A Performance Ranking of Seven Different Types of Loudspeaker Line Arrays

D. B. (Don) Keele, Jr.
DBK Associates and Labs
Bloomington, IN 47408
www.DBKeele.com
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Overview

- Introduction
  - Arrays Analyzed
  - Arrays Not Analyzed
  - Performance Parameters Evaluated
  - Array Simulation Conditions
  - Performance Ranking
- Analysis
- Analysis Results and Ranking
- Summary

Arrays Analyzed

1. An un-shaded straight-line array
2. A Hann-shaded straight-line array
3. An un-shaded "J"-line array with straight top half and circular-arc bottom half
4. An un-shaded spiral- or progressive-line array
5. An un-shaded circular-arc array
6. A Legendre-shaded circular-arc CBT array
7. A Legendre-shaded delay-curved straight-line CBT array

Arrays Not Analyzed!

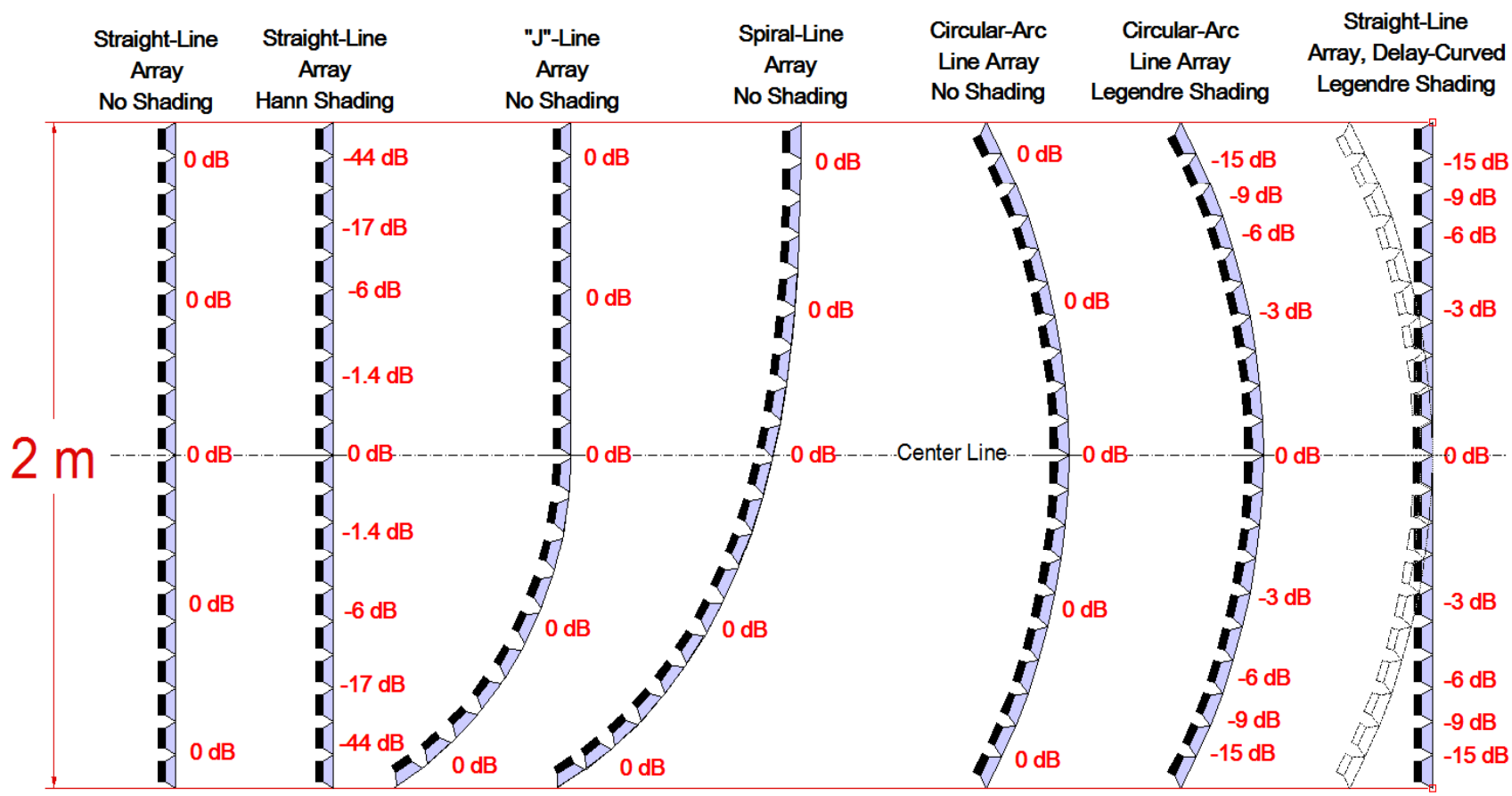
- Any array that requires complex DSP frequency-dependent processing.

- Other potentially complicated constant beamwidth designs such as:
  - Arrays that maintain a constant acoustic aperture size in wavelengths.
  - Horbach-Keele pair-wise symmetric multi-way crossover-based designs.
  - Etc.

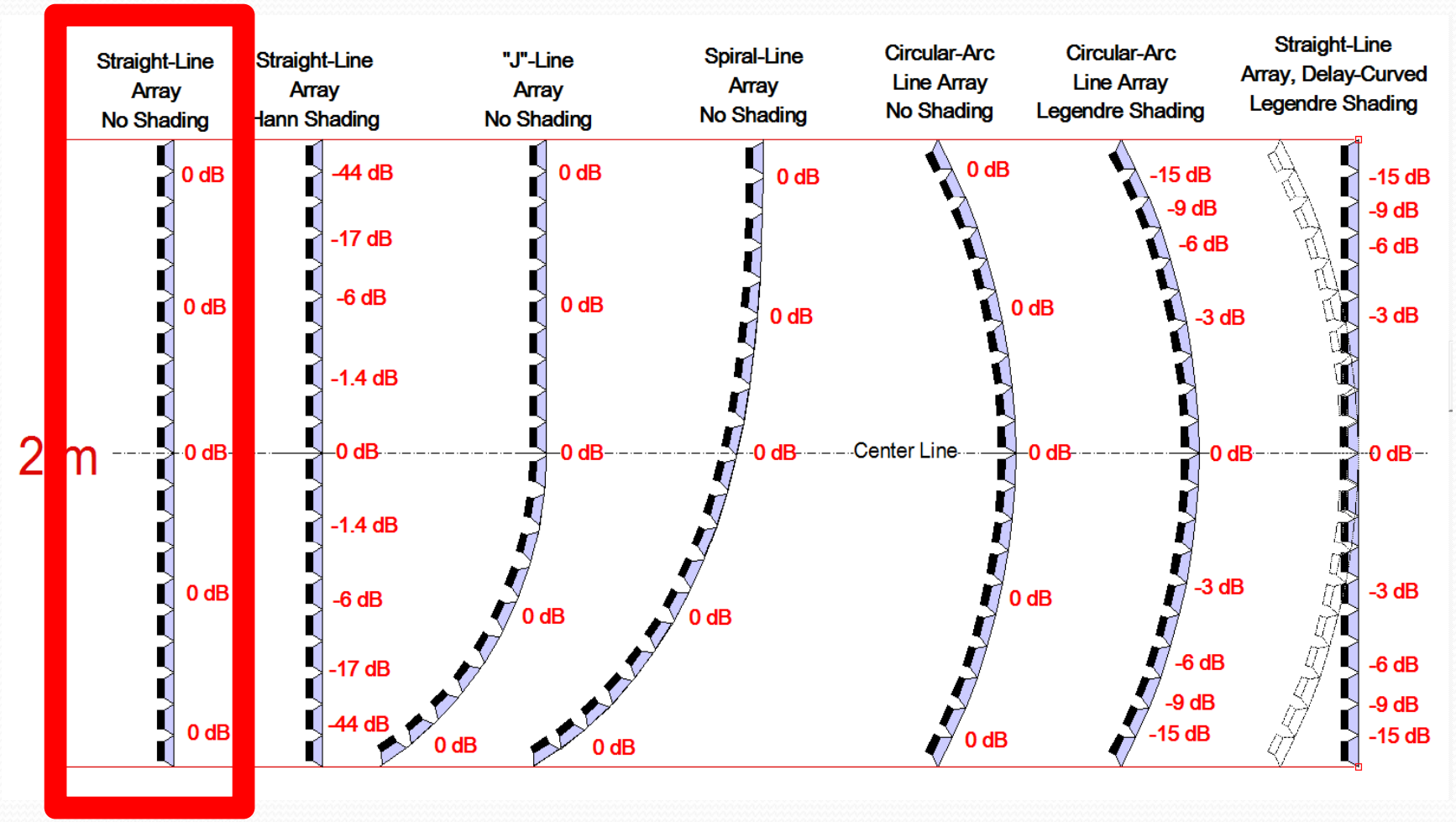
Caution! Disclaimer!

- Take what you are going to hear in the following presentation with a grain of salt!
- CBT = ***C***onstant ***B***eamwidth ***T***ransducer
- The CBT technology was first described by the U.S. Military in a series of JASA papers describing simple spherical-cap underwater transducers that provide wide-band extremely constant beamwidth and directivity behavior with virtually no side lobes.
- I was the first to apply the CBT concept to loudspeakers.
- ***Therefore, I'm biased!!!***

Array Depictions



Array Depictions



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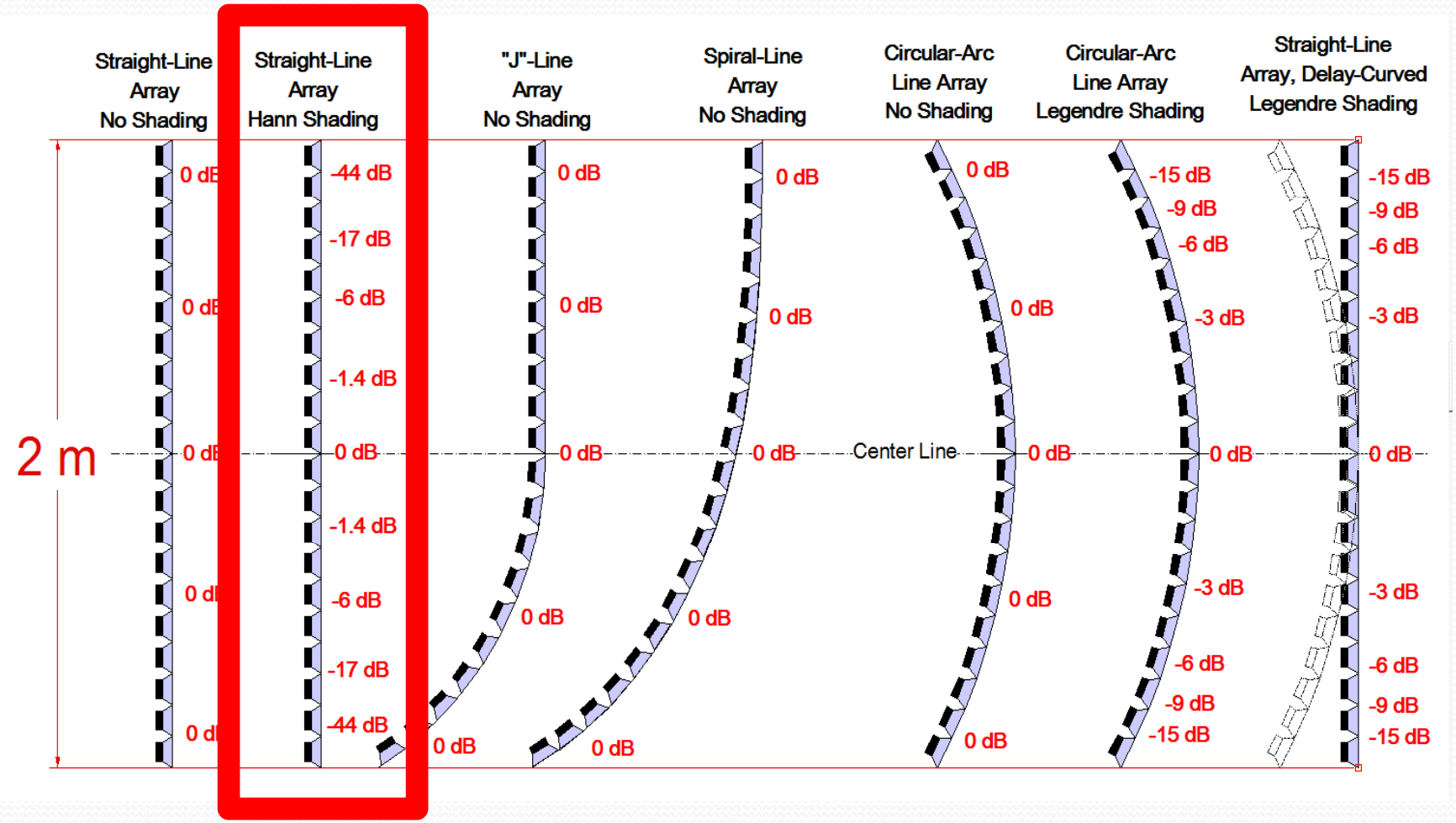

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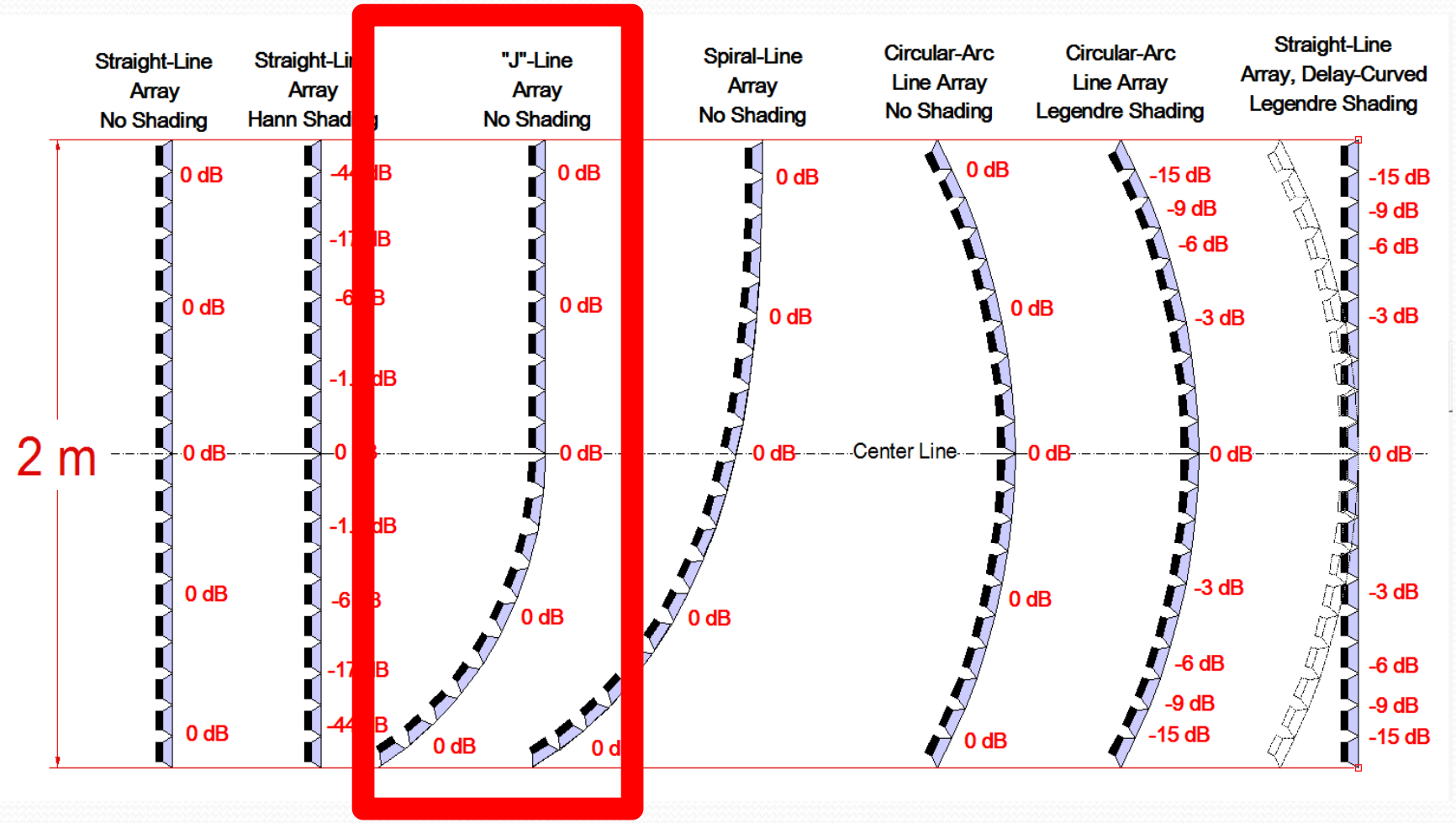

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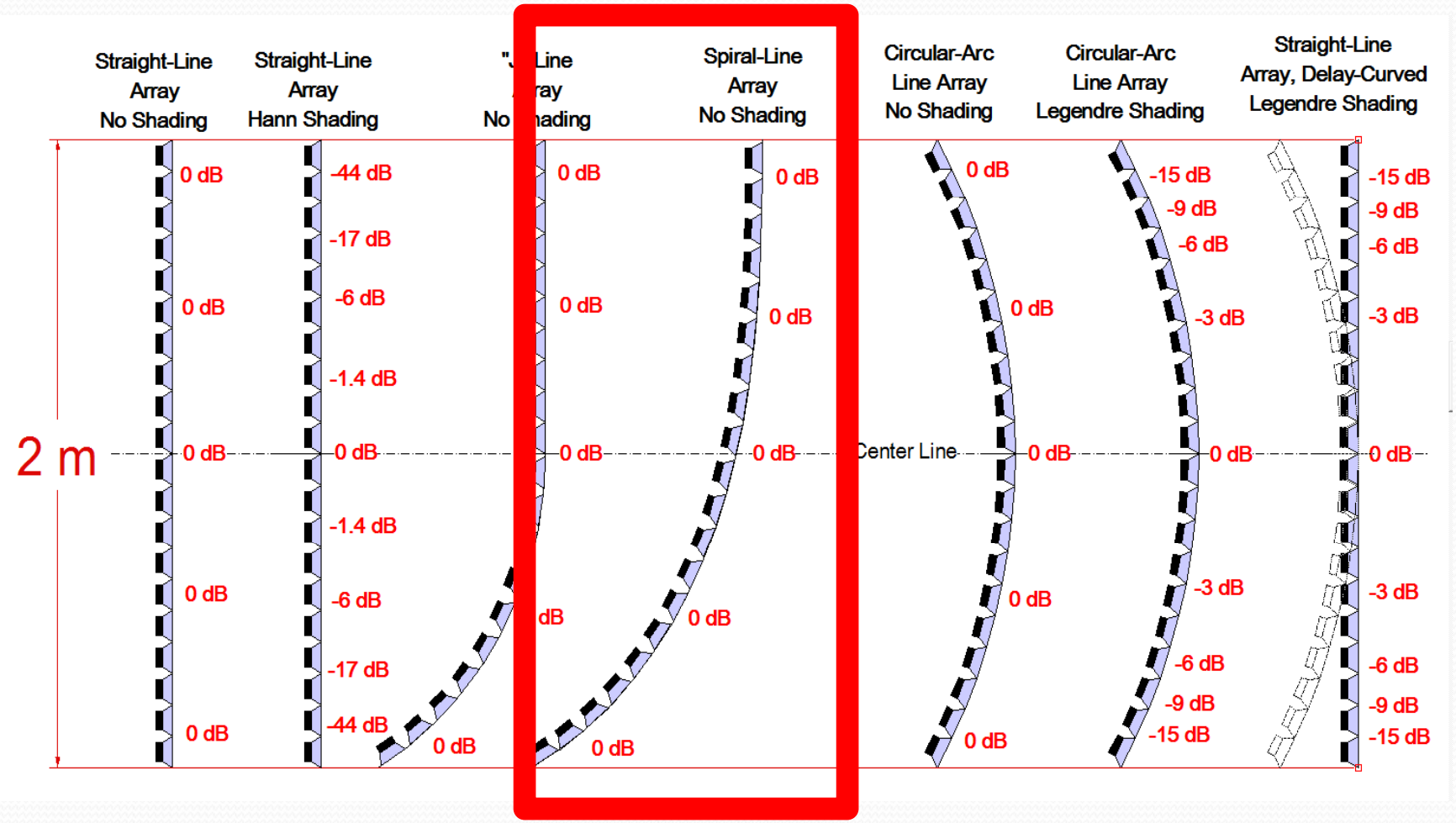
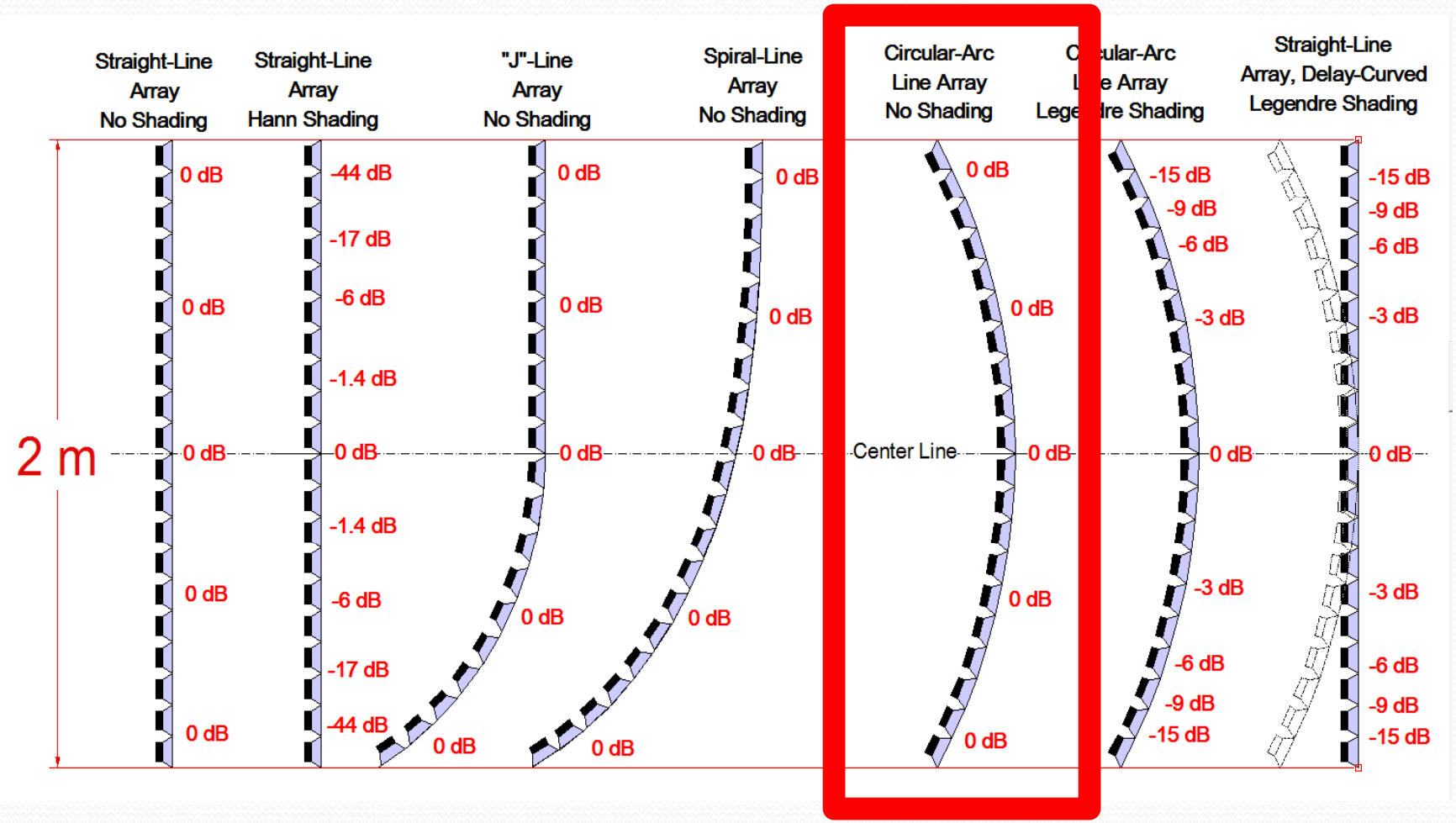
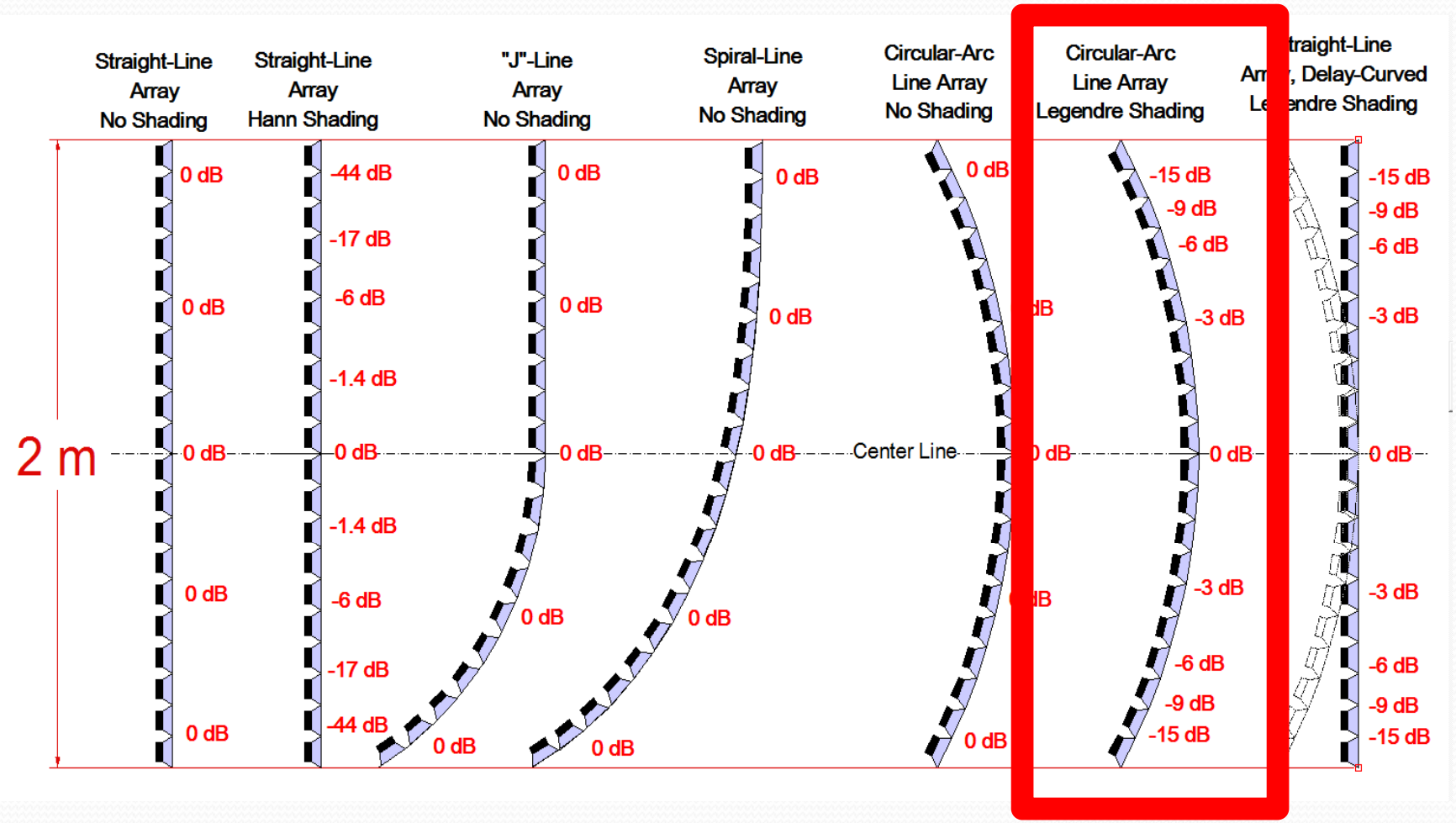


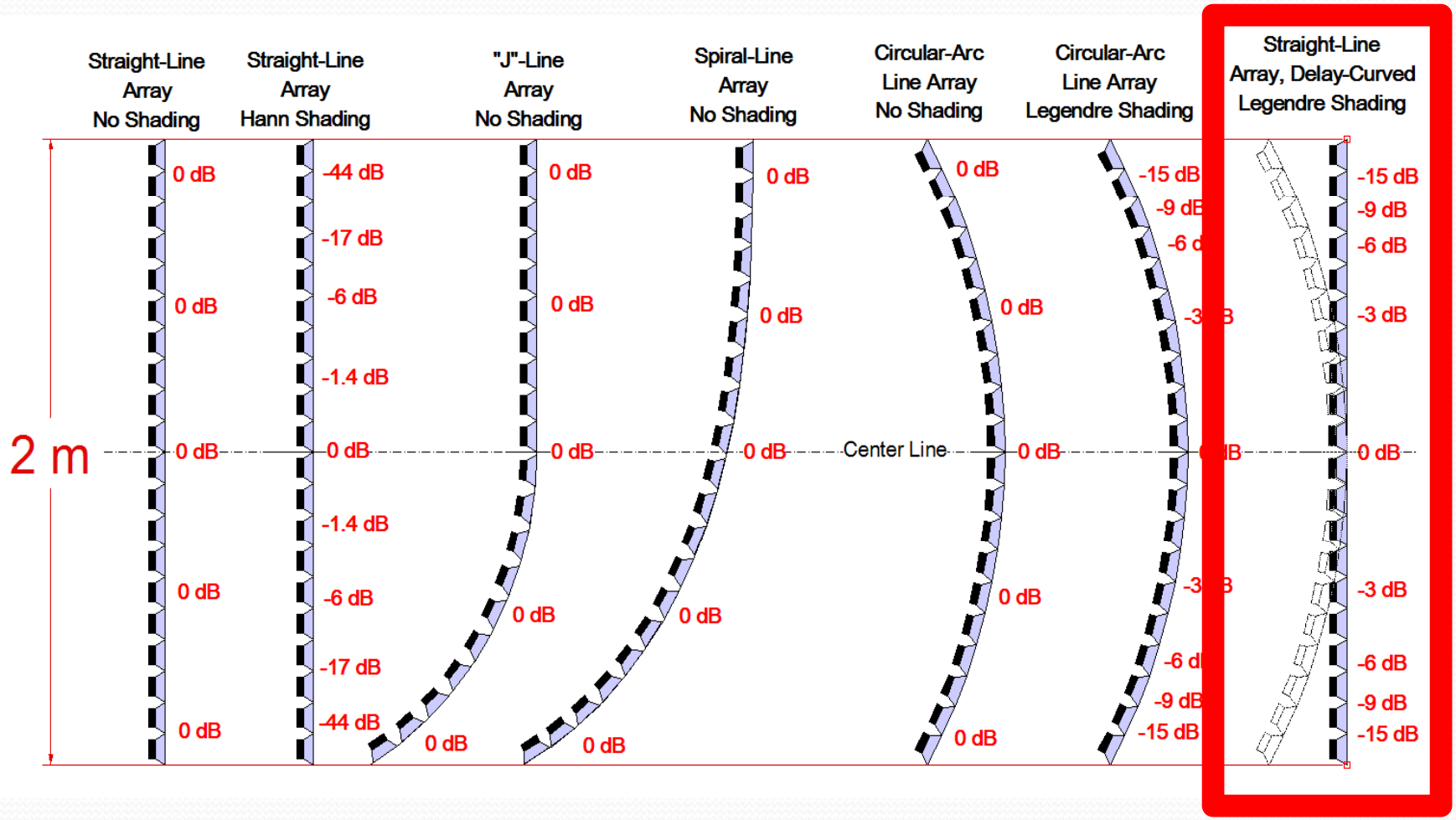
Array Depictions



Array Depictions



Array Depictions



Performance Parameters Evaluated

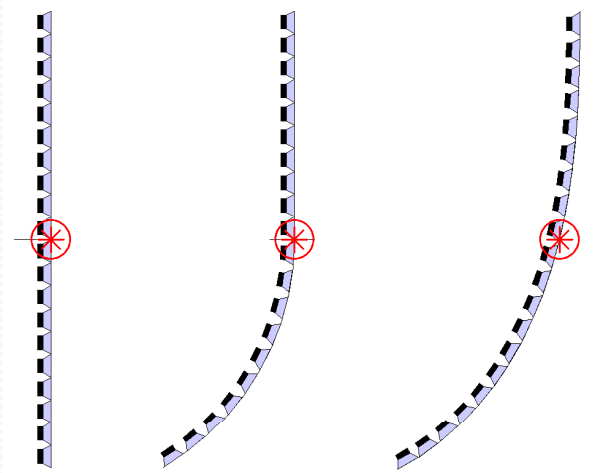
- Beamwidth uniformity
- Directivity uniformity
- Vertical sound-field uniformity
- Polar side lobe suppression
- Uniformity of polar response
- Smoothness and flatness of off-axis frequency response
- Sound pressure rolloff versus distance, and
- Near-far polar pattern uniformity.

Array Simulation Conditions

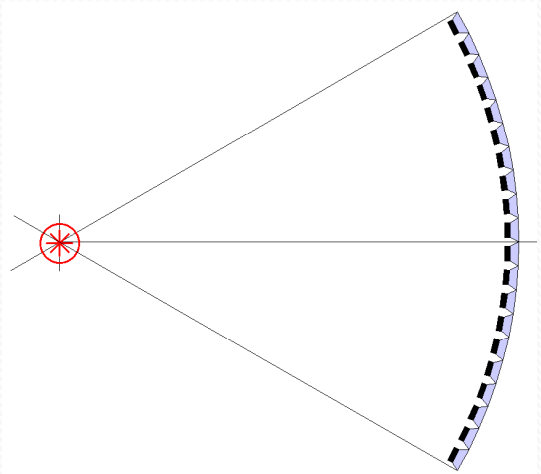
- All modeled arrays were 2m high and composed of 100 equal-spaced point sources.
- Each of the circular-arc arrays were 60°.
- No complicated signal processing was permitted except for frequency-independent inter-element shading and delay, plus in-line equalization to flatten the frequency response at a specific location.
- All data was calculated at one-third-octave intervals over the range of 20 Hz to 20 kHz.

Array Rotation Point for Polars

- Most arrays were rotated around the front center of the array. →



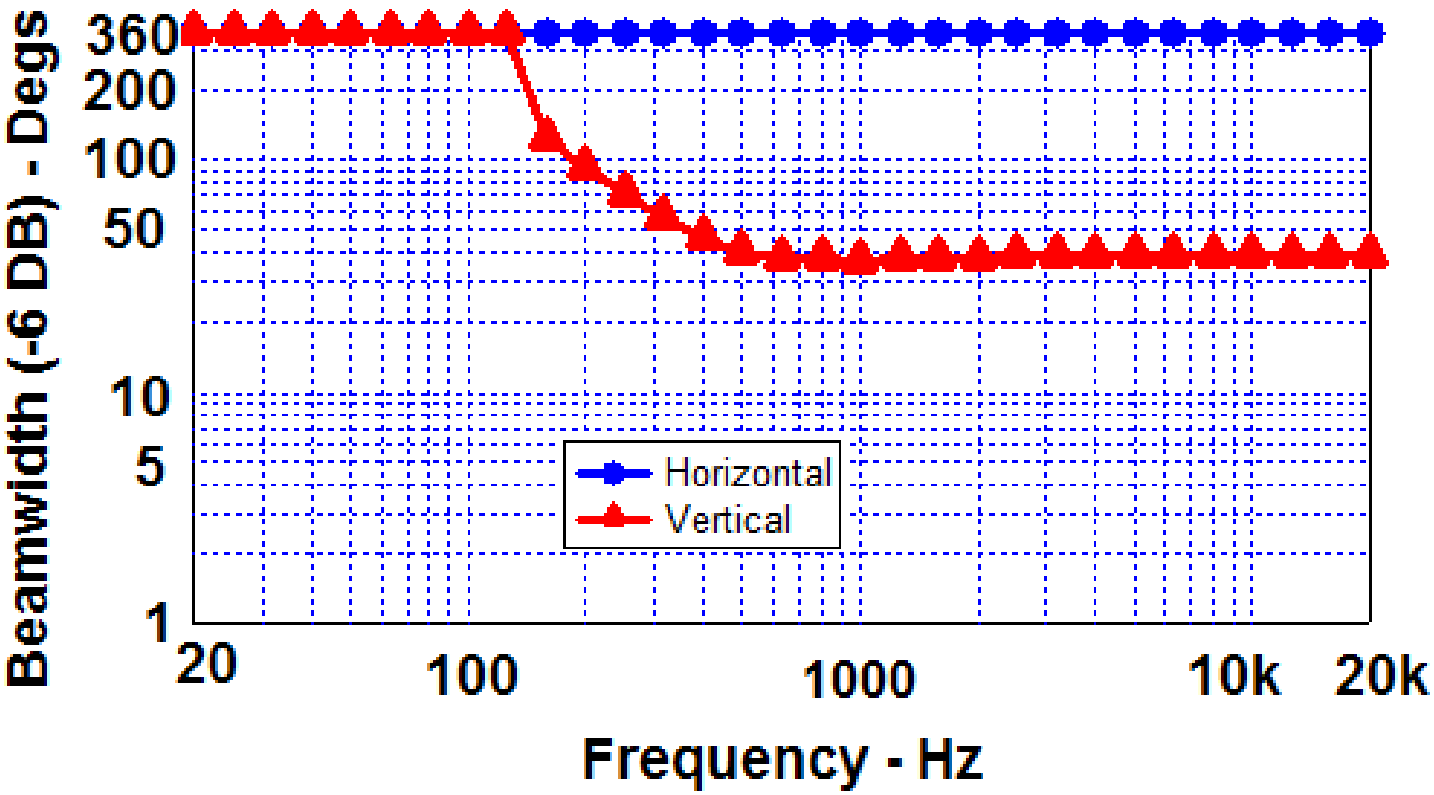
- The circular-arc arrays were rotated around the arc's center of curvature. →



Performance Ranking

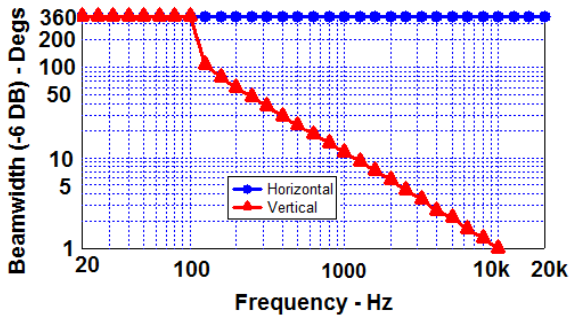
- The eight performance parameters were simulated for each array type and then *subjectively* (by me!) scored on a scale from 1 to 10 with 10 highest.
- The subjective score of the eight parameters was then used to rank each array with respect to each other for each parameter.
- The final array ranking was calculated by adding up the individual performance parameter scores for each array in a table which then determined the final ranking.

