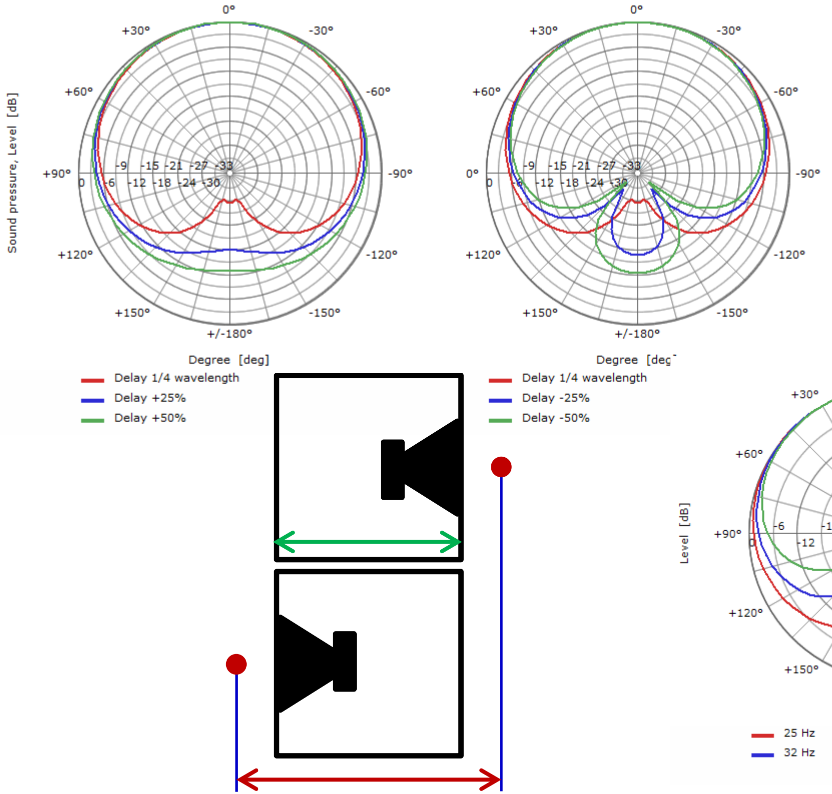
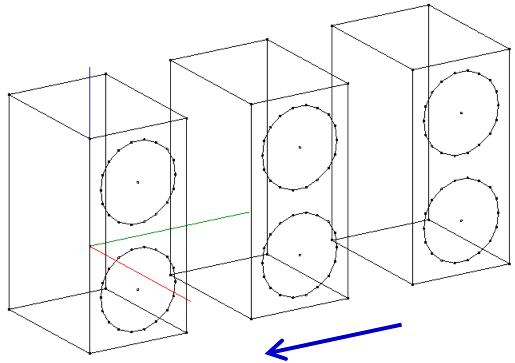
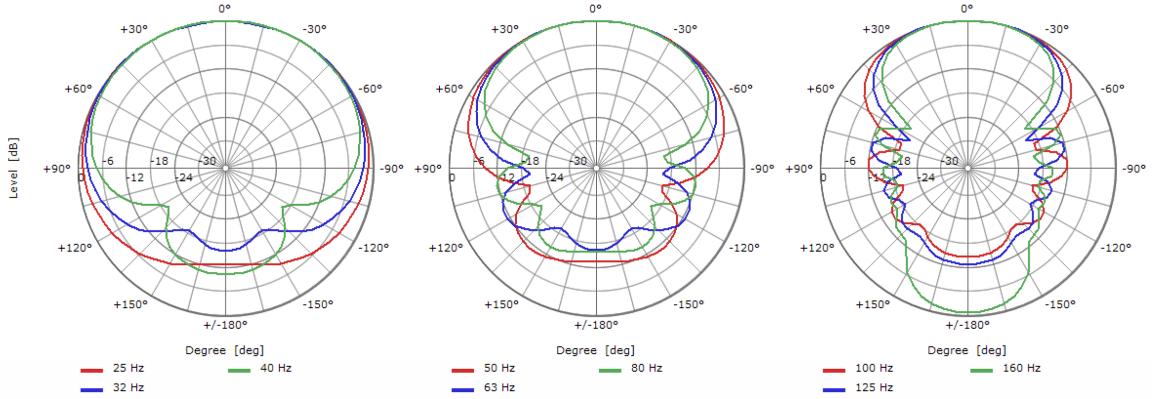
Subwoofer Arrays





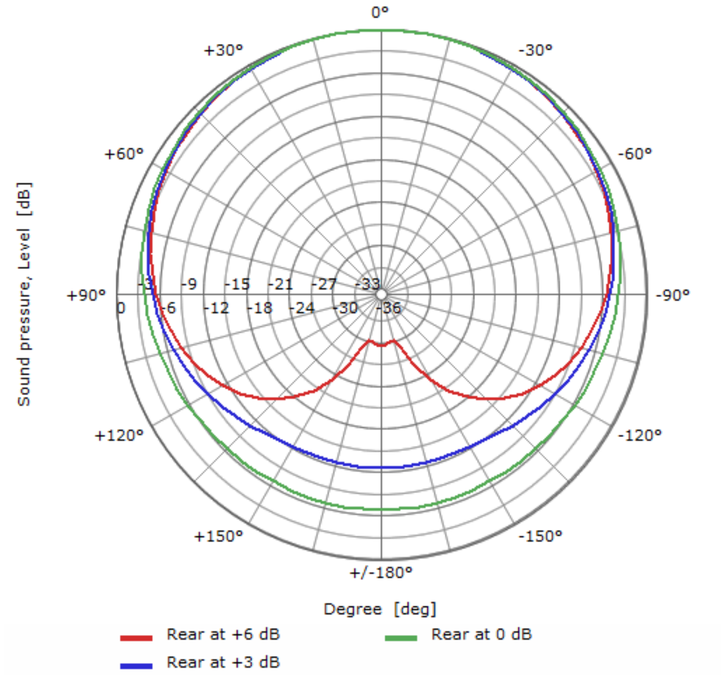


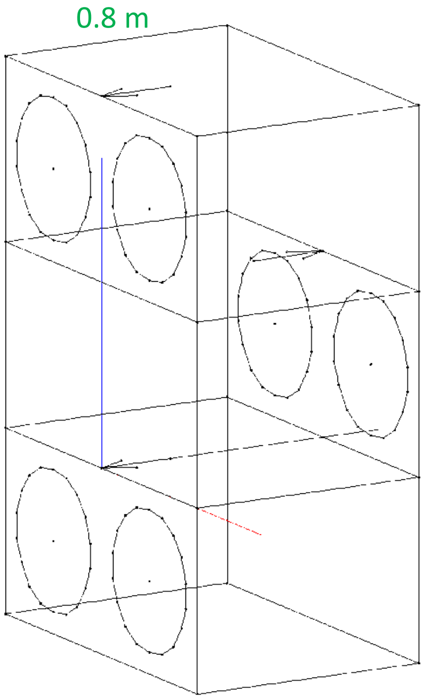
Topics

1) Cardioid Arrays
2) End-Fire Arrays
3) Electronically Curved Arrays

Cardioid Arrays

Used when it's desirable to minimize output behind the array





Rear sub is located 1/4 wavelength behind the front sub(s), 0.8 m

Rear sub is delayed 1/4 wavelength, 2.3 ms

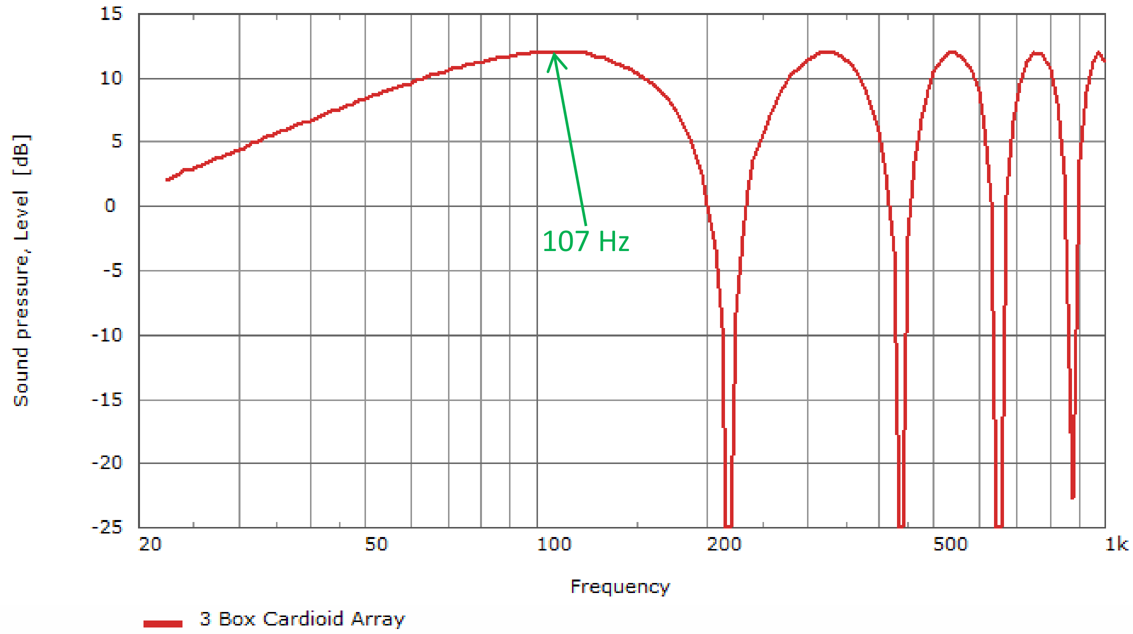
Rear sub has its polarity reversed

The 1/4 wavelength is for the maximum frequency at which the array will be used.

