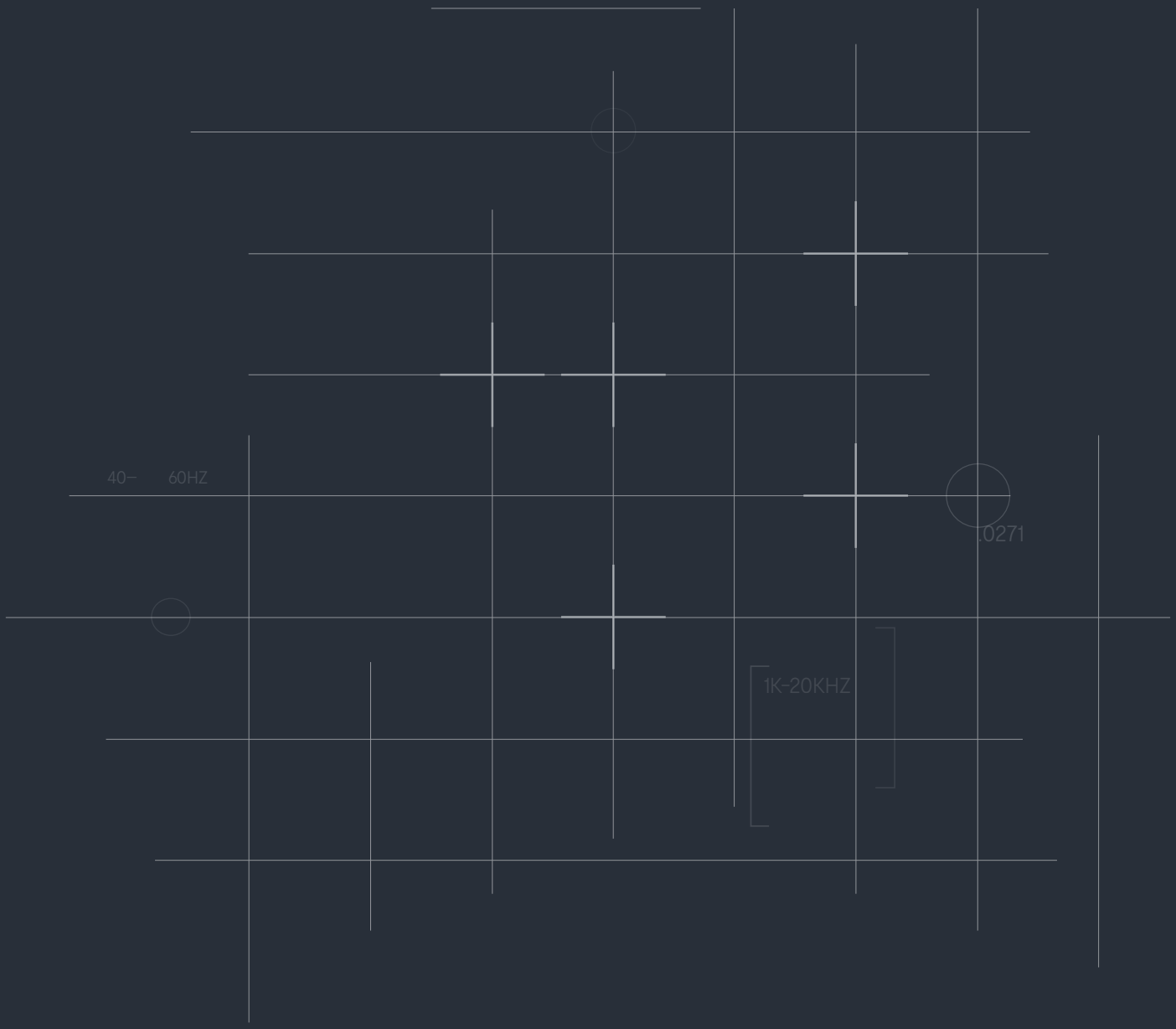

A LOOK INTO

Dirac's MIMO Framework for Active Room Treatment and Unison

Dirac 2024

DIRAC

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Introduction

This document provides background and technical information about Dirac's MIMO sound field control technology, the technology behind Dirac Unison and Active Room Treatment.

