ACOUSTIC SYSTEMS

IMMERSIVE AUDIO ARCHITECTURES

Technical Classification of Electro-Acoustic System Architectures

Technical White Paper

SIAP ACOUSTICS BV

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Executive Summary

Immersive Audio has become an umbrella term encompassing a broad range of electro-acoustic techniques used to shape spatial perception, envelopment, and acoustic character within performance venues. In current practice, this umbrella increasingly covers systems with fundamentally different architectural principles, signal paths, and degrees of interaction with the physical acoustic environment. As a result, systems with very different physical behaviour are often discussed, specified, or evaluated under similar terminology.

This technical white paper provides a clear architectural classification of electro-acoustic system principles encountered within immersive audio contexts, **with deliberate convergence toward Active Acoustic Systems as a distinct subset defined by physical room interaction**. Rather than redefining Immersive Audio as a whole, the document clarifies which immersive approaches genuinely extend or modify the acoustic behaviour of a space, and which operate exclusively within the signal-processing domain.

F**our core architectural principles are defined and analysed at a system level:**

- Regenerative Active Acoustic Systems, which extend the physical diffuse-field energy of a room through controlled microphone–loudspeaker interaction, thereby modifying real acoustic decay behaviour;
- In-line Active Acoustic Systems, which generate a parallel synthetic reverberant field without physically altering the room's inherent acoustics;
- Hybrid Active Acoustic Systems, integrating regenerative and in-line domains into a single phase-aligned, coherent architecture;
- Virtual Acoustic Systems, which use convolution-based processing to create immersive impressions without interacting with the room's physical acoustic properties.

By classifying immersive audio systems according to their architectural interaction with the acoustic environment rather than processing complexity or terminology, this document establishes a clear technical framework for distinguishing Active Acoustic Systems from other immersive audio approaches.

The purpose of this classification is to support accurate system specification, expectation management, and technical evaluation by acoustic consultants, system designers, engineers, and other technically informed stakeholders operating within the broader Immersive Audio domain.

Introduction

Immersive Audio has become an umbrella term covering a broad range of electro-acoustic techniques aimed at shaping spatial perception, envelopment, and acoustic character within performance spaces. Within this landscape, fundamentally different architectural approaches coexist, each based on distinct signal paths, interaction models, and relationships with the physical acoustic environment.

This white paper provides a **technical classification of four core architectural principles** commonly encountered within immersive and electro-acoustic enhancement systems:

- regenerative Active Acoustic Systems (AAS),
- in-line Active Acoustic Systems,
- hybrid Active Acoustic Systems,
- and virtual acoustic systems.

Although these approaches are often grouped together under similar terminology, their **underlying system behaviour, room interaction, and acoustic consequences differ substantially**. In practice, this can lead to misunderstandings during system specification, design evaluation, or expectation management between consultants, integrators, and end users.

The purpose of this document is to **differentiate these architectural principles at a system level**, explain their respective operating mechanisms, and clarify how each category interacts - or deliberately does not interact - with the physical acoustic environment. By separating these architectures clearly, it becomes possible to understand:

- which systems genuinely interact with and extend the acoustic behaviour of a room,
- which systems remain fully signal-path based,
- and why certain approaches fall outside the definition of an Active Acoustic System.

This document focuses exclusively on **architectural and physical system behaviour**, independent of brand names, product implementations, or commercial positioning. It is intended for acoustic consultants, system designers, engineers, and technically informed stakeholders seeking a clear conceptual framework within the broader Immersive Audio domain.

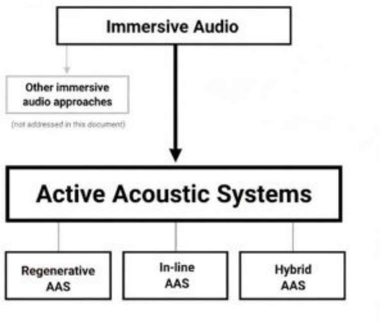

Figure 1. *Conceptual overview of the architectural scope addressed in this document.*

Scope and Technical Context

This white paper provides a **conceptual and architectural classification** of electro-acoustic system principles within immersive audio environments. It does not evaluate, compare, or reference any specific manufacturer, brand, or commercial product.