$$\frac{1}{4} * \frac{343\ m/s}{0.8\ m} = 107\ Hz$$

Cardioid Arrays

The cardioid pattern holds only below the maximum frequency



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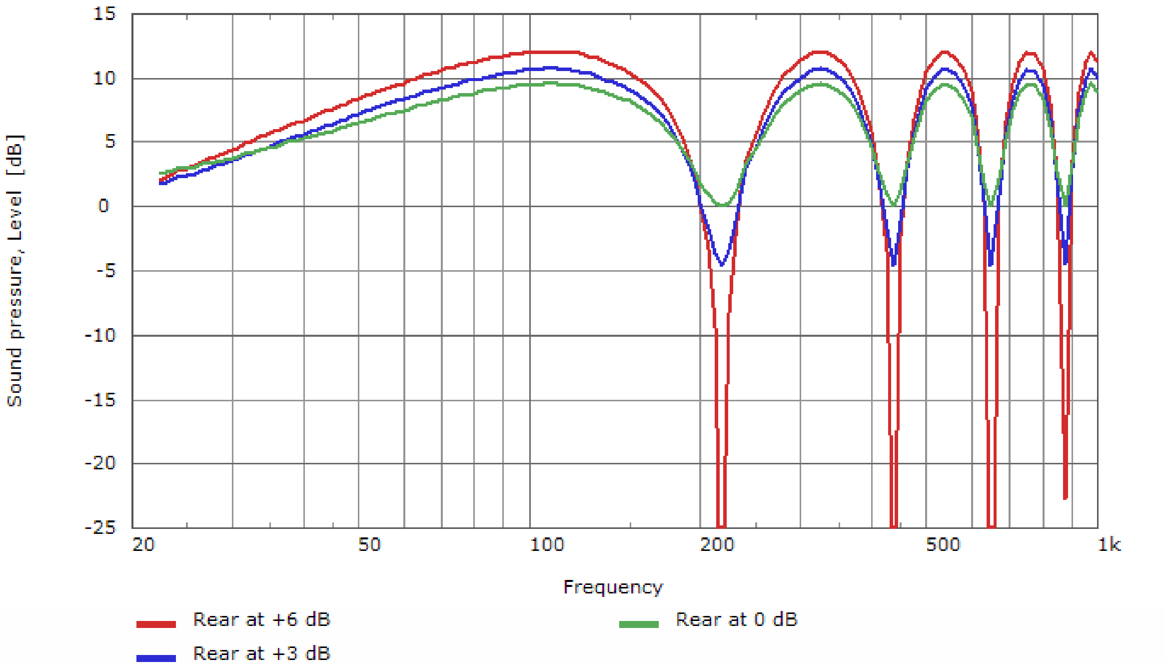
$$\frac{1}{4} * \frac{343\ m/s}{0.8\ m} = 107\ Hz$$

Cardioid Arrays

Level change for the rear sub



Decreasing the level of the rear sub can lower the overall output

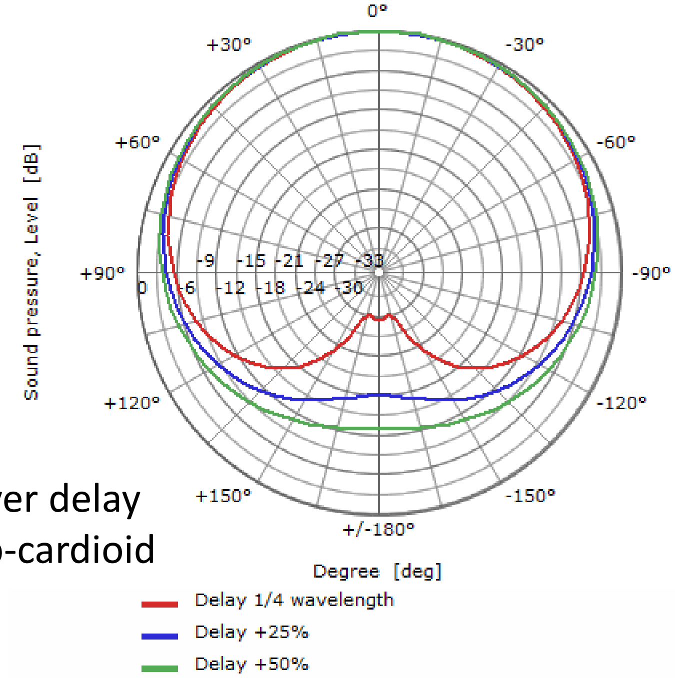
Same acoustical output level from front & rear subs

Acoustical output of rear sub is -3 dB compared to the front.

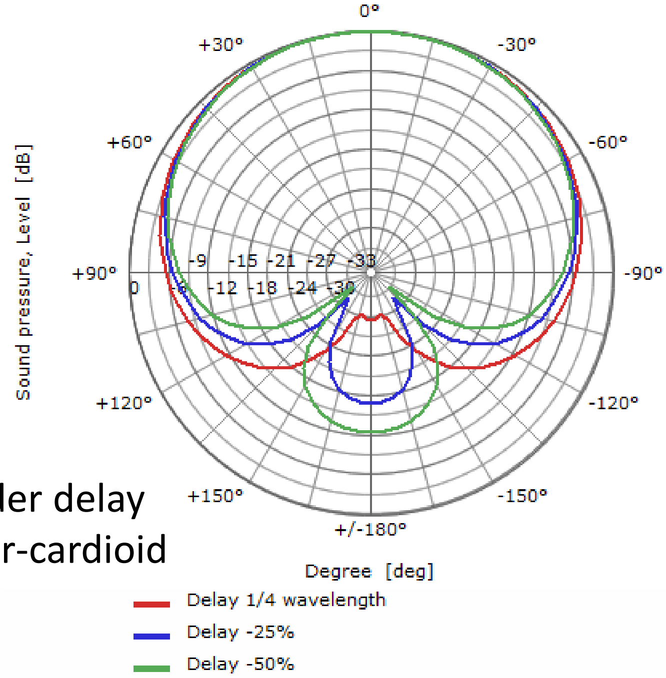
Acoustical output of rear sub is -6 dB compared to the front.

Cardioid Arrays

Over delay or under delay can change the cardioid pattern



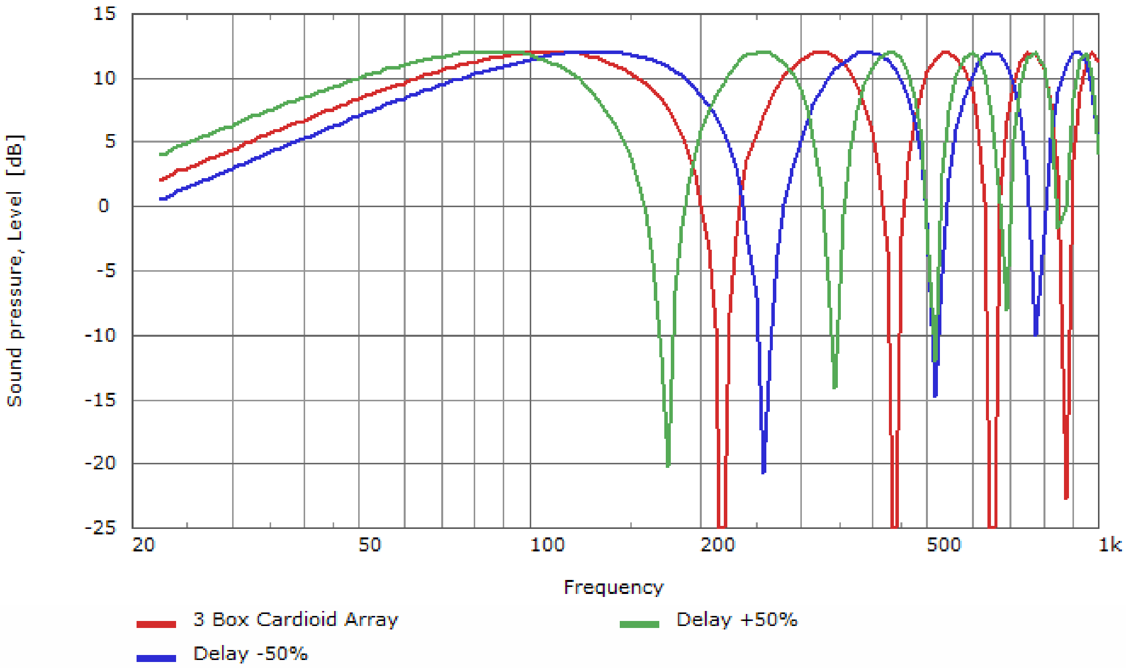
Over delay
Sub-cardioid



Under delay
Hyper-cardioid

Cardioid Arrays

Changing the delay time can alter the maximum frequency



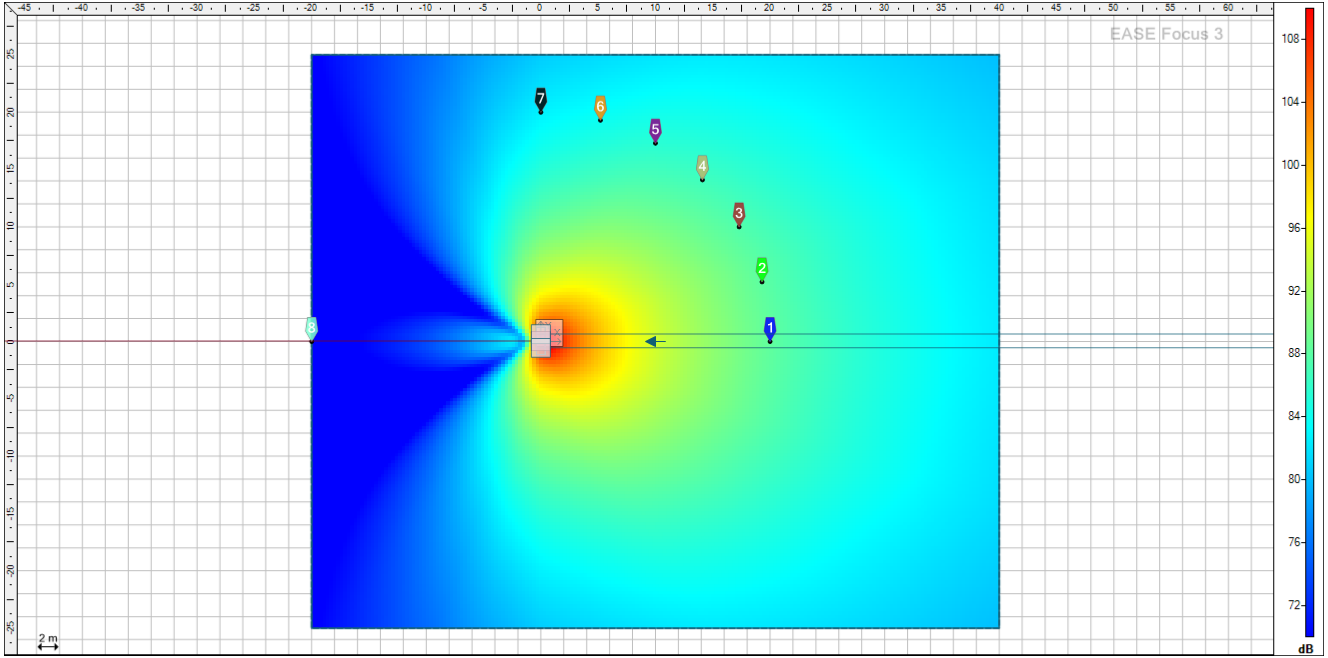
Delay = 2.3 ms (108 Hz)

