MORE MINDING THE GAP

Delving further into inverted stack cardioid subwoofer configurations.

by Merlijn van Veen

The subwoofer deployment for this evaluation.

Previously *(Mind The Gap, December 2017 LSI)*, we looked at my preliminary findings about the possibly beneficial effect of introducing gaps between adjacent enclosures in cardioid stacks and arrays. Here, I'd like to delve into that further.

The conditions for perfect cancellation are very stringent. I've come to call this state the "center of tranquility at the eye of the storm." Notice how the chart in **Figure 1** resembles a tornado.

A two-dimensional rendering of this chart (**Figure 2**) shows that relative level offsets should remain within ±1.5 dB and relative phase offsets within ±10 degrees in order to achieve 15 dB cancellation or more.

Let's look at an example of the measurements I conducted on the grounds of a former air force base. **Figure 3** shows the relative back-to-front (rear-facing vs. front-facing subwoofers) level at a distance of 105 feet (32 meters) behind a horizontal front-back-front-back-front (FBFBF) array in portrait orientation.

Notice the increasing level difference towards higher subwoofer frequencies when the array is closed (without gaps). This is caused by diffraction that increases with the overall baffle size of the entire array. Remaining within the ±1.5 dB corridor is quite challenging.

Evidently, this could easily be remedied with either electronic level adjustments and/or equalization. However, this is a practice I refrain from out of concern for "pattern implosion" when limiters engage at different stages due to these electronic adjustments. Changing the ratio of back-to-front-facing subwoofers, in my opinion, is a more elegant solution.

With gaps, the diffractive effect is less pronounced (due to the breakup of the combined baffle) and relative level differences remain better predictable, unless one has access to something such as Boundary Element Method (BEM) modeling that exhibits these phenomena.

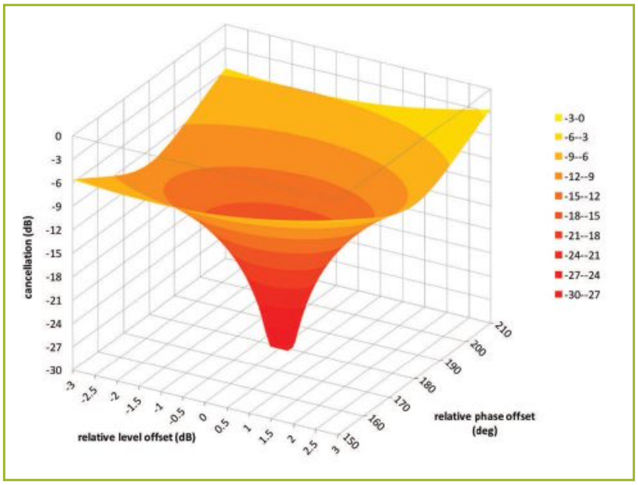


Figure 1: A 3-D view of the "center of tranquility at the eye of the storm."

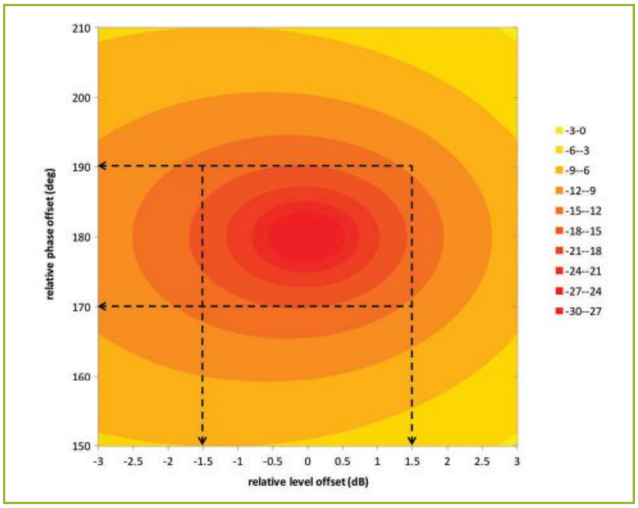


Figure 2: The "center of tranquility" in 2-D.

