Application Guide

3-Element Steered Bass Arrays

Rick Kamlet (initially Jan/2004; updated Aug/2021)

Using three subwoofer or bass loudspeakers in a Forward Steered Array (FSA) configuration can yield excellent bass directional control along with high output level.

This paper utilizes a 3 x SB2210 array as an example, but similar steered bass/subwoofer arrays can be structured utilizing just about any subwoofer or low-frequency loudspeaker model. The key is to know the spacing distance between the speakers (as measured from the center of the radiation outlet of the speakers), and then after converting that distance to the time-of-flight for sound corresponding to that distance (in milliseconds), applying either a straight delay (ie, delay of exactly that distance), a 30% over-delay, or a 50% over-delay setting via DSP. Each of these delay conditions is detailed in the scenarios to follow. Each scenario results in a different center-frequency of maximum rear-rejection. The needs of a variety of applications can be met by choosing the optimum scenario for that circumstance.

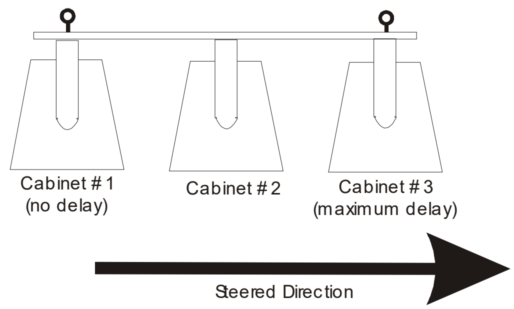
This level of low frequency directionality can be useful for a variety of purposes, including:

- Reduced subwoofer-band reflections from room surfaces that are behind the subwoofers.
- Venues such as nightclubs where you want high SPL on the dance floor yet might want to lower the SPL in nearby seating areas to allow conversation.
- Noise control in outdoor locations.
- To reduce destructive bass interaction venues such as enclosed stadiums and arenas. This reduces bass "rumble" and time smearing, improving bass fidelity and in many cases allowing bass where it would not have been possible otherwise.
- Providing for "delay subs" situated partway back in a room. The sound of these delay subs does not wrap around to project forward, which would produce muddiness in the front-most listening area (from multiple sources at different time syncs.
- For keeping low frequencies off a stage area in live performance venues and houses of worship, reducing feedback and rumble. This reduces bleed-back through to performance microphones, resulting in an overall improvement to the quality of the sound reinforcement.

By utilizing this method, directionality of a sound system can be controlled down to a much lower frequency than simply relying on spaced non-delayed omnidirectional sources or pattern control devices such as horns. For the bass frequency range, horns would have to be much larger than what is practical. The result is often better than what can be achieved via a cardioid subwoofer array, with higher SPL on-axis coherent summation.

Description of the Scenarios
Three speakers are spaced 24” apart (on center) with a delay settings of either straight delay, 30% over-delay, or 50% “over-delay. These systems yield very well-controlled coverage lobes and excellent rear attenuation in the 50 Hz to 100 Hz range. Other models of subwoofers can be utilized and the spacing distance between elements can be different, but new polars would have to be computed for each configuration. The main point is that this kind of directional control can be achieved using multiple spaced elements and Forward Steered Array principles.

Delay Settings
Different delay settings are sent to each speaker cabinet. Using a “straight delay” means matching the delay to equal the time it takes for sound to travel the distance between cabinets. “Over-delay” means increasing the delay figures – ie, 30% over-delay means increasing the delay time 30% longer than the straight delay setting, and 50% over-delay means increasing the delay time 50% longer than the straight delay.



When Each Delay Scenario is Best

The choice of setting depends on factors such as the bandwidth in which the subwoofer will be operational and what frequency needs to have the maximum rear rejection. The straight delay maximizes rear rejection in the mid-bass to low-bass region, while 30% delay is better for low-bass to mid-subwoofer range, and 50% delay is best for the true subwoofer range. 50% also provides the greatest degree of side rejection for instances where side projection to a stage must be minimized. In general, the 30% over-delay scenario may be the most effective for general sound reinforcement applications.

