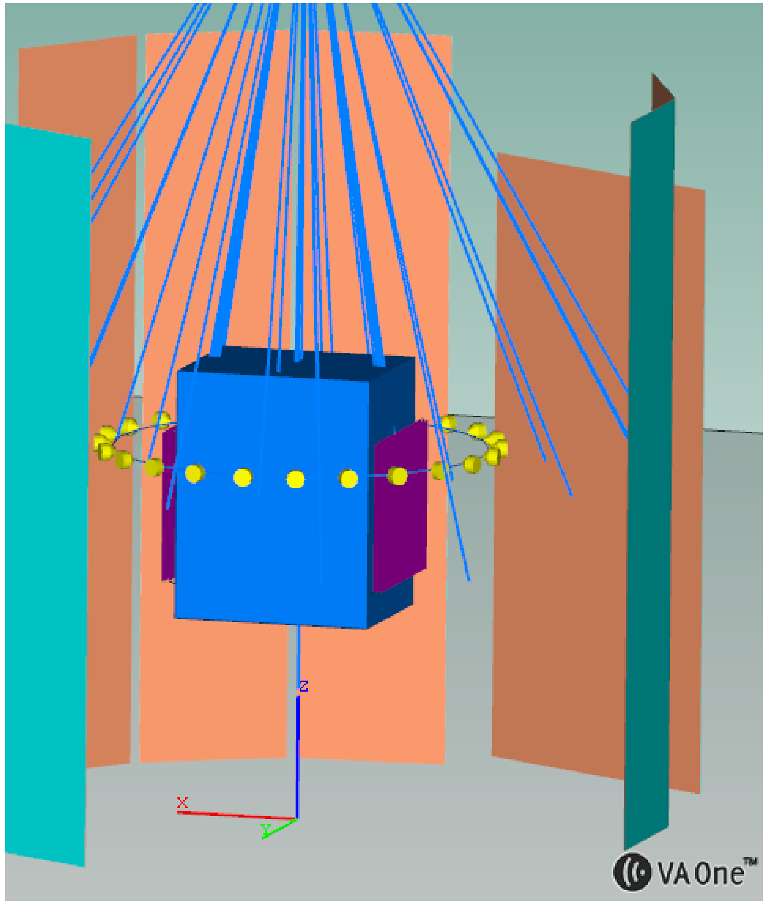
Test article is excited with stacks of speakers and a control loop

$$[S_{pp}] = [H_{pw}][S_{ww}][H_{pw}]^H$$

$$[S_{qq}] = [H_{qw}][S_{ww}][H_{qw}]^H$$

Cross Spectral Excitation matrix is `n_stacks x n_stacks` and is optimized to have a diffuse field at the control microphones

- New testing method
- Speaker stacks are represented by faces with constraints at their surface
  - Measured impedance is placed at the stack surface
  - Here each stack is correlated but alternative configurations can be studied
- Ground is modeled with an infinite rigid plane



DFAT setup

Test article is excited with stacks of speakers and a control loop

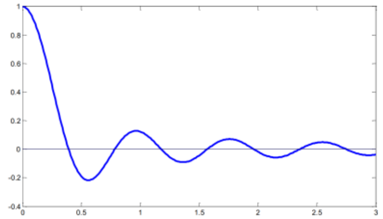
$$[S_{pp}] = [H_{pw}][S_{ww}][H_{pw}]^H$$

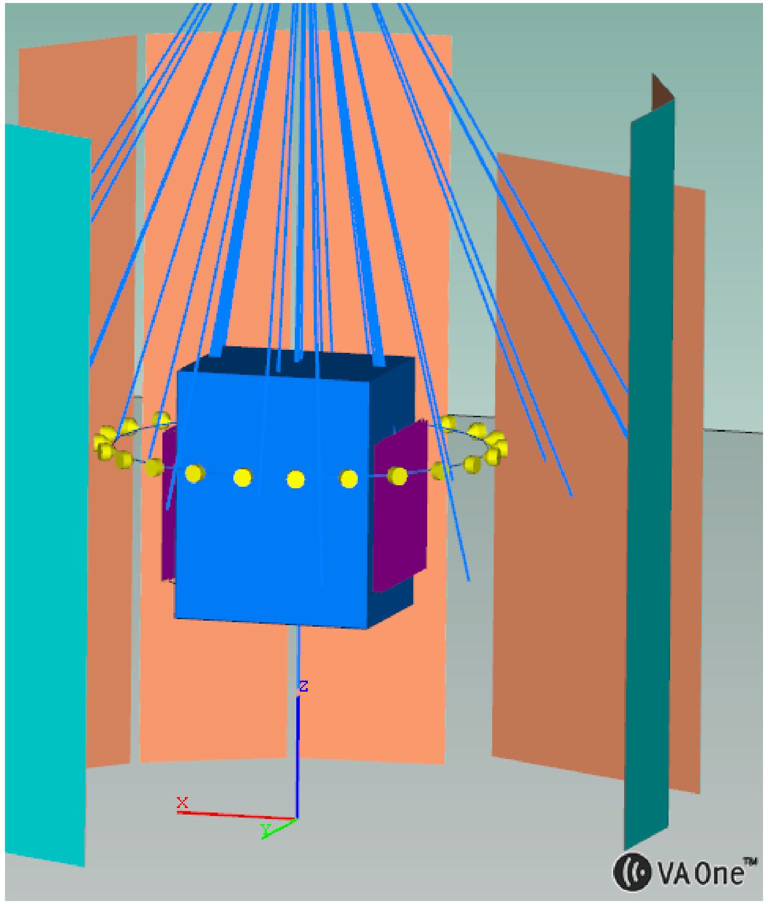
$$[S_{qq}] = [H_{qw}][S_{ww}][H_{qw}]^H$$

Cross Spectral Excitation matrix is `n_stacks x n_stacks` and is optimized to have a diffuse field at the control microphones

- $[S_{ww}]$ is optimized using pseudo inverse of $[H_{pw}]$ for an ideal $[S_{pp}]_{\text{Control\_Mic}}$ based on the control microphone locations
  - $[S_{pp}]_{\text{Control\_Mic}}$ can be obtained based on the known cross correlation of a diffuse acoustic field between any two known control microphones

$$S_{pp}(r) = A\frac{\sin(k_0 r)}{k_0 r}$$





Additional “complicating” effects

- Stacks are made of subwoofers and mid-frequency speakers
  - Terms of $[H_{pw}]$ and $[H_{nw}]$ are then null when speakers do not output power
  - Here subwoofers output power up to 240Hz
  - Mid-frequency speakers do not output power below 200Hz

- f < 200 Hz, 6 active stacks
- f > 200 Hz & f < 240 Hz, 15 active stacks
- f > 240 Hz, 9 active stacks

- Certain speakers may be correlated with each other
  - Introduction of a control matrix defining which speakers are correlated with each other
  - For this example, all speakers within stack are correlated

- MSI uses a proprietary Matrix Switch that combines drives
  - This can be accounted for
  - For this study, 24 control microphones are placed around the tested structure (no Matrix switch)

What can we compare?

Uniformity

- Pressure field amplitude is expected to be uniform
  - A reverberant room is expected to show less than 1.5dB of pressure standard deviation
- Simulation can recover a lot of pressure information
  - We can easily quantify the pressure standard deviation

In the 3rd Octave band!

What can we compare?

