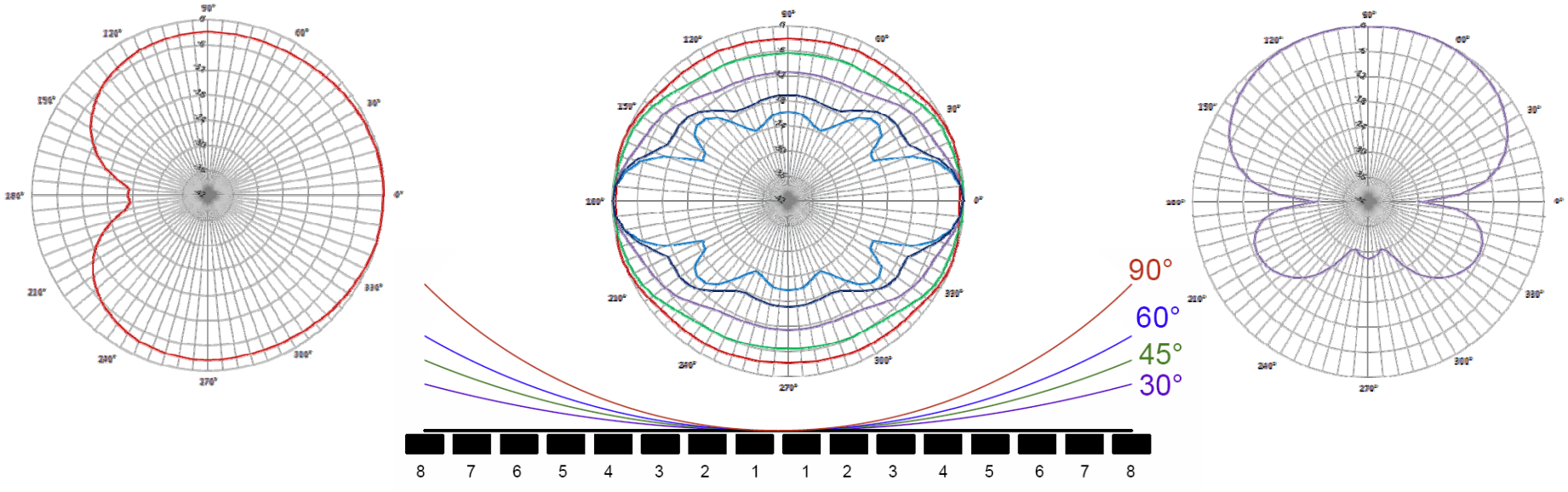
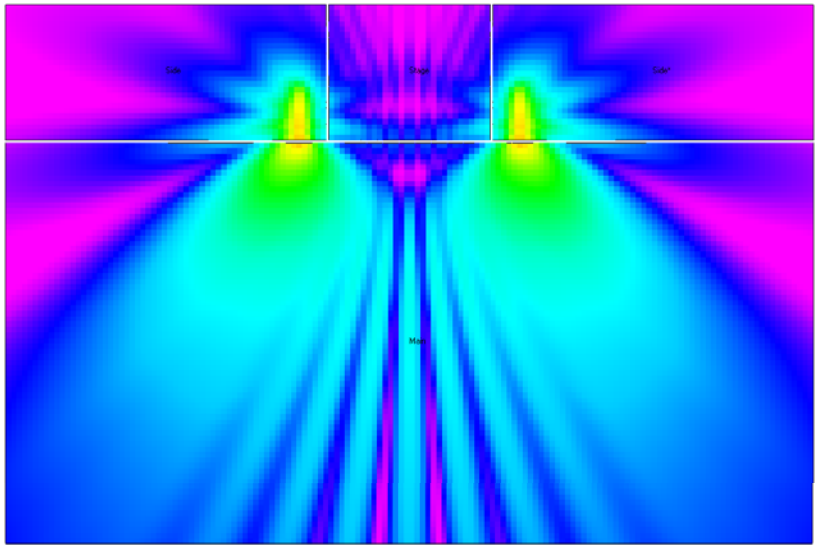
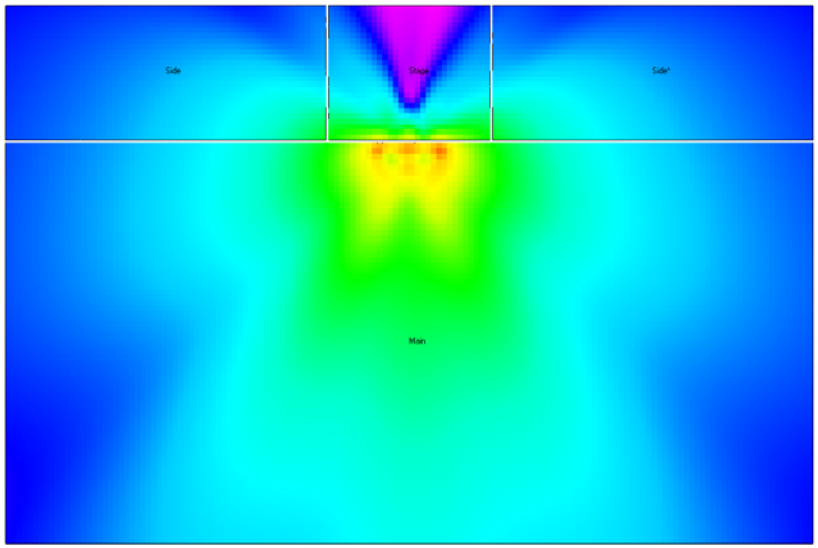
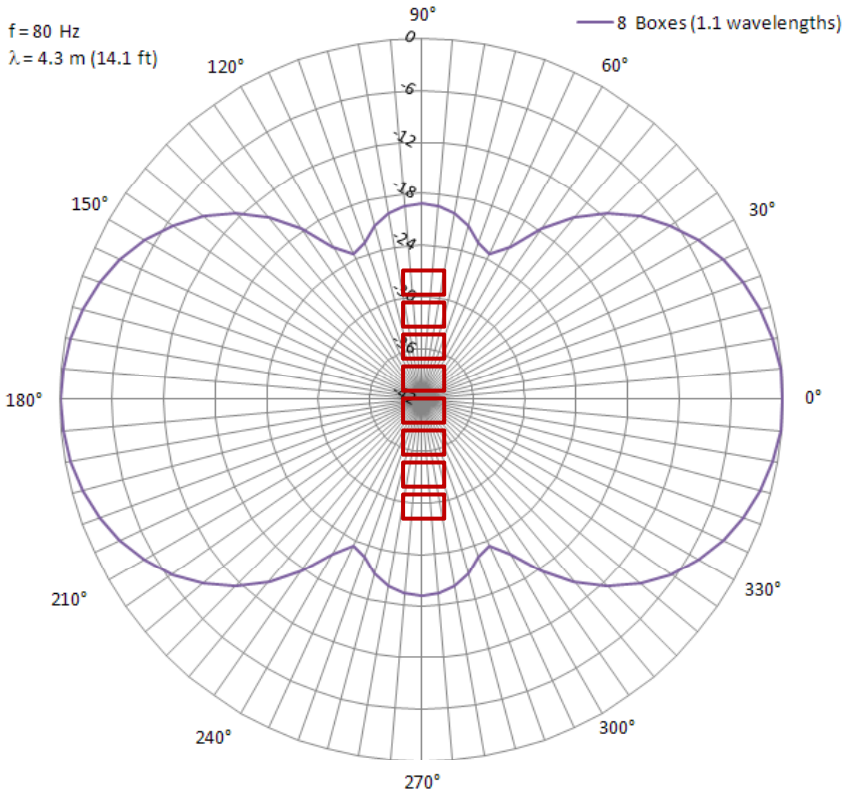
Subwoofer Arrays & Applications



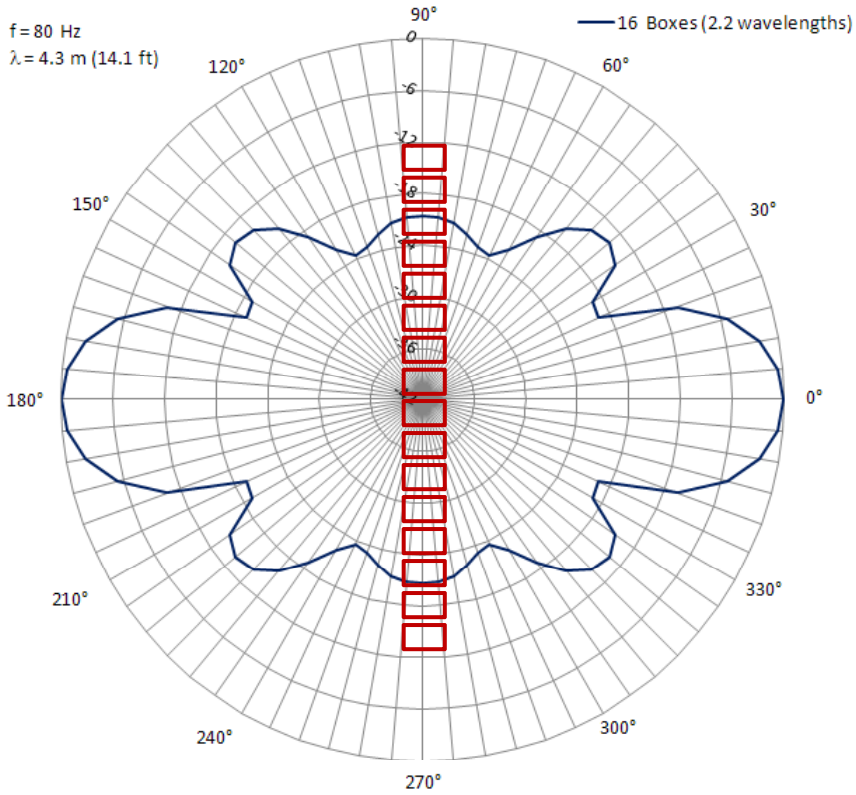




Directivity is a Result of Source Size



80 Hz polar graph of 8x dual 18” subwoofers

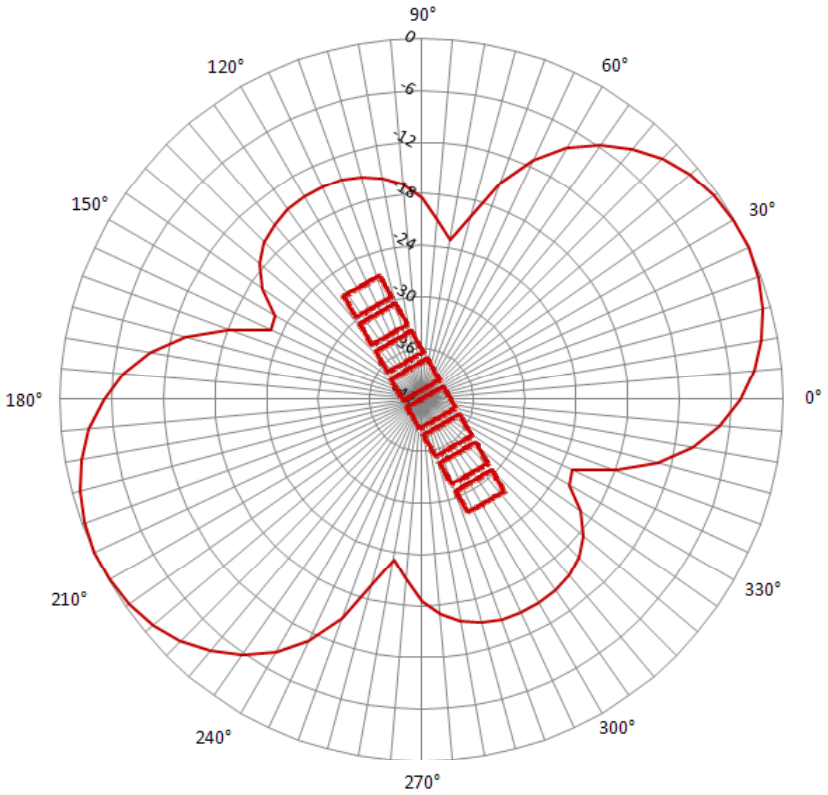


80 Hz polar graph of 16x dual 18” subwoofers

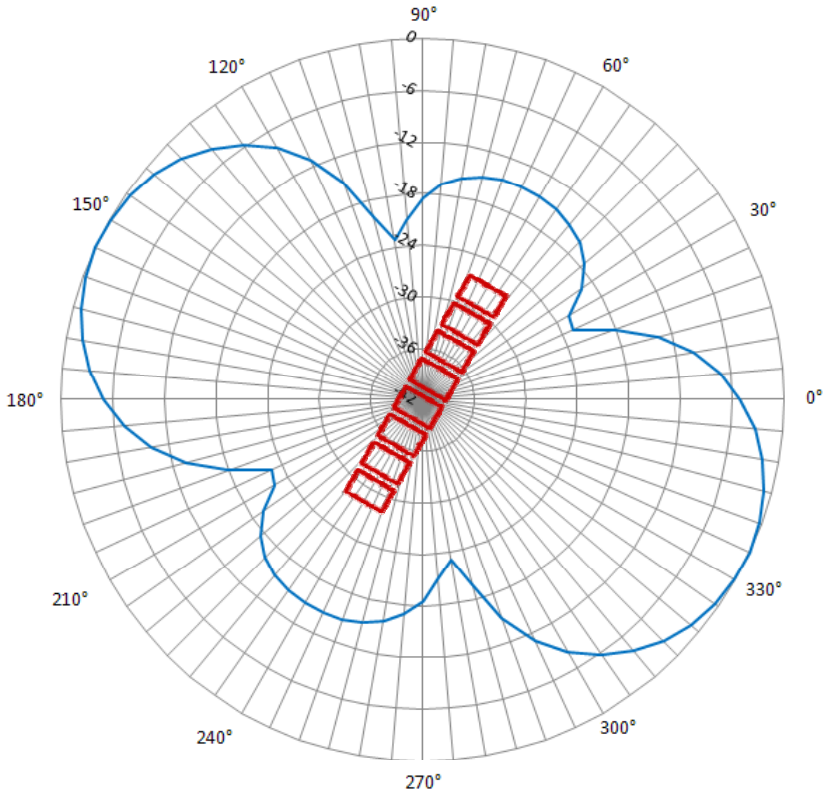
When the array size is one wavelength or greater there is substantial directivity control.