Aiming
Because there is no vertical offset between drivers, no down-angle aiming of coverage can be done electronically with this array (as some larger 3-dimensional FSA arrays can do). If an aiming angle other than horizontal is desired, the 3-speaker array must be physically aimed in the desired direction.

Ceiling-Mounting for Additional SPL (via Acoustic Boundary Loading)
For indoor locations, an array can be installed on the ceiling. The relative coverage at off-axis angles will be similar to that shown, just restricted to the lower half of the polar. The increase in sensitivity and therefore in SPL capability due to acoustic boundary loading will increase the SPL capability of the array by 3 dB (as would be the increase of placing a single speaker against an acoustic boundary).

Suspension
The installer is responsible for fabricating or constructing a frame and suspending the assembly safely.

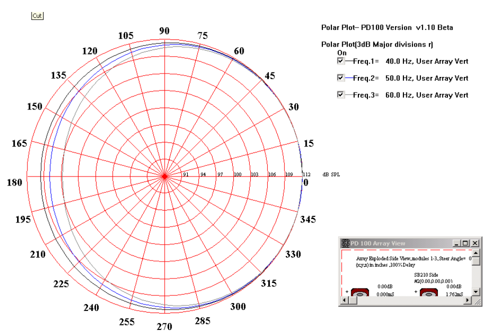
SCENARIO 1 ARRAY
3 Speakers 24" Apart (On-Center) with "Straight" Delay

Following are predicted (and verified) coverage curves at frequencies from 40 Hz to 160 Hz with standard (straight) delay. Gridlines are 3 dB per division.

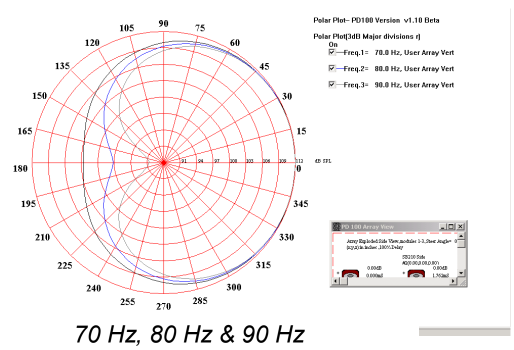
Delay Settings
The delays are 1.76 mS to the 2nd speaker and 3.52 mS to the 3rd speaker. This equals the spacing between the loudspeaker sources.

Rear Attenuation
40 Hz shows only 3 dB rear attenuation and 50 Hz shows 4 dB. 60 Hz shows 6 dB rear attenuation. 70 Hz shows 9 dB. 80 Hz shows 15 dB. 90 Hz shows 21 dB. 100 Hz shows 21 dB. Small rear lobes appear at higher frequencies, with the rear lobe still being down 10 dB at 150 Hz.

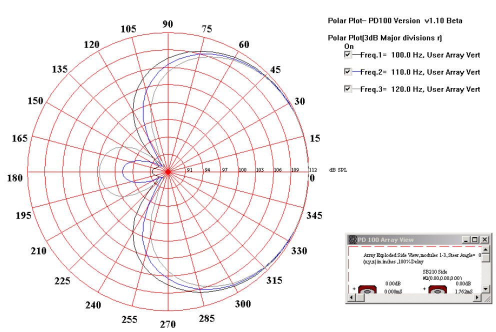
Pattern Control
Pattern control, defined as minimum 6 dB rear attenuation, is effective from 60 Hz through 150 Hz, with maximum rear rejection (of 15 dB or greater) being in the 80 Hz through 110 Hz frequency range.



