DYNACORD

BASS! BASS! BASSARRAYS!

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The satisfactory reproduction of bass frequencies is one of the most emotional and controversial topics in sound reinforcement.

The widespread use of high-power high-quality car audio and home audio systems has shifted the requirements of the patrons during the last 15 years towards significantly higher bass SPLs at significantly lower frequencies.

The quality of the reproduction of bass heavily depends on the physical placement of the cabinets, not only on the quality of the transducers and the cabinet design.

Either cars or typical living rooms have longest physical dimensions which are similar in size to the reproduced wavelenghts in the bass region, let us say 3m – 8m. A typical small to medium sized sound reinforcement system projects bass frequencies into the open air or an environment with dimensions often much larger than the typical wavelengths in the bass region. In addition, the physical dimensions of professional loudspeaker cabinets or cabinet arrays are much larger than car audio or home audio components and therefore often cannot be treated as idealized point sources.

So, conventional wisdom of car audio and home audio regarding bass reproduction must not necessarily always be applicable to small, medium or large scale sound reinforcement systems.

Conventional stereophonic Left-Right speaker setups inherently suffer from interference induced 'hot-spots' and 'dead-spots' in the audience area and on the stage. The perceptibility is most pronounced for low frequencies. The so-called 'Bass-Alleys' or 'Hi-Fi-Alleys' are the regions where the signals of the left and right speaker stack interfere constructively. The regions between the alleys suffer from undefined bass due to destructive interferences.

Horizontal ground-stacked bass arrays or bass center clusters on the contrary create a comparably even coverage of the audience. In addition, the perceived quality and the SPL of the bass inside of the audience and on the stage is less dependent on room acoustics because of the excellent directivity characteristics of ground-stacked bass arrays or bass center clusters.

'Flying' left-right bass line arrays in principle suffer from the bass alley problems too but has the advantage of excellent vertical directivity control down to very low frequencies. So very large audience areas can be served with a controlled amount of bass SPL. Large-scale sound reinforcement systems have to be handled differently from small to medium-sized systems and are beyond the scope of this paper.

1 Some common misconceptions regarding bass frequencies and bass cabinets

1.1 ‘Bass is radiated omnidirectional’

This is true only if the cabinet dimensions are much smaller than the wavelengths of the respective bass frequencies. The dimensions of professional cabinets are not negligibly small as can be seen in Fig. 1. The diagram shows the frequency response of a typical 18” sub placed on the floor. One measurement was done in 10m distance from the front, the other measurement was 10m behind the rear side of the cabinet. One can see that the radiation to the rear side is less than the front radiation. So the cabinet is not an omnidirectional radiator for higher bass frequencies due to the influence of the cone diameter and the cabinet dimensions.

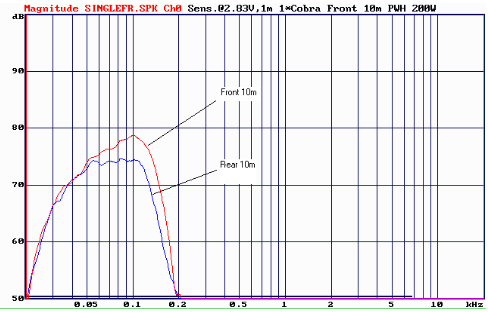

Fig. 1. Frequency response of a typical 18” vented cabinet. Measurement shows front vs rear radiation. Crossover frequency 124Hz, Linkwitz-Riley 24dB/Oct.

1.2 ‘Bass is not localizable, the position of the bass cabinets does not play any role’

This is true only if if one is in a completely diffuse bass field, e.g. a comparably large living room with strong bass reflections. The bass in such a situation cannot be localized by our listening system because the distance of the ears does not allow a localization of the source position for low frequencies. If we do not have a completely diffuse field for the bass, we can localize the source position of the bass simply by listening to level differences and ‘mechanical feeling’ of the bass.