Steering the Main Lobe

Mechanical Steering – the array is tilted



30° Up

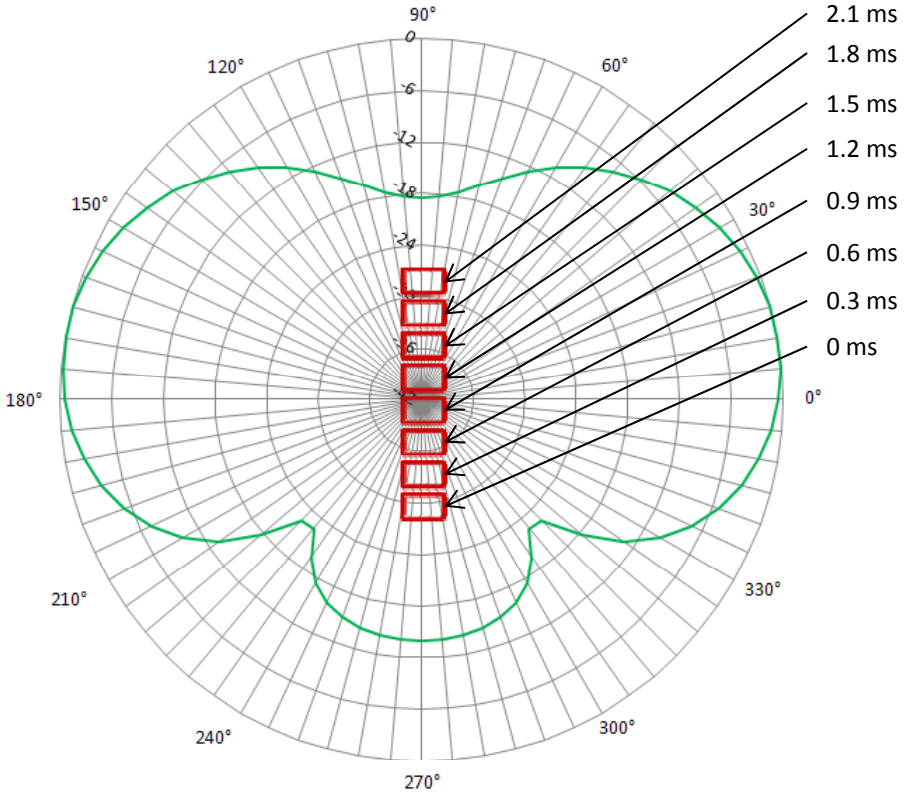


30° Down

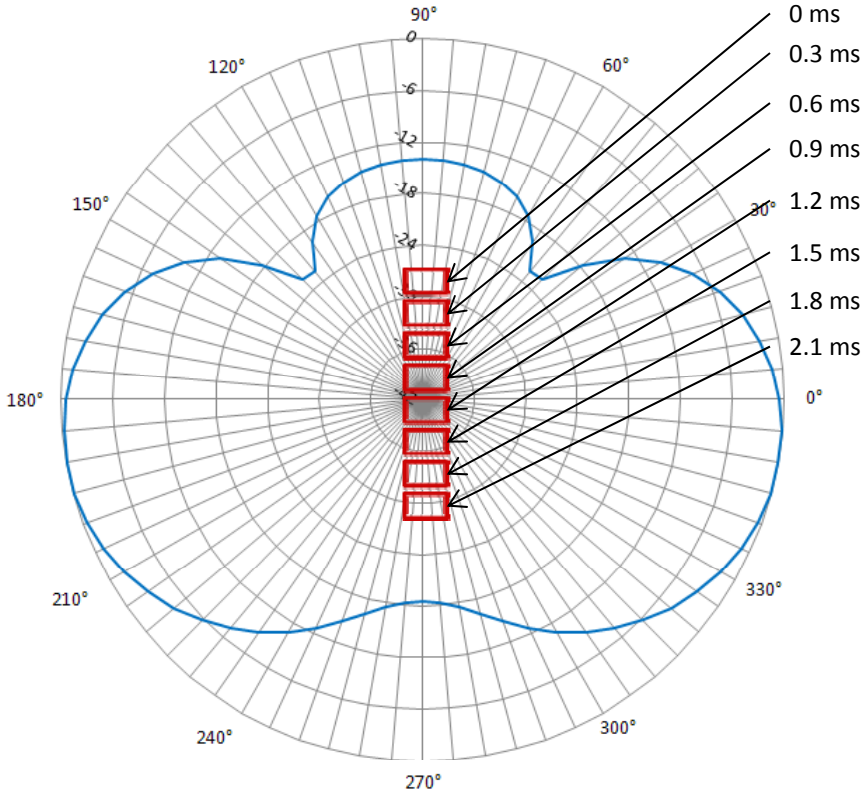
Note that the rear lobe also follows the orientation of the array. It points in the opposite direction of the front lobe.

Steering the Main Lobe

Electrical Steering – the same incremental delay is applied to each box



10° Up

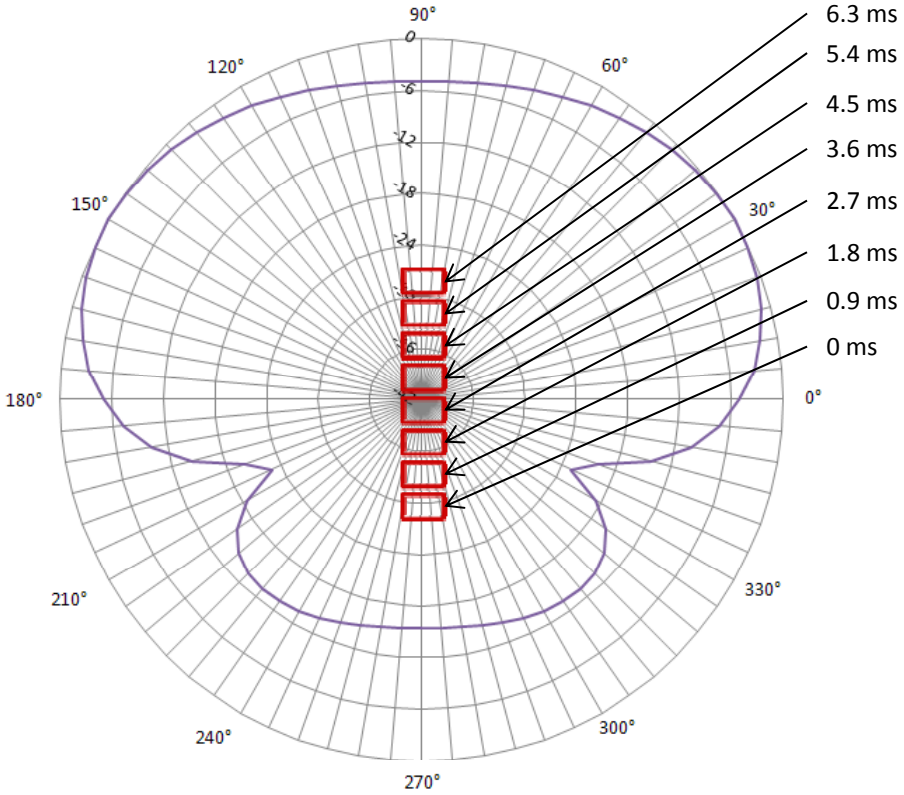


10° Down

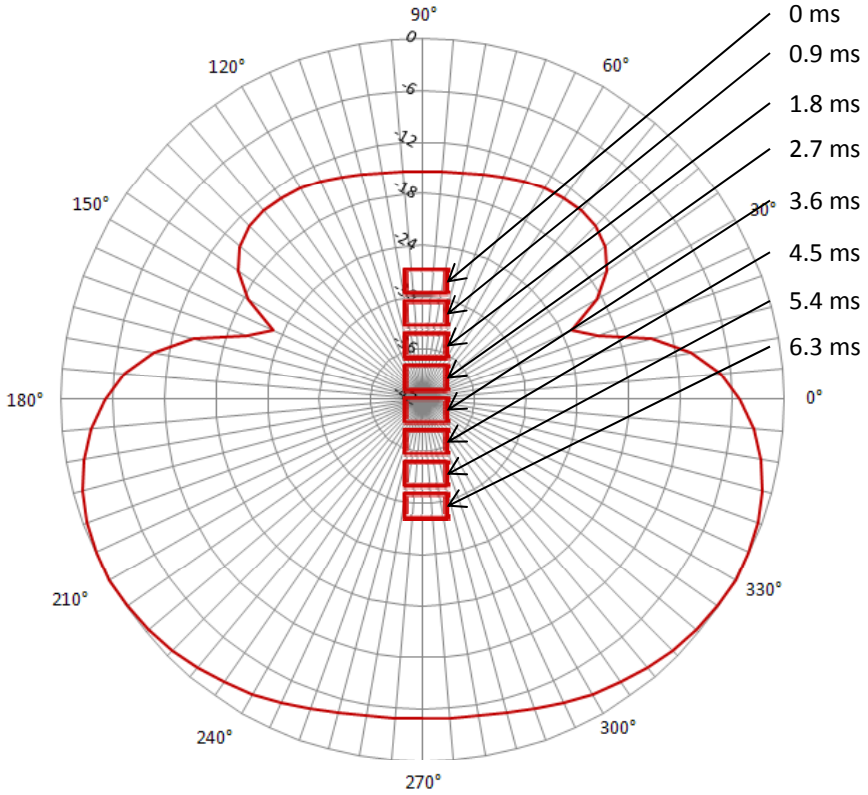
Note that the rear lobe is pointing in the ***same*** direction as the front lobe.

Steering the Main Lobe

Electrical Steering – the same incremental delay is applied to each box



30° Up

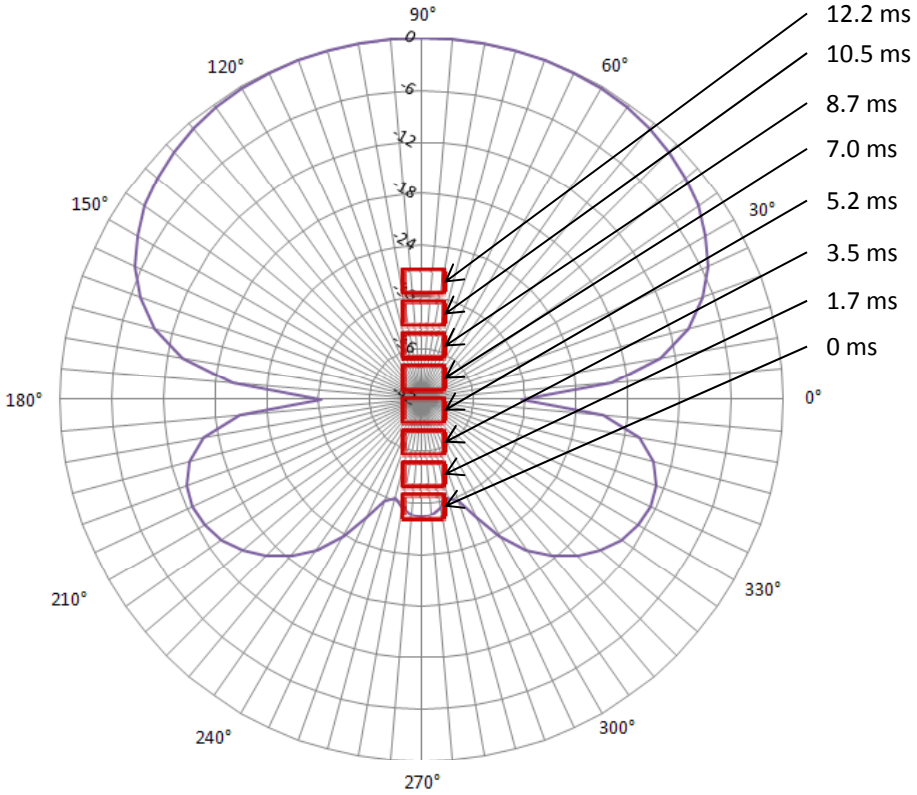


30° Down

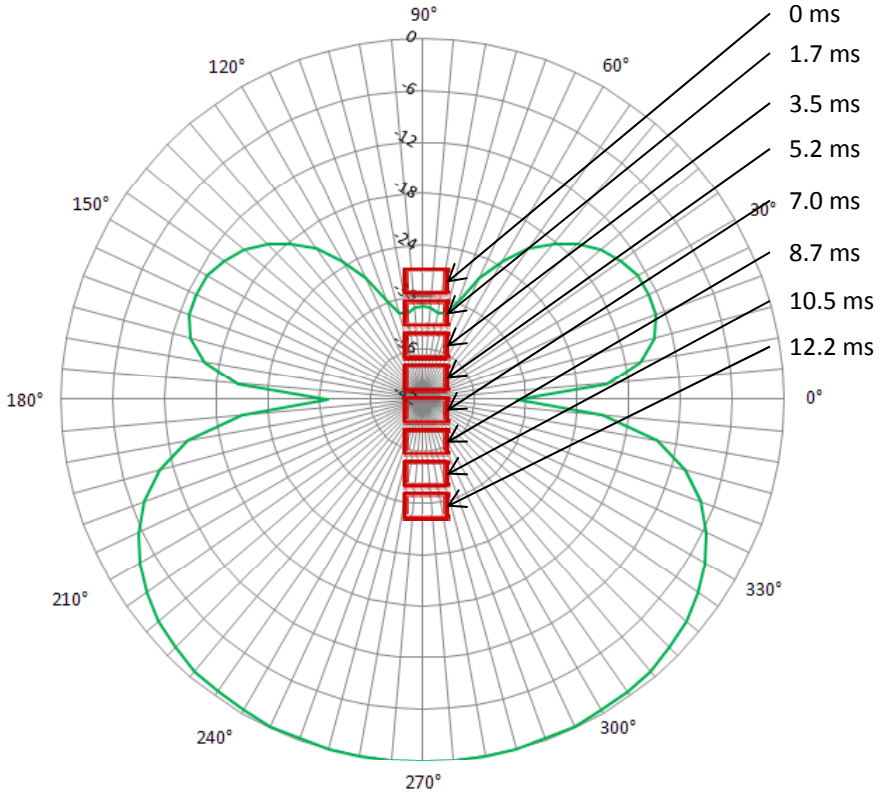
Note that as the steering increases the front and rear lobes begin to merge.

Steering the Main Lobe

End-Fire Array – when the inter-box delay is equal to the inter-box spacing



90° Up



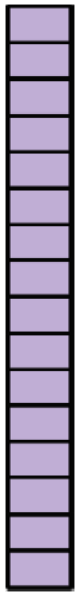
90° Down

Each individual box is delayed back to the rear box so that, on-axis, all of the energy arrives at the same time.

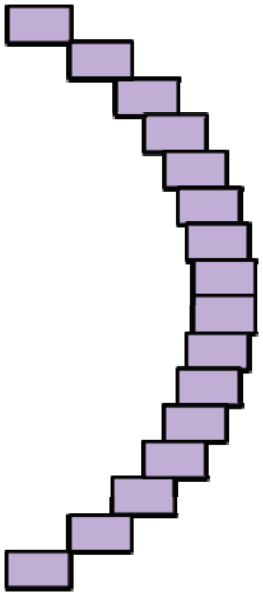
Wave Front Shaping – Broadening the Main Lobe

Curving the array will decrease the directivity and broaden the coverage pattern.

Often there may not be sufficient space for a curved subwoofer array or time to accurately position each box in the array.



16 Box Straight Array

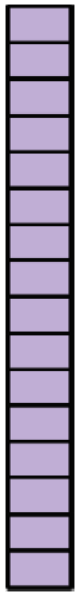


16 Box Circular Curved Array

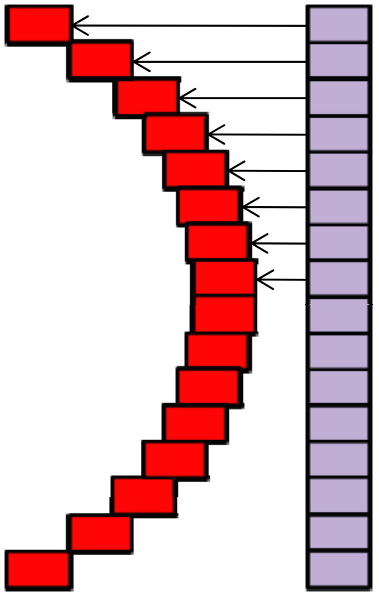
Wave Front Shaping – Broadening the Main Lobe

The array can be curved electrically, instead of mechanically, by using delay.

The boxes farther from the center must be delayed progressively more. The curve is symmetrical so one delay output can drive two boxes.



