Stair Cardioid Subwoofer Array

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Abstract

The advantages of cardioid sub configurations are well known, however they also have some drawbacks. Because of the nature of the arrays in their two-in-line and inverse-stacked variations, cardioid systems reduce the acoustical pressure not only on the stage, but also at FOH, the most important area! This is in front of the array, where the audience is located. SPL can be decreased by greater than 3 to 6 dB when compared to a simple mono cluster. This makes the technique unviable in situations where maximum SPL is needed. Measurements are presented to illustrate the problems with traditional cardioid sub configurations, followed by an introduction of our new way to create a cardioid array. In this new method, we achieve the same output levels as a mono cluster across most of the subwoofers bandwidth, while maintaining the benefits of a cardioid configuration.

1 Introduction

We went to a subwoofer measurement party the other day to test out some well known cardioid and gradient concepts. While there, we wanted to demonstrate and measure an idea that had been in our minds for a while.

The commonly used approaches to cardioid alignment are of great use, but they have some drawbacks. The worst problem is that the FOH and audience level is reduced when compared to a typical mono stack. That makes the cardioid configurations non-viable in certain situations.

Lets start with some background on this problem, accompanied by theory and measurements we put together just for this article. Well focus on the two most common variations: the two-in-line and inverse stacked approaches. Then well see if we are able to reduce the main problems of these approaches.

2 Two in Line Cardioid

Most of the time, subwoofer configurations are only analyzed based on theory, using math and simulation software. The actual behavior of transducers and sound waves in air are more complex than software can simulate. Simulation programs are invaluable tools for comprehension and planning use, but results in the real world will always be slightly different, depending on the situation. For example, if we want to sync two sources in the time domain, as in Figures 1 and 2, we know that 1 meter (3 feet) of separation requires approximately 3 milliseconds of delay.

Figure 2 shows something that most software cant "see." In reality, the sound waves from the rear sub must propagate as shown to reach the microphone because there is an obstacle in their way

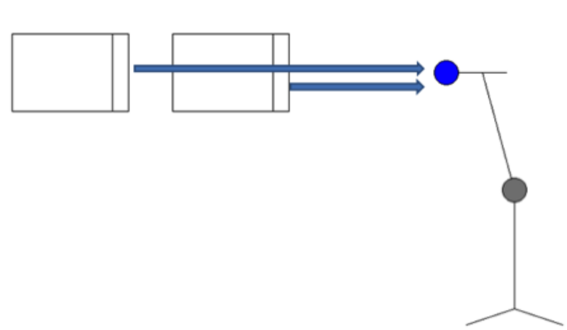

Figure 1: Propogation Simulation

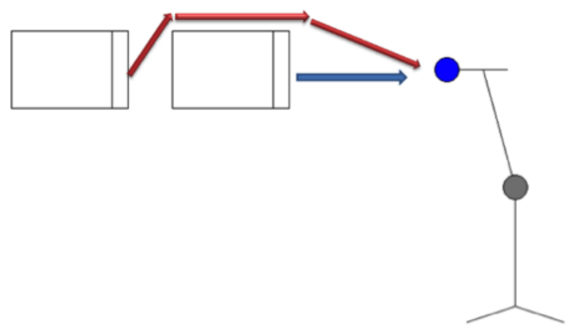

Figure 2: Propogation Reality

- the front sub. Depending on the frequency and wavelength, that obstacle may not be transparent as believed in the ideal case. This is why, when setting delay time in the field, measurements always suggest that more delay is required than the prediction indicated. The time variation is not what produces problems on the two-in-line cardioids configurations - it is the variation of level.

Disclaimer: The reader must understand that the purpose of this article is far from judging simulation programs. They are invaluable working tools in education, understanding, and implementation of electro acoustical systems. A part of knowing these tools is knowing their limitations. With limitations in mind, we can get the most out of them.

It is well known that, in order to fine-tune a cardioid system, we need to have not only equal timing but also equal level at the rear position. Since the rear sub is closer to the measurement location, the sound has a shorter path to travel, and therefore the attenuation by distance is less than that for the front sub. Lets take a look at a simulation of the level difference produced by each box at the rear microphone location.