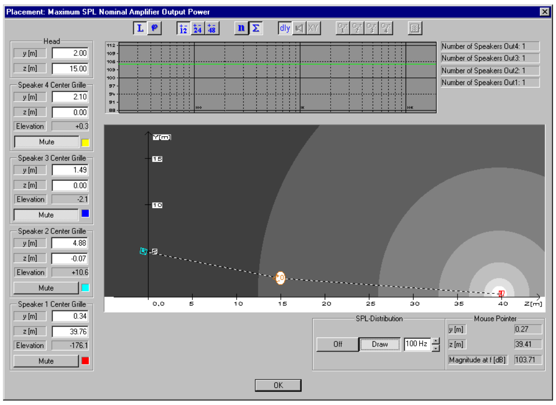

Fig. 2. An extreme example for localizable bass

1.3 ‘Ground-stacking bass cabinets increases the bass level by 3dB’

When a bass cabinet is placed on the floor, the cabinet radiates all its acoustic power just into the half-space above the floor, so the acoustic power is increased by 3dB compared with radiation into full space, far away from any reflecting surface.

But at the same time the radiation resistance of the cabinet is doubled, so the SPL increases by 6dB, not by 3dB. [1]

Hence, for the same SPL, a ground stack only requires half the number of cabinets compared with flying the bass cabinets.

When placing a bass cabinet near a fully reflecting surface, a ‘mirror image’ of the cabinet is created behind the surface. So a bass cabinet placed on the reflecting floor is accompanied by a ‘mirrored cabinet’ below the floor. The SPL is increased by 6dB and the height of the cabinet is virtually doubled. Fig. 3 shows the SPL and directivity of an omnidirectional point source without any reflecting surface. For reasons of clarity, only the upper half of the radiation is shown.

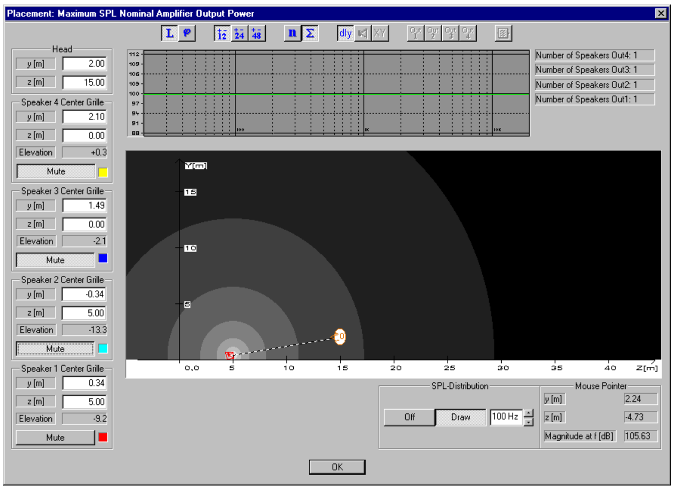

Fig. 3. SPL and directivity of an omnidirectional point source without any reflecting surface, 100Hz

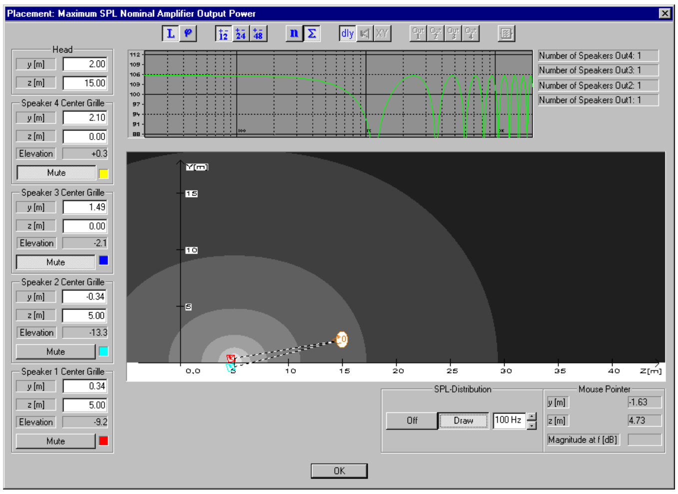

Fig. 4. Ground-stacked bass cabinet with mirrored cabinet, 100Hz

Fig. 4 shows a bass cabinet placed on a floor together with the accompanying mirror cabinet. The SPL increases by 6db for low frequencies and the directivity for low frequencies changes due to the physical separation of the acoustical centers.

1.4 ‘Placing cabinets at a wall or in a corner increases the bass’

Sometimes yes, sometimes no, some frequencies yes, some frequencies no. This again fully depends on the physical size of the cabinet, the diameter of the cone and the respective frequency. Fig 5 shows an idealized cabinet with 70cm depth. The acoustic center cannot be placed directly at the wall due to the cabinet’s physical dimensions, so the mirror image is approximately 70cm behind the wall. We have two sources with 1.4m distance that destructively interfere at approximately 125Hz in the direction towards the audience and have a ‘constructive’ 6dB increase in level at 125Hz towards the ceiling. So the ‘kick’ of the bass drum is now projected to the ceiling, not to the audience.