16 Box Straight Array

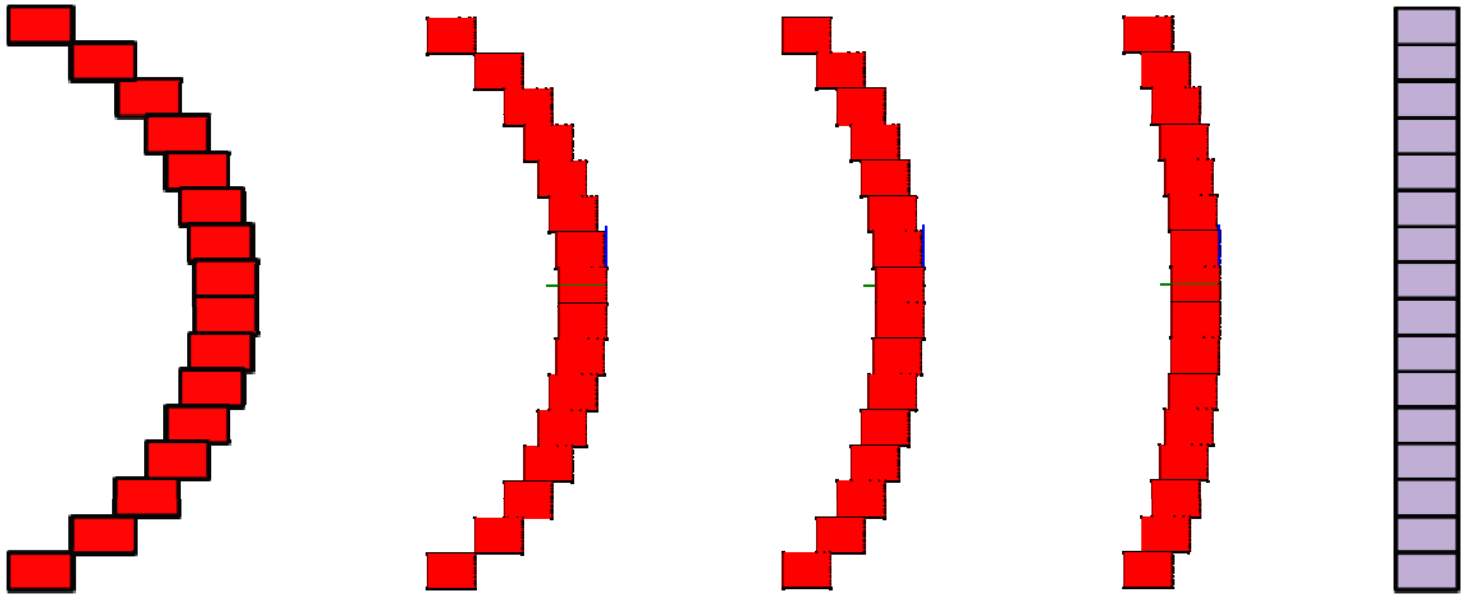


16 Box Circular Curved Array

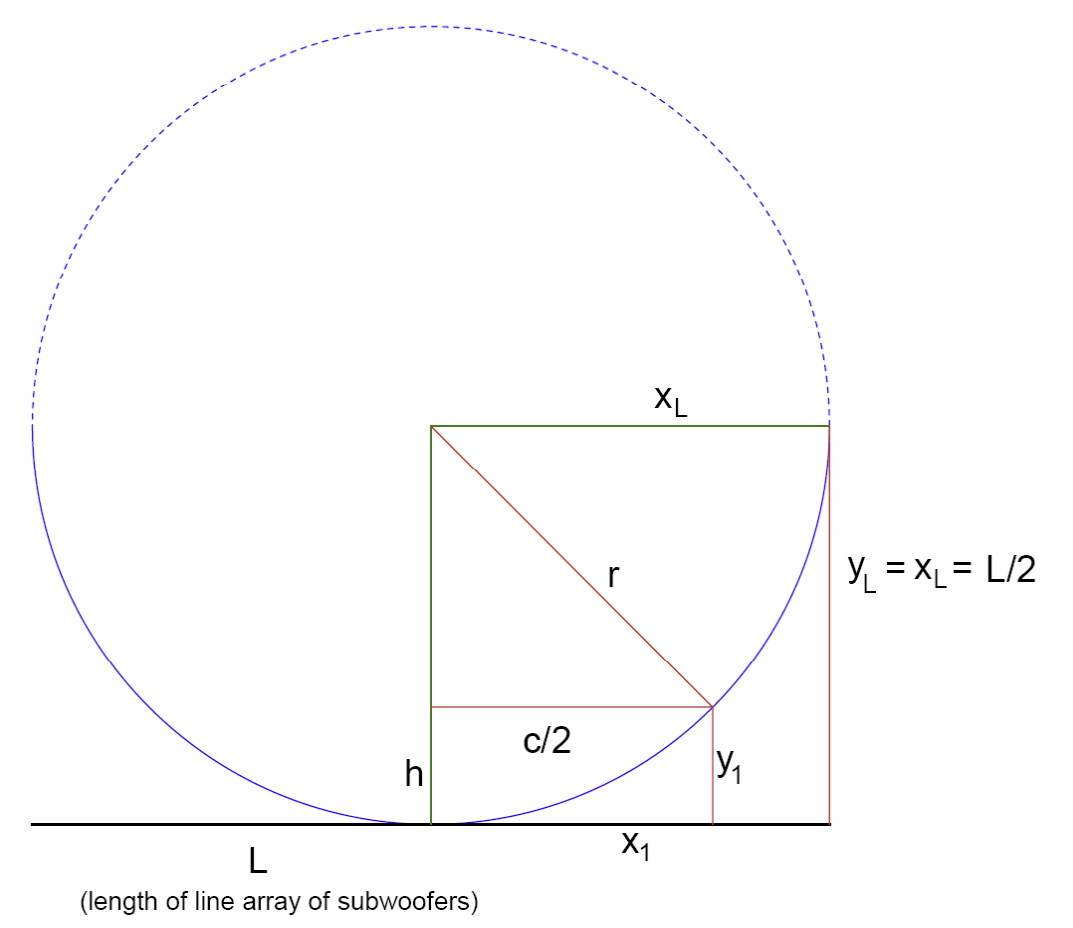
Wave Front Shaping – Broadening the Main Lobe

The array is configured mechanically as a straight line.

The amount of delay can be varied to yield any amount of curvature from 0° to 180°.



Wave Front Shaping – Broadening the Main Lobe



$$h = r - \tfrac{1}{2}(4r^2 - c^2)^{1/2}$$

$$y_1 = h$$

$$c/2 = x_1 , \quad c = 2x_1$$

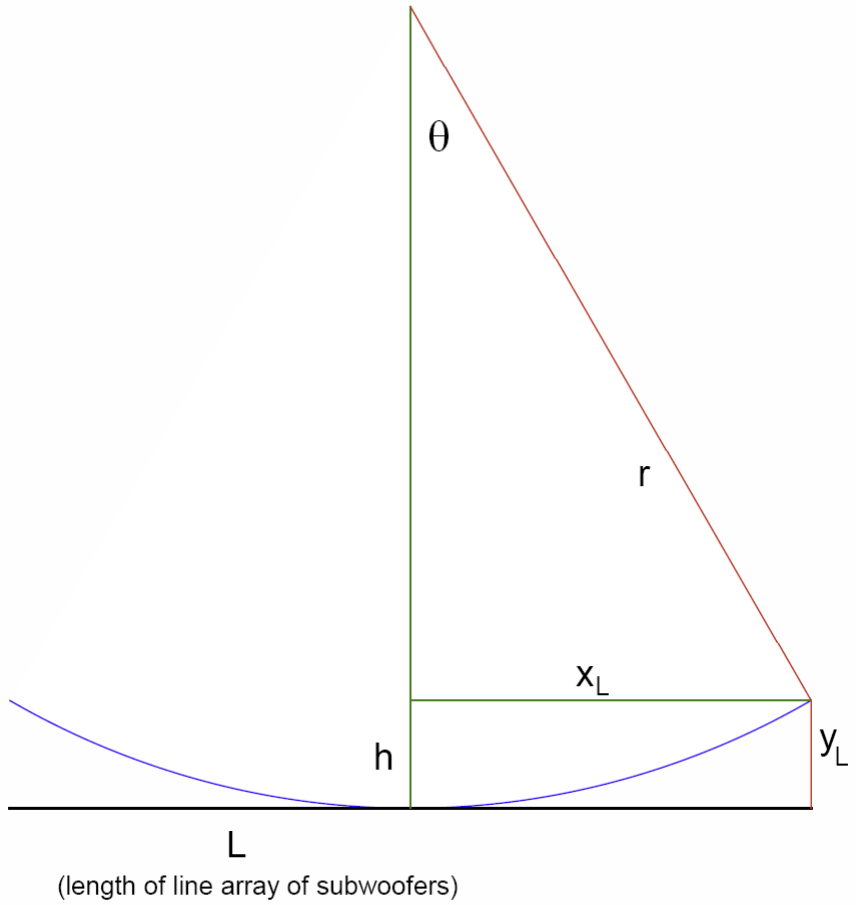
$$h = r - \tfrac{1}{2}(4r^2 - 4x_1^2)^{1/2}$$

$$h = r - (r^2 - x_1^2)^{1/2}$$

$$y_1 = r - (r^2 - x_1^2)^{1/2}$$

Line curved fully to 180° arc. Maximum curvature allowed.

Wave Front Shaping – Broadening the Main Lobe



For a smaller angle of curvature the radius has a larger value.

$$r = x_L / \sin(\theta)$$

$$(0° \leq \theta \leq 90°)$$

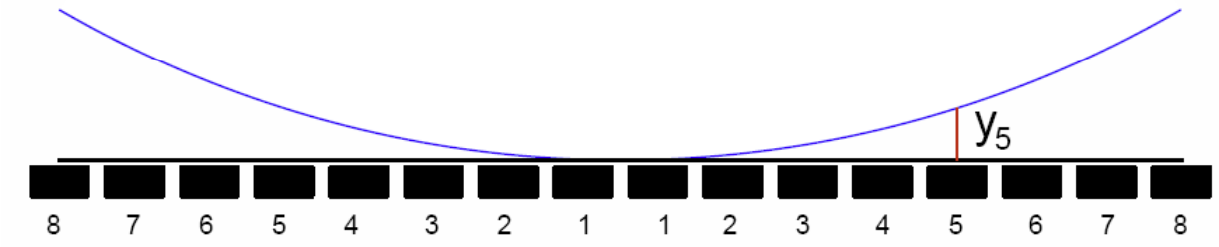
$$y_n = r - (r^2 - x_n^2)^{½}$$

Line only partially curved to an angle of 2θ.

Wave Front Shaping – Broadening the Main Lobe

Delay times required for 60° curvature

Sub Spacing	1.050	**Freq (spacing = λ/4)**	81.90	**Freq (spacing = λ/2)**	163.81	
Number of Subs	16	**Line Length**	16.80	**Freq (length = λ)**	20.48	
Speed of Sound	344	**Half Line Length**	8.4			
Coverage Angle	60					
Desired Line Curvature (deg)	30.0	**Source**	**Position (m)**	**Distance Offset**	**Normalized Offset**	**Delay for Curvature**
radius	16.800	1	0.525	0.01	0.00	0.000
		2	1.575	0.07	0.07	0.191
		3	2.625	0.21	0.20	0.576
		4	3.675	0.41	0.40	1.159
		5	4.725	0.68	0.67	1.947
		6	5.775	1.02	1.02	2.952
		7	6.825	1.45	1.44	4.188
		8	7.875	1.96	1.95	5.674

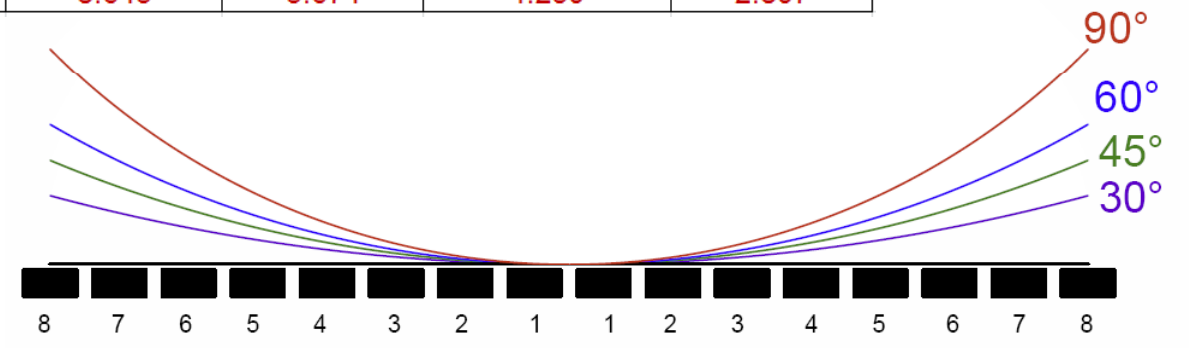


Cabinet	Position	60° Delay
Left 8	7.875	5.674
Left 7	6.825	4.188
Left 6	5.775	2.952
Left 5	4.725	1.947
Left 4	3.675	1.159
Left 3	2.625	0.576
Left 2	1.575	0.191
Left 1	0.525	0.000
Right 1	-0.525	0.000
Right 2	-1.575	0.191
Right 3	-2.625	0.576
Right 4	-3.675	1.159
Right 5	-4.725	1.947
Right 6	-5.775	2.952
Right 7	-6.825	4.188
Right 8	-7.875	5.674

Wave Front Shaping – Broadening the Main Lobe

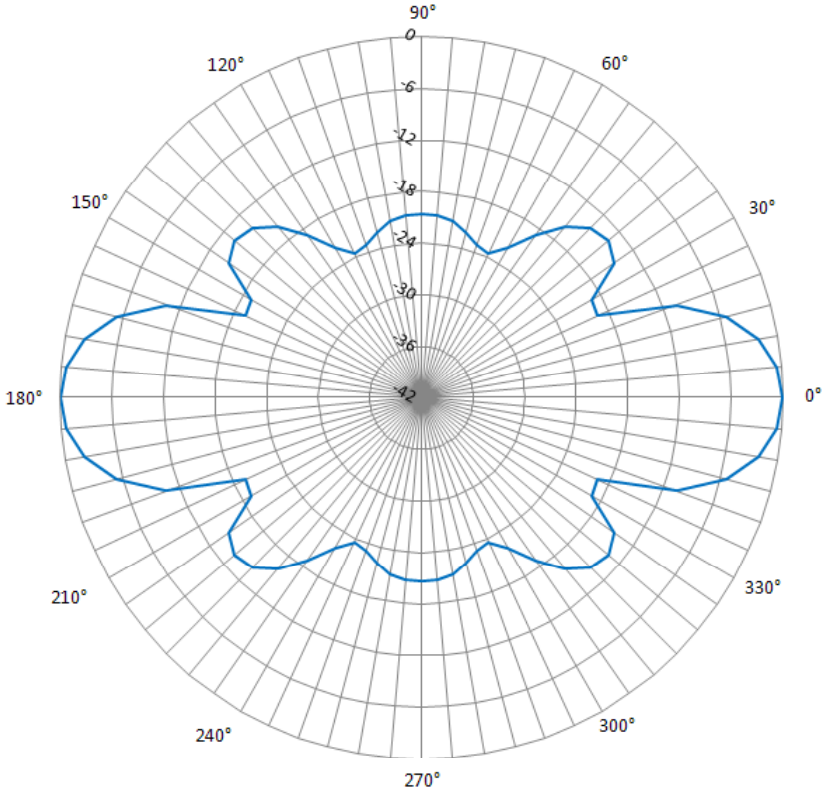
Delay times required for various curvatures