Analysis: Beamwidth Uniformity
Ideal Beamwidth

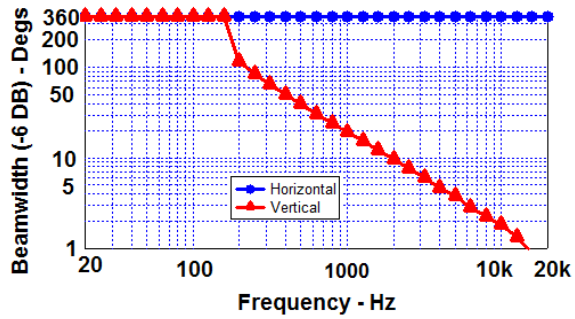


Analysis: Beamwidth Uniformity

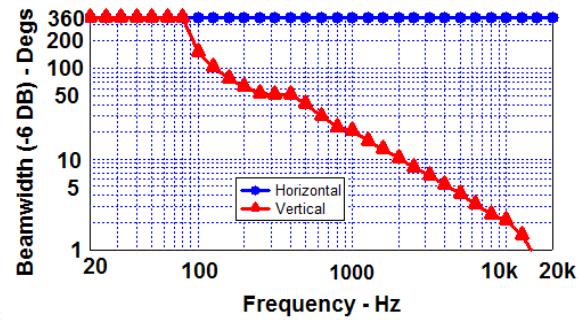
Un-Shaded Straight-Line Array



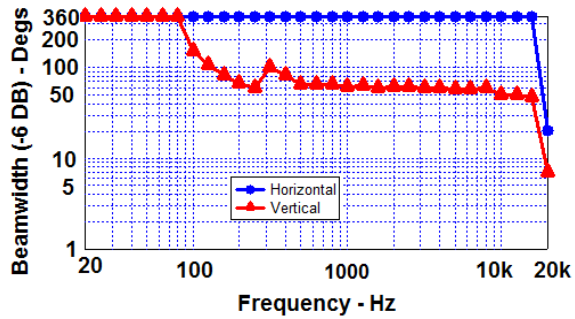
Shaded Straight-Line Array



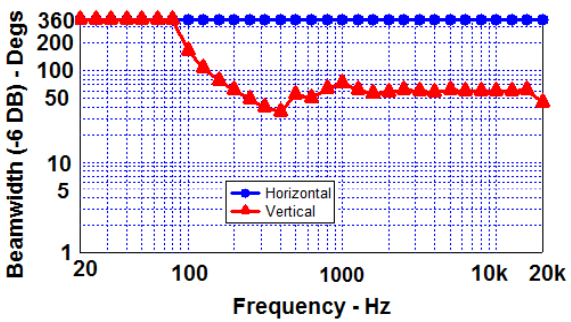
Un-Shaded "J"-Line Array



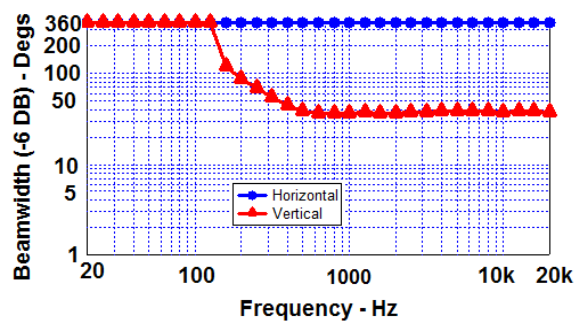
Un-Shaded Spiral-Line Array



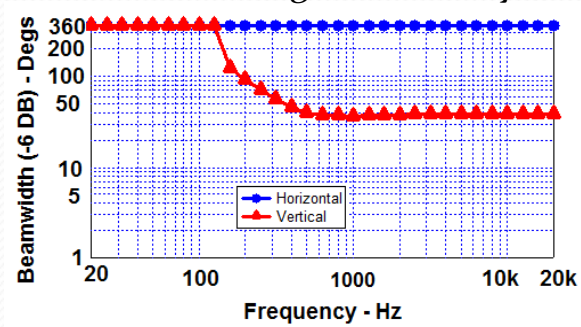
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array

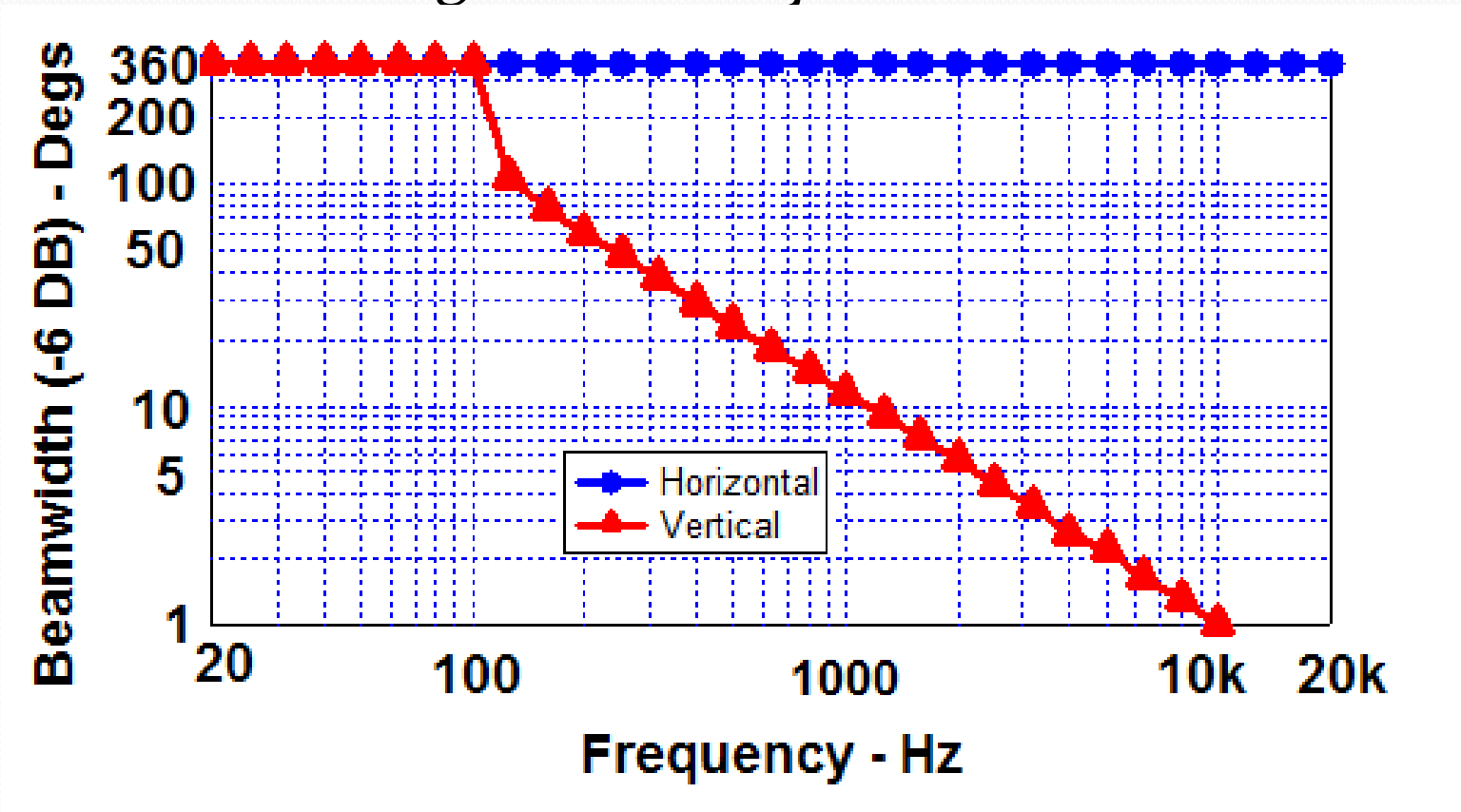


Shaded Delay-Curved CBT Straight-Line array



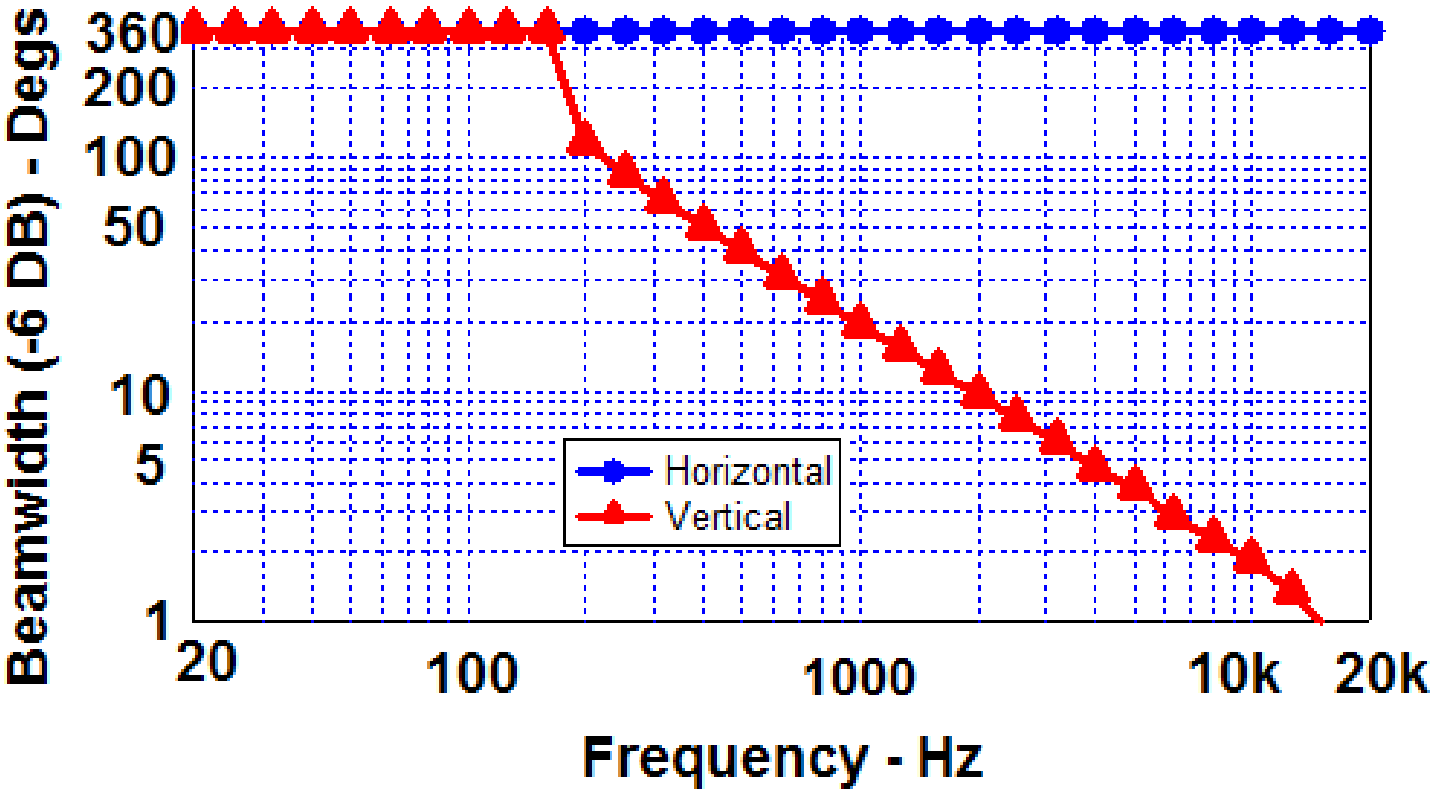
Analysis: Beamwidth Uniformity

- Un-shaded straight-line array



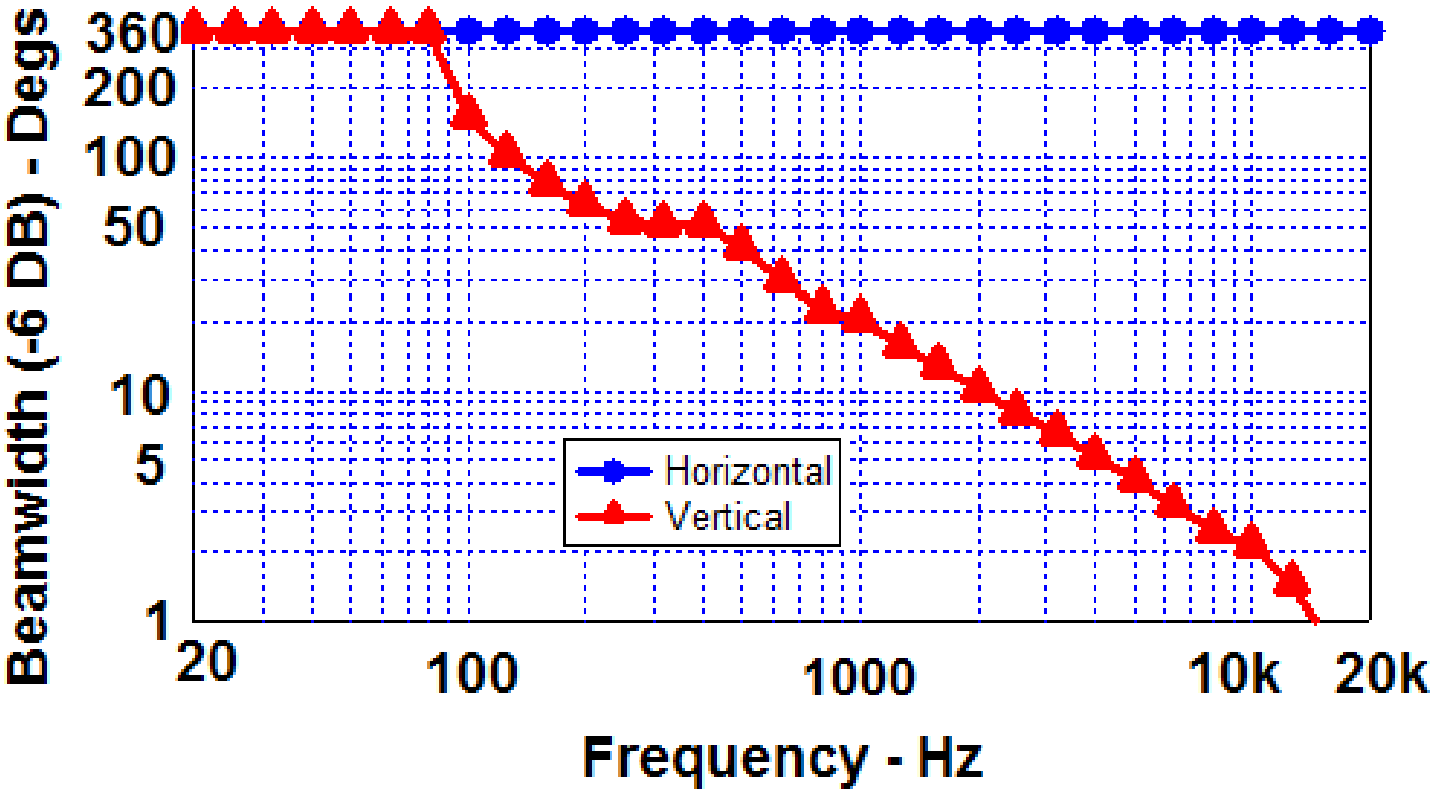
Analysis: Beamwidth Uniformity

- Hann-shaded straight-line array



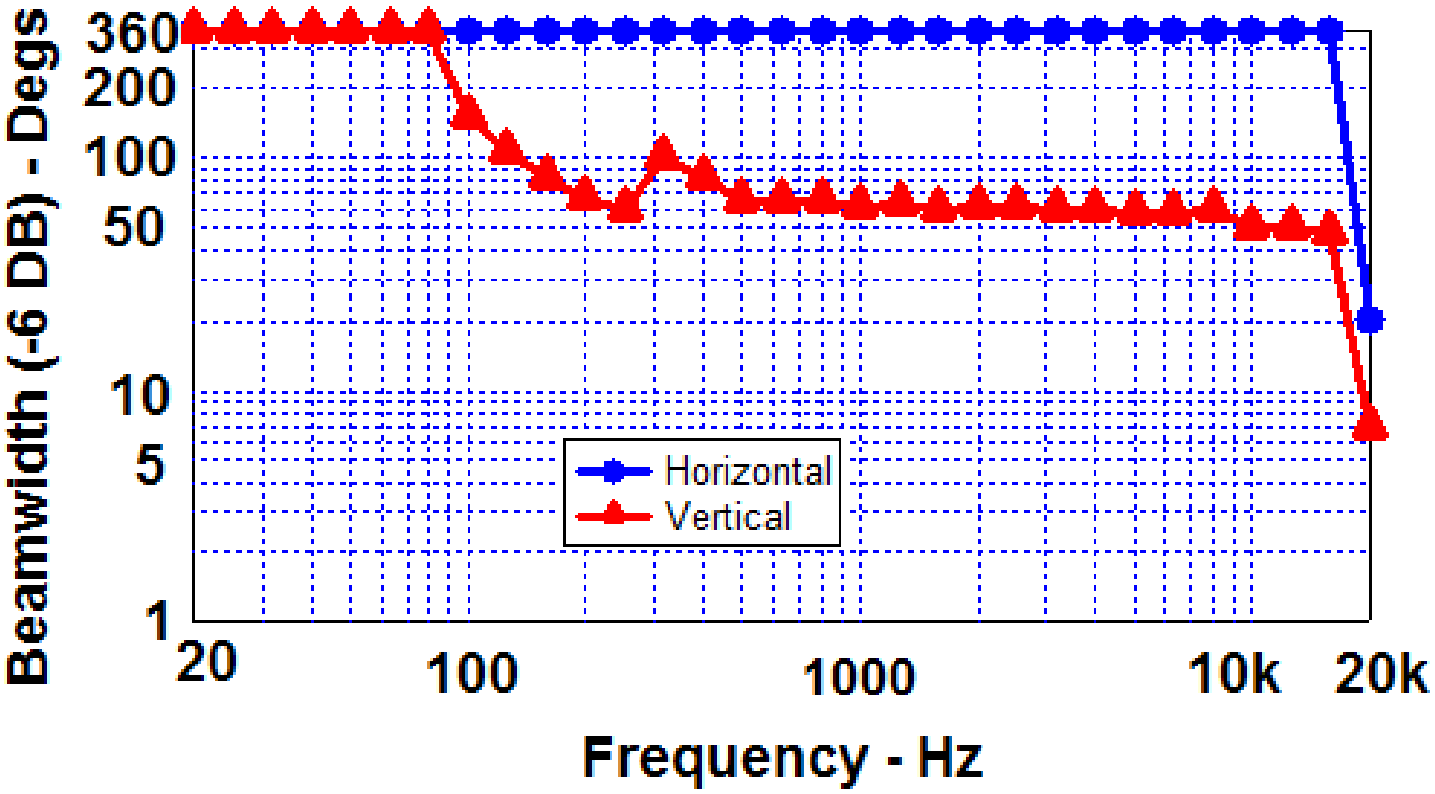
Analysis: Beamwidth Uniformity

- Un-shaded "J"-line array



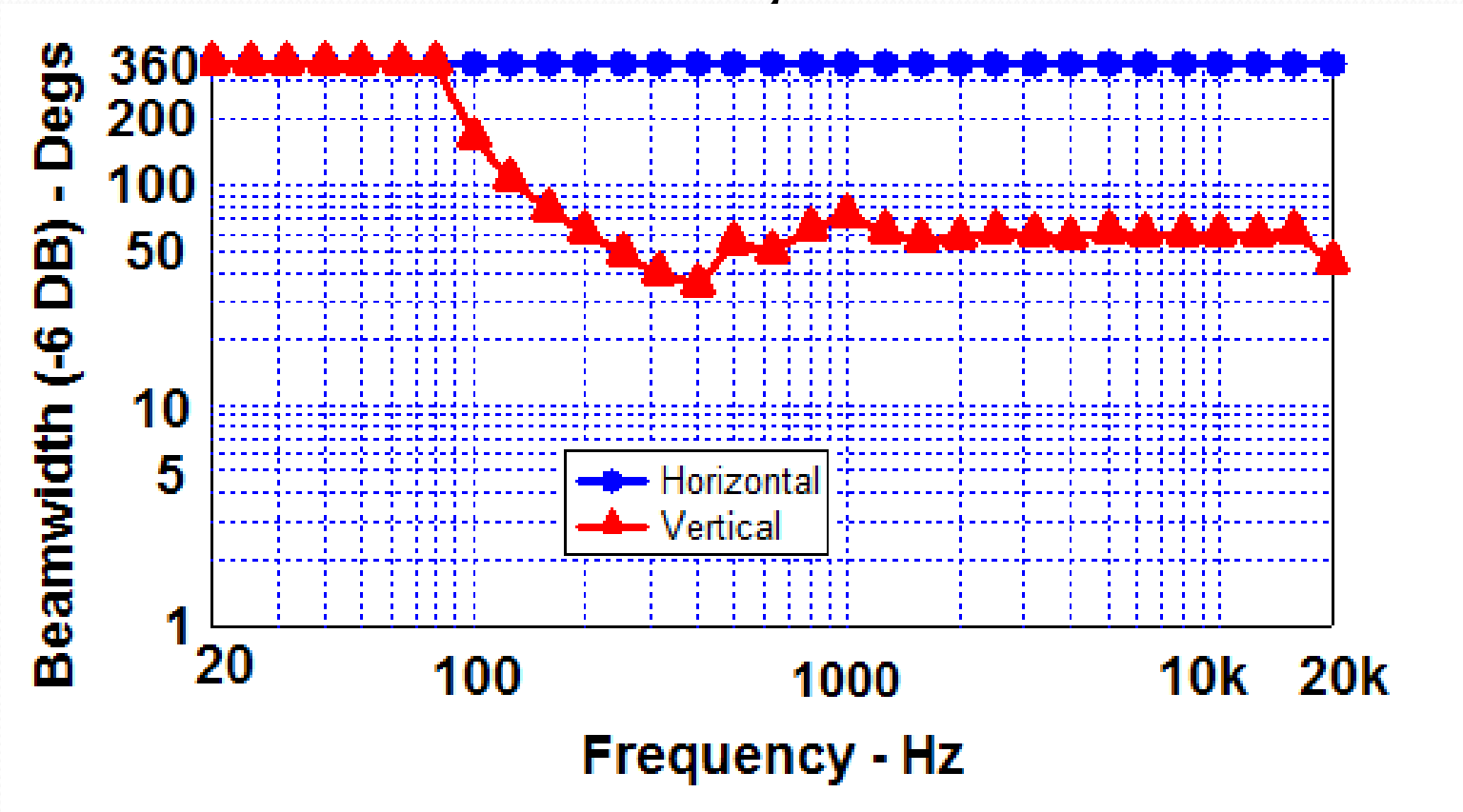
Analysis: Beamwidth Uniformity

- Un-shaded spiral- or progressive-line array



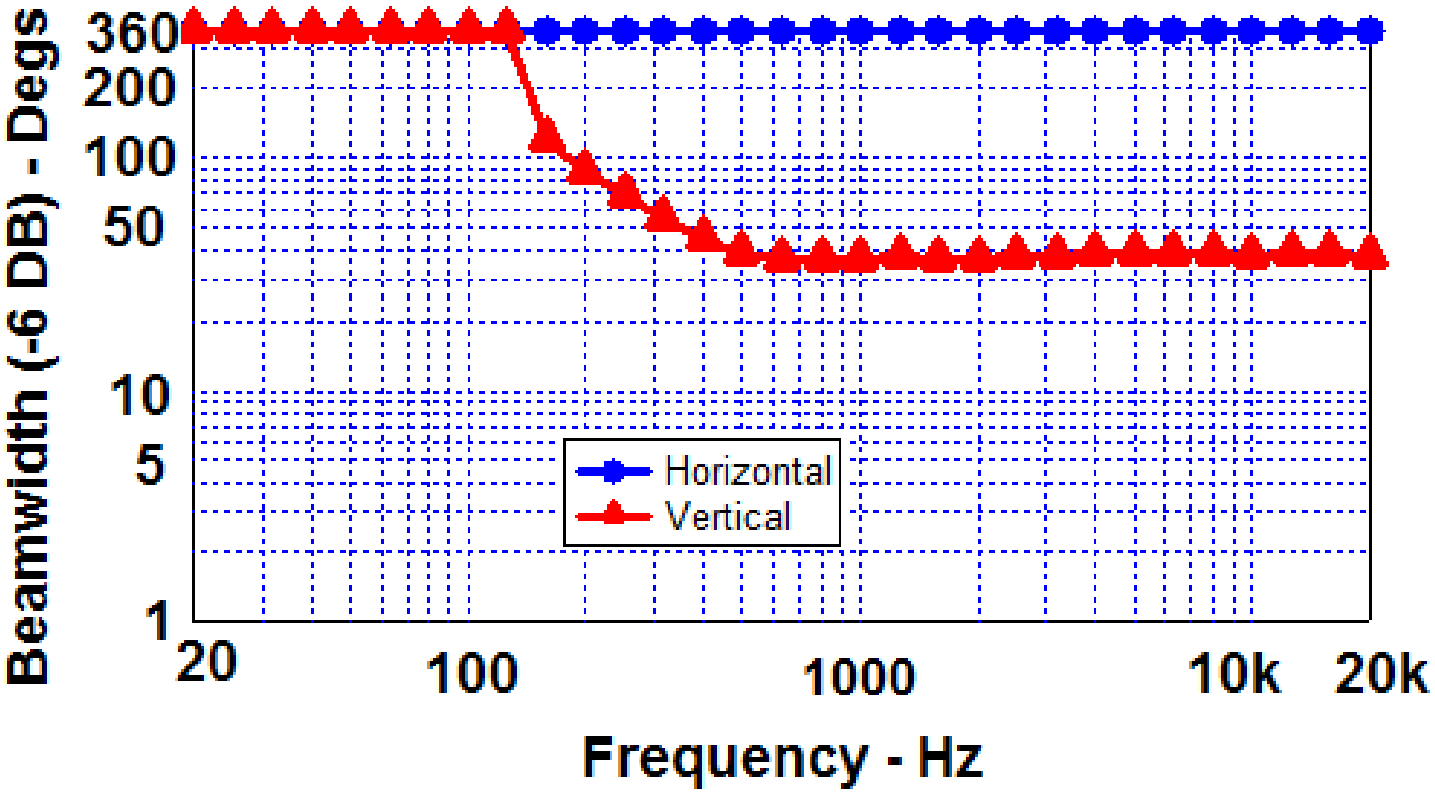
Analysis: Beamwidth Uniformity

- Un-shaded circular-arc array



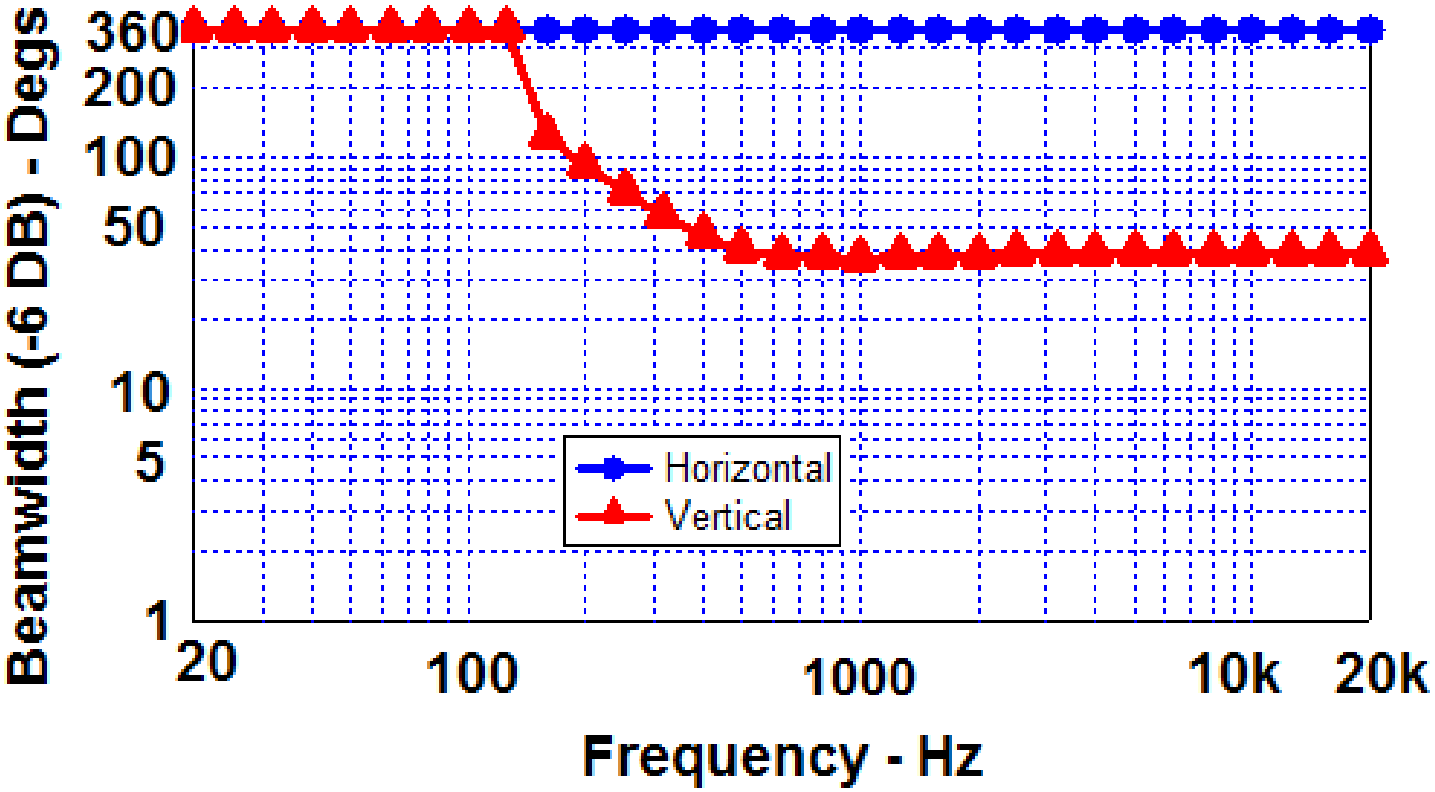
Analysis: Beamwidth Uniformity

- Legendre-shaded CBT circular-arc array



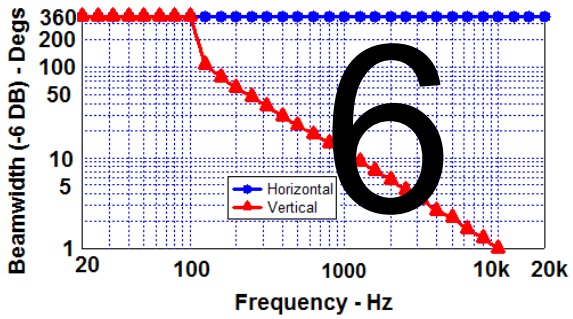
Analysis: Beamwidth Uniformity

- Legendre-shaded delay-curved CBT straight-line array

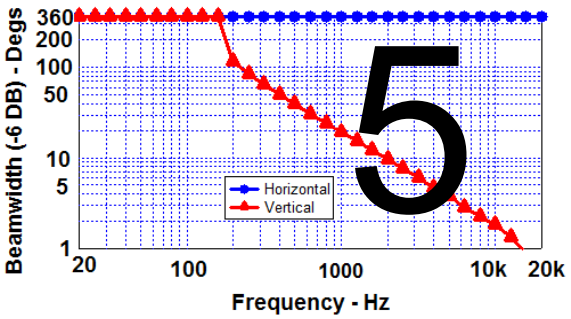


Beamwidth Ranking

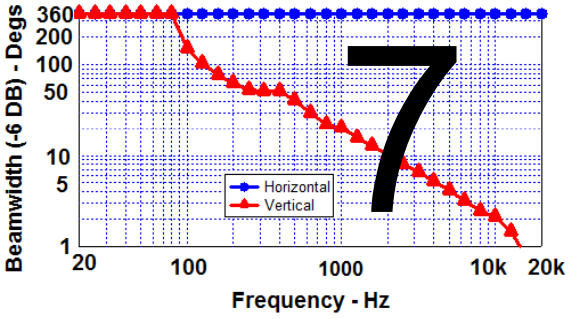
Un-Shaded Straight-Line Array



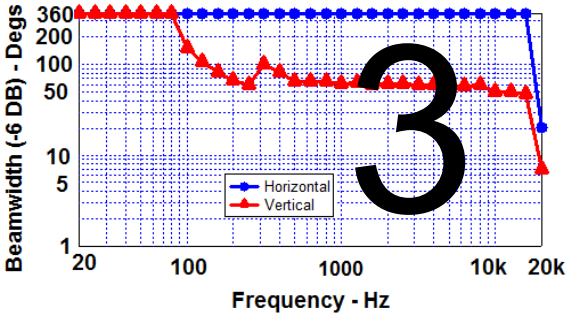
Shaded Straight-Line Array



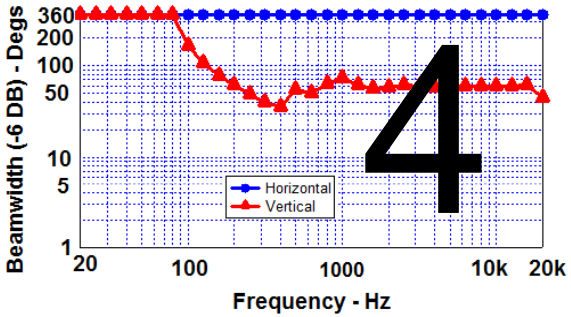
Un-Shaded "J"-Line Array



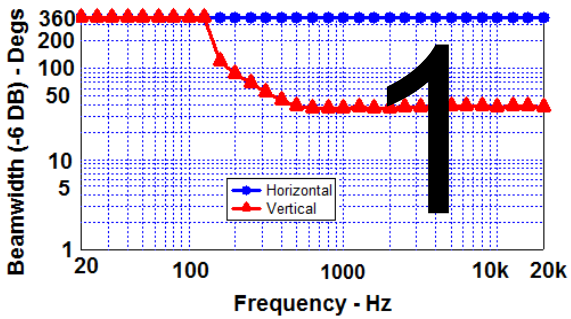
Un-Shaded Spiral-Line Array



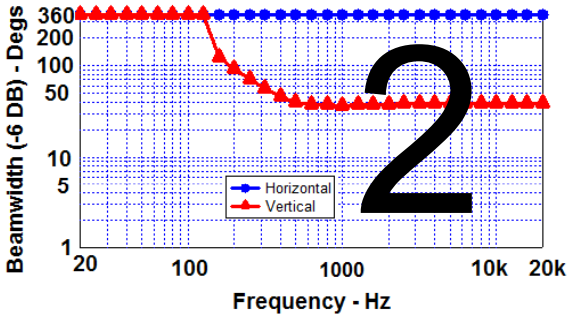
Un-Shaded Circular-Arc Line Array



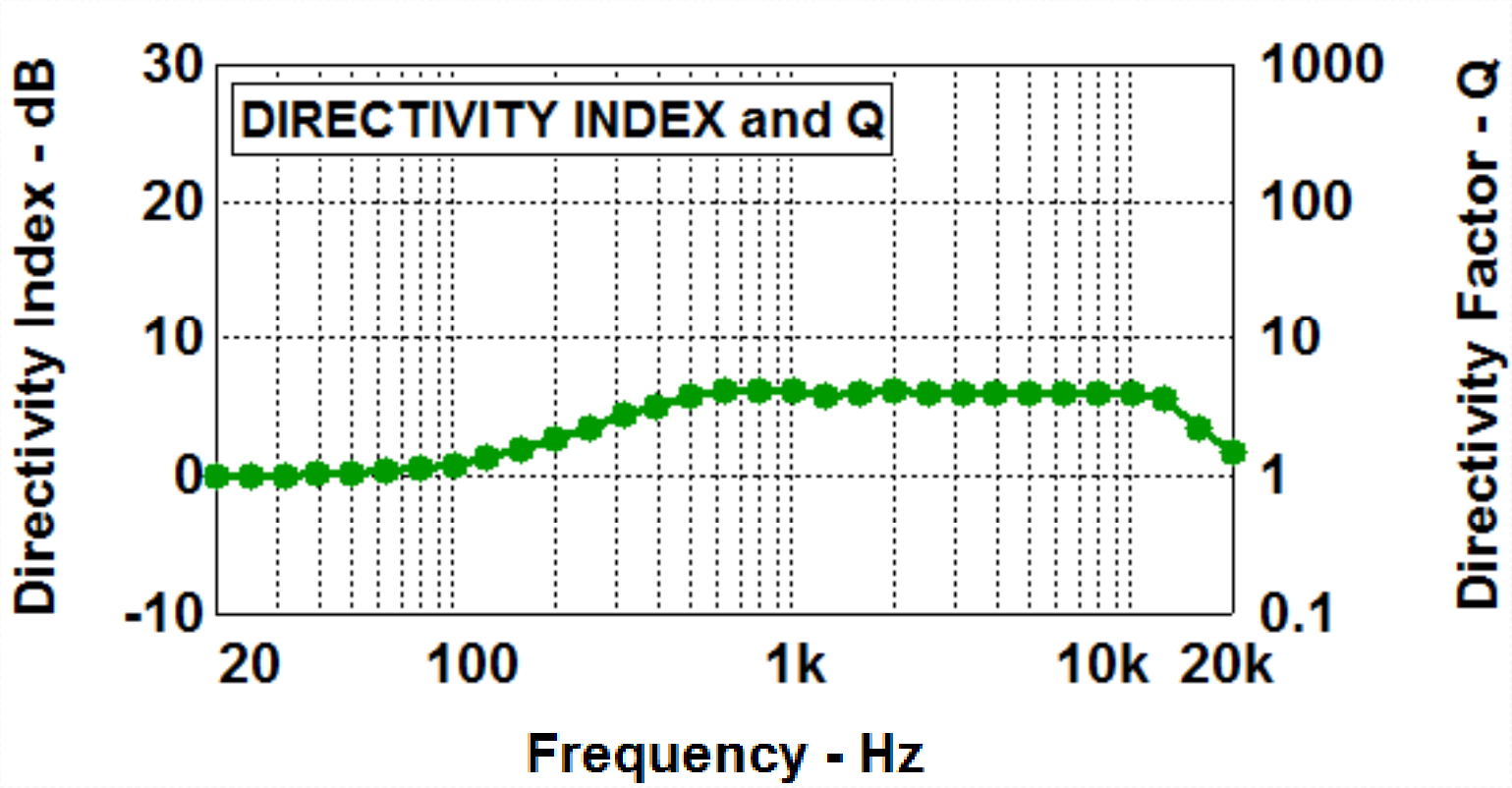
Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array

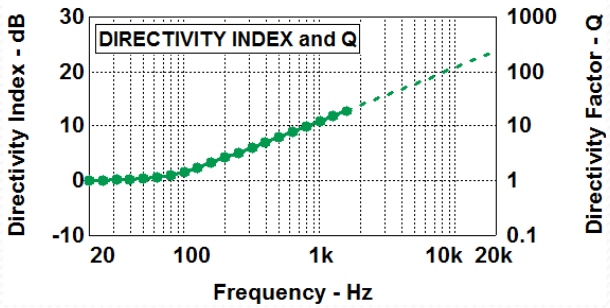


Analysis: Directivity Uniformity Ideal Directivity

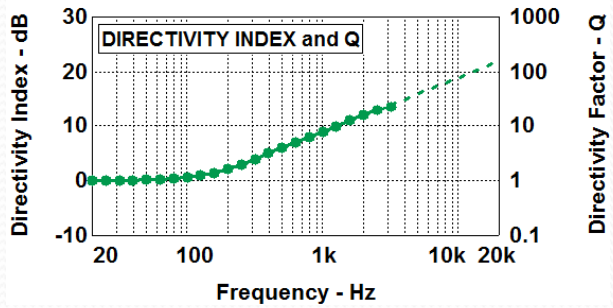


Analysis: Directivity Uniformity

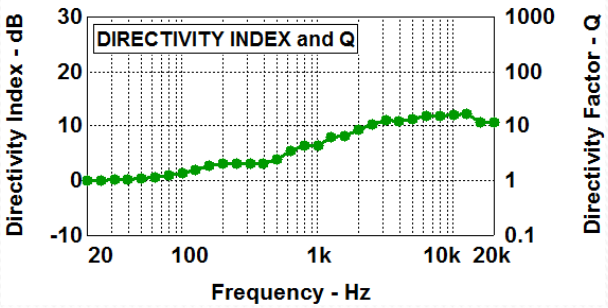
Un-Shaded Straight-Line Array



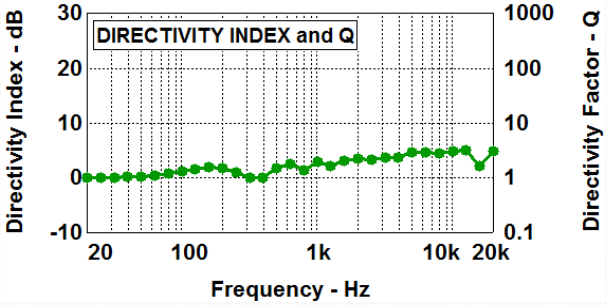
Shaded Straight-Line Array



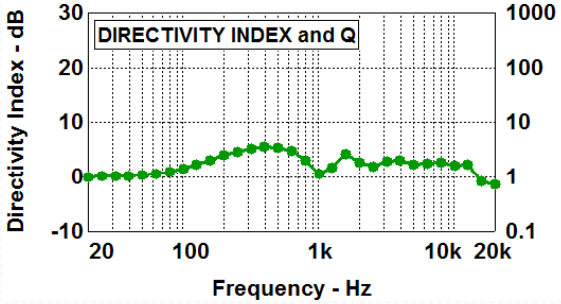
Un-Shaded "J"-Line Array



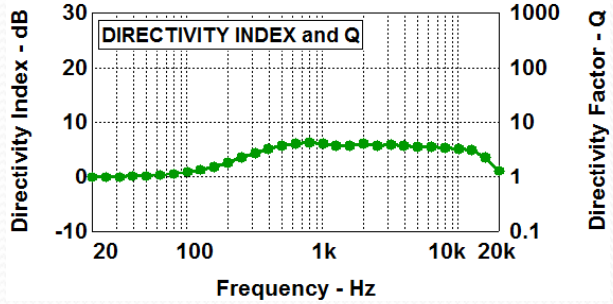
Un-Shaded Spiral-Line Array



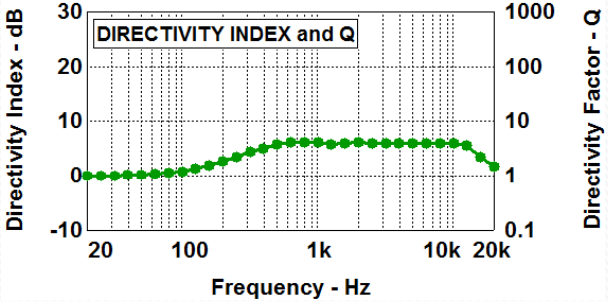
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array

