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Upfiring or Downfiring, Exploring The Tradeoffs

November 2017

With the introduction of the UpShot speaker system, we've received a lot of questions. Among them, "Is upfiring better than downfiring?" "What's the difference between the two?" And "If I turn my Contra/Coda/Ten2 upside down, would it sound even better?" Before we answer, let's take a quick look at the physics.

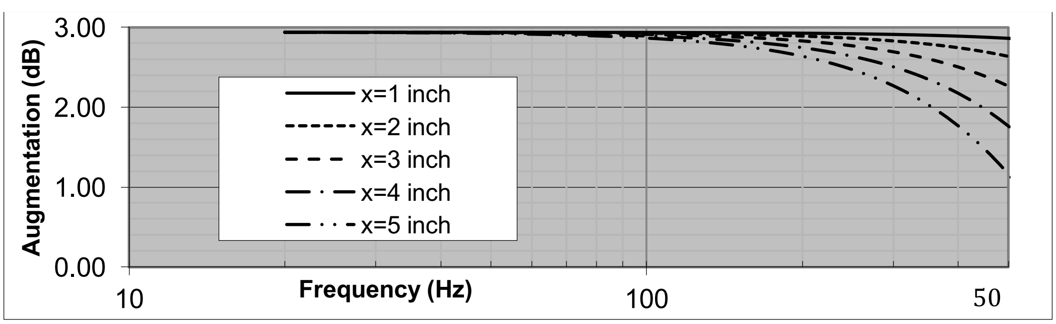
There are three main considerations when analyzing upfiring and downfiring woofers:

1. Boundary augmentation
2. Frequency response of the driver mounted in the cabinet
3. Beaming

Each is discussed below.

Boundary Augmentation

When a radiator—like a loudspeaker or antenna—is brought close to a reflecting surface, boundary augmentation occurs. This phenomenon is analyzed by assuming a "dipole configuration". In the case of a downfiring woofer facing the floor, this means we hear a *virtual* second woofer that is a mirror image of the one in the cabinet and located equidistantly below the floor. More specifically, the virtual woofer boosts the output of a range lower frequencies (those with a larger wavelength than the distance from the downfiring woofer to the floor) by 3 dB.

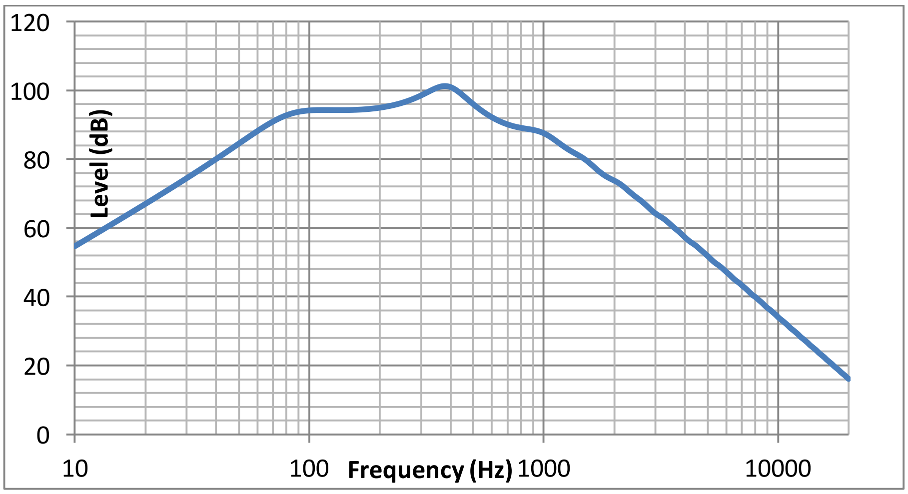


As you can see, the amount of boundary augmentation is a function of frequency and the distance of the driver from the boundary. Since the downfiring woofer is closer to the boundary than its upfiring counterpart, its output is higher at certain frequency levels. Typically, the acoustic center of the downfiring woofer in our designs is 2 to 3 inches from the floor. In the case of the UpShot's upfiring woofer, it is 4 to 5 inches from the boundary. Practically speaking, augmentation for both the upfiring and downfiring woofer is basically the same below 100 Hz. At 500 Hz, there can be as much as 1.5 dB difference. That's a difference just barely audible to the human ear.