Cabinet	Position	90° Delay	60° Delay	45° Delay	30° Delay
Left 8	7.875	8.645	5.674	4.230	2.807
Left 7	6.825	6.234	4.188	3.145	2.097
Left 6	5.775	4.321	2.952	2.230	1.493
Left 5	4.725	2.815	1.947	1.478	0.993
Left 4	3.675	1.660	1.159	0.882	0.594
Left 3	2.625	0.820	0.576	0.440	0.297
Left 2	1.575	0.271	0.191	0.146	0.099
Left 1	0.525	0.000	0.000	0.000	0.000
Right 1	-0.525	0.000	0.000	0.000	0.000
Right 2	-1.575	0.271	0.191	0.146	0.099
Right 3	-2.625	0.820	0.576	0.440	0.297
Right 4	-3.675	1.660	1.159	0.882	0.594
Right 5	-4.725	2.815	1.947	1.478	0.993
Right 6	-5.775	4.321	2.952	2.230	1.493
Right 7	-6.825	6.234	4.188	3.145	2.097
Right 8	-7.875	8.645	5.674	4.230	2.807

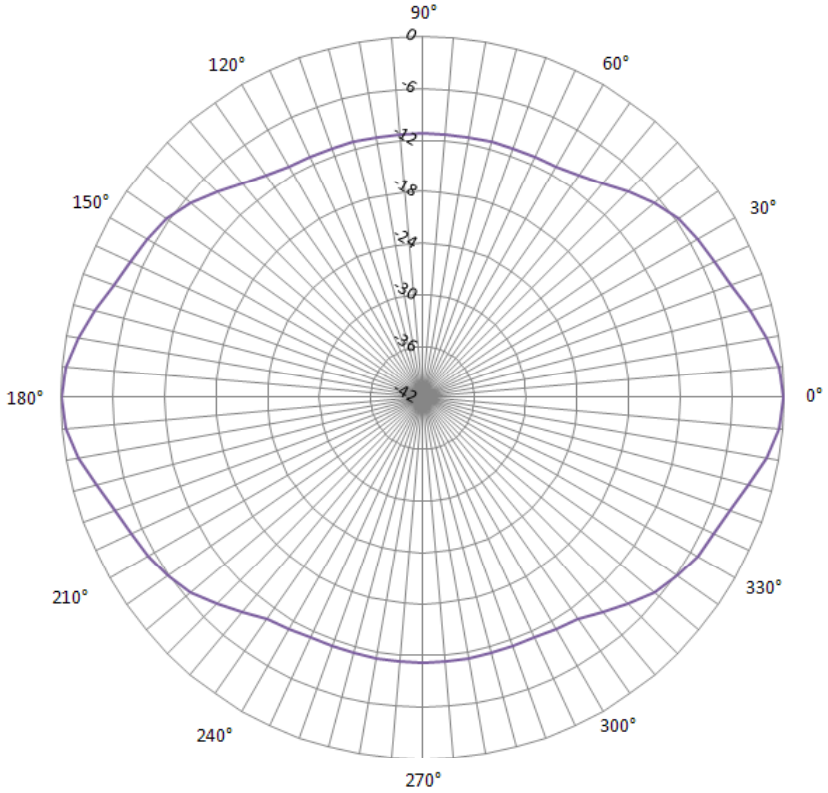


Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



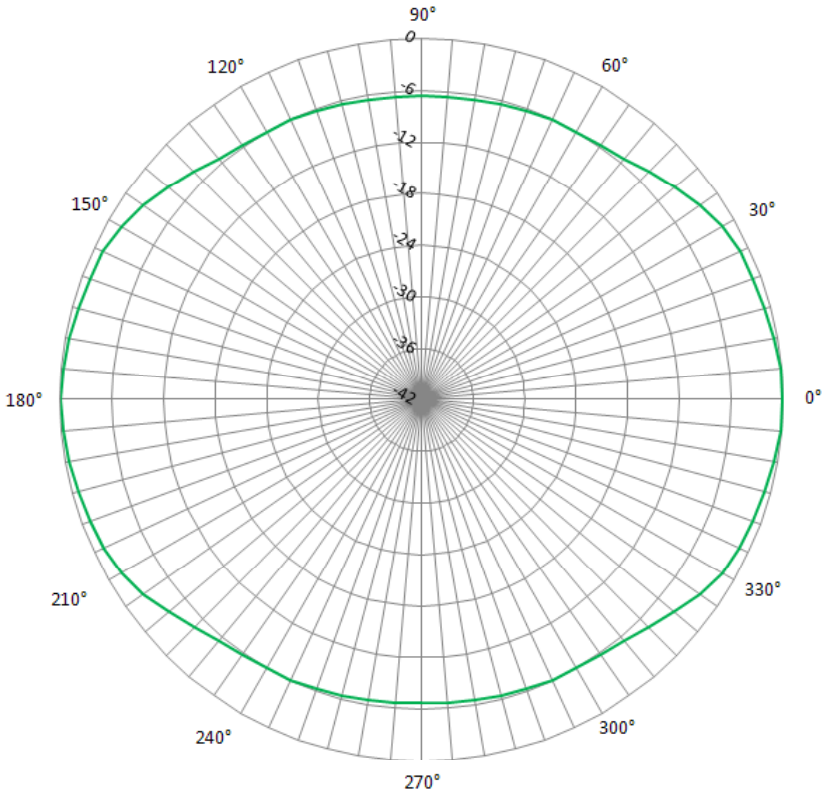
16 Box Straight Array, No Delay Curvature



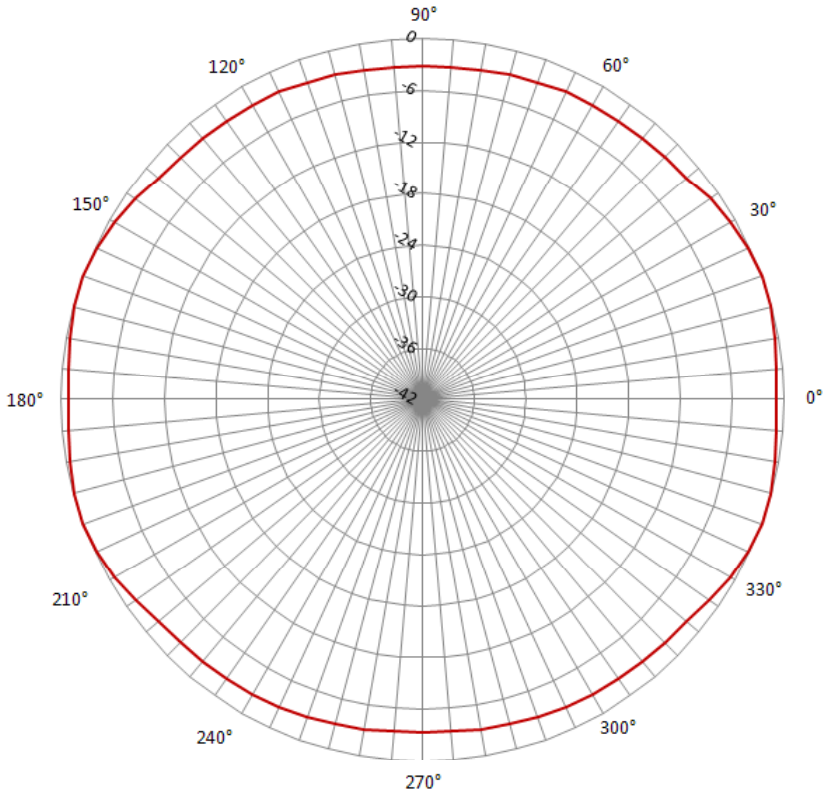
16 Box Straight Array, Curved 30° with Delay

Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



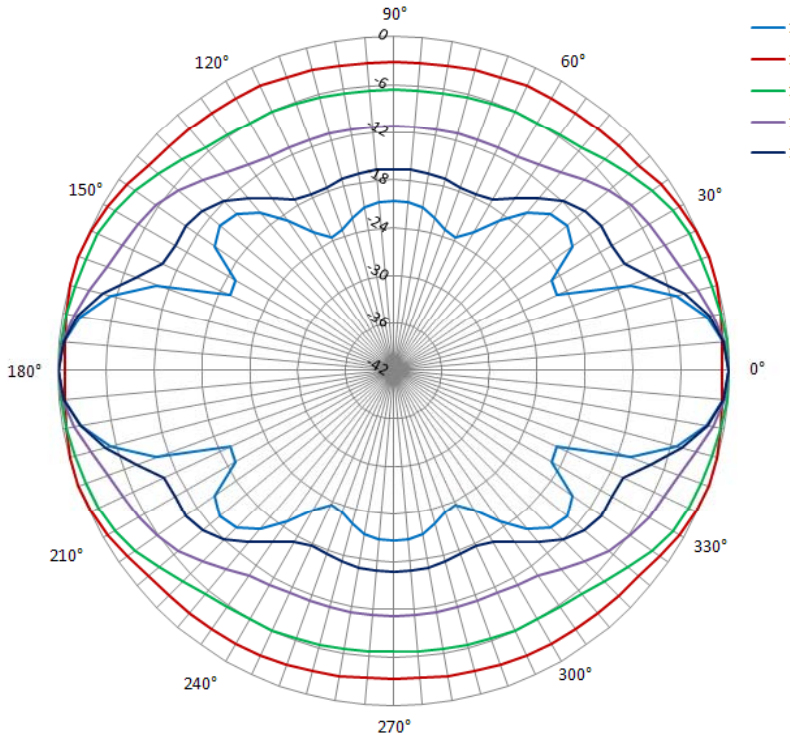
16 Box Straight Array, Curved 45° with Delay



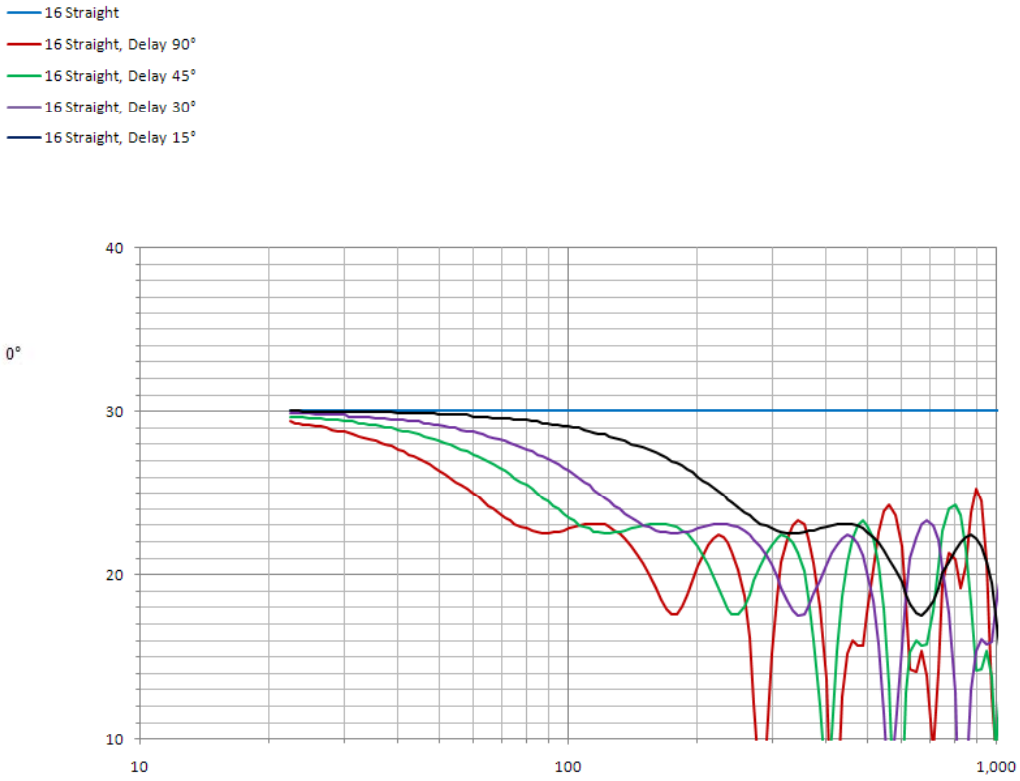
16 Box Straight Array, Curved 90° with Delay

Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



Polar Response at 80 Hz



On-Axis Magnitude Response

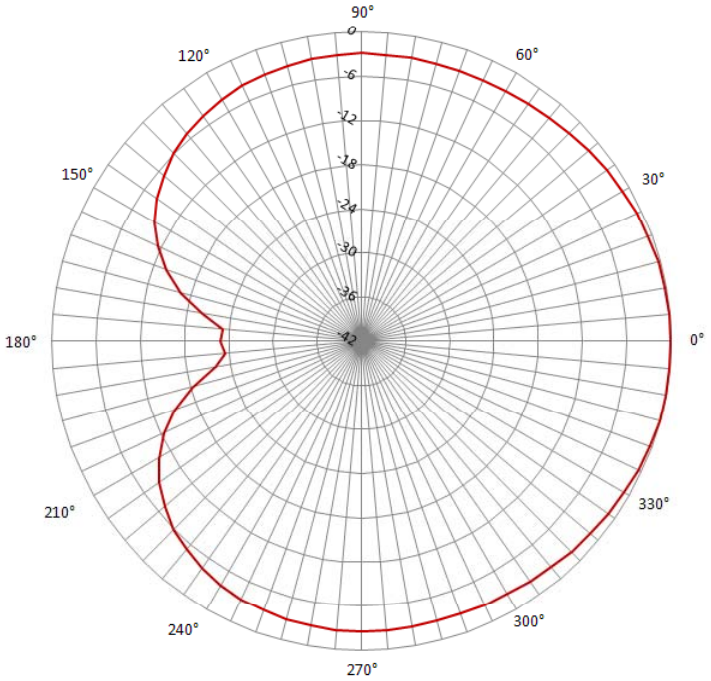
16 Box Straight Array, Curved with Delay

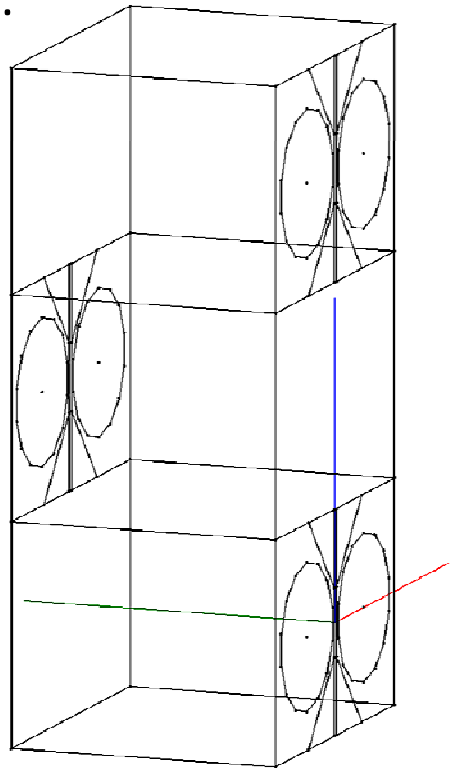
Cardioid Array – Controlling Rear Radiation

Sources must be physically offset by ¼ wavelength at the highest frequency to be used.

Rear source must be delayed by ¼ wavelength at the highest frequency to be used.

Polarity of rear source must be inverted.



