



AUROMAX®

Next generation Immersive Sound system

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1 INTRODUCTION

Auro Technologies and Barco are proud to introduce to you the next generation format for Immersive Sound in Cinema: **AuroMax®**.

AuroMax® is the newest member of the **Auro-3D®** Immersive Sound format and combines the superior 3-dimensional listening experience provided by the Auro-3D® speaker layout and formats with the proven high-quality rendering for Object-Based Audio (OBA) from Barco Audio Technologies (formerly IOSONO). This combination makes AuroMax® the ultimate immersive sound system on the market.

1.1 Auro 11.1

In 2011, Auro Technologies and Barco changed the cinematic landscape with the announcement of the first theatrical release in Immersive Sound using the Auro 11.1 format: Red Tails, produced by George Lucas.

The **Auro-3D®** concept and listening formats were conceived in 2005 by Wilfried Van Baelen (CEO Galaxy Studios & Auro Technologies) with the intention to add the missing and final dimension in sound (Height) with end-to-end solutions for all markets. He created the most efficient true 3-dimensional sound reproduction system without any concession on quality and backwards compatibility. A scalable channel-based system based on 5.1 Surround Sound was chosen to guarantee the best audio reproduction quality with the addition of the minimum amount of channels to get a maximum 3-Dimensional sound reproduction. The Auro-3D® speaker configurations are designed to get a better compatibility between small and large rooms and between various media formats in order to consistently deliver the same immersive experience as intended by the creators.

Auro 11.1 became the format of choice for cinematic use and employs Auro-3D®'s unique concept of three layers of speakers and 6 screen channels. The lower layer, based on the standard 5.1 Surround speaker layout, is used to reproduce the most common sounds in real life at ear level. The Height layer, positioned higher up the walls at about 30° elevation, is able to reproduce distinct elevated sounds, but also crucial reflections that help creating a truly lifelike immersive sound-field, enveloping the listener as in real life. The combination of both layers creates a "*vertical stereo field*" around the audience, which is the key element to Auro-3D®'s immersive and natural sound experience. Lastly, the Top layer, positioned above the audience on the ceiling, is then mostly used to reproduce special effects such as fly-overs or a Voice-of-God. The 6 screen channels divided in 2 rows create an on-screen vertical stereo field, allowing much better screen sound with more depth, transparency and more space for the dialogue.

The power of Auro-3D®'s unique Height Layer is its ability to create a true 3D sound field on screen and around the audience without using the ceiling speakers. Additionally, thanks to the fact that Auro-3D®'s Height Layer is a copy of the existing Surround layer, it ensures backwards compatibility.

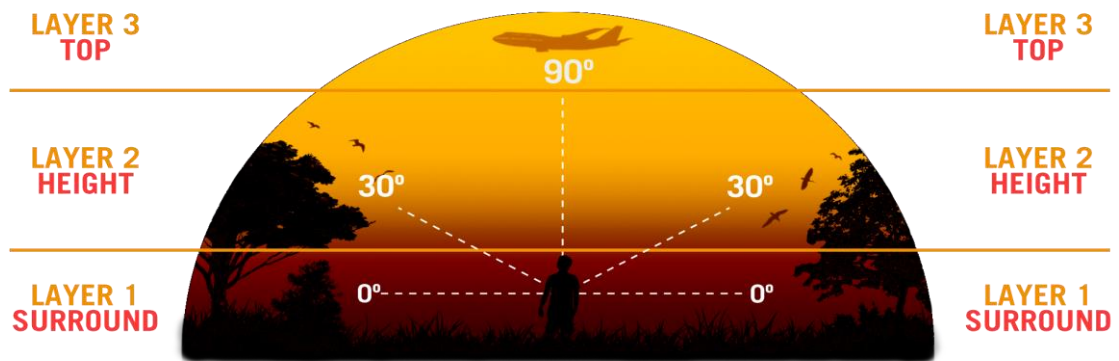


Figure 1 - Auro-3D®'s unique three-layer concept

By 2015, thanks to the combined efforts with our partner Barco for digital cinema, Auro 11.1 became an established format with more than 550 theatres worldwide committed to the format, with more than 35 leading post-production studios and 120 international films released.

Auro-3D®'s ground-breaking technology allows for the easy implementation of Immersive Sound in all existing standards without requiring any change of specifications. This unique technology can deliver the 5.1 surround mix and the Auro-3D® mix in single deliverable, both versions as intended by the creators while keeping High Resolution Audio in each channel without the need for any extra bandwidth.

1.2 An open Immersive Sound Standard

The introduction of Auro 11.1 as the most efficient "Immersive Sound System" for cinema sparked new life in the development of new sound systems for cinema and home. Various competitors responded with their own format and technologies for cinematic sound. Most notably was the re-introduction of the use of Object-Based Audio, originally launched in cinematic use by IOSONO in 2007 and later followed by Immsound and SRS

Labs. Object-based technology gained a lot of attention in the industry and became another element of consideration for creatives and exhibitors alike.

Organisations such as NATO (National Organisation of Theater Owners), UNIC and DCI (Digital Cinema Initiative), representing the exhibitors and major Hollywood studios, expressed the wish for a single, open standard for Immersive Sound, which can then be used as a distribution format for all Immersive Sound systems. This standard was to be developed by SMPTE, the Society of Motion Pictures and Television Engineers

Auro Technologies and Barco committed themselves to support this effort and have shown a strong participation and the creation of this standardized delivery format.

1.3 AuroMax®

AuroMax® is the resulting format of these efforts, bringing the life-like immersive sound capabilities and backwards compatibility of the Auro-3D® systems, combining them with the flexibility of Object-Based Audio (OBA) and a standardized bit-stream format for cinema.

AuroMax® systems provide superior rendering of the audio objects at a low cost, thanks to the use of the proven high-quality rendering technology of Barco Audio Technologies (formerly IOSONO).