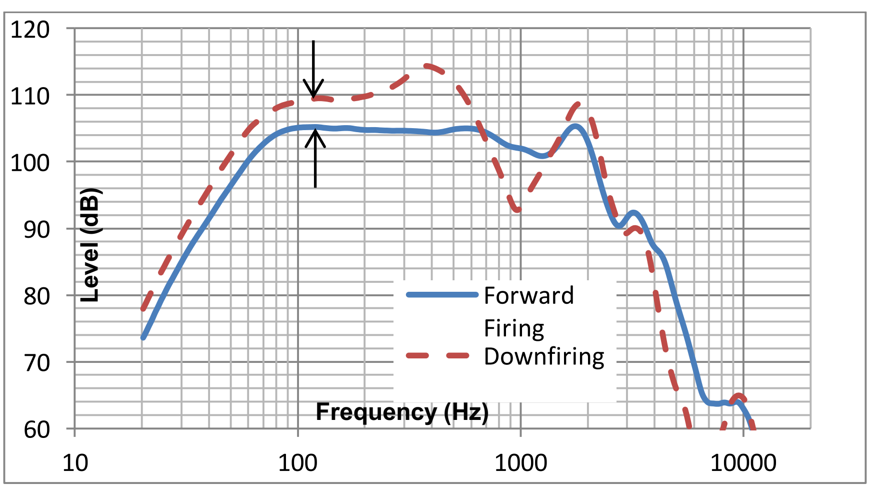
Conclusion: boundary augmentation benefits both downfiring and upfiring designs, with a slight edge to downfiring because the driver is closer to the floor.

Frequency Response of Driver as Mounted in Cabinet

With the downfiring woofer, a “conical horn” formed by the bottom of the cabinet and the floor has an effect on the frequency response of the woofer’s output. We use a program called *HornResp* to analyze the output of the downfiring woofer. The output versus frequency result is shown below.



We also measure the output (in red) of the downfiring woofer to compare with the predicted response. Also shown (in blue) is the measured result for the same woofer in a forward-firing configuration.



Let’s assess some of the results.

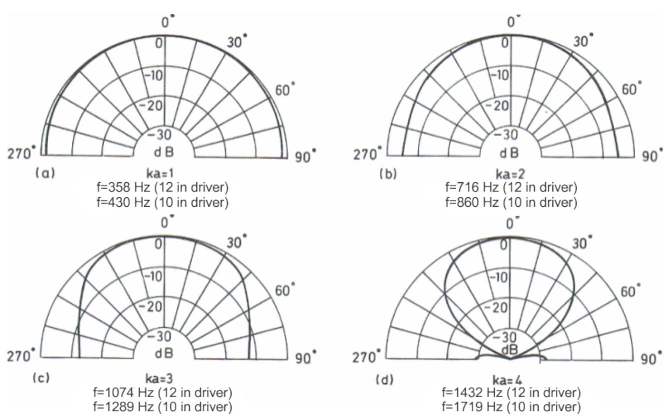
1. The model predicts the response with good accuracy. The bump in response at around 400 Hz is caused by a resonance in the conical horn. The measured result shows that resonance.
2. In the measured result, the output of the downfiring woofer is higher than that of the forward firing woofer due to as predicted by the boundary augmentation model.
3. There is a null at 900 Hz in the measured result caused by the reflection from the floor. This result can be accurately modeled by an analysis of the reflection patterns in the floor/woofer configuration.

In contrast to the downfiring woofer, the upfiring driver—which is not loaded to the floor in the same way—has a response similar to the forward firing-result in the graph.