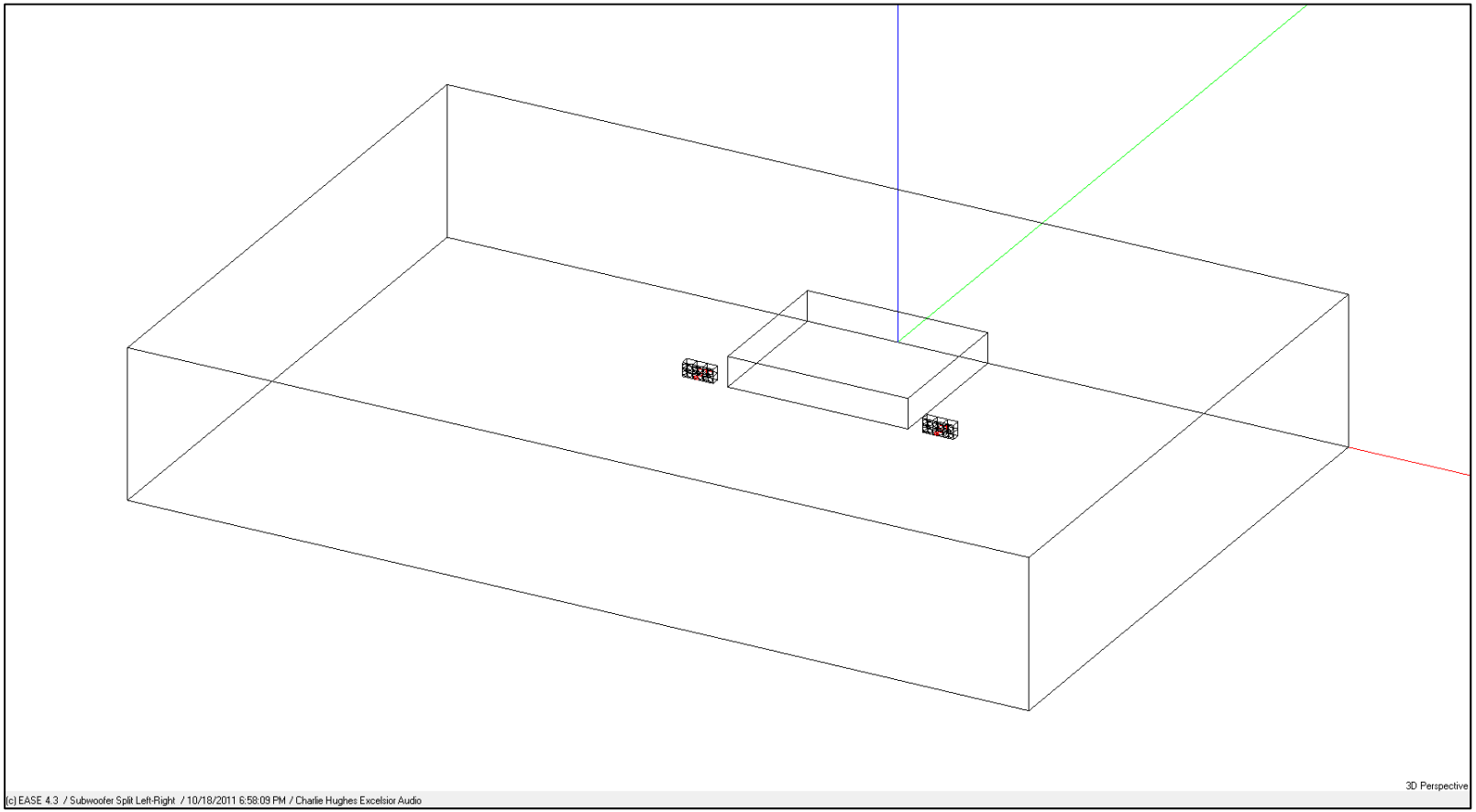


3 Box Cardioid Array

Vertical symmetry keeps vertical pattern symmetrical.

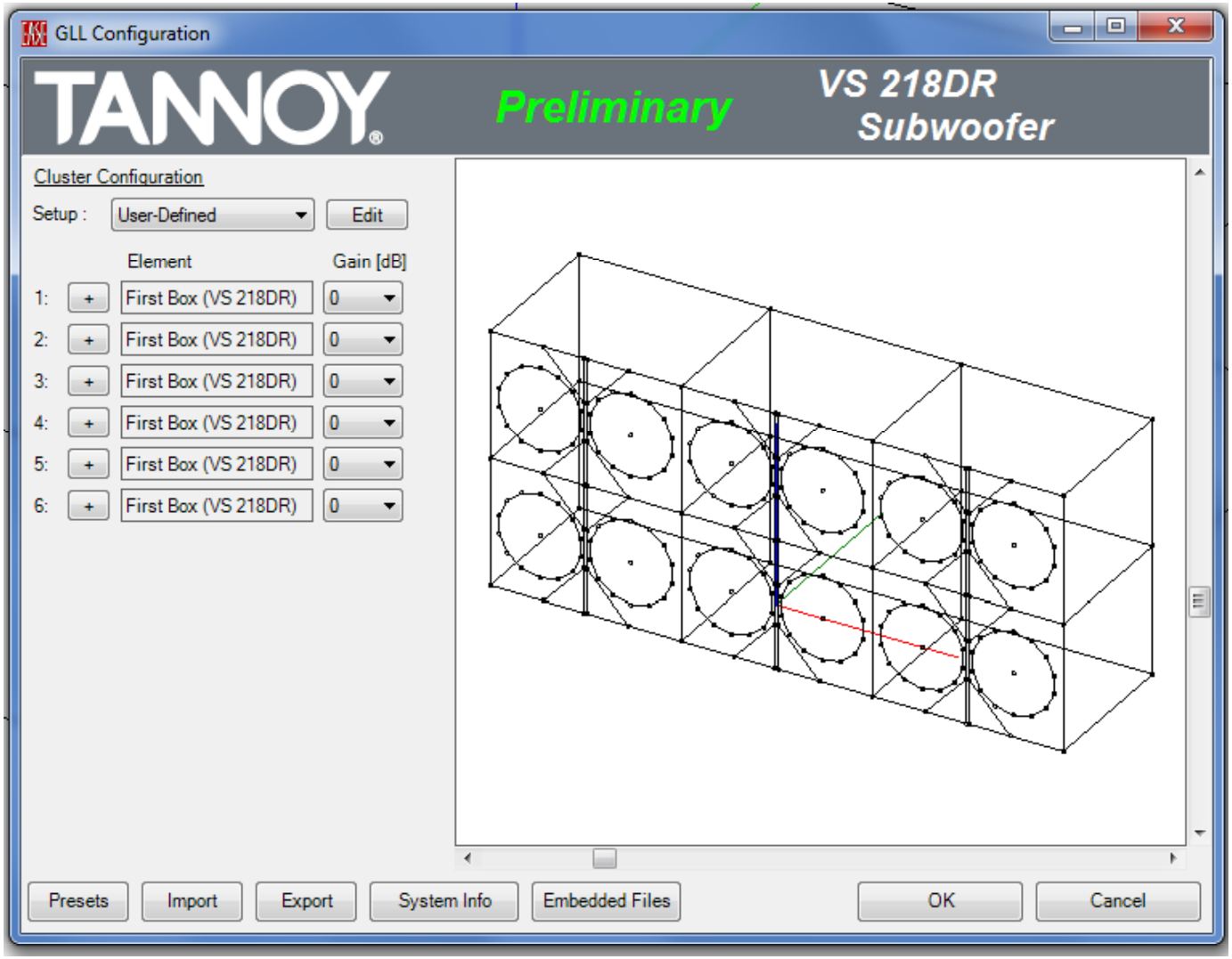
Conventional Stacks Split Left & Right

Large room (walls, floor, & ceiling are non-reflective; direct field only)
Stage approx. 60 ft (18.3 m) wide. Subs spaced approx. 80 ft (24.4 m).



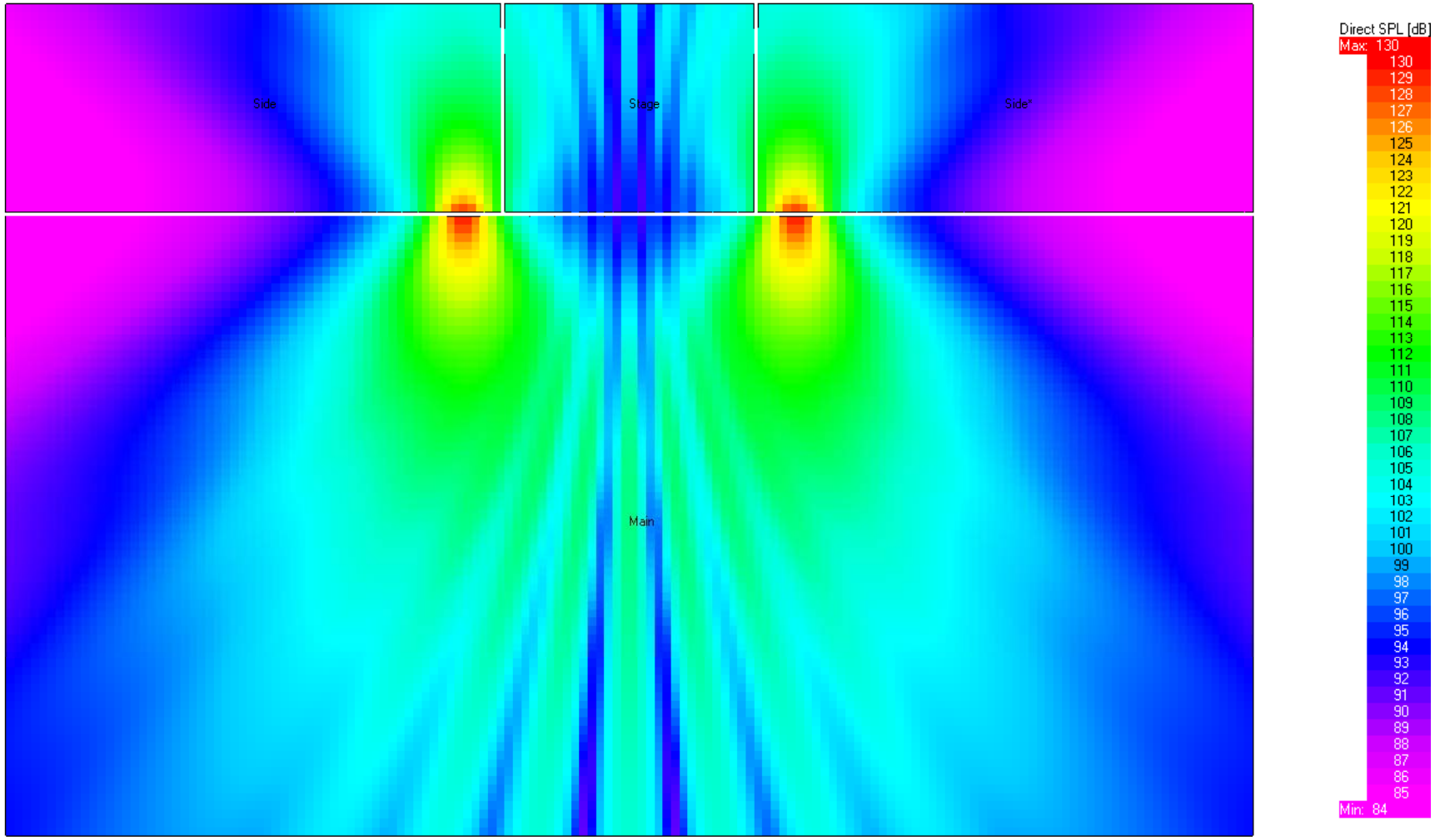
Conventional 2 x 3 stack on left & right side of the stage