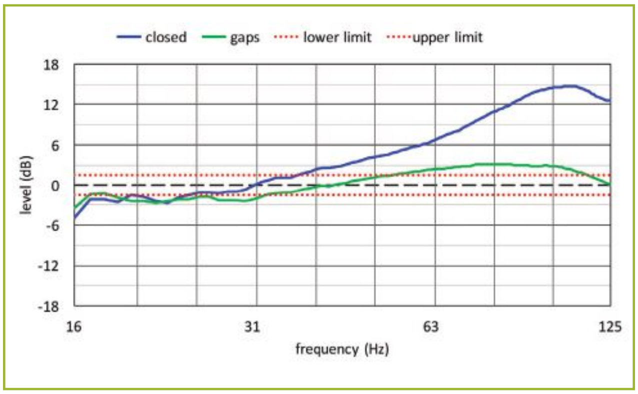


Figure 3: Diffraction affects level with increase in baffle size.

PHASED OUT

Figure 4 shows the relative phase offsets. This observation alone, made the entire measurement process worthwhile for me. With or without gaps, using the same delay time mandatory for gradient (CSA) setups has a profound effect on the relative phase offset, bordering the point that neither cancellation nor summation will occur (120-degree phase offset).

Interestingly enough, group delay (phase slopes) remains virtually identical and yet we observe a "broadband" constant phase offset. It's something that, to my knowledge, can't be corrected with simple (pure) electronic delay. Staying at 180 degrees (±10 degrees) is again very challenging.

In the past I would blame this on arrival times as well as the "wraparound" time, i.e., the time it takes for the sound to warp around its own enclosure or array (think obstacles). But the geometry of this setup does not support this.

Figure 5 shows the dimensions we're dealing with. At a distance of 105 feet, the spacing effect is negligible for path lengths – certainly not to the degree we're measuring.

The table in **Figure 6** shows that we're literally talking centimeters, resulting in approximately 10 degrees of additional phase delay at most for the highest subwoofer frequencies only.

In addition, in either case, the spacing does very little to the shortest possible path anyway (Figure 5, bottom left). If anything, the gaps only make it shorter. A different way of thinking is required.

WHERE'S THE CENTER?

In his 2006 AES paper called "The Acoustic Center: A New Concept for Loudspeakers at Low Frequencies," professor John

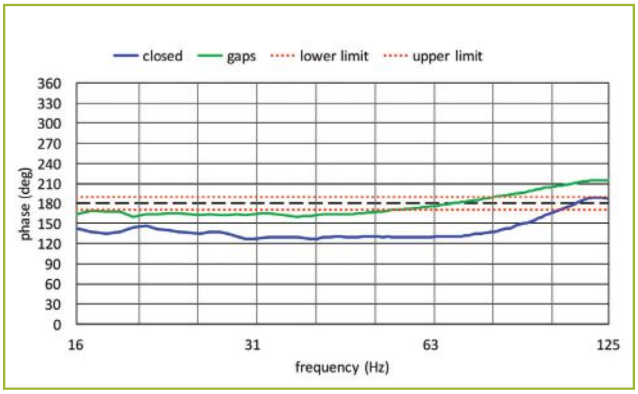


Figure 4 offers a look at the relative phase offsets.