Delay +50% = 3.45 ms (88 Hz)

Delay -50% = 1.53 ms (130 Hz)

Cardioid Arrays

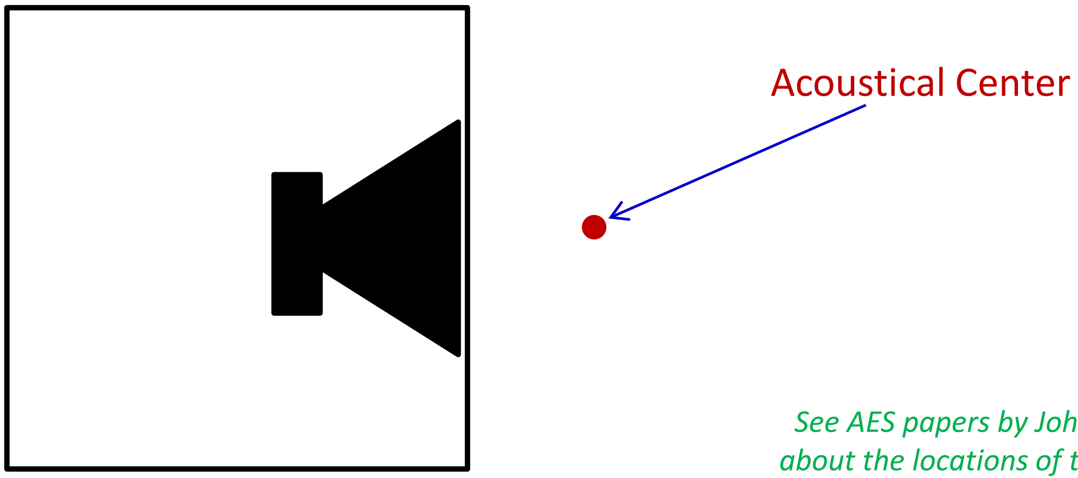
Let's look at a cardioid array in Focus 3



Cardioid Arrays

Acoustical Center

The acoustical center of the subwoofer is typically in front of the enclosure.
How far in front of the enclosure depends on the size of the enclosure.

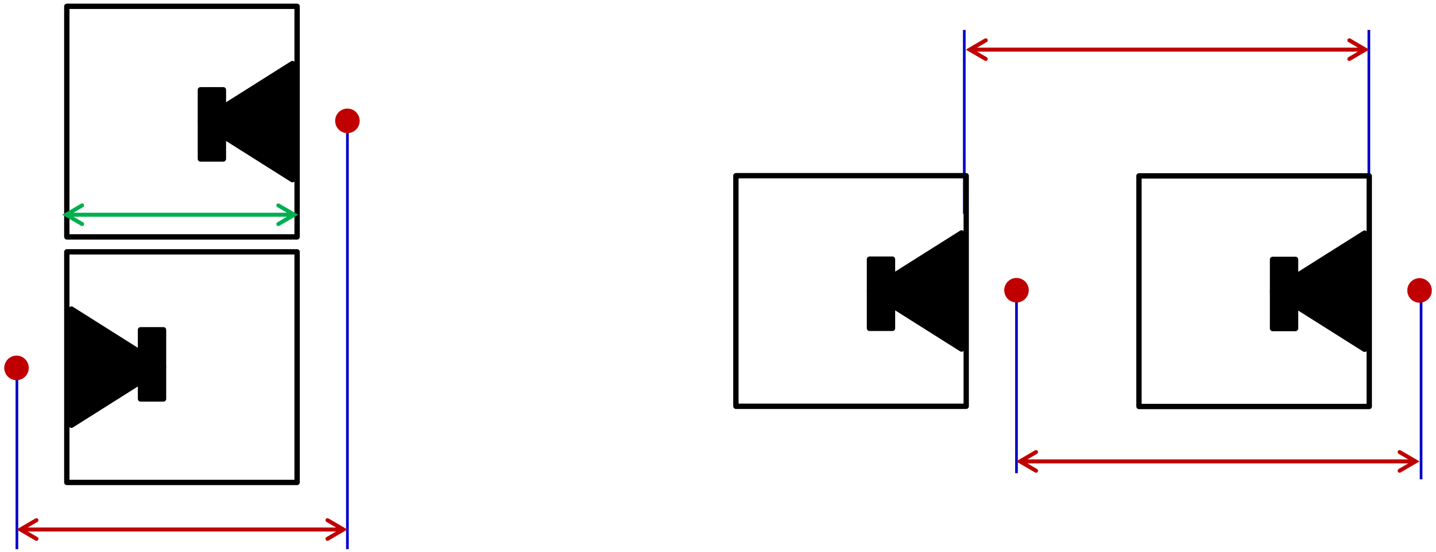


See AES papers by John Vanderkooy for more detailed info about the locations of the acoustic center at low frequencies
http://www.aes.org/e-lib/browse.cfm?elib=15289

Cardioid Arrays

Acoustical Center

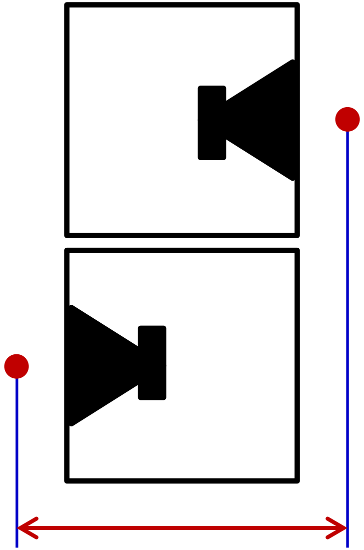
The 1/4 wavelength spacing is from acoustic center to acoustic center, not necessarily the spacing between the enclosures.



Cardioid Arrays

Acoustical Center

Measure each sub individually (mute the other) to determine the arrival time difference. This is the spacing of the acoustical centers.

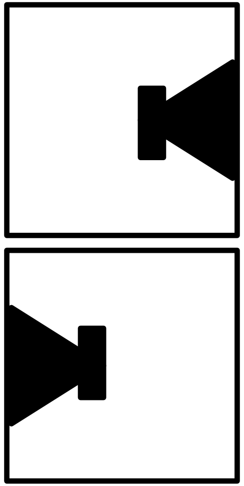


Place the measurement mic far away from the subs. Try to center it between the front-facing & rear-facing subs

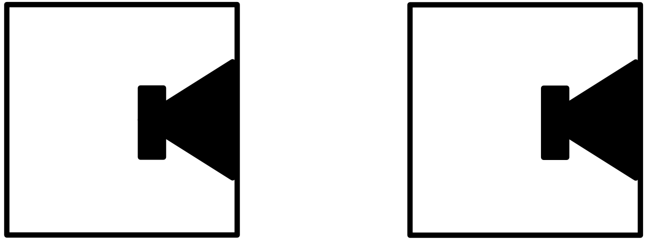
Cardioid Arrays

Acoustical Loading

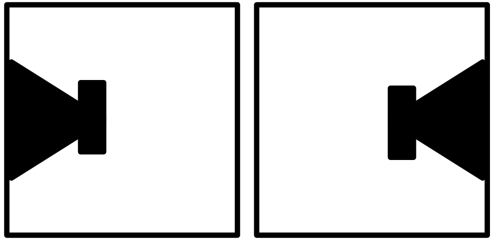
Same acoustical load on each sub



Different acoustical load on each sub

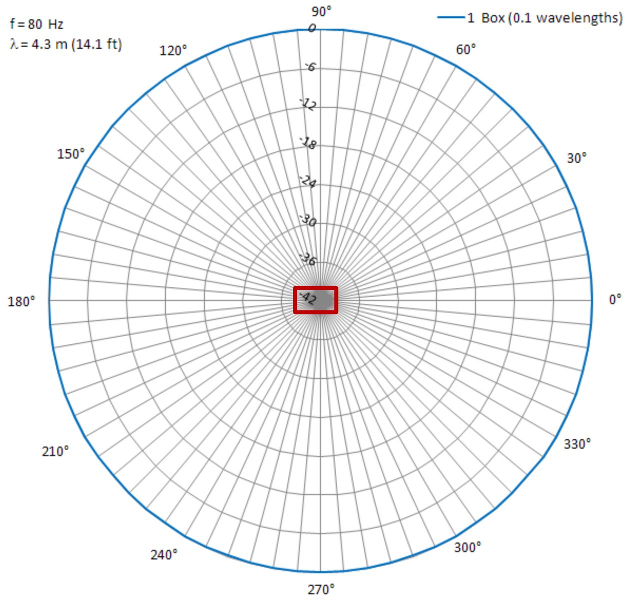


Same acoustical load on each sub



End-Fire Arrays

Directivity is a result of the source (array) size



80 Hz polar graph of a dual 18" subwoofer

The acoustical size of a source, or array, is relative to the wavelength which it is radiating.

A source is acoustically small when its is smaller than a given wavelength.

A source is acoustically large when it is approximately the same size or larger than a given wavelength.

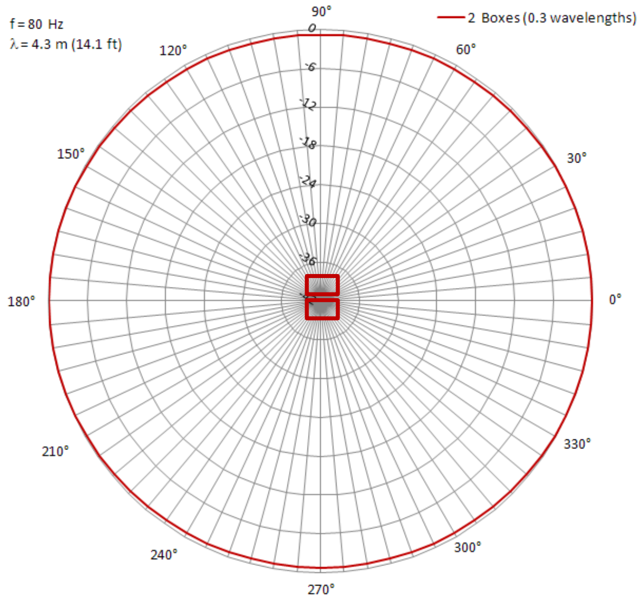
Higher frequency, shorter wavelength

Lower frequency, longer wavelength

The dimension of the subwoofer is approximately 0.6 m (2 ft). This about 1/7 of a wavelength at 80 Hz. No directivity control.