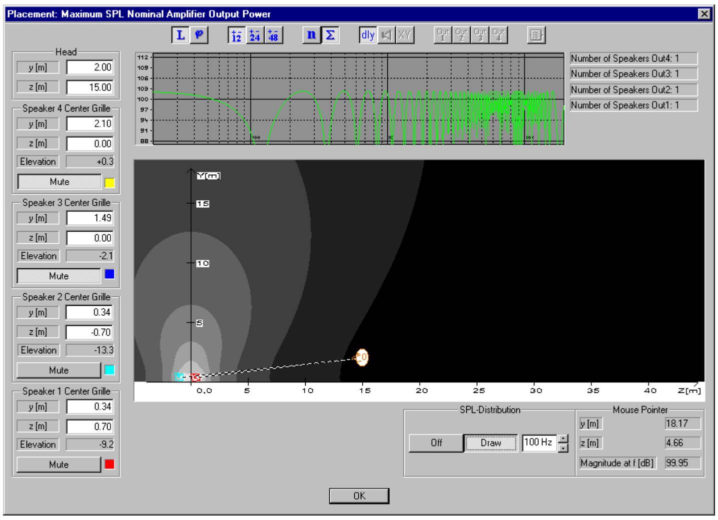

Fig. 5. Idealized cabinet with 70 cm depth placed against a wall at 100Hz (shown with mirror cabinet)

In many situations it is probably best not to place single bass cabinets near walls or corners.

But tightly packed large and medium-sized arrays or clusters of bass cabinets have well defined directivity characteristics for low frequencies and a comparably large front-to-back SPL ratio. Placing such arrays near walls therefore does not create too many problems. This situation will be discussed in more detail below.

If a cabinet can be placed completely inside a wall or corner, flush mounted , the situation is completely different because then the acoustic centers of the real cabinet and the mirror image are in close vicinity and no destructive interference exists in the frequency range of interest.

2 The 'Bass-Alley' problem of stereophonic set-ups

Stereophonic set-ups are widely used for small to medium-sized sound reinforcement applications. Even though the acoustic localization may not be as good as in central cluster systems, a satisfactory coverage of the audience can be achieved without the inherent acoustic feedback problems of central cluster systems. But stereophonic set-ups suffer from interference problems due to different distances from the speaker cabinets to the listeners.

Fig. 6 shows two bass cabinets with a large horizontal distance. For a listener on the symmetry axis between the cabinets the travel time for sound waves from both cabinets is equal and the waves constructively add at the listener's position.

For a listener off symmetry axis, path length differences from the respective cabinets lead to almost full cancellation for all frequencies where the path length difference equals half a wavelength (and odd multiples of half a wavelength). The respective SPL levels at the listener position are slightly different due to the path length difference, but this is ignored here for reasons of simplicity.

A linear frequency response only exists on the points of the symmetry axis, all other positions have a comb-filter type frequency response. This problem exists not only for the bass frequencies but for all other frequencies too. But for mid and high frequencies this 'horizontal' comb filter is much less annoying due to some psychoacoustic reasons. This problem is inherent with all stereophonic set-ups and not dependent on the type of loudspeaker cabinet.

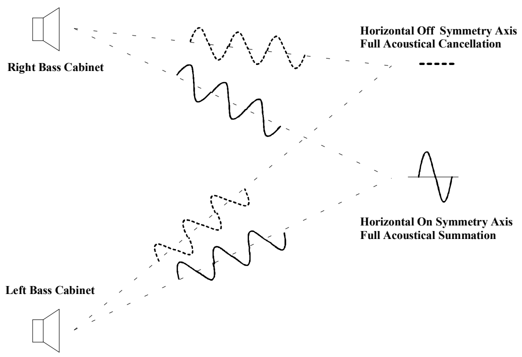

Fig. 6. Two bass cabinets with large horizontal distance. Large travel distance differences lead to almost full cancellation for certain frequencies off symmetry axis

Fig. 7 shows as an example a simulation of the horizontal coverage of two bass cabinets with 10m distance at 100Hz. Every change in the grey scale towards black is 6dB attenuation and we have a lot of listener positions with virtually no 100Hz information. The center 'bass-alley' and the left and right alleys have a linear frequency response steady-state, but the left and right 'bass-alleys' are different from a standpoint of signal arrival time. The soundwave from the more distant cabinet arrives 5ms later than from the less distant cabinet.