Conventional Stacks Split Left & Right



Conventional 2 x 3 stack on left & right side of the stage

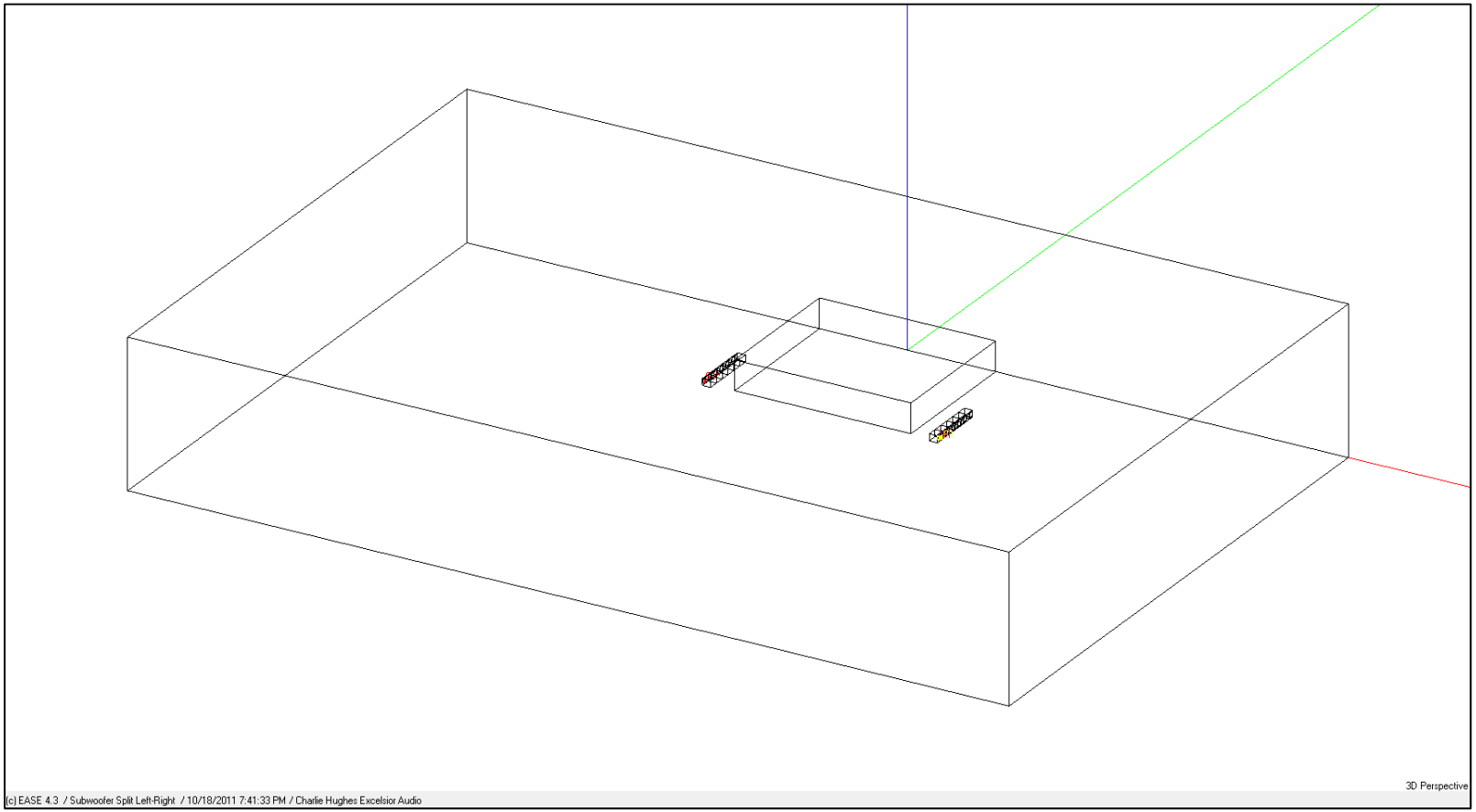
Conventional Stacks Split Left & Right



SPL Map

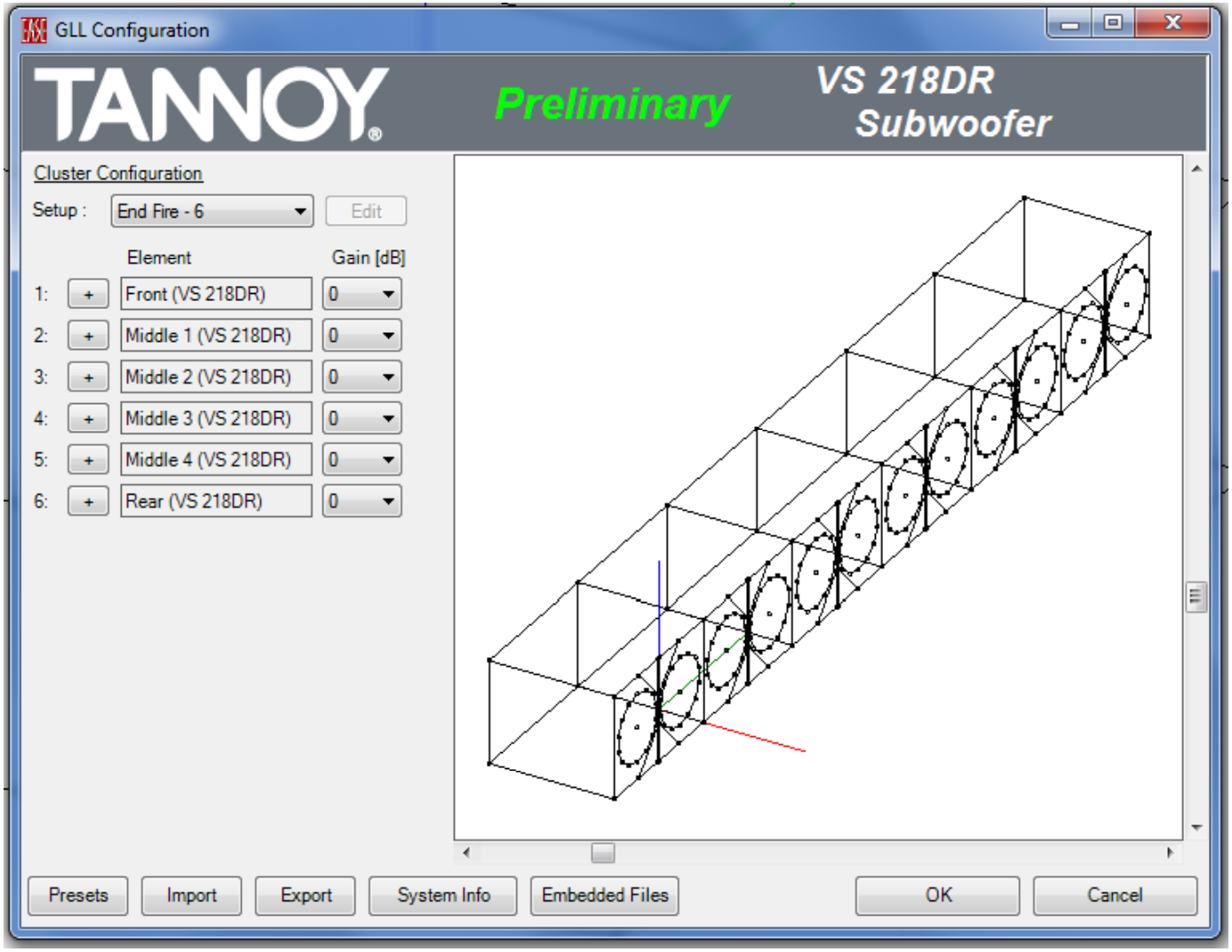
End-Fire Arrays Split Left & Right

Large room (walls, floor, & ceiling are non-reflective; direct field only)
Stage approx. 60 ft (18.3 m) wide. Subs spaced approx. 80 ft (24.4 m).



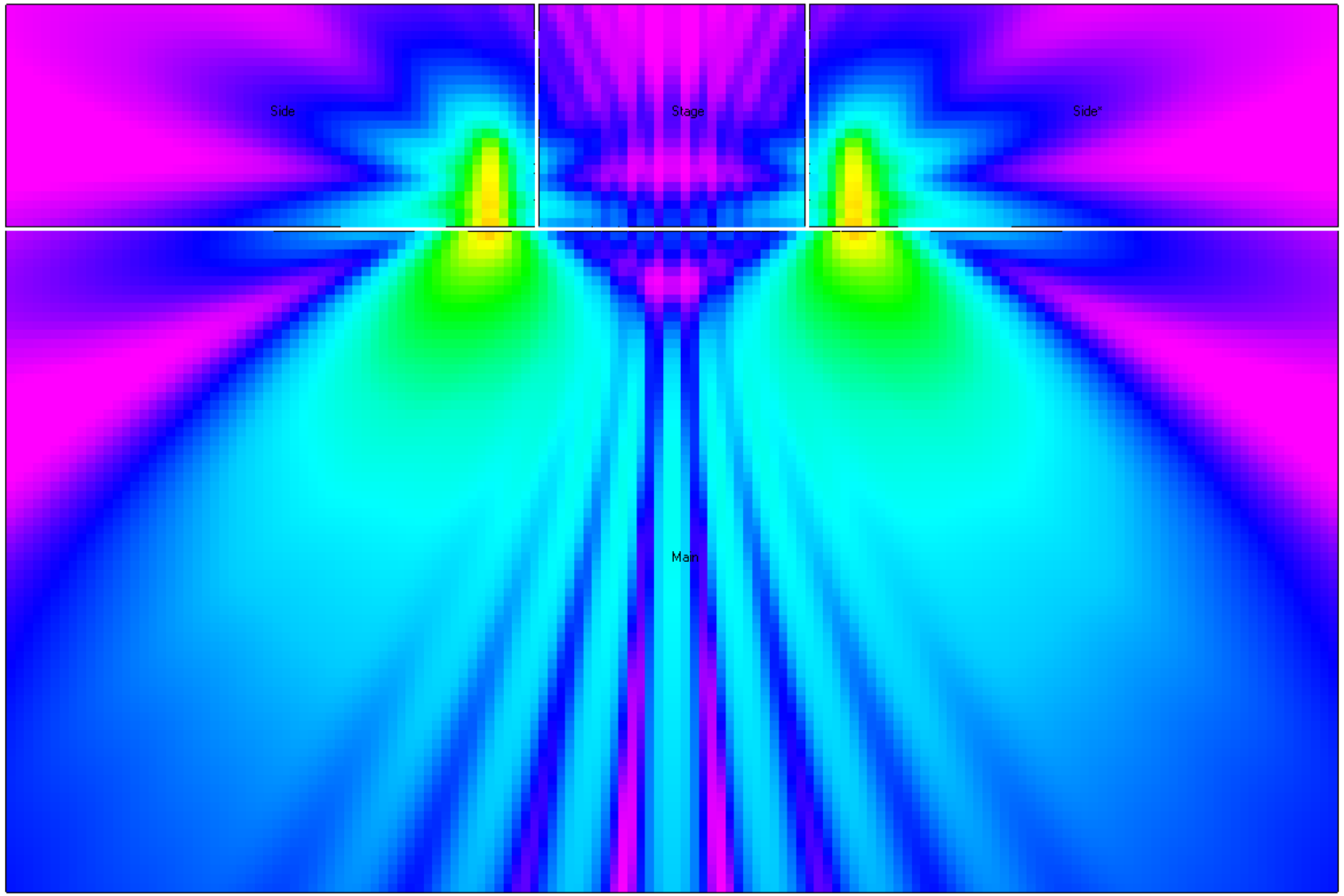
6 box end-fire array on left & right side of the stage