2 AUROMAX® VISION

Auro-3D® is known for its superior life-like immersive sound, evoking a higher emotional response to the story on the screen. This is most noticeable with music and ambient sound elements, especially when those are natively recorded and mixed in one of Auro-3D®'s channel-based formats (Auro 9.1 up to Auro 13.1). The channels in these formats can reproduce the crucial 3D reflections around the sound sources which are key to achieve a natural immersive sound reproduction. These reflections not only create a better tone colour (still the most dominant parameter for the reproduction of a natural sound) but also enhance the localization of the recorded sounds.

The unique 3-layered systems of Auro-3D® allow for even more precision in the localization of sounds in the vertical axis than systems using only object-based technology represented over 2 layers. This is, because our hearing system is horizontally oriented and cannot experience sounds as phantom sources in the vertical axis between 2 speakers in the same way as in the horizontal axis. Internal experiments at Auro Technologies have proven that using 3 layers is the most eloquent way to create a natural spread of sound in the hemisphere from ear-level up above the listener. Others have also shown that with only 2 height channels (as in e.g. 5.1+2 or 7.1+2), a true 3D space cannot be created (H. Lee, ICSA2015).

A good Immersive mix is seldom achieved by creating a two-dimensional Surround base mix and spreading a number of monophonic objects around in the 3D space. The vision behind the AuroMax® format is therefore to first create a natural, immersive listening experience with channel-based "beds", using the 'traditional' and proven methods to record, mix and distribute sound tracks. Once the channel-based foundation is made, objects can be added for further refinement of the mix. This approach has numerous

advantages, not only in the workflow from recording to the creation of deliverables for all markets, but also in the quality of the experience.

Real-life immersive sound, such as complex ambiances cannot be easily captured (recorded) directly as objects. This is fairly straightforward using stereophonic microphone techniques or Ambisonics, resulting in a number of channels representing the recorded sound field. These can then be used by both channel-based and object-based systems (as part of the beds or as static objects). However, directly capturing individual elements of a complete scene, such as e.g. each bird in the sound field of a forest, for use as separate objects is not possible.

It is currently also not possible to apply the ubiquitous mastering process on the complete mix in (pop) music with the established tool-sets when objects are used.

Starting with scalable channel-based beds (up to 14 channels), capable of recording and reproducing a true 3D space on compatible playback systems and then adding objects thus provides the best of both worlds.

With AuroMax®, Auro-3D® now also adds the flexibility provided by Object-Based Audio, allowing for more precise placement and movement of sounds on speaker systems that are capable of taking advantage of this additional information. This requires a higher number of reproduction channels (speakers and amplifiers), typically between 20 and 32, and specific hardware for the rendering.

Just like with Auro 11.1, the AuroMax® speaker layouts are based on the existing 5.1 Surround layouts, maintaining the largest possible sweet spot and providing the same experience as intended by the creators to almost every seat in the theatre, for all kinds of content (5.1, 7.1, Auro 11.1 and AuroMax®).

3 AUROMAX® CHANNELS AND OBJECTS

3.1 Channel-based Audio (CBA)

Figure 2 shows the typical flow of a channel-based audio production.

Audio elements from various sources such as microphones, synthesizers and effect units are represented as tracks and snippets. The mixing engineer then defines how these elements are positioned and at what levels they need to be reproduced in the mix. In digital systems it can be said that the engineers creates metadata to do so, although this is not always visible as such. The mix is then 'rendered' by an engine (either as part of a mixing console or a Digital Audio Workstation) for a specific speaker layout, using the audio elements and metadata. The result is a set of channels, each representing the signal for a specific speaker (e.g. Left and Right for a stereo mix).

Those channels are then stored on a distribution medium, such as a DVD, BD or even on servers from streaming to various online devices, using various compression methods where applicable.

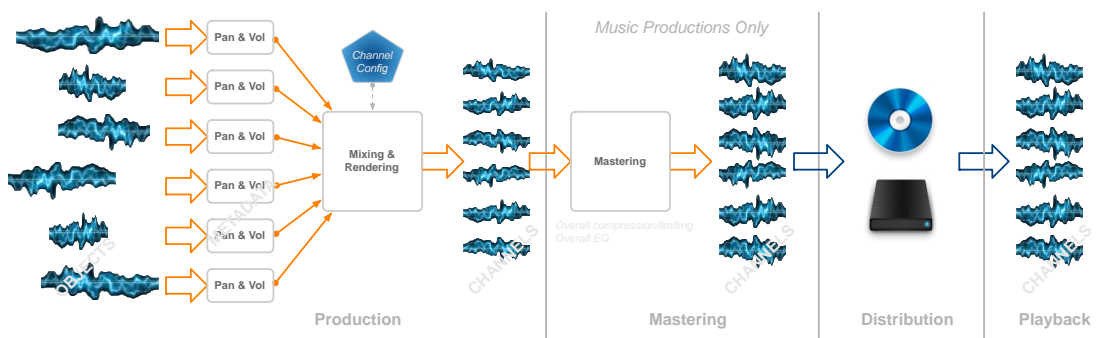


Figure 2 - Channel-based Audio Flow

3.2 Object-Based Audio (OBA)

In a pure Object-Based Audio system, such as shown Figure 3, the audio elements and metadata are not rendered to channels (except for local monitoring), but rather stored as Audio Objects (the combination of an audio element and its related metadata) in a container or bit-stream. During playback, a renderer reads this information and locally produces the individual signals for the specific installed speaker setup.