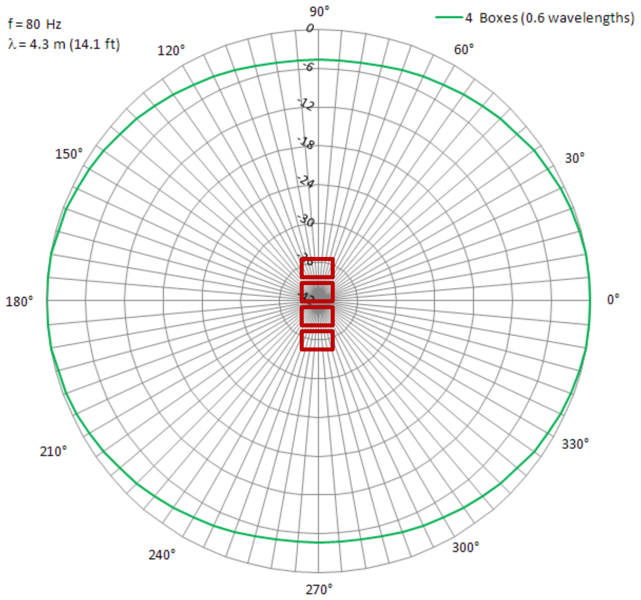
End-Fire Arrays

Broad-side array – directivity is a result of the source (array) size



80 Hz polar graph of 2x dual 18” subwoofers

Spacing approximately 0.6 m

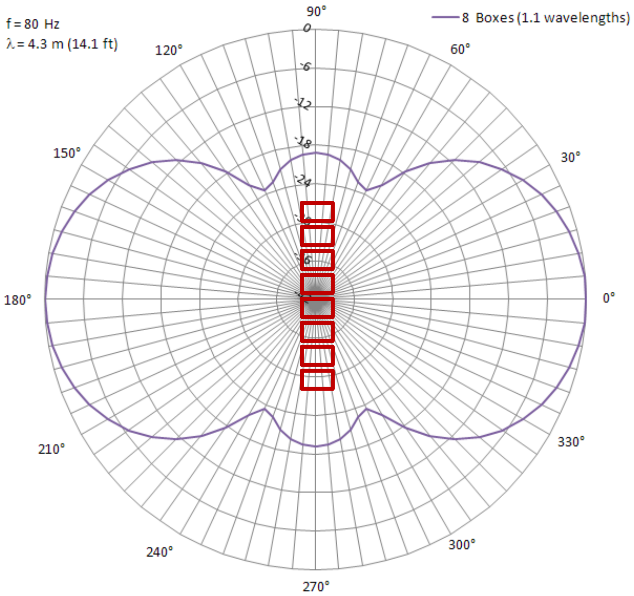


80 Hz polar graph of 4x dual 18” subwoofers

As the size of the array increases in a particular dimension, so does the directivity control in the plane of that dimension.

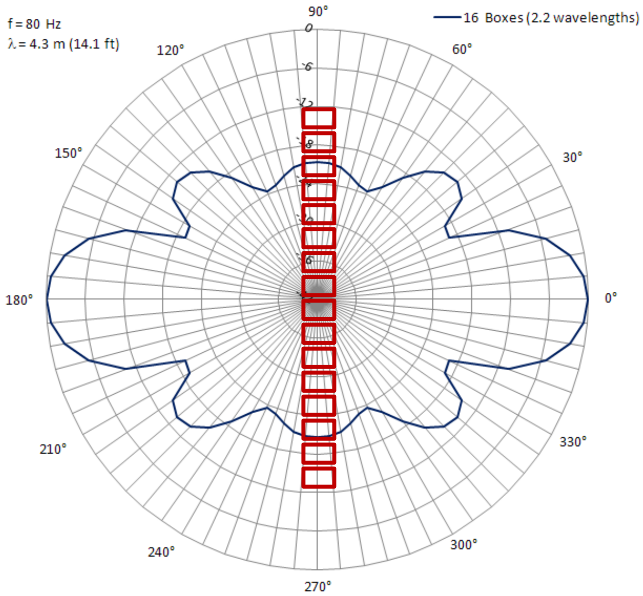
End-Fire Arrays

Broad-side array – directivity is a result of the source (array) size



80 Hz polar graph of 8x dual 18" subwoofers

Spacing approximately 0.6 m

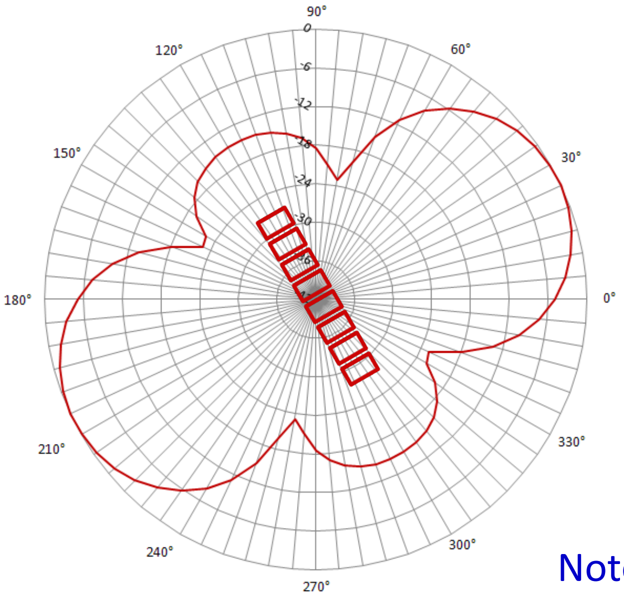


80 Hz polar graph of 16x dual 18" subwoofers

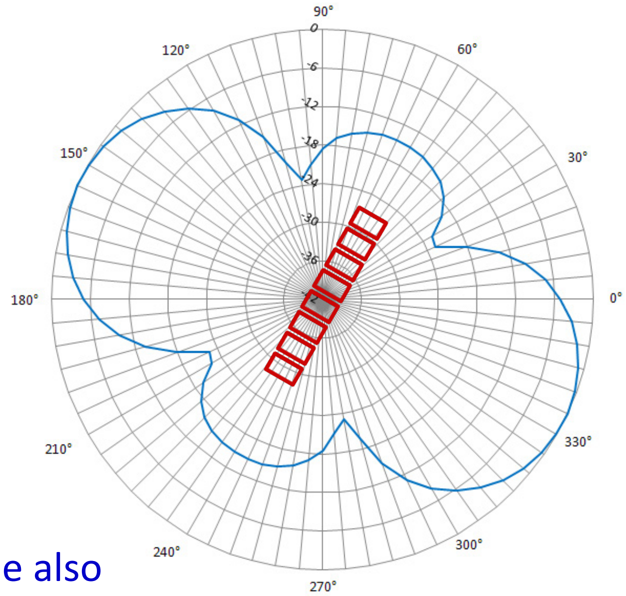
When the array size is one wavelength or greater there is substantial directivity control.

End-Fire Arrays

Broad-side array – directivity is a result of the source (array) size



30° Up

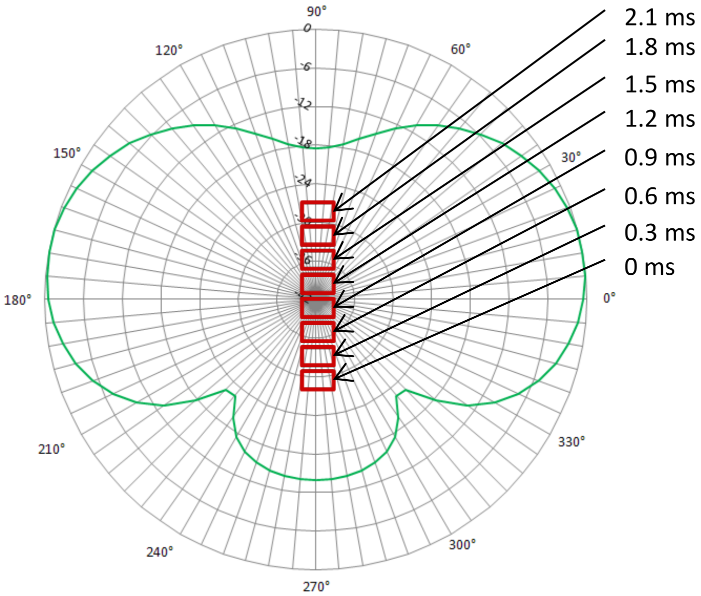


30° Down

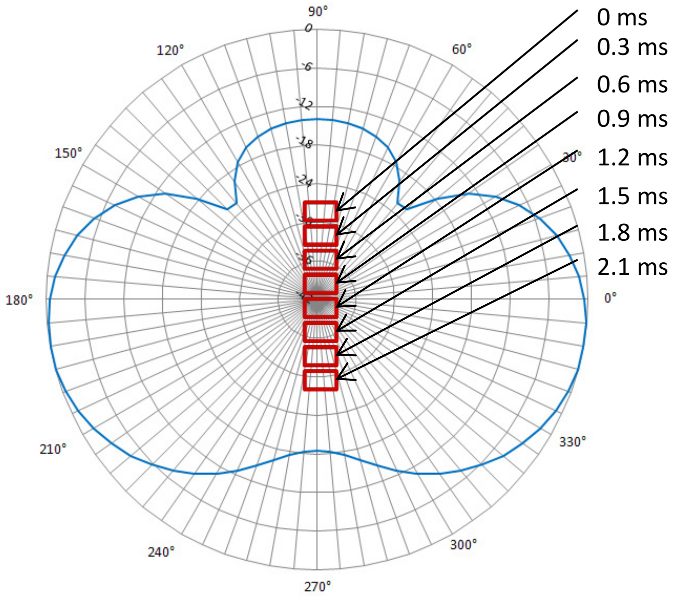
Note that the rear lobe also follows the orientation of the array. It points in the opposite direction of the front lobe.