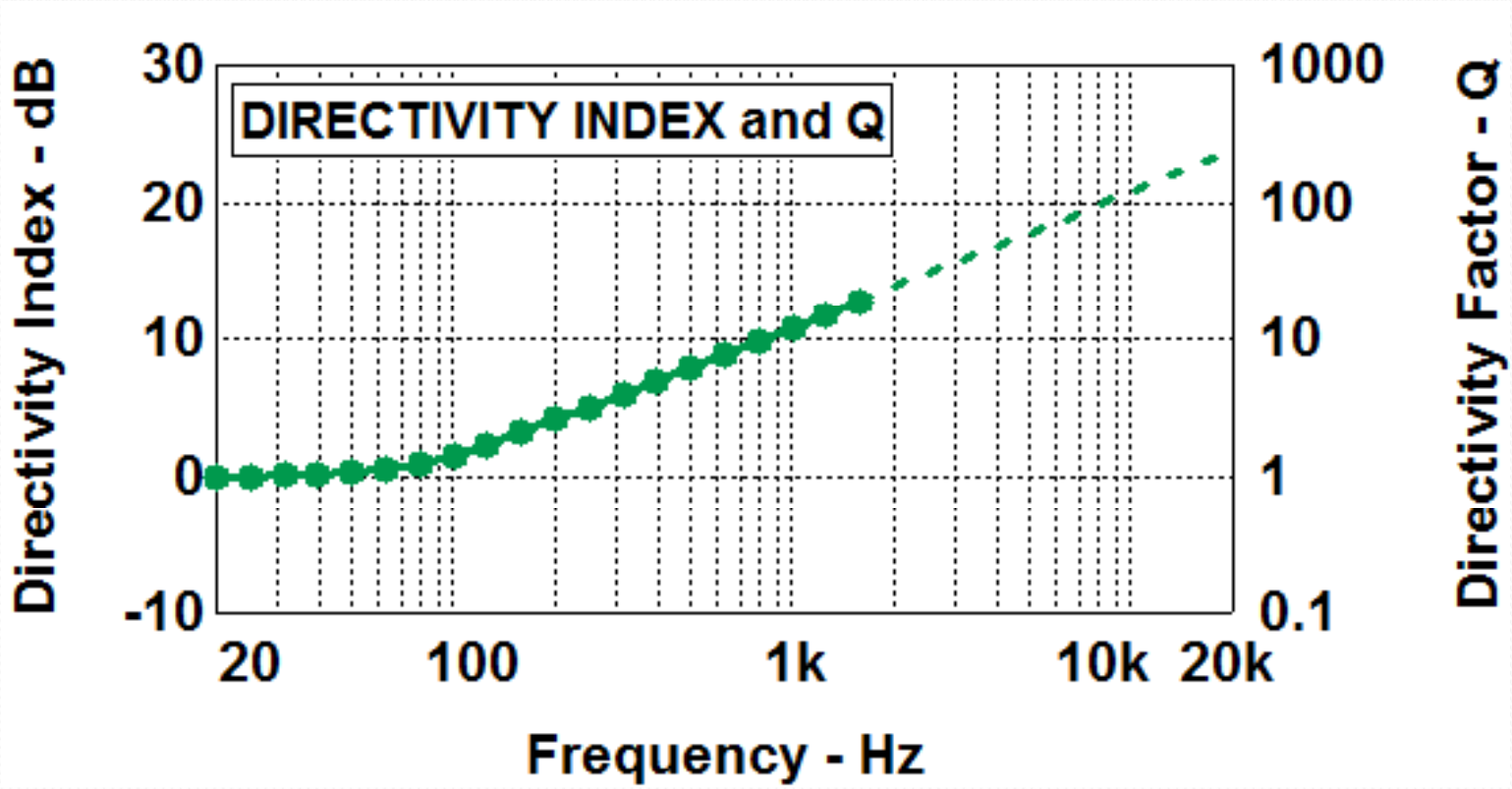


Shaded Delay-Curved CBT Straight-Line array



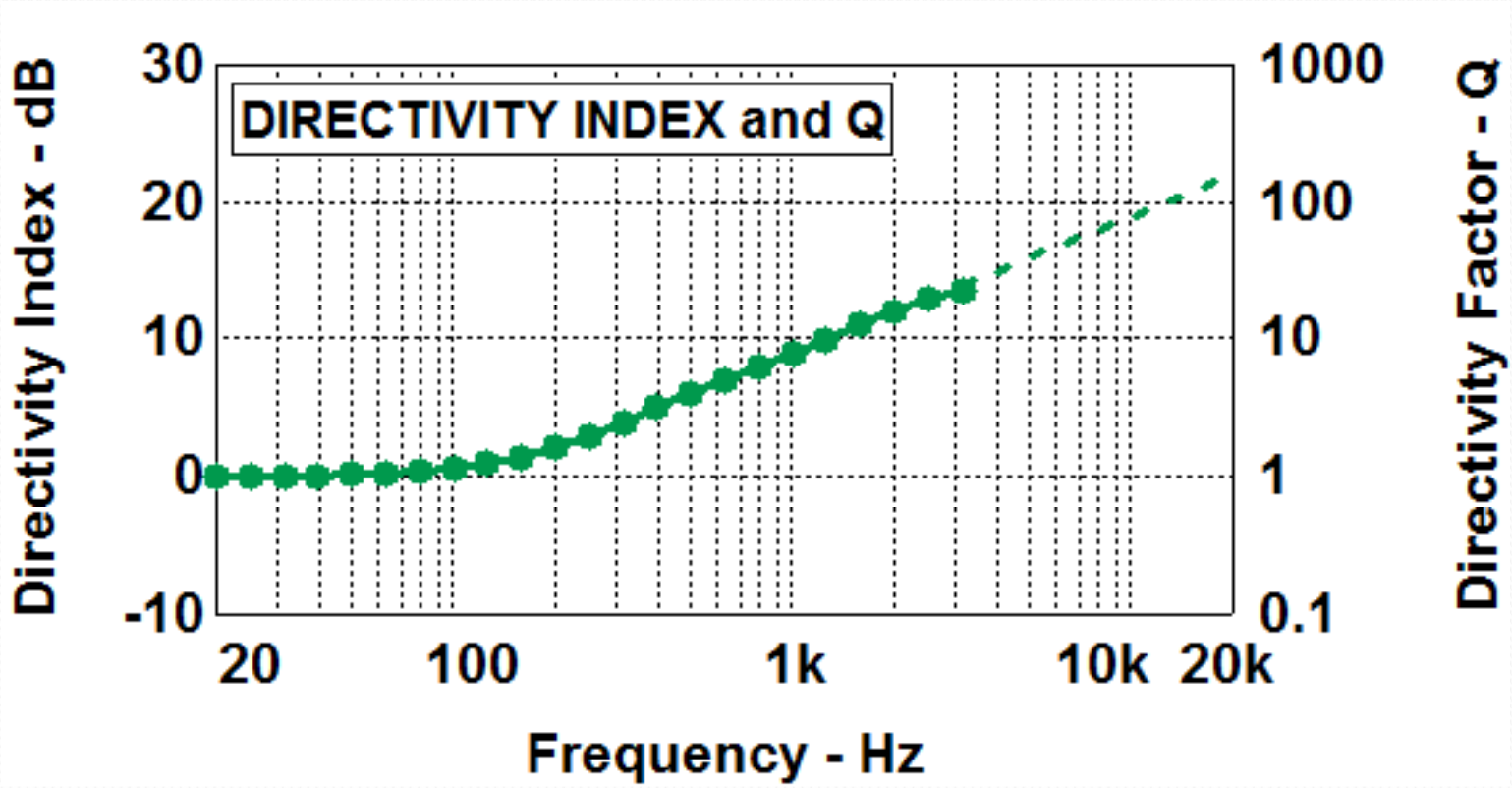
Analysis: Directivity Uniformity

- Un-shaded straight-line array



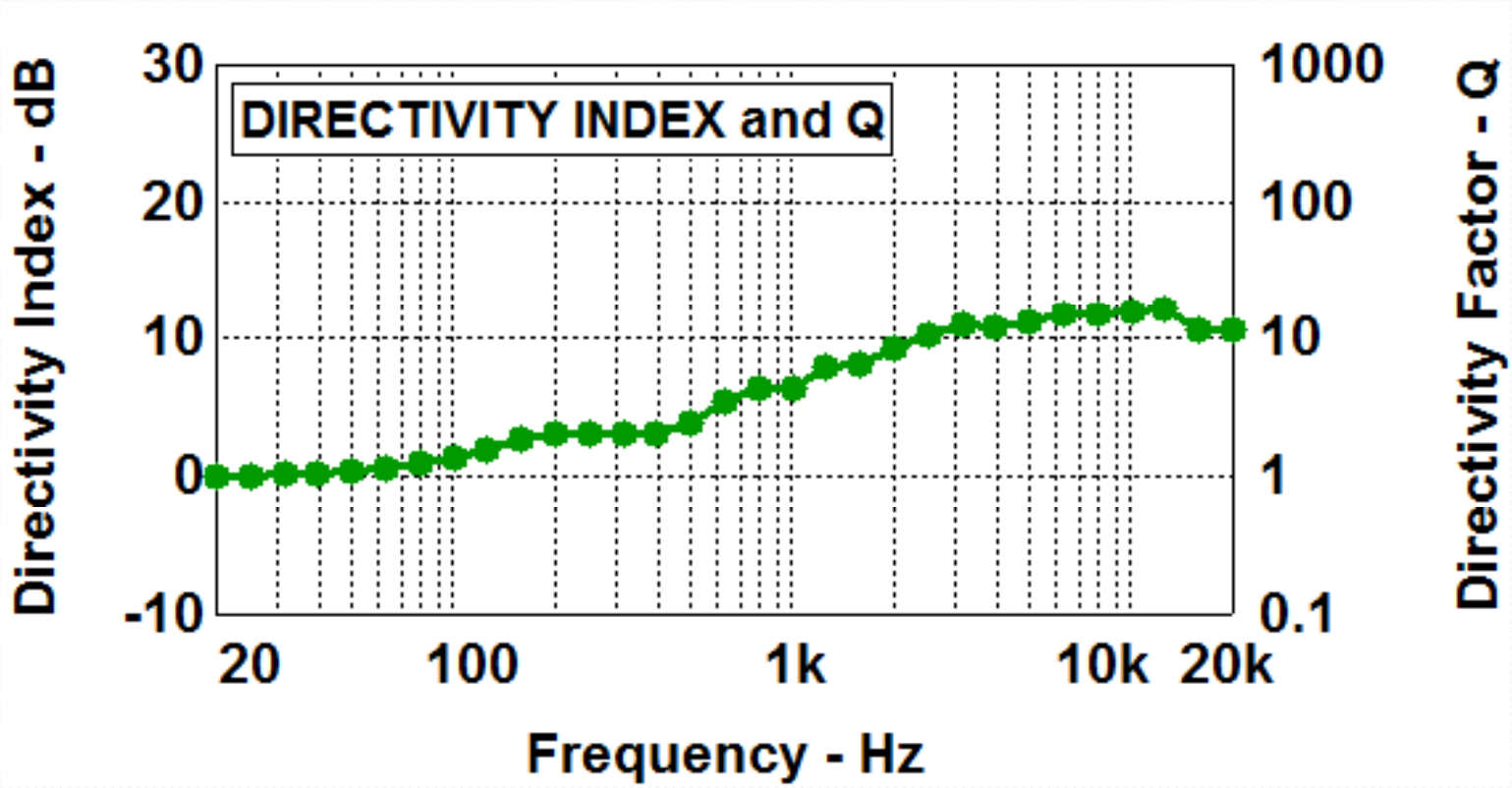
Analysis: Directivity Uniformity

- Hann-shaded straight-line array



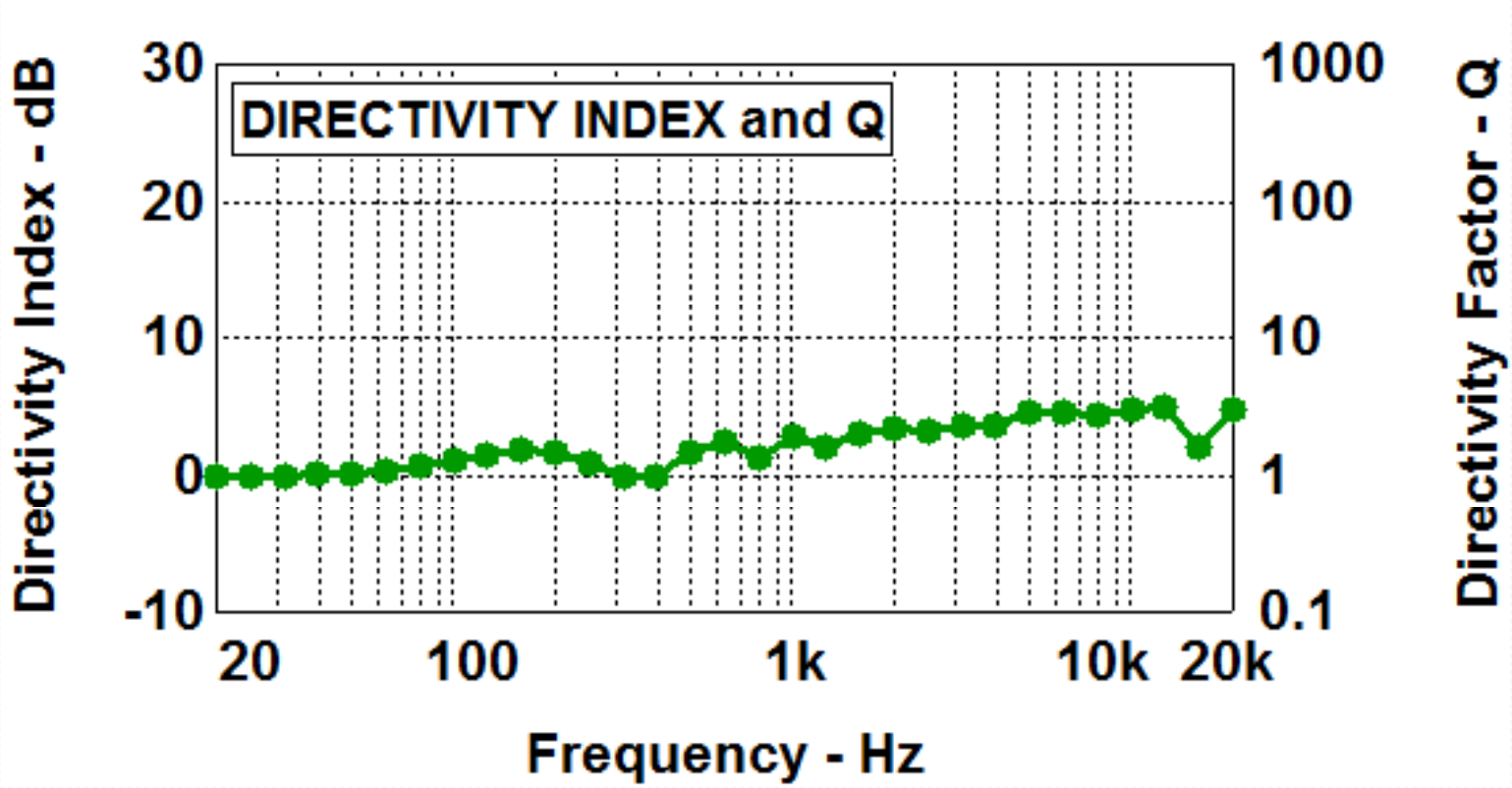
Analysis: Directivity Uniformity

- Un-shaded "J"-line array



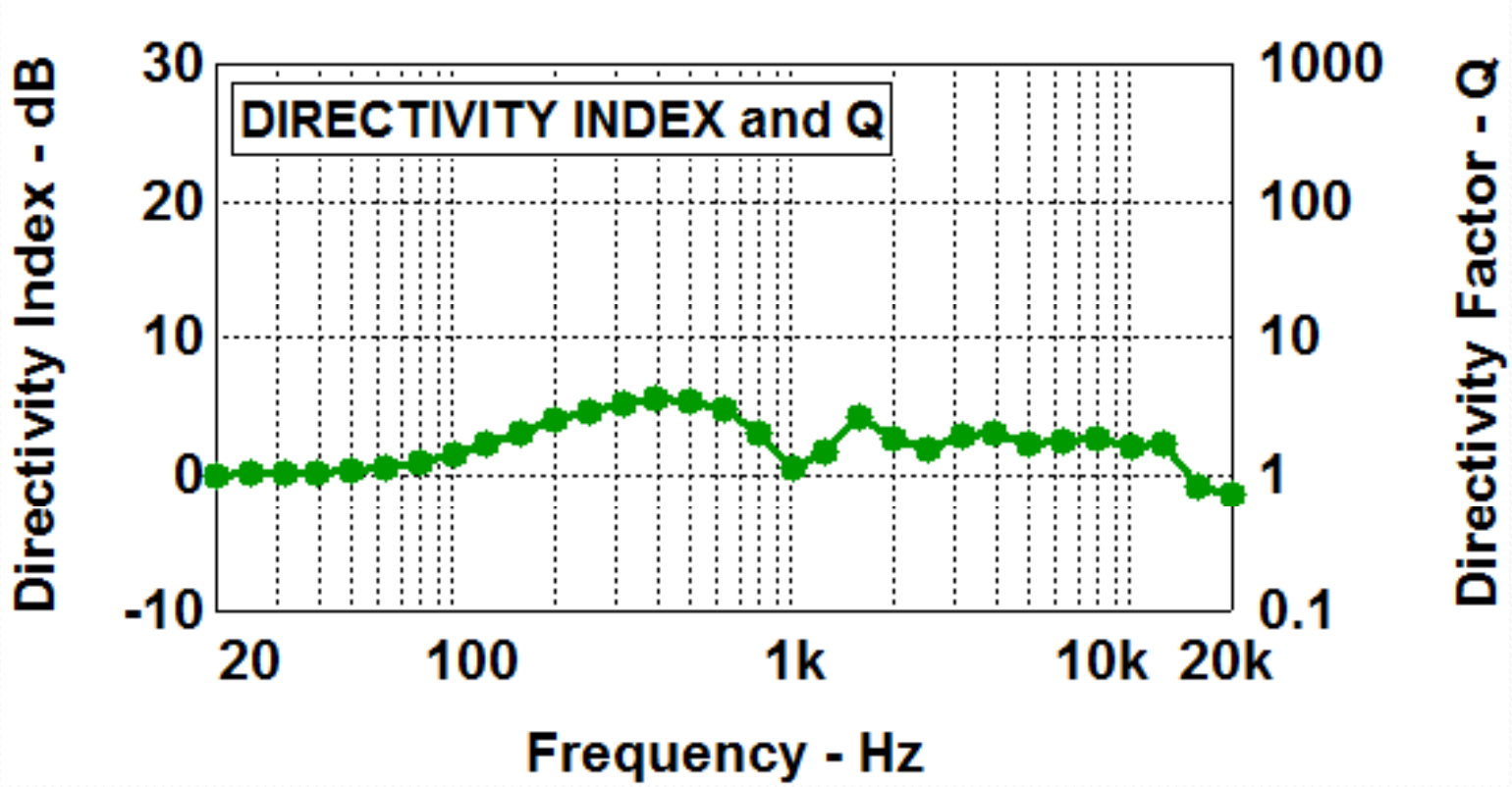
Analysis: Directivity Uniformity

- Un-shaded spiral- or progressive-line array



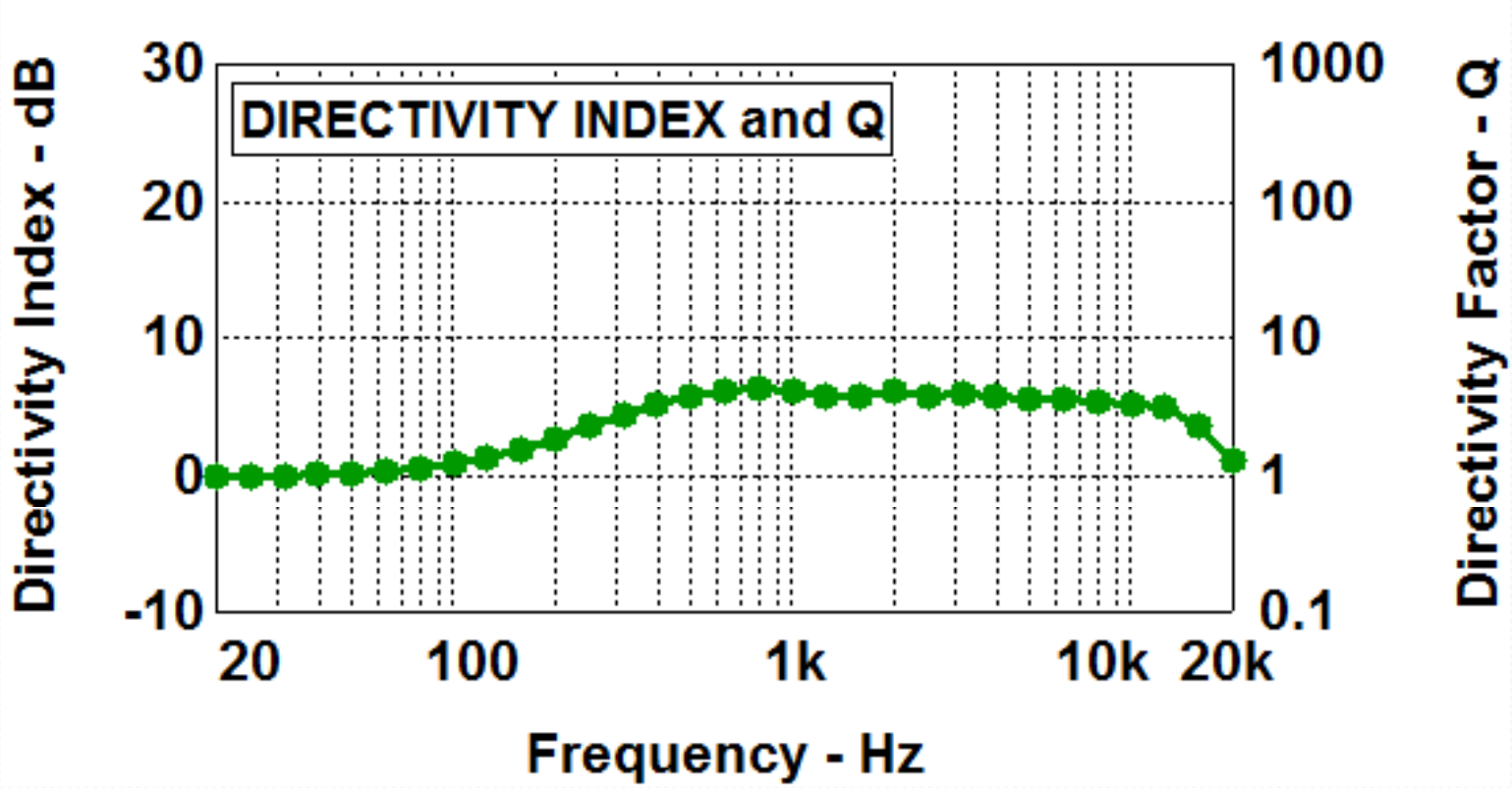
Analysis: Directivity Uniformity

- Un-shaded circular-arc array



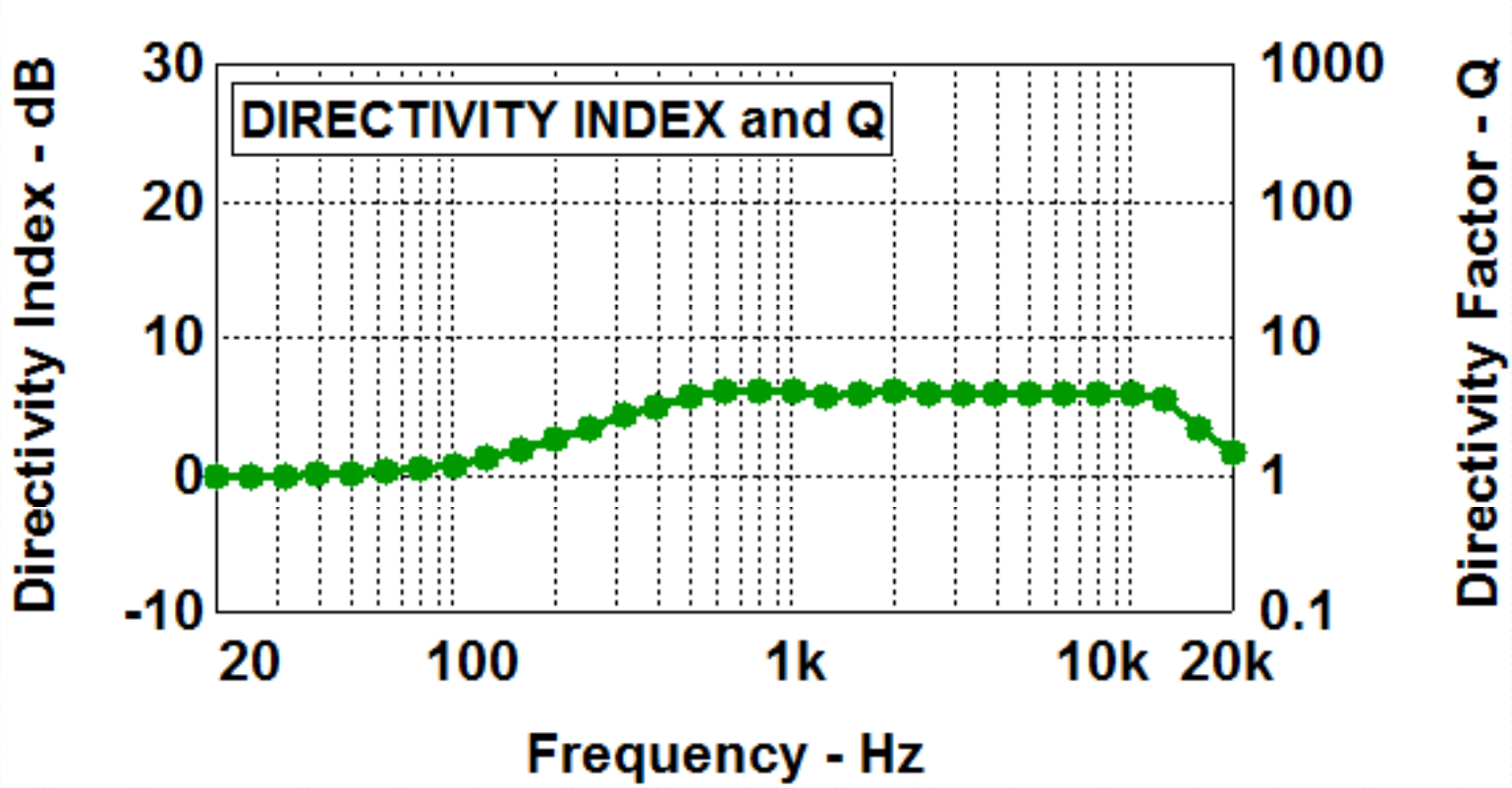
Analysis: Directivity Uniformity

- Legendre-shaded CBT circular-arc array



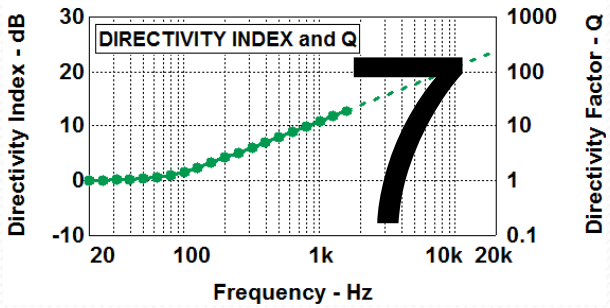
Analysis: Directivity Uniformity

- Legendre-shaded delay-curved CBT straight-line array

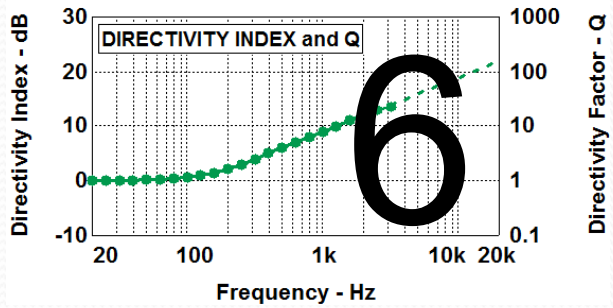


Directivity Ranking

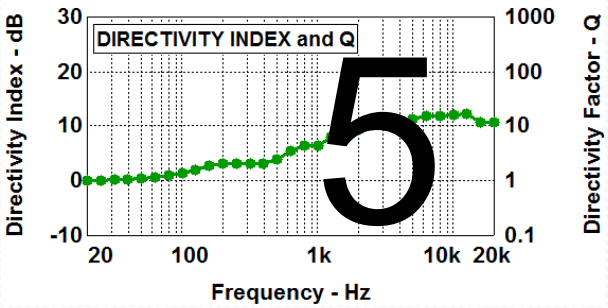
Un-Shaded Straight-Line Array



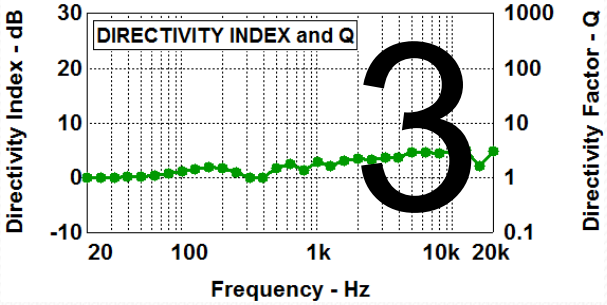
Shaded Straight-Line Array



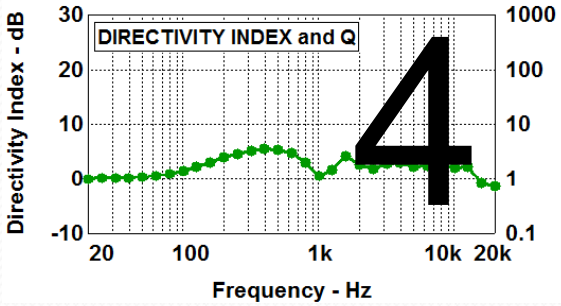
Un-Shaded "J"-Line Array



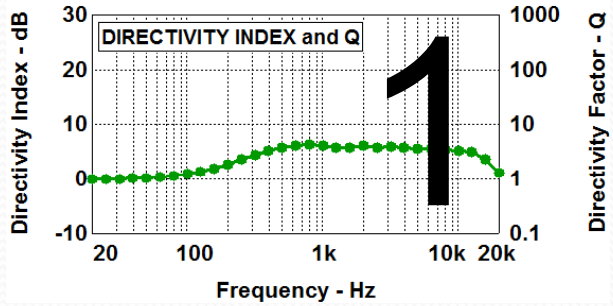
Un-Shaded Spiral-Line Array



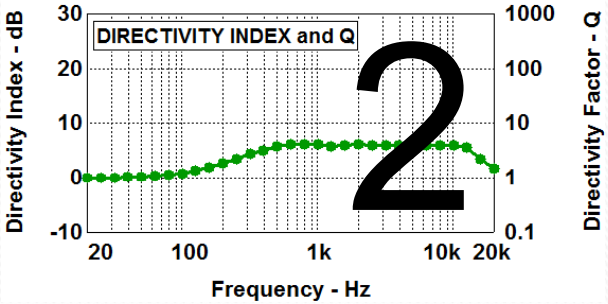
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array

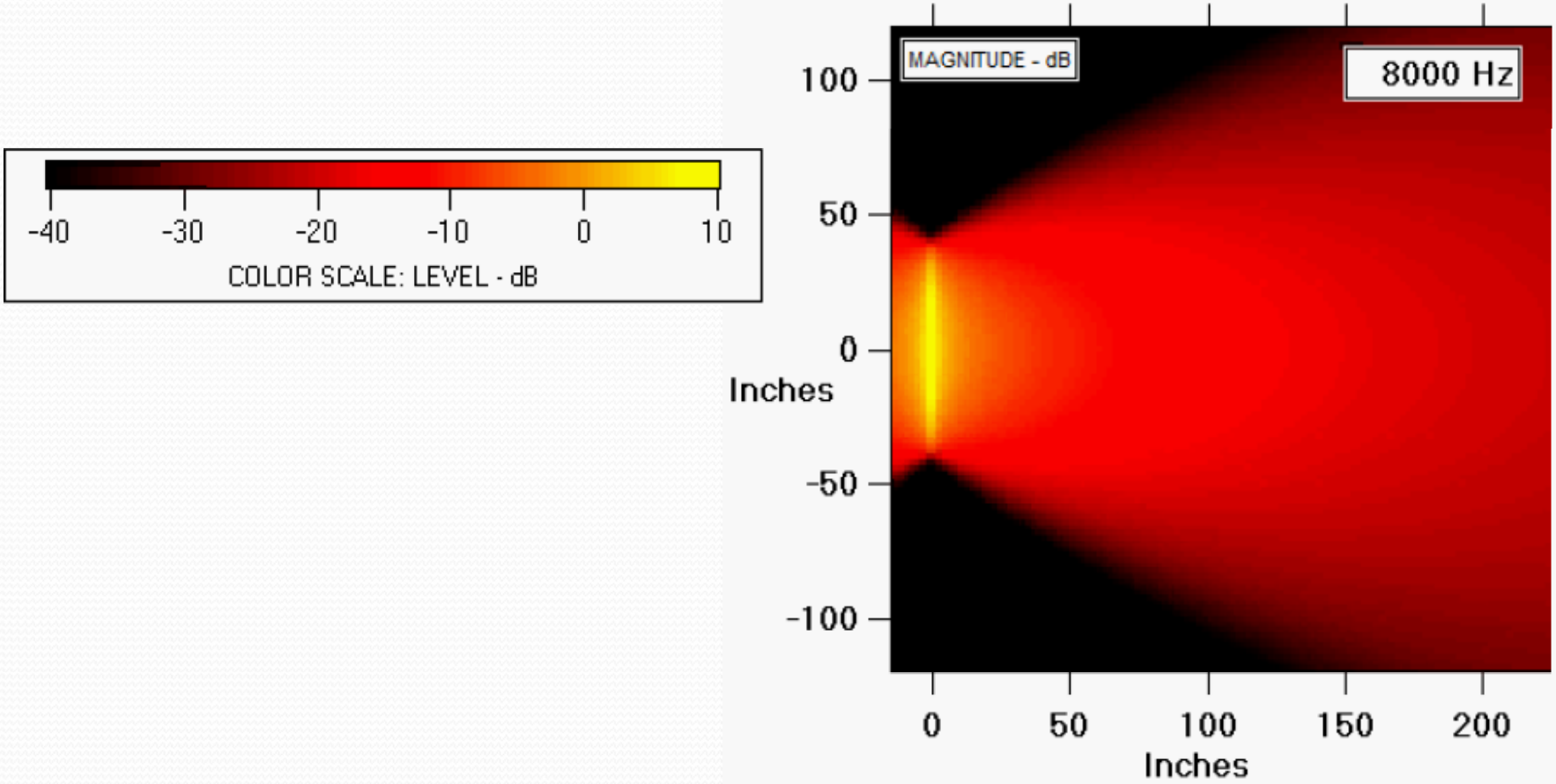


Shaded Delay-Curved CBT Straight-Line array

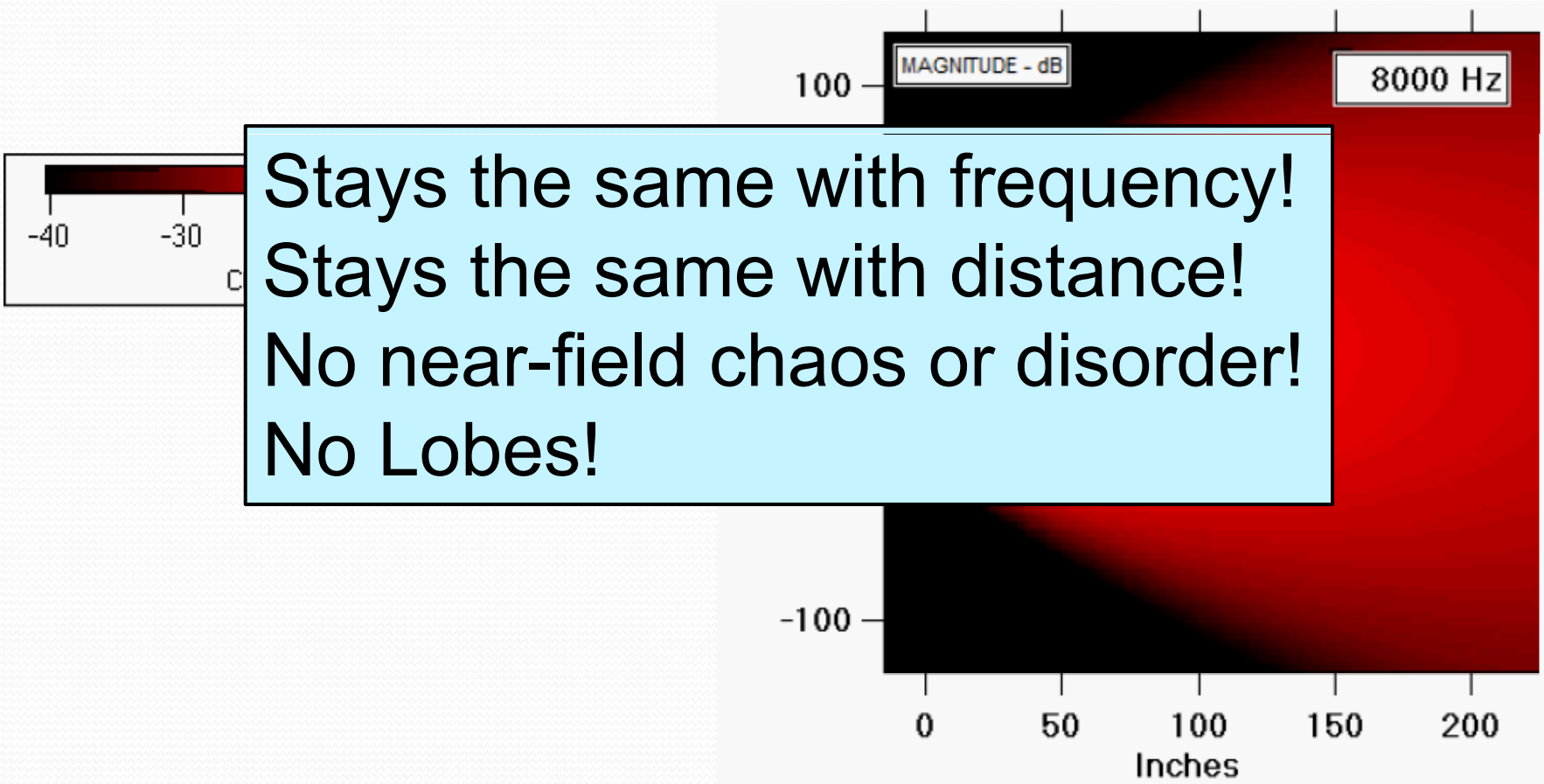


Analysis: Sound-Field Uniformity with Frequency

Ideal Vertical Sound-Field



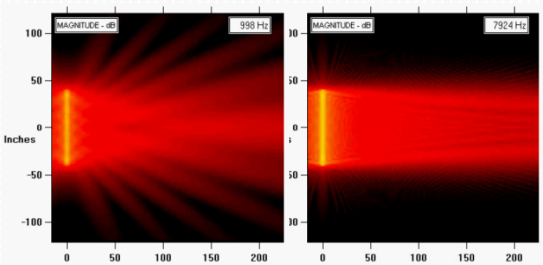
Analysis: Sound-Field Uniformity
Ideal Vertical Sound-Field



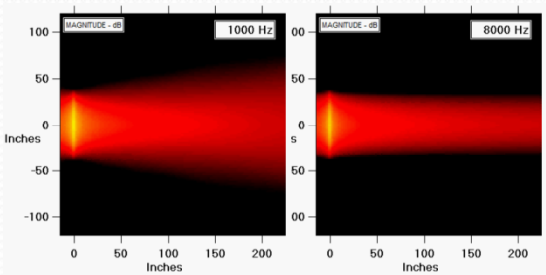
Stays the same with frequency!
Stays the same with distance!
No near-field chaos or disorder!
No Lobes!