A new approach to Sound Fields

In 2009, during the 36th International AES Conference, we introduced a research paper titled "Soundfield control with a limited number of speakers" that described a technique for using a specific number of speakers to generate a desired target sound field. This sound field can be thought of as the way sound waves travel through space, over time, and across different frequencies, tailored to our listening area, measured at various points within the given space—controlled by us.
This technique is particularly useful in car sound systems, where the goal would be to simulate the experience of being surrounded by speakers in a virtual reference room, thereby replacing the car's interior acoustics and speakers with a virtual surround sound setup.

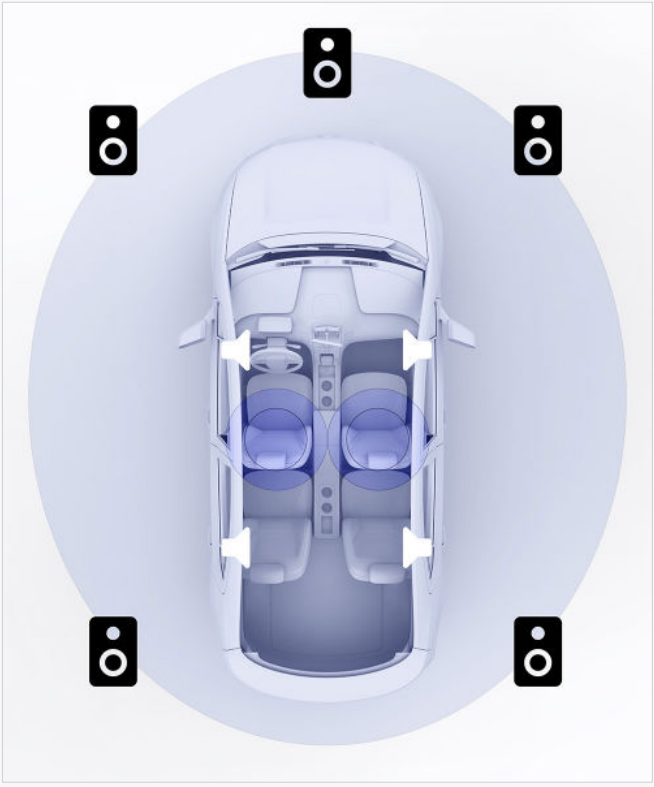


Figure 1. The aim of Dirac Dimensions was to create a sound field as if speakers were outside the car.

Our method turned out to be quite effective to this end, creating very convincing results. Marketed as Dirac Dimensions, this method was used in several car models from big brands like BMW, Bentley, and Rolls Royce. Technically, Dimensions is a full-blown MIMO (Multiple-Input Multiple-Output) system, meaning it optimizes several speakers together, with each sound channel (like left, right, center, etc.) processed through a complex network of filters (either IIR or FIR) before it's played through every speaker.

Dirac Live, another product, operates on a SIMO (Single Input Multiple Output) basis. It optimizes each speaker individually using a single sophisticated filter, adjusted based on sound measurements from various positions within the room.

Creating an exact sound field reconstruction is only theoretically achievable with endless speakers. Dirac Dimensions was therefore designed to significantly enhance the sound field within the limitations of real-world settings. That said, Dirac Dimensions still needed quite a few speakers to excel. One of the main challenges was to craft a sound that not only feels spacious, giving the impression of being in a larger room or at a specific distance from the speakers, but that also maintains the crisp, precise sound quality that Dirac is known for.

This led us to explore a method that could achieve similar results with fewer speakers by jointly optimizing the speakers, creating the desired sound field or wave pattern. This time, we didn't aim to simulate a completely different acoustic environment.

With this in mind, we chose a strategy where the speakers wouldn't work together above a specific frequency. Instead, we concentrated their collaboration on the lower frequencies. In these ranges, the longer wavelengths make teamwork highly efficient, even with just a few speakers. Critically, this approach focuses on the most challenging aspect of room acoustics: the bass.

We developed a new framework that combines a MIMO strategy for bass frequencies with a SIMO method for higher frequencies. This approach aims to refine the sound wave patterns of the actual high-range speakers, rather than creating a virtual speaker set in a pre-defined acoustic space. Essentially, the goal was to enhance the measured wave propagation characteristics across all positions.