End-Fire Arrays

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



10° Up

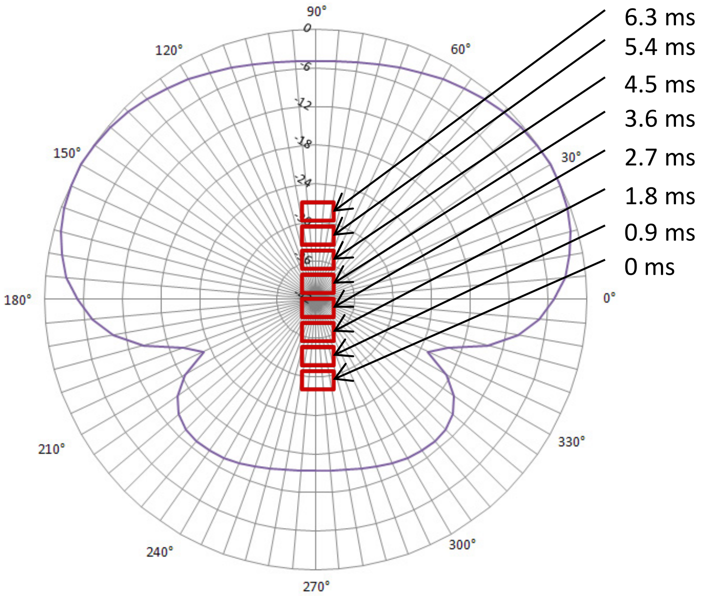


10° Down

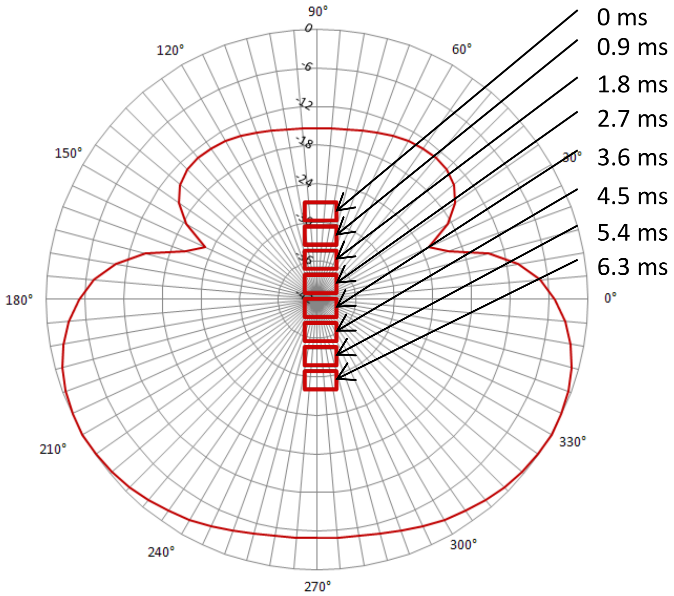
Note that the rear lobe is pointing in the ***same*** direction as the front lobe.

End-Fire Arrays

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



30° Up

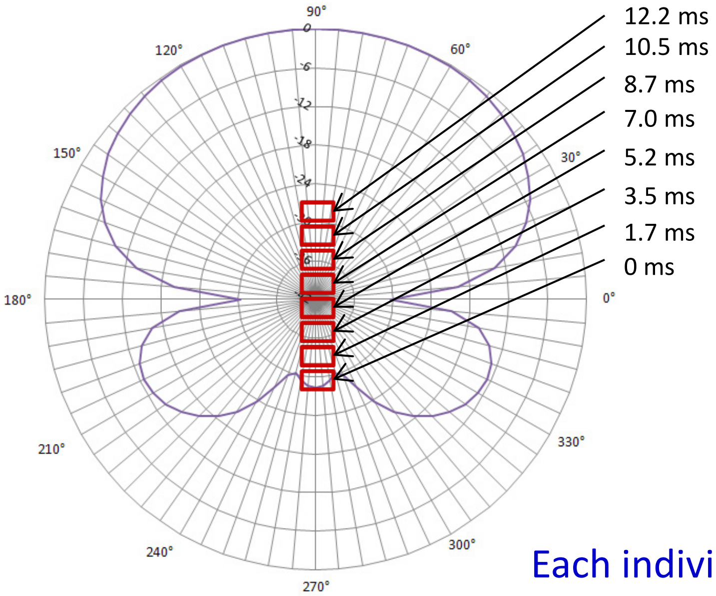


30° Down

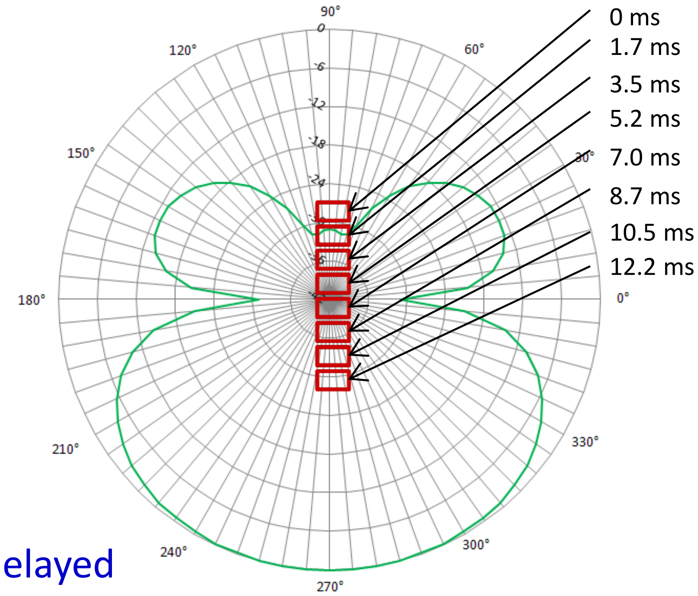
Note that as the steering increases the front and rear lobes begin to merge.

End-Fire Arrays

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



90° Up

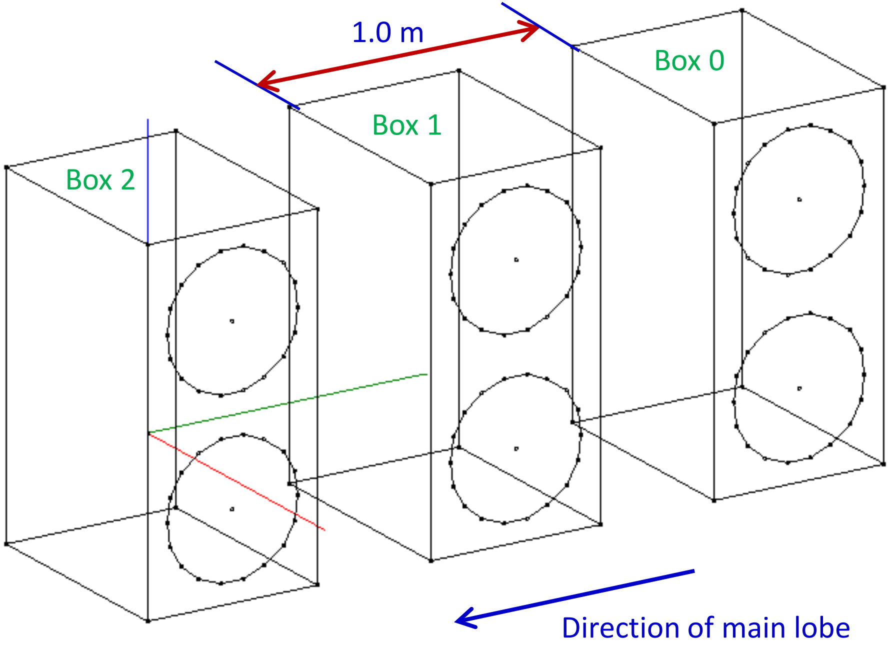


90° Down

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

End-Fire Arrays

Used when it's desirable to narrow the coverage pattern



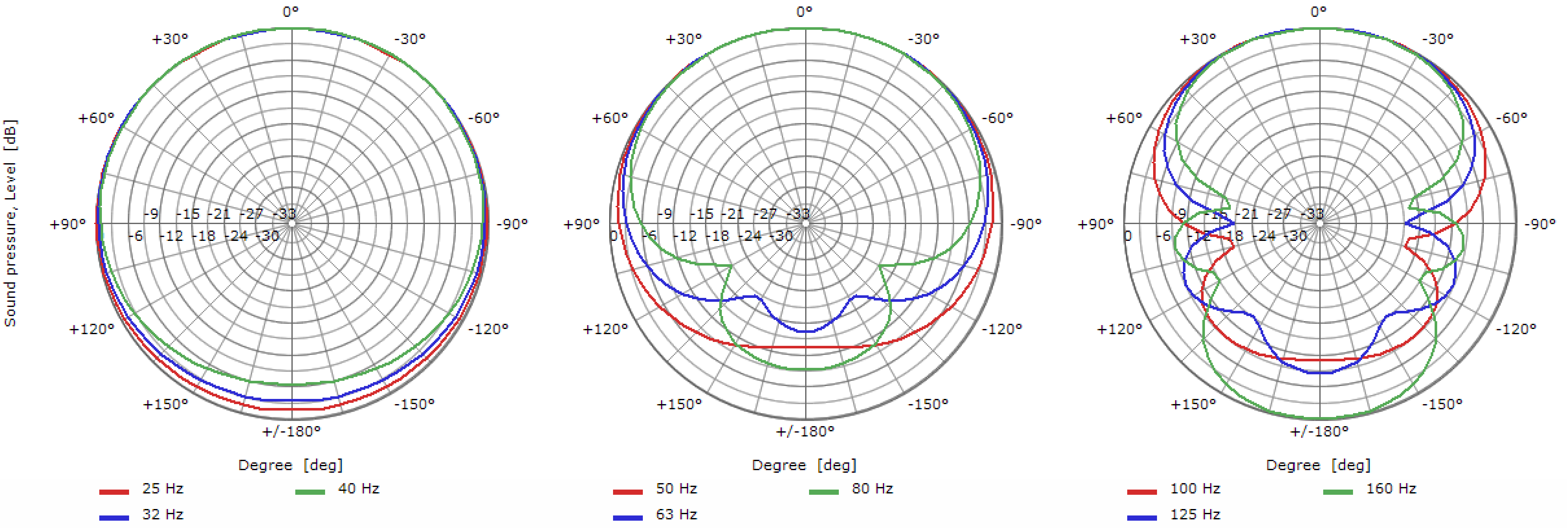
Each subwoofer box is delayed back to the rear-most box