Analysis: Sound-Field Uniformity

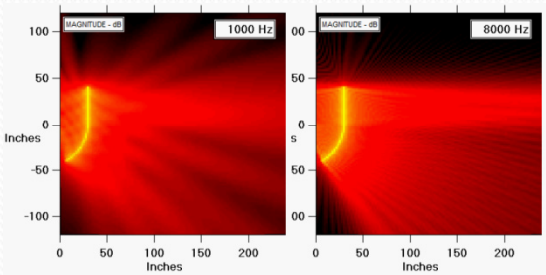
Un-Shaded Straight-Line Array



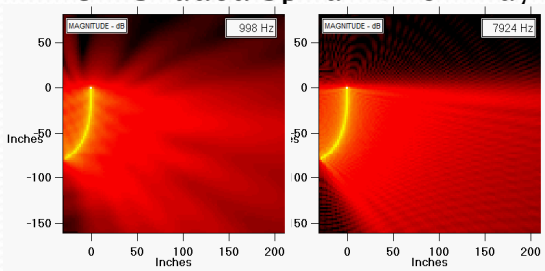
Shaded Straight-Line Array



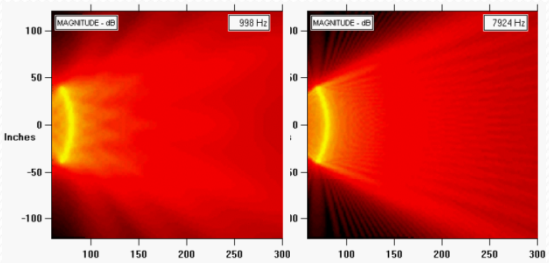
Un-Shaded "J"-Line Array



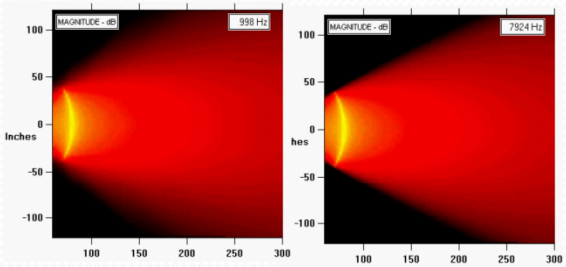
Un-Shaded Spiral-Line Array



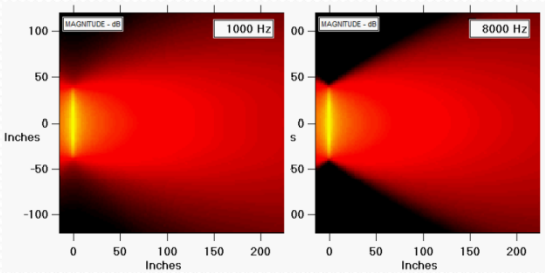
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



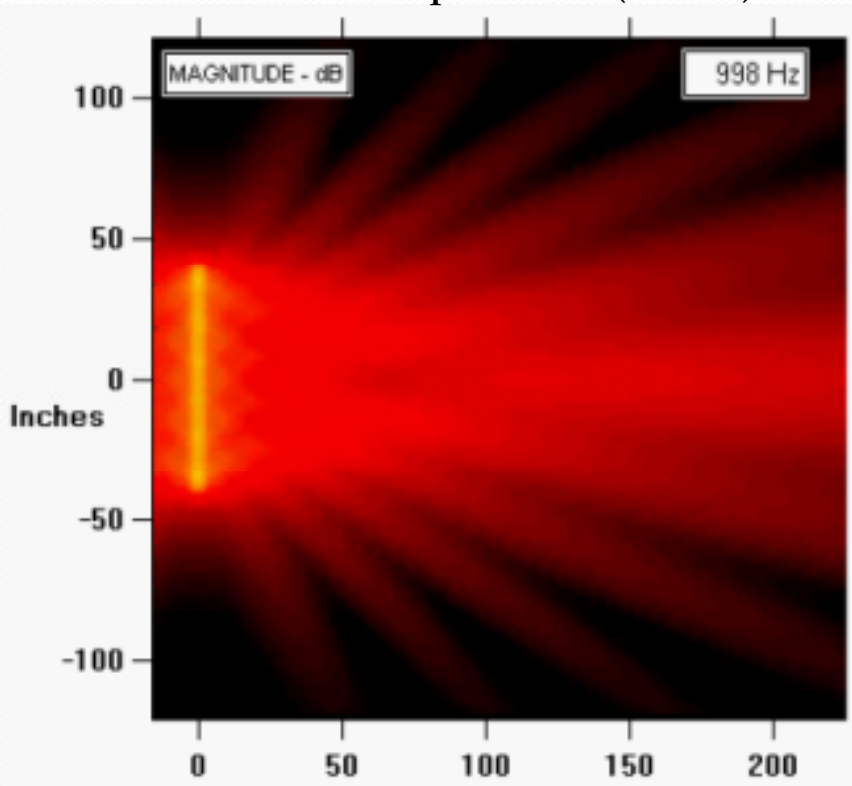
Shaded Delay-Curved CBT Straight-Line array



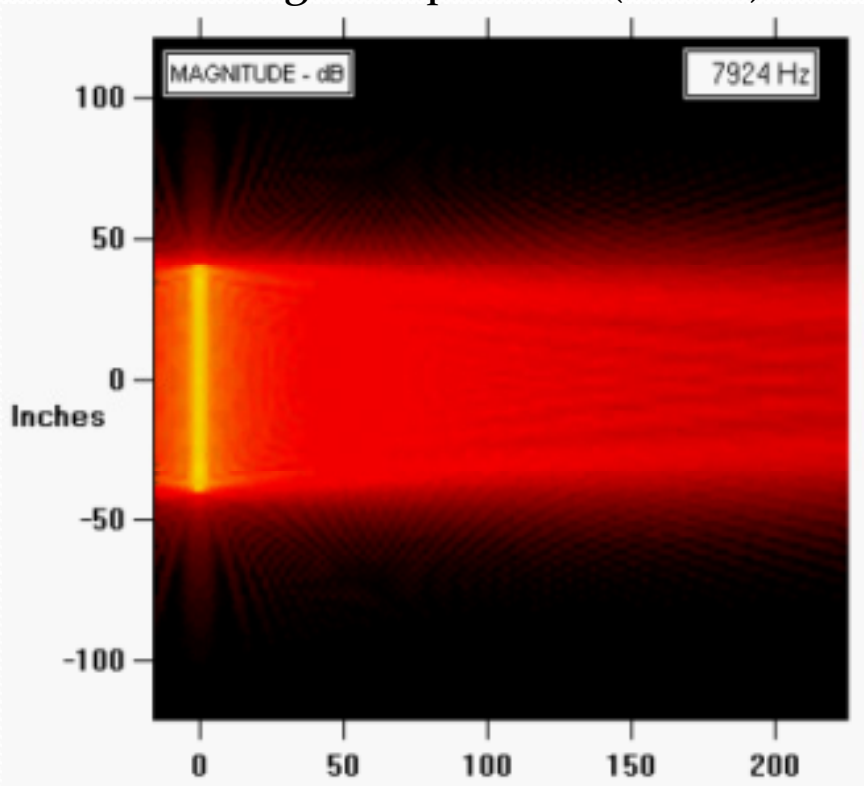
Analysis: Sound-Field Uniformity

- Un-shaded straight-line array

Mid Frequencies (1 kHz)



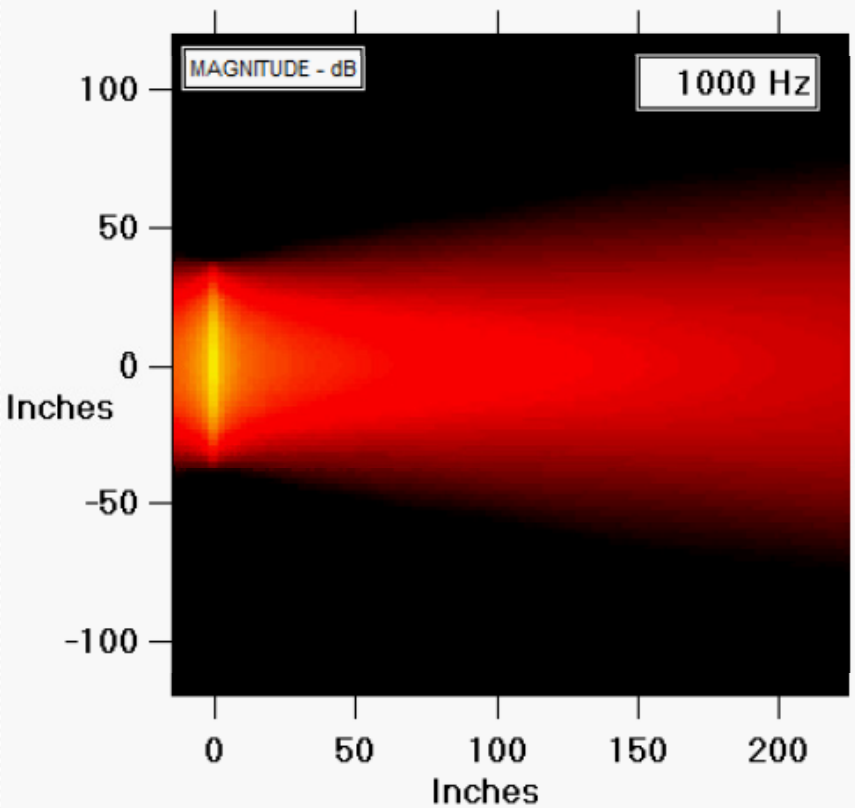
High Frequencies (8 kHz)



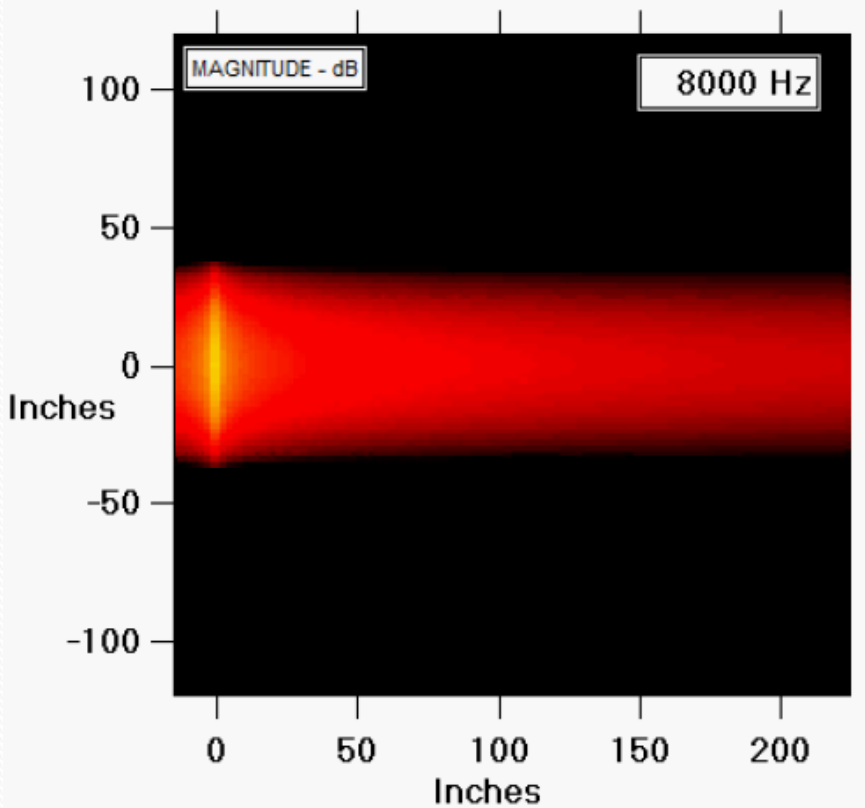
Analysis: Sound-Field Uniformity

- Hann-shaded straight-line array

Mid Frequencies (1 kHz)



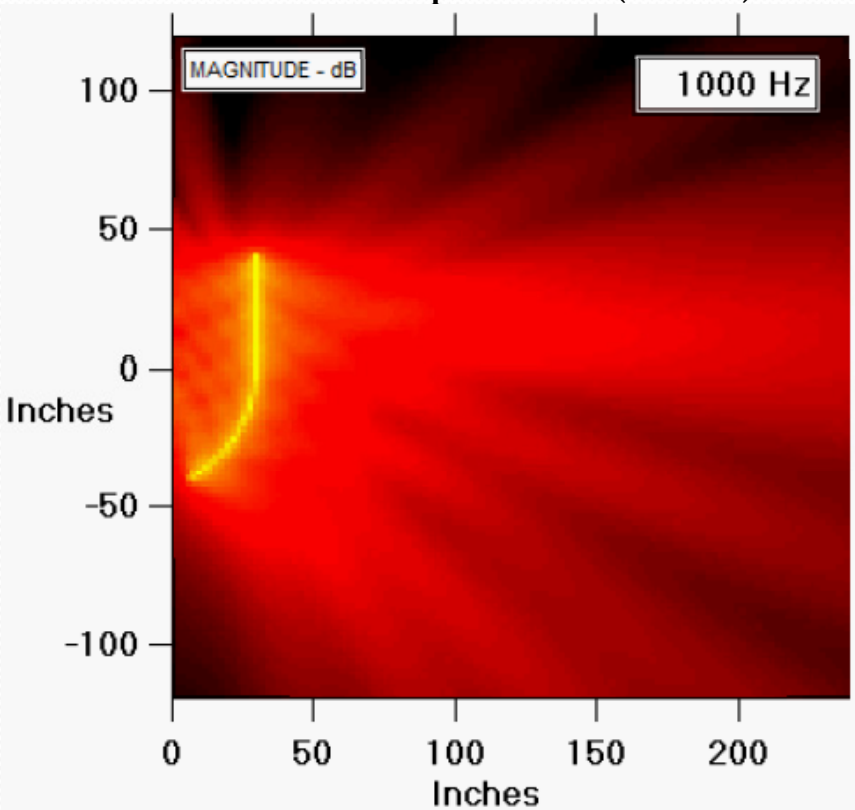
High Frequencies (8 kHz)



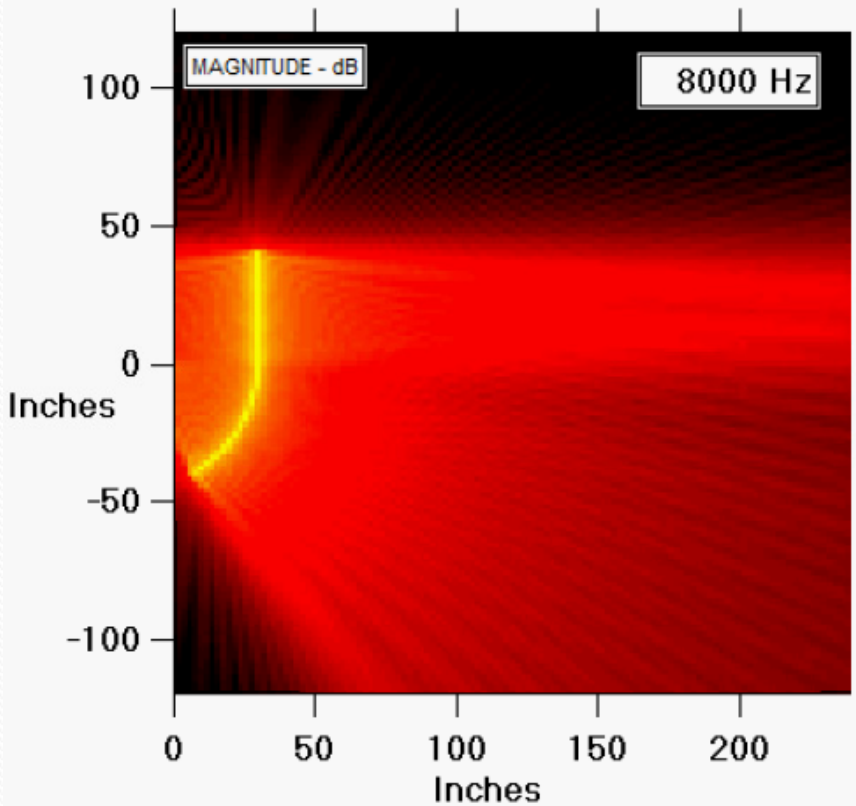
Analysis: Sound-Field Uniformity

- Un-shaded "J"-line array

Mid Frequencies (1 kHz)



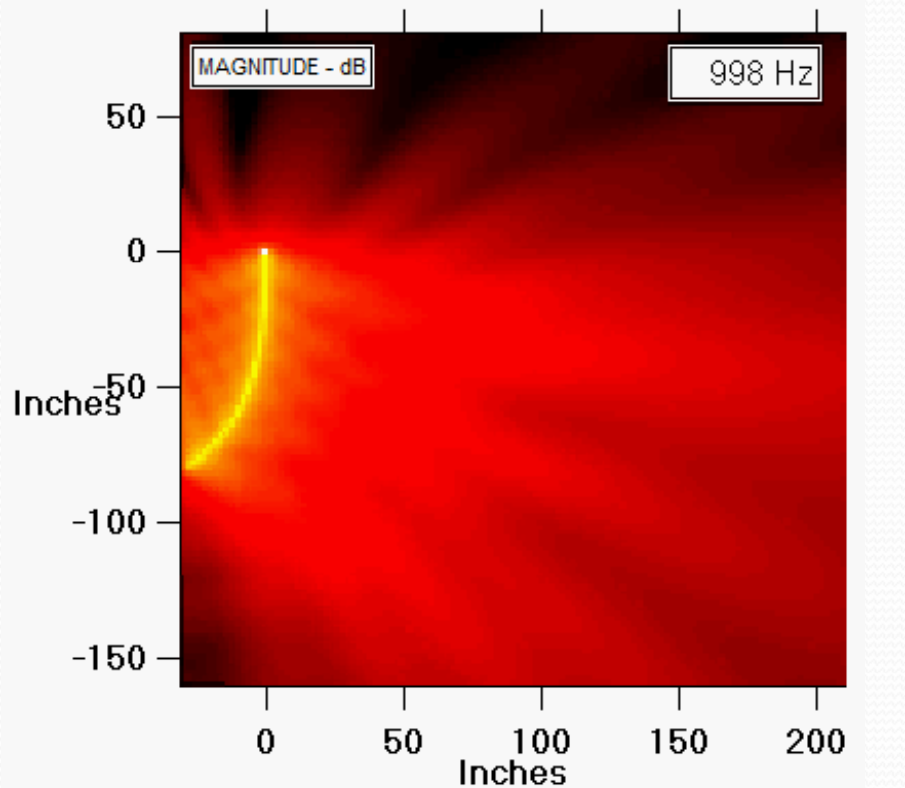
High Frequencies (8 kHz)



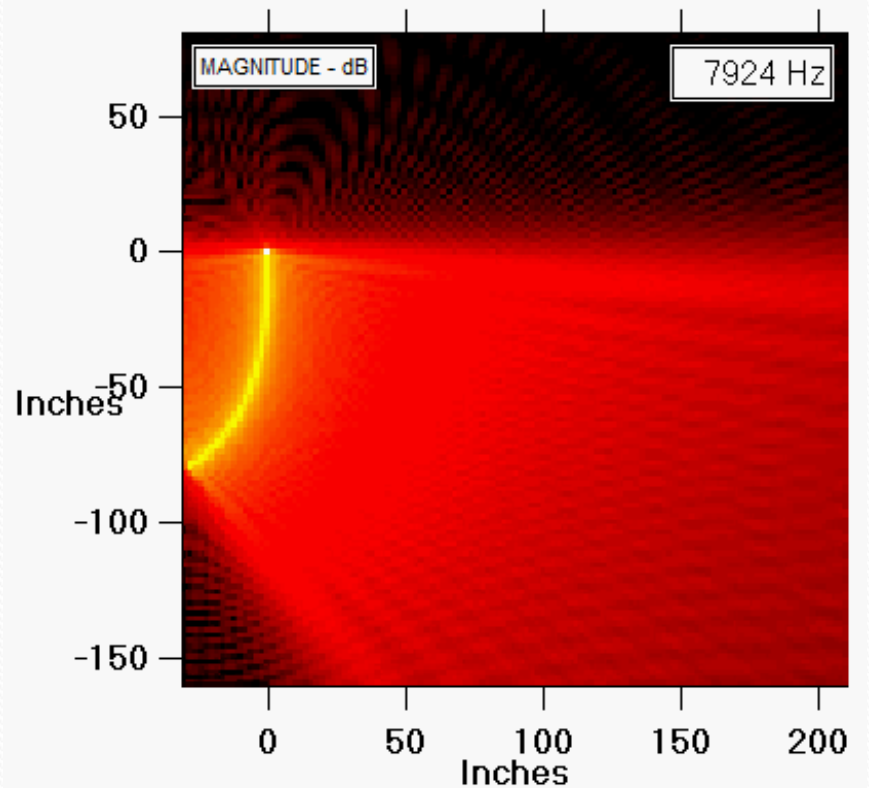
Analysis: Sound-Field Uniformity

- Un-shaded spiral- or progressive-line array

Mid Frequencies (1 kHz)



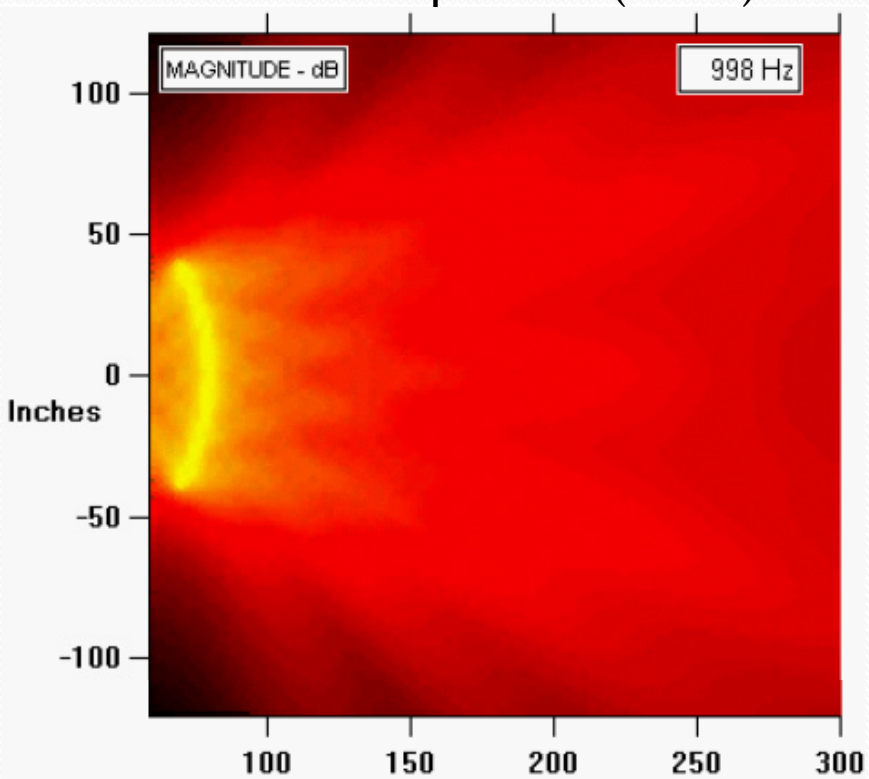
High Frequencies (8 kHz)



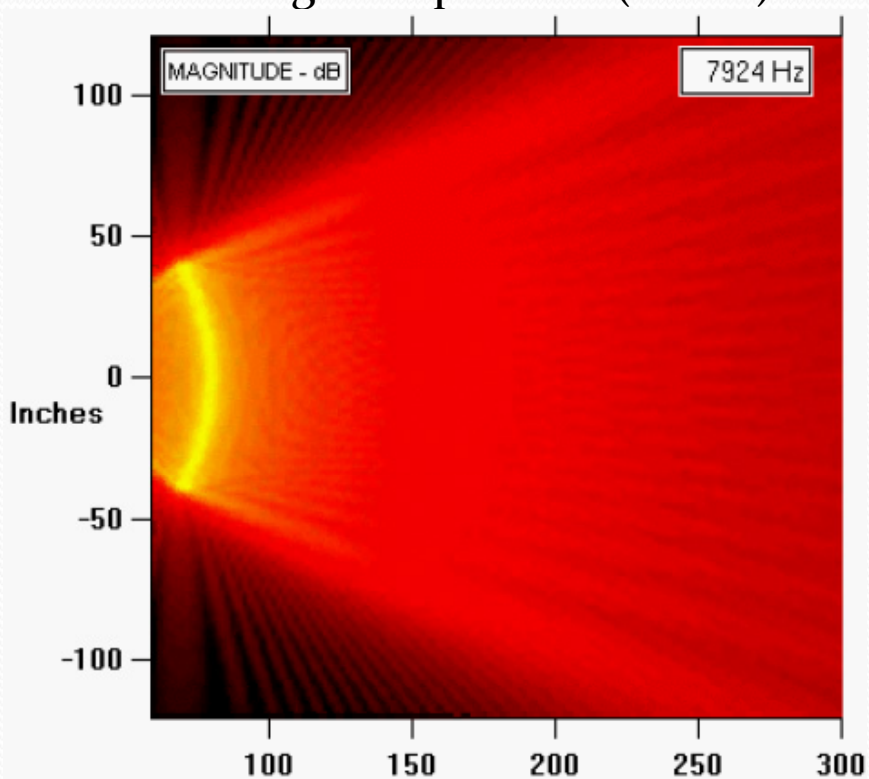
Analysis: Sound-Field Uniformity

- Un-shaded circular-arc array

Mid Frequencies (1 kHz)



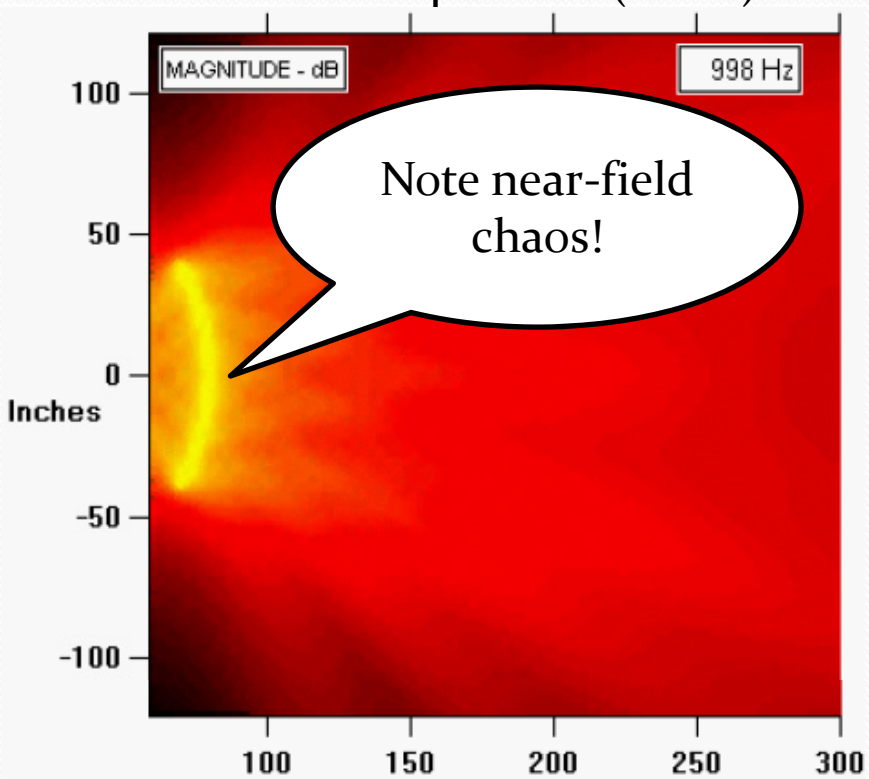
High Frequencies (8 kHz)



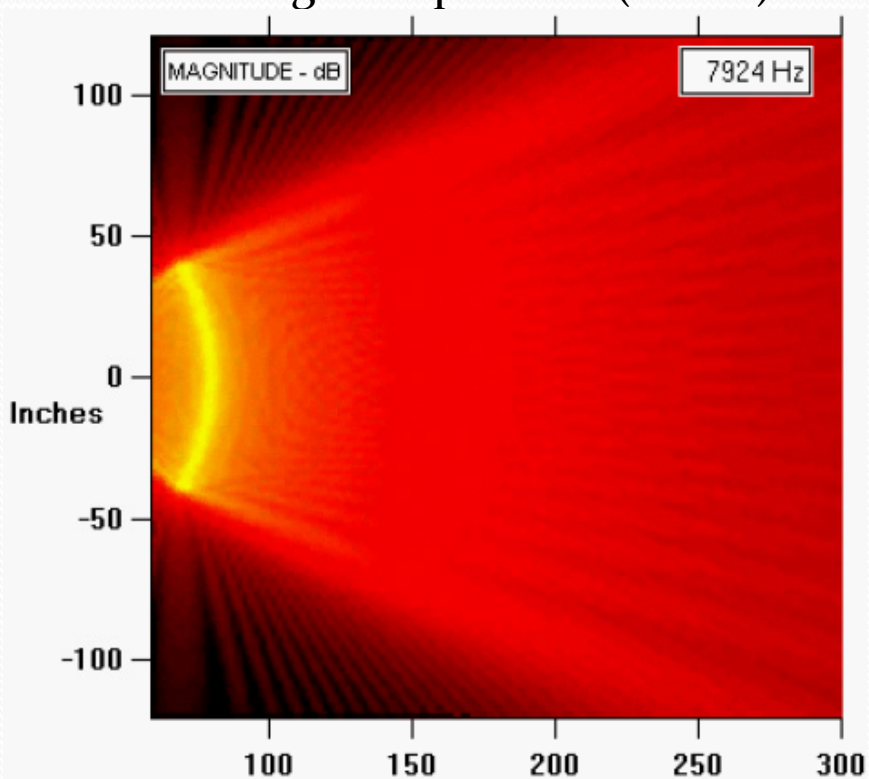
Analysis: Sound-Field Uniformity

- Un-shaded circular-arc array

Mid Frequencies (1 kHz)



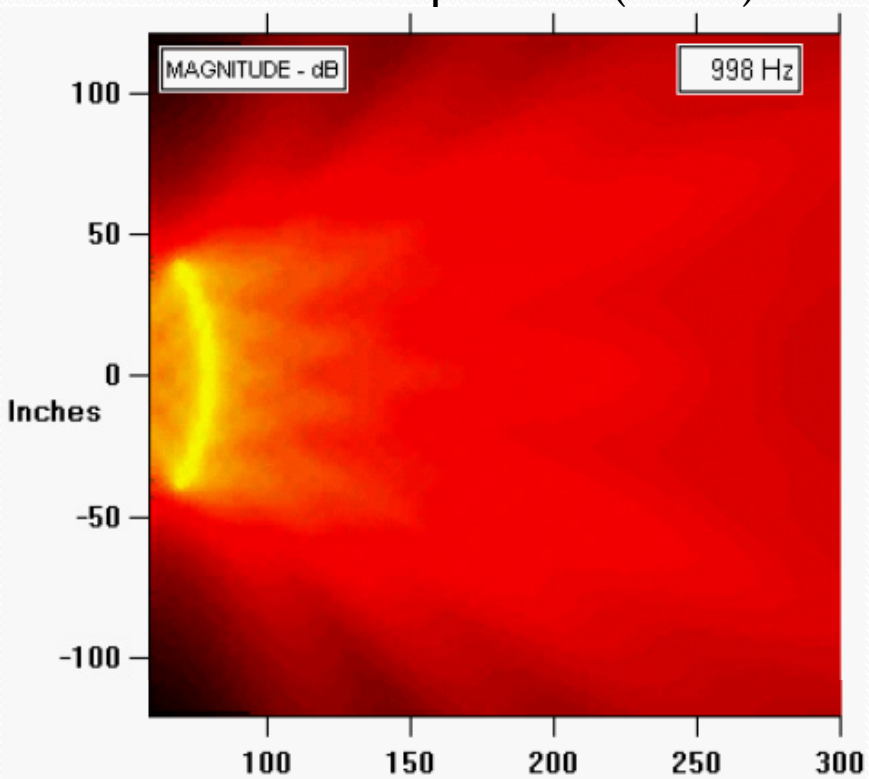
High Frequencies (8 kHz)



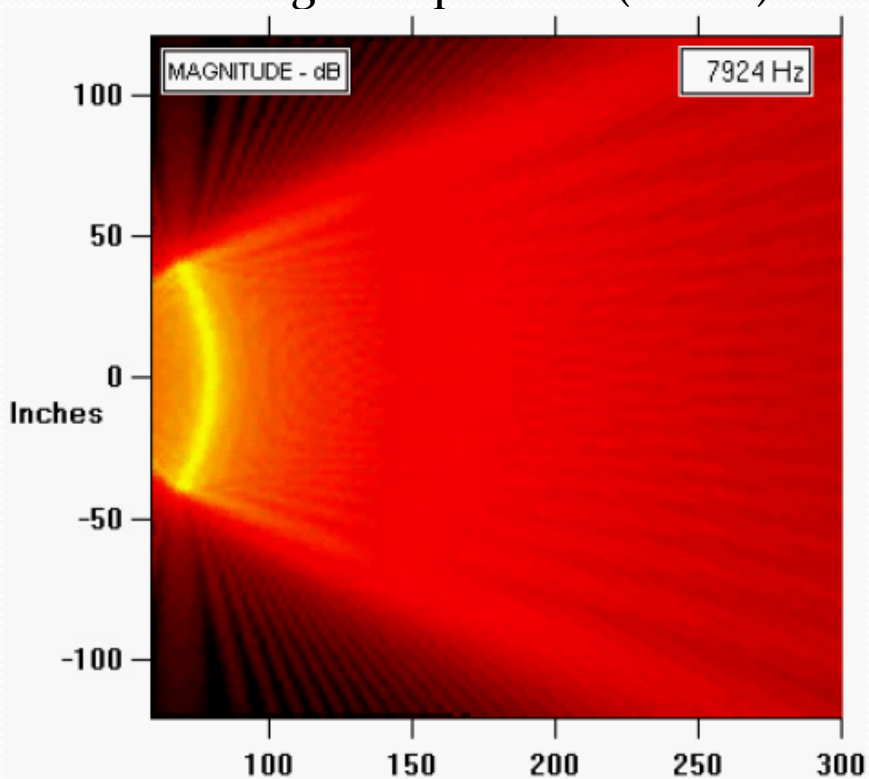
Analysis: Sound-Field Uniformity

- Un-shaded circular-arc array

Mid Frequencies (1 kHz)



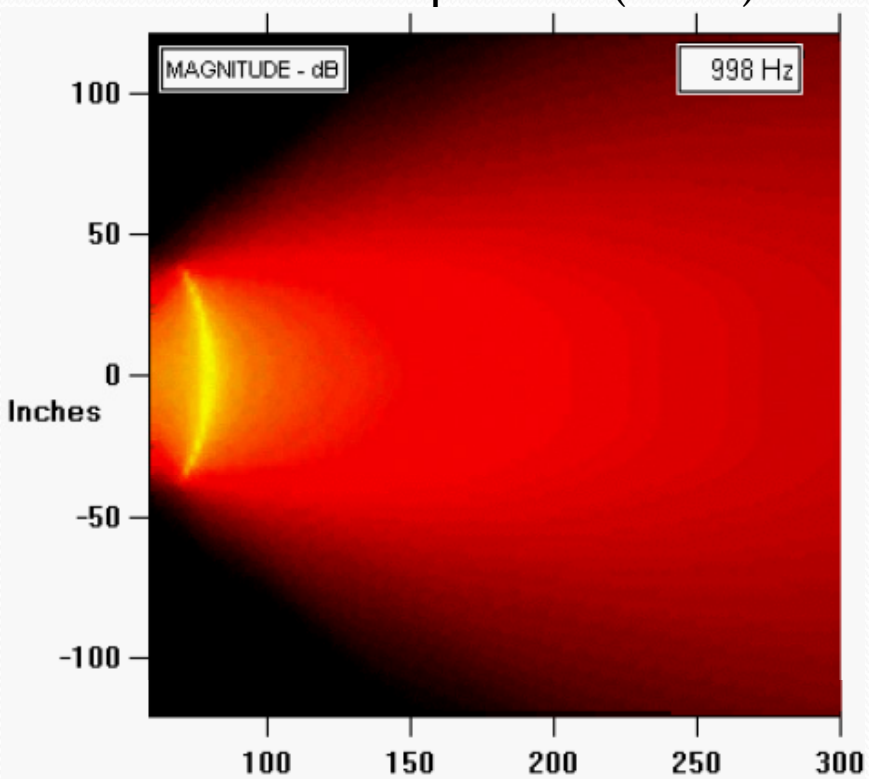
High Frequencies (8 kHz)



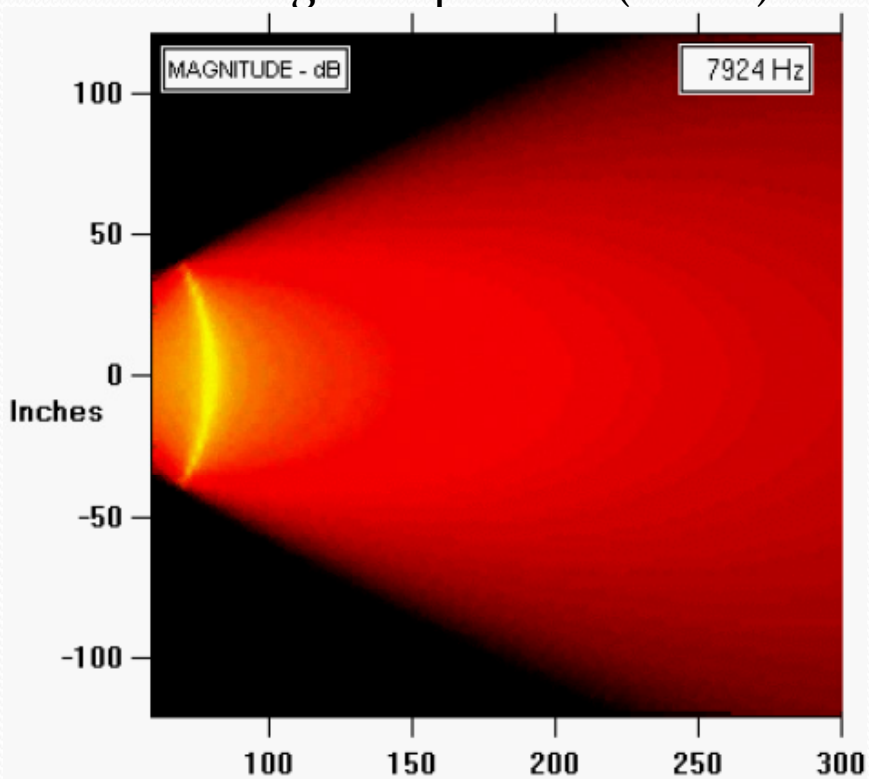
Analysis: Sound-Field Uniformity

- Legendre-shaded CBT circular-arc array

Mid Frequencies (1 kHz)



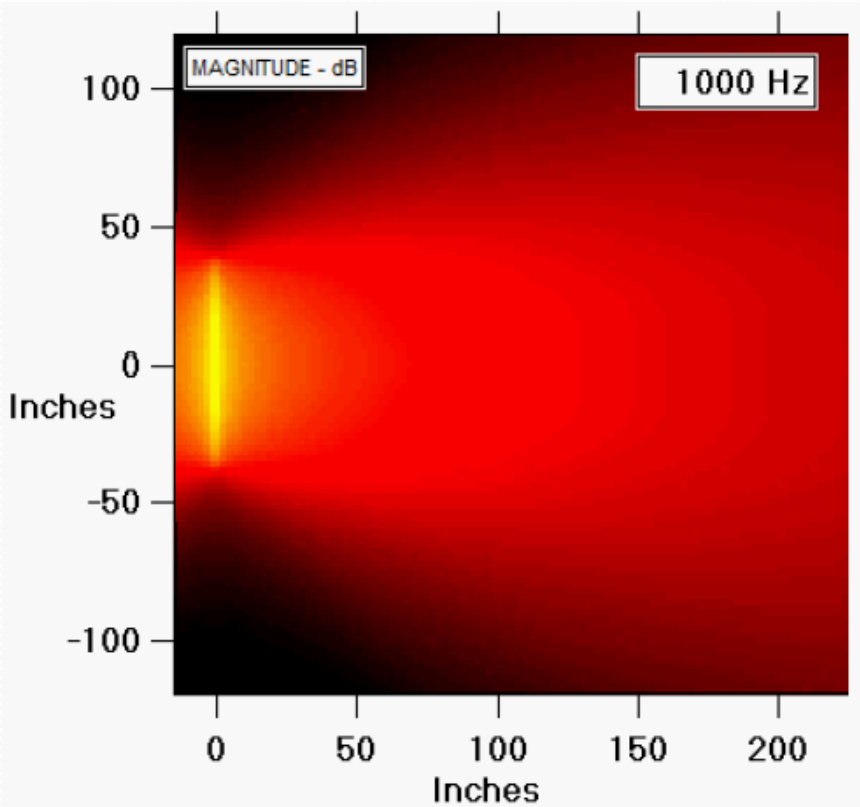
High Frequencies (8 kHz)



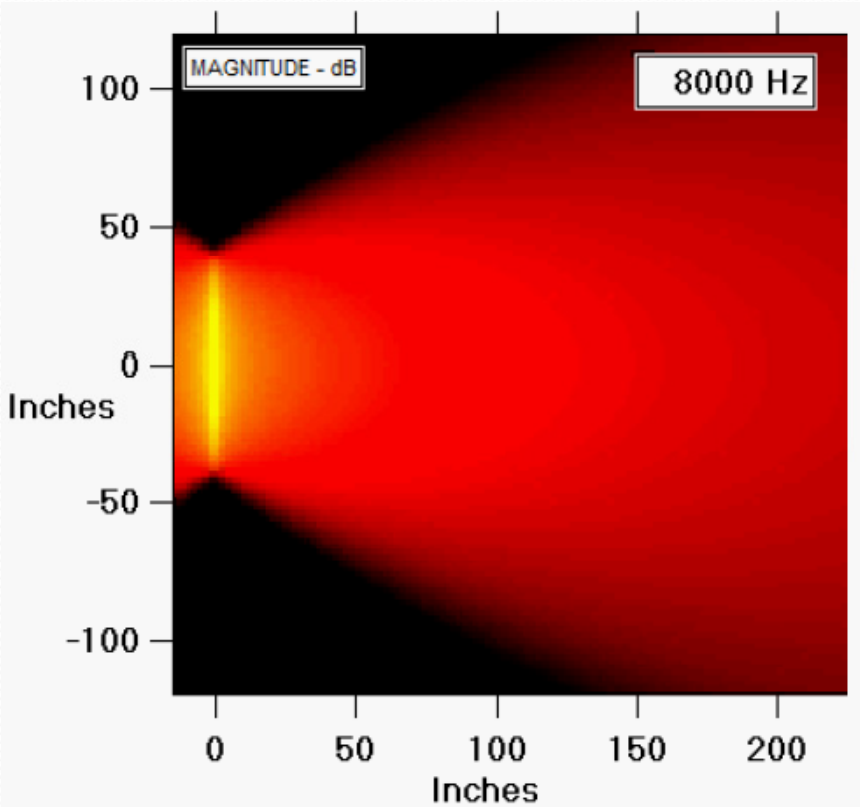
Analysis: Sound-Field Uniformity

- Legendre-shaded delay-curved CBT straight-line array

Mid Frequencies (1 kHz)