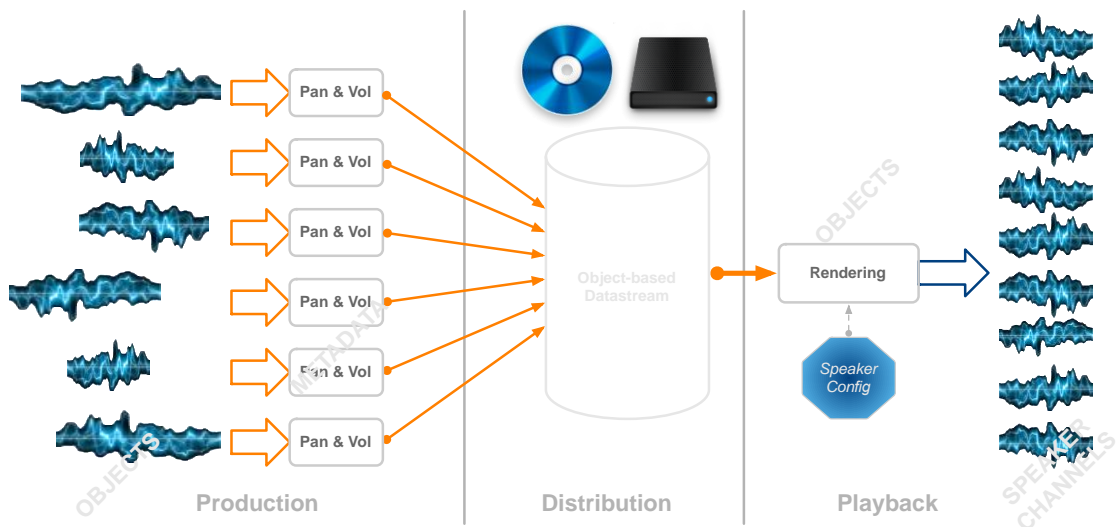


Figure 3 - Object-Based Audio Flow

The main theoretical advantage of such system is that the same mix can be 'speaker-agnostic' and thus potentially be used for virtually any speaker layout, at the expense of predictability and data rate. In practice, however, there are also some challenges concerning this flexibility.

3.3 Beds and Objects

Any cinematic Immersive Sound mix with OBA contains two types of audio content: Beds and Objects.

Beds represent the channel-based content of a mix, in a specific format, chosen by the creatives and are thus rendered at the production stage, in the mixing tool-chain. They are typically used for the majority of the content that does not need the flexibility or increased playback resolution of the Objects, such as music, ambiance and on-screen sounds (e.g. dialogue).

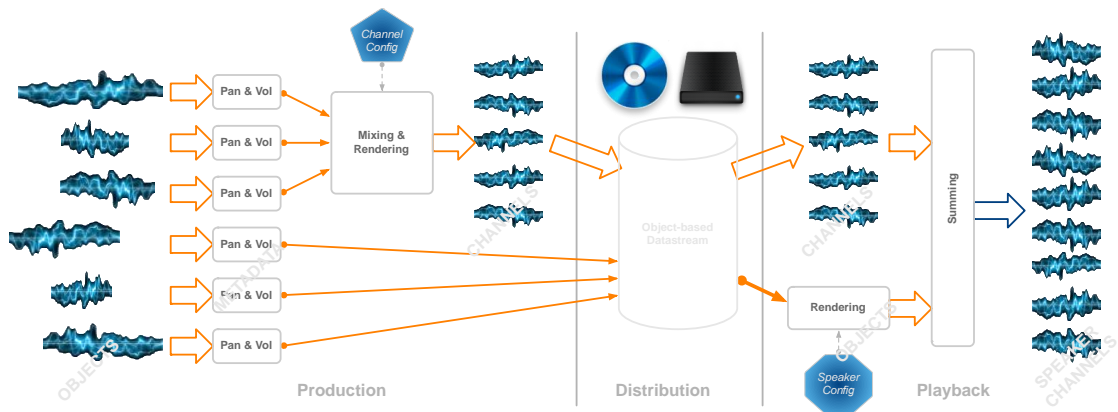


Figure 4 - Hybrid Channel- and Object-based Flow

The distribution container will thus contain both the audio Objects as well as channel-based audio, representing these Beds. It should be noted that Beds can also be treated as "static objects" and carried in the same bit stream as the objects.

3.4 AuroMax® Channels and Beds

AuroMax® thus not only contains the Objects, but also Beds in the Auro-3D® formats, up to 14 channels (Auro 11.1 and Auro 13.1).

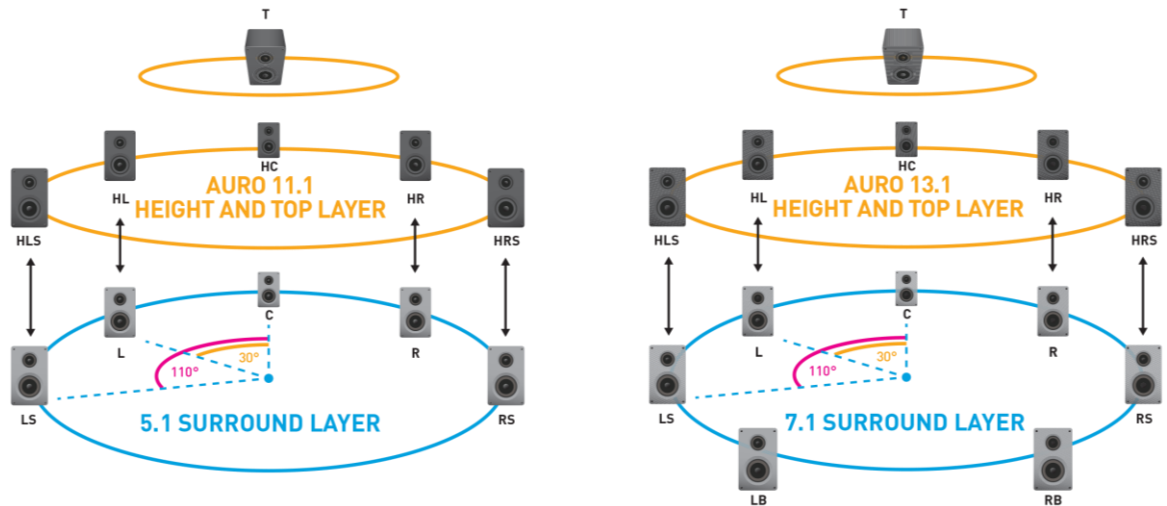


Figure 5 - Auro 11.1 and Auro 13.1 Bed configurations

This thus also provides the highest compatibility with Auro 11.1 systems, as well as standard 5.1 and 7.1 Surround systems.