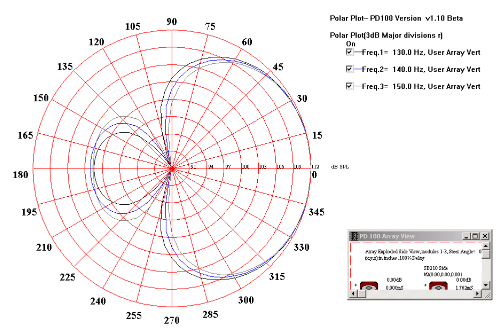
40 Hz, 50 Hz & 60 Hz



70 Hz, 80 Hz & 90 Hz



100 Hz, 110 Hz & 120 Hz



130 Hz, 140 Hz & 150 Hz

SCENARIO 2 ARRAY
3 SPEAKERS 24" APART (On Center) with 30% Over-delay

Increasing the delay setting by 30% improves the rear attenuation below 100 Hz and narrows the coverage lobe, resulting in greater off-axis rejection. Following are the coverage curves with delay times increased 30% over standard (straight) delay.

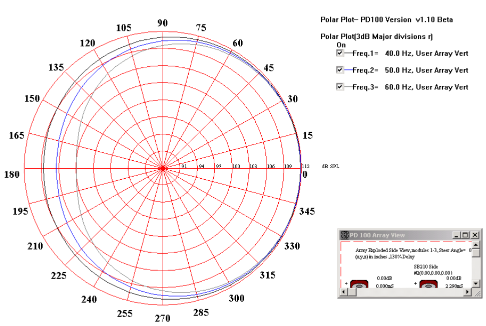
Delay Settings
The delay times are 2.29 mS to the 2nd speaker and 4.58 mS to the 3rd speaker.

Rear Attenuation
Compared to straight delay 40 Hz and 50 Hz show a slight improvement to 4 dB and 5 dB rear attenuation respectively. 60 Hz attenuation increases 50% to 9 dB. 70 Hz attenuation increases 60% to 15 dB. 80 Hz attenuation increases 70% to 25 dB. 90 Hz attenuation stays high at 25 dB. The rear lobes start showing up at 100 Hz attenuation which reduces 30% to 15 dB. Compared to 50% delay, rear attenuation is less at all frequencies except the top-end frequency of 100 Hz.

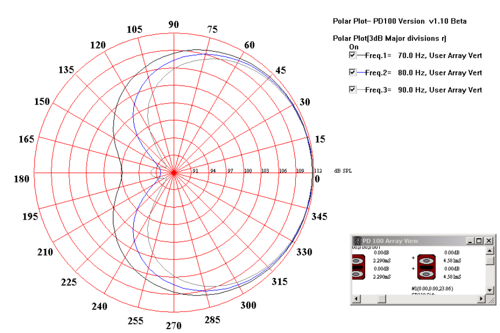
Rear Lobes
Rear lobes start appearing at lower frequencies than with the straight delay but a higher frequency than with the 50% over-delay. Even when lobes appear, the rear attenuation is still excellent.

Pattern Control Range
The 30% over-delay extends the pattern control frequency down to 55 Hz, with maximum rear rejection (of 15 dB or greater) being in the 70 Hz through 100 Hz frequency range.

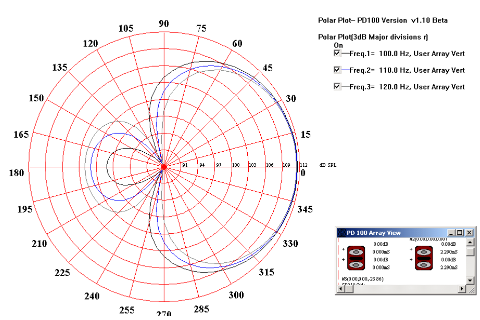
Width of Main Coverage Lobe
The 30% over-delay setting predictably results in coverage lobe widths narrower than with the straight delay, but not as narrow as with 50% over-delay.