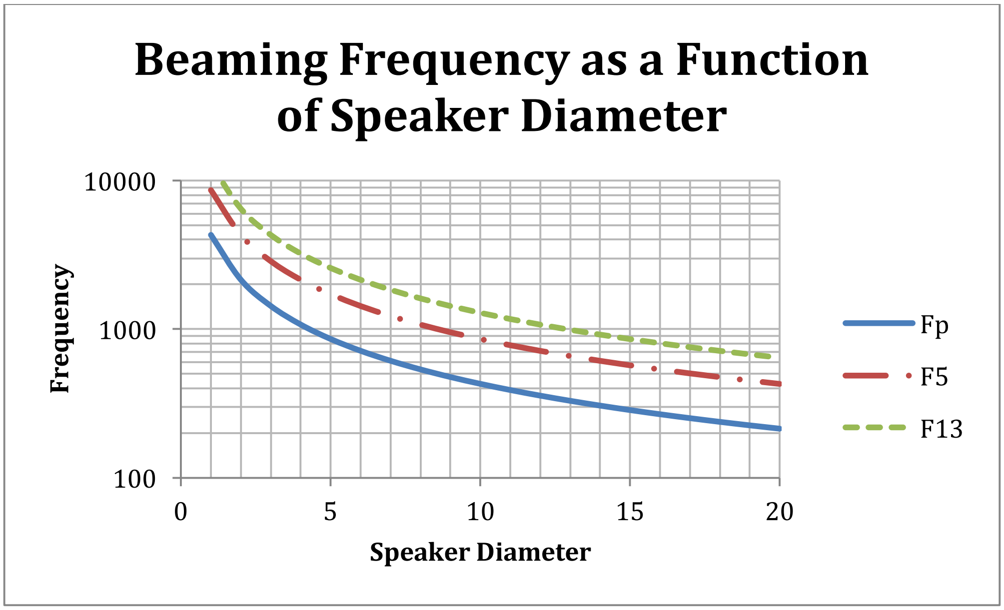
Conclusion: the downfiring configuration creates some frequency response issues that have the be dealt with in the design process. The upfiring system doesn't have these same issues and can utilize the full response of the woofer.

Beaming

All loudspeakers exhibit something called "beaming." At low frequencies (those where the wavelength is large compared to the diameter of the speaker), the output of the speaker is omnidirectional. The sound radiates in all directions equally. As the wavelength of the sound being reproduced by the speaker approaches the diameter of the speaker, the output becomes focused in a narrower beam. This is illustrated by the figure below, where the output power of a theoretical driver is shown as a function of the angle with respect to the axis perpendicular to the driver. The effect of frequency on this emission pattern is shown by the variable, ka. When ka=1, the wavelength is about three times the diameter of the driver, when ka=4, the wavelength is about ¾ of the diameter of the driver. The equivalent frequency for each value of ka is shown on the figure for 10-inch and 12-inch drivers.



This result can be presented in simpler format, one that allows quicker interpretation of the effects of beaming on speaker output. Shown below is a graph of beaming frequency as a function of speaker diameter for various beaming conditions.

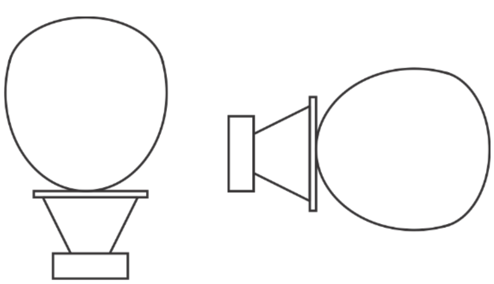


Fp is the highest frequency at which the driver operates as a "piston."
F5 is frequency at which output at 45 degrees off axis is
5 dB lower than on axis.
F13 is frequency at which output at 45 degrees off axis

So, what does this figure tell us? At 358 Hz for a 12-inch driver, the output to the side of the speaker is essentially the same as the output in front of the speaker. But, at 1074 Hz, the output to the side is 13 dB less than the output in front, and at 1432 Hz, there is virtually no output to the side compared to the front. For the 10-inch driver, the result is a little better but the conclusion is that over the frequency range of most instruments, there will be considerable loss of output to the side in a single speaker system. This problem can be overcome by adding a second, smaller diameter speaker that better disperses the sound in the mid bass frequencies. Or, you could use a downfiring speaker!

Because the downfiring driver faces the floor, there is a built-in reflector which diffuses the directional beam and creates an omnidirectional output over the full range of frequencies the driver is reproducing, even if the driver itself is beaming. So, the downfiring woofer, through the phenomenon of reflection, creates an omnidirectional output that makes the instrument being amplified more easily heard all over the bandstand.