	Auro 13.1	Auro 11.1		Auro 13.1	Auro 11.1
L	X	X	HL	X	X
C	X	X	HC	X	X
R	X	X	HR	X	X
Ls		X	HLS	X	X
Rs		X	HRs	X	X
Lss	X		T	X	X
Rss	X		LFE	X	X
Lrs	X				
Rrs	X				

Table 1 – AuroMax® Bed configurations

4 AUROMAX® REPRODUCTION SYSTEMS

As mentioned earlier, the use of Object-Based Audio brings some advantages to cinematic productions, as well as various challenges.

To ensure the best experience in all circumstances with AuroMax®, great consideration was made to address these possible issues in the best possible way.

4.1 Challenges when using OBA

As already described above, the use of Object-Based Audio theoretically provides a 'format-agnostic' mix that should work on any speaker layout. In practice this has proven to have some limitations. One element is the number of individually driven speakers required to take advantage of the spatial resolution of the OBA essence is higher than before. The speaker layout itself then also needs to be in line with what was envisioned by the content creators; different speaker arrangements will invariably lead to different results.

The use of more individually driven speakers in combination with Object-Based Audio also potentially leads to a smaller sweet spot, due to a combination of speaker positioning, directivity and power handling. In some cases, a single speaker now needs to project a single sound into the whole theatre, whereas in the past speaker arrays were used to evenly spread the energy of this same sound throughout the whole theatre. Depending on the size of the theatre, this can lead to more unwanted variations in level and timbre.

The AuroMax® system provides the best of both worlds, maximizing the sweet spot while enabling the use of Object-Based Audio and the reproduction of regular 5.1 and 7.1 content as defined by existing standards.

4.1.1 Level drop

The Inverse Square Law tells us that in open air, the sound Pressure Level drops by 50% for each doubling of the distance from the source. A sound of an object reproduced by just one speaker instead of an array will thus create a very different perceived volume and spectrum (timbre) depending on the seat in the theatre.

In larger rooms this effect will be more pronounced than in smaller rooms, reducing the area where the film can be experienced as intended by the creators.

4.1.2 Spectrum

All speakers have characteristics defining how the sound is projected in the room. This is called 'dispersion' or 'directivity' and changes with frequency. The best sound is experienced 'on axis', meaning directly in front of the speaker, while off-axis the speaker does not project as much high frequencies, leading to a 'duller' sound.

If objects are moving around in a smaller theatre, the sound will not differ that much. But in a large theatre, the object will sound very different depending on where the listener is seated, creating a result that might differ substantially from the creators intent.

This thus leads to two extreme cases:

- *"Optimizing for the sound of the objects"*

This requires each speaker around the theatre to be directed towards a small sweet spot area, where the spectrum is almost the same. This avoids that movements around the room will sound very filtered and that a static object reproduced by a single speaker would sound too different depending on where seated in the theatre.

- *"Optimizing for the sound of the beds (channels)"*

These are reproduced by an array of speakers (each speaker of an array on the wall reproduces the same sound in order to optimally deliver the same experience in each seat of the theatre), which requires the speaker arrays to be installed as defined by the 5.1 installation standard.

Aiming the speakers in these arrays to the same sweet spot changes the interference patterns that impacts phasing artefacts as each speaker reproduces the same sound leading to a clustered and more distorted sound when playing back Surround channels. However, keeping the existing install to maximize the

sound quality of the channel-based sound can create issues with the tone colour of objects, especially in large theatres.

4.2 AuroMax® Zones

To provide the best listening experience while guaranteeing the highest degree of compatibility with existing Auro 11.1 systems and also the highest degree of delivering to almost every spectator the same mix as intended by the creators, multiple AuroMax® playback configurations have been defined. These make use of 'Zones', dividing the traditional Surround speaker arrays in the room into smaller groups of speakers. These individually addressable zones provide the increased resolution for Object-Based Audio, while not requiring the level of investment often associated with these systems to make each speaker its own channel. It also allows existing Auro 11.1 systems to be easily converted into an AuroMax® system, by simply rewiring the speakers ("home-run wiring" is recommended for all Auro 11.1 installations) and installing a few additional amplifiers, when necessary.

4.3 Wide Screen speakers

The use of the Wide Screen or 'Proscenium' speakers is recommended for AuroMax®. These allow a smooth transition from the screen to the front-most zone of Surround speakers.

In cinema theatres the front-most Surround speakers are installed near the first row of seats, which creates a gap between the Left or Right screen channel to the first surround speakers. This effect can especially be noticed when sounds are moving from the screen into the front-most surround zones. In order to fill that gap, it is recommended to optionally add 4 more speakers: one on each side wall in the Lower Layer and in the Height Layer. The 4 wide screen speakers will only be used for the Objects and can be

directed towards the middle of the theatre in order to have a good spread of sound over the whole room without any influence on the channel-based sounds of the Beds.

4.4 Full Range Surrounds

With the advent of Immersive Sound in cinema, full range surrounds capable of reproducing the full sound spectrum have become a much welcomed possibility as well, bringing the sound quality of all output channels to the same level as the screen channels. This can be achieved using full-range speakers or, more practically, by adding subwoofers in the room and applying bass management.