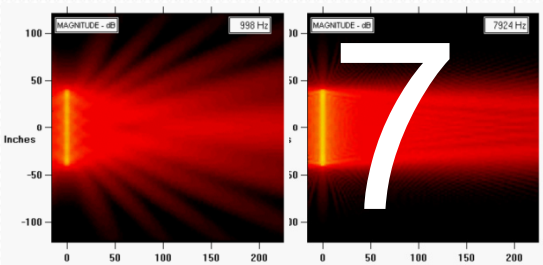


High Frequencies (8 kHz)

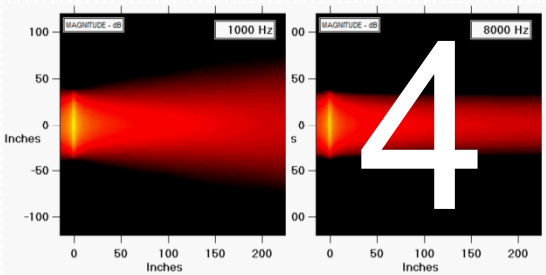


Analysis: Sound-Field Ranking

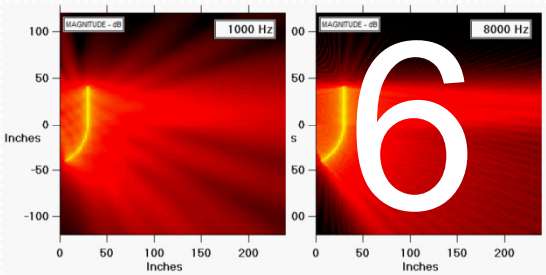
Un-Shaded Straight-Line Array



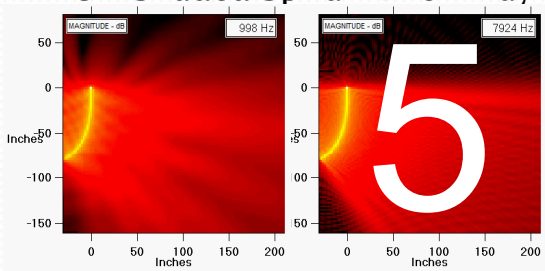
Shaded Straight-Line Array



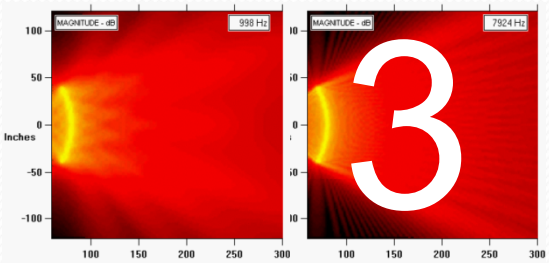
Un-Shaded "J"-Line Array



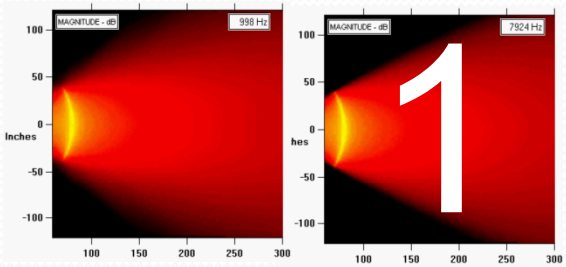
Un-Shaded Spiral-Line Array



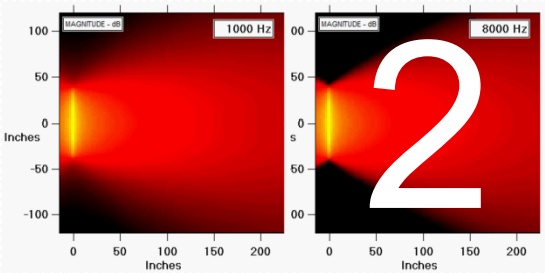
Un-Shaded Circular-Arc Line Array



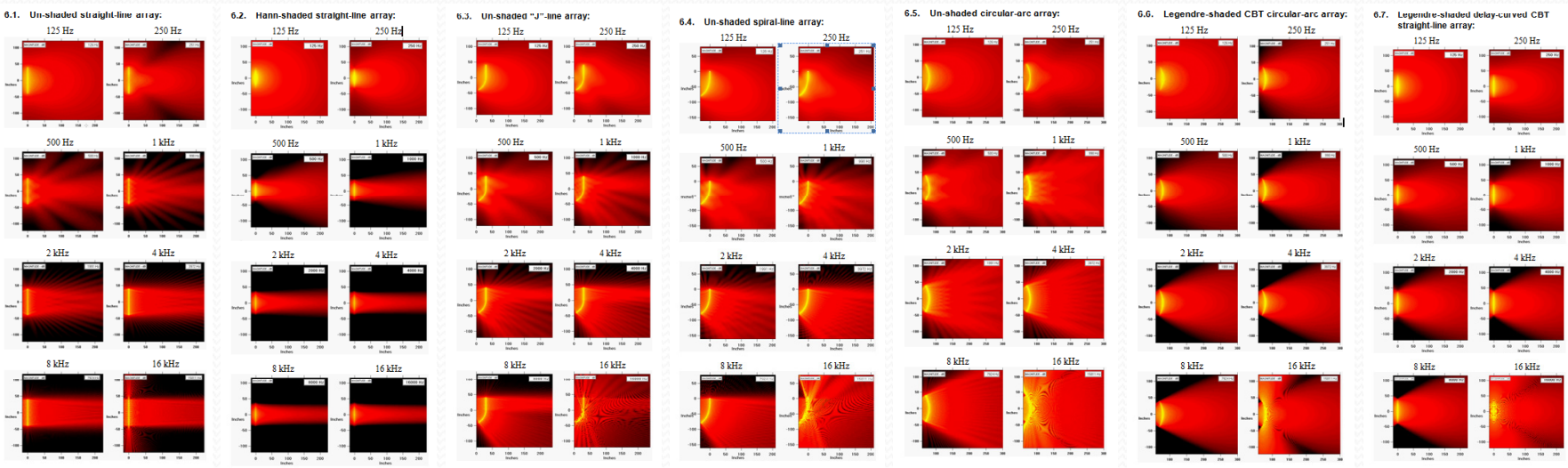
Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array

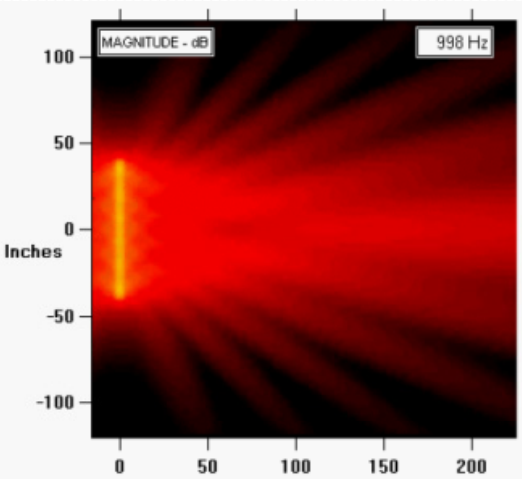


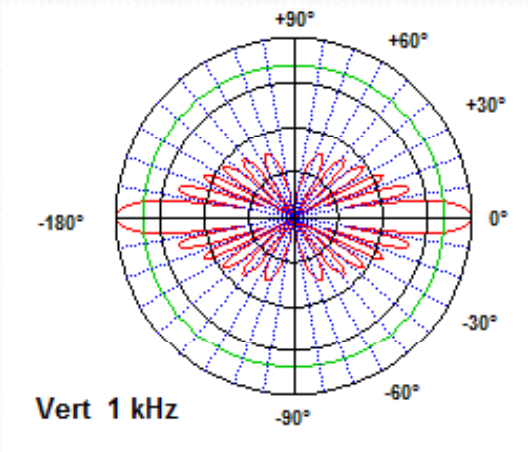
Analysis: Sound-Field Uniformity

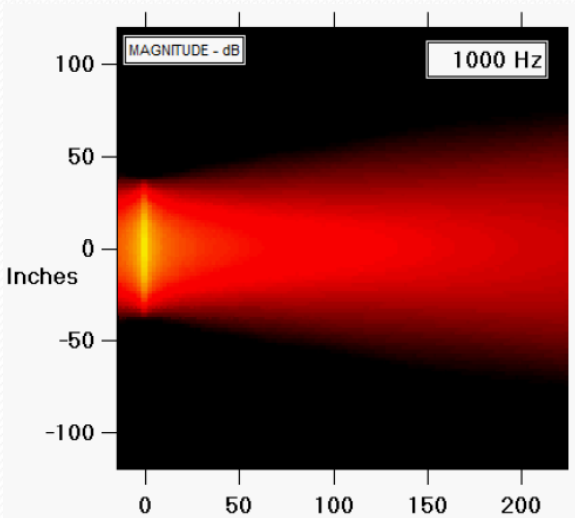


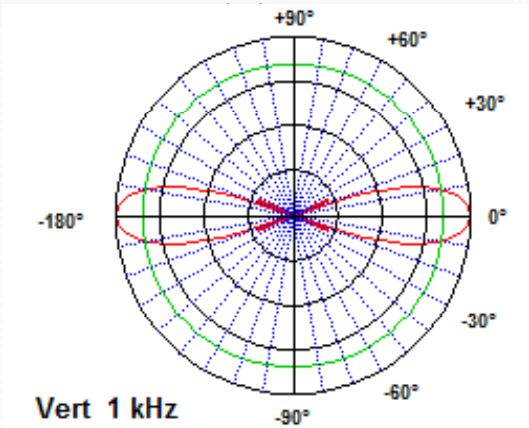
- Note: The appendix of my paper has a complete set of octave sound-fields for each array from 125 Hz to 16 kHz!

Analysis: Polar Side-Lobe Suppression



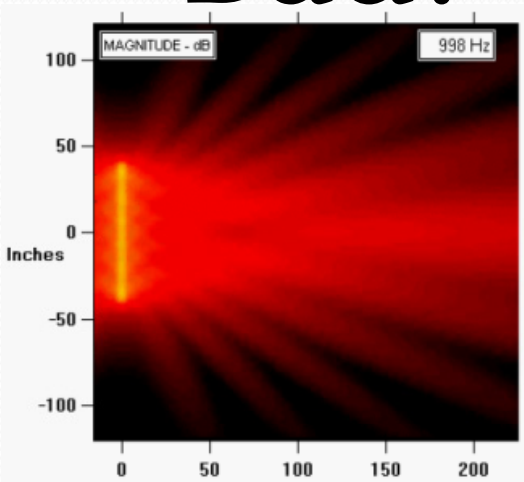


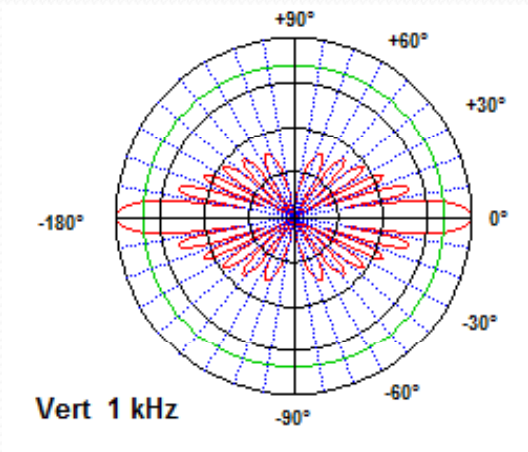




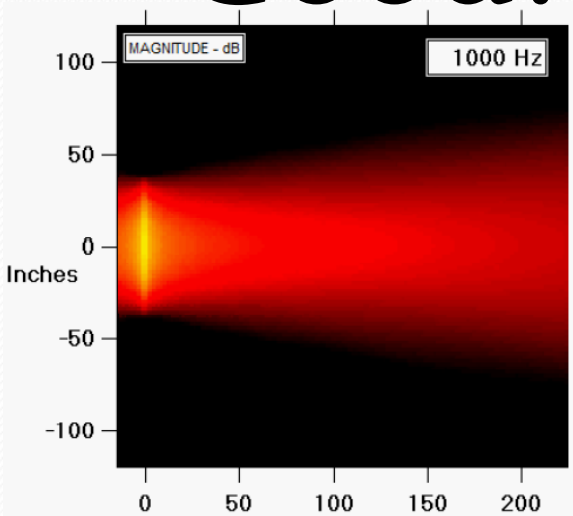
Analysis: Polar Side-Lobe Suppression

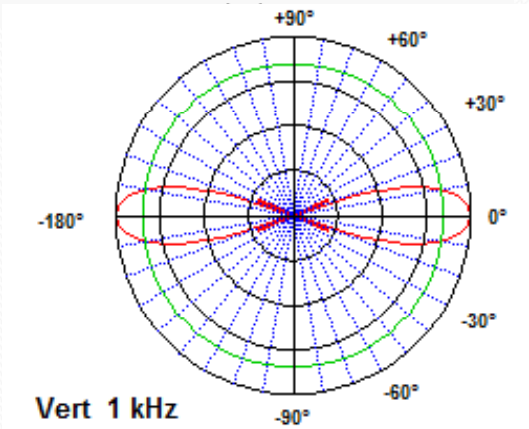
Bad!





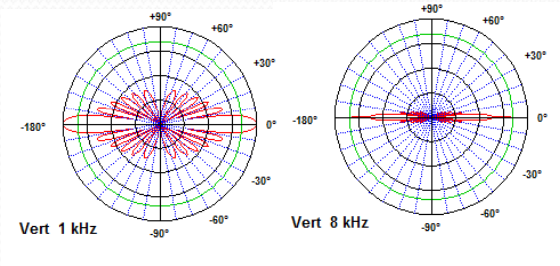
Good!



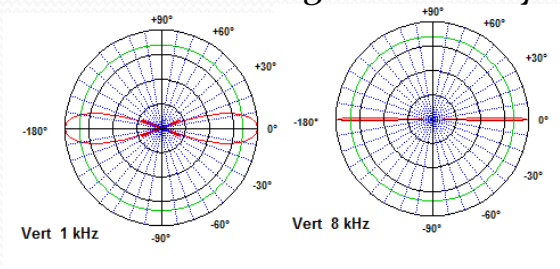


Analysis: Polar Side-Lobe Suppression

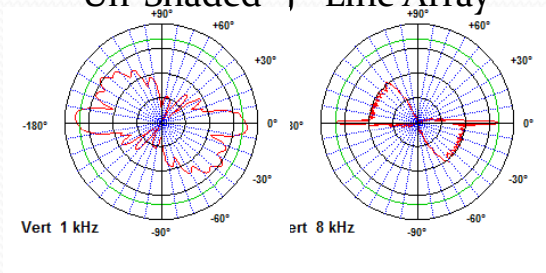
Un-Shaded Straight-Line Array



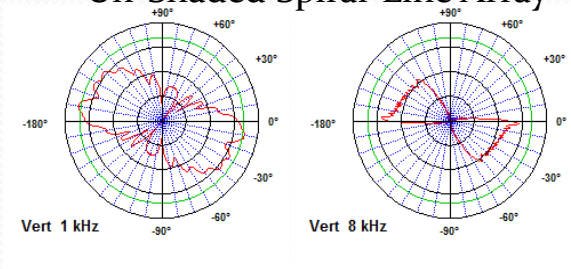
Shaded Straight-Line Array



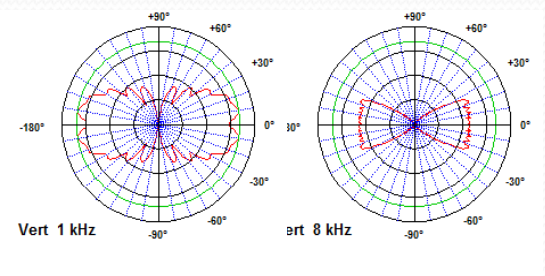
Un-Shaded "I"-Line Array



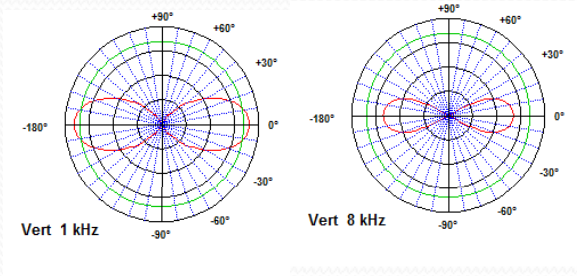
Un-Shaded Spiral-Line Array



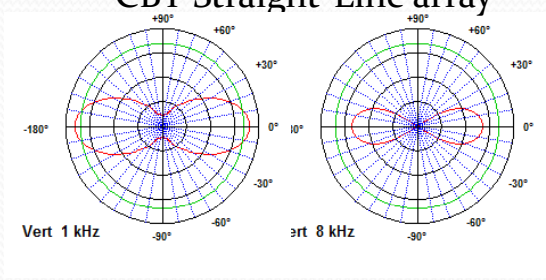
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



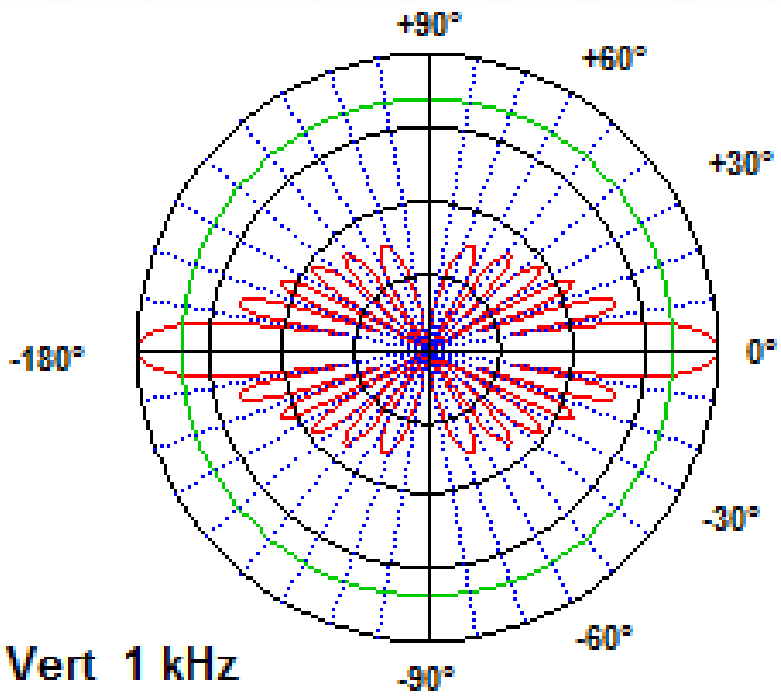
Shaded Delay-Curved CBT Straight-Line array



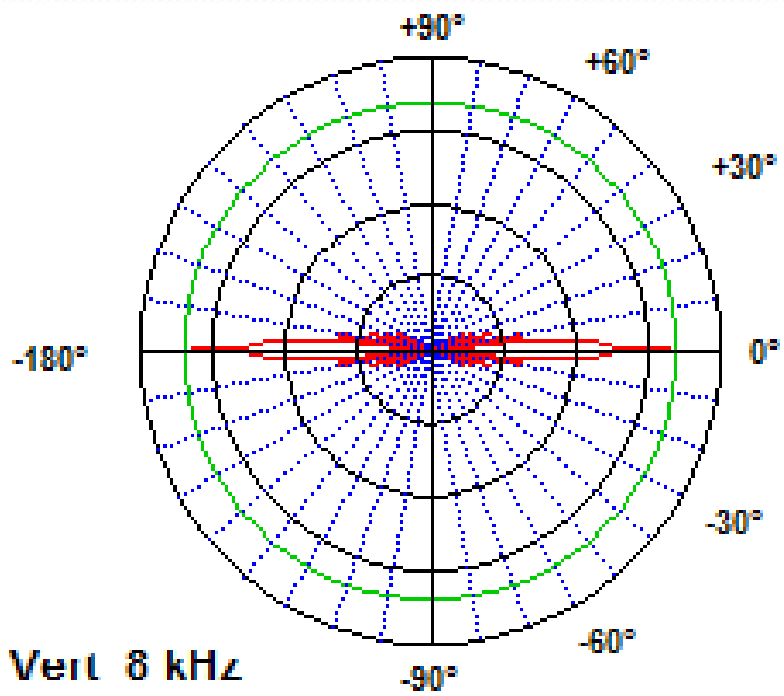
Analysis: Polar Side-Lobe Suppression

- Un-shaded straight-line array

Mid Frequencies (1 kHz)



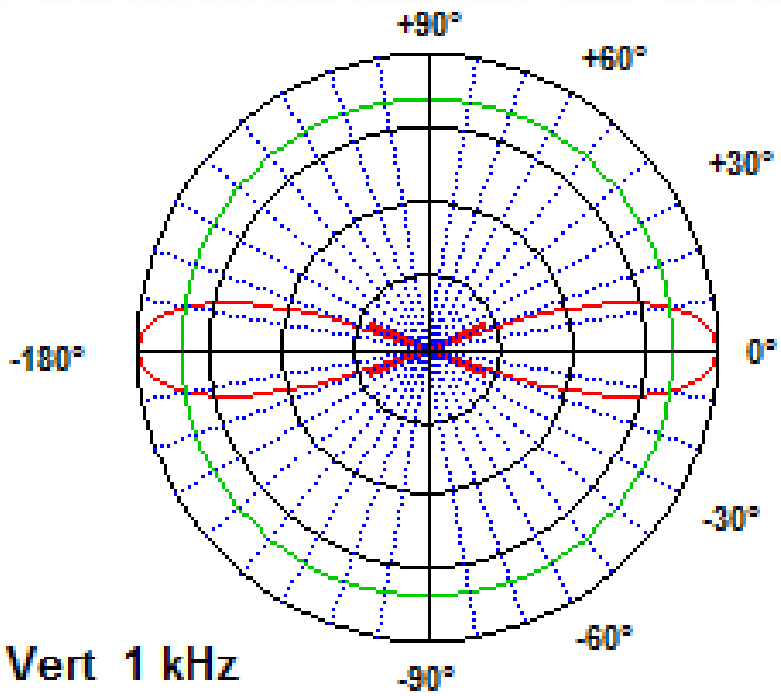
High Frequencies (8 kHz)



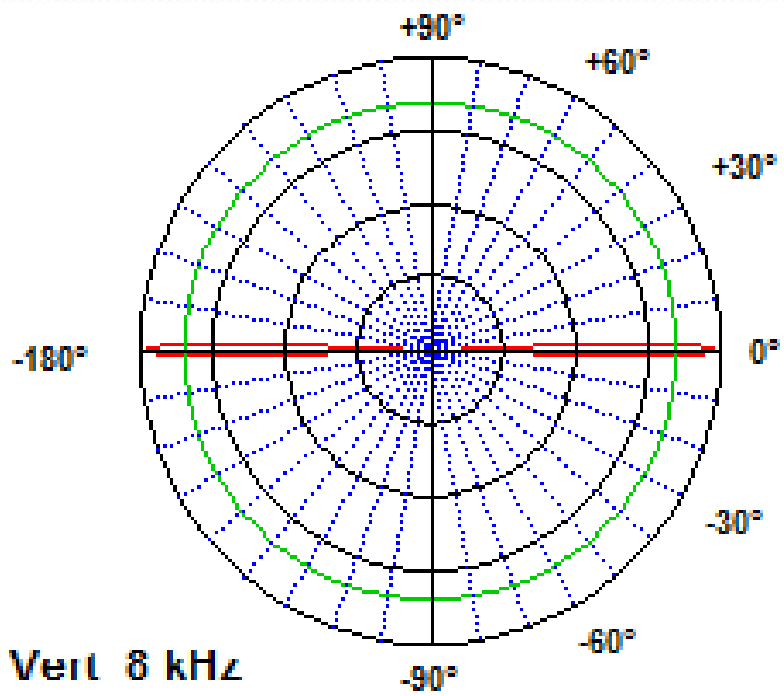
Analysis: Polar Side-Lobe Suppression

- Hann-shaded straight-line array

Mid Frequencies (1 kHz)



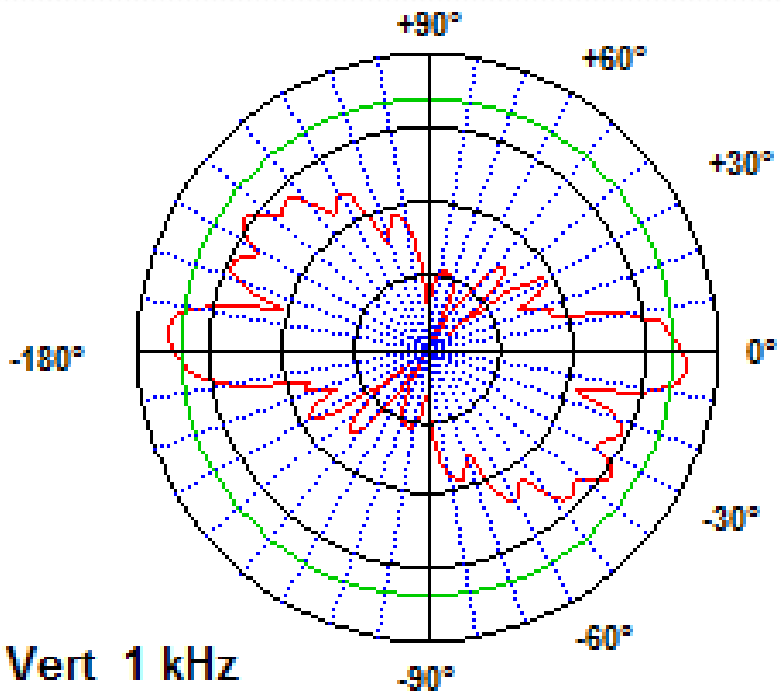
High Frequencies (8 kHz)



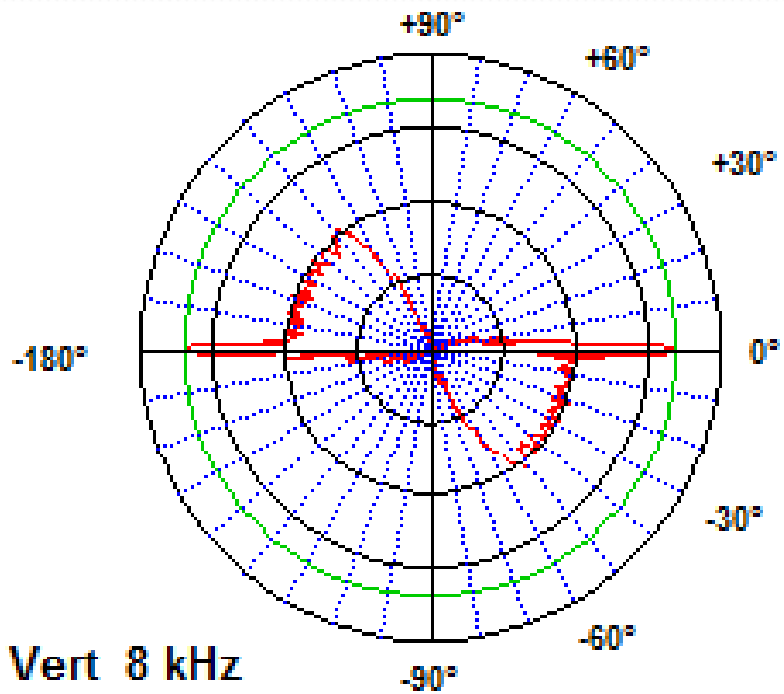
Analysis: Polar Side-Lobe Suppression

- Un-shaded "J"-line array

Mid Frequencies (1 kHz)



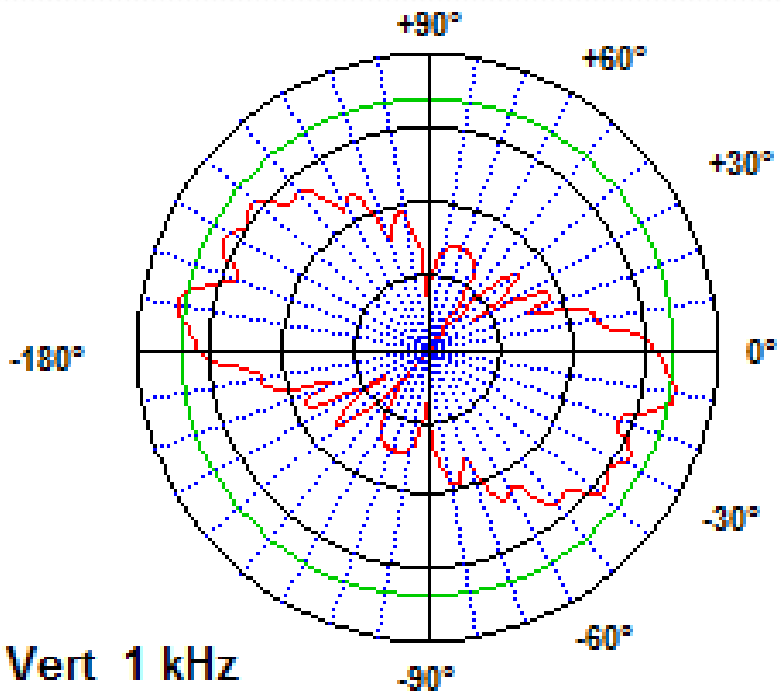
High Frequencies (8 kHz)



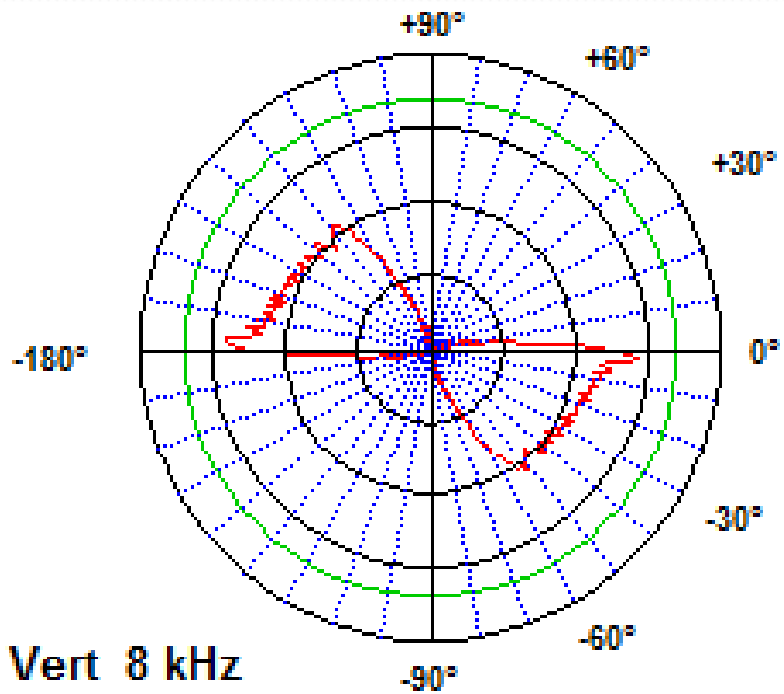
Analysis: Polar Side-Lobe Suppression

- Un-shaded spiral- or progressive-line array

Mid Frequencies (1 kHz)



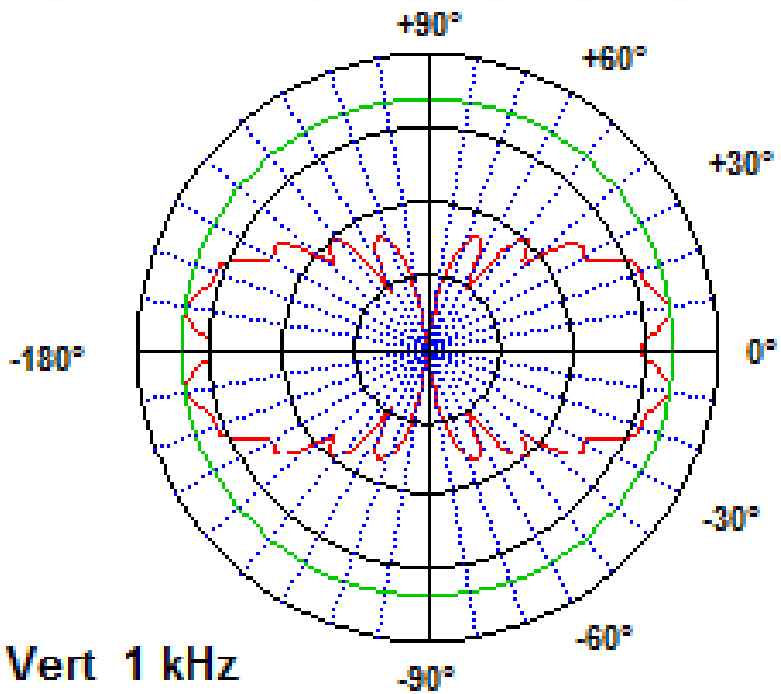
High Frequencies (8 kHz)



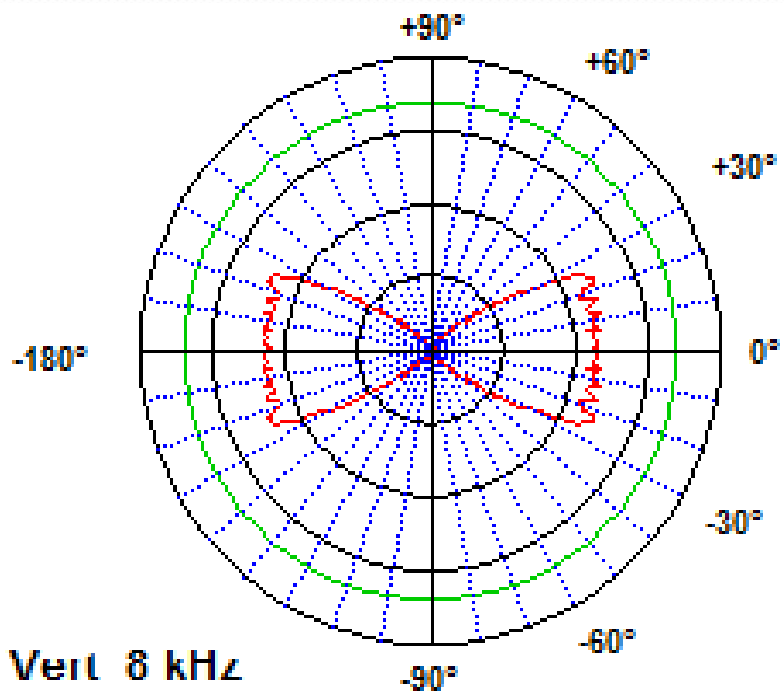
Analysis: Polar Side-Lobe Suppression

- Un-shaded circular-arc array

Mid Frequencies (1 kHz)



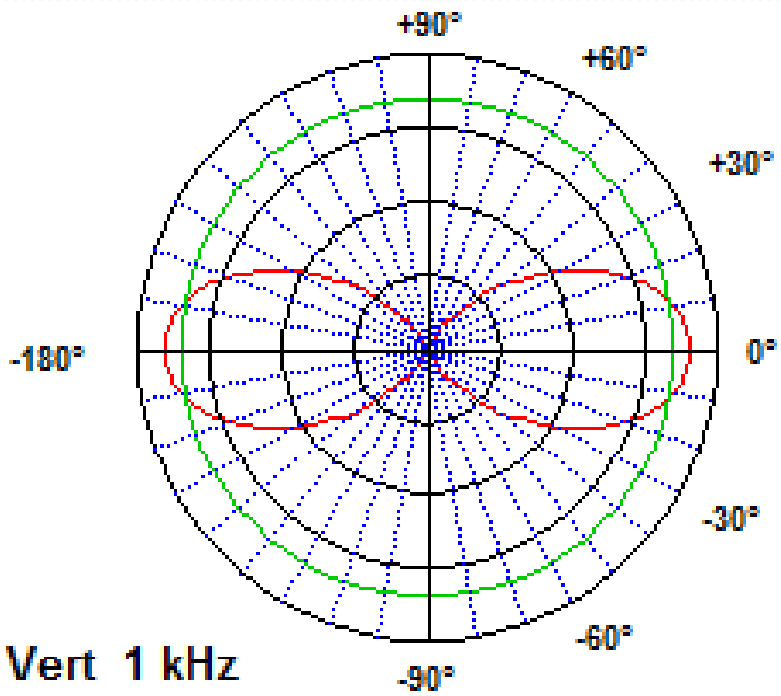
High Frequencies (8 kHz)



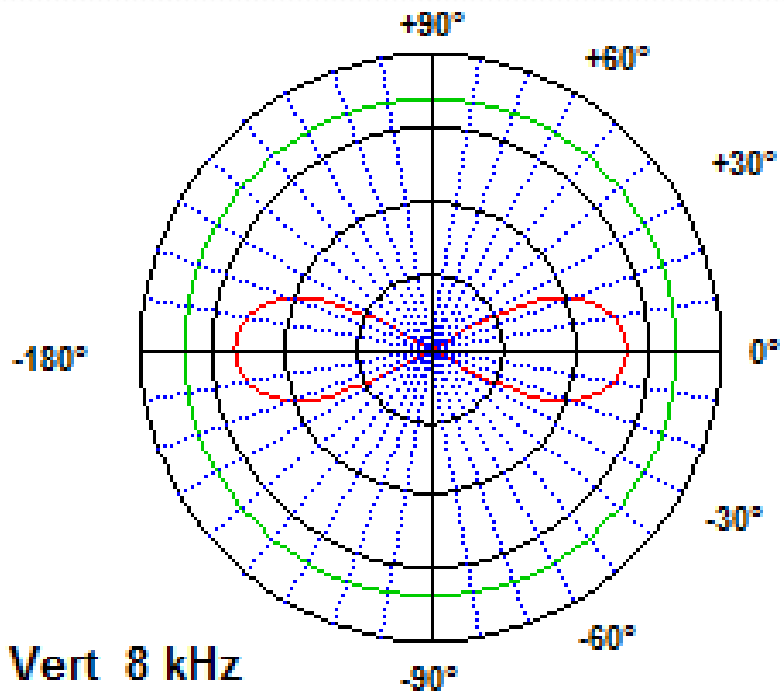
Analysis: Polar Side-Lobe Suppression

- Legendre-shaded CBT circular-arc array

Mid Frequencies (1 kHz)



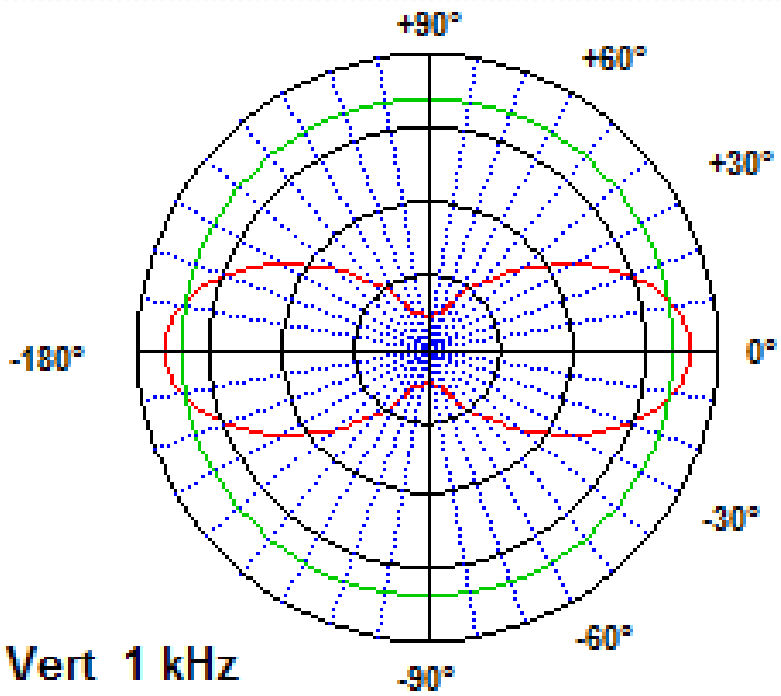
High Frequencies (8 kHz)