For all simulations an omnidirectional point source model was used [2].

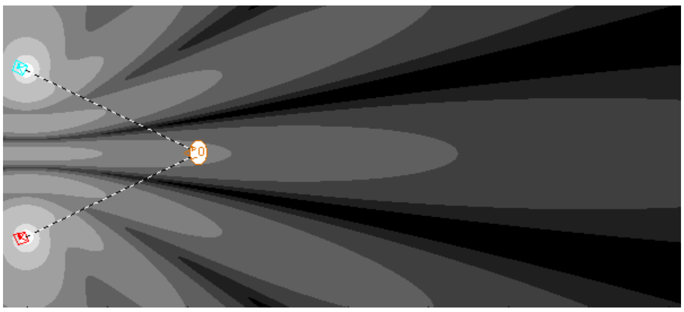

Fig. 7. 'Bass Alleys'. Two bass cabinets with 10m distance. Horizontal coverage at 100Hz

3 Bass Arrays

3.1 How to get rid of 'Bass Alleys'

Placing the bass cabinets side-by-side in the center is the easiest way to overcome the problem. This is shown in Fig. 8 schematically. Now the path length differences are comparably small and we do not have full cancellation off symmetry axis as long as the wavelengths of the sound are much larger than the width of the 'bass array'.

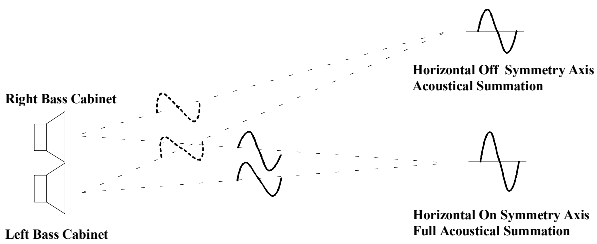

Fig. 8. Two bass cabinets placed side-by-side. Only small travel distance differences for low frequencies

As can be seen in Fig. 9, placing the cabinets side-by-side completely eliminates the 'Bass-Alleys' and we have a nearly uniform horizontal coverage of the audience area.

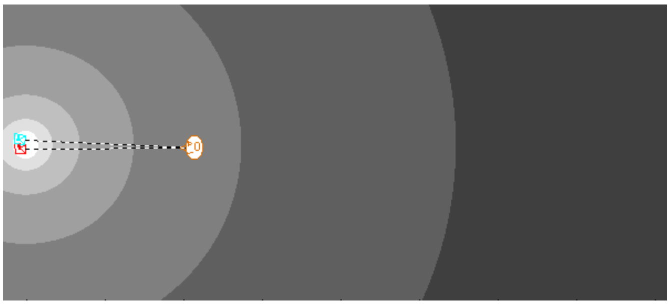

Fig. 9. 1-by-2 Array horizontal coverage at 100Hz. Two 90cm*60cm Bass cabinets side-by-side

Fig. 10 shows a front view of the simulated bass array. The small cabinets 'on stage' at the left and right side are just shown for reasons of clarity.

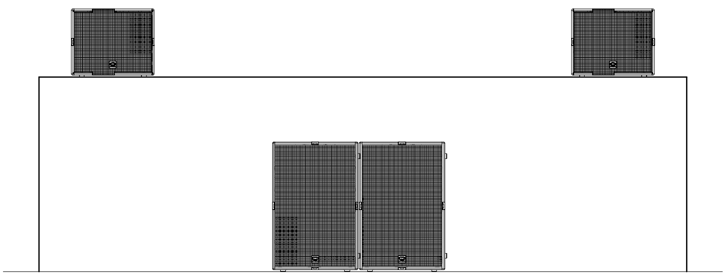

Fig. 10. 1-by-2 Bass array together with mid-high cabinets on stage

3.2 Horizontal directivity control

Looking at Fig. 9 meticulously, we see that the coverage is not circular but slightly oval. The width of the array is approximately 1.20m and we already have some degree of destructive interference perpendicular to the symmetry axis.

We now add two additional bass cabinets on each side to our array. The width of the array is now 2.4m. The resulting horizontal coverage at 100Hz is shown in Fig. 11. The array has become highly directional towards the listener. The height of the array has no influence on the horizontal pattern. The horizontal characteristics are the same for a 1*4 array or 2*4 array or 3*4 array and so on.