Bass management is strongly recommended in the Surround and Top channels and, while optional in all Auro 11.1 and AuroMax installations in theaters, is mandatory on mixing stages. Adding bass management to the surround system typically involves installing a subwoofer at each side of the theatre, either on the side walls or in on the back wall.

4.5 AuroMax® 26.1

The ideal configuration using the 'zones' approach, adds the so-called "Proscenium" speakers between the screen channels and the front-most surround speakers. These allow for smoother movements of sounds from the screen into the room, and are often used to bring the music slightly into the room, away from the screen.

The Surround speaker arrays are divided into two zones for each wall, while the Top layer (overhead) consists of four zones, arranged in a square.

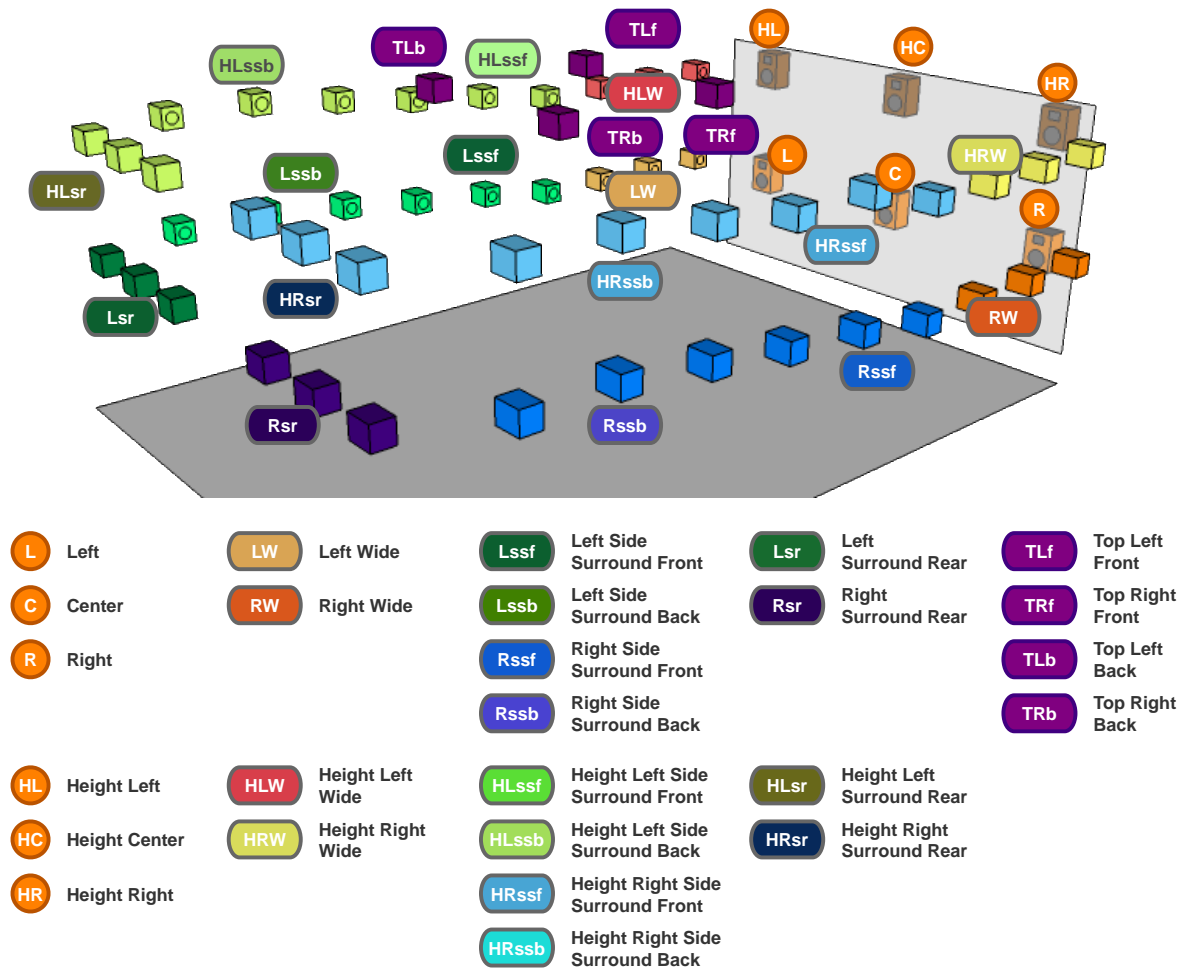


Figure 6 - AuroMax® 26.1 layout

This configuration is the recommended configuration for most rooms and provides the best immersive sound experience with the highest compatibility with standard Surround and Auro 11.1 productions and provides a large sweet spot.

4.6 AuroMax® 20.1

The smallest configuration for AuroMax® is based on the standard Auro 11.1 installation and splits the Surround and Top speaker arrays into two zones for each wall.