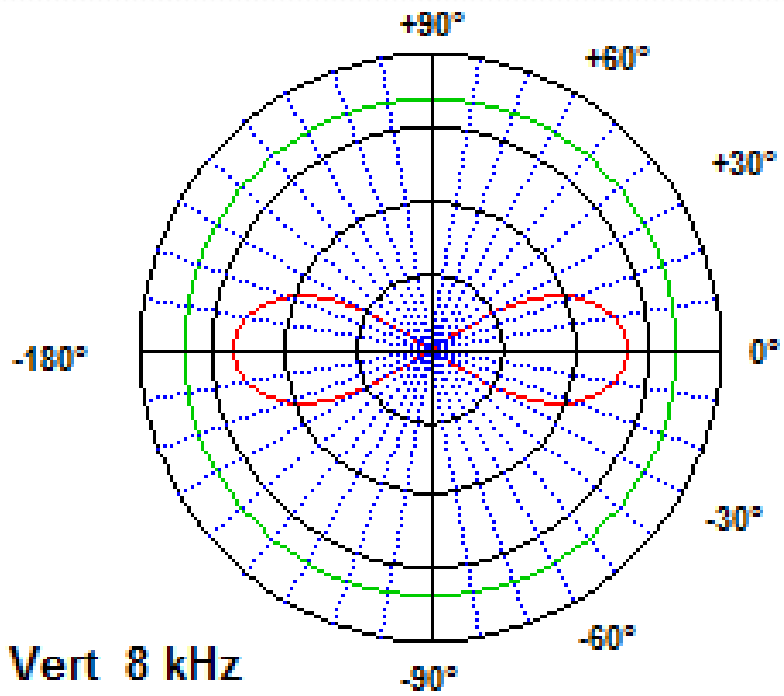
Analysis: Polar Side-Lobe Suppression

- Legendre-shaded delay-curved CBT straight-line array

Mid Frequencies (1 kHz)

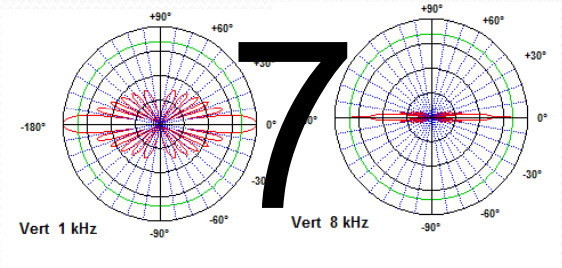


High Frequencies (8 kHz)

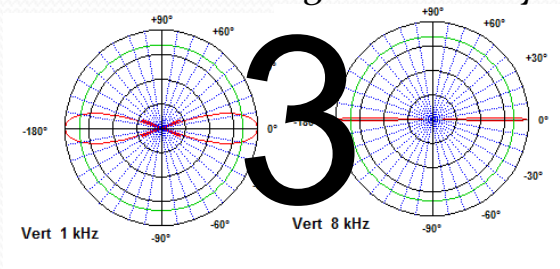


Analysis: Side-Lobe Supp. Ranking

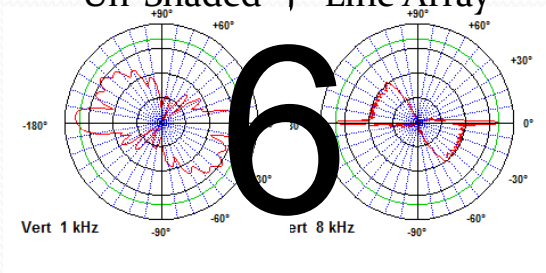
Un-Shaded Straight-Line Array



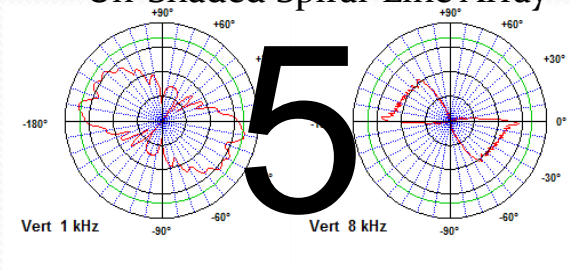
Shaded Straight-Line Array



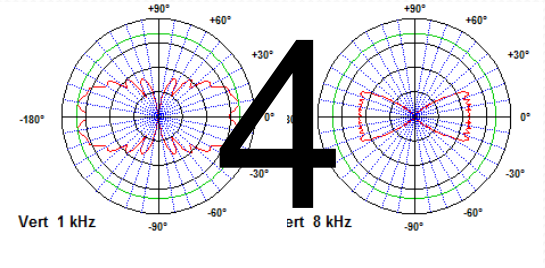
Un-Shaded "I"-Line Array



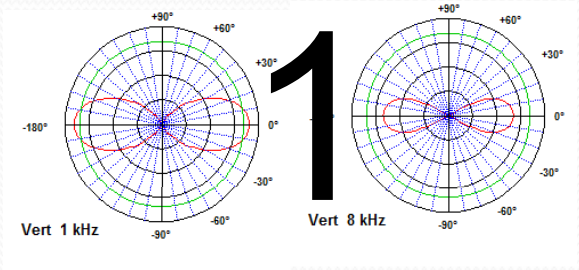
Un-Shaded Spiral-Line Array



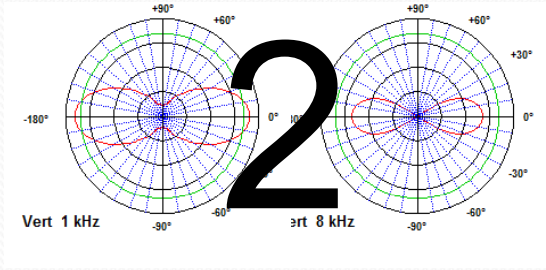
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array

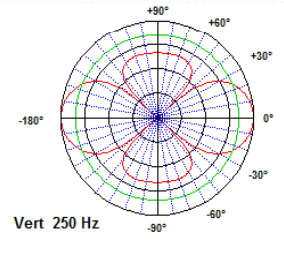


Shaded Delay-Curved CBT Straight-Line array

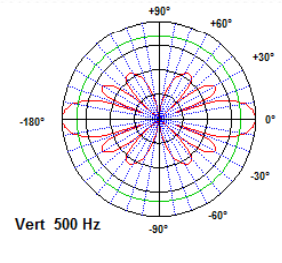


Analysis: Uniformity of Vertical Polar Response with Frequency

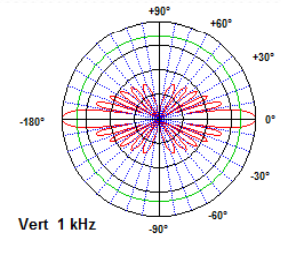
250 Hz



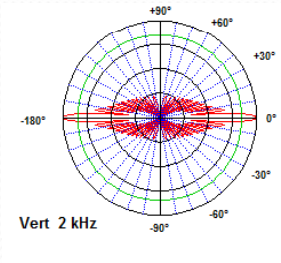
500 Hz



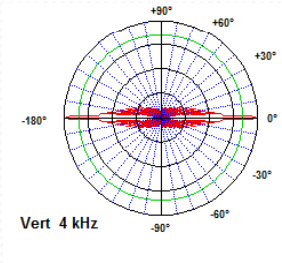
1 kHz



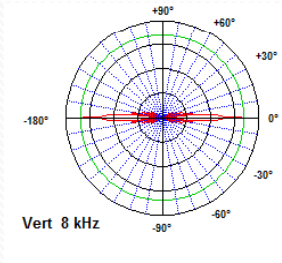
2 kHz



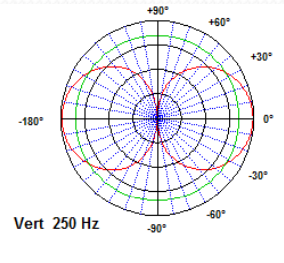
4 kHz



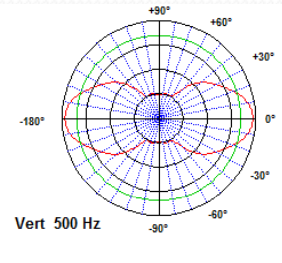
8 kHz



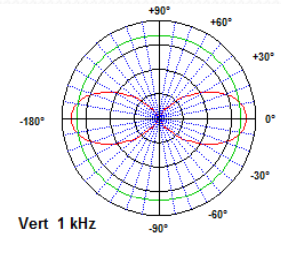
250 Hz



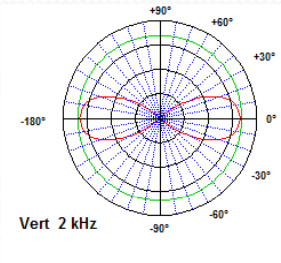
500 Hz



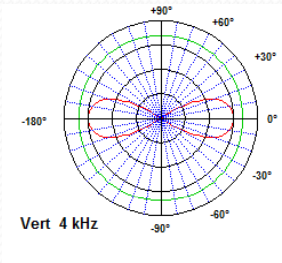
1 kHz



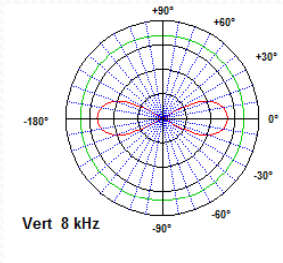
2 kHz



4 kHz

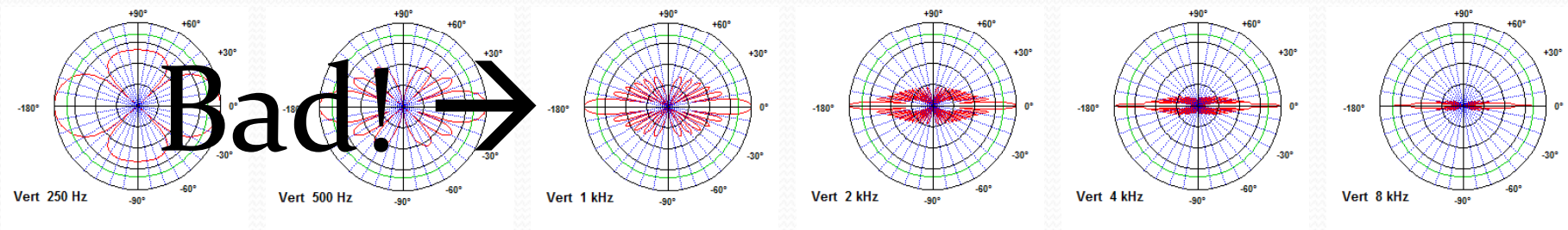


8 kHz

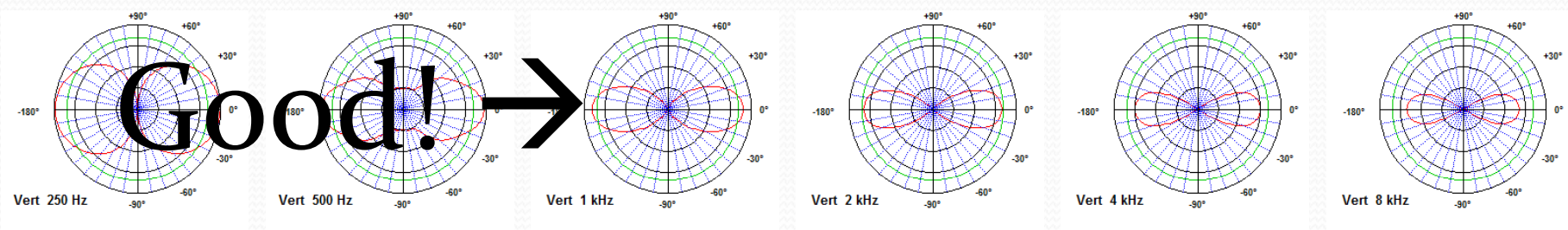


Analysis: Uniformity of Vertical Polar Response with Frequency

250 Hz 500 Hz 1 kHz 2 kHz 4 kHz 8 kHz

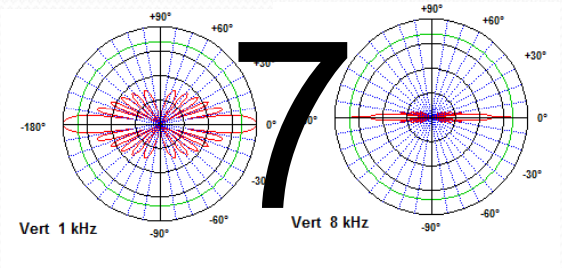


250 Hz 500 Hz 1 kHz 2 kHz 4 kHz 8 kHz

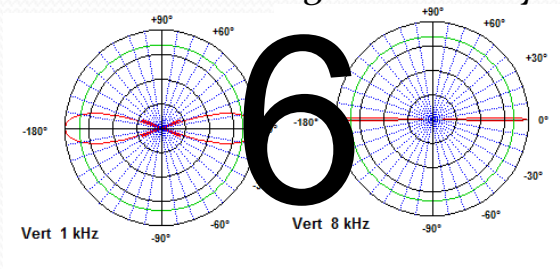


Analysis: Uniformity of Polar Response with Frequency Ranking

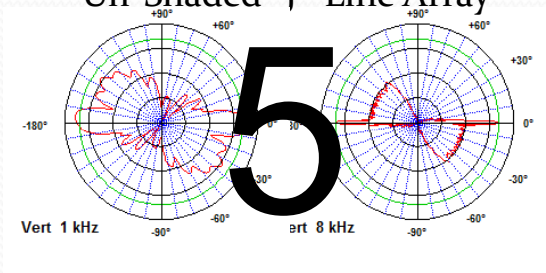
Un-Shaded Straight-Line Array



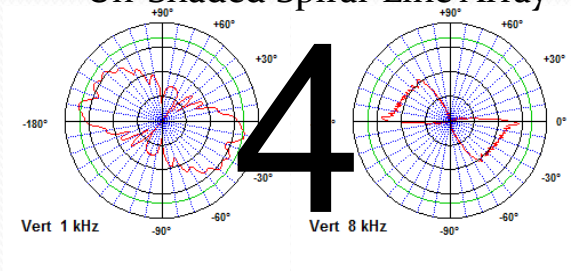
Shaded Straight-Line Array



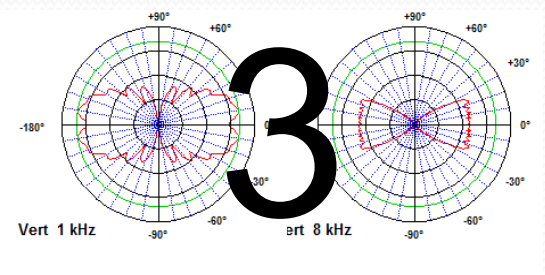
Un-Shaded "J"-Line Array



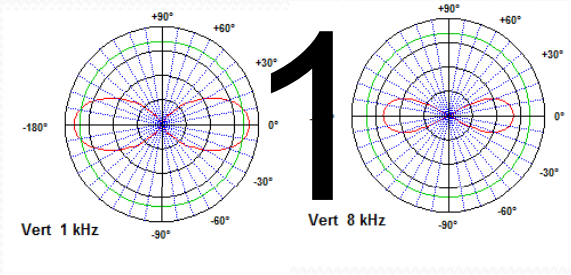
Un-Shaded Spiral-Line Array



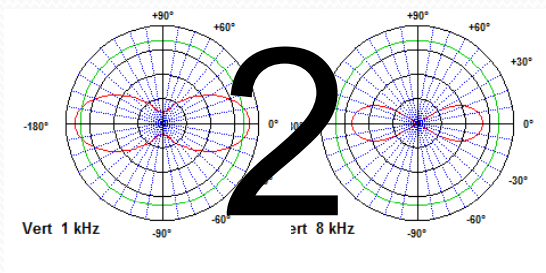
Un-Shaded Circular-Arc Line Array



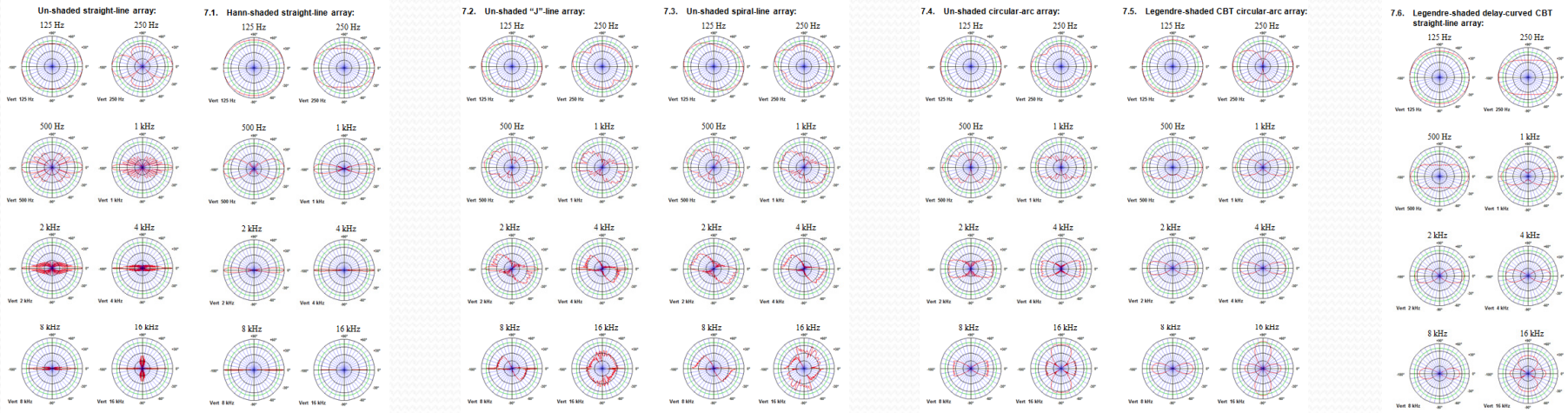
Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array



Analysis: Uniformity of Polar Response with Frequency Ranking



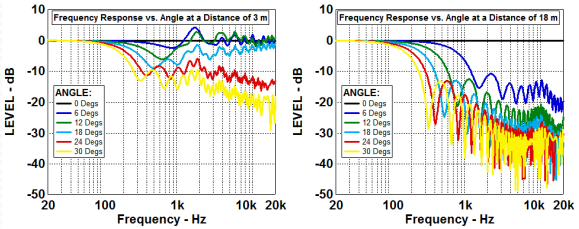
- Note: The appendix of my paper has a complete set of octave polars for each array from 125 Hz to 16 kHz!

Analysis: Smoothness and Flatness of Off-Axis Response

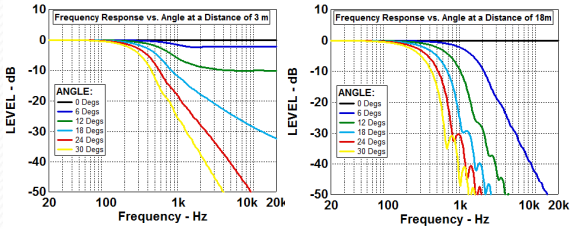
Ideally, the off-axis frequency response should be well-behaved, smooth and flat, and be independent of distance. In order to assess this, the off-axis frequency response of the arrays was simulated at two distances of 3 m and 18 m. Frequency responses were simulated at six on- and off-axis angles from 0° to 30°, with a step of 6°, with the on-axis response equalized flat.

Analysis: Smoothness and Flatness of Off-Axis Response

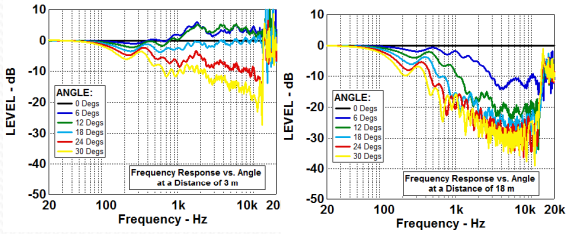
Un-Shaded Straight-Line Array



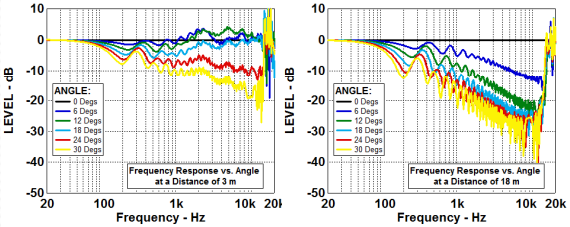
Shaded Straight-Line Array



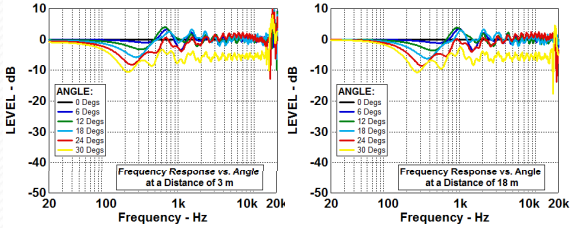
Un-Shaded "J"-Line Array



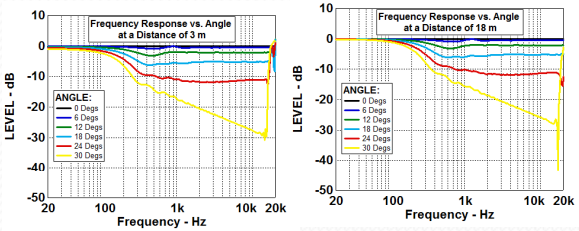
Un-Shaded Spiral-Line Array



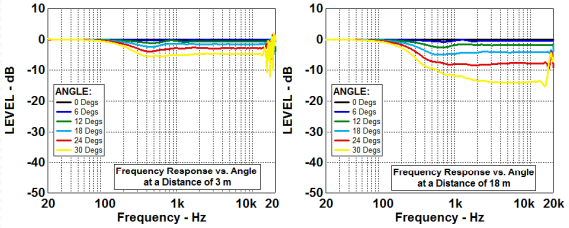
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



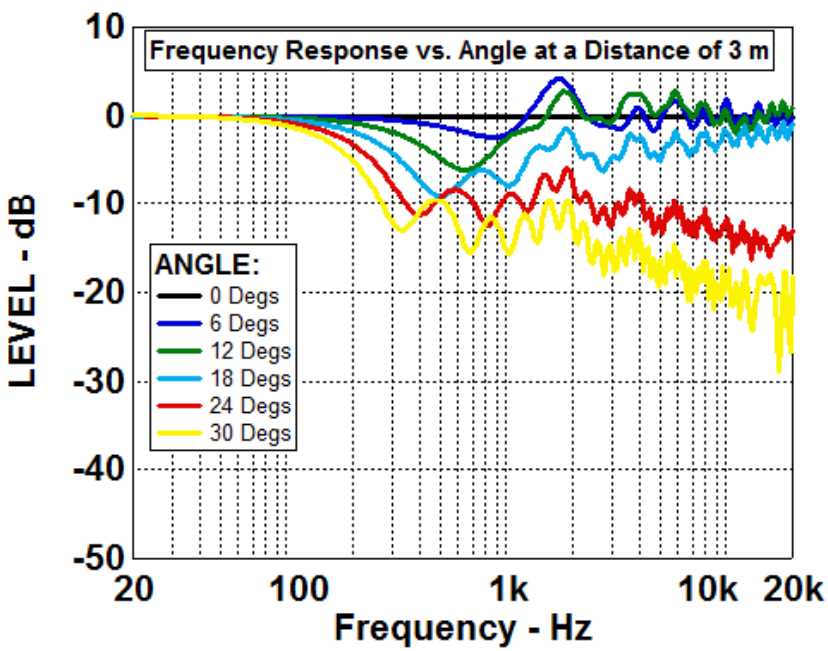
Shaded Delay-Curved CBT Straight-Line array



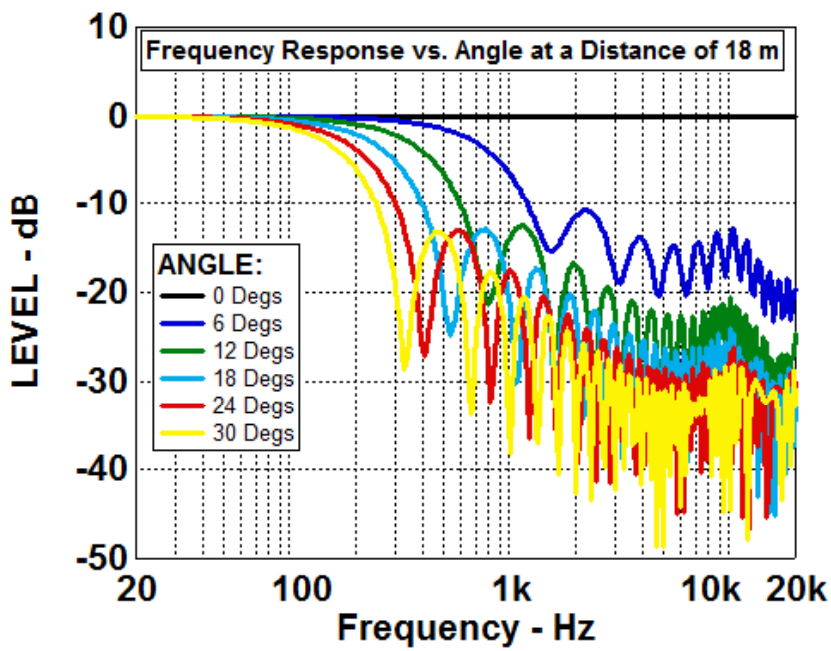
Analysis: Smoothness and Flatness of Off-Axis Response

- Un-shaded straight-line array

3 m



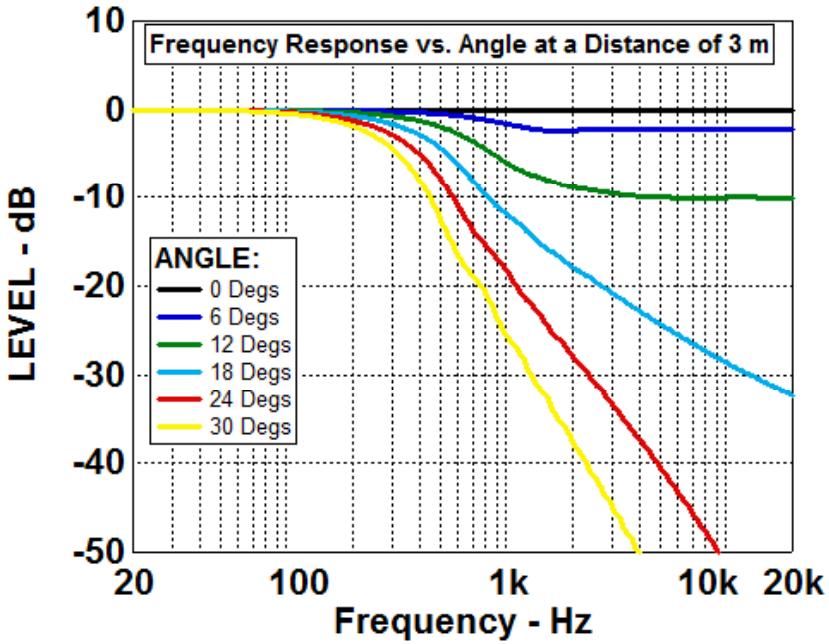
18 m



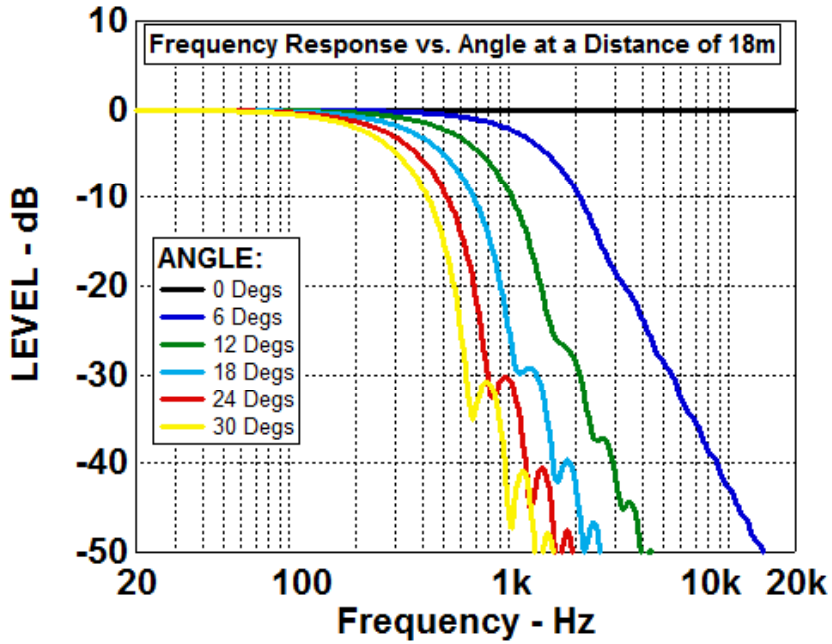
Analysis: Smoothness and Flatness of Off-Axis Response

- Hann-shaded straight-line array

3 m



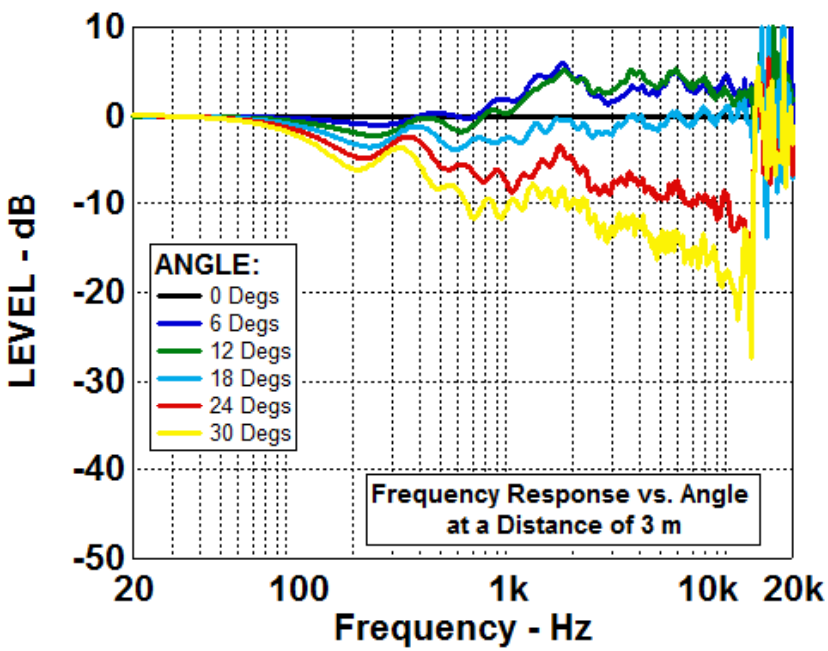
18 m



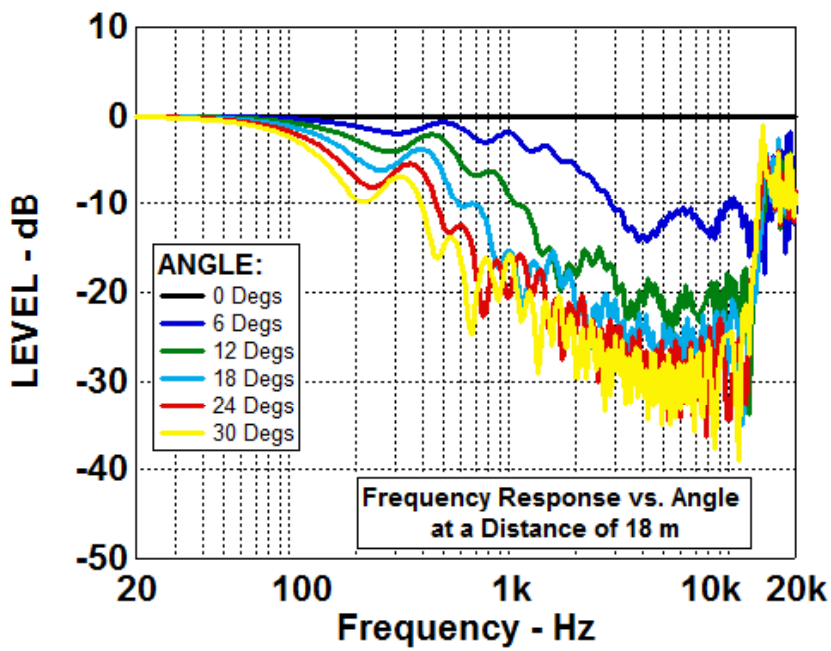
Analysis: Smoothness and Flatness of Off-Axis Response

- Un-shaded "J"-line array

3 m



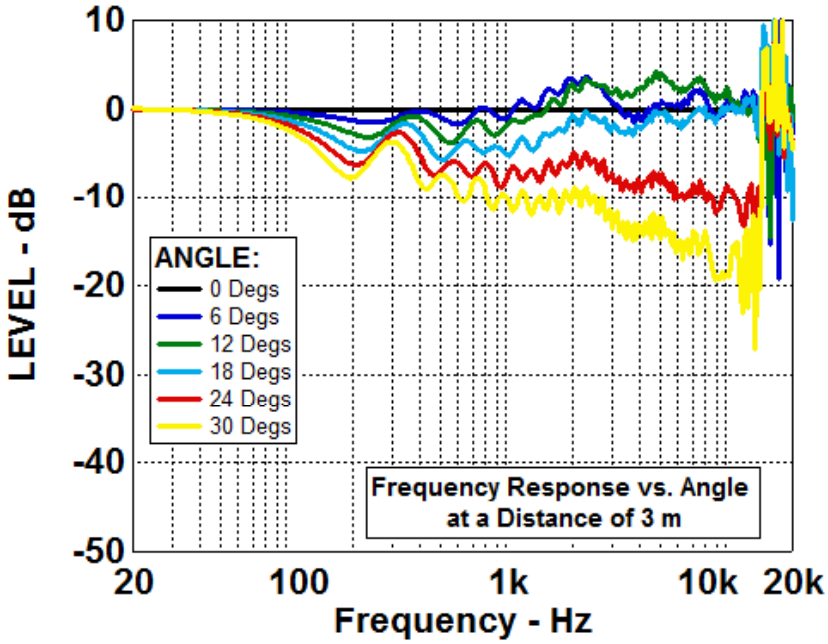
18 m



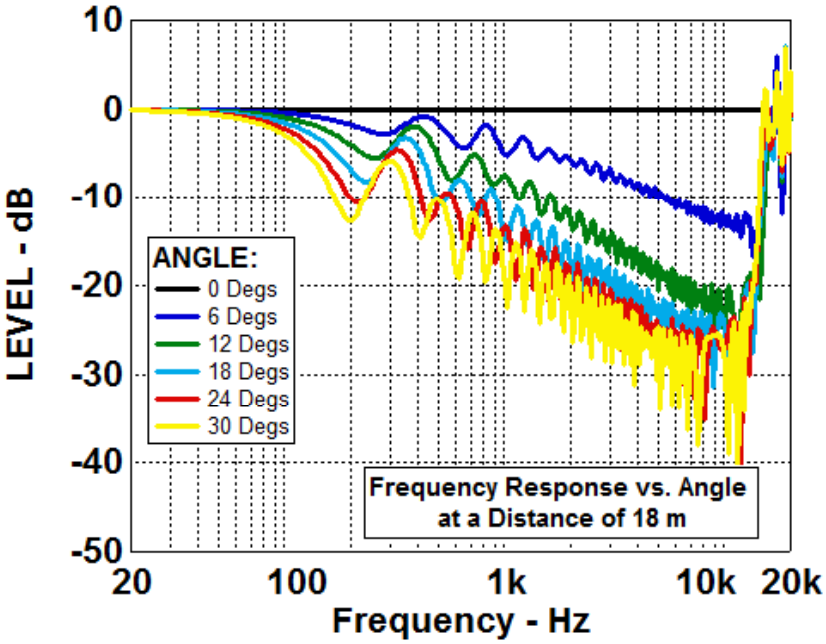
Analysis: Smoothness and Flatness of Off-Axis Response

- Un-shaded spiral- or progressive-line array

3 m



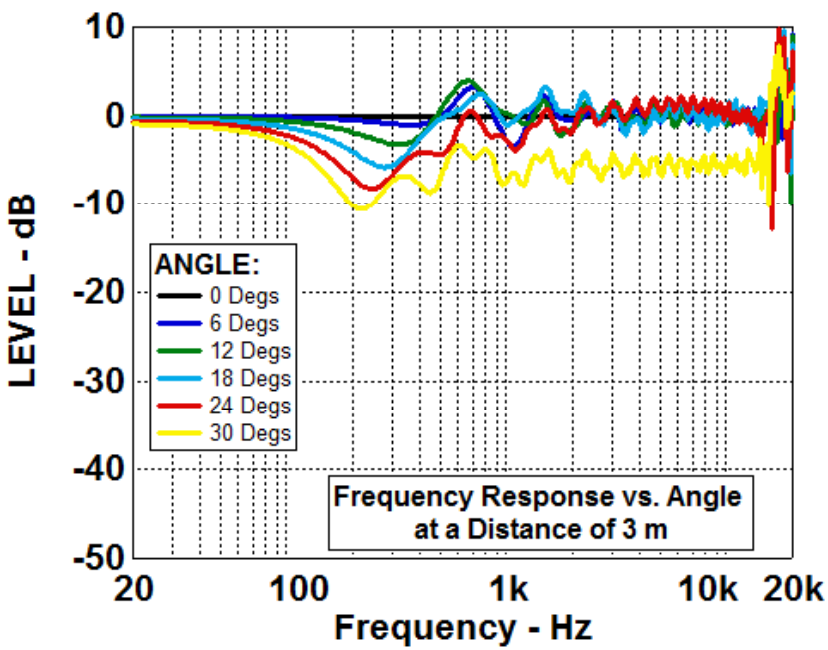
18 m



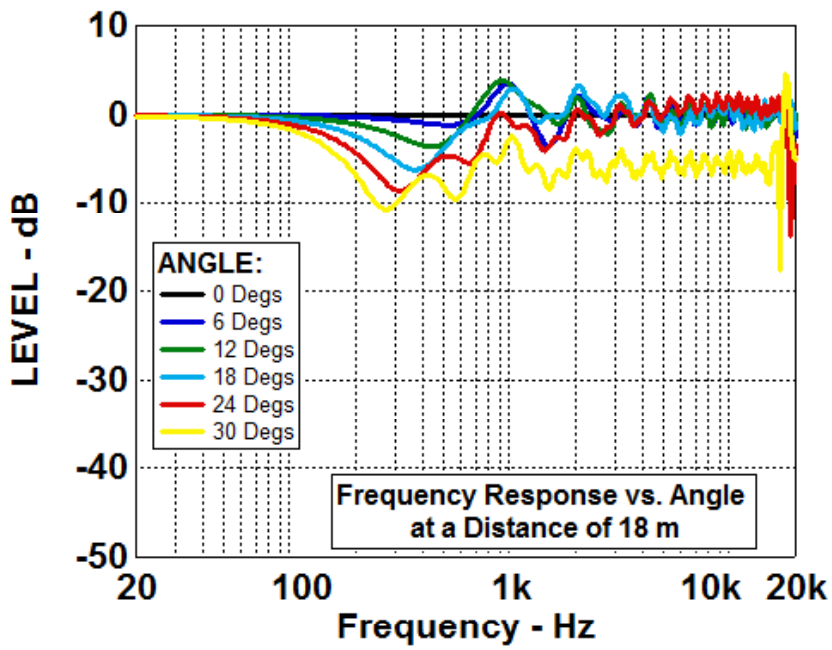
Analysis: Smoothness and Flatness of Off-Axis Response

- Un-shaded circular-arc array

3 m



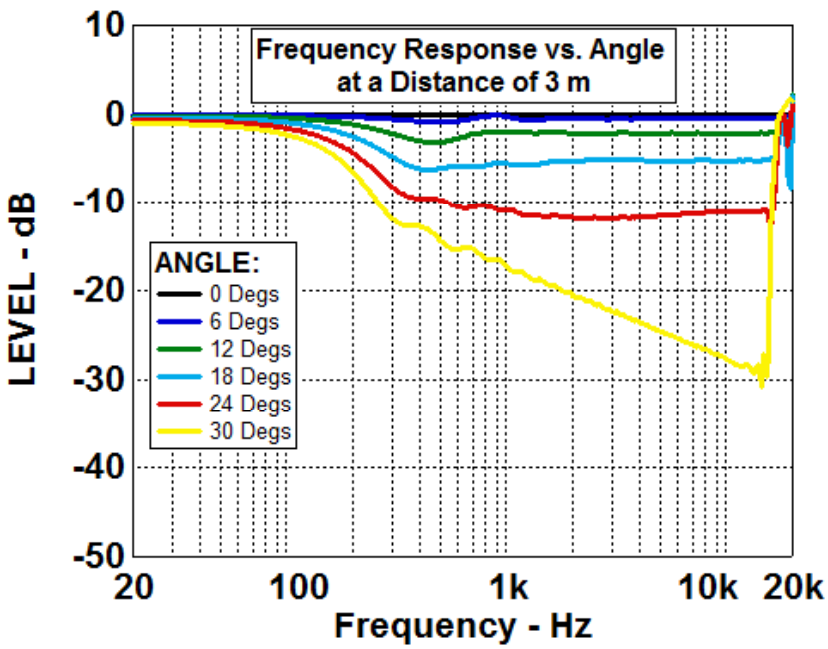
18 m



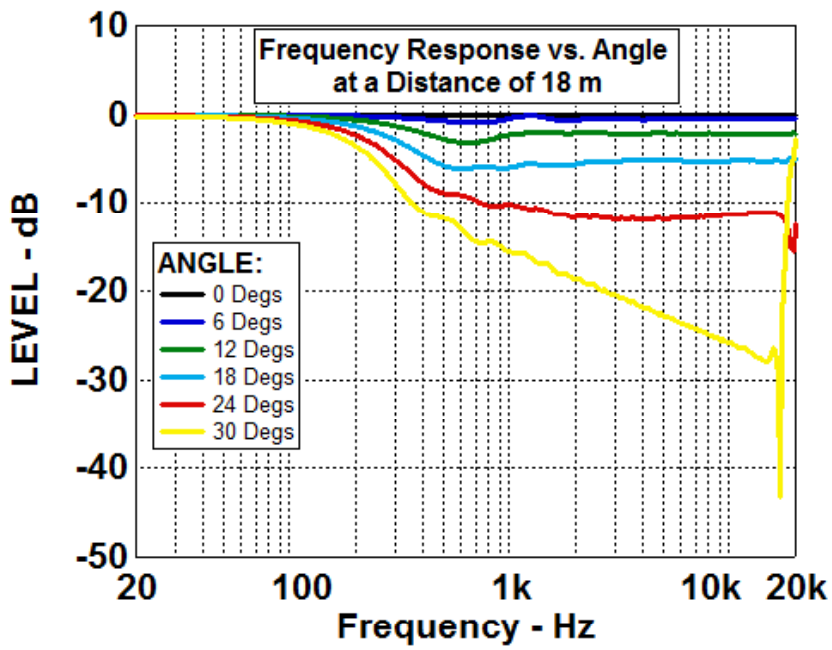
Analysis: Smoothness and Flatness of Off-Axis Response