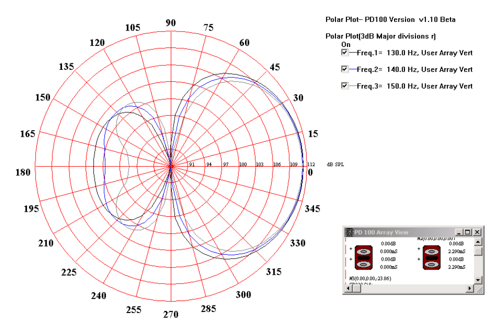
40 Hz, 50Hz & 60 Hz



70 Hz, 80Hz & 90 Hz



100 Hz, 110Hz & 120 Hz



130 Hz, 140Hz & 150 Hz

SCENARIO 3 ARRAY
3 SPEAKERS 24" APART (On Center) with 50% Over-delay

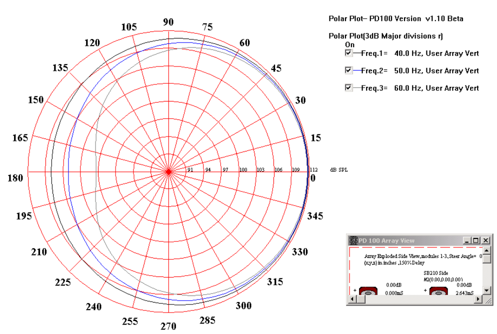
Following are coverage curves with delay times increased 50% over standard delay.

Delay Settings
The delay times are 2.64 mS to the 2nd speaker and 5.29 mS to the 3rd speaker.

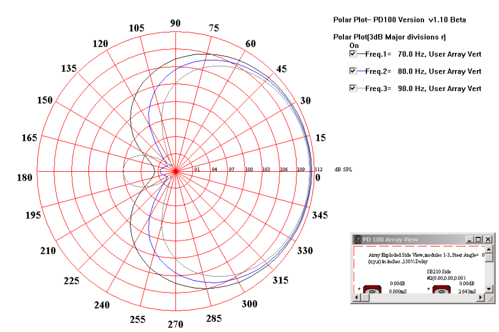
Rear Attenuation
Compared to the straight delay, 40 Hz shows a slightly higher 4 dB rear attenuation and 50 Hz shows a better 6 dB. 60 Hz attenuation doubles to 12 dB. 70 Hz attenuation almost doubles to 17 dB. 80 Hz attenuation increases 70% to 25 dB. A small rear lobe starts appearing at 90 Hz, lowering its attenuation to 15 dB. 100 Hz attenuation halves to 10 dB.

Rear Lobes
Rear lobes start appearing at lower frequencies with the 50% over-delay, and while the lobes are slightly wider, they are the rear attenuation is considerably better.

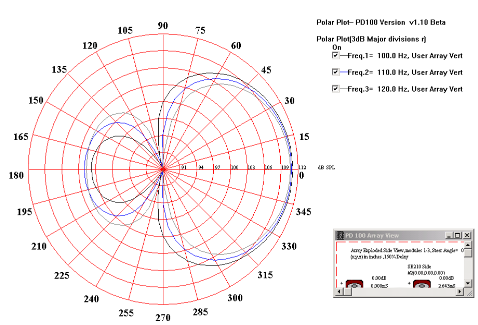
Pattern Control Range
The over-delay extends pattern control down to 50 Hz, with maximum rear rejection being in the 70 Hz through 90 Hz frequency range.



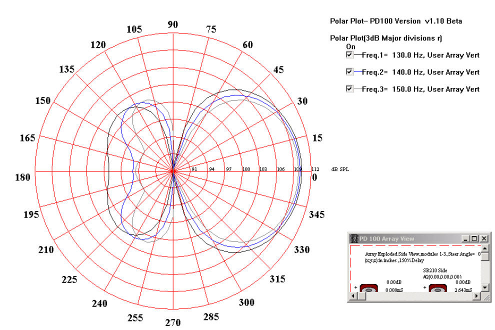
40 Hz, 50 Hz & 60 Hz



70 Hz, 80Hz & 90 Hz



100 Hz, 110Hz & 120 Hz



130 Hz, 140Hz & 150 Hz

SUMMARY

Width of Main Coverage Lobe

Over-delay narrows the coverage lobe and providing more defined coverage at all frequencies of interest. Below are coverage widths (defined as 6 dB down points).