In the bass range, our method uses multiple speakers together (MIMO) to refine the bass quality beyond what's possible with a SIMO approach, which optimizes each speaker individually based on different measurement spots. A main speaker is selected, and other speakers are considered support speakers, jointly optimized to bolster the main speakers' wave propagation.

It's worth noting that any speaker can serve both as a main and a support speaker. The core idea is to use all speakers in the bass frequency together to enhance the natural wave propagation characteristics of the main speaker while eliminating the distortions caused by the room's acoustics.

This new approach, an evolution of the Dirac Dimensions technology that used MIMO across all frequencies, was first commercialized in automotive applications, where it was known as Dirac Unison. Unison was first introduced in the B&W sound system option in Volvo XC90 in 2015 and has, since then, expanded rapidly to many high-end car audio systems from various car brands. Recently, the technology has been adapted to the home audio environment as Active Room Treatment (ART) that was launched in May 2023 through products from StormAudio.

How do Active Room Treatment and Dirac Unison work?

ART is an enhancement to our Dirac Live consumer room correction software. It leverages the same measurements as Dirac Live but introduces the possibility for any bass-capable speaker to contribute to the correction of (i.e., to "support") other speakers. Below 150 Hz, ART uses a sophisticated MIMO filter matrix designed to optimize impulse responses at all measured points. Above 150 Hz, it shifts to using SIMO for mixed-phase impulse response correction, marking 150 Hz as the upper support frequency. Unlike automotive Dirac Unison, where the tuning engineer can adjust the upper support frequency higher, ART's limit is fixed at 150 Hz. This system allows for flexible speaker support, with any speaker able to assist others and function as either a main or support speaker.

By optimizing the interaction between the main speaker and its supporting speakers, we can create a "super speaker." The goal is to achieve an optimized pattern of sound waves, stripped of adverse effects from the room (like uneven frequency responses, too much low-frequency reverberation, or standing waves).

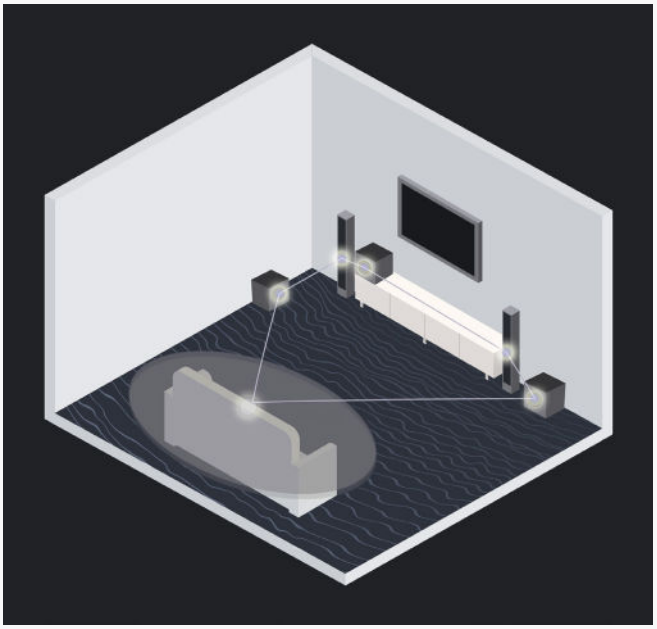


Figure 2. ART creates a "super speaker" of all speakers that together cancel out unwanted responses, reverberation and standing waves.

ART and Dirac Unison enhance the concept of bass management by not only directing low frequencies to speakers capable of handling them but also by allowing speakers to share the same frequency ranges. This overlap helps even out sound variations throughout the listening area. The technology customizes bass playback for each speaker, considering the unique acoustics of the room, based on detailed measurements and advanced filters for low frequencies. While it's simple to present a smooth bass response using broad 1/3 octave frequency plots, this method can be misleading. It glosses over the complexities of bass reproduction. To truly understand and improve what happens in the bass region and how it's experienced by listeners, a much finer analysis is necessary.

Dirac's MIMO sound field control technology adjusts the wave propagation in a room at lower frequencies to create an optimized movement of sound through the space. This customization is specific to each room, guided by precise measurements of the actual space.

In Dirac's MIMO approach, there are two distinct steps:

First, it tackles the sound field control challenge—aiming for a specific wave propagation or time-domain characteristics across various points within the listening area. This goal is achieved using an advanced error-minimization algorithm.