- Legendre-shaded CBT circular-arc array

3 m



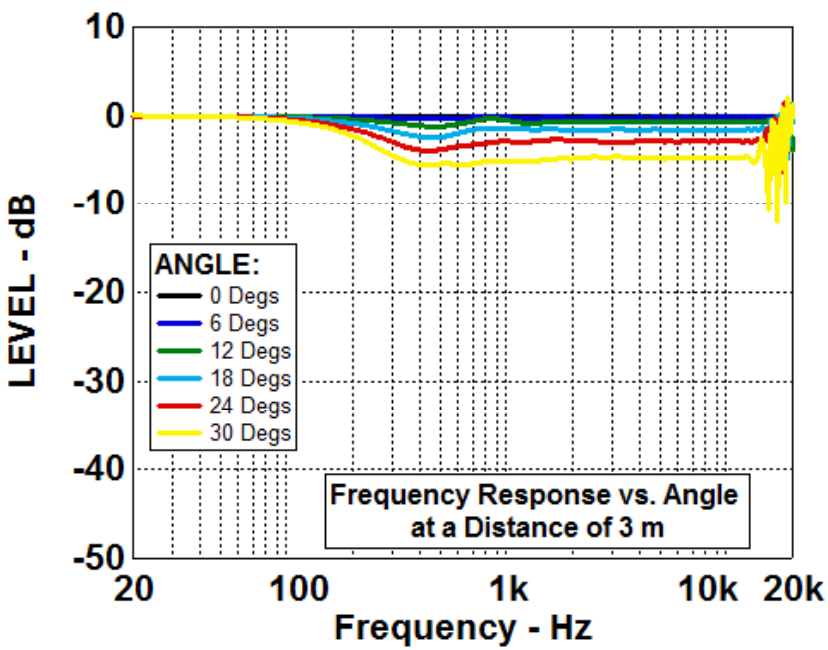
18 m



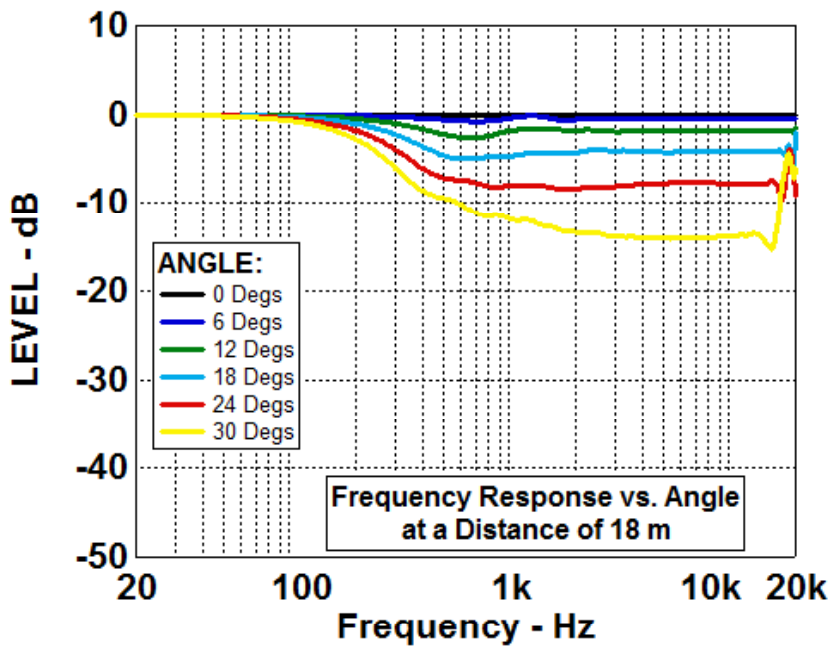
Analysis: Smoothness and Flatness of Off-Axis Response

- Legendre-shaded delay-curved CBT straight-line array

3 m

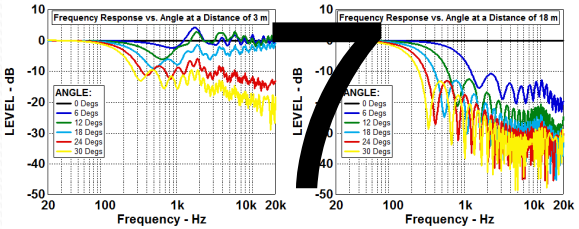


18 m

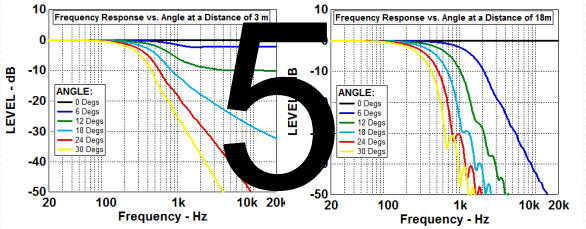


Analysis: Smoothness and Flatness of Off-Axis Response Ranking

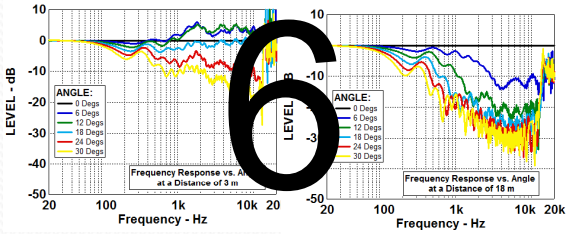
Un-Shaded Straight-Line Array



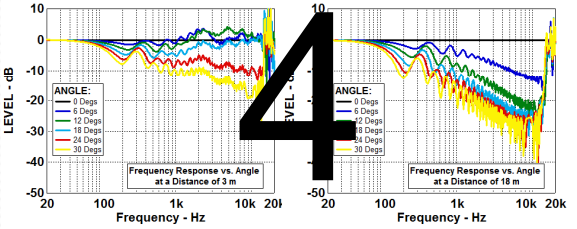
Shaded Straight-Line Array



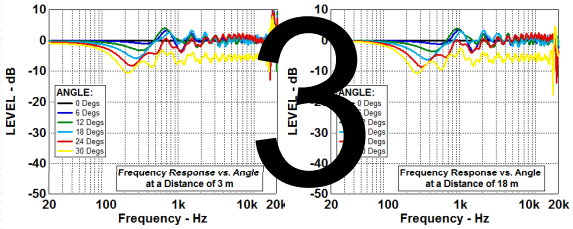
Un-Shaded "J"-Line Array



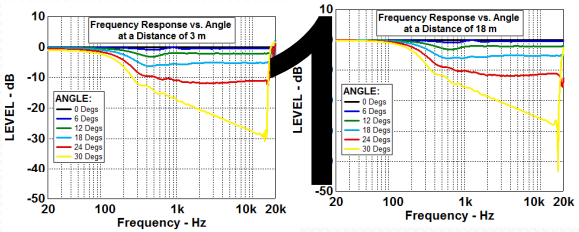
Un-Shaded Spiral-Line Array



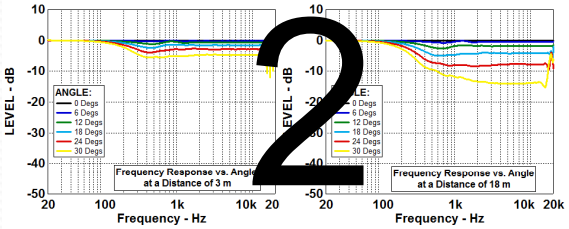
Un-Shaded Circular-Arc Line Array



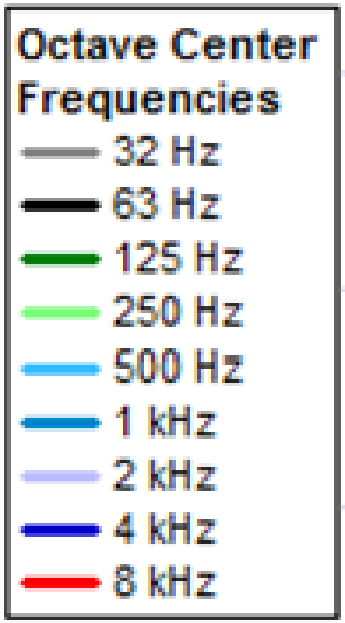
Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array

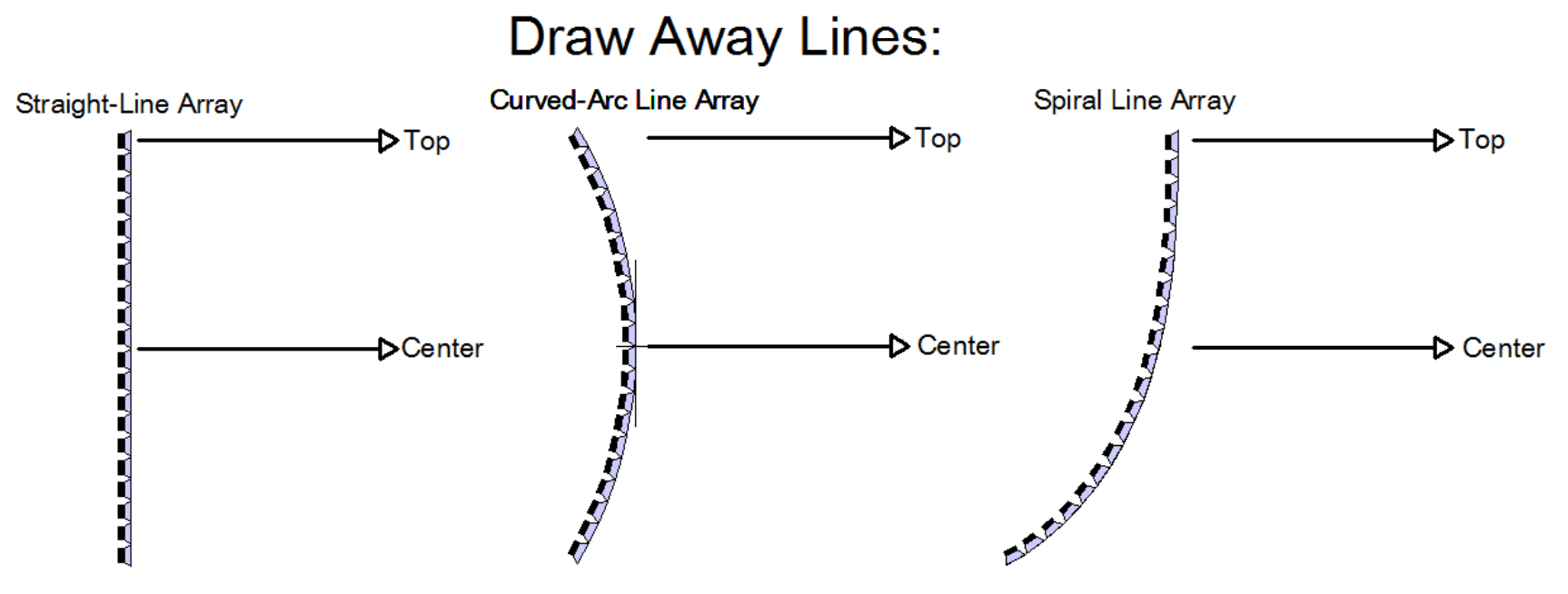


Analysis: Sound Pressure Level vs. Distance



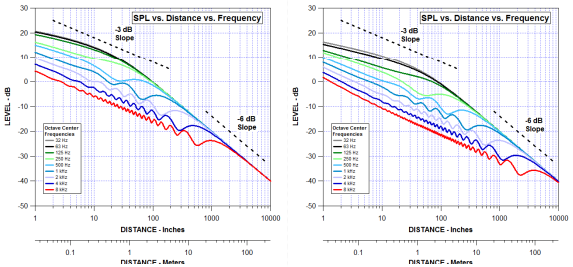
The sound pressure level (SPL) versus distance of the arrays was evaluated at octave frequencies of 62.5 Hz to 8 kHz. The SPL vs. distance was evaluated at two different array launch heights: a) the center of the array and b) the top of the array.

SPL Launch Points and Trajectories

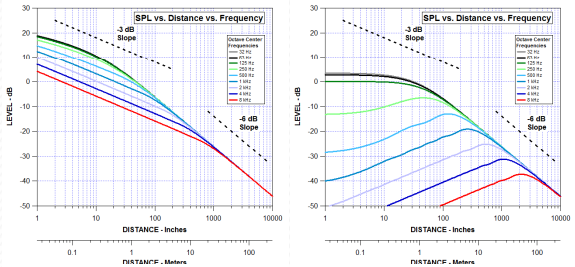


Analysis: SPL vs. Distance

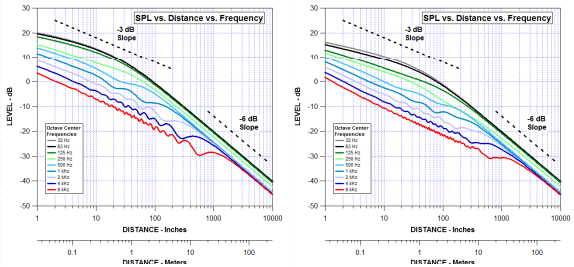
Un-Shaded Straight-Line Array



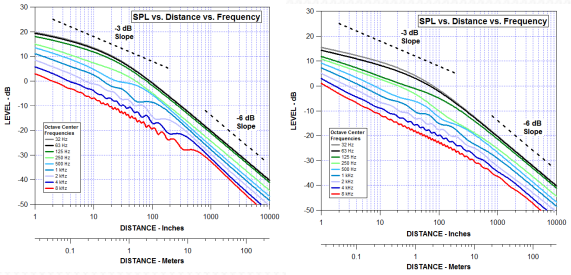
Shaded Straight-Line Array



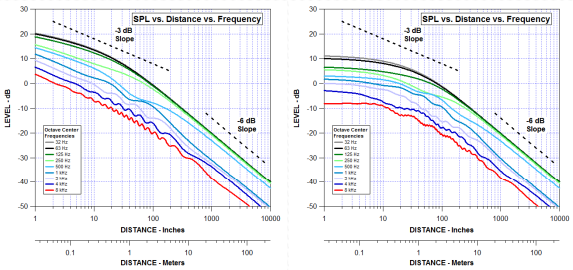
Un-Shaded "J"-Line Array



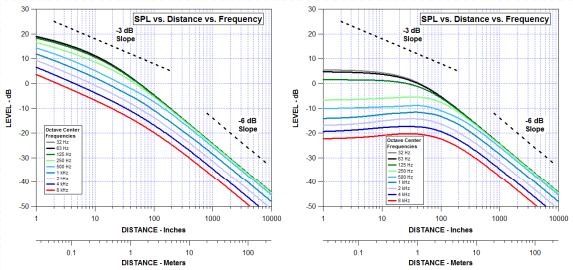
Un-Shaded Spiral-Line Array



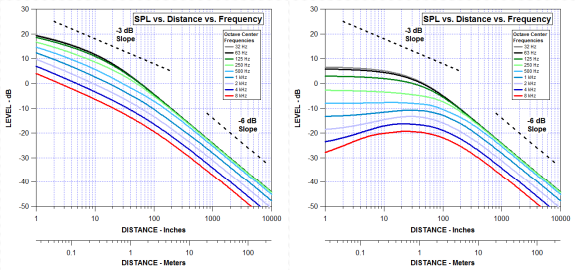
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



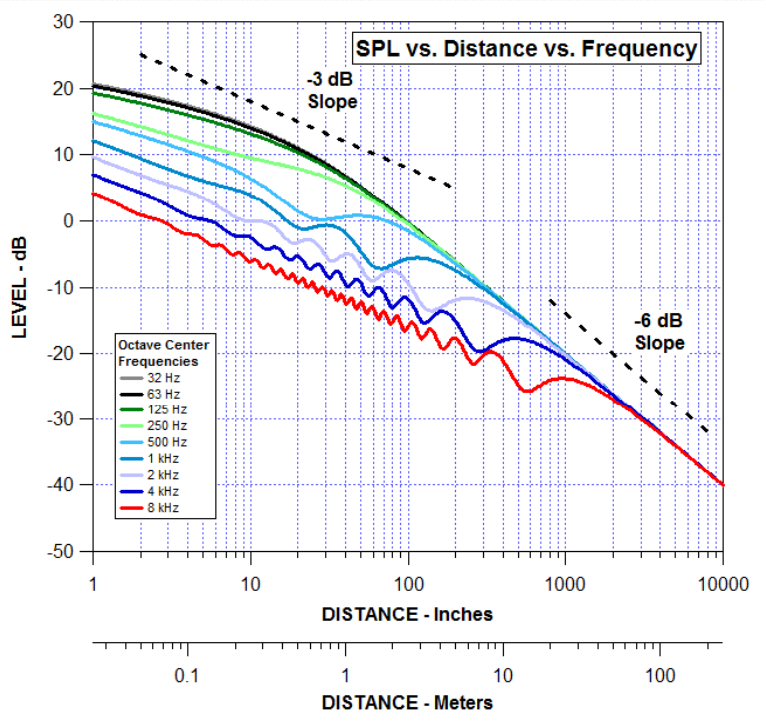
Shaded Delay-Curved CBT Straight-Line array



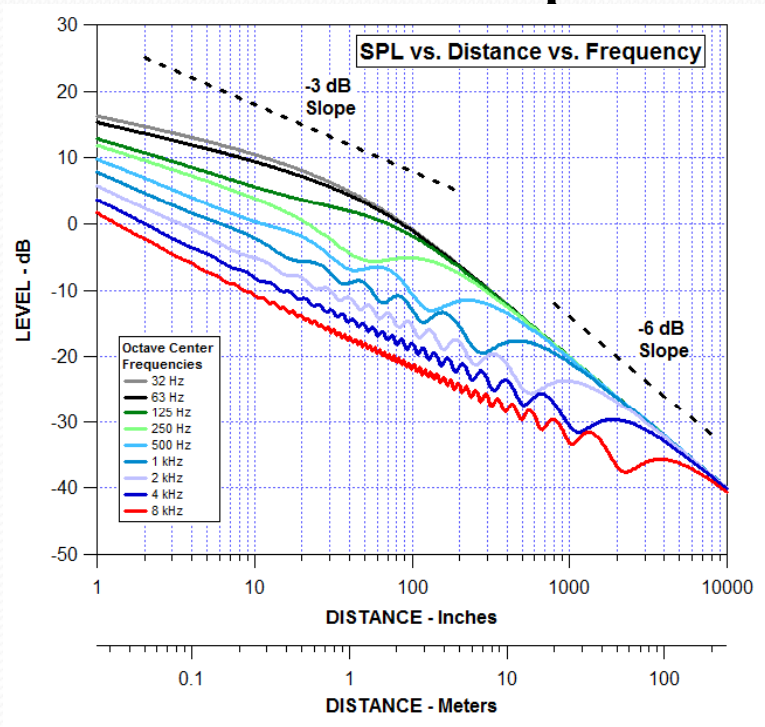
Analysis: SPL vs. Distance

- Un-shaded straight-line array

From Center



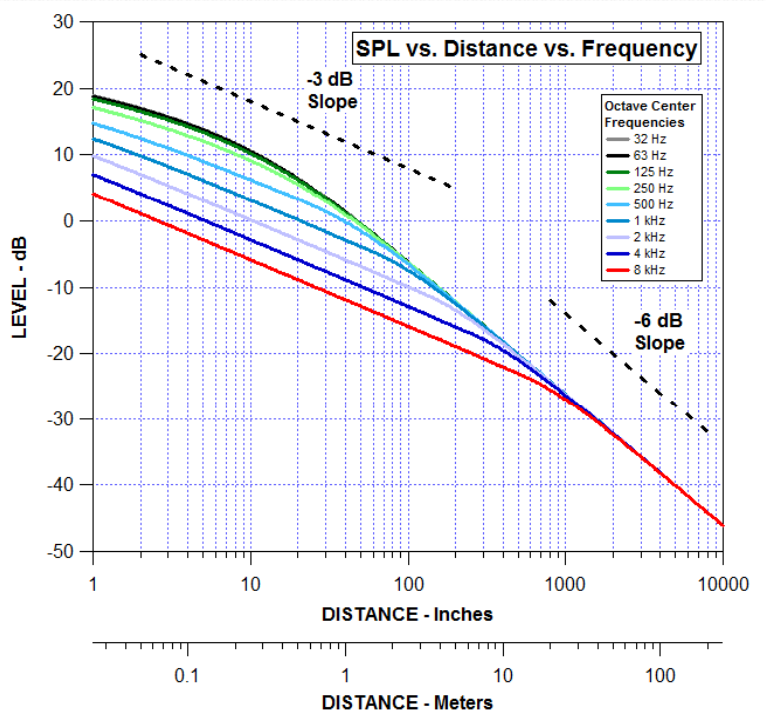
From Top



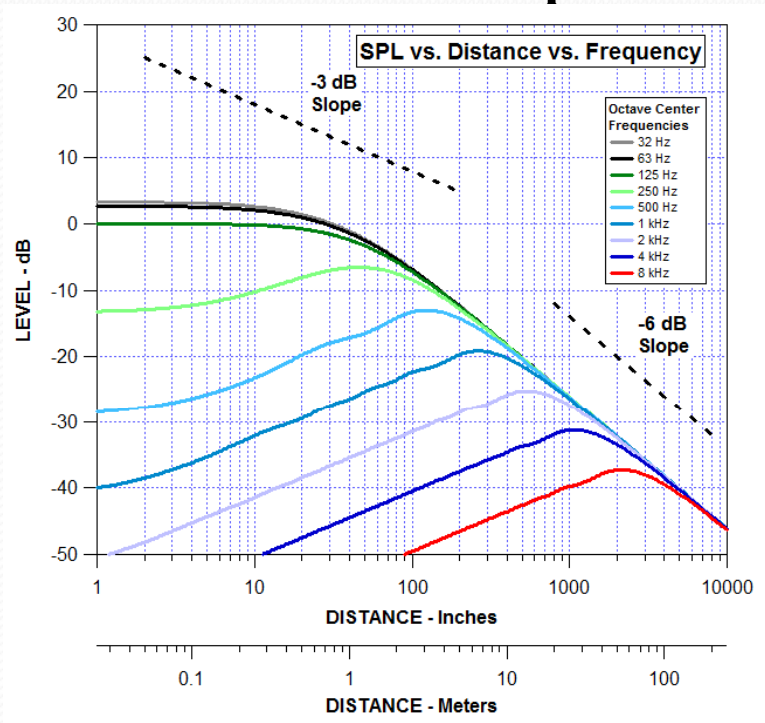
Analysis: SPL vs. Distance

- Hann-shaded straight-line array

From Center



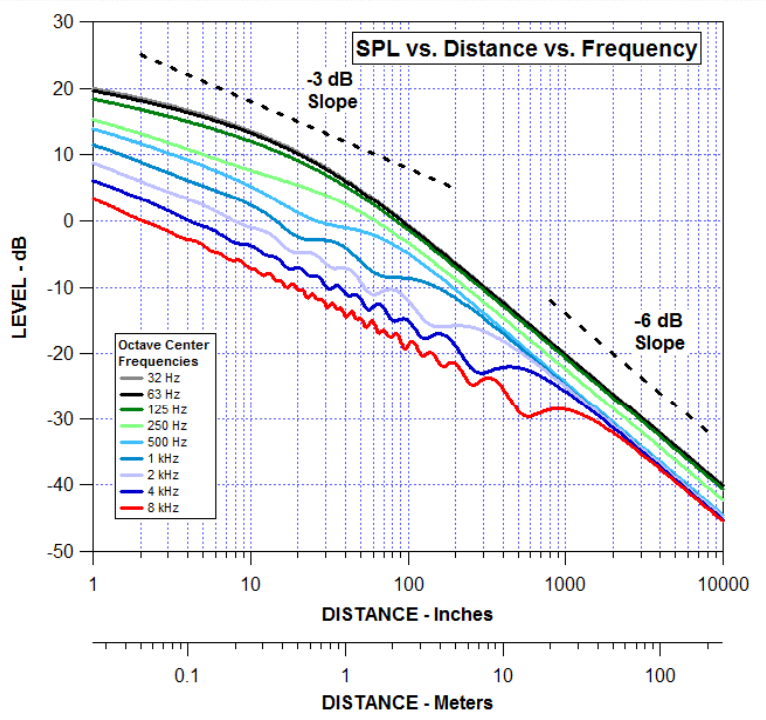
From Top



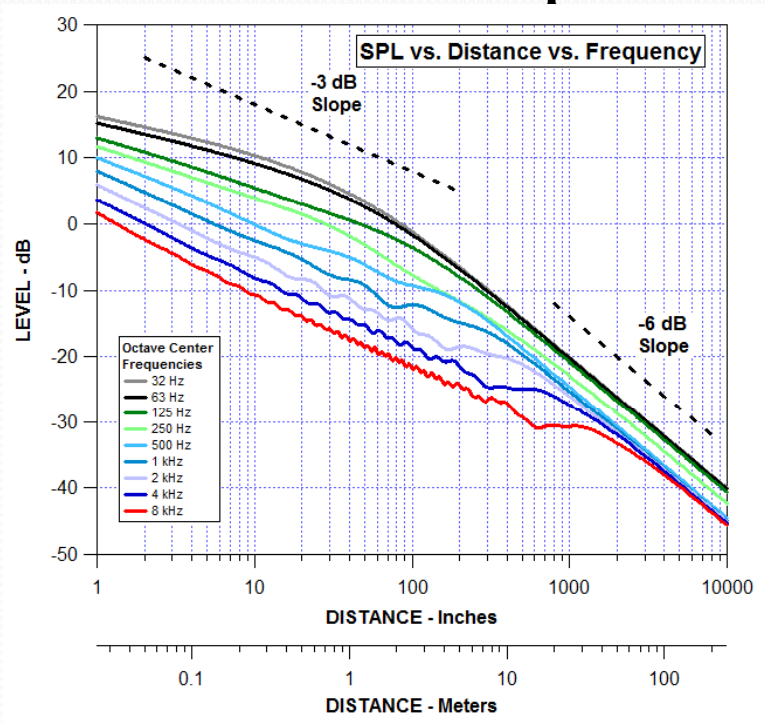
Analysis: SPL vs. Distance

- Un-shaded "J"-line array

From Center



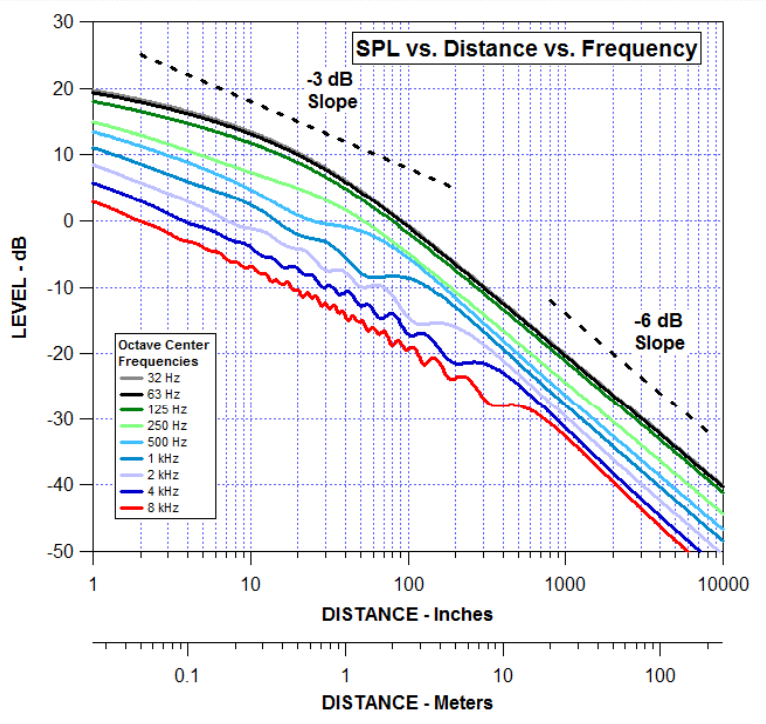
From Top



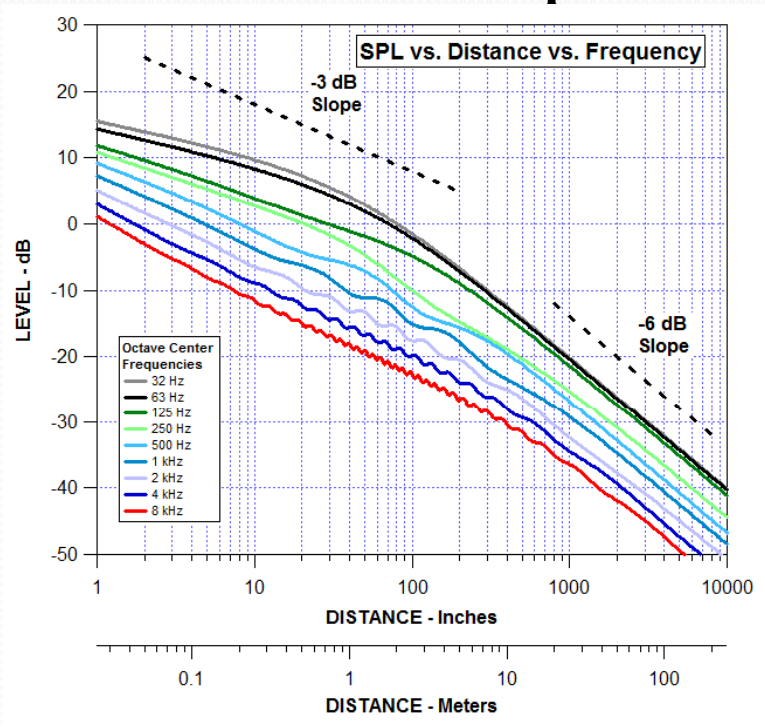
Analysis: SPL vs. Distance

- Un-shaded spiral- or progressive-line array

From Center



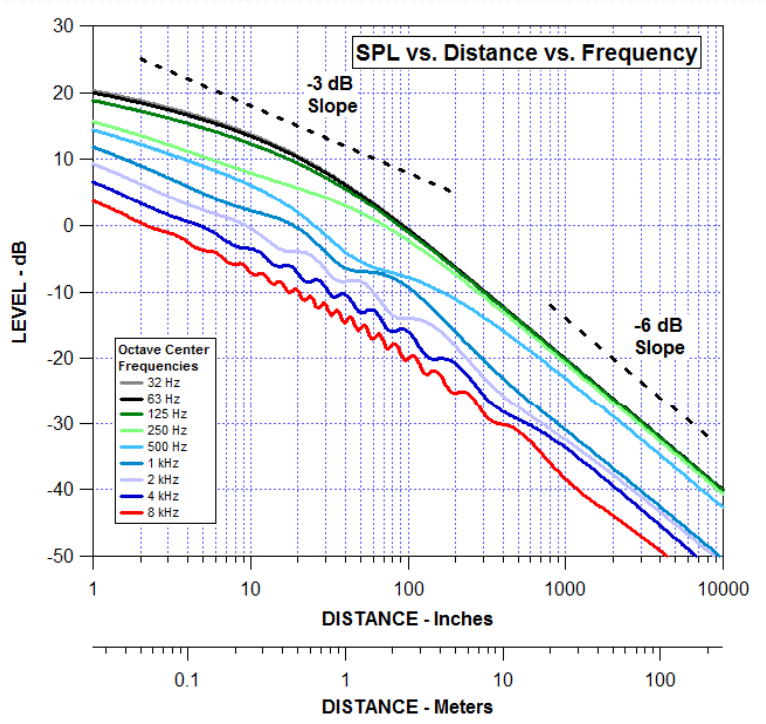
From Top



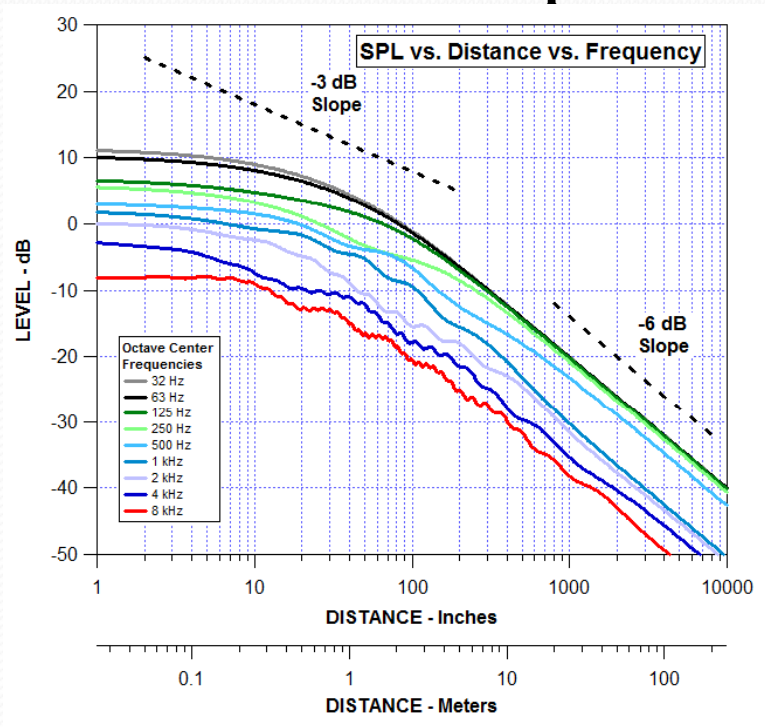
Analysis: SPL vs. Distance

- Un-shaded circular-arc array

From Center



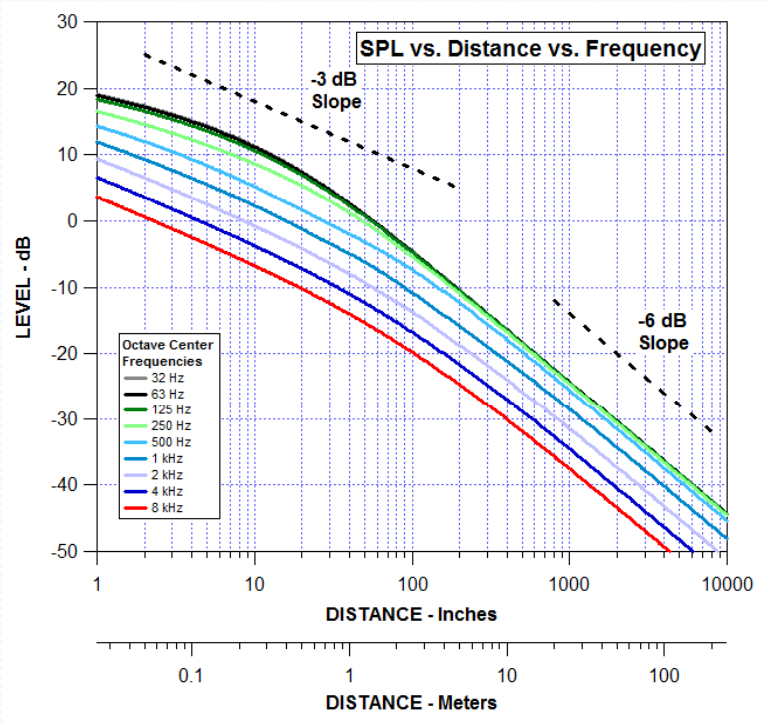
From Top



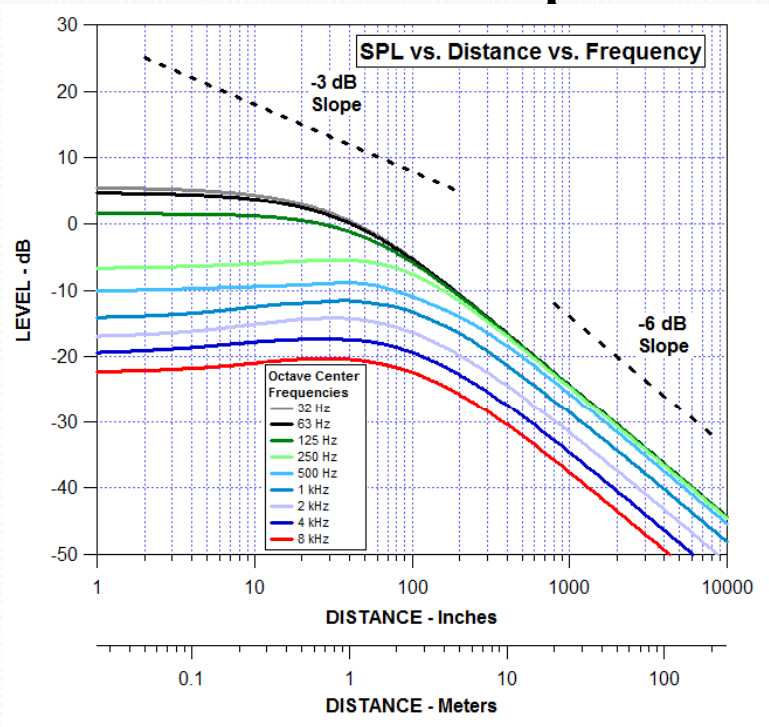
Analysis: SPL vs. Distance

- Legendre-shaded CBT circular-arc array

From Center



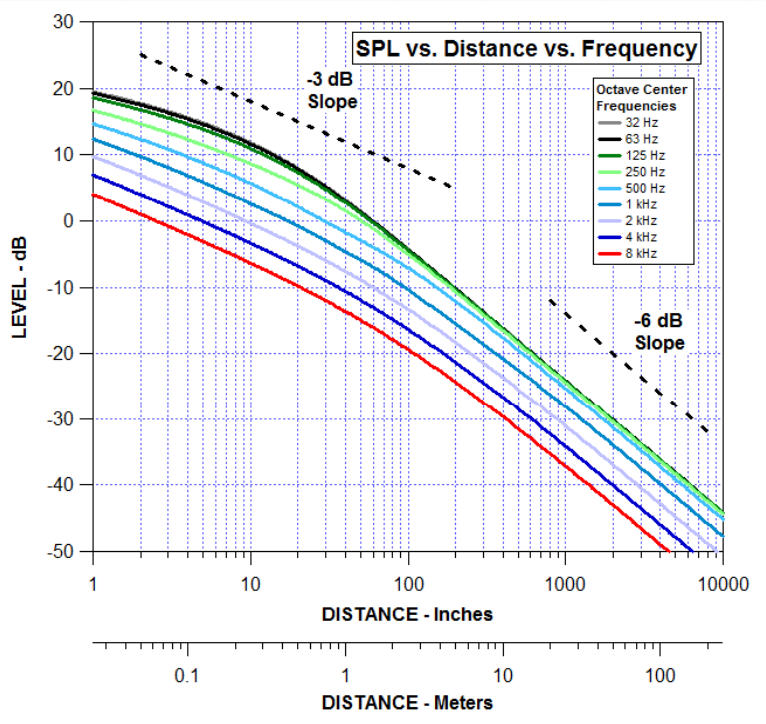
From Top



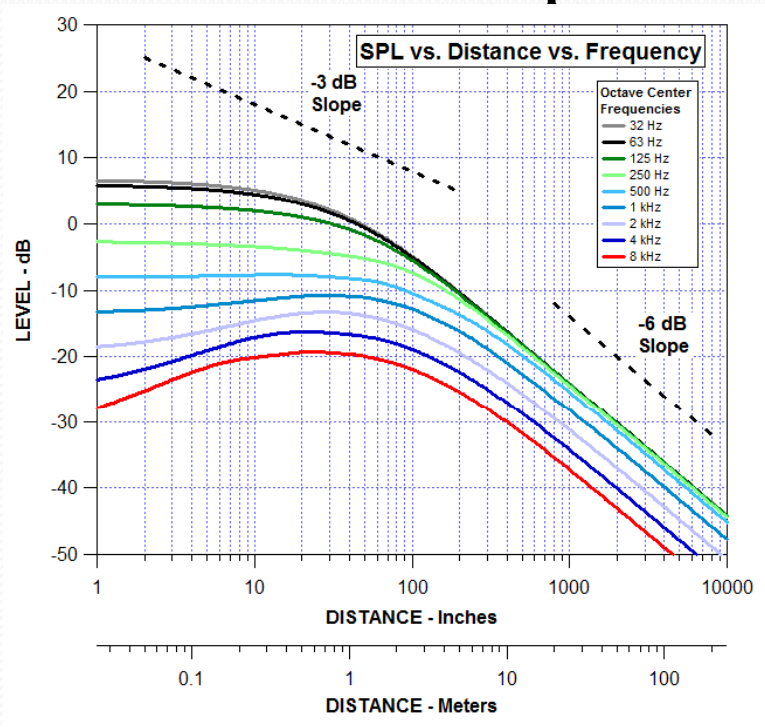
Analysis: SPL vs. Distance

- Legendre-shaded delay-curved CBT straight-line array

From Center

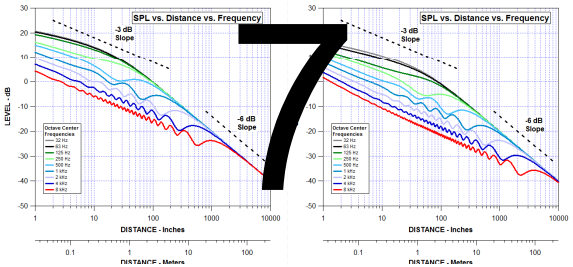


From Top

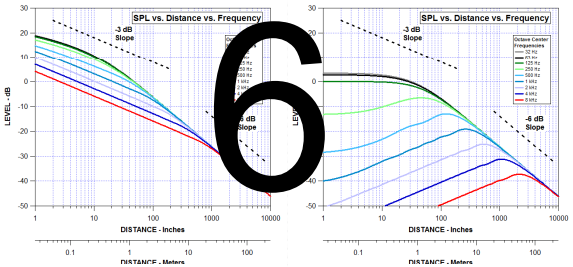


Analysis: SPL vs. Distance Ranking

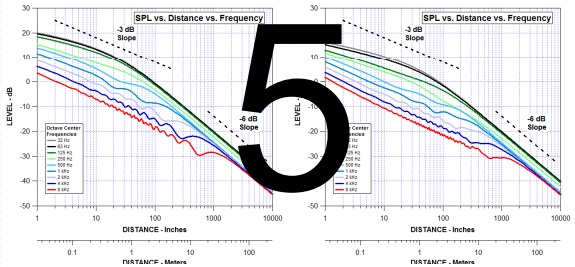
Un-Shaded Straight-Line Array



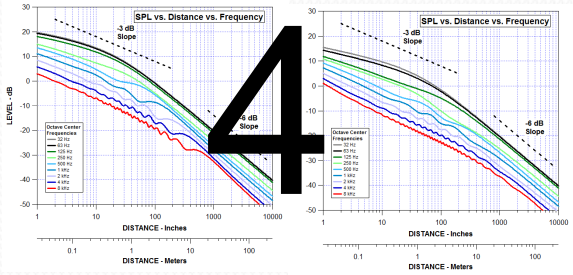
Shaded Straight-Line Array



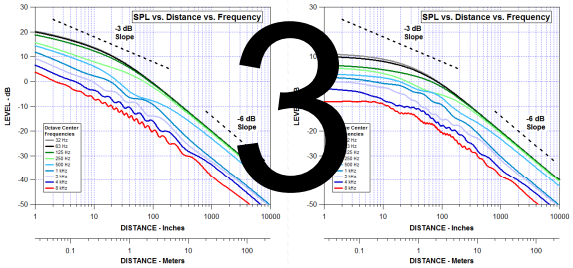
Un-Shaded "J"-Line Array



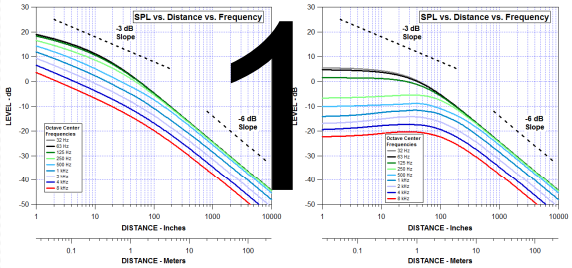
Un-Shaded Spiral-Line Array



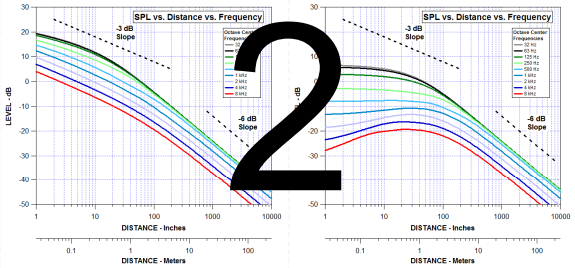
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array

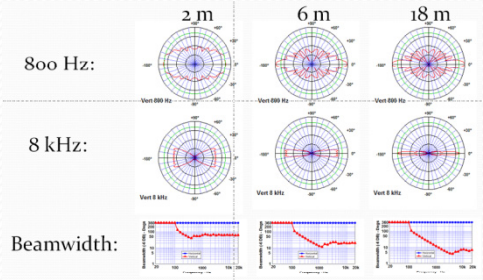


Analysis: Near-Far Polar Pattern Uniformity

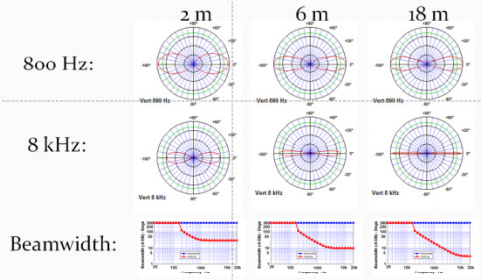
- The polar pattern of the array was evaluated for its uniformity with distance.
- The following graphs show polar pattern shapes and beamwidth vs. frequency data at three distances from the array: 2 m, 6 m, and 18 m.
- Two sets of polars are shown for the three distances at 800 Hz and 8 kHz.
- This information yields a reasonable estimate of the changes in the polar patterns with distance.