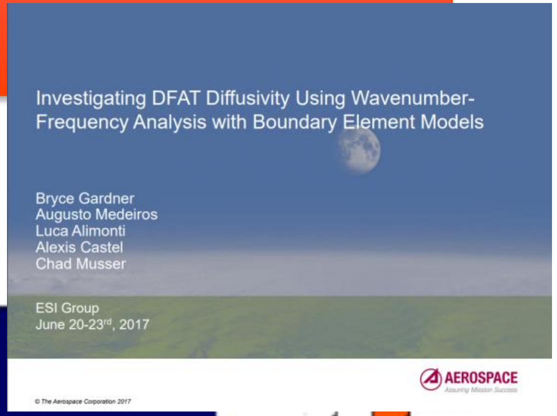
Diffusivity

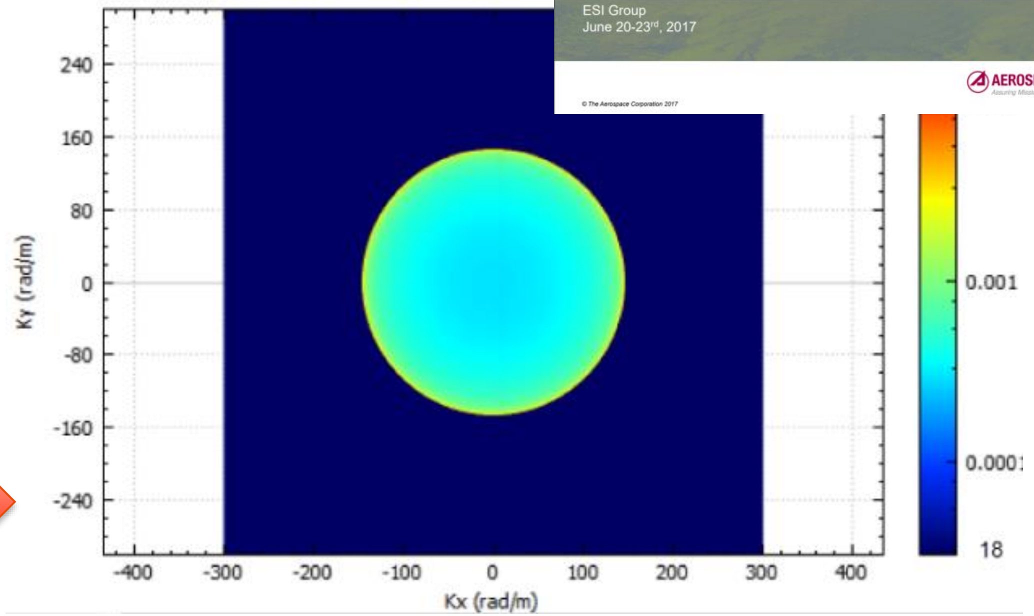
One can then evaluate the field diffusivity by comparing the simulated $S_{pp}(\mathbf{k},\omega)$ to its analytical form for a DAF

- $[S_{pp}]$ is known for all data recovery faces
  - Defines the cross-correlation between any two nodes where the pressure is recovered
  - $[S_{pp}]$ is known for a Diffuse Acoustic Field (DAF) but is difficult to visualize
  - The corresponding Wavenumber-Frequency spectrum can also be calculated

$$S_{pp}(\mathbf{k},\omega) = \mathrm{FFT}\left(\left[S_{pp}(\mathbf{x},\omega)\right]\right)$$

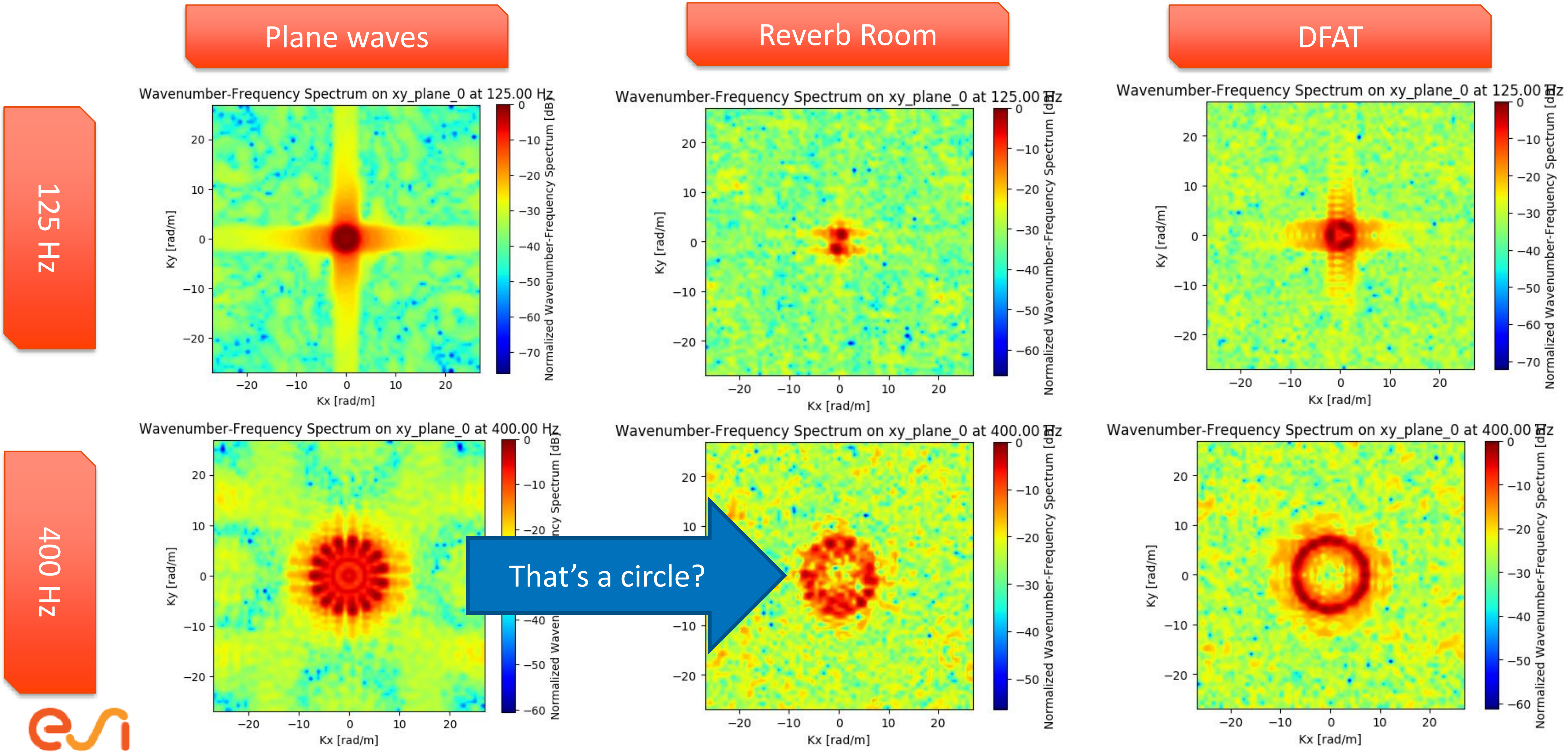
  - For a DAF, $S_{pp}(\mathbf{k},\omega) = \frac{2\pi}{k_0^2}\frac{1}{\sqrt{1-|\mathbf{k}|^2/k_0^2}}, |\mathbf{k}| < k_0$





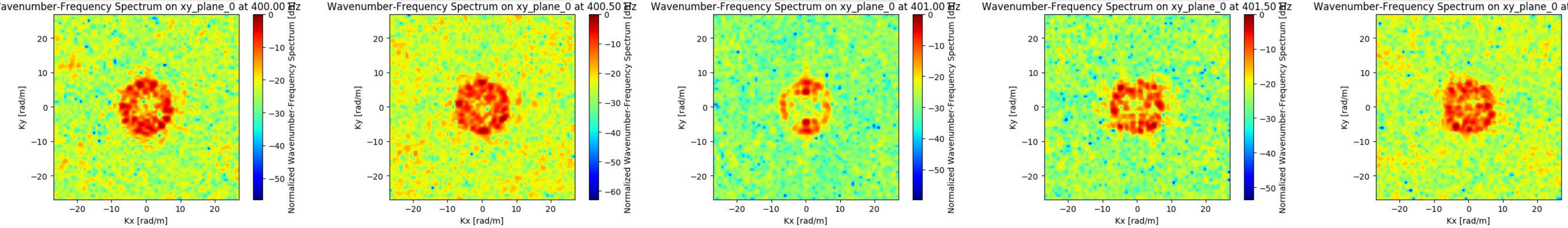
Who wins the diffusivity competition?