The upfiring woofer, even though it doesn't benefit from reflection off of the floor, has more omnidirectional output than the forward firing configuration. Compare the ka=4 result in a horizontal versus a vertical orientation of the speaker.



Because the beam is facing up, the upfiring configuration has better horizontal dispersion. In addition, the output of the upfiring speaker can reflect off of the ceiling, creating an omnidirectional output. However, the effect is less than in the downfiring case because the ceiling boundary is a long way from the driver.

Conclusion: the downfiring woofer is omnidirectional due to reflections from the floor which diffuse the directional beaming. The upfiring woofer is not omnidirectional but has better dispersion than the equivalent forward firing-woofer and there is a reflection from the ceiling that improves the diffusion of sound.

Designing Downfiring and Upfiring Systems

Now that you know the trade-offs involving upfiring and downfiring designs, let's discuss how we went about implementing our designs for these approaches.

Let me summarize what we know.

1. Downfiring system
    a. Boundary augmentation increases the output of the woofer.
    b. Proximity to the floor creates some frequency response anomalies.
    c. Proximity to the floor creates an omnidirectional diffuser that overcomes the problem of beaming.
2. Upfiring system
    a. Boundary augmentation increases the output of the woofer, but slightly less than the downfiring case.
    b. There are no frequency response anomalies, the full response of the woofer can be utilized.
    c. The woofer does suffer from beaming, but it has better horizontal dispersion and "sounds" more omnidirectional than the front-firing approach. The ceiling can also act as a diffuser to increase sound dispersion.

In designing a system with a downfiring woofer, frequency response anomalies have to be accounted for. There are the benefits of the boundary augmentation and omnidirectional diffusion but those come with problems with the frequency response. We solve these by rolling off the frequencies above 600 Hz to reduce the effect of the anomalies and using a second driver to cover the higher frequencies. The result is a full range cabinet that exploits the advantages of the downfiring woofer while minimizing its shortcomings. You see this approach in all of our downfiring designs.

The upfiring design is more straightforward. If the woofer itself has a broad enough frequency response, we can achieve our objectives with a single driver. There is no need to correct for frequency response issues and the speaker can be mounted to take advantage of augmentation effects. Further, the upfiring approach has a more spatially diffuse output than a front-firing design, with a more omnidirectional sound.

There is an additional reason for the upfiring or downfiring configurations: by putting the woofer on the top or bottom of the cabinet, the cabinet can be smaller. That is one of the main driving factors for the upfiring design—facilitating the most compact cabinet possible.

In the case of the UpShot, the goal was to design a simple, compact and lightweight speaker system. The upfiring design allowed us to meet those goals with a great sounding cabinet.

Of course, designing a speaker system involves more than what we've discussed. Picking the driver, designing the cabinet to match the driver, designing the crossover (if needed) are beyond the scope of this paper. What I've tried to do here is give some insights into the tradeoffs between the upfiring and downfiring configurations based on their differences, which we've explored in detail.

Finally, let's answer two other questions I posed at the beginning.

If I turn my Contra/Coda/Ten2 upside down will it sound better? In other words, if I turn my downfiring combo into an upfiring design will it sound better? Compared to the downfiring design, the upside-down combo will have 1) a lower boundary augmentation (the speaker will be 10 inches away from the boundary and that will diminish the effect), 2) a more narrowly focused output (less "omnidirectional") and 3) the frequency response will be altered since the conical horn loaded woofer is no longer loaded that way. So, the short answer is no, the upside-down combo won't sound better.

Is upfiring better than downfiring? Ultimately, the two approaches have different design goals. Our downfiring cabinets are full frequency range systems that attempt to be the ultimate for amplifying acoustic instruments. Our one upfiring design is somewhat of a compromise. Its design goal is to be the smallest and lightest speaker available that still has great performance for acoustic instruments. The UpShot has a single driver so its frequency response is more limited than the two-way systems used in the Contra/Coda/Ten2. But it still has sufficient response to accurately reproduce bass, guitar and other instruments. That level of performance plus its exceptional portability makes for a very attractive product.