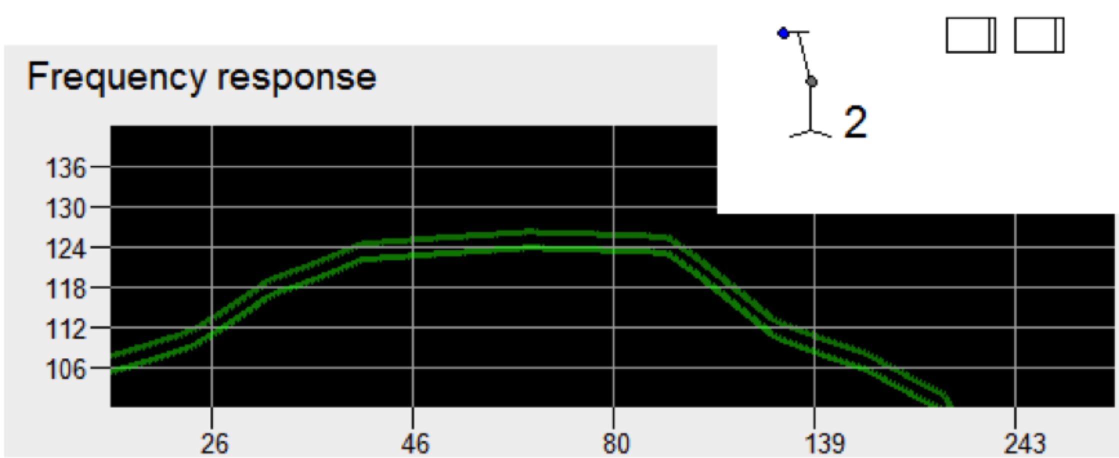

Figure 3: Two in Line Cardioid - Levels at Rear Measurement Location

In Figure 3, the top trace corresponds to the pressure generated at the microphone by the rear sub. As you can see, since the rear sub is closer to the microphone, the SPL is greater as there is less distance attenuation. For the configuration to work best, the rear sub must be attenuated by 2 dB. That way the levels will be the same and maximum attenuation will be reached.

When we attenuate 2 dB, the acoustical sum at the front area will be less, but just by a little - its nothing to worry about. If we dont perform this attenuation, however, well have no problems. The 2 dB difference is minimal; time alignment and inverted polarity will still do a very good job.

In Figures 4 and 5, the red trace shows the level at the front position, and green illustrates what happens at the back.

Figure 4: Without rear box attenuation. 12 dB of rear attenuation occurs.

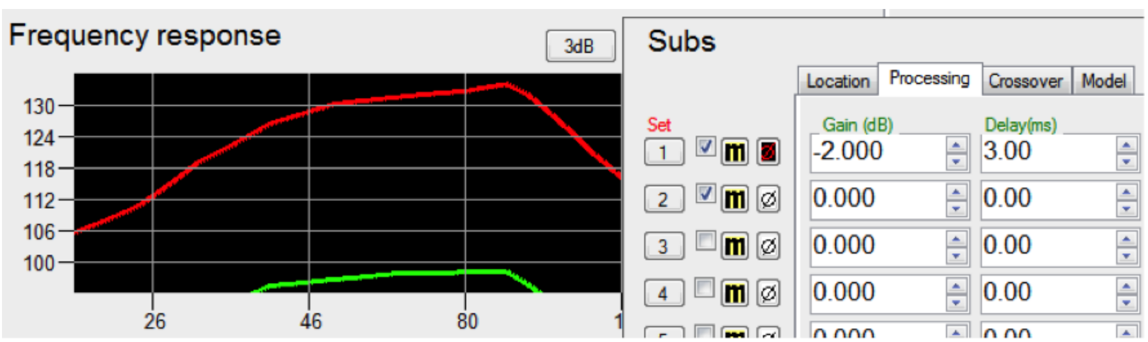

Figure 5: With rear box attenuation. 30 dB of rear attenuation occurs.

It is easy to see this increased rear attenuation from attenuating the rear subs gain by 2 dB. If we take a look at the front location trace, well notice that 1 dB is lost. Anyway, the 1 dB loss is not such a big deal compared to other losses we can account for in a minute.

The problem is that in reality, a double-sided effect is produced. That will make us lose a lot more than 1 dB at the frontal location. The front sub acts like an obstacle for the rear one, which will not only produce differences in the arrival times of the waves, but also in their pressure level! These effects will be frequency dependent, which makes them especially difficult to compensate for.