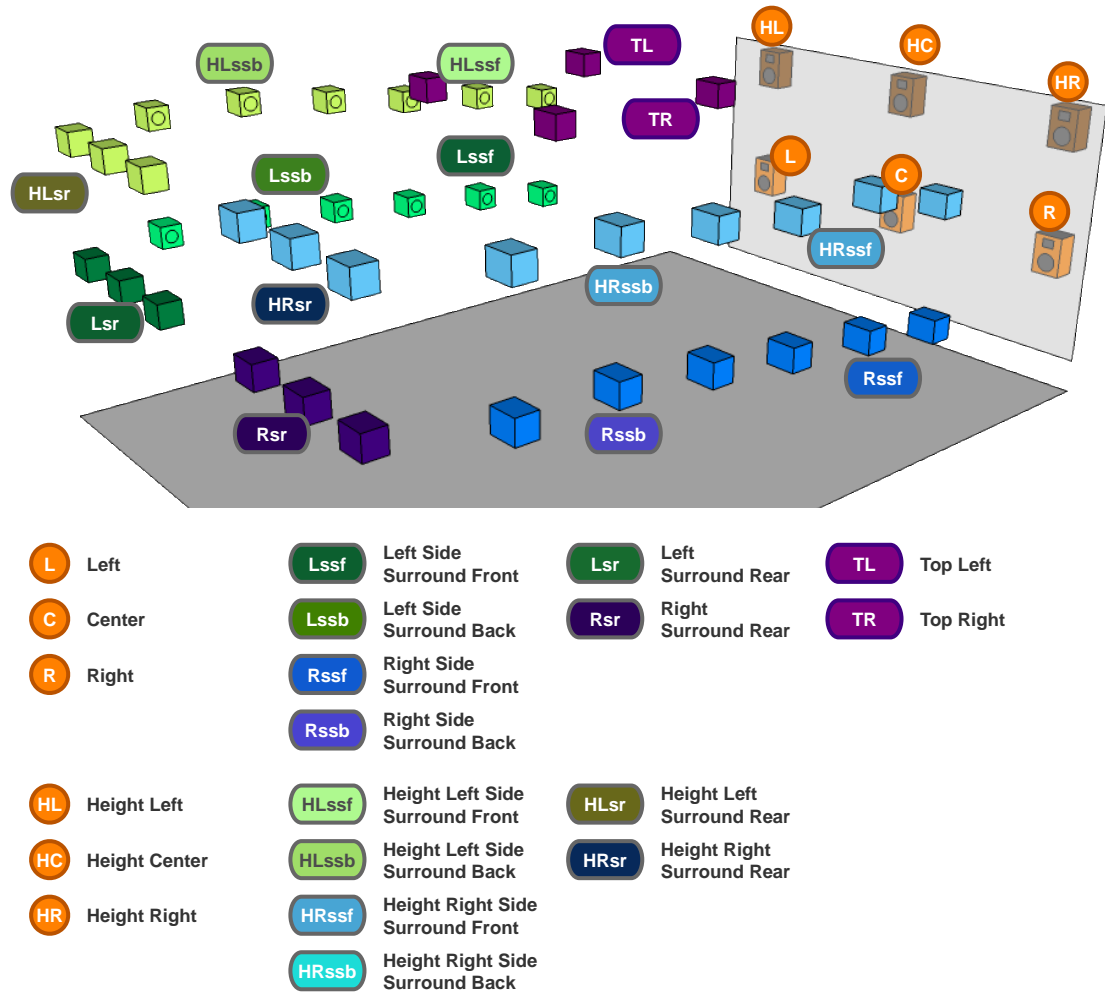


Figure 7 - AuroMax® 20.1 layout

4.7 AuroMax® 22.1

In a second configuration the Top layer is further divided into 4 distinct zones.

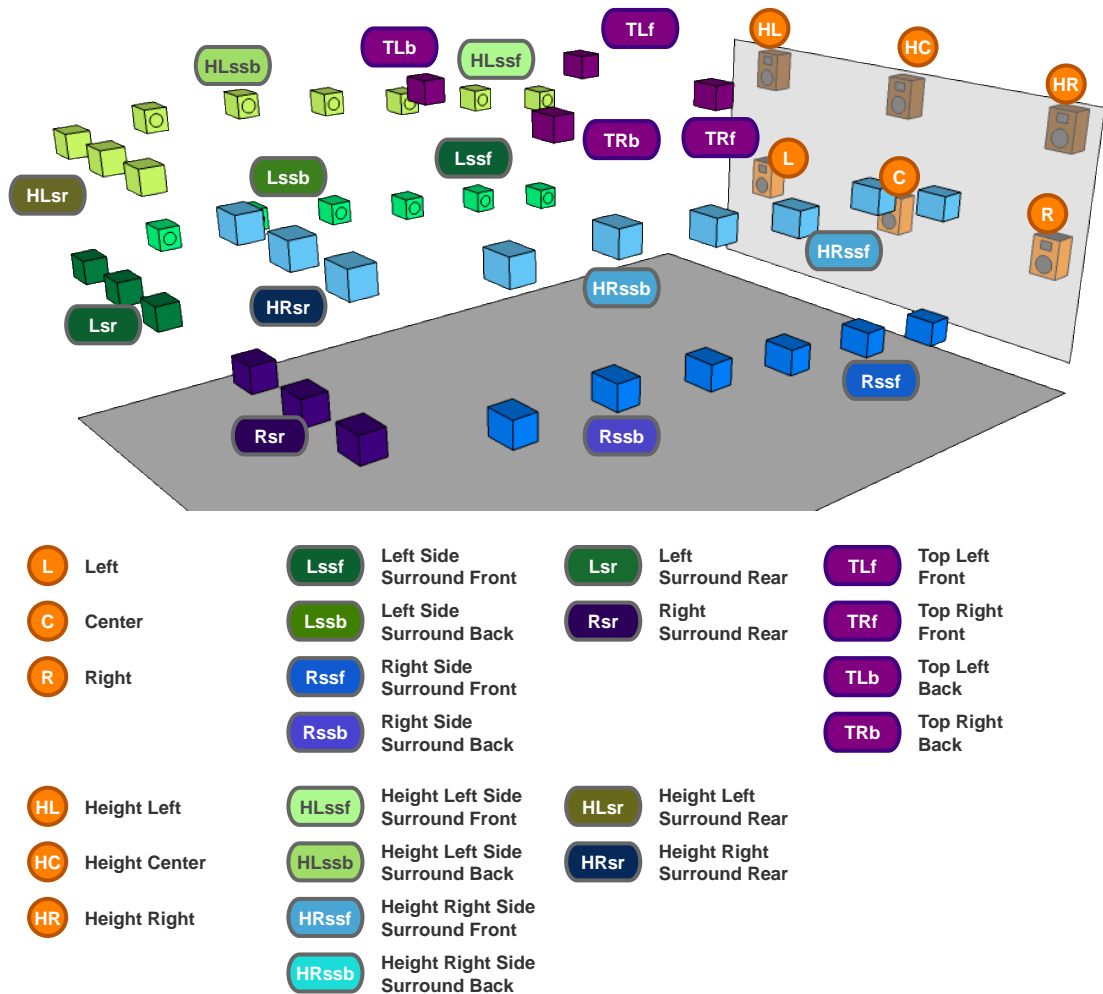


Figure 8 - AuroMax® 22.1 Layout

This configuration is recommended for theatres that want to convert an existing Auro 11.1 system without changing the speaker installation.