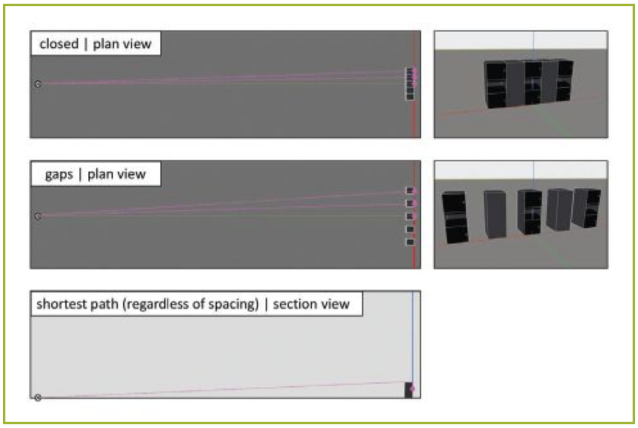
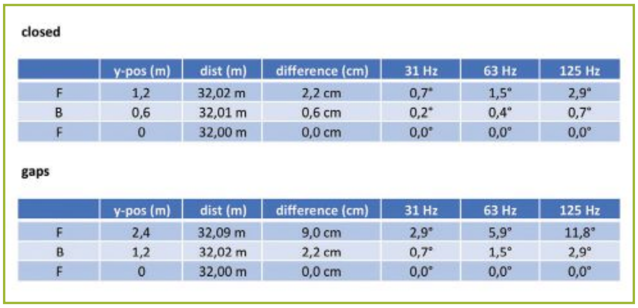


Figure 5: Dimensions and flight times at 105 feet (32 meters).



closed

	y-pos (m)	dist (m)	difference (cm)	31 Hz	63 Hz	125 Hz
F	1,2	32,02 m	2,2 cm	0,7°	1,5°	2,9°
B	0,6	32,01 m	0,6 cm	0,2°	0,4°	0,7°
F	0	32,00 m	0,0 cm	0,0°	0,0°	0,0°

gaps

	y-pos (m)	dist (m)	difference (cm)	31 Hz	63 Hz	125 Hz
F	2,4	32,09 m	9,0 cm	2,9°	5,9°	11,8°
B	1,2	32,02 m	2,2 cm	0,7°	1,5°	2,9°
F	0	32,00 m	0,0 cm	0,0°	0,0°	0,0°

Figure 6: A further breakdown shows that dimensions/flight times come down to centimeters.

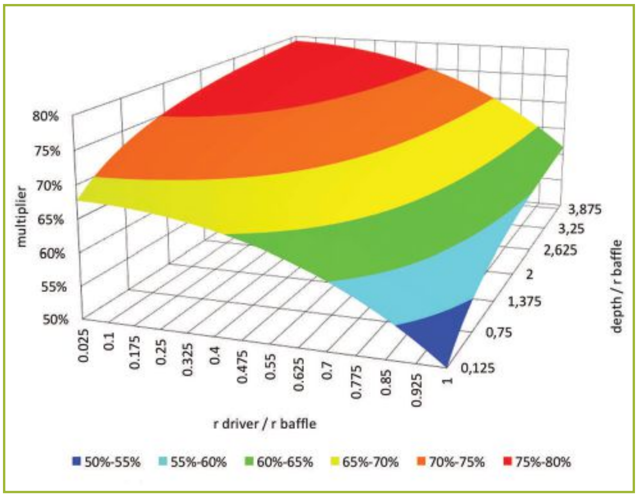


Figure 7: The three variables that determine the acoustic center position.

Vanderkooy presents analytical proof and compelling evidence suggesting that the acoustic center of sealed or vented direct radiator subwoofers resides in front of the enclosures. This behavior persists up to frequencies where the physical size of the source is about half of a wavelength.

There are three variables that determine the acoustic center position for a subwoofer: driver radius, baffle radius and enclosure depth. Their effects can be condensed into a single chart (with respect to baffle radius) shown in **Figure 7**.

If the driver radius is relatively small with respect to the baffle radius (x-axis) and/or the enclosure is relatively deep with respect to the baffle radius (y-axis), the acoustic center is propelled outwards by a certain factor or multiplier (z-axis), away from the driver (on axis). This multiplier times the baffle radius will produce the acoustic center distance.

When we build stacks or arrays, the combined baffle area increases. However, due to the alternating orientation of subwoofers in gradient (CSA) configurations, the increase in combined baffle area typically exceeds the increase in combined cone area.