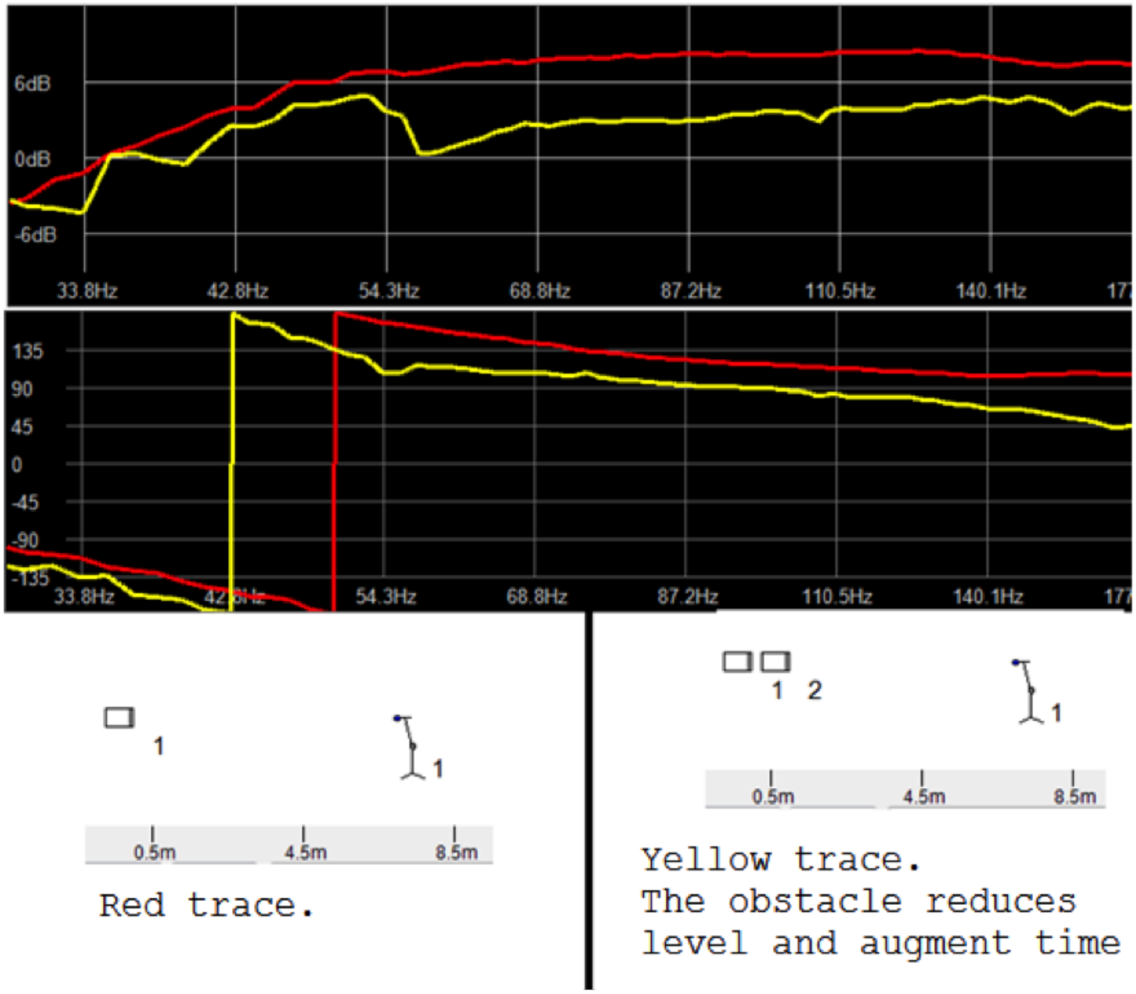

Figure 6: Two in Line Cardioid - Only Sub 1 Working

Starting with measurements: [1]

The measurements in Figure 6 were taken with the microphone placed at a distance of 6 meters (18 feet) from the front side of the sub. Its very important to note that in both traces **only sub 1 is working**. The only change made was placing sub 2 (turned off) in front of sub 1, just like in a cardioid configuration. In this special case, the only purpose of sub 2 is to act as a passive obstacle. Keeping all else the same, we wanted to observe only the effect that the obstacle would have on level and timing in front of the array.

We saw a lot! Results were very significant, we even saw 5 dB attenuation at some frequencies. This shows us that in a cardioid configuration we lose energy from the rear sub due to the obstacle presented by the front sub. That, plus the reductions we discussed earlier, adds up to a meaningful effect.

[1] Details about the measurements done can be found at the end of this document. Measurements are shown on the Freq Explorer program.

Its important to note that frontal attenuation caused by the obstacle sub is very sensitive to the distance between the rear sub and the front sub. In the case shown here, that distance was just 20 centimeters (0.7 feet).

Figure 7: Critical Distance between Front and Rear Subwoofers. For a big separation distance of this kind (¿0.5m - 1.5ft), the obstacle effect becomes less and less important (negligible), so in the 2 elements in line gradient is recomended a box-to-box distance that increases this distance, according to the box depth. New measurements are needed to study this phenomena in detail.