End-Fire Arrays Split Left & Right



6 box end-fire array on left & right side of the stage

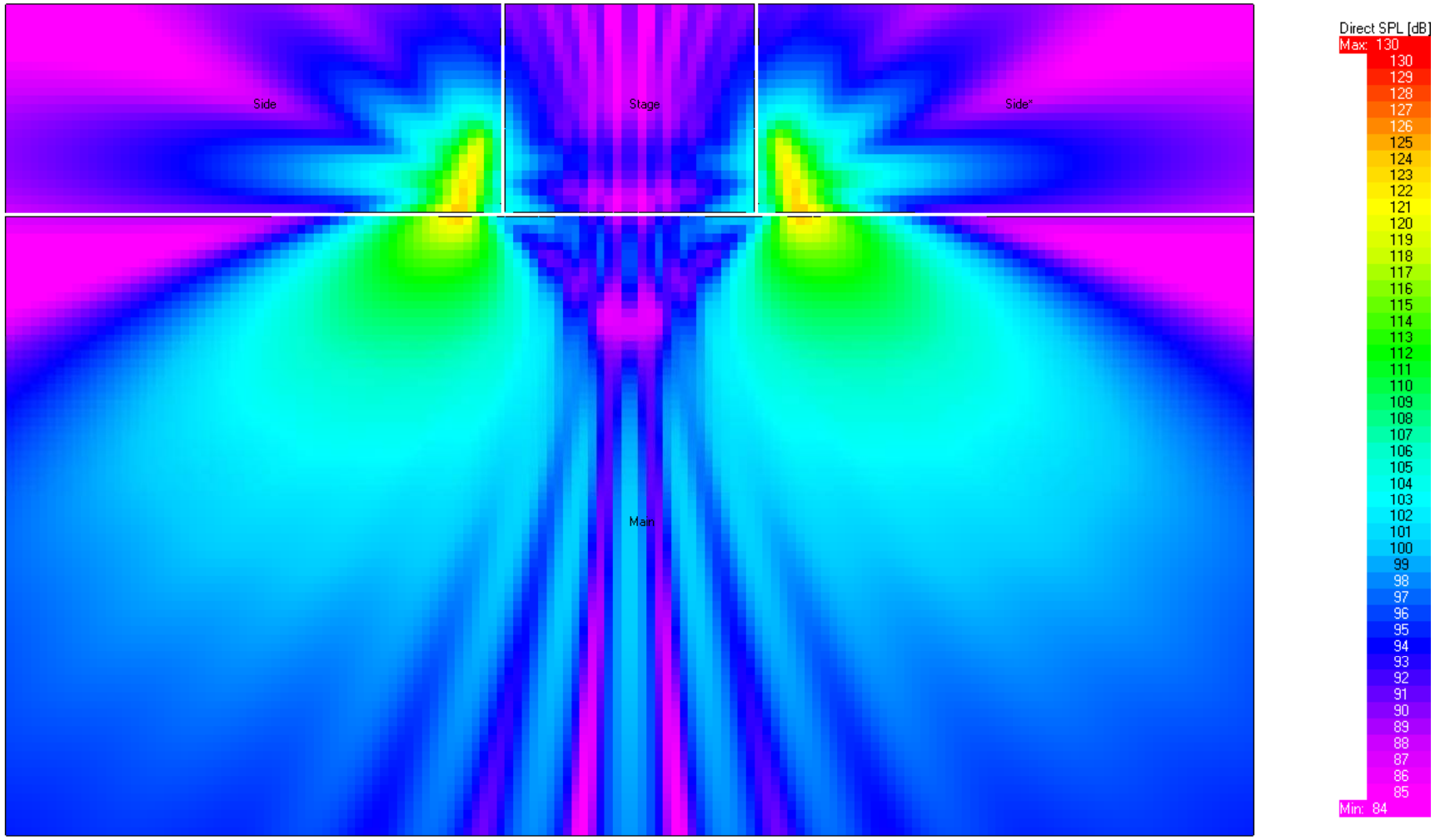
End-Fire Arrays Split Left & Right



SPL Map

End-Fire Arrays Split Left & Right

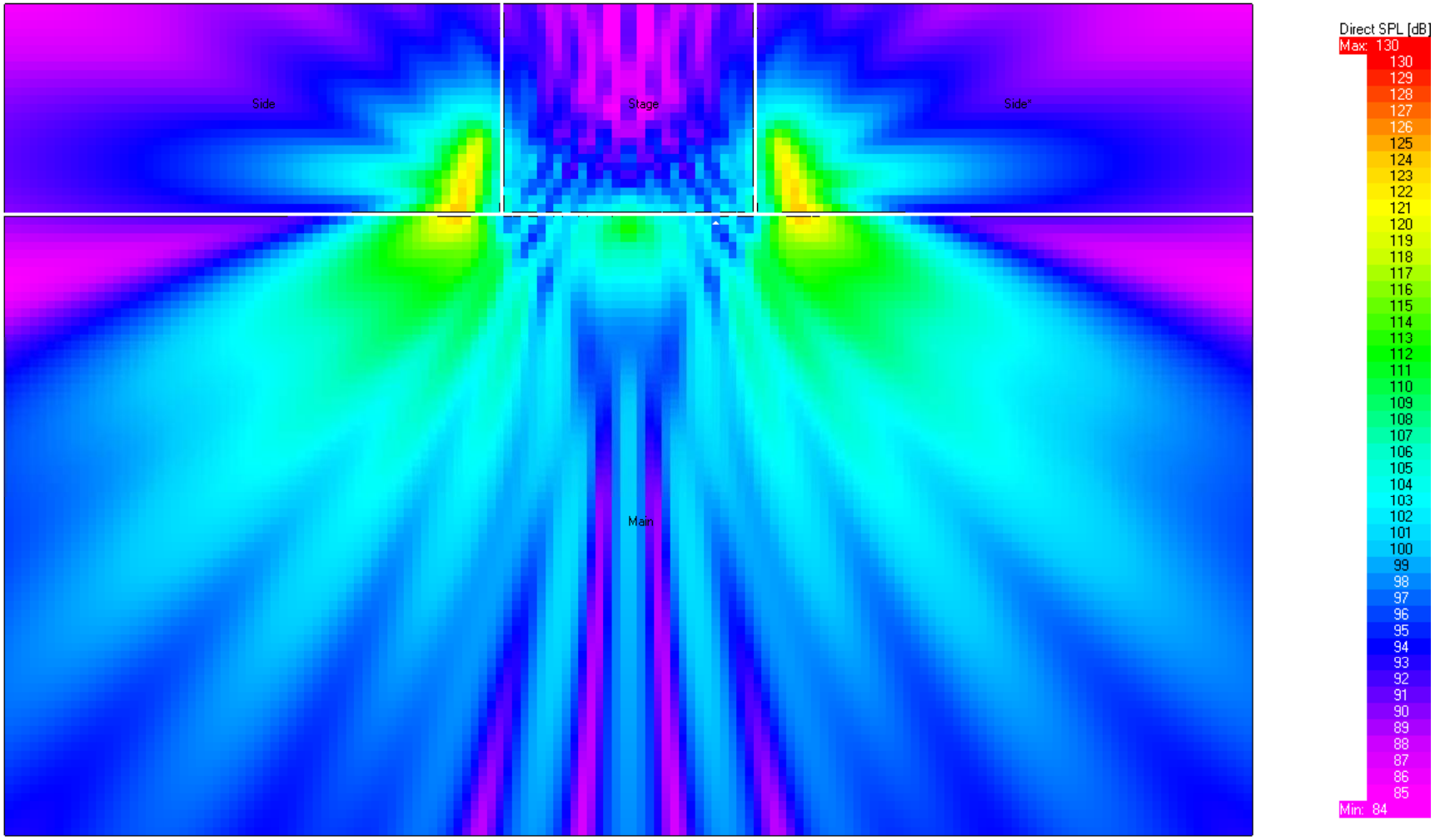
Each array rotated 15°



SPL Map

End-Fire Arrays Split Left & Right

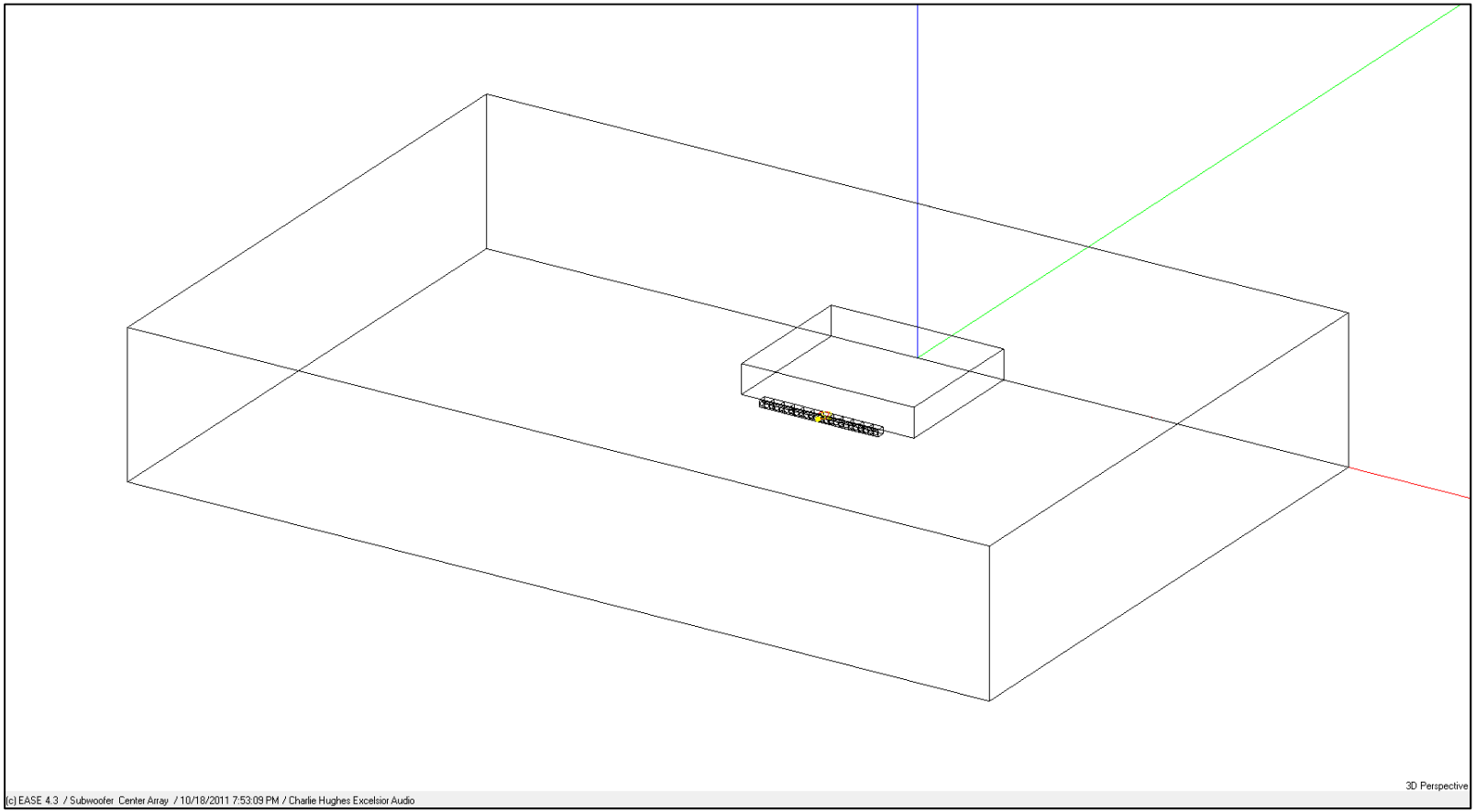
Each array rotated 15°. Center 3 box cardioid array added.



SPL Map

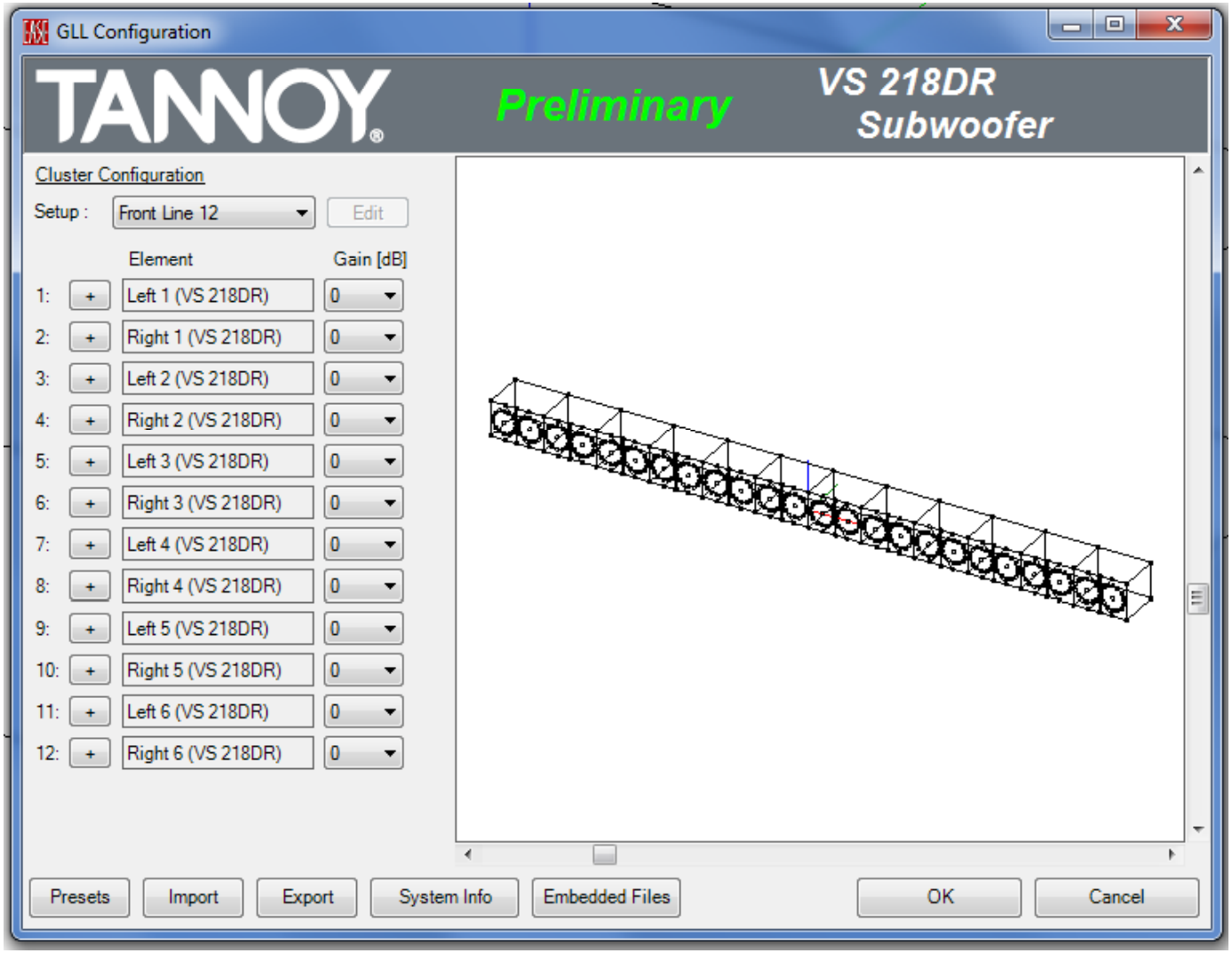
Center Array

Large room (walls, floor, & ceiling are non-reflective; direct field only)
Stage approx. 60 ft (18.3 m) wide.



12 box straight array in center position

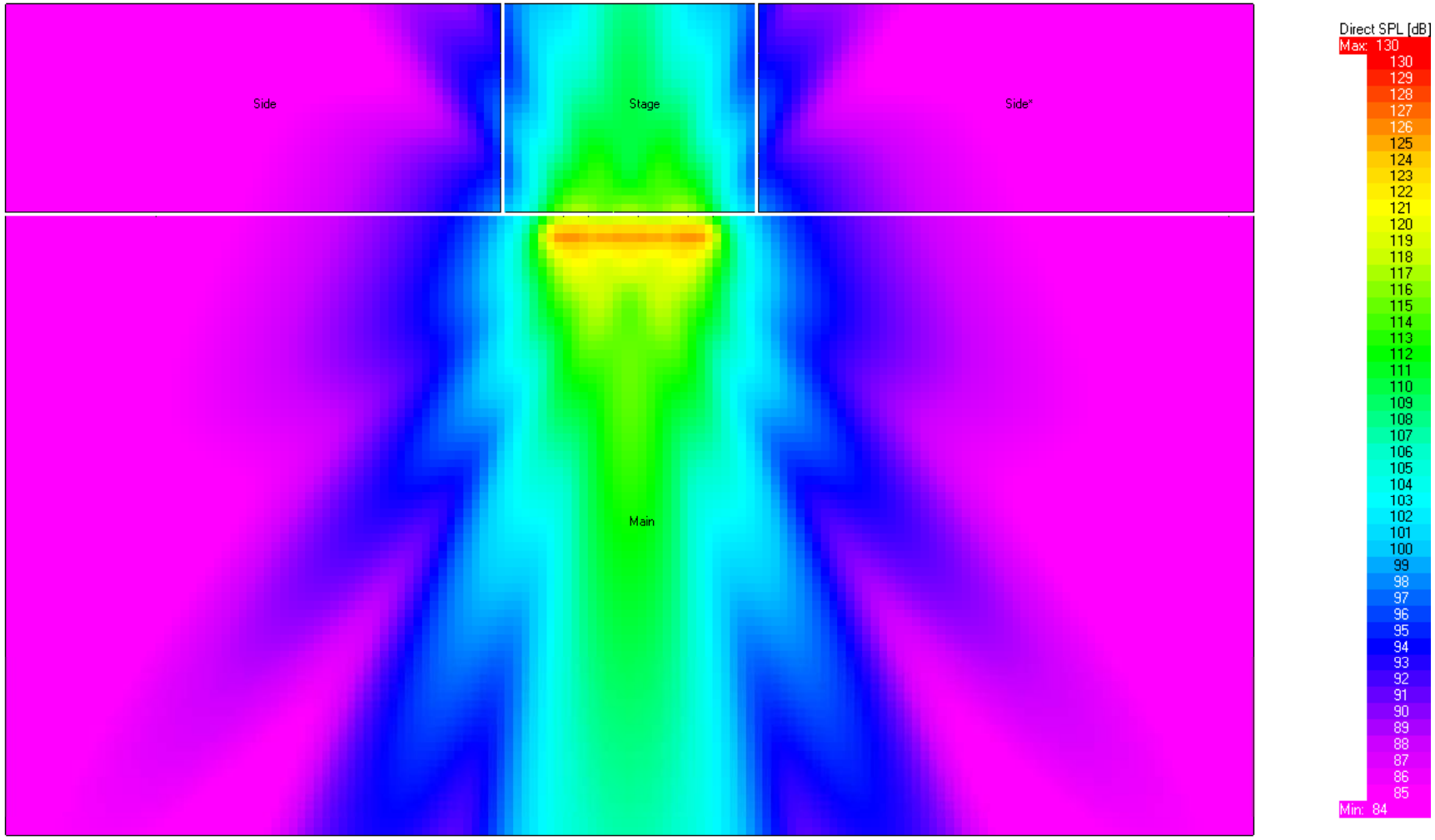
Center Array



12 box straight array in center position

Center Array

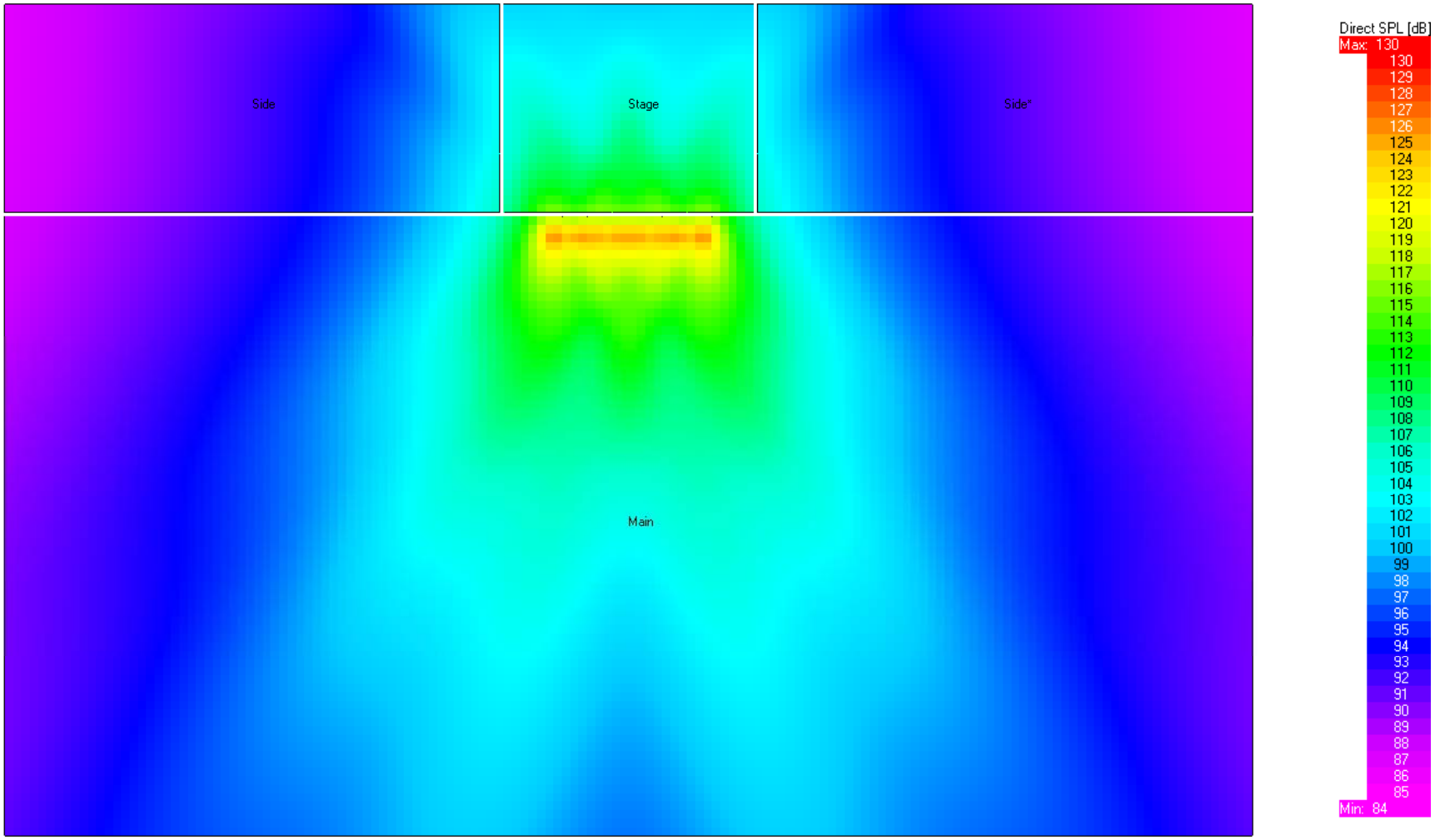
Straight array (12 box) with no electronic curvature