Fig. 11. 1-by-4 Array horizontal coverage at 100Hz. Four 90cm*60cm bass cabinets side-by-side

Fig. 12 shows a front view of the simulated 1-by-4 bass array. The small cabinets 'on stage' at the left and right side are just shown for reasons of clarity.

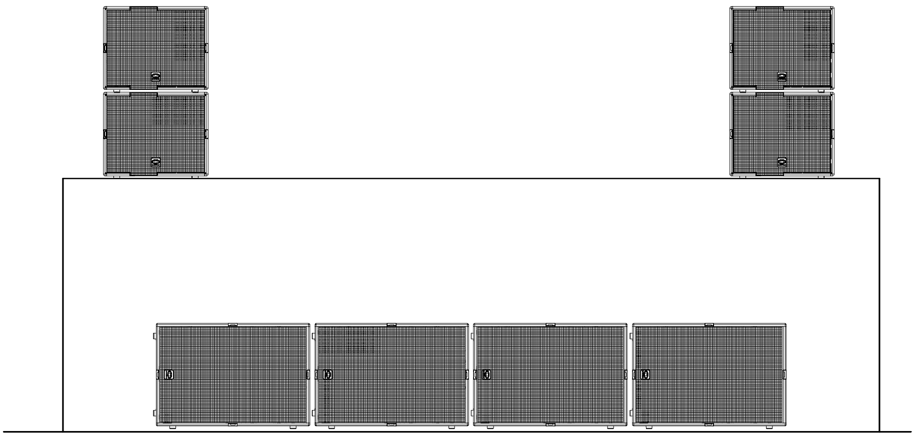

Fig. 12. 1-by-4 Bass array together with mid-high cabinets on stage

For some applications, e.g. sound reinforcement in long and narrow halls, one can extend the width of the array and achieve an even stronger directional characteristic towards the audience. Fig. 13 shows a simulation with 16 cabinets. The width of the array is approximately 10m.

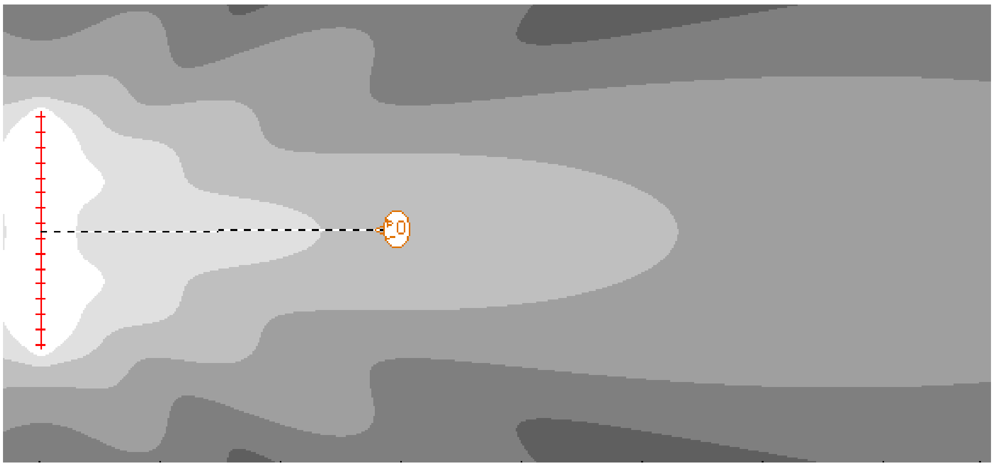

Fig. 13. Horizontal bass array with 16 cabinets, width approximately 10m, horizontal coverage at 100Hz

3.3 Vertical directivity control

We now add a second row of speaker cabinets in order to realize a 2*4 bass array. Fig. 14 shows the simulation of the vertical radiation characteristics of this array. Two mirror cabinets are now 'below the floor', doubling the virtual height of the array. The ground stacked 2*4 bass array radiates like a 4*4 bass array far away from any reflecting surface.
The radiation characteristic is symmetrical around the main axis of the complete array.