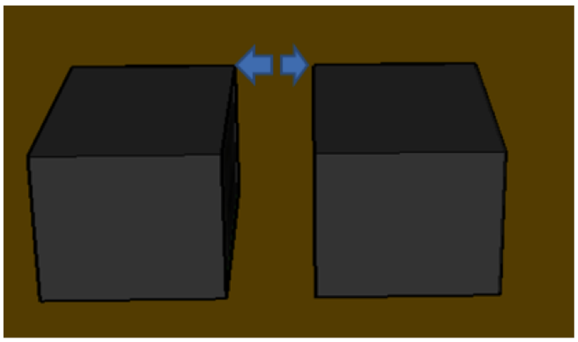

Figure 7: Critical Distance between Front and Rear Subwoofers

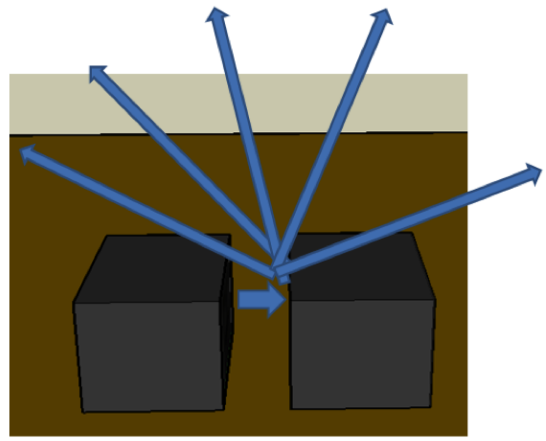

Figure 8: Reflections off Front Sub

The effect of attenuation due to an obstacle is strongly related to the distance shown in Figure 7. For a large separation distance (greater than 5 meters or 1.5 feet), the obstacle effect becomes negligible. Therefore, as box depth increases, the critical distance of separation must increase as well. New measurements are needed to study this phenomena in detail.

This distance is not directly related to the important center-to-center distance chosen for the array. This is because for the same 1 meter (3 feet) separation, different subwoofer models with different depths will require different center-to-center distances.

Now, we could ask the following interesting question: Where does the energy lost at the frontal location go? Lets go to the second part of the problem.

Its hard to believe, but part of that energy is being **reflected** to the back side! This effect can be seen in Figure 8.

And we don't just say this. Our measurement does![2]

In Figure 9, the dark green trace corresponds to the rear sub working by itself, without the front box in front of it. Then we took the second box and placed it where required for a cardioid array. The second box is NOT working. The difference is illustrated by the light green trace.

We see that from 50 Hz and up, on the rear side of the array, the rear sub will produce at least 2.5 dB of gain solely due to that "reflection."

[2]The first time I heard about this measurement of the rear reflected sound was thanks to the work of Alejandro Campero and Ricardo KaitoBarragan.

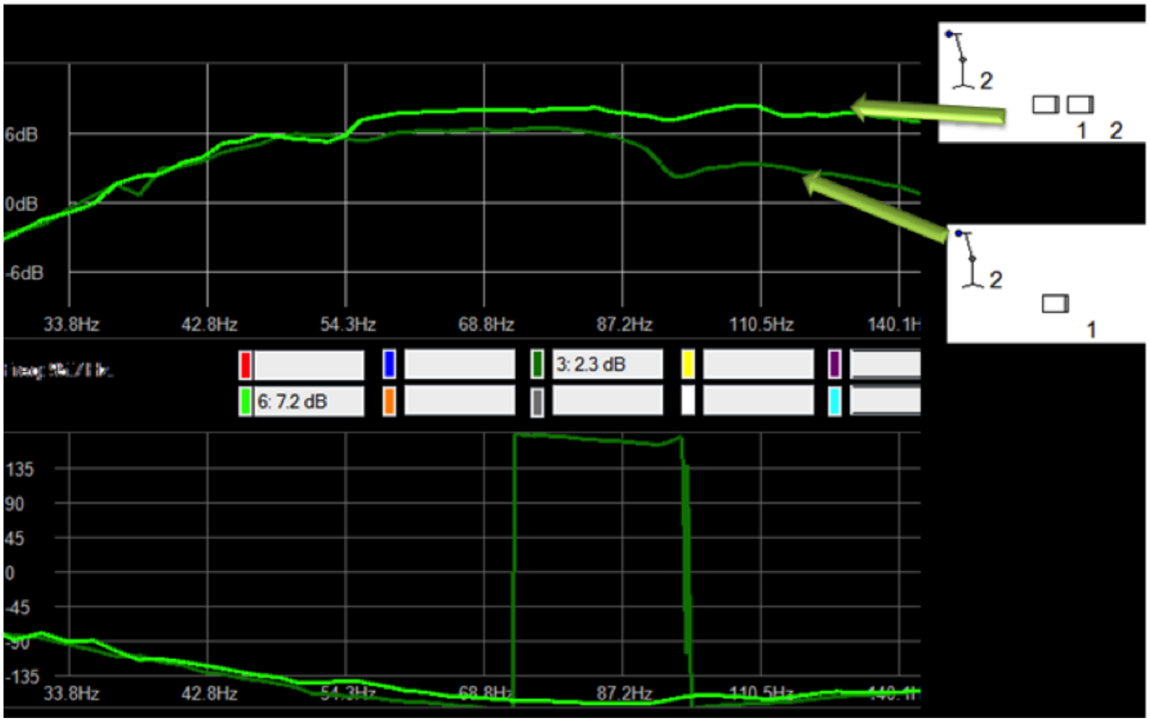

Figure 9: Measuring at the back side of the array. Only the rear box is working.