The second step focuses on attaining a specific magnitude response. This aims to create a smooth response across the listening space, avoiding unwanted resonances and other issues that can affect sound quality.

Imagine a scenario where you have a single speaker in an anechoic room, but there's still one echo

coming from a specific direction. Just tweaking that one speaker won't get rid of the echo everywhere in the room; it might improve things at one spot or in areas where the echo behaves similarly. Now, picture placing another speaker at the origin of the echo and playing back the sound at precisely the right moment but in reverse phase, adjusting for how the sound travels, effectively cancelling out the echo. This concept is close to Active Noise Cancellation (ANC), where unwanted sound is neutralized by introducing its opposite.

ART operates on a similar principle but focuses on eliminating the "noise" created by room acoustics affecting the bass quality. Unlike ANC, which typically targets a specific area, ART aims to enhance the sound across all evaluated spots in the room. It not only clears up the bass in these areas but also enriches the overall bass output from the main speaker and makes the bass sound tighter by reducing how long it lingers. However, it's important to note that completely getting rid of an echo isn't always entirely possible or even preferred. The real objective is to minimize those aspects of room acoustics that detract from the listening experience.

To give another example, let's assume a traditional 7.1 speaker system. Now consider one of the speakers – say, the left front – as your main speaker. (All speakers would eventually also be considered main speakers.)

With ART, all the other speakers in the system can assist our main speaker to perform better. They help extend its frequency range and achieve the desired collective sound response at every listening spot. Similarly, the Low-Frequency Effects (LFE) channel can be distributed among all speakers capable of handling bass frequencies, creating a powerful, room-filling "super subwoofer" effect through the optimized, combined output of the eight speakers. However, typical surround speakers, which usually don't reach deep into the bass spectrum, might not contribute to supporting the lower frequencies down to 20 Hz.

In the Dirac Live software, users have the flexibility to adjust these settings. While the software offers parameter suggestions based on its measurements, users have the freedom to modify them, with the exception that the maximum support frequency cannot exceed 150 Hz.

How does it sound?

Once your audio system has been fine-tuned using either ART or Dirac Unison, you'll notice some significant improvements:

Tighter bass: Grouping several speakers to handle bass frequencies together decreases the bass's lingering time.

More uniform bass: By coordinating multiple speakers to work in sync with the room's acoustics, the distribution of bass frequencies becomes more consistent across all the measured listening positions. This method effectively alters the room's modal pattern.

Extended bass response: When multiple speakers contribute together in the bass region, each one adds extra power to the lower frequencies. This collective effort broadens the range of bass sounds your system can produce, lowering the overall frequency cutoff point.

Furthermore, in some cases, you might also experience higher sound pressure levels (SPL) with your setup. By spreading the bass workload across multiple speakers, no single speaker is overburdened, reducing the risk of distortion at high volumes. This distribution allows your system to achieve louder volumes, especially in the bass, where achieving high SPL without distortion is often challenging due to the high power requirements at lower frequencies.

Above 150 Hz, you'll get the clear and precise sound quality that Dirac Live is known for. In the specific context of a car's interior, Dirac Unison provides engineers the option to apply MIMO correction

even above 150 Hz. This is particularly beneficial in high-end car audio systems that often include several independently controlled subwoofers and woofers, enabling the achievement of a tight and consistent bass response throughout the vehicle. The impact of these improvements is significant. According to research findings, bass quality accounts for roughly 30% of a speaker's overall preference rating in typical listening scenarios. However, we would argue that for many audio systems, the influence of bass on the perceived quality of the listening experience is even more substantial.

ART setup and requirements

ART can enhance systems with any number of subwoofers, from none to many, by also improving the performance of full-range speakers.

There are no strict rules for where to place subwoofers with ART; it's designed to optimize sound regardless of speaker positioning. Though some spots are better than others, Dirac's MIMO technology enhances sound quality in any setup.

- ART enhances both subwoofers and full-range speakers together up to 150 Hz.
- It's not just subwoofers; ART improves all speakers in the bass range.
- ART aims to create a consistent sound field at all locations, smoothing out bass variations and shortening the sound's decay time* in the room below 150 Hz.
- Support speakers boost the performance of a main speaker, like the Left Front or Surround Right.
- A speaker can serve as both a main and a support speaker, depending on the setup.
- Subwoofers usually act as support speakers, enhancing the sound from the main speakers.
- The LFE (Low-Frequency Effects) channel can be optimized by assigning one subwoofer as the main speaker, with the others (and possibly full-range speakers) supporting it.