For a 1.0 m spacing this is 2.9 ms

Box 0 has 0 ms delay
Box 1 has 2.9 ms delay
Box 2 have 5.8 ms delay

End-Fire Arrays

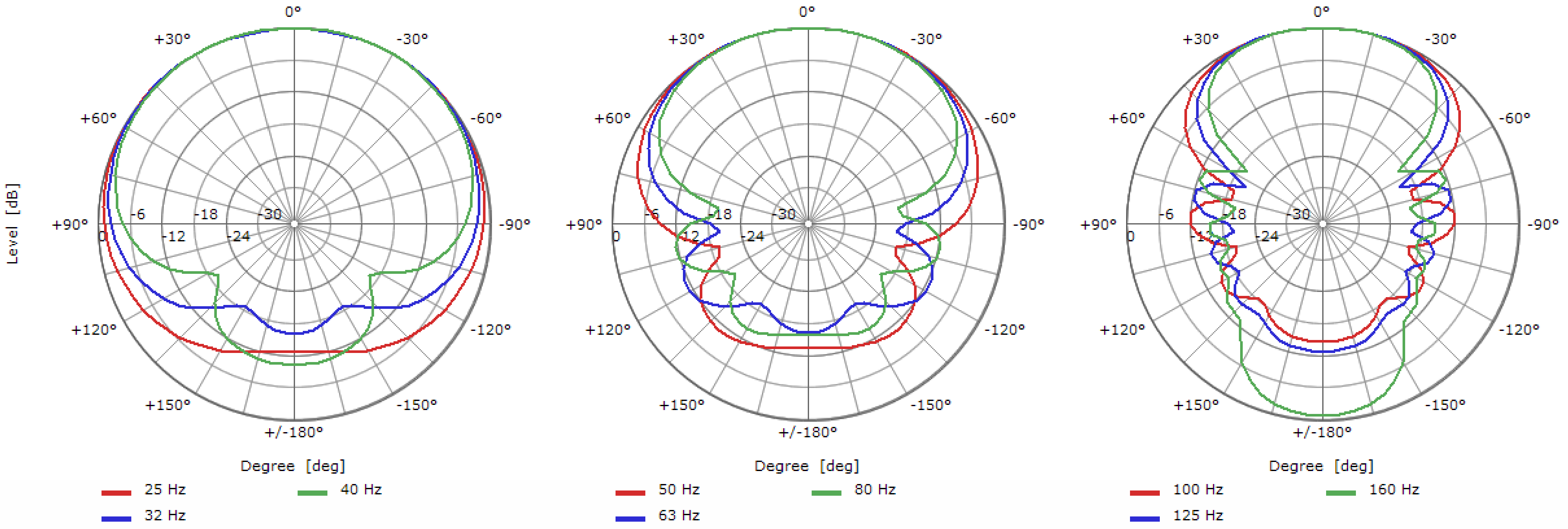
Used when it's desirable to narrow the coverage pattern



For a 1.0 m spacing the delay is 2.9 ms. This is 1/4 wavelength at 86 Hz and 1/2 wavelength at 172 Hz.

End-Fire Arrays

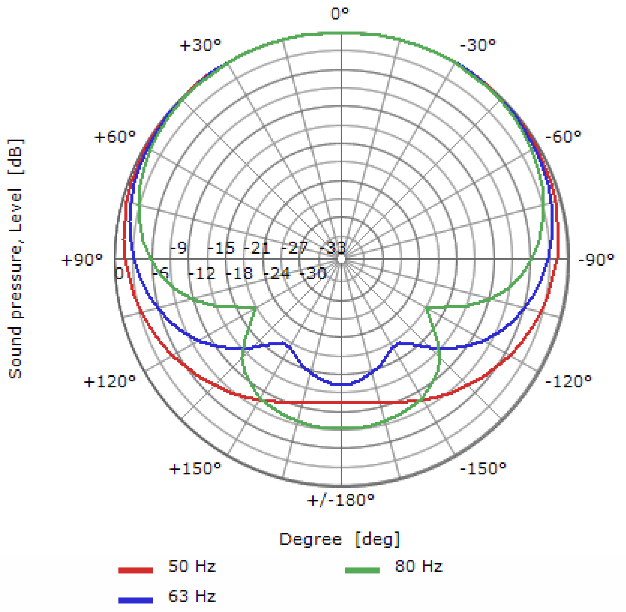
More boxes in the array results in a tighter coverage pattern