Open field study



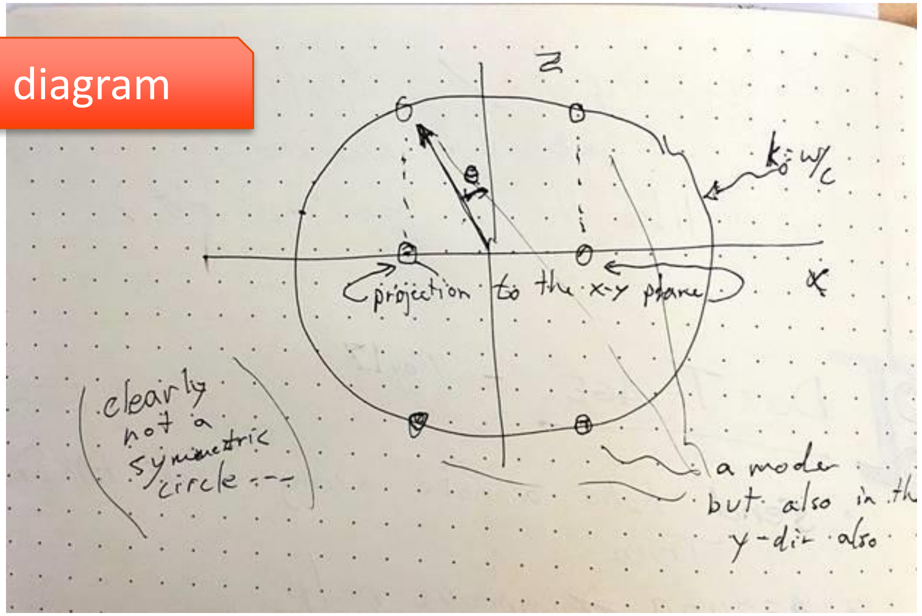
What’s happening in the reverb room?

400.0Hz | 400.5Hz | 401.0Hz | 401.5Hz | 402.0Hz



- Each discrete frequency does not seem diffuse

Bryce’s diagram



Individual modes are projected on the data recovery and form high intensity regions at discrete frequencies

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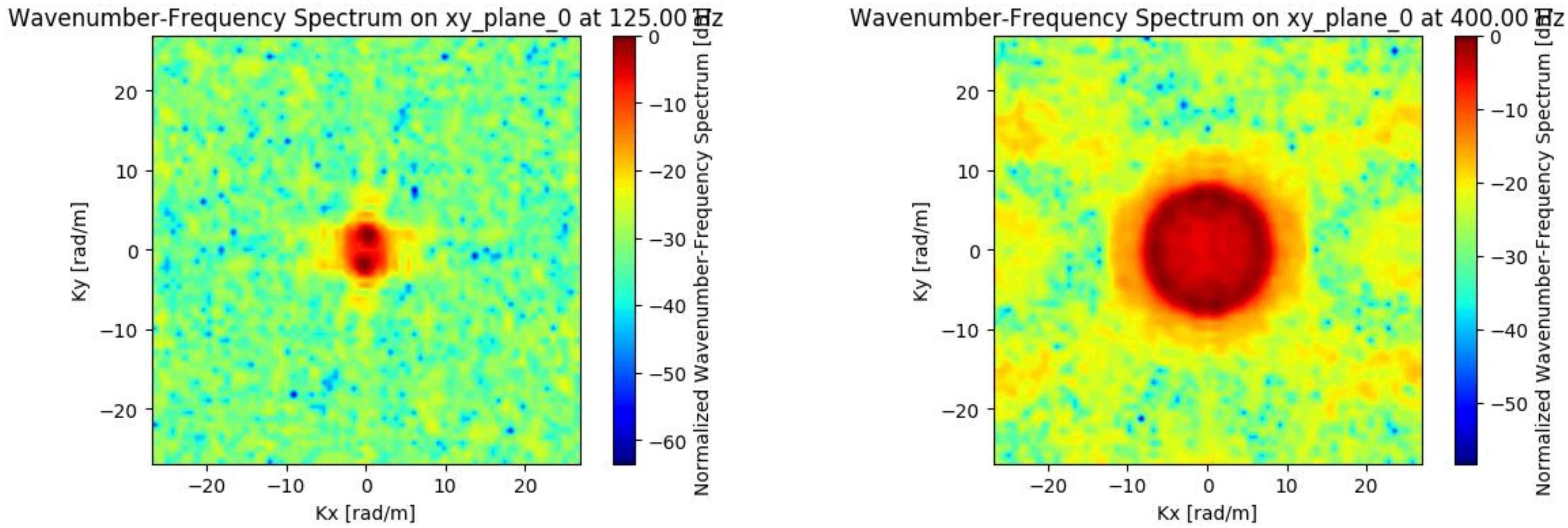
What's happening in the reverb room?

- Looking at the WFS in the third Octave band



The room has indeed a diffuse field in the high frequency!

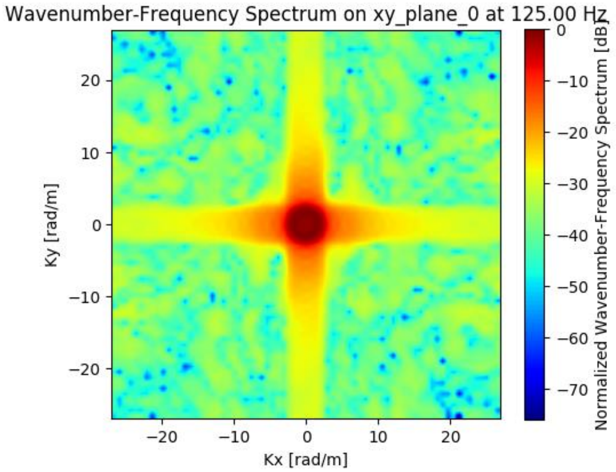
Who wins the diffusivity competition?