* With decay time, we do not mean RT60, as this is not an appropriate model for reverberation in small rooms. RT60 is based on the slope of a straight line fitted to the Schroeder decay curve. However, ART may shape the Schroeder decay curve in such a way that it no longer resembles a straight line, and its decay profile can then not be interpreted in terms of RT60. The decay in small rooms is best visualized through a waterfall plot.

When is MIMO the best solution?

Dirac's MIMO control, which encompasses speaker co-optimization, enhances sound quality across any multi-speaker setup compared to traditional SIMO control, where each speaker is adjusted independently. This method results in a more uniform and precise bass response and a reduction in variations experienced by listeners in different seats. When compared with Bass Control, ART further refines bass precision and achieves a more seamless integration with the main speakers. It allows for configurations without the need for conventional crossovers, providing greater versatility in system design. (For an in-depth analysis of how ART relates to Bass Control, please refer to the section below.)

Dirac's MIMO sound field control technology introduces a flexible approach to bass manage-

ment by utilizing both subwoofers and full-range speakers across various locations. This method enhances sound quality and reduces variations in listening experiences across different seating positions. Unlike traditional systems, this technology does not rely on conventional crossovers to separate frequencies between subwoofers and full-range speakers. Instead, it allows for an overlap in the frequency ranges they cover, enabling a more cohesive and controlled sound environment.

Finding the perfect spot for subwoofers can be tricky because the "ideal" location changes with each room and speaker setup; there's no one-size-fits-all rule, like placing subs in corners. ART lets you place your subwoofers wherever it works for you, then optimizes performance for that specific arrangement. It doesn't demand subs be placed in specific locations, so exploring non-traditional placement could yield better results. The aim is to position subwoofers to maximize diversity in sound distribution.

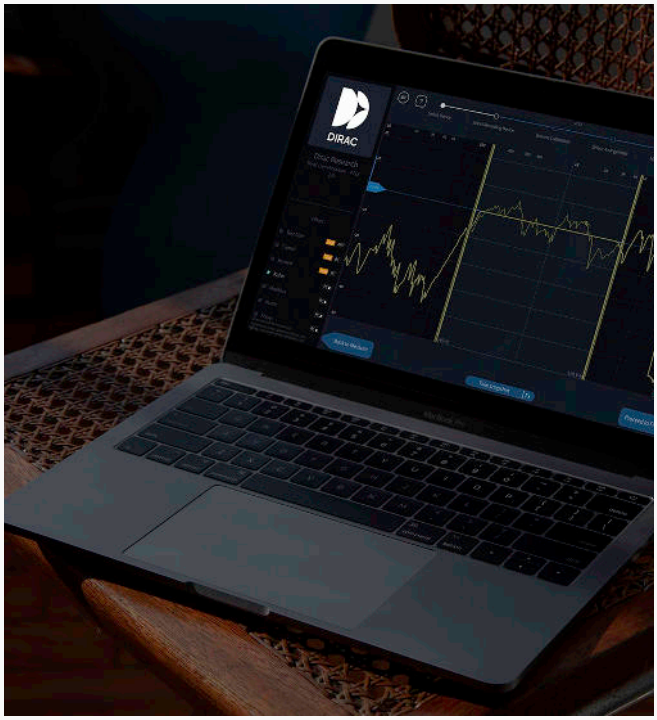
Even if you go with traditional placements, like corners or a double bass array (subs along both the front and back walls), ART will still enhance the setup. Different placements might still improve system performance even more by providing greater sound diversity. Real-world rooms, with their three-dimensional characteristics and various elements like doors and furniture, create complex conditions that challenge simple theoretical predictions. This complexity means that optimal subwoofer placement often requires a more nuanced approach than standard models suggest.

ART isn't just for multi-channel systems with subwoofers; it offers exciting possibilities for stereo setups as well. In such configurations, the left and right speakers can support each other. This mutual support helps eliminate bass variations and enhances the impulse and frequency responses through the added diversity in the bass region. Essentially, any speaker setup with at least two speakers can benefit from MIMO sound field control, with any bass-capable speaker able to act as a support for the entire system.