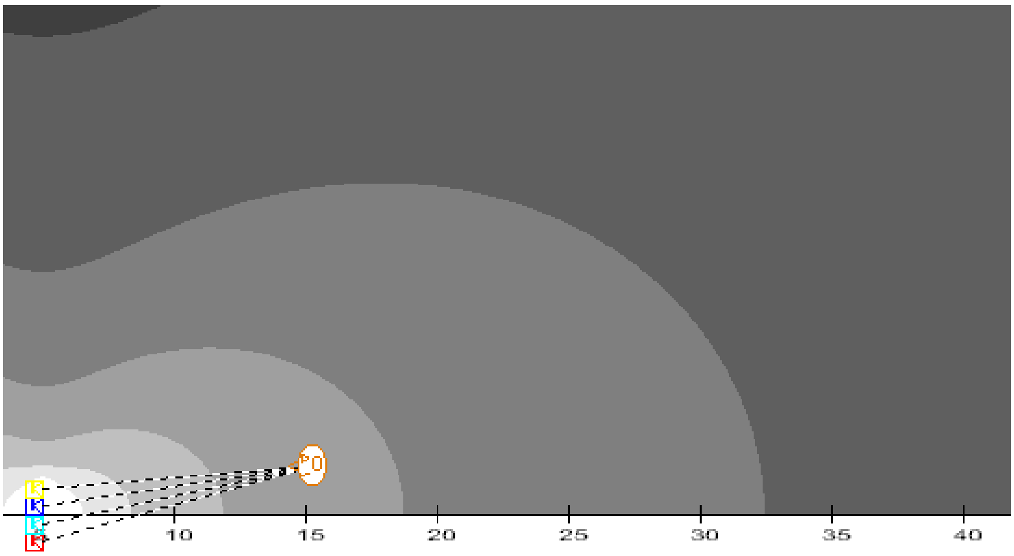

Fig. 14. 2-by-4 Array at 100Hz with mirror cabinets. Vertical coverage. Side view

Fig. 15 shows a front view of the simulated 2-by-4 bass array. The small cabinets 'on stage' at the left and right side are just shown for reasons of clarity.

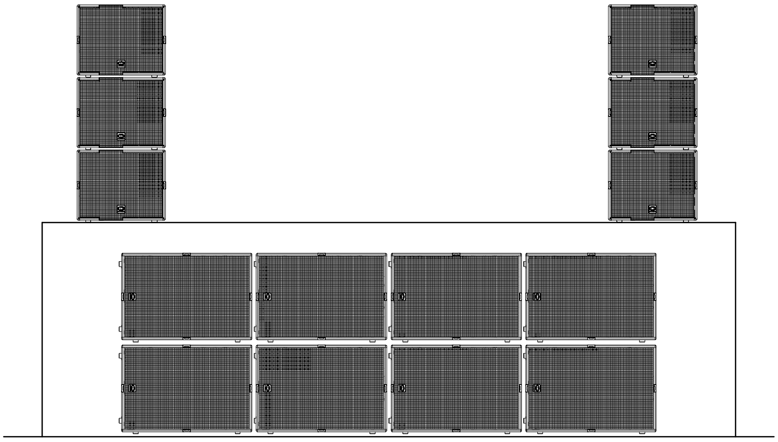

Fig. 15. 2-by-4 Bass array together with mid-high cabinets on the stage

3.4 The frequency response of small and medium-sized bass arrays

When building bass arrays, the question arises how the frequency response will be altered due to the close coupling of the cabinets and the resulting increase in radiation resistance. Fig. 16 shows a measured comparison of a single COBRA-PWH cabinet compared with a 2*4 array of COBRA-PWHs. The level increase is 18dB as expected, the frequency response curve shows a slight change. A modification of any preset parameter of a digital loudspeaker controller is probably not necessary. For smaller arrays the deviations from a single cabinet are less pronounced.

For larger bass arrays or for other types of cabinets, e.g. bass horns or closed cabinets, the situation may be different.

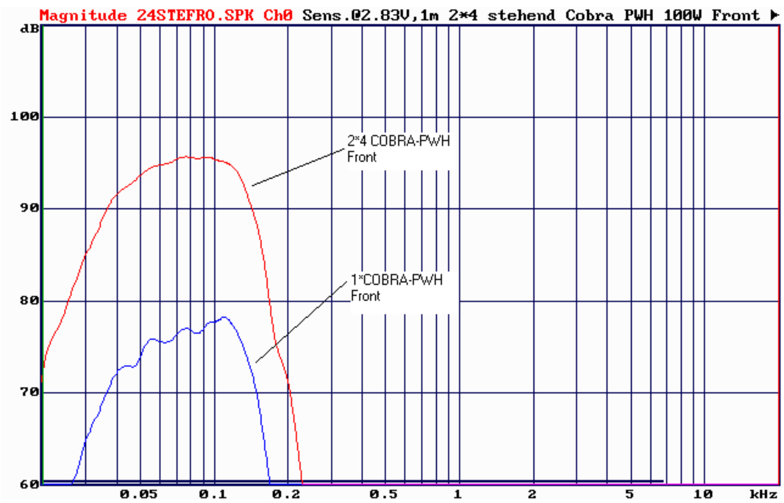

Fig. 16. Comparison of the frequency response of a single 18” vented cabinet vs an array of 2*4 cabinets.

