White Paper

ACE

Advanced Crossover Engine

Abstract

Most portable systems for high-power music reinforcement use a combination of full-range speakers and subwoofers to extend frequency bandwidth and deliver consistent sound pressure levels to the audience. Crossover filter design and time alignment are essential for efficient summation at low frequencies, enhancing perceived definition and impact. Properly aligned sound waves from the main/top speaker and the subwoofer reinforce each other, preventing cancellation or comb filtering, and leading to a robust and unified sound. Unlocking a sub-top system's full potential requires precise adjustment of time delay and phase settings, along with occasional equalization, to enhance overall sound quality and intensify the perception of deep, tactile bass.

Introduction

In live audio engineering, subwoofers (subs) differ significantly from higher-directivity drivers regarding frequency range and dispersion characteristics. Subwoofers are designed to handle low frequencies, typically below 100 Hz. Subwoofers in small setups are typically placed on the ground for practical reasons (size and weight) and because low-frequency sound waves are nearly omnidirectional and their direction largely indiscernible. Additionally, obstacles such as audience bodies do not significantly block long wavelengths. Ground placement also leverages the boundary effect, where the half-space interaction enhances bass response and efficiency.

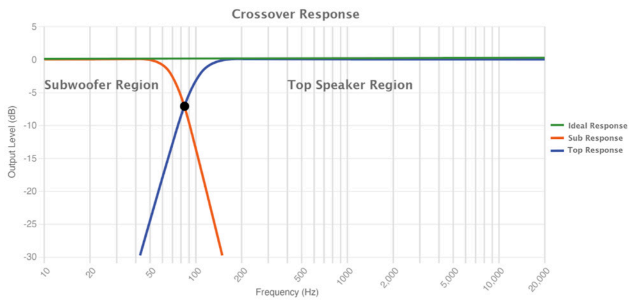
In contrast, the short wavelengths produced by mid-range and high-frequency transducers allow for more narrow and directional sound projection. This directional focus helps control the sound field and reduce unwanted reflections from ceilings and walls. However, these frequencies are subject to significant attenuation or interference when obstructed by physical barriers, such as the bodies of audience members. To mitigate this effect, full-range (or broadband) speakers are typically positioned above the audience's ears, ensuring unimpeded sound projection and facilitating the delivery of clear, intelligible audio. Additionally, full-range speakers are designed to produce a broad spectrum of frequencies, including those overlapping with the subwoofer's operational range (c.ca 60 to 120 Hz).

On the left: combination of a full-range speaker on top of a subwoofer (RCF ART 912-A + SUB 18-AX). On the right, a similar crossover concept can be applied to line arrays stacked on top of subwoofers ([6] HDL 6-A + SUB 9029-AS).

Appropriately dividing the frequency range between the subwoofer and full-range speakers avoids acoustic interference and ensures a seamless blend without attenuations or comb filtering. This is accomplished using a crossover network, which can be implemented through either analog or digital circuits.

Causes of misalignment

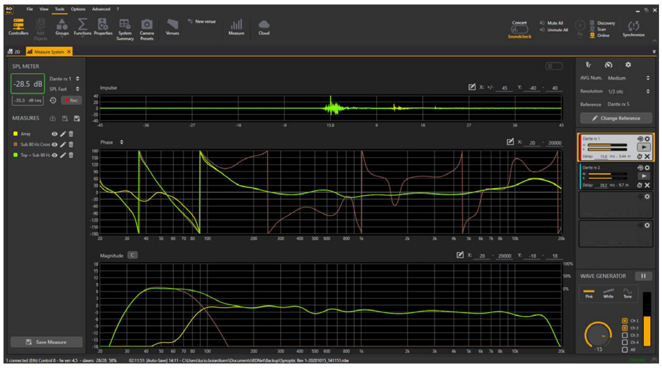
Acoustic interference can also arise from the physical distance between subwoofers and broadband speakers. This issue is a supplemental destructive interference that results in muddy, weak, and indistinct bass, with cancellation of frequencies occurring at 180 degrees of phase difference. Time misalignment is either acoustic, when sources do not match in distance or phase, or electric, when there is a latency in the signal chain, often within a digital signal processor (DSP). Without proper adjustment, these interferences cause delays that disrupt wavefront timing, altering the system's output at the critical crossover point.