This flexibility means you can design stereo systems that pair two main speakers with additional bass-support speakers, allowing for a high-quality audio setup without needing large main speakers. ART's effective range up to 150 Hz—beyond the traditional subwoofer range—enables the use of unique bass speakers paired with compact main speakers to create a full-spectrum, high-end stereo system without the bulk of conventional full-range speakers.

Such innovative approaches offer numerous possibilities for building unconventional yet high-performance stereo systems that deliver great value. You could even complement a pair of full-range stereo speakers with additional bass speakers, extending their performance up to 150 Hz. This configuration could eliminate the need for large, passive acoustic treatments in your room.

Modern multi-purpose rooms, designed with a "live" acoustic quality, can now achieve exceptional bass performance through ART and strategic placement of multiple bass speakers. While a lively sound at higher frequencies usually isn't problematic, managing lower frequencies in such environments has traditionally been challenging. With ART, however, you can attain high-end sound quality in aesthetically pleasing spaces, marrying form and function beautifully in modern listening environments.



Bass Control vs. ART and Sound Field Control

One way to understand the technology behind ART and Dirac Unison better is also to compare it to Bass Control. Bass Control is crucial for setups with multiple subwoofers as it orchestrates how these subwoofers combine their sounds and work with the main speakers. Without such a system, there's no way to manage the collective output of the subwoofers, which is key to achieving a balanced and cohesive sound experience.

There are two types of variations that Bass Control with multiple subwoofers reduce:

- Uneven frequency response, which occurs due to the phase interactions between the subwoofers and the room, leading to a frequency response that isn't consistent across the bass spectrum.
- Variations across listening positions, where the bass can vary significantly from one seat to another due to the room's natural acoustic modes and speaker placement. This variation is problematic, affecting even the perception of bass at a single seat.

Despite precise calibration of individual subwoofers aimed at optimizing bass quality, the overall system may still suffer from uneven bass response. This inconsistency stems from unmanaged collective output, where frequencies from different subwoofers may align (add up) or misalign (cancel out) at various listening positions. The potential for a more uniform bass experience exists but requires strategic management of how subwoofers interact within the room.

The value of Bass Control becomes evident when considering a system with three separately calibrated subwoofers. Without Bass Control, the averaged frequency response across listening positions showed significant unevenness below 80Hz, notably a considerable loss of bass between 30 and 40 Hz due to phase cancellations.

