Subwoofer Arrays

System Measurement & Optimization: Subwoofer Arrays

© 2018-19 Excelsior Audio Design & Services, LLC

www.excelsior-audio.com

AES Academy – Anaheim, CA
17 Jan 2020
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.

\[
\frac{1}{4} \times \frac{343 \, m/s}{0.8 \, m} = 107 \, Hz
\]
Cardioid Arrays

The cardioid pattern holds only below the maximum frequency

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.

\[
\frac{1}{4} \times \frac{343 \text{ m/s}}{0.8 \text{ m}} = 107 \text{ Hz}
\]
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

Delay 1/4 wavelength
Delay +25%
Delay +50%
Delay -25%
Delay -50%
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

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

A source is acoustically small when it 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

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

Spacing approximately 0.6 m
End-Fire Arrays

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

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

Spacing approximately 0.6 m
End-Fire Arrays

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

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

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

10° Down
End-Fire Arrays

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

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

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

Direction of main lobe
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

Different acoustical load on each sub

Same acoustical load on each sub

Direction of main lobe
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.
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.
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.
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