All descriptions and definitions are intentionally architecture-focused and describe system behaviour at a conceptual and physical level. The document does not prescribe design choices nor claim completeness with respect to all possible implementations.

Interpretation of individual sections without the full architectural context may lead to incorrect conclusions. SIAP Acoustics BV accepts no responsibility for interpretations outside the intended technical scope of this document.

1. Regenerative Active Acoustic Systems (Non-inline, Room-Interactive)

Regenerative AAS systems extend the **real acoustic energy** of the physical space through controlled microphone–loudspeaker interaction. This architecture reinforces the existing diffuse-field energy of the room. As a direct consequence of this reinforcement, the total energy in the space decays more slowly, resulting in an extended physical reverberation time. This extension is a byproduct of diffuse-field reinforcement, not the result of generating a parallel synthetic field.

Key characteristics:

- The room's diffuse-field energy is captured via microphones and reinjected through loudspeakers.
- Extends the *physical* decay field of the venue.
- System behaviour strongly depends on occupancy, absorption, and modal characteristics of the room.
- Requires precise modal management and surgical notch filtering for stability.
- Gain-before-feedback limits the maximum achievable extension.
- Acts as an extension of the physical space, modifying real decay constants.

This architecture directly interacts with the acoustic environment and changes the room’s natural behaviour.

Although regenerative, hybrid, and in-line active acoustic architectures all employ loudspeaker reproduction, only regenerative and hybrid systems reinject real room energy into the space through a controlled feedback loop, thereby altering the physical decay behaviour of all acoustic events in the room.

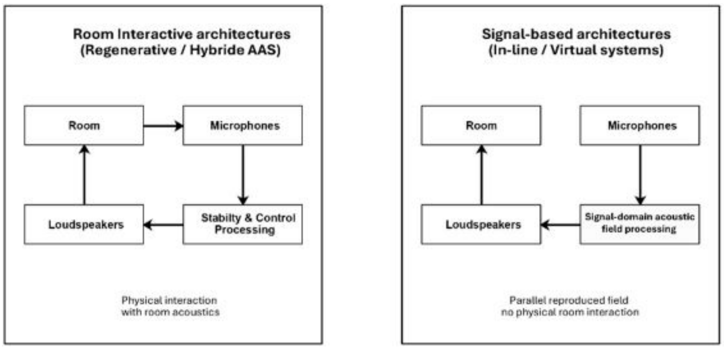

Figure 2. *Qualitative distinction between room-interactive and signal-based active acoustic system architectures.*

2. In-line Active Acoustic Systems (Parallel Reverberant Field Generation)
In-line Active Acoustic Systems form the second architectural category within Active Acoustic System design. These systems may use hall or ambient microphones as inputs, but they fundamentally remain **signal-path based**, generating reverberation as a parallel synthetic field. Although in-line systems may capture room sound via hall or ambience microphones, any such sound is repeatedly reprocessed within the signal domain rather than recirculated as controlled acoustic energy, and therefore does not constitute physical room interaction.

Key characteristics:

- Capture room sound via ambient or hall microphones, but **do not** regenerate the room’s energy.
- Microphone signals are routed into a DSP engine (algorithmic or convolution-based).
- A synthetic reverberant field is created and reproduced through a distributed loudspeaker system.
- Perceived reverberation time can be extended, but this occurs as a **parallel overlay**, not a modification of the physical room decay.
- Does not physically alter the room’s natural decay constants or diffuse-field behaviour. Any perceived reverberation extension is generated as a parallel field within the DSP domain rather than through reinforcement of the real acoustic energy.
- Spatial diffusion, coherence and envelopment depend on DSP decorrelation, IR resolution, and processing power/quality.

In-line AAS systems extend perceived reverberation through synthesis, not through physical feedback interaction with the room.