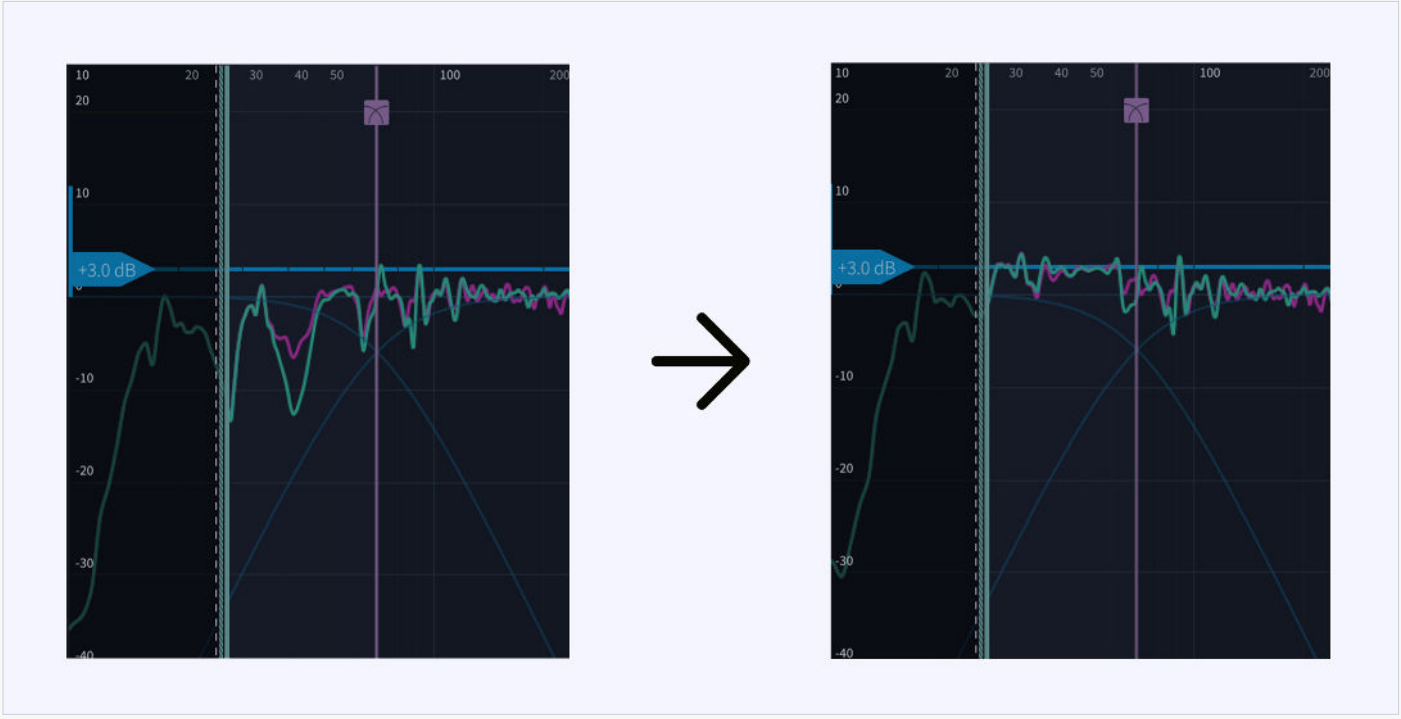


Figure 3. Before and after aftivating Bass Control. Green and purple curves show the average left/right channel bass response using 3 subwoofers (individually equalized) below 80 Hz.

By applying Bass Control, using all-pass filters, gains, and delays to optimize the combined response of the subwoofers, the result was a much more uniform average frequency response. This optimization not only smoothed out the response curve but also reduced variations across different seats, demonstrating the effectiveness of strategic bass management in enhancing the overall listening experience. Bass Control is highly useful as it co-optimizes multiple subwoofers to even out frequency response variations across the room and to achieve better summation and an even sum frequency response. However, a key distinction sets Bass Control apart from MIMO sound field control: Bass Control does not explicitly optimize how sound waves travel through the space (the wavefront). ART and Dirac Unison, which utilize MIMO sound field control, instead aim to create ideal sound wave propagation from a main speaker by employing other bass-capable speakers in the system.

In contrast, Bass Control focuses on creating a unified bass channel. It optimizes the phase of multiple subwoofers, so they work together as effectively as possible. Crossovers between bass and other speakers are then fine-tuned with all-pass filters. While Bass Control improves on traditional bass management, it's not designed to replace it entirely. Rather, it's a natural evolution that leverages multiple speakers for better bass.

A similar approach, Sound Field Management by Todd Welti at Harman, also aims to reduce spatial variations in bass. However, it uses parametric biquads instead of all-pass filters for optimization.

Bass Control uses all-pass filters to shape the phase response of each subwoofer, along with gains and delays, for a unified, powerful bass channel. But it doesn't optimize wave propagation throughout the listening space, focusing instead on the combined bass response at the measurement points. In contrast, the revolutionary aspect of ART and Dirac Unison lies in explicitly optimizing how sound waves travel from the main speaker and support speakers. Their goal is to create a more ideal wave front (in terms of space, time, and frequency) while minimizing the impact of room acoustics. This results in a tighter, more controlled bass compared to Bass Control. Additionally, ART and Dirac Unison allow all speakers to work together optimally in the bass region, even with overlapping frequencies.

While ART and Dirac Unison offer enhanced sound field control, they are indeed more computationally demanding than Bass Control. Bass Control effectively reduces spatial variations in bass for a consistent response, all with low processing requirements. MIMO sound field control, used in ART, goes further by optimizing the full time-domain response across the listening area. Unlike Bass Control, ART places a central focus on directionality, ensuring bass waves align perfectly with those from the main speaker.

Our experience, though subjective, consistently shows an upgrade path with these technologies. Moving from an uncalibrated system to Dirac Live room correction offers a major boost in clarity, transparency, and a tighter sound overall.