3.5 Front-to-Back SPL ratio

Fig. 11 above shows the increase in directivity towards the audience area using a horizontal bass array.
But how is the coverage situation on stage changed using such an array directly in front or below the center of the stage?

Fig. 17 shows measurements of the 2*4 bass array. One measurement was taken in 10m distance from the front of the bass array, the other in 10m distance from the rear side of the arrayed cabinets.

The higher frequencies of the bass are significantly attenuated. Even between 30Hz and 50Hz we still have 3dB-6dB attenuation to the rear side. The bass array acts like a single 2.4m*2.4m square speaker cone. Not easily available in the market place.

This strong attenuation is only existent as long as the array is tightly packed. The backward attenuation of a tightly packed bass array is very helpful for fighting against low-frequency acoustic feedback.

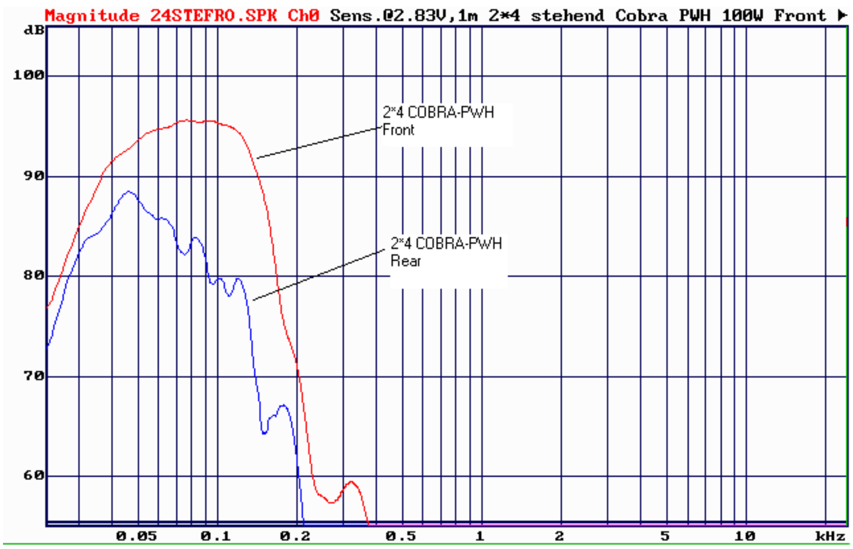

Fig. 17. Front vs back radiation of a 2*4 tightly packed bass array

In very reverberant environments it can happen that the reflections from the walls are louder than the back radiated sound from the bass array and the artists on the stage have the subjective impression of a wrong timing of the performing drummer. One can overcome this problem with sufficient monitoring or separating the cabinets of the bass array in the horizontal plane by 30cm-60cm. The problem often disappears when the audience is present due to the higher absorption for the reverberant sound.

3.6 Left-Center-Right arrays, often a good compromise

Ground stacks on the left and right side of a stage are frequently used in portable applications because of the ease of setup. Adding a center array can significantly improve the acoustic situation and is often a good compromise between a no-compromise center array and a left-right system. The small mid-high cabinets in Fig. 18 are just shown for reasons of clarity. Fig. 19 shows the simulated horizontal coverage with all cabinets driven with equal signal levels.