This reflection off the backside of the front sub gives us more problems, as itll sum to what the rear sub naturally produces in that same direction. Those waves sum and the result is shown in the light green trace. Thats a problem because now we will need even more attenuation on the rear sub! Obviously, that attenuation will have negative results in the front.

Summary of the problems of a "two-in-line" cardioid configuration:

1. The frontal sub acts like an obstacle that lowers the sound pressure produced in front of the system by the rear sub.
2. The frontal sub acts like a surface where part of the rear subs produced waves will reflect backwards. To achieve useful cancellation, we need to add supplemental attenuation to match the level of the frontal sub.

To finalize the analysis of the problems with the "two-in-line" variation, here is an interesting comparison. In the Figure 10, we compare the typical and simple mono cluster against the cardioid array. The measurement is done at 12 meters (36 feet) of distance.

In sound, nothing is free. The cost of having the advantages of attenuation in a cardioid configuration is to lose 3-6 dB in a significant part of the bandwidth.

Figure 10: Red trace: mono cluster. Green trace: 2 in line cardioid. Measurement taken at 12m (36 ft) of distance.

3 Inverse Stack Cardioid

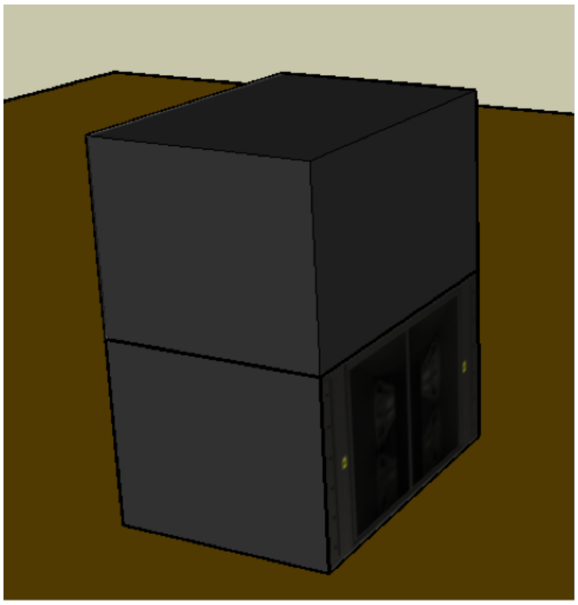

Figure 11: Inverse Stack Cardioid

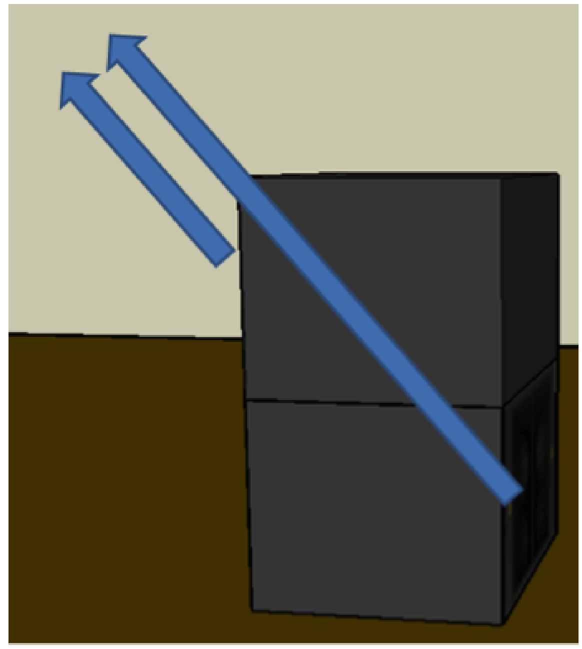

Figure 12: Inverse Stack Cardioid - Wave Propogation

The inverse stack is another very common variation of the cardioid configuration. One sub is placed above the other, but pointing backwards, as shown in Figure 11.

By turning the box backwards, we move the point from which waves propagate. The source has been moved to the back (and upwards).

In Figure 12, we can see the path sound wave propagation to the cancellation spot.

One of the advantages of the inverse stack is that it takes up less space between the stage and the first row of the audience. However, the inverse stack is taller than the two-in-line approach... Again, no free lunch.

The principle here is the same. In this case, the upper sub would be the "rear" sub, since the source point is moved backwards.

The analysis of frontal loss on the inverse stack cardioid is simpler. The main problem here is the backwards orientation of the upper sub.

We often hear that subs are "omni-directional" devices, but thats just a simplification. Several measurements have shown that a small difference exists between the sound produced by a subwoofer in the front and back. That difference becomes much more apparent when we increase frequency. We measured a difference of 5 dB at 50 Hz to more than 10 dB at 100 Hz. This way, by pointing one box to the rear, we lose level in front.

Now what happens at the back? Our level in the rear increases for the same reason. As a result, we can imagine that more attenuation will be necessary on the upper box to have an equal or similar magnitude response before polarity inversion. That attenuation will have a negative effect on the sum in front.