3. Hybrid Active Acoustic Systems (Phase-Coherent Integration)
Hybrid AAS designs combine regenerative and in-line components into a **single coherent engine**. This architecture blends the natural authenticity of regenerative extension with the precision shaping of in-line processing.
Key characteristics:

- Regenerative domain extends real diffuse-field energy.
- In-line domain provides spectral shaping, spatial tailoring and decay optimisation.
- Both domains operate in **phase-aligned synchronisation**.
- Avoids double-decay or layering artefacts.
- Preserves tonal continuity across the full spectrum.
- Offers greater tuning flexibility across diverse acoustic spaces.

Scalability and Venue-Dependent Balance
In hybrid systems, the ratio between regenerative and in-line contributions is **not fixed**, but meticulously adjusted based on venue characteristics. The balance is determined by:

- room geometry,
- absorption behaviour,
- modal distribution,
- gain-before-feedback margins.

Precisely controlled synchronisation between the regenerative and in-line domains ensures that both behave as one coherent acoustic field rather than as separate layers. This scalability allows hybrid systems to perform consistently in venues ranging from highly absorptive environments to reflective concert halls. The performance of any hybrid architecture depends entirely on the quality of the integration between regenerative and in-line domains; the more precisely these components are synchronised and phase-aligned, the more coherent, stable and natural the resulting acoustic field will be.

It is important to recognise that not all hybrid implementations behave the same - differences in design philosophy, processing resolution, timing accuracy and integration strategy can result in substantially different levels of realism and stability among systems classified as "hybrid."

4. Virtual Acoustic Systems (Convolution-based, 100% In-line, Non-AAS)
Virtual acoustic systems form a **separate category** from Active Acoustic Systems, even though they are often mistakenly grouped together. Their processing is entirely dependent on routed audio signals and does **not** interact with or modify the room's physical acoustic behaviour.
Key characteristics:

- Utilise recorded impulse responses (IRs) of real halls or acoustic environments.
- Apply convolution processing to closed-mic'd or line level sources routed through the FOH mixing desk.
- Create a virtual representation of another venue by convolving direct sources with the IR.
- Only processed sources receive the virtual acoustics; unamplified room sound remains completely natural.
- Do not regenerate diffuse-field energy and do not modify the physical reverberation characteristics of the room itself.
- Produce a parallel synthetic reverberant field reproduced through loudspeakers.

Virtual acoustics is therefore a powerful artistic tool, but it is **not** an Active Acoustic System, because it does not extend or alter the acoustic behaviour of the actual room.

To avoid misunderstanding: because virtual acoustic systems do not use hall microphones to influence the physical room, they cannot extend or modify any acoustic event that takes place in the space itself.

5. Clarification of Terminology
The terms *in-line*, *regenerative* and *hybrid* describe **architectural principles**, not brands or products. Misuse of these terms can easily lead to misunderstanding. This document provides the correct internal reference definitions.

6. Convergence of Active Acoustic Systems within Immersive Audio
Within the broader Immersive Audio landscape, Active Acoustic Systems occupy a distinct position due to their potential interaction with the physical acoustic environment. While many immersive audio techniques rely on signal-based spatial reproduction or synthetic field generation, only certain system architectures directly influence the real acoustic decay behaviour of a space.

Regenerative and hybrid Active Acoustic Systems operate by extending or shaping the diffuse-field energy of the room itself, thereby affecting all acoustic events occurring within that space, whether amplified or unamplified. In contrast, in-line and virtual acoustic systems generate immersive impressions through parallel synthetic fields that coexist with, but do not alter, the room's inherent acoustic properties.
Understanding these architectural distinctions is essential when specifying immersive audio solutions for performance venues, as the perceptual outcome, system stability, and long-term acoustic behaviour depend fundamentally on the chosen system principle rather than on processing complexity alone.

7. Summary

- Virtual acoustic systems: convolution-based, fully in-line, no room interaction, no regeneration.
- In-line AAS: hall-mic input possible, parallel reverb generation, no physical room-extension.
- Regenerative AAS: non-inline, room-interactive, extends physical decay field.
- Hybrid AAS: integrated regenerative + in-line architecture with phase-aligned coherence.

This document offers architectural classification only and does not relate to any specific commercial implementation.

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