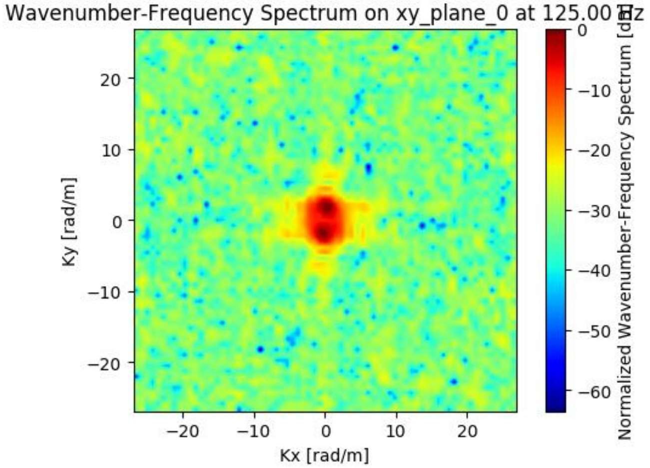
Open field study

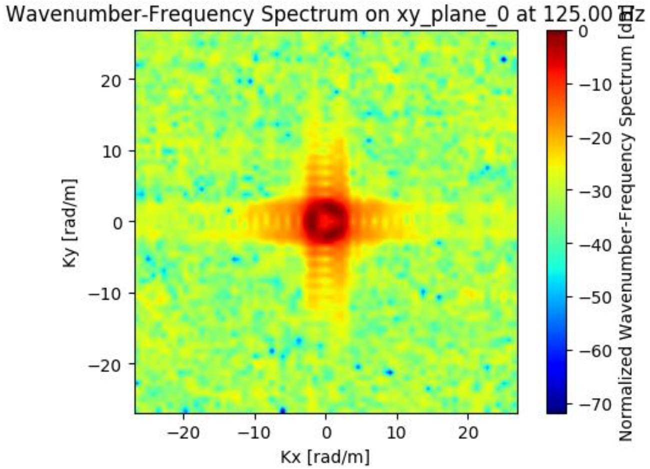
3rd Octave band results

Plane waves | Reverb Room | DFAT

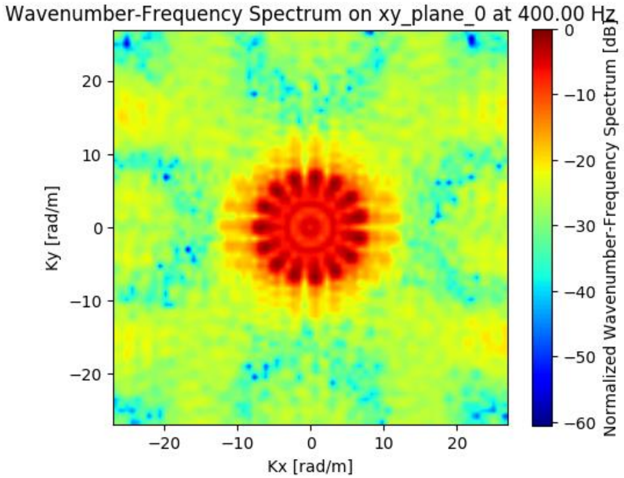
125 Hz

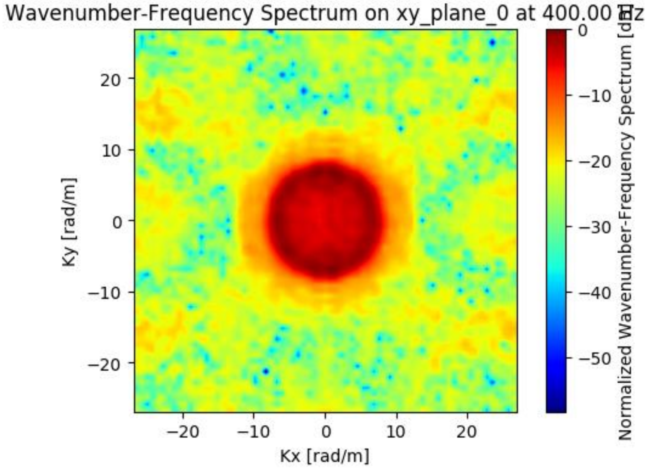


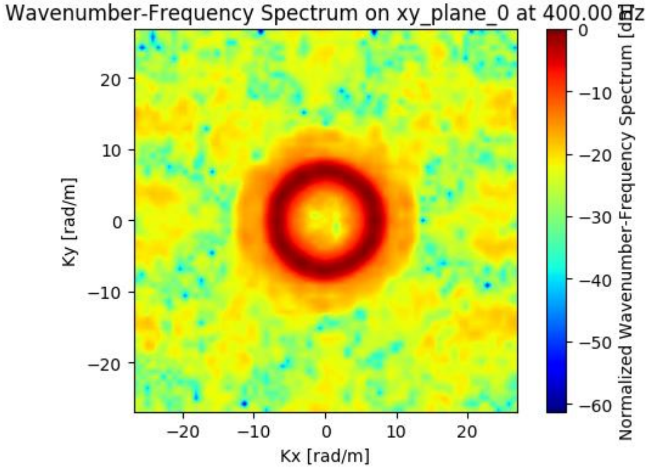




400 Hz







How about uniformity?