Figure 8 shows that the relative ratio of r_{driver} to r_{baffle} decreases when the array becomes bigger compared to a single loudspeaker where radius is derived from an area as if it were a perfect circular disk. This decreasing ratio (x-axis, Figure 7) propels the acoustic center outwards, away from the driver (on axis).

On the other hand, when the array becomes bigger, the enclosure depth remains constant but the effective baffle radius increases. Compared to a single loudspeaker, the relative ratio of depth to r_{baffle} decreases and the acoustic center moves closer (y-axis, Figure 7) to the cabinet in the opposite direction. A push-pull situation.

The multiplier value shown along the z-axis shown in Figure 7 remains virtually constant over array size, but when applied to an also inherently larger baffle radius, the acoustic center will still move outwards which is consistent with my measurements.

It's also interesting to note that the front-back-front configuration still shows a similar but lesser progression (smaller array) in terms of relative phase offset. If we convert the difference in relative phase offset between "closed" and "gaps" from Figure 4 into distance, we get **Figure 9**.

CLOSING THE GAP

It's readily apparent that the array without gaps (closed) increases the separation on a frequency dependent basis between acoustic centers on both (front- and rear-facing) sides of the array due to a larger combined baffle.

In accordance with Vanderkooy's paper, lower subwoofer frequencies will exhibit this behavior more. Simple (pure) electronic delay, as mentioned before, can't fix this.

It's unlikely that this behavior, which clearly changes with frequency, is the result of flight and/or "wraparound" times caused by constant physical detours and/or increased path lengths.

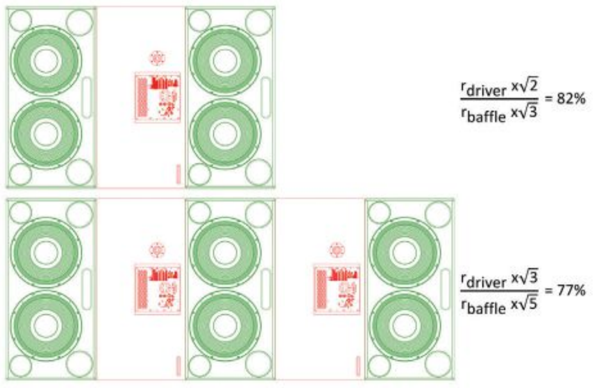


Figure 8: The ratio of driver to baffle decreases when the array becomes bigger.

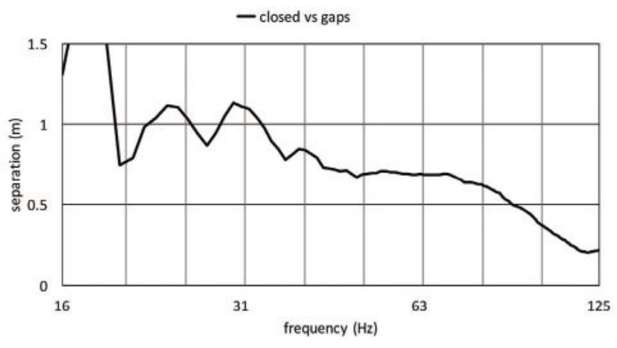


Figure 9: The array without gaps increases the separation on a frequency dependent basis between acoustic centers on both sides of the array.

However, breaking up the baffle for gradient (CSA) stacks and arrays not only restores the level imbalance but also the time offset. Bringing us close again to the "center of tranquility at the eye of the storm." The configuration becomes easier to predict based upon the performance of a single subwoofer.

As noted in my previous article, the challenge becomes to determine the minimum required gap size for improved rejection without a noticeable increase in lobing. In fact, colleagues with whom I shared my preliminary findings started experimenting with air gaps between adjacent enclosures as little as the size of a fist and reported improved rejection.

My own observations confirm this. I intend to further experiment with simple spacers between vertically stacked subwoofers, and it might very well turn out that even the casters underneath a dolly or wheel board could prove advantageous. LSI

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