Ideal response of the system (green line) at the crossover region, where sub range (red line) and top range (blue line) intersect.

The typical workflow of sound system optimization

Sound system optimization involves manual adjustments for time and phase alignment to ensure that sound from various speakers arrives at the listener's ears simultaneously and coherently. This meticulous process involves multiple measurements with professional microphones and specialized software across a venue, setting system delays, phase/amplitude correction, and equalization on external or embedded DSPs. These calibration techniques pose significant challenges and technical demands. They require a deep understanding of acoustics and electronics, as well as practical skills in manipulating hardware and software tools. Technicians must interpret measurements and make precise adjustments to achieve a reasonable approximation for the entire coverage area, often in complex acoustic environments.



Example of a real-time analyzer used in live sound system optimization. RDnet Measure is a 4-input Dual-Channel FFT Audio Analyzer that measures Magnitude, Phase, RTA, Coherence, and Impulse Response. This tool is included with RDnet management software.

Economically, traditional calibration methods can be limiting for smaller setups. The investment in time and specialized equipment—such as microphones for capturing test signals and software for analysis and adjustment—can be substantial. This makes advanced calibration techniques less accessible for smaller venues or prosumer setups, where budget constraints necessitate simpler, more cost-effective solutions.

Role of DSPs in Modern Active Speaker Systems

In addition to a well-engineered electroacoustic design of transducers, enclosures, and vented ports, Digital Signal Processors (DSPs) are crucial for achieving optimal sound linearity and clarity. DSPs allow precise control over the audio signal, enabling fine-tuning of crossovers, delays, equalizers and other parameters to enhance overall sound quality.

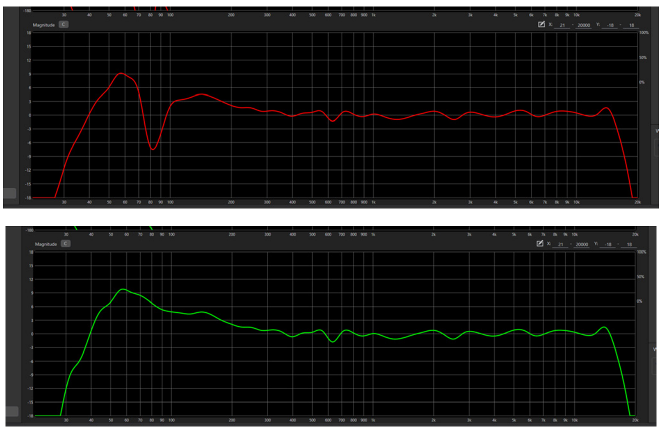
Active speakers include onboard or external DSP-based crossover networks that can be tailored to individual multi-way speaker designs. These DSPs allow changes to the speaker's behavior through management platforms or by recalling a preset. For instance, this feature is useful when the speaker is used as a stage monitor, when line array modules are coupled, or when a speaker is paired with a subwoofer. All active full-range RCF speakers are equipped with a proprietary crossover filtering approach called FiRPHASE.

FiRPHASE processing technology ensures a 0° linear phase response. This feature provides optimal phase alignment across the low-mid to high-frequency range, simultaneously delivering the entire audio spectrum with constant group delay and near-zero latency. However, implementing FiRPHASE at very low frequencies requires more latency from the DSP, making it unsuitable for subwoofers in live sound reinforcement, which demands real-time processing.

Aligning broadband speakers with subwoofers using delays is one of the most effective and straightforward methods. Speakers with built-in variable delay have time delay control on-board and/or via related management platforms. Speakers without variable delay require an external delay device.

Some manufacturers, including RCF, already provide guidelines for their active speaker models, detailing the exact time delay values needed for perfect time alignment with subwoofers. This implementation allows users to pair tops and subs effectively but indeed with some approximation.