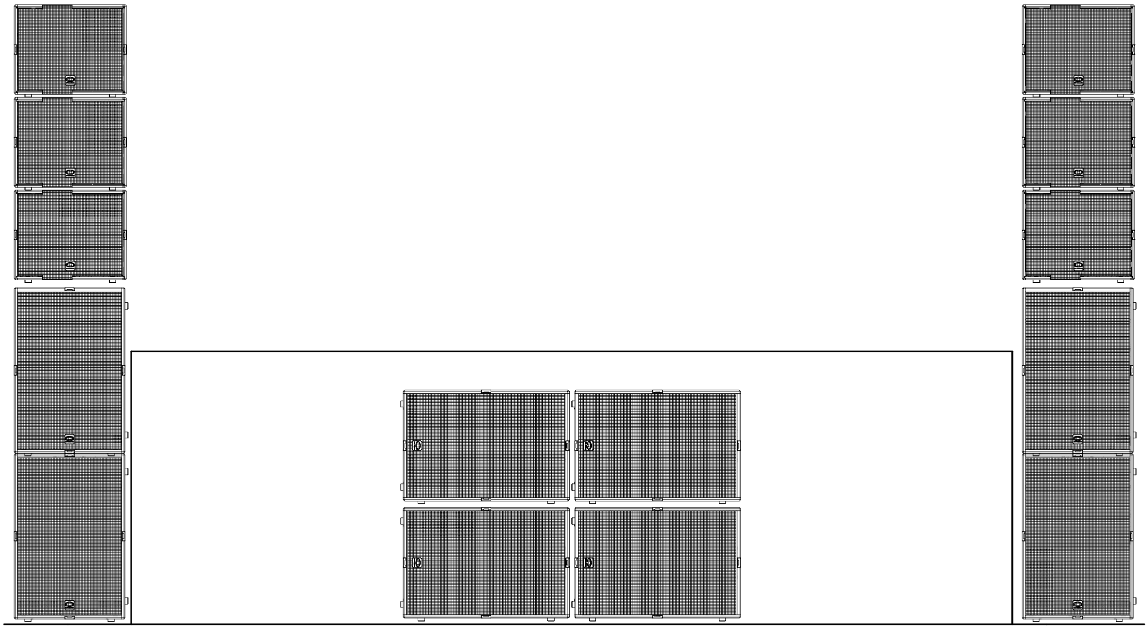

Fig. 18. Left-Center-Right bass array

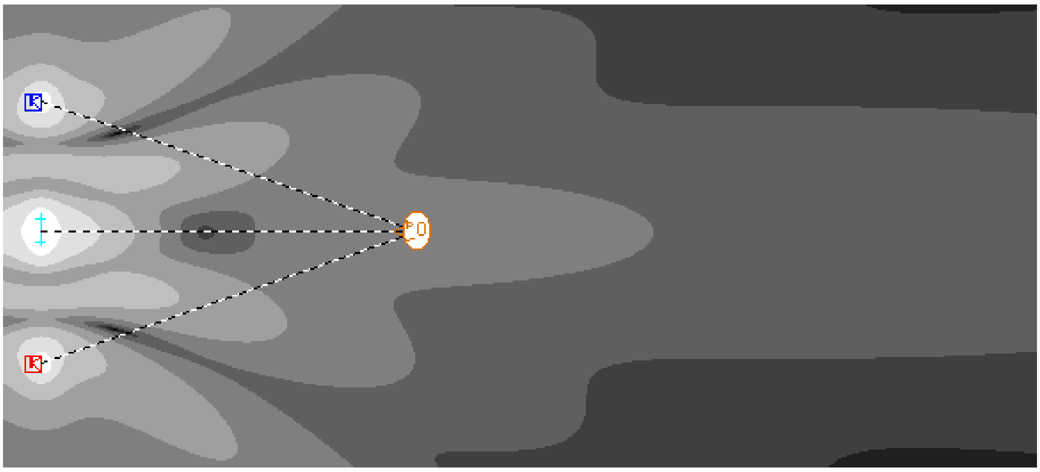

Fig. 19. Horizontal coverage of Left-Center-Right bass arrays

Conventional stereophonic Left-Right speaker setups inherently suffer from interference induced 'hot-spots' and 'dead-spots' in the audience area and on the stage. The perceptibility is most pronounced for low frequencies. The so-called 'Bass-Alleys' or 'Hi-Fi-Alleys' are the regions where the signals of the left and right speaker stack interfere constructively. The regions between the alleys suffer from undefined bass due to destructive interferences.

Horizontal ground-stacked bass arrays or bass center clusters on the contrary create a comparably even coverage of the audience. In addition, the perceived quality and the SPL of the bass inside of the audience and on the stage is less dependent on room acoustics because of the excellent directivity characteristics of ground-stacked bass arrays or bass center clusters.

4 Bibliography

[1] Morse P.M., "Vibration and Sound", 2d ed., McGraw-Hill Book Company, Inc., New York, 1948

[2] Beranek L.L., "Acoustics", McGraw-Hill Book Company, Inc., New York, 1958