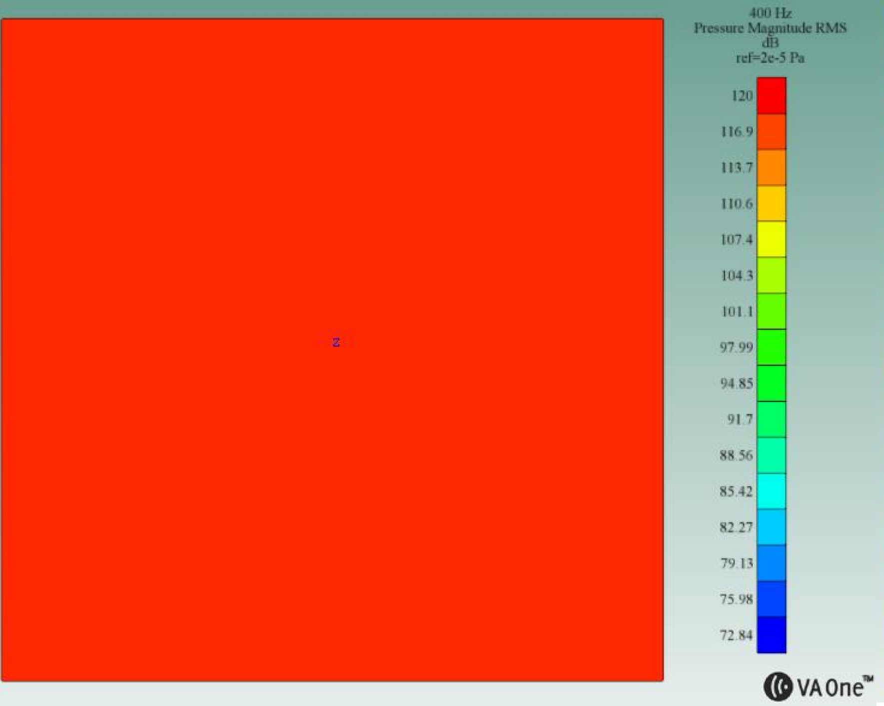
Narrow band results

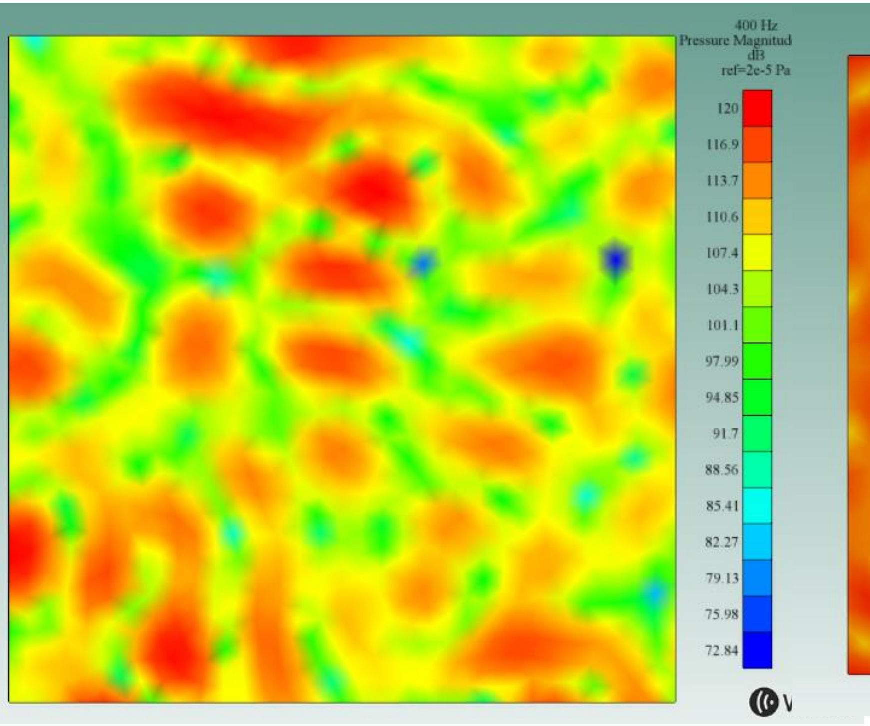
Discrete Frequency Contour

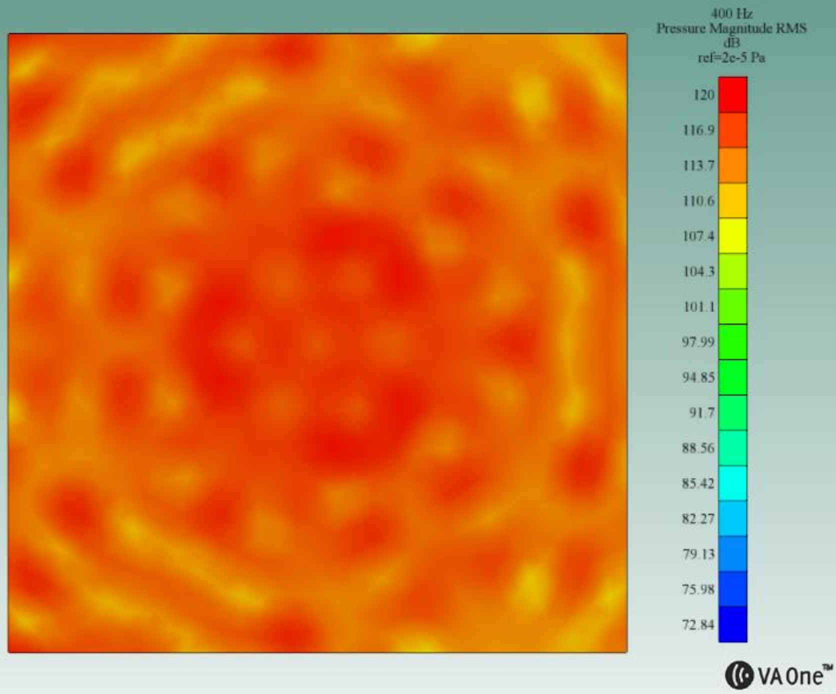
Plane waves

Reverb Room

DFAT







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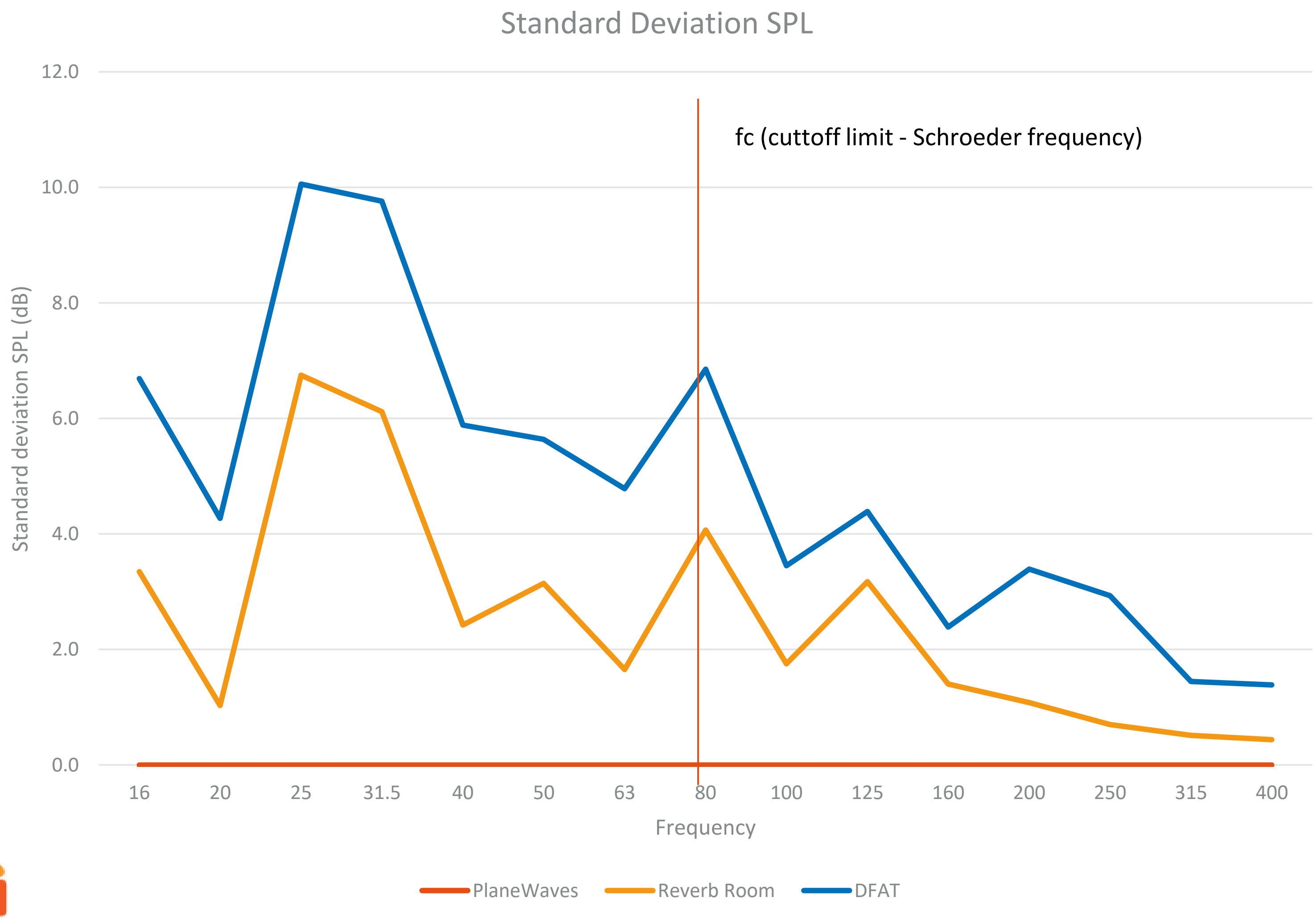
How about uniformity?

3rd Octave Standard deviation



3rd Octave band results

Again, we can't look at the field uniformity for a single discrete frequency.

Data needs to be converted to the 3rd Octave band.