The upper rotation of the box is also a double-bladed sword. It reduces level in front, and increases level in back.

Figure 13 shows a measurement comparing the ”invincible” mono cluster to an inverse stacked cardioid configuration. This measurement was taken at the same point as that above, with a distance of 12 meters (36 feet).

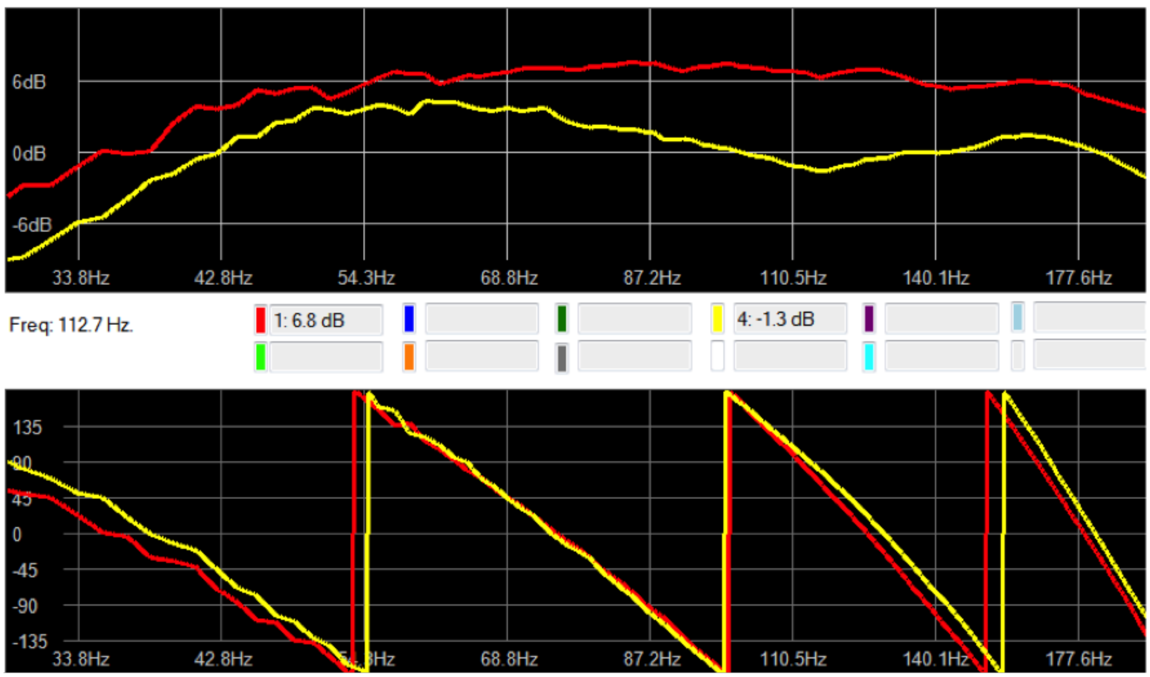

Figure 13: Red: Mono cluster. Yellow: inverse stacked cardioid.

Summary of the problems for the inverse stacked cardioid:

1. One of the boxes is pointed backwards. That will produce less level on the frontal side.
2. One of the boxes is pointed backwards. That will produce more level on the back side. Then that level has to be attenuated to equalize magnitude for the cardioid system to work properly. That extra attenuation will lower the resultant level at the front.

Lets take a look at a comparison of the three systems seen until now: Mono cluster, 2 in line cardioid, and inverse stacked cardioid:

