



AURO3D

AURO-3D[®] ENGINE

THE ULTIMATE SOLUTION FOR IMMERSIVE SOUND AT HOME

Auro-3D[®] Engine version: v3.2

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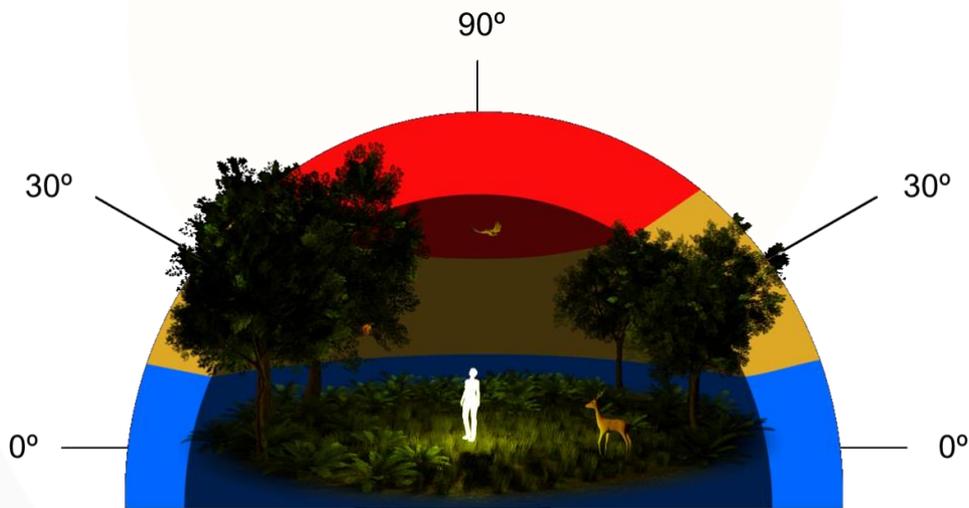
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1 AURO-3D® ENGINE FUNDAMENTALS

The reproduction of sound has seen an enormous evolution, even though the original intent has not changed: to deliver the *most natural, immersive listening experience* to the audience. Over the years, the technology and formats to achieve this have been evolving, starting with mono. Stereo recording was the first major revolution and has been (and still is) the main audio format for many decades. Only since the mid 1990's Surround recording became popular in consumer homes, with the 5.1 Surround format being the standard for more than 20 years. Amongst audio professionals, however, it was always felt that this established format, originally developed for cinema theatres, was still not able to achieve the old-age goal for natural sound.

In 2005 the AURO-3D® listening format was introduced and finally the ultimate listening experience became available: 3-dimensional sound, sometimes referred to as multichannel sound with Height. Indeed, the introduction of the *Height* layer in the AURO-3D® format is considered to be the ultimate step in providing a lifelike immersive experience to the audience, both in movie theatres and consumer homes.

Nowadays, the breathtaking AURO-3D® immersive sound can be experienced at home thanks to the revolutionary Auro-Codec® decoder, usually integrated in AVR devices, along with the deployment of – speakers over 3 different layers – Surround, Height and Top – to make the most of the latest AURO-3D® productions.



Full-fledged AURO-3D® speaker setups that make optimal use of all three layers include up to 13.1 speakers to maximize the experience. More information on how to set up your home theater system can be found in the “Home Theater Setup Guidelines” on www.auro-3d.com.

Moreover, enjoying the AURO-3D® experience is not only restricted to original AURO-3D® productions. In fact, bringing already existing stereo and surround content to the next level of immersion through AURO-3D® speaker setups has also been an important driving factor since the early days of Auro and led to the development of the already much acclaimed Auro-Matic® upmixing technology.

In recent years, the consumer audio market has seen the emergence of new kinds of audio reproduction devices such as soundbars and smart speakers as great alternatives to AVR systems for music as well as movie audio playback. Bringing the opportunity for soundbars and smart speakers customers to enjoy the AURO-3D® immersive experience became an important commitment for Auro Technologies, leading to the development of the groundbreaking Auro®-Scene™ virtual 3D audio technology to enable the AURO-3D® immersive sound on all those different devices as well.

Combining these core technologies resulted in the easiest and most flexible way to enjoy the AURO-3D® listening experience: the **Auro-3D® Engine**. It is Auro Technologies' integrated solution dedicated to provide the ultimate immersive listening experience from almost any sound reproduction device and for any type of content starting from stereo to the latest immersive audio productions. Indeed, the Auro-3D® Engine has been designed to automatically adapt the input content to the installed sound system and allow the audience to enjoy the best-in-class AURO-3D® experience in most situations encountered by audio consumers. The Auro-3D® Engine DSP solution is a great fit for various audio devices such as AV-Receivers or AV-processors, first-class soundbars, and even smart speakers.