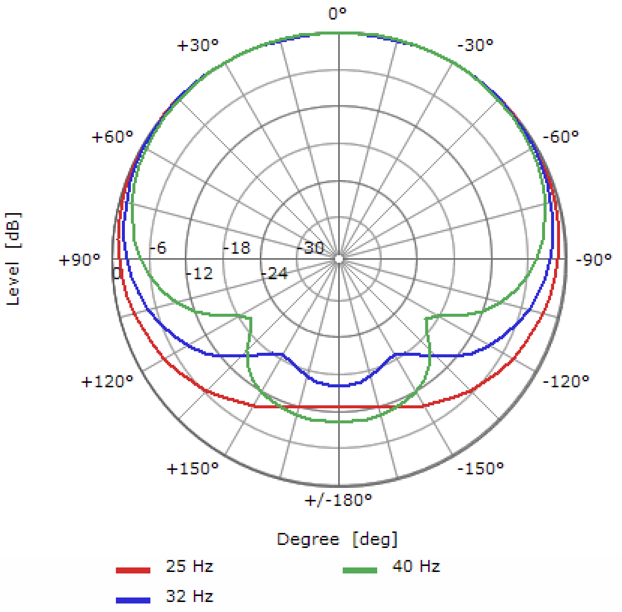
6 box array at 1.0 m spacing

End-Fire Arrays

Compare the directivity for the larger array an octave lower

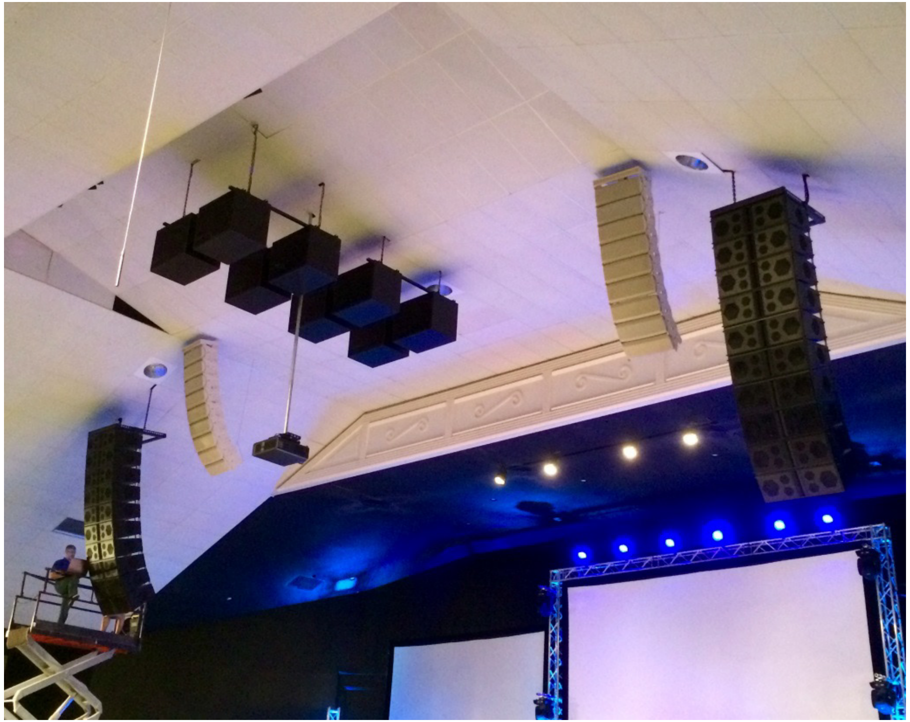


3 box array at 1.0 m spacing



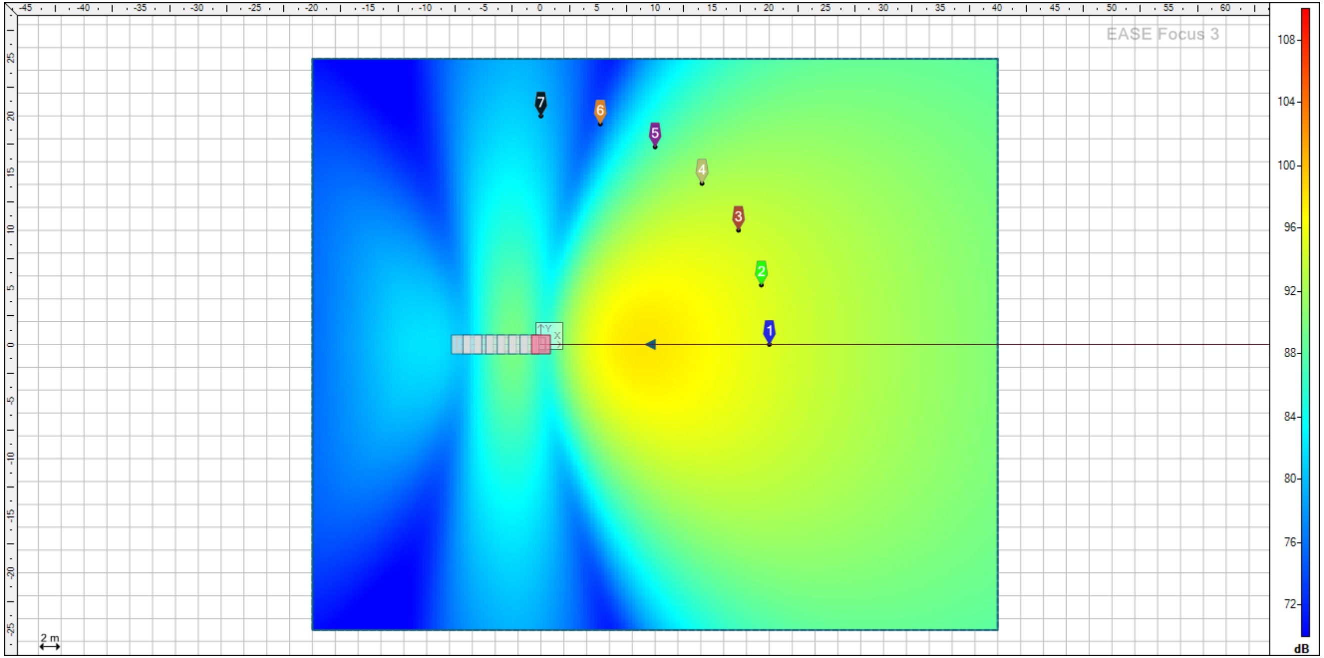
6 box array at 1.0 m spacing

End-Fire Arrays



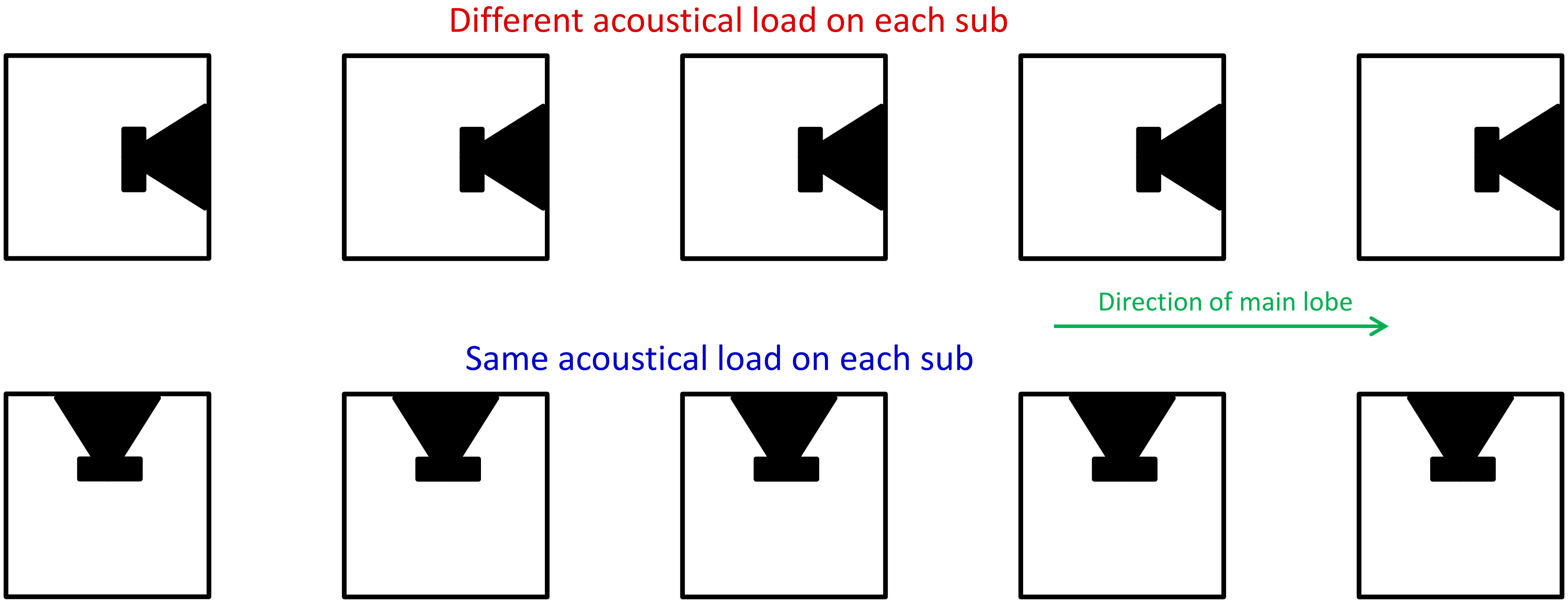
End-Fire Arrays

Let's look at an end-fire array in Focus 3



End-Fire Arrays

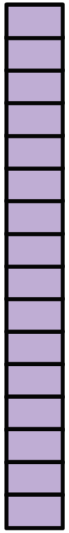
Acoustical Loading



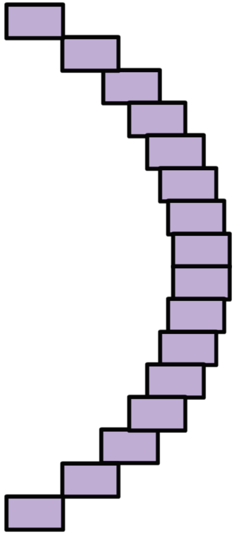
Wave Front Shaping – Broadening the Main Lobe

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

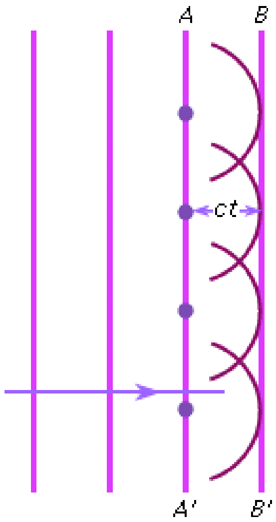


16 Box Circular Curved Array

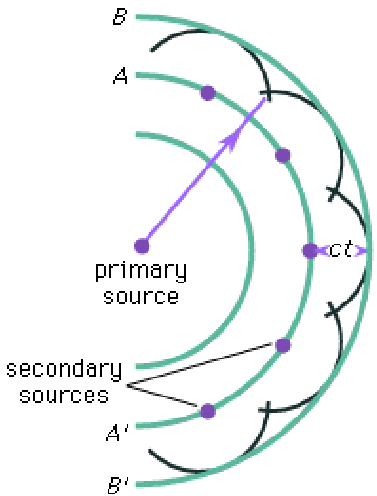
Wave Front Shaping – Broadening the Main Lobe

Huygens' Principle

A wave front can be represented by a collection of point sources on that wave front. These point sources can be thought of as radiating secondary wave fronts. The propagation of the original wave front can be constructed from the superposition of the propagation of the secondary wave fronts.



plane wavefronts

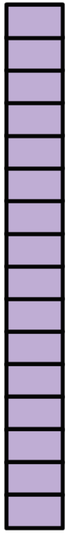


spherical wavefronts

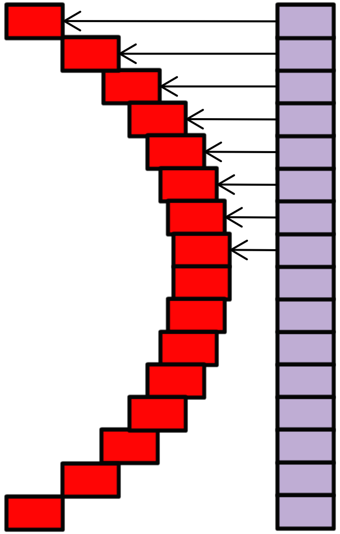
Wave Front Shaping – Broadening the Main Lobe

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

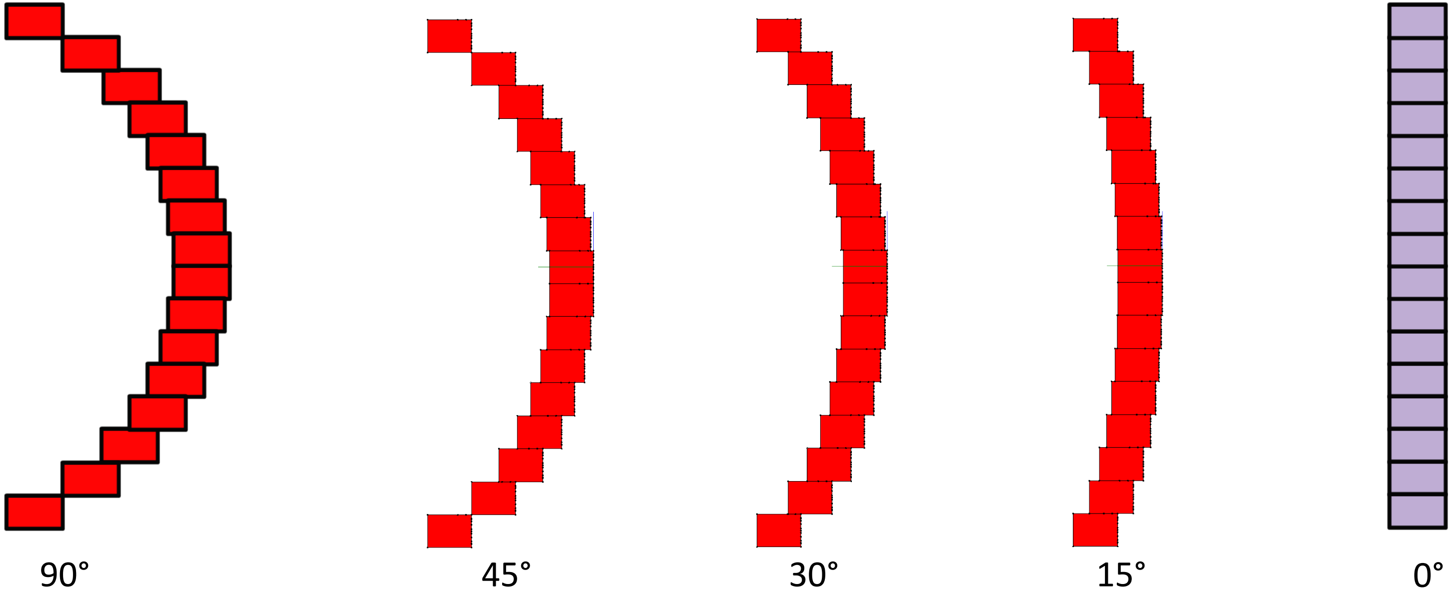


16 Box Circular Curved Array

Wave Front Shaping – Broadening the Main Lobe

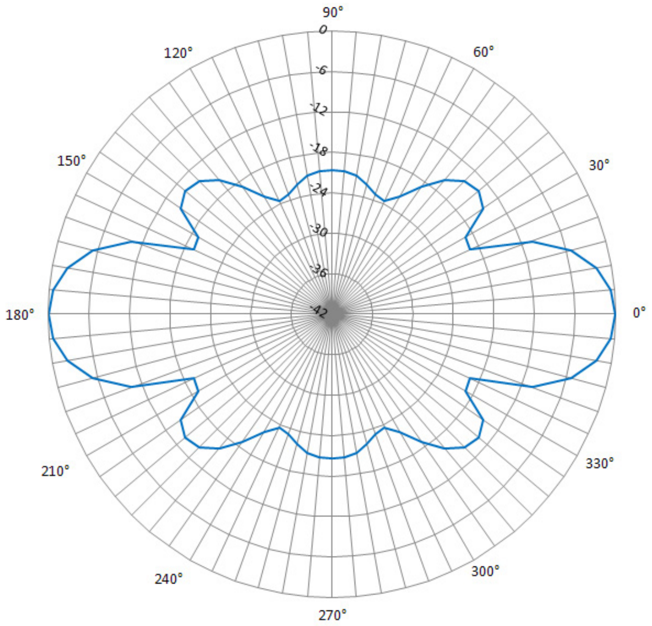
The array is configured mechanically as a straight line.

The amount of delay can be varied to yield any amount of curvature from 0° to 90°.