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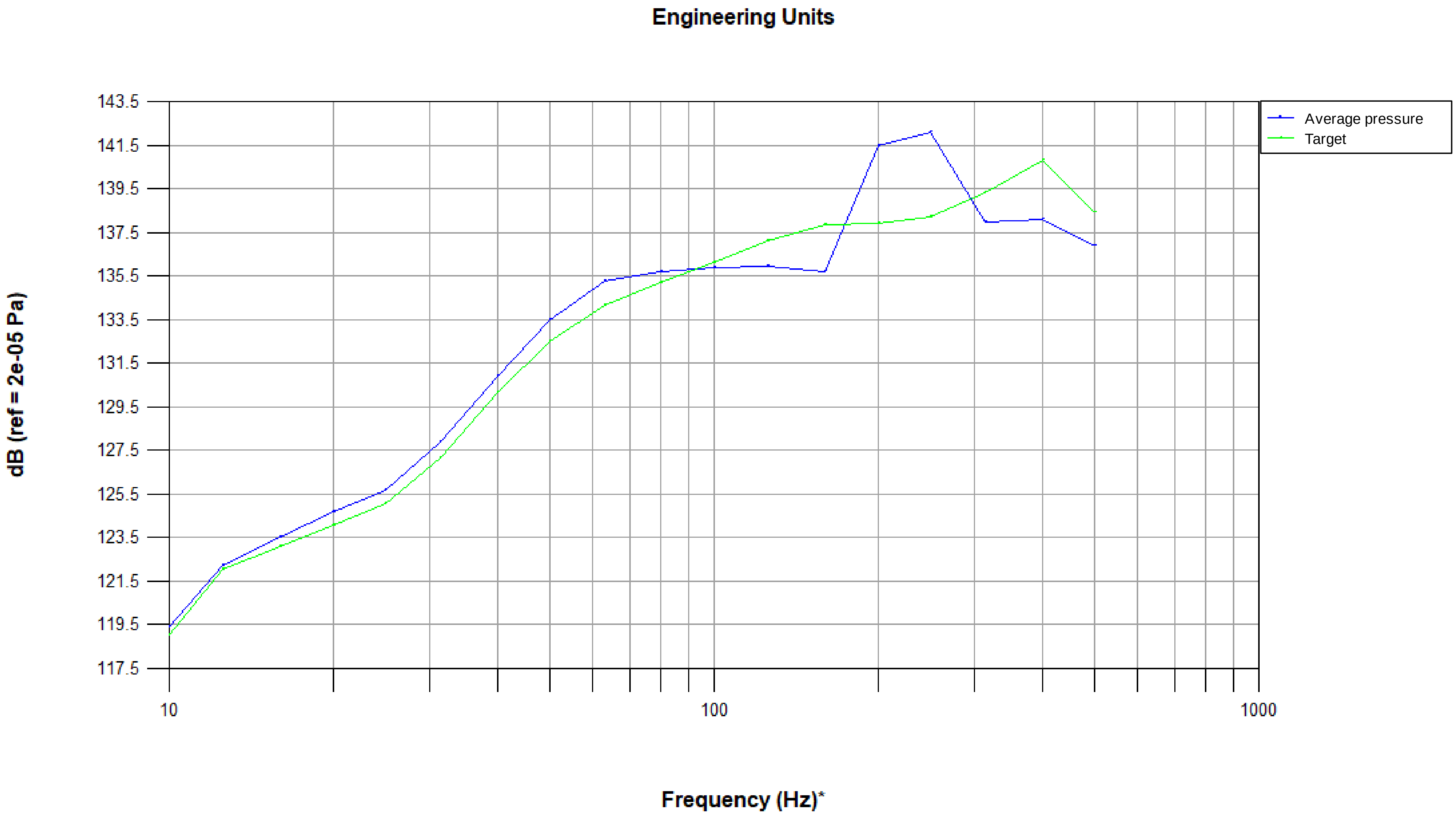
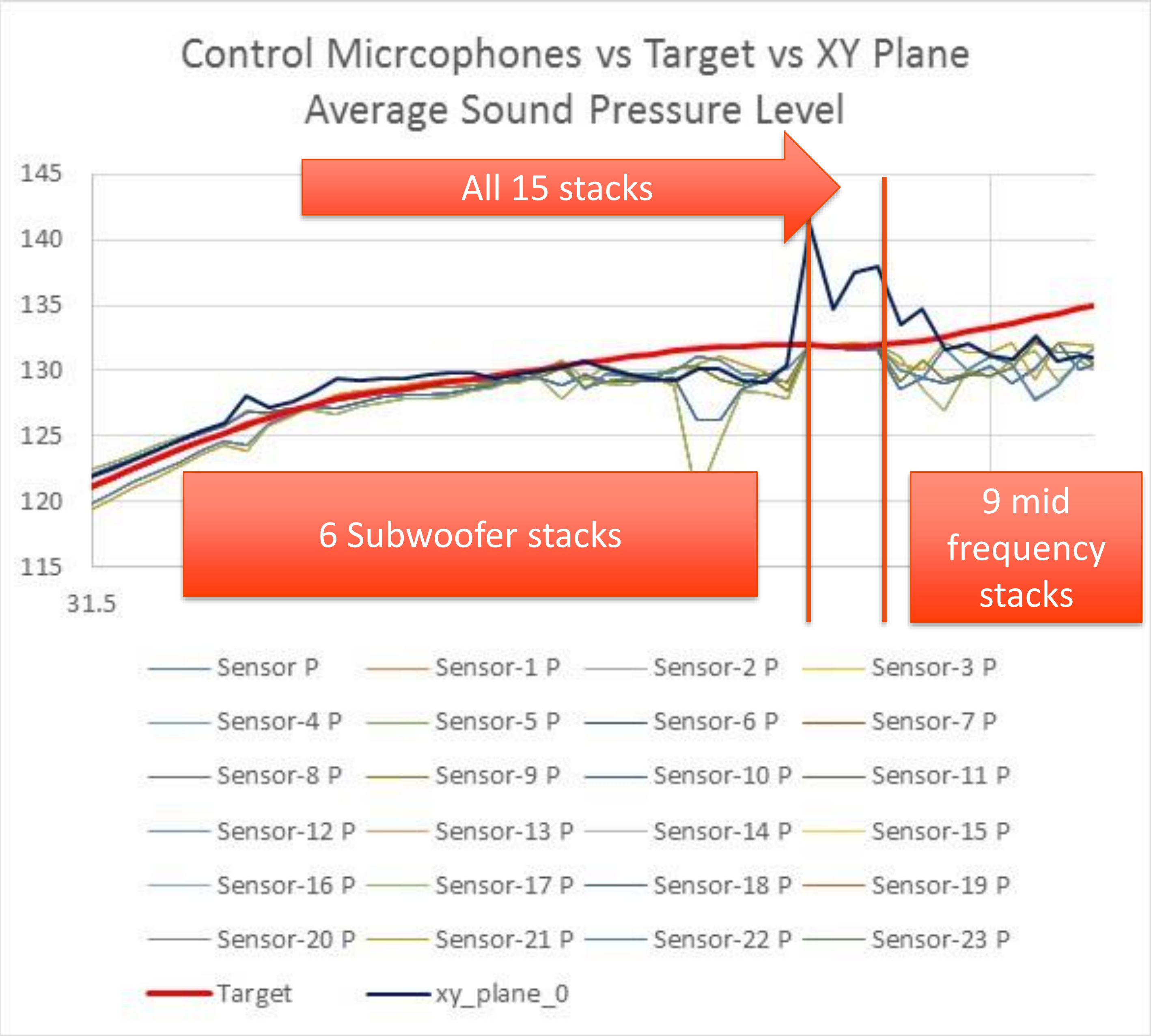
DFAT Average Plane Pressure vs Target

3rd Octave band results



- Control microphones do not exceed the target level

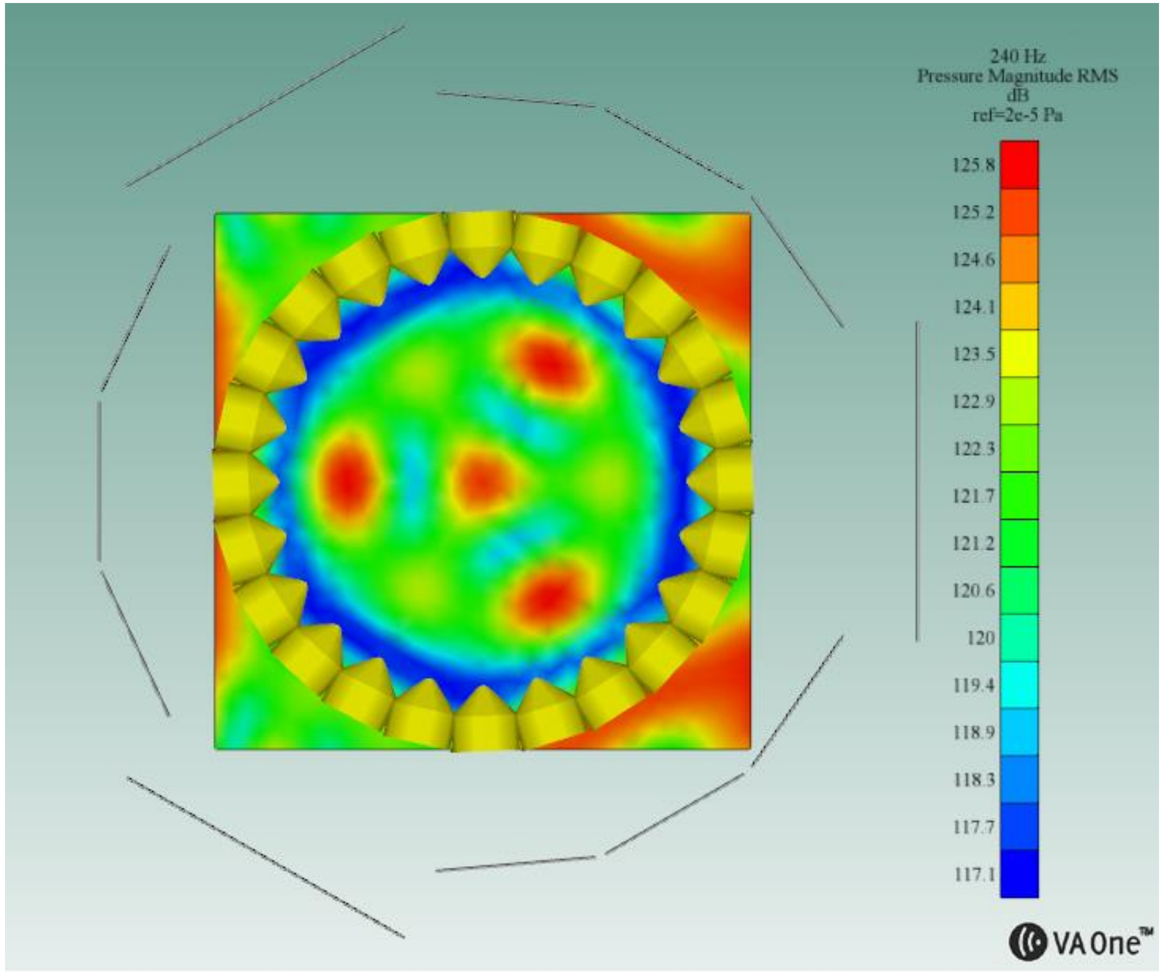
- Levels are better matched when the number of stacks is greater