The following diagram gives an overview of the Auro-3D® Engine architecture:

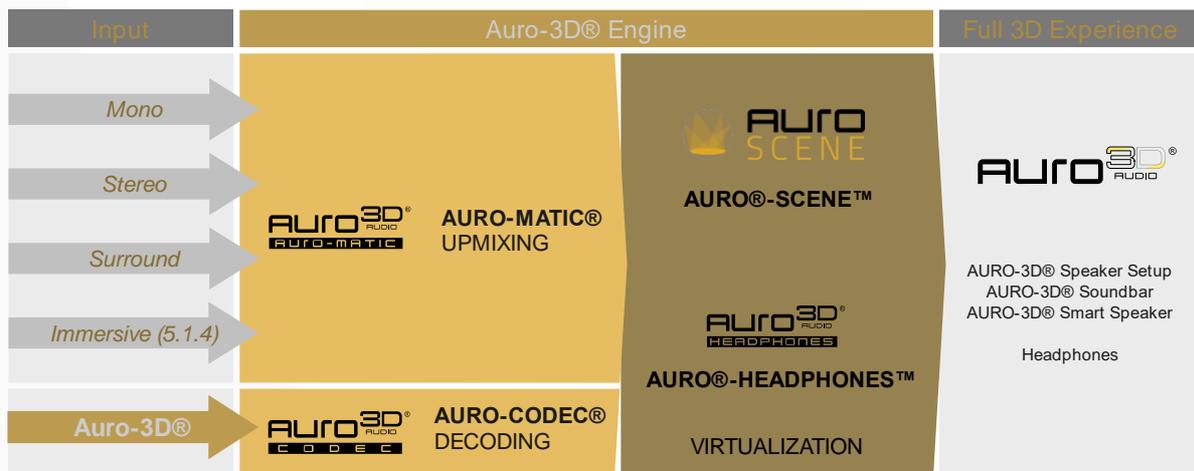


Figure 1 - AURO-3D® Engine Overview

Up-, Down-, What-mix?

Downmix

The combination of multiple audio channels from existing content into a reduced number of channels (e.g., from Auro 9.1 to 5.1 surround).

Upmix

Generation of new, additional audio channels from existing content (e.g., from stereo to Auro 13.1)

Unmix

Separation of multiple audio channels included in a single channel from an existing mix, using embedded metadata (e.g., to decode an Auro 9.1 mix from a 5.1 encoded signal)

2 AURO-3D® ENGINE HIGHLIGHTS

The Auro-3D® Engine is a complete DSP solution including different key processing blocks articulated as illustrated in the following block diagram:

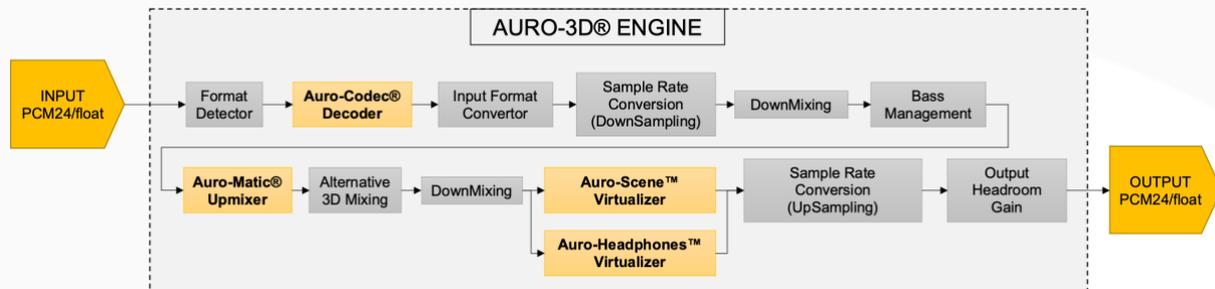


Figure 2 - Auro-3D® Engine Block Diagram

Several input formats and output configurations, as well as different sampling rates are supported. Highlighted are the 4 main core technologies around which the Auro-3D® Engine is built: the Auro-Codec® Decoder, the Auro-Matic® upmixer, the Auro®-Scene™ virtualizer for speakers and the Auro®-Headphones™ binaural processing. The Auro-3D® Engine DSP solution is intended to be integrated into an audio processing framework between an optional third-party bitstream decoder and some compatible post-processing blocks. Its main features are highlighted in the following chapters.