SPL Map

Center Array

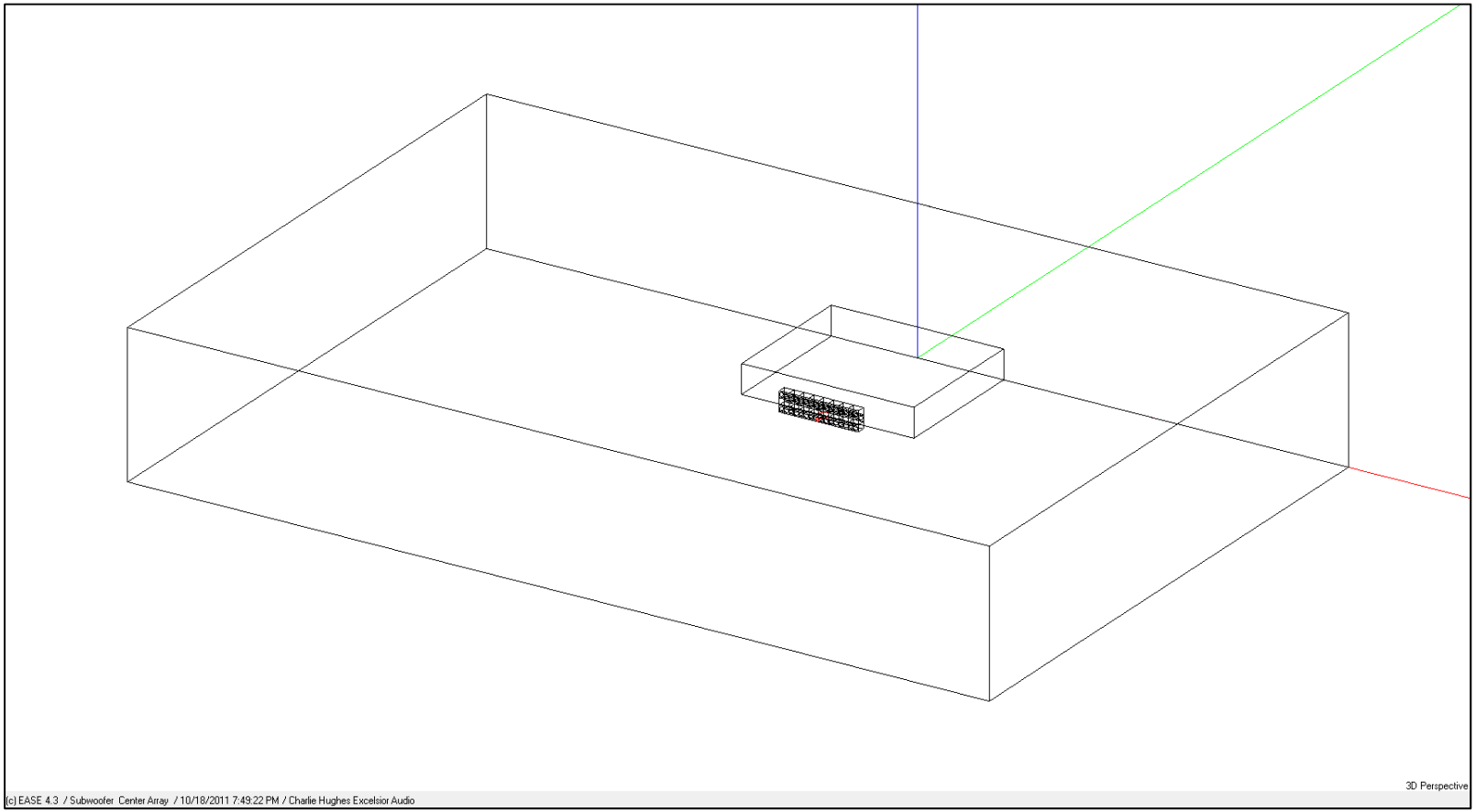
Straight array (12 box) with 90° electronic curvature



SPL Map

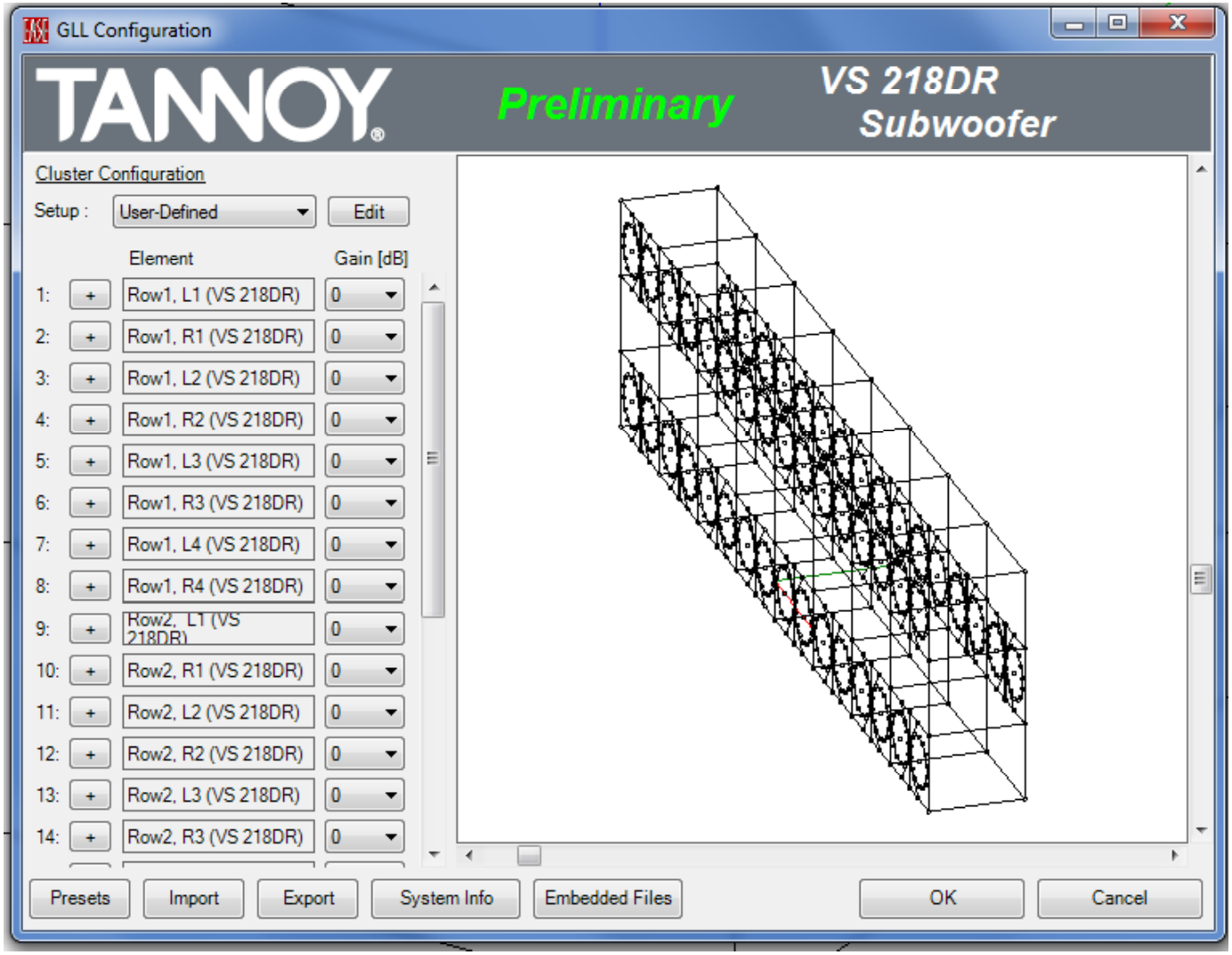
Center Cardioid Array

Large room (walls, floor, & ceiling are non-reflective; direct field only)
Stage approx. 60 ft (18.3 m) wide.



3x8 box straight array in center position

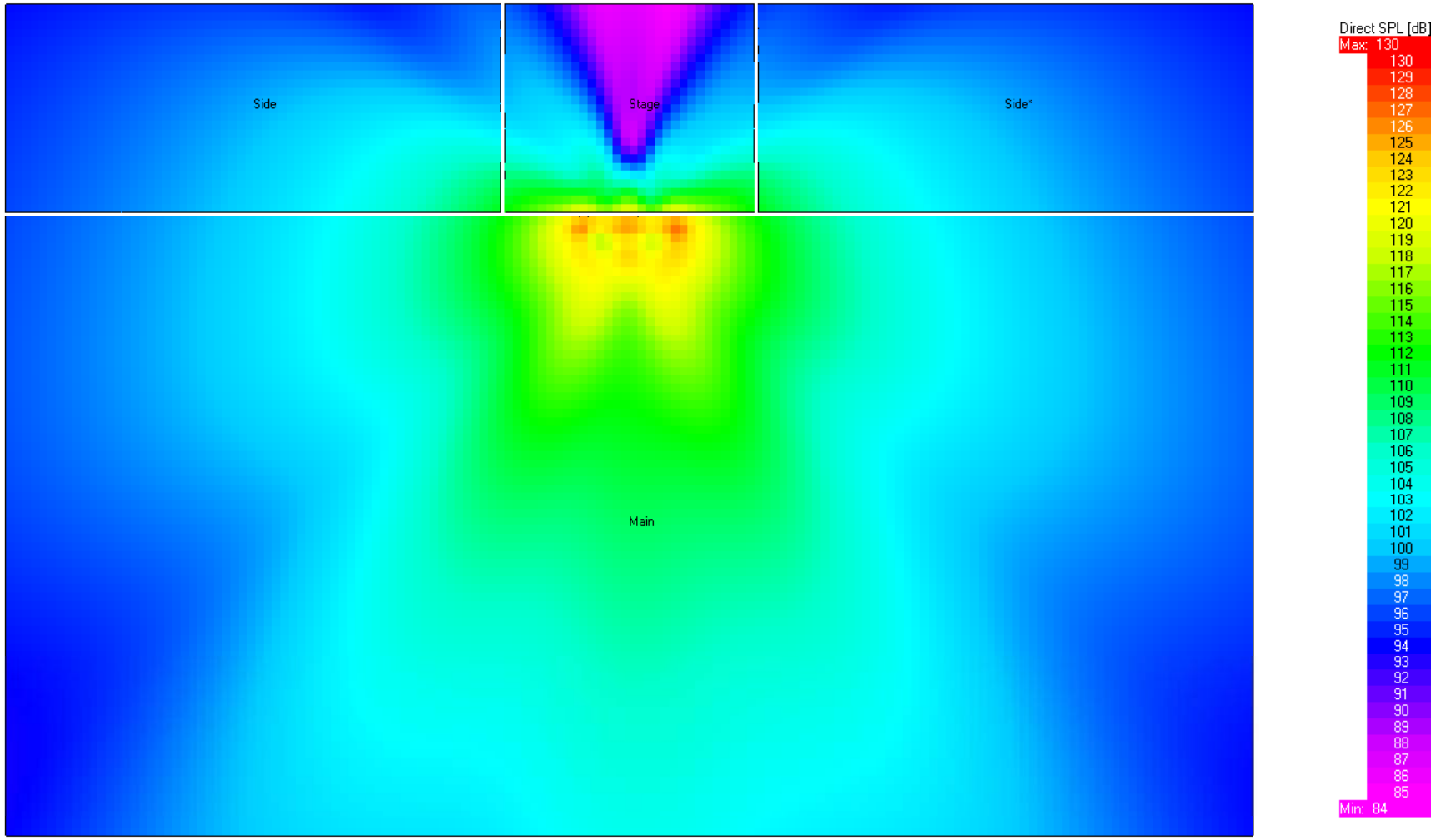
Center Cardioid Array



3x8 box straight array in center position

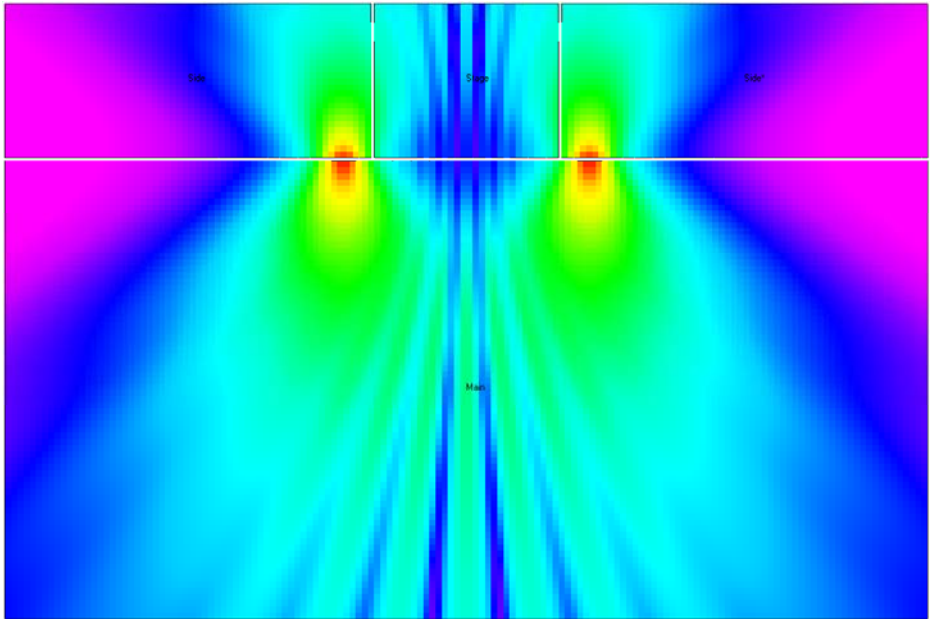
Center Array

Straight array (3x 8 box stack) with 90° electronic curvature & cardioid

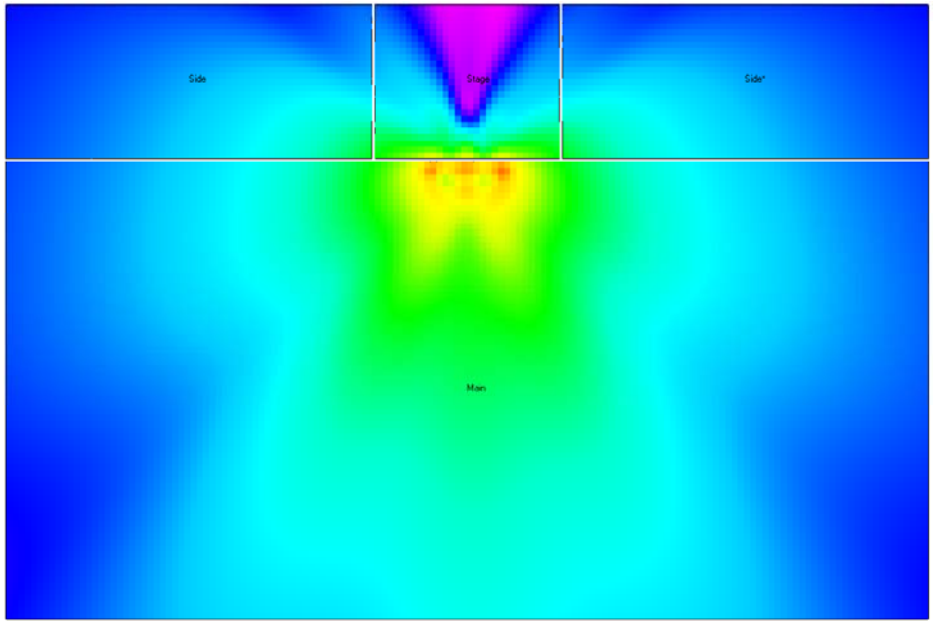


SPL Map

Comparison



Conventional split left & right



Center cardioid array eCurved 90°

Recap

Steering of the main lobe can be done electrically by applying delay to the individual subwoofer boxes.

Wave front shaping can be used to broaden the directivity, or coverage pattern, and can yield fairly constant directivity. This can also be done using delay in a DSP.

Split left & right stacks of subwoofers will always cause comb filtering & lobing.

A center array can be used to eliminate the comb filtering & lobing.

A long center cardioid array can be electronically curved to yield even coverage that is a good match to the audience area & decrease the SPL on the stage area.