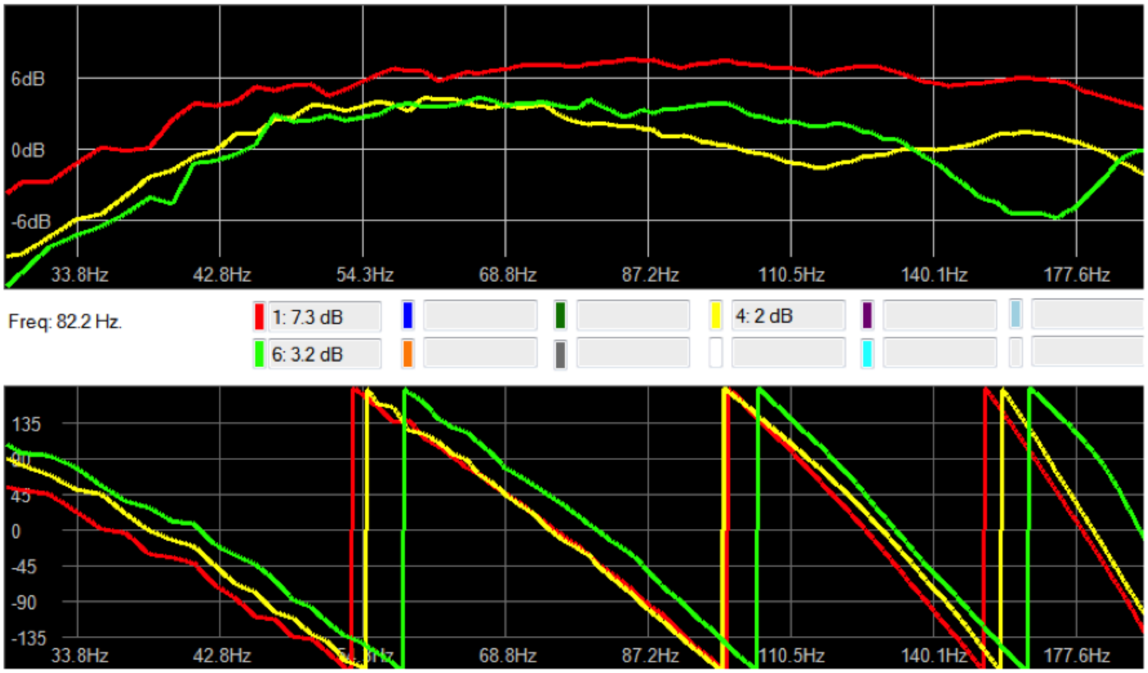

Figure 14: Red: Mono cluster, Yellow: Inverse stacked cardioid, Green: 2 in line cardioid

Based on these controlled measurements, it is obvious why many engineers reject cardioid systems. When maximum SPL is needed, 3 to 6 dB may be a good enough reason to avoid going with cardioid; this is easy to understand. Very high levels of low frequency reproduction arent cheap, electrically and logistically, and the decrease in SPL can be unacceptable. In the next section, we envision an alternative variation of the cardioid array.

4 Stair Cardioid

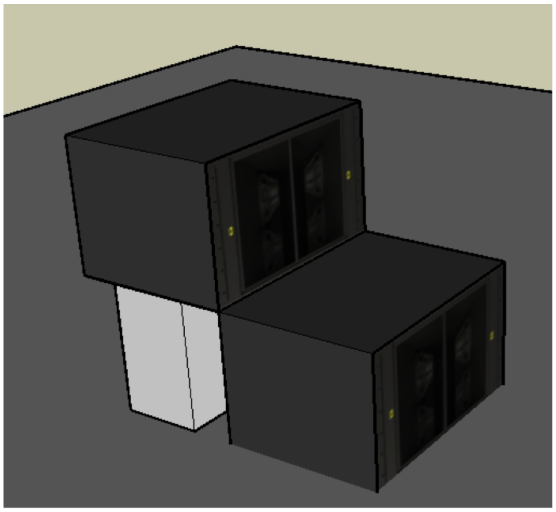

Figure 15: Stair Cardioid Configuration: The main advantage is that it can be used as a stair to go up to the stage quickly!

This idea has been in the back of my mind for a while now. The deployment is simple and clean. Its a bit of a combination of the two approaches we have already discussed.

The idea is to avoid the worst problems found in the other cardioid configurations:

1. Dont put an obstacle in front of the rear sub.
2. Dont point any box backwards.

Since the rear box is separated from the ground, it will produce less output level. That will help to compensate its greater level at the cancellation spot because of its closer location (less or no negative gain is needed).

There isnt much more to argue here. The last point I mentioned allowed us to avoid using any negative gain for the upper rear box.

Figure 16: Mono Cluster and Stair Cardioid Comparison: Red: Mono Cluster. Cyan: Stair Cardioid.

In Figure 16, we see that from less than 40Hz up to 80Hz, there is no excuse not to use this method. The level is equivalent to that produced by the mono cluster. Below 35 Hz, the natural soft cardioid roll off will occur.

The center-to-center separation used in this configuration was 1.5 meters (4.5 feet). This way, the configuration may be used for frequencies up to 90Hz, which is fine for most situations.

One drawback to this variation is that it requires lifting the rear box. Cases or specially designed scaffolding may be used to create this vertical lift.

Lets take a look at the comparison between the 4 situations.