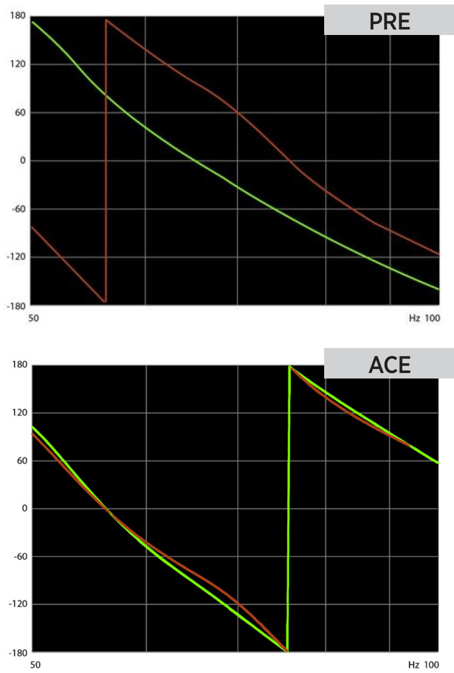
Introducing more capable internal DSPs and specifically designed algorithms, RCF has now developed a technology that simplifies and enhances this process, ensuring users can achieve the best performance without extensive manual. Phase corrections at low frequencies also enable perfect pairing with FiRPHASE full-range speakers.



Sub-Top Pairing: Measurements before (Red line) and after alignment (Green line). This example shows the potential significant loss at the crossover range. While such severe cancellation is not always observed, some degree of loss is quite common in commercially available speakers.

Advanced Crossover Engine

RCF's proprietary Advanced Crossover Engine (ACE) is engineered to optimize audio performance by enhancing clarity at the crossover region. ACE technology utilizes a custom-designed algorithm to precisely match the time delay and align the phase at the crossover's frequency range between RCF subwoofers and FiRPHASE-enabled full-range speakers.



Phase Measurements of a Sub + Top Configuration taken in an Anechoic Chamber (50H to 100Hz window). In the 'PRE' image, no alignment was applied, while in the 'ACE' image, Top and Sub were aligned using the appropriate preset. The red curve represents the Sub phase, and the green curve the Top phase, with the Sub low-pass filter fixed at 85 Hz and the Top set to full range.

This is a critical operation because time alignment can be confused with phase alignment. The two are interconnected: time offset causes phase offset, but phase offset doesn't necessarily cause time offset. Phase offset, however, introduces perceivable distortions to the output signal; again, we can define them as destructive interference. Acting on both the time and phase behavior of the system, ACE transforms a sub+top system into a seamlessly tuned 3-way system, ensuring low-distortion, unified sound output and improving overall sound quality and listener experience.

ACE operates across a broader frequency range than the typical crossover range, allowing the top speaker to extend its operation to the lowest frequency available. This full-range usage generates a coherent energy summation with the subwoofer's overlapping frequency range. This approach provides two primary benefits: increased power at low frequencies and reduced phase-related cancellations.

Hitting the ACE: optimization workflow

The creation of optimized ACE presets for top and sub speakers begins in the RCF headquarter's anechoic chambers, where clean measurements of the speakers' direct sound are obtained. The subwoofer's phase response is measured, followed by positioning one of the chosen speakers on the subwoofer pole support and setting initial alignment by applying delay directly to the speaker's DSP.

Once the preliminary time alignment is performed, a filter is generated to match FiRPHASE response and further optimizes the phase behavior. The added latency to the entire system is minimal (2 ms), but the phase control benefits are significant. Once the sub and top are perfectly aligned, RCF experts and engineers carefully listen to the system in a real-world environment to compare it with professional reference systems, make final corrections, and fine-tune the equalization.

Each sub and top speaker combination is measured and aligned in an anechoic chamber before the listening tests and final fine-tuning.

This process is fully implemented into a single ACE Definition File for each sub-top combination, which can be recalled from the speaker's or sub's internal preset list. This automatically sets the best possible amplitude/phase alignment, making the sub and top perceived as a single system rather than separate speakers, with more punch and presence.

RCF products featuring Advanced Crossover Engine (ACE) come pre-loaded with presets for pairing with compatible speakers.

Conclusions: just one tap away with RCF ACE-enabled models

With RCF's ACE-enabled speakers, bands and DJs can now leverage the technical expertise of RCF's system engineers at the touch of a button. As an industry first, RCF offers effortless alignment of subs and tops by quickly recalling presets from the back panel menu or the companion smartphone app. This innovative approach saves time and ensures precise and consistent audio performance across various venues and setups, making advanced audio calibration accessible to a broader user base.

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