2.1 Four main core technologies

The Auro-3D® Engine has been designed as a combination of three outstanding core technologies:

- **Auro-Codec® Decoder:** the revolutionary audio codec that delivers native, discrete AURO-3D® content in a single PCM file at studio-grade quality. Encoded using the unique capabilities of the Auro-Codec®, native AURO-3D® content can be seamlessly decoded from a standard surround PCM carrier.
- **Auro-Matic®:** the groundbreaking upmixing algorithm that converts legacy stereo and surround content without height channels into a AURO-3D® format, or any other 3D compatible format.
- **Auro®-Scene™:** the cutting-edge AURO-3D® virtualizer that aims at bringing the breathtaking fully immersive AURO-3D® sound from any supported sound reproduction device by virtualizing sound from missing speakers above and behind the audience.
- **Auro®-Headphones™:** to reproduce a *binaural* immersive soundfield of the AURO-3D® content on headphones, earbuds, etc....

These four core technologies, combined with a number of extra features, deliver the best possible immersive 3D listening experience from any type of content, from legacy to native AURO-3D®, to any compatible speaker setup, soundbar, smart speaker or standard pair of headphone and earbuds.

2.2 Sampling rates

The Auro-3D® Engine supports different input and output sampling frequencies up to 96 kHz. Next to internal conversion required by some processing blocks running at a standard rate of 48 kHz, sample rate reduction can be optionally performed to provide a downsampled output signal. Upsampling is not supported, though. The following table shows which input/output combinations are supported by the Auro-3D® Engine.

Table 1 - Supported Sample Rates and Reduction

Input fs (kHz)	Output fs (kHz)	Ratio
44.1	44.1	1:1
48.0	48.0	1:1
88.2	88.2	1:1
96.0	96.0	1:1
88.2	44.1	2:1
96.0	48.0	2:1

2.3 Input formats

A large number of input formats are supported including standard stereo and multi-channel surround formats (5.1, 7.1). Of course, any AURO-3D® native format can be decoded using the Auro-Codec® decoder. In addition, alternative 3D audio content (i.e., not AURO-3D®) can be processed by the Auro-3D® Engine, assuming the corresponding third-party decoder is used upfront and configured to produce a compatible intermediate format. Example scenarios are the processing of such content with the Auro®-Scene™ virtualizer for an optimal soundbar/smart speaker rendering or upmixing with Auro-Matic® for playback on the AURO-3D® speaker configurations.

2.4 Output configurations

A large number of speaker configurations are supported for three different reproduction modes: AVR, Soundbar and Smart Speaker mode.

- AVR mode:** in this mode, assuming the Auro-3D® Engine is integrated into an AV-Receiver or an AV-Processor, any speaker configuration ranging from standard stereo to an Auro 13.1 setup, with or without height speakers, is supported. An overview indicating which channels are used for each AURO-3D® configuration is given in the table below. Examples of 2-layers and 3-layers AURO-3D® output configurations are also illustrated in the following figures:

Table 2 - Typical AURO-3D® Configurations

Configuration	L	R	C	Ls	Rs	Lb	Rb	LFE	HL	HR	HLs	HRs	HC	T
Auro-222 (4.0+2H)	x	x		x	x				x	x				
Auro 8.0 (4.0+4H)	x	x		x	x				x	x	x	x		
Auro 9.1 (5.1+4H)	x	x	x	x	x			x	x	x	x	x		

Configuration	L	R	C	Ls	Rs	Lb	Rb	LFE	HL	HR	HLs	HRs	HC	T
Auro 10.1 (5.1+4H+T)	X	X	X	X	X			X	X	X	X	X		X
Auro 11.1 (7+4H)	X	X	X	X	X	X	X	X	X	X	X	X		
Auro 11.1 (5.1+5H+T)	X	X	X	X	X			X	X	X	X	X	X	X
Auro 13.1 (7.1+5H+T)	X	X	X	X	X	X	X	X	X	X	X	X	X	X

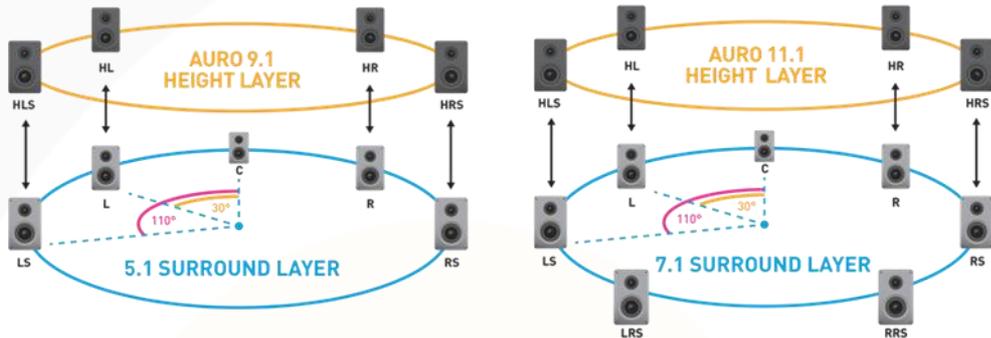


Figure 3 - Examples of 2-layer AURO-3D® Configurations: Auro 9.1 (5.1+4H) - Auro 11.1 (7.1+4H)