Adding Bass Control for multi-subwoofer setups delivers a powerful bass experience: smoother, more consistent response throughout the room. Upgrading further to ART yields even tighter bass, extending into the lower mids for improved precision and clarity across vocals and instruments. It also further reduces variations in sound quality between different listening positions.

Each technology builds on the previous one, offering distinct and noticeable improvements to your listening experience.

Understanding parameters in Dirac Live ART

ART and Dirac Unison rely on a complex algorithm with several adjustable settings that determine how the final sound is shaped. While the Dirac Live software automatically chooses these settings based on measurements of your speakers and room, understanding these parameters is helpful. In some cases, adjusting them manually can further optimize the final sound.

A key setting that affects how ART and Dirac Unison work is, as mentioned, the upper frequency limit. This setting determines the highest frequency at which speakers can work together to adjust the sound. Currently, the software limits this to 150 Hz, but you have the option to lower it.

Why adjust this limit? If speakers support each other at too high of a frequency, the sound optimization might become less effective across a wider area. 150 Hz is a safe default, but in rare cases involving speakers placed very close to a listener, it's possible to (faintly) localize content coming from a support speaker instead of the main speaker. Lowering the upper support frequency can help in these situations.

Generally, it's best to leave the upper support frequency untouched as it's unlikely to cause issues.

Another crucial setting is the lower support frequency limit. This determines the lowest frequency at which a support speaker can contribute to the main speaker's sound. Unlike the upper limit, this setting is more critical because pushing speakers beyond their natural low-frequency range can lead to distortion or even damage at high volumes.

The Dirac Live software estimates this limit for each speaker based on measurements. However, it's important to compare these values with the manufacturer's recommended speaker range. Ideally, the estimated limits should be within or slightly above the specified range. If you find significant discrepancies (lower estimated limits), we recommend adjusting the setting to a value closer to the manufacturer's specifications. Remember, it's best to stay within the speaker's comfortable operating range.

You adjust support frequencies and parameters for each group of support speakers connected to a main speaker. Therefore, group speakers with similar operating ranges together. For example, if you have multiple subwoofers of different models, put each into its own group. This allows you to apply the most suitable settings based on each subwoofer's capabilities.

If you're playing content loudly and notice distortion coming from a support speaker, focus on the lower support frequency setting. Increase that frequency for the specific speaker that's having trouble. This reduces the power sent to that speaker and helps prevent distortion.

Dirac's MIMO framework also offers a setting called "Support Level" that allows you to influence how much each support speaker contributes to the sound of a particular main speaker. Think of it as a penalty assigned to each speaker – a lower value means the speaker has more influence, while a higher value reduces its influence.

- Increase Support Level (more penalty): Use this if you want a particular support speaker to contribute less. This might be helpful if you hear distortion from that speaker at high volumes.

- Decrease Support Level (less penalty): Use this if you want a specific support speaker to play a more prominent role.

It's important to note that support Level affects the speaker indirectly. You might need to experiment with the settings to hear the impact. Also, even with a high penalty, the algorithm might still use a speaker if it's crucial for achieving optimal performance. A heavily relied-upon support speaker might indicate a lack of "speaker diversity" in your

setup. In such cases, consider relocating some speakers for better room acoustic correction.

MIMO sound field control thrives on diversity. For the best results, spread out your support speakers in different locations and directions. This gives the algorithm more options to break up room acoustic problems. Don't be afraid to experiment with speaker placement beyond just those close to the main speaker. The algorithm is powerful and can work surprisingly well with diverse speaker configurations. However, one important rule to follow: don't use support speakers below their operating range. While the software estimates safe lower frequency limits, it can't perfectly predict every speaker's capability.

A final note on directional bass – as ART and Dirac Unison always target a wave propagation across the entire frequency range based on that of the main speaker, they will inherently create a bass response with propagation and direction like the main speaker. If you're using ART or Dirac Unison, disable any directional bass settings in your AVR. These technologies already manage bass directionality across all your speakers, including those positioned away from your main speakers, for optimal sound. Traditional directional bass settings will interfere with the way ART and Dirac Unison work.

Sound field control truly shines when you give it freedom. Be sure to adjust the lower frequency limit and Support Level for optimal performance, but then step back and let the system surprise you with the results it can achieve.

Thank you for reading

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