Looking at the contour plot

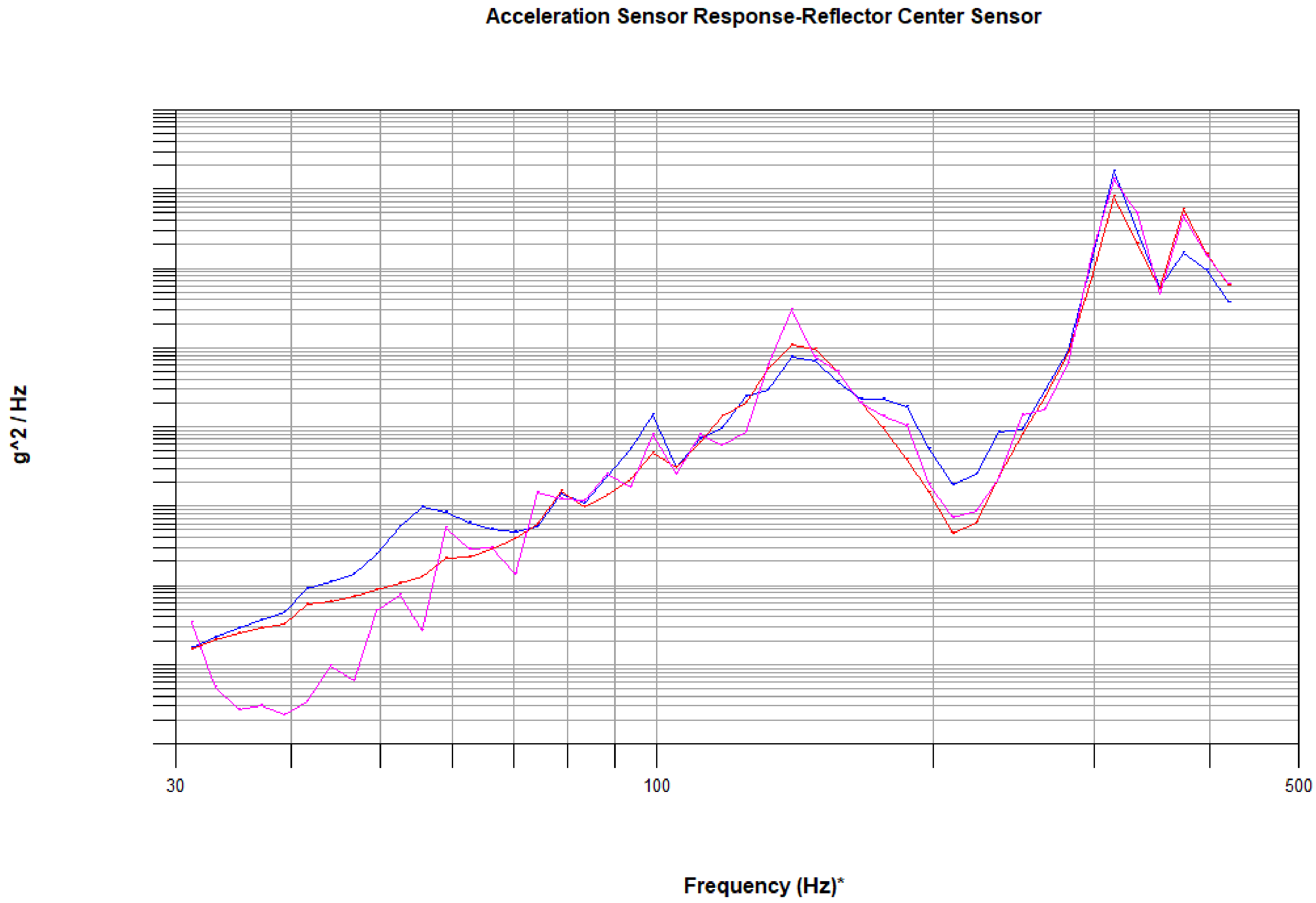
- Average SPL on the plane may not be ideal
  - Too large
  - Receives direct field from speaker

- After discussing with MSI, having the spacecraft present helps eliminating hot spots within the circle



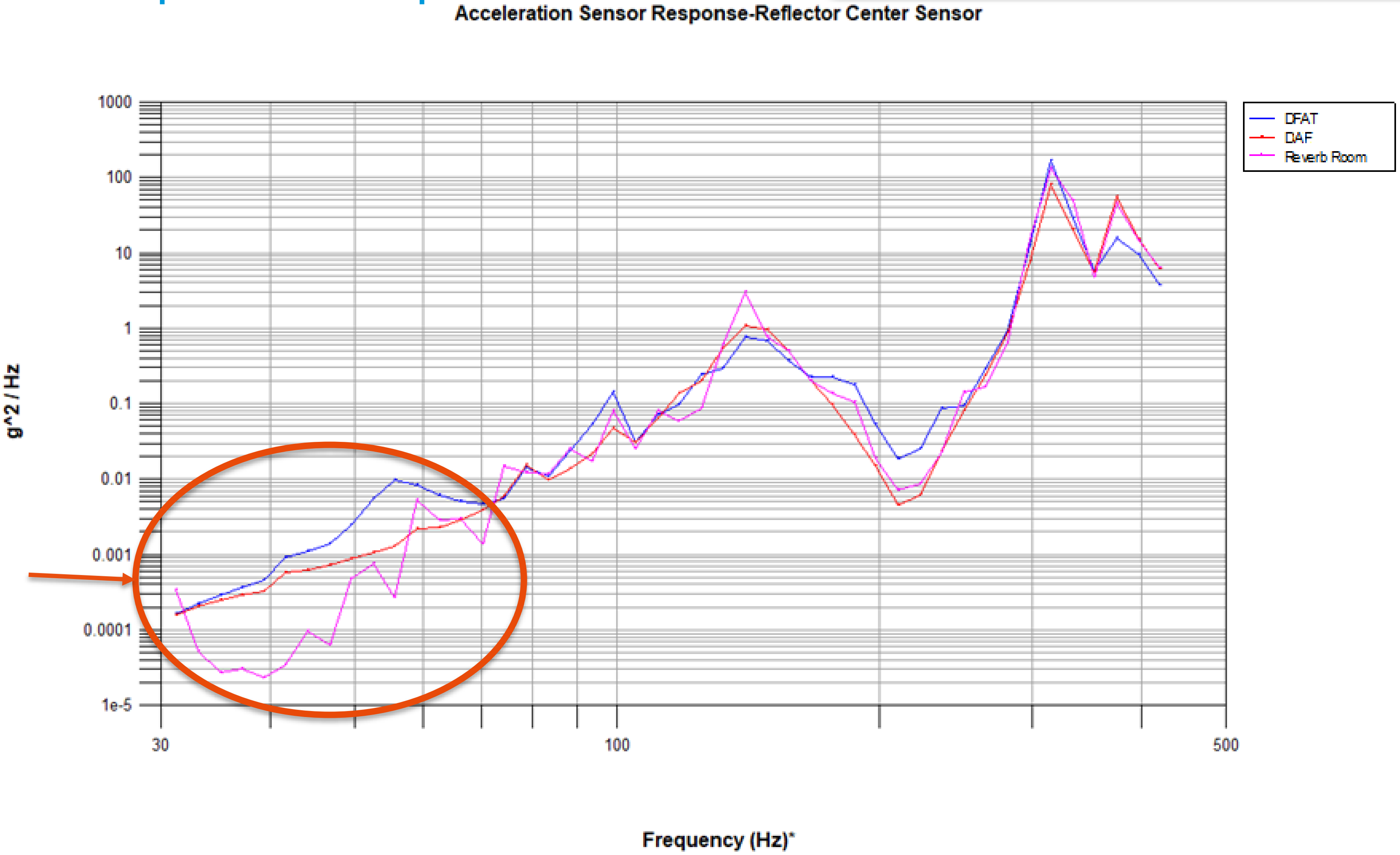
In the end, is it all the same?
Structural response comparison

Guess which is DFAT?