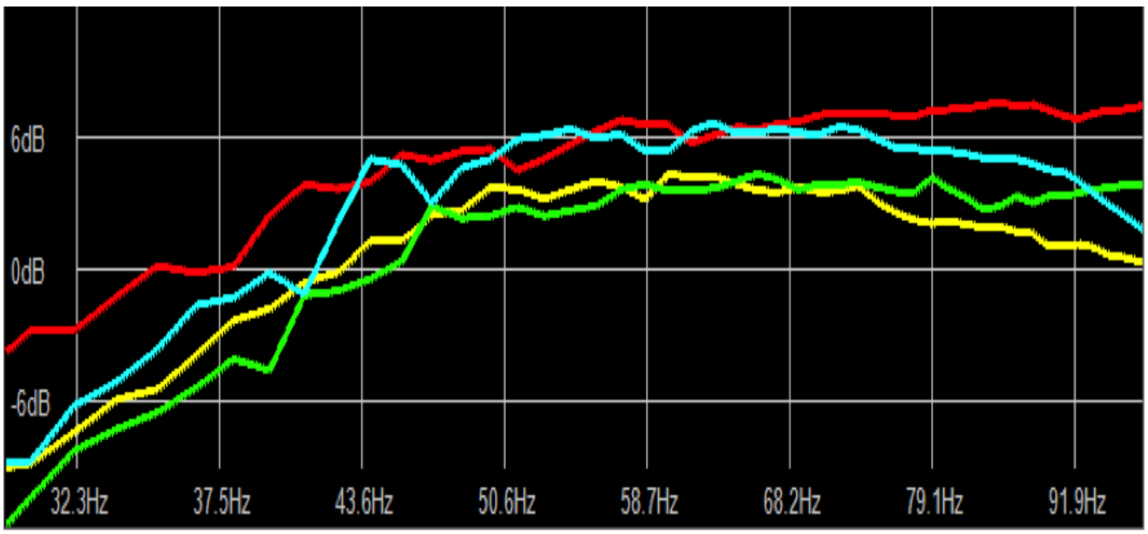

Figure 17: Red: Mono cluster, Cyan: Stair cardioid, Green: 2 in line, Yellow: inverse stack

The dedicated reader can imagine some possibilities.

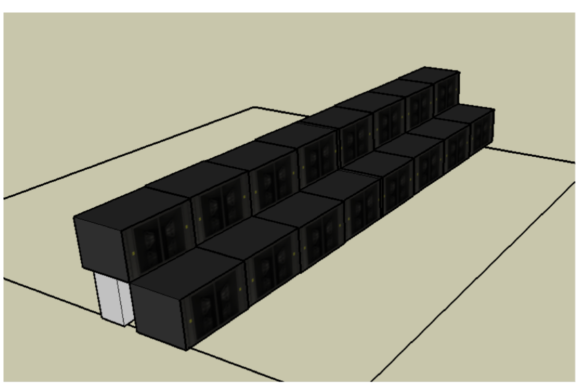

Figure 18: Stair Cardioid Line

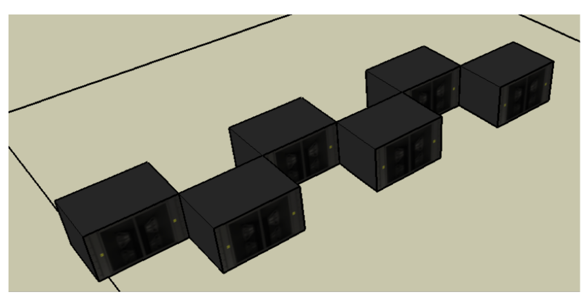

Figure 19: Zig-Zag Cardioid Line

We couldn't try it during our field testing, but another good idea is the zig-zag cardioid line shown above, where it wouldn't be necessary to lift the rear boxes.

In this case, there are no boxes pointing backwards and no obstacles. Since the the two lines are at the floor, however, some negative gain may be required.

A high stage and a lot of scaffolding or cases would let us create the Stair End Fire Array..

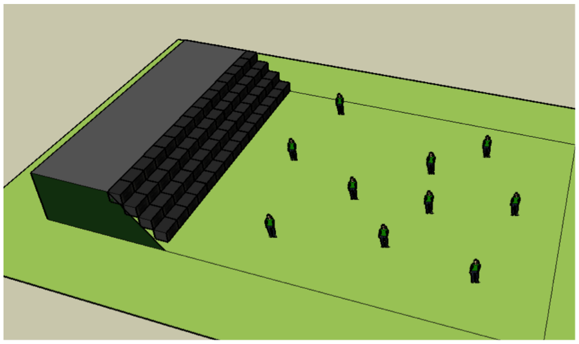

Figure 20: Stair End Fire Array

So, that's all folks. We invite you to try and implement these variations. The measurements seen here were taken very carefully, so the results should be totally replicable.

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A About the Measurements

Measurements were taken on March 13, 2014, just outside of Temuco City, Chile, Huichahue Area. All were performed on a clear field with no walls or obstacles. Noise floor was very low. (¡40 dB)

The first measurement was to check both subs used to be exactly the same in terms of magnitude and phase.

A.1 Equipment used:

- Cesva Sonometer
- 2x Dual 18” Subwoofers
- Yamaha P7000 Amplifier
- Focusrite Interface
- Smaart v7
- Sat-Live 1.6
- Behringer Ultra Drive Processor
- Behringer ECM8000 Microphone.

A.2 Credits

Thanks to:

- **Oscar Troppa**, sound engineer, for helping with measurements.
- **Claudio Pedemonte**, acoustical engineer, Santo Tomas University, for the equipment.

Special thanks to:

- **David Karol** for LaTeX layout and help with english translation.
- **Sound Forums Network** for publishing the article.

List of Figures