4.8 AuroMax® WFS

Next to the zone-based approach, the AuroMax® system has the unique ability to be reproduced using Wave-Field Synthesis (WFS) technology. The AuroMax® WFS system provides features such as reproducing sounds at distances beyond the boundaries of the

room. More information on this system can be provided on request by Barco Audio Technologies.

4.9 Overview

The table below gives an overview of the reproduction channels of the different zone-based AuroMax® playback configurations.

	Zone	Auro-Max 20.1			Auro-Max 22.1			Auro-Max 26.1		
		Obj	Chan 11.1	Chan 13.1	Obj	Chan 11.1	Chan 13.1	Obj	Chan 11.1	Chan 13.1
1	L	L	L	L	L	L	L	L	L	L
2	C	C	C	C	C	C	C	C	C	C
3	R	R	R	R	R	R	R	R	R	R
4	Lw	-	-	-	-	-	-	Lw	-	-
5	Rw	-	-	-	-	-	-	Rw	-	-
6	Lssf	Lssf	Ls	Lss	Lssf	Ls	Lss	Lssf	Ls	Lss
7	Rssf	Rssf	Rs	Rss	Rssf	Rs	Rss	Rssf	Rs	Rss
8	Lssb	Lssb	Ls	Lss	Lssb	Ls	Lss	Lssb	Ls	Lss
9	Rssb	Rssb	Rs	Rss	Rssb	Rs	Rss	Rssb	Rs	Rss
10	Lrs	Lrs	Ls	Lrs	Lrs	Ls	Lrs	Lrs	Ls	Lrs
11	Rrs	Rrs	Rs	Rrs	Rrs	Rs	Rrs	Rrs	Rs	Rrs
12	HL	HL	HL	HL	HL	HL	HL	HL	HL	HL
13	HC	HC	HC	HC	HC	HC	HC	HC	HC	HC
14	HR	HR	HR	HR	HR	HR	HR	HR	HR	HR
15	HLw	-	-	-	-	-	-	HLw	-	-
16	HRw	-	-	-	-	-	-	HRw	-	-
17	HLssf	HLssf	HLs	HLs	HLssf	HLs	HLs	HLssf	HLs	HLs
18	HRssf	HRssf	HRs	HRs	HRssf	HRs	HRs	HRssf	HRs	HRs
19	HLssb	HLssb	HLs	HLs	HLssb	HLs	HLs	HLssb	HLs	HLs
20	HRssb	HRssb	HRs	HRs	HRssb	HRs	HRs	HRssb	HRs	HRs
21	HLrs	HLrs	HLs	HLs	HLrs	HLs	HLs	HLrs	HLs	HLs
22	HRrs	HRrs	HRs	HRs	HRrs	HRs	HRs	HRrs	HRs	HRs

	Zone	Auro-Max 20.1			Auro-Max 22.1			Auro-Max 26.1		
		Obj	Chan 11.1	Chan 13.1	Obj	Chan 11.1	Chan 13.1	Obj	Chan 11.1	Chan 13.1
23	TLf	TL	T	T	TLf	T	T	TLf	T	T
24	TRf	TR	T	T	TRf	T	T	TRf	T	T
25	TLb	TL	T	T	TLb	T	T	TLb	T	T
26	TRb	TR	T	T	TRb	T	T	TRb	T	T
27	LFE	-	LFE	LFE	-	LFE	LFE	-	LFE	LFE

5 AUROMAX® PLAYBACK ARCHITECTURE

Based on the requirements described by the DCI¹, a high-level architecture is defined using the following main components:

1. DCP Server, with Bit-stream output capabilities
2. (Integrated) Media Block (IMB)
3. Audio Processor, defined as an Outboard Media Block (OMB)
4. Amplifiers & Speakers

The following diagram shows the various audio-related streams between these devices.

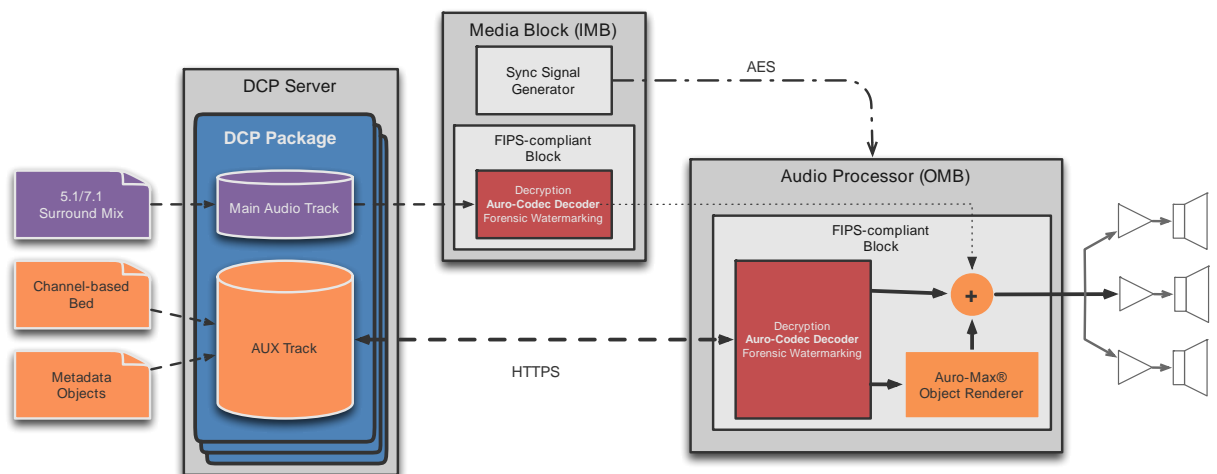


Figure 9 - High-level Block Diagram AuroMax System

5.1 DCP Playback Server

In this architecture, the DCP server has the following requirements:

- DCI-compliance
- Capable of correctly handling SMPTE-DCPs (as well as Interop DCPs)

¹ DCI: Digital Cinema Initiative - Digital Cinema Object-Based Audio Addendum, 9 September 2013 & Digital Cinema Multiple Media Block (MMB) Architectural Description, 26 June 2014 (www.dcmovies.com)

- Capable of outputting AUX Track data according to SMPTE ST429-14

5.2 Integrated Media Block (IMB)

The Integrated Media Block (IMB) is responsible for the decryption, decoding and forensic watermarking of a movie's picture and Main Audio Track. The Main Audio track contains the standard 5.1 or 7.1 Surround mixes (potentially Auro-Codec® encoded), as well as the mandatory tracks for Hearing Impaired and Visually Impaired aiding tracks. Next to this, it can also contain the Motion Data used for e.g. D-Box applications.

Some Media Blocks also have a certified Auro-Codec® implementation for compatibility with standard Auro 11.1/13.1 content.

5.3 AuroMax® Audio Processor (OMB)

The AuroMax® Audio Processor is the heart of the AuroMax® system. Its main functions are:

1. Decryption/Decoding of the SMPTE standardized bitstream
2. Rendering of OBA essence with the AuroMax® renderer
3. Re-distribution of channel-based beds
4. Auro-Codec® decoding (e.g. for Alternative content)
5. Forensic Watermarking of the audio outputs
6. Calibration of installed speaker system
 - a. Level- and Time Alignment
 - b. Room Equalization
7. Bass Management
8. Volume Control

6 AUROMAX® CONTENT CREATION

6.1 Auro-3D® Authoring Tools

Content creation for AuroMax® is easier than ever using the award-winning Auro-3D® Creative Tool Suite, which includes the **Auro-3D® Authoring Tools (AAT)**, and **Auro-Matic® Pro 2D/3D**, available for Pro Tools on Mac and PC.





Figure 10 - Auro-Panner with Object-setting

AAT is developed to enable the **Auro-3D® Unified Workflow** concept, which enables the creation of multiple deliverables, Channel- and Object-based, from a single mix.

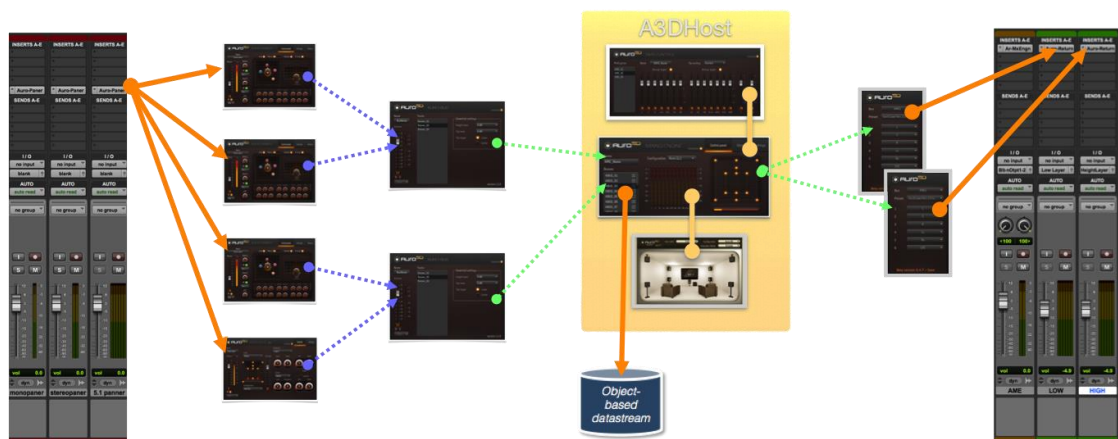


Figure 11 - Typical signal flow for Auro-3D® Authoring Tools

The Auro-Panner can be inserted in any Pro Tools audio track and provides 3D panning capabilities for both Beds and Objects. By simply enabling the 'Object'-setting in the

Auro-Panner an audio element automatically becomes an object, without the need for any re-configuration or re-routing, making the mixing process extremely simple. The audio and metadata of these objects are then sent to the AuroMax® renderer, either AAT's internal rendering engine or the Barco/IOSONO external rendering unit for large projects and for monitoring.

Next to this, the Auro-Mixing Engine in AAT is used to export the various deliverables, including the Immersive Sound Bit-stream, as well as the channel-based versions such as Auro 11.1, encoded with the Auro-Codec®, and 5.1/7.1 Surround.

6.2 Large Format Consoles

Several years ago, AMS-NEVE and HARRISON, both manufacturers of Large Format Consoles, integrated the 3D panning and routing in their consoles to allow the easy creation of Auro-3D® content using the traditional workflows on such consoles. It is expected that, as soon as the metadata of the bit-stream related to the SMPTE Interoperable Immersive Sound standard is defined, both console manufacturers will provide an upgrade in order to create AuroMax® content in combination with AAT and the Barco/IOSONO external AuroMax® rendering unit.

6.3 Immersive Sound made easy

A major advantage of the AuroMax® beds and their backwards compatibility with Surround sound formats is that sound designers can easily create true immersive sound in their sound design room with or without the need of object-based effects.

AuroMax® provides an easy workflow and helps sound designers to prepare a true immersive experience in the most efficient way while keeping the option for special object based effects.