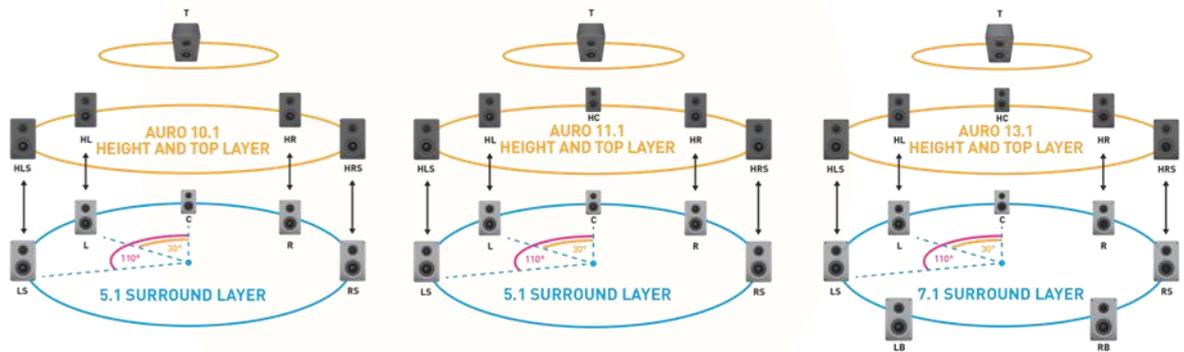


Figure 4 - Examples of 3-layer AURO-3D® Configurations:
Auro 10.1 (5.1+4H+T) - Auro 11.1 (5.1+5H+T) - Auro 13.1 (7.1+5H+T)

Note that the AVR mode can also be used in other products when combined with proprietary post-processing in , e.g., soundbars. Please contact NEWAURO to evaluate your use-case.

- **Soundbar mode:** in this mode, multiple configurations from stereo to 5.1.2, including two up-firing and two side-firing speakers, are supported. A typical 5.1.2 speaker configuration is illustrated below:

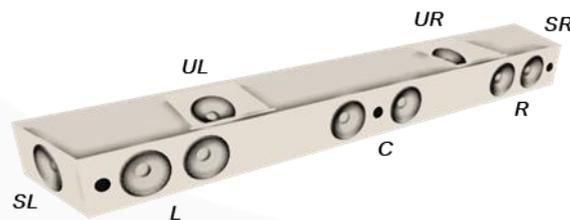


Figure 5 - 5.1.2 Soundbar Speaker Configuration

Two extra satellite speakers, including one front-firing and one up-firing speaker, can also be added to complete the soundbar setup. In that case, two options are available where the satellites can be used as surround speakers or front height speakers, which is totally unique to AURO-3D®. For the Front Height use-case, the speakers can simply be rotated by 90° so the up-firing speakers become side-firing speakers for a truly immersive experience, as illustrated below:



Figure 6 - Satellite speaker positioning as Surround (a) and Front Height (b)

- **Smart Speaker mode:** currently, only a 3.1.1 speaker configuration is supported, with or without woofer depending on the capabilities of the speakers used in the device. The 3.1.1 speaker configuration is illustrated below:

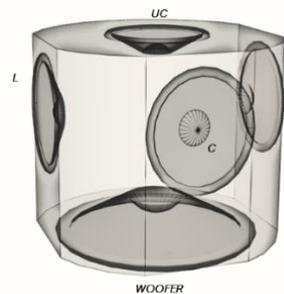


Figure 7 - 3.1.1 Smart speaker configuration

All supported configurations can be with or without a (sub)woofer. The Auro-3D® Engine can generate a subwoofer output thanks to its built-in bass management unit, including a set of cross-over filters that can be perfectly tuned to the output setup.

3 AURO-3D® ENGINE KEY TECHNOLOGIES EXPLAINED

In this section we provide more details about the key technologies used in the Auro-3D® Engine - Auro-Codec®, Auro-Matic®, Auro®-Scene™ and Auro®-Headphones™- to better understand its power and the complexity behind.

3.1 Auro-Codec®

The Auro-Codec®'s magic lies in its ability to deliver near-lossless audio quality as it stays within the PCM domain, the main format used to convert analog sound into uncompressed digital audio. Moreover, it allows multiple formats to be combined into one single PCM carrier. In fact, it is capable of mixing and “unmixing” up to three channels of PCM audio from a single encoded carrier channel. While mainly intended to enable the distribution of content in the AURO-3D® format, the Auro-Codec® also provides a unique set of features and capabilities that were previously unattainable in consumer products:

- **Single File Distribution:** A single PCM carrier-