Analysis: Near-Far Polar Pattern Uniformity

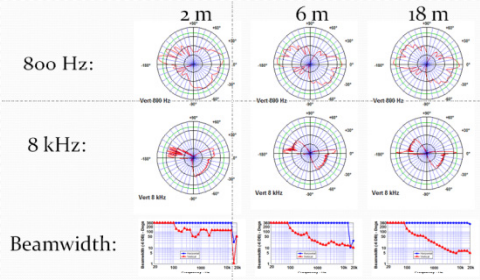
Un-Shaded Straight-Line Array



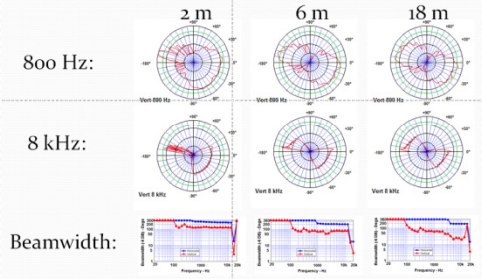
Shaded Straight-Line Array



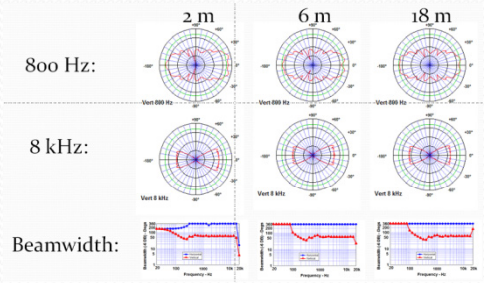
Un-Shaded "J"-Line Array



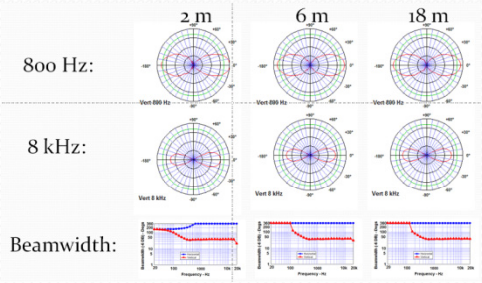
Un-Shaded Spiral-Line Array



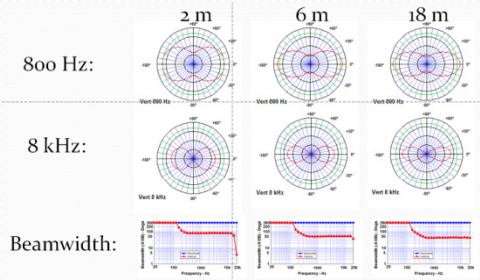
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array

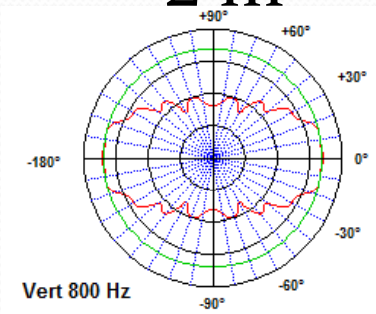
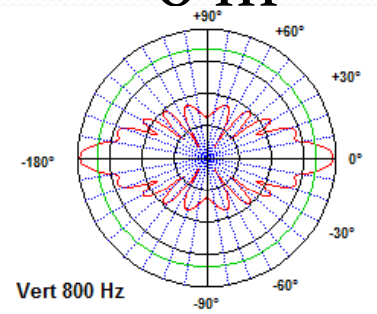
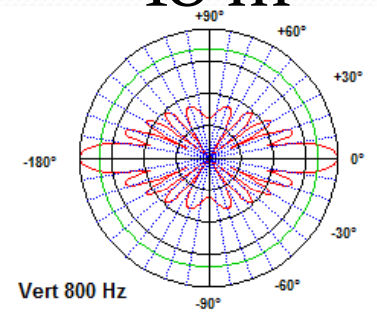
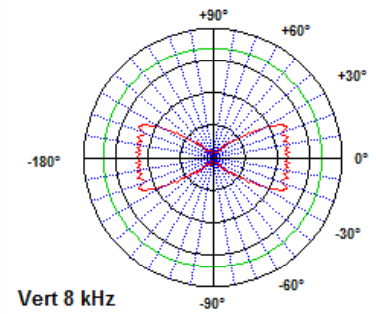
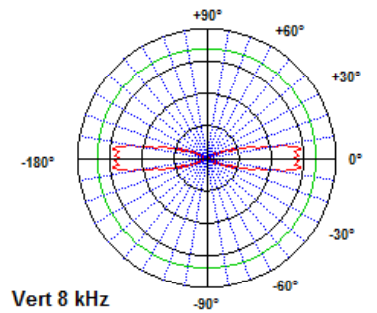
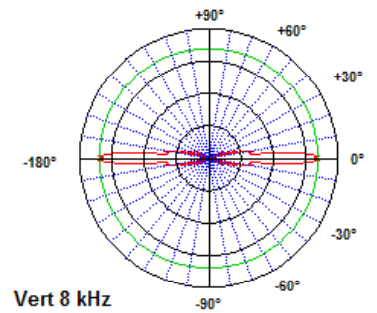
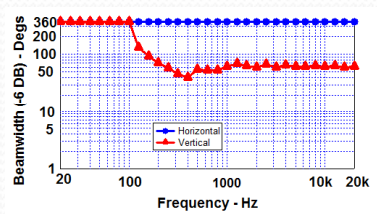
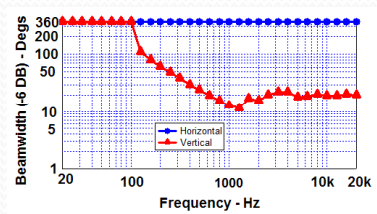
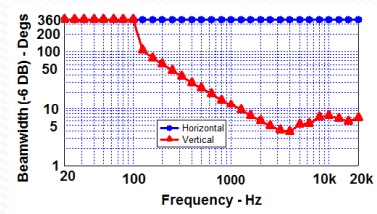


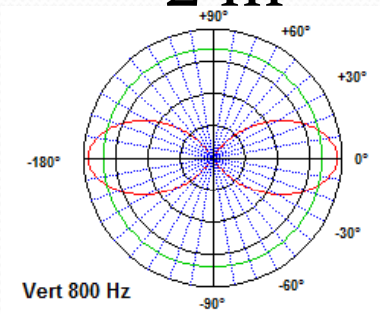
Shaded Delay-Curved CBT Straight-Line array

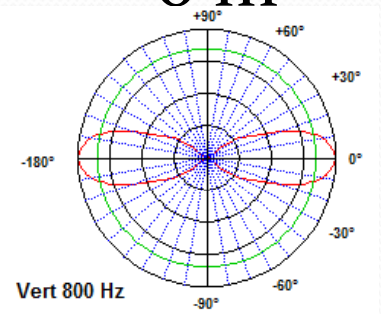


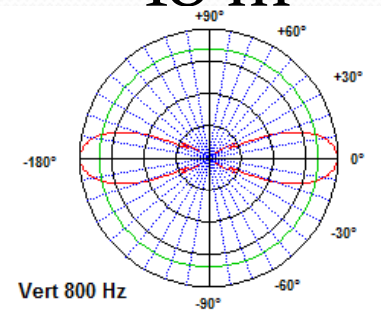
Analysis: Near-Far Polar Pattern Uniformity

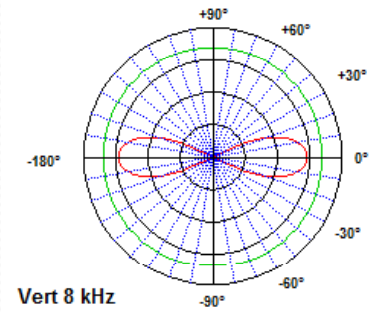
- Un-shaded straight-line array

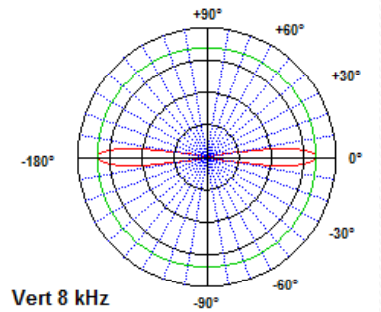
	2 m	6 m	18 m
800 Hz:			
8 kHz:			
Beamwidth:			

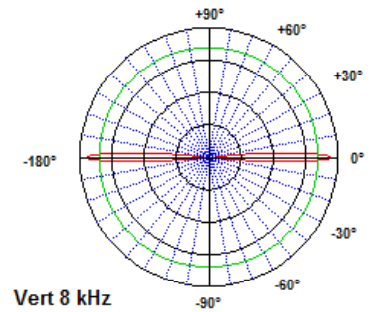


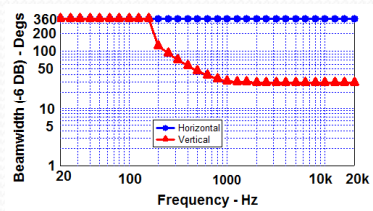


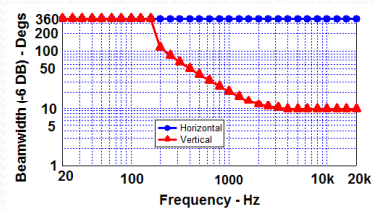


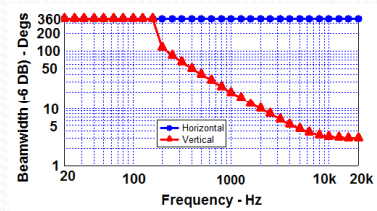












Analysis: Near-Far Polar Pattern Uniformity

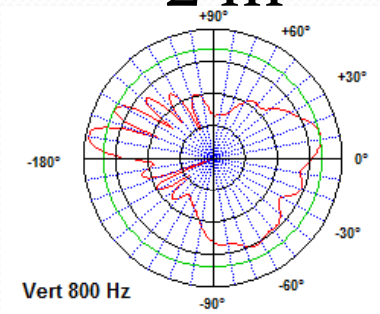
- Hann-shaded straight-line array

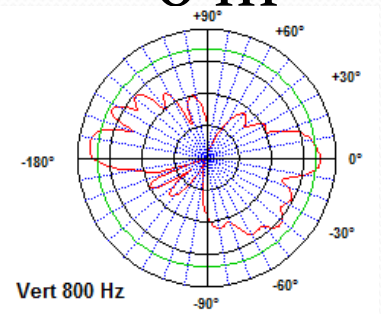
2 m 6 m 18 m

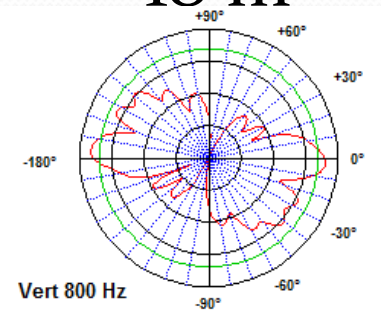
800 Hz:

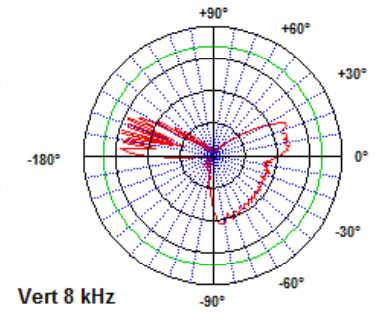
8 kHz:

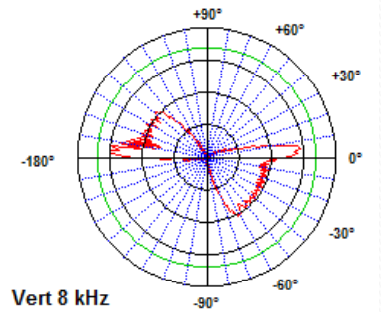
Beamwidth:

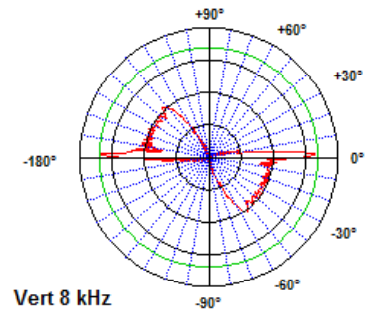


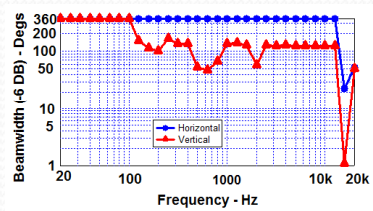


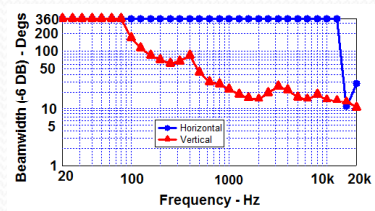


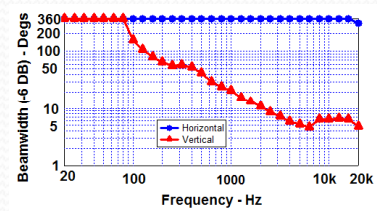












Analysis: Near-Far Polar Pattern Uniformity

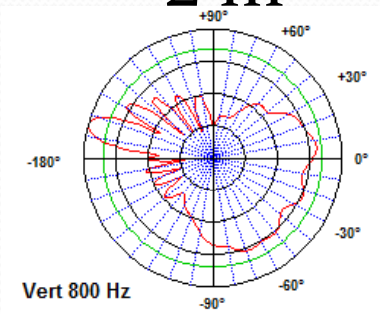
- Un-shaded "J"-line array

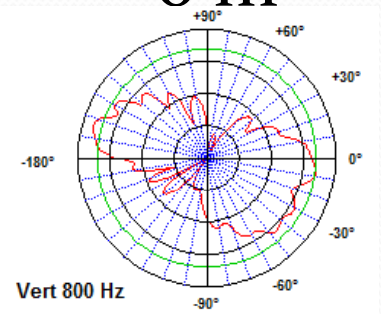
2 m 6 m 18 m

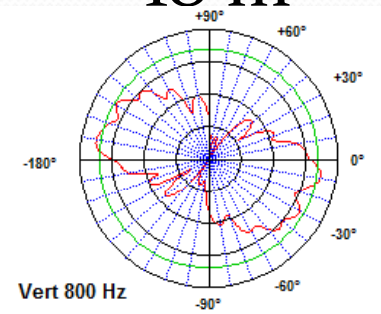
800 Hz:

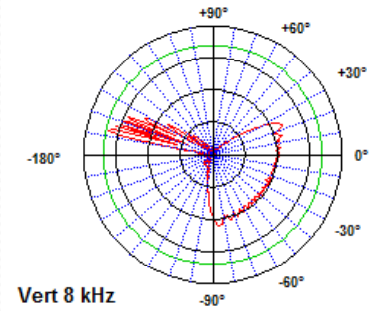
8 kHz:

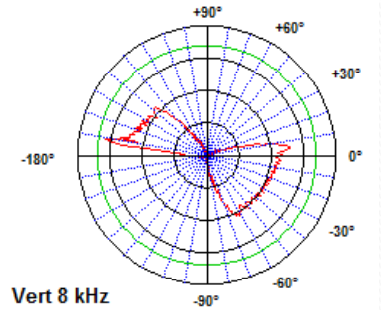
Beamwidth:

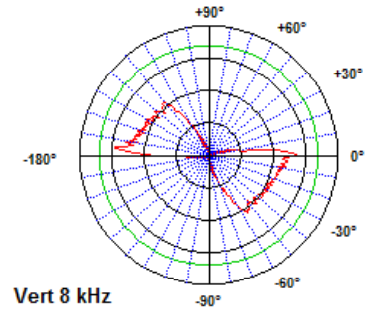


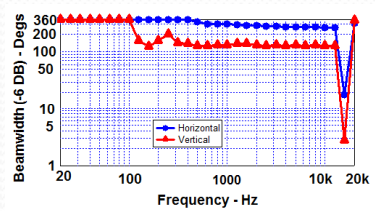


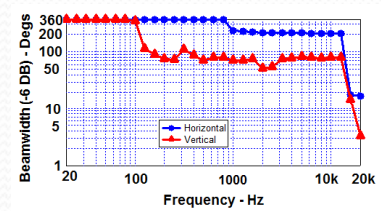


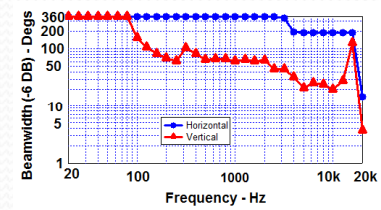












Analysis: Near-Far Polar Pattern Uniformity

- Un-shaded spiral- or progressive-line array

2 m 6 m 18 m

800 Hz:

8 kHz:

Beamwidth:

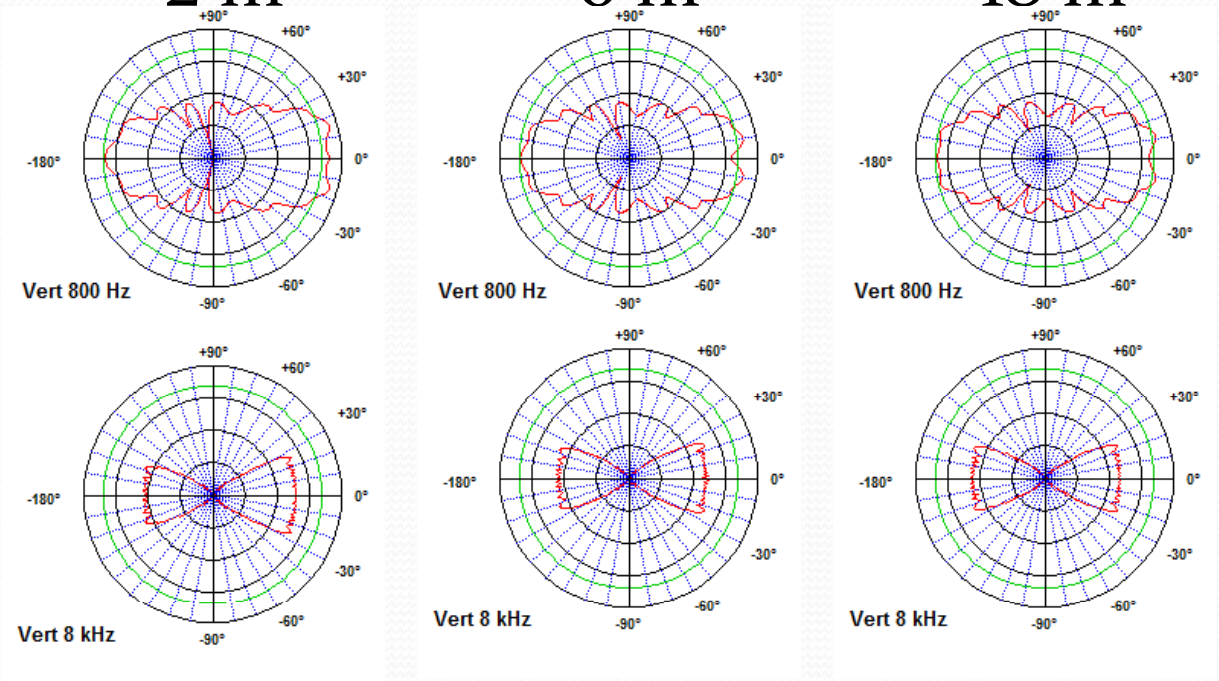
Analysis: Near-Far Polar Pattern Uniformity

- Un-shaded circular-arc array

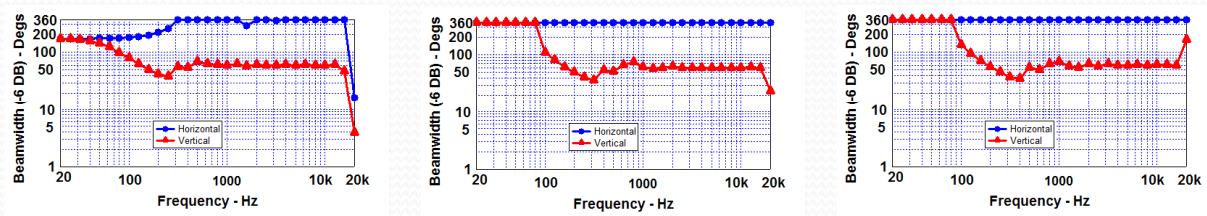
2 m | 6 m | 18 m

800 Hz:

8 kHz:



Beamwidth:



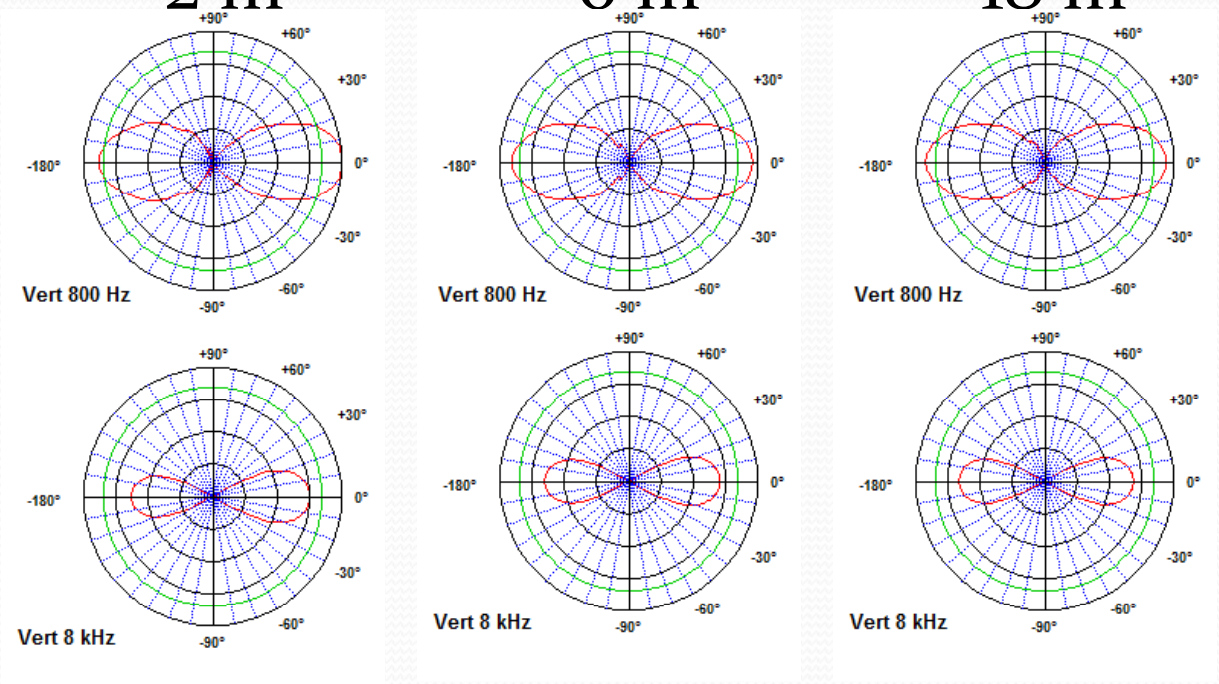
Analysis: Near-Far Polar Pattern Uniformity

- Legendre-shaded CBT circular-arc array

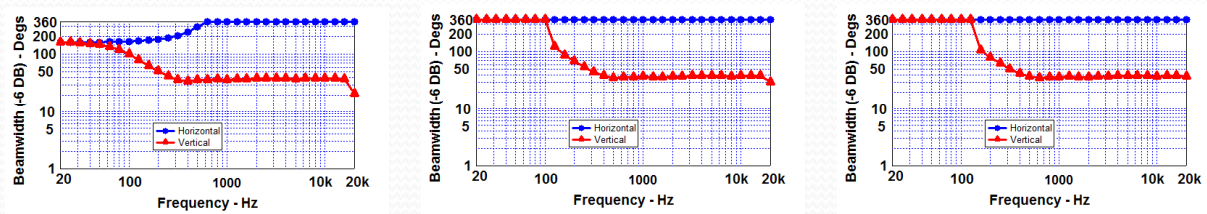
2 m | 6 m | 18 m

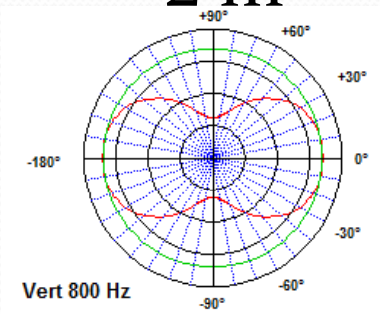
800 Hz:

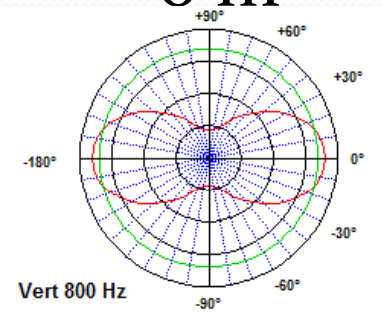
8 kHz:

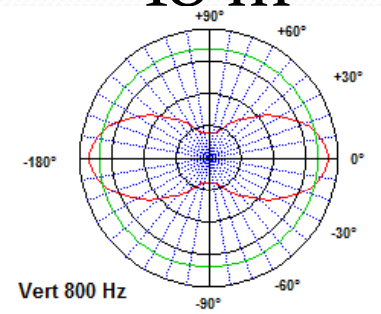


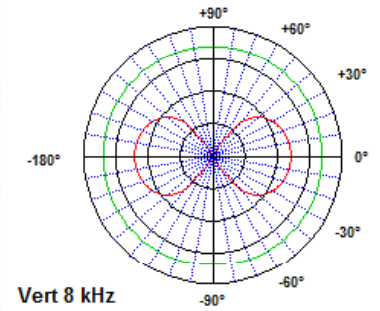
Beamwidth:

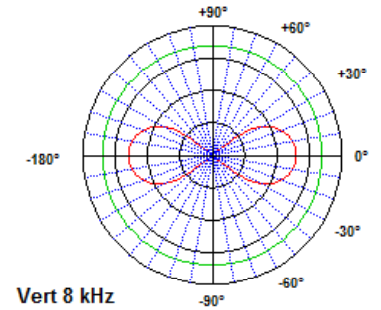


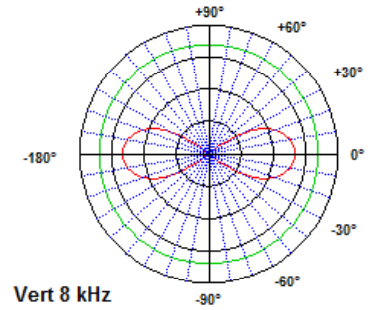


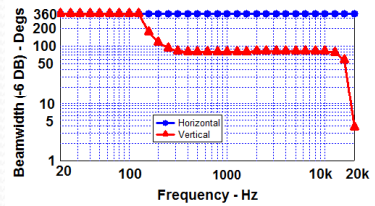


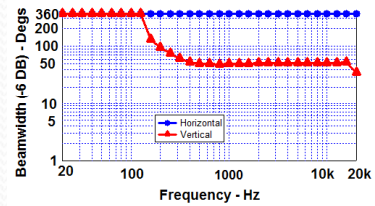


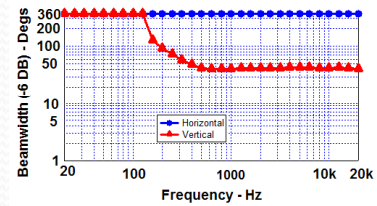












Analysis: Near-Far Polar Pattern Uniformity

- Legendre-shaded delay-curved CBT straight-line array

2 m 6 m 18 m

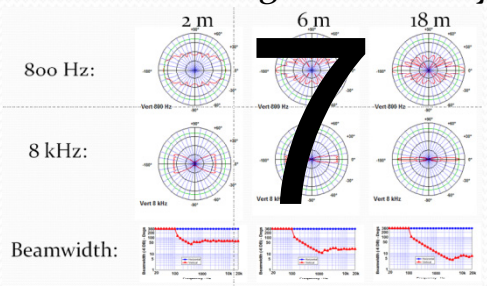
800 Hz:

8 kHz:

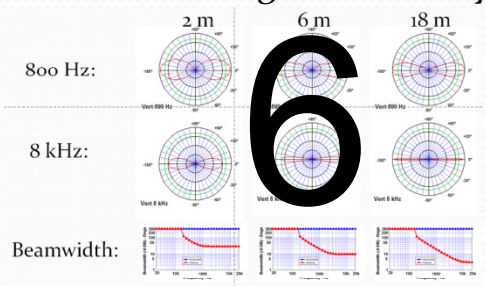
Beamwidth:

Analysis: Near-Far Polar Pattern Uniformity Ranking

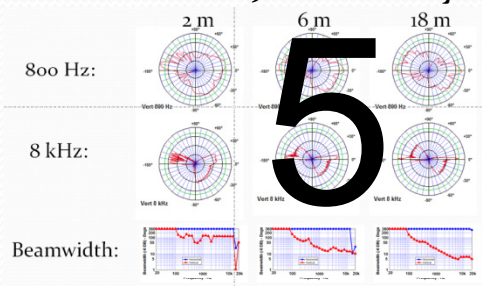
Un-Shaded Straight-Line Array



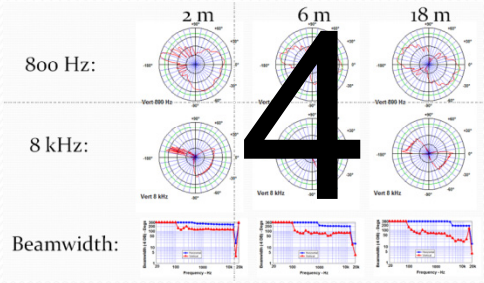
Shaded Straight-Line Array



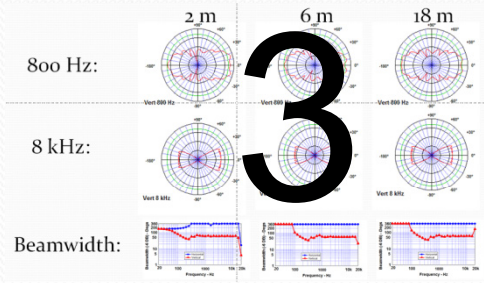
Un-Shaded "J"-Line Array



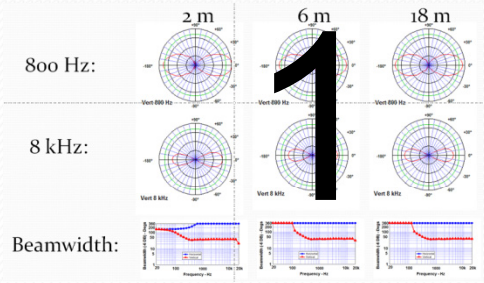
Un-Shaded Spiral-Line Array



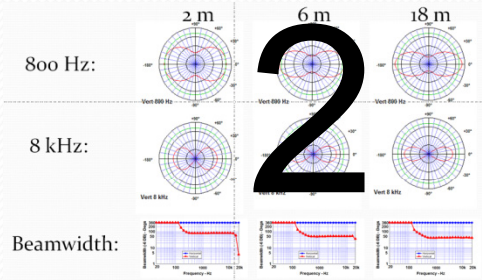
Un-Shaded Circular-Arc Line Array



Shaded Circular-Arc CBT Line Array



Shaded Delay-Curved CBT Straight-Line array



Analysis Results and Final Ranking

TABLE: ARRAY PERFORMANCE RANKING

Array Type, Across: Array Performance Parameter, Down:	(1) Un-shaded straight-line array	(2) Hann-shaded straight-line array	(3) Un-shaded "J"-line array	(4) Un-shaded spiral-line array	(5) Un-shaded circular-arc array	(6) Legendre-shaded CBT circular-arc array	(7) Legendre-shaded delay-curved CBT straight-line array
Beamwidth uniformity:	2	2	1	9	8	10	10
Directivity uniformity:	1	1	4	7	5	10	10
Vertical sound-field uniformity:	1	4	2	2	4	10	10
Polar side lobe suppression:	1	9	6	7	7	10	10
Uniformity of polar response:	1	2	5	6	6	10	10
Smoothness and flatness of off-axis frequency response:	1	2	1	3	8	10	9
Sound pressure rolloff versus distance:	2	1	3	5	8	10	9
Near-far polar pattern uniformity:	1	2	4	7	8	10	9
TOTALS: (Scale 8 to 80)	**10**	**23**	**26**	**46**	**54**	**80**	**77**

Analysis Results and Final Ranking

TABLE: ARRAY PERFORMANCE RANKING

Array Type, Across: Array Performance Parameter, Down:	(1) Un-shaded straight-line array	(2) Hann-shaded straight-line array	(3) Un-shaded "J"-line array	(4) Un-shaded spiral-line array	(5) Un-shaded circular-arc array	(6) Legendre-shaded CBT circular-arc array	(7) Legendre-shaded delay-curved CBT straight-line array
Beamwidth uniformity:	2	2	1	9	8	10	10
Directivity uniformity:	1	1	4	7	5	10	10
Vertical sound-field uniformity:	1	4	2	2	4	10	10
Polar side lobe suppression:	1	9	6	7	7	10	10
Uniformity of polar response:	1	2	5	6	6	10	10
Smoothness and flatness of off-axis frequency response:	1	2	1	3	8	10	9
Sound pressure rolloff versus distance:	2	1	3	5	8	10	9
Near-far polar pattern uniformity:	1	2	4	7	8	10	9
TOTALS: (Scale 8 to 80)	**10**	**23**	**26**	**46**	**54**	**80**	**77**

Analysis Results and Ranking

TABLE: ARRAY PERFORMANCE RANKING

Array Type, Across: Array Performance Parameter, Down:	(1) Un-shaded straight-line array 7	(2) Hann-shaded straight-line array 6	(3) Un-shaded "J"-line array 5	(4) Un-shaded spiral-line array 4	(5) Un-shaded circular-arc array 3	(6) Legendre-shaded CBT circular-arc array 1	(7) Legendre-shaded delay-curved CBT straight-line array 2
Beamwidth uniformity:	2	2	1	9	8	10	10
Directivity uniformity:	1	1	4	7	5	10	10
Vertical sound-field uniformity:	1	4	2	2	4	10	10
Polar side lobe suppression:	1	9	6	7	7	10	10
Uniformity of polar response:	1	2	5	6	6	10	10
Smoothness and flatness of off-axis frequency response:	1	2	1	3	8	10	9
Sound pressure rolloff versus distance:	2	1	3	5	8	10	9
Near-far polar pattern uniformity:	1	2	4	7	8	10	9
TOTALS: (Scale 8 to 80)	**10**	**23**	**26**	**46**	**54**	**80**	**77**

Final Ranking (with scores, range 8 -80)

1. CBT circular-arc array: 80
2. CBT delay-curved straight-line array: 77
3. Un-shaded circular-arc array: 54
4. Spiral-line array: 46
5. "J"-line array: 26
6. Straight-line array (Hann shaded): 23
7. Straight-line array (not shaded): 10

Summary

- This paper presented simulated performance data that allowed several different types of loudspeaker line arrays to be compared and ranked.

- The performance data for all the arrays was subjectively ranked for each performance type on a scale from 1 to 10 and then totaled (scale 8 to 80) for each array, to yield the final array rankings.

Summary, Cont.

- The performance data clearly shows the ***superiority of the circular-arc and delay-curved CBT arrays***. All the performance data for these two arrays was extremely uniform and well behaved.
- The Legendre-shaded ***circular-arc CBT array is clearly the winner here*** because of its uniformity of coverage and the independence of its performance with distance.
- The performance of the ***delay-curved straight-line CBT array is also very uniform and well behaved*** and nearly matches the performance of the circular-arc CBT array.
- A distant third to the CBT arrays is the spiral-line array with the remaining "J"-line and straight-line arrays holding up the bottom of the rankings.

The End.

Phew, I'm glad that guy stopped talking!!!