Frequency	Coverage with Straight Delay (Array 1)	Coverage with 30% Over-delay (Array 2)	Coverage with 50% Over-delay (Array 3)
60 Hz	330°	270°	240°
70 Hz	270°	220°	200°
80 Hz	240°	200°	180°
90 Hz	210°	180°	150°
100 Hz	190°	160°	140°

Rear Attenuation

The frequency band of optimum control changes with the delay settings. For a low-pass crossover setting of 80 Hz, the 50% over-delay setting provides the best rear attenuation below 80 Hz. For a crossover setting of 100 Hz, while the 50% over-delay setting has the best side-rejection, the 30% over-delay setting has better rear-attenuation at the higher frequencies of that subwoofer band. For crossover settings above 100 Hz, the straight delay setting may be a good option if the objective is to provide best rear-attenuation in the 80 Hz to 110 Hz range.

Scenario →	Array 1	Array 2	Array 3
# of SB2210 Speakers	3	3	3
Description	3 speakers, straight delay	3 speakers, medium over-delay	3 speakers, maximum over-delay
Spacing between speakers (on- center)	24”	24”	24”
Delay setting	Straight, 1.762 & 3.523 mS	30%, over-delay, 2.290 & 4.581 mS	50%, over-delay 2.643 & 5.285 mS

	Rear Attenuation in dB		
Scenario →	Array 1	Array 2	Array 3
40 Hz	3	4	4
50 Hz	4	**5**	6
60 Hz	6	**9**	12
70 Hz	9	**15**	17
80 Hz	15	**25**	25
90 Hz	21	**25**	15
100 Hz	21	**15**	10
110 Hz	16	11	11
120 Hz	12	10	10
130 Hz	11	16	17
140 Hz	10	13	17
150 Hz	10	10	13

Primary Band of Interest (50 Hz – 100 Hz)

Maximum SPL Capability

This "Forward Steered Array" method allows for coherent summation in the steered direction. FSA achieves near-ideal mutual coupling (ie, coherent summation), which increases SPL by 6 dB for each doubling of number of loudspeakers (+3 dB for greater cone area and another +3 dB for doubling of power). By comparison, in 2-element cardioid subwoofers, a percentage of the sound from the rear-cancelling element wraps around the cabinet and cancels out sound in the front. In FSA -- unlike cardioid subwoofers -- none of the sound in the steered direction is cancelled. With FSA, the near-ideal summation of the multiple cabinets is achieved in the steered direction, providing for substantially higher overall SPL levels.

Qty of SB2210s	Maximum Continuous On-Axis SPL *(free space – no acoustic boundary loading)*
1 x SB2210	116 dB *(Peak of 122 dB)*
3 x SB2210s in FSA	125 dB *(Peak of 126 dB)*

Caution about Cabinet Obstruction

Avoid obstructions directly between radiating devices -- including the cabinets of the subwoofers. Side-facing cabinets (such as the cabinet orientation shown in the diagram on page 2) tend to result in maximum rear cancellation and coherent front summation. The polars in all the scenarios are based on there being no interference in the path between sound sources. While low frequencies tend to diffract around obstructions, large obstructions such as the cabinets of the loudspeakers themselves can break up the coherence of the wave fronts and change – and often smear -- the time of flight. Asymmetrical cabinets can result in further smearing of the wave that's going around it because the portion of the wave that goes around via the long dimension takes longer than the portion that goes around via the short dimension. That prevents the wave-fronts from adding coherently (or even predictably).

Conclusions – Choosing the Optimum Delay Scenario for the Application

The choice of optimum delay scenario depends on the bandwidth in which the loudspeakers will be operational and which center-frequency is desired for the maximum rear rejection.

Straight Delay -- The straight delay maximizes rear rejection in the mid-bass to low-bass region – in the 80 Hz through 110 Hz frequency range.

30% Over-Delay -- 30% over-delay provides the best rear rejection of any of the scenarios in the low-bass to mid-subwoofer range – 70 Hz through 100 Hz.

50% Over-Delay -- The 50% over-delay may be best for lower crossover frequencies, such as 80 Hz, because it provides its highest rear rejection in the 70 Hz through 100 Hz range (although not as deep of rear-rejection as 30% over-delay) while also providing the highest rear-rejection of any of the scenarios below 70 Hz. 50% over-delay also provides the greatest degree of side rejection for instances where side projection (for example, to a stage) must be minimized.

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