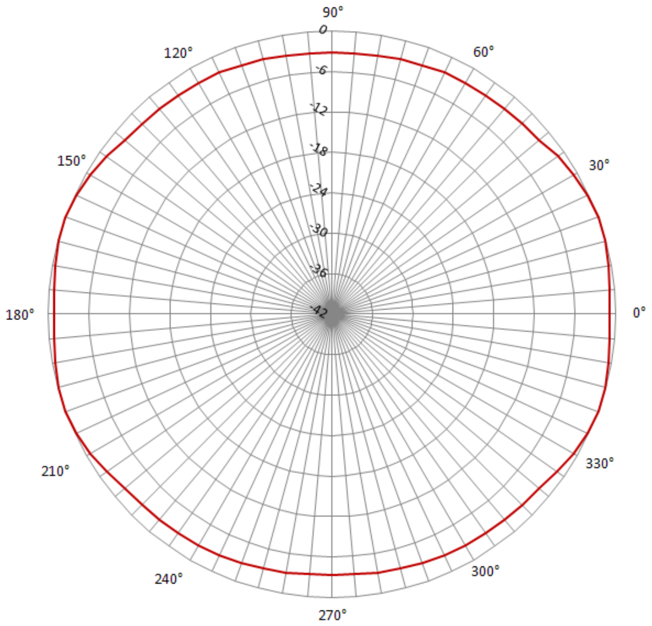


Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



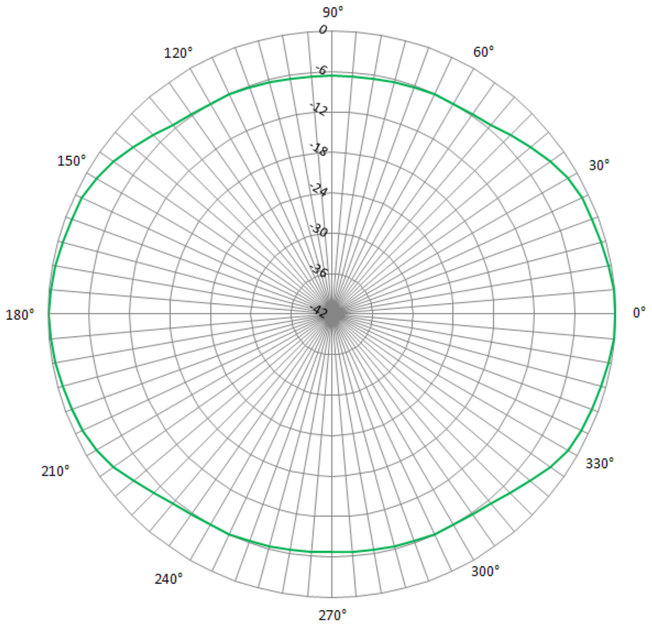
16 Box Straight Array, No Delay Curvature



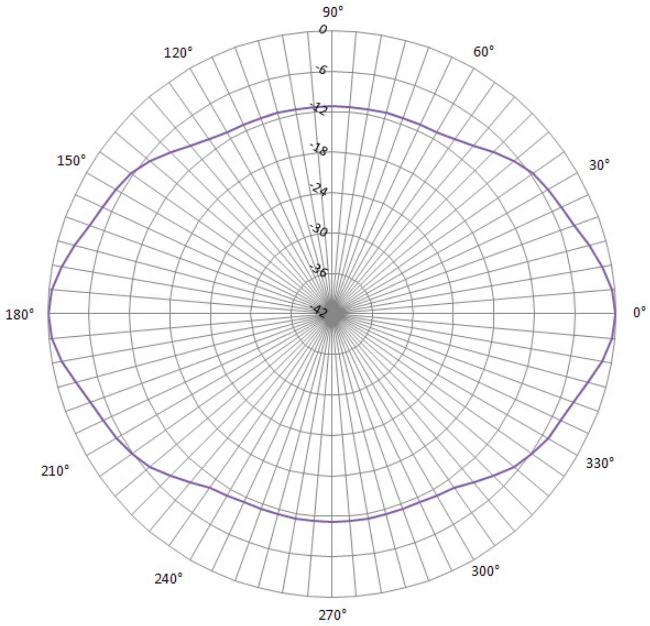
16 Box Straight Array, Curved 90° with Delay

Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



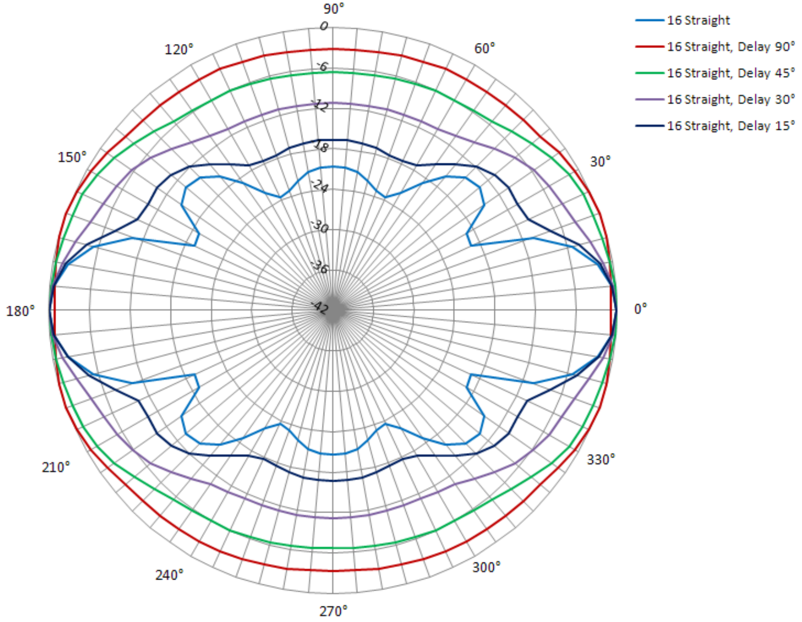
16 Box Straight Array, Curved 45° with Delay



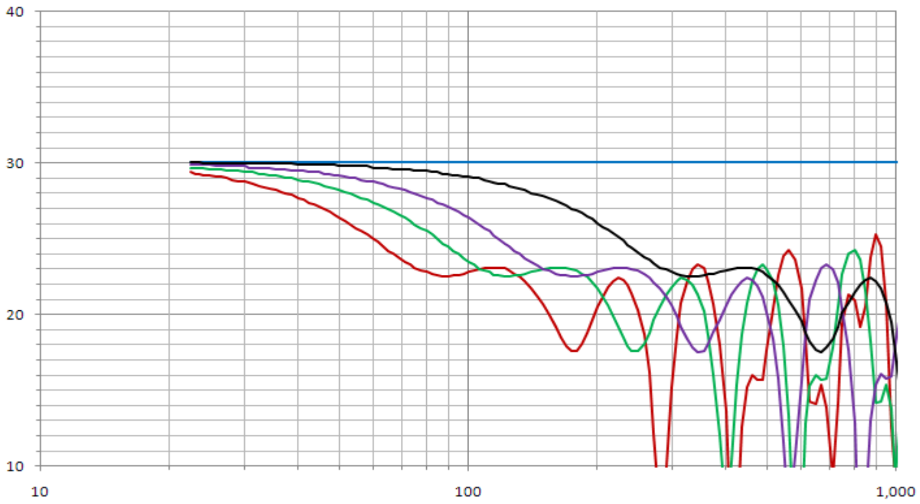
16 Box Straight Array, Curved 30° with Delay

Wave Front Shaping – Broadening the Main Lobe

Comparison of straight array with various amounts of curvature via delay



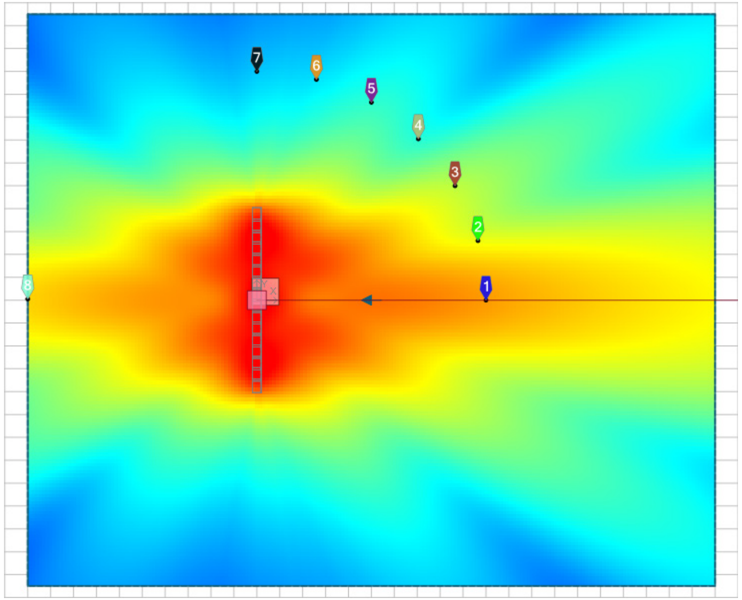
Polar Response at 80 Hz



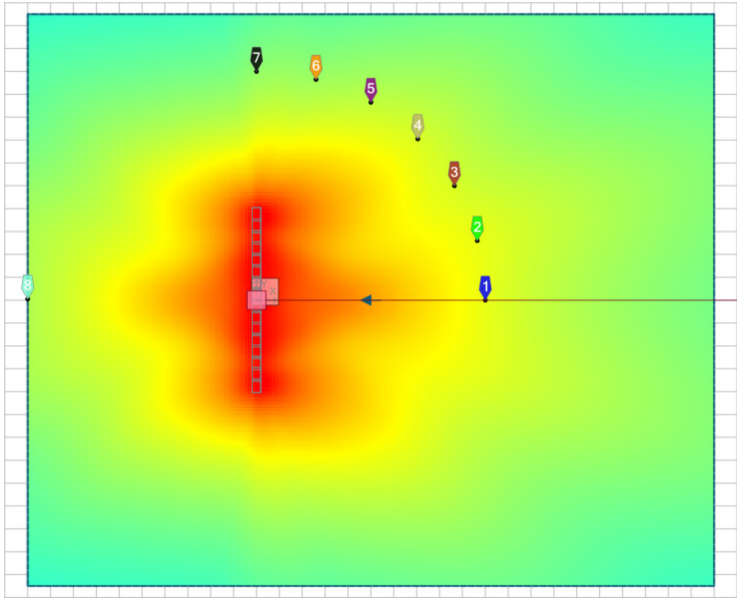
On-Axis Magnitude Response

Wave Front Shaping – Broadening the Main Lobe

Let's look at an electronically curved array in Focus 3



No delay/curvature



Delayed for 90° of curvature