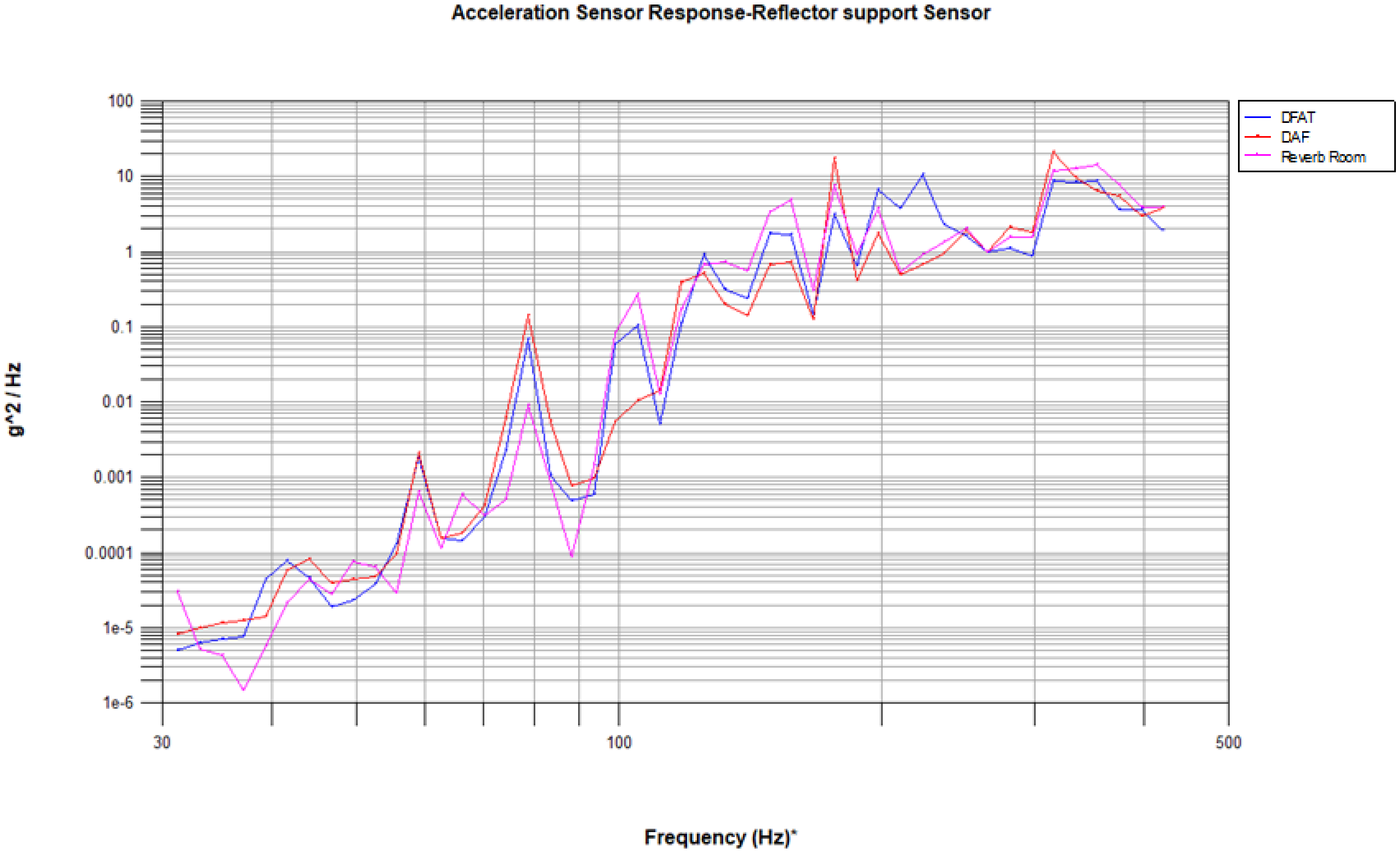
In the end, is it all the same?
Structural response comparison

Solution



Reverb room is less uniform in the low frequency

In the end, is it all the same?
Structural response comparison



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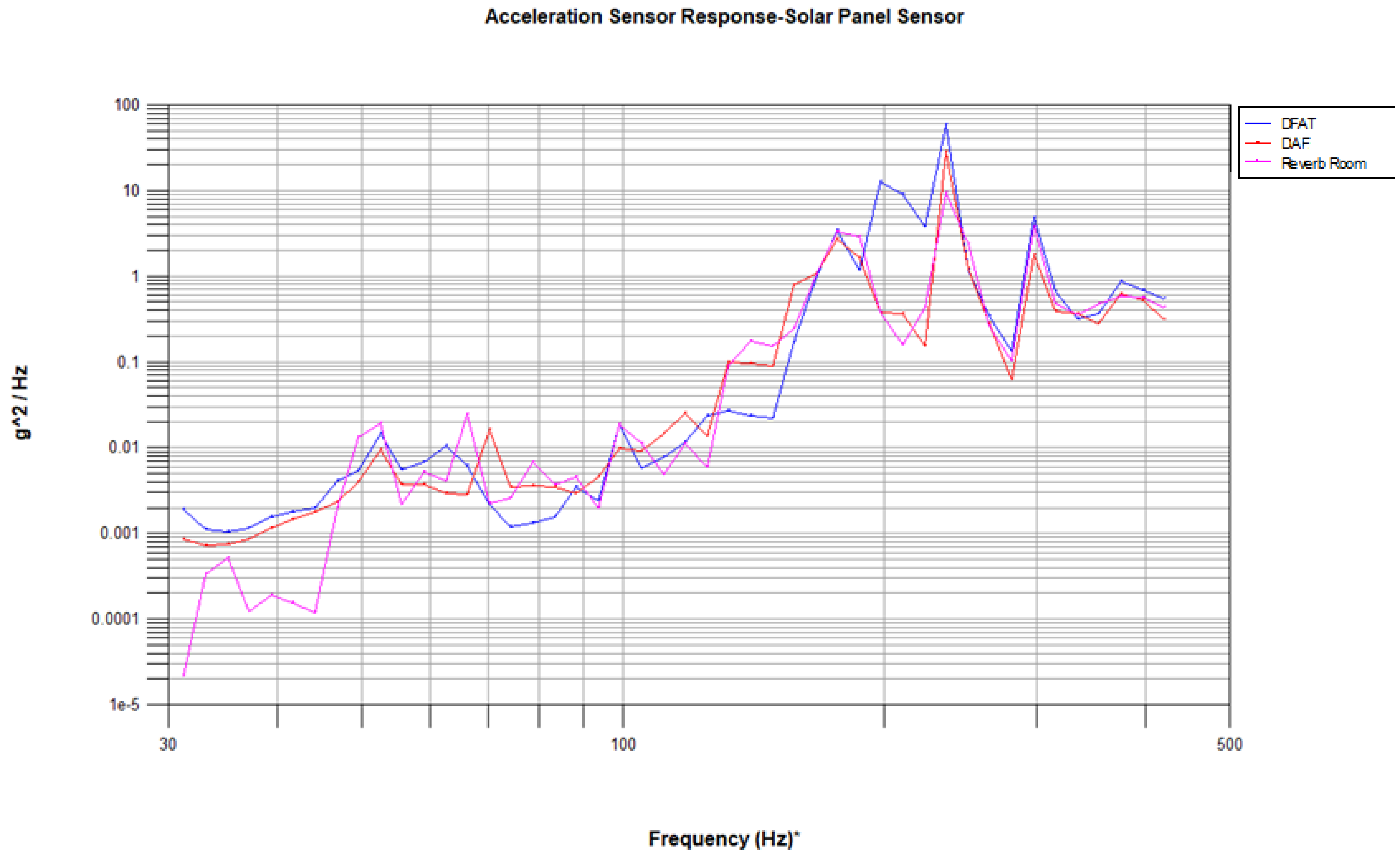

Conclusions

- Simulation processes are available to simulate diffuse acoustic field excitations
  - DFAT simulation process is now available
- Simulating analytic DAF vs simulating the test shows major differences
  - Reverberant room is only exhibiting DAF properties
    - In the high frequency range (>160 Hz for the simulated case)
    - When looking at specifications in the third octave band
  - DFAT field is more diffuse and more uniform at discrete frequencies
  - Reverb room is still diffuse and uniform when the results are in the third octave band
- Once a test article is present, the field is more uniform and it is hard to distinguish responses from any of the three simulation methods
- Next step
  - Correlation study of DFAT test data
  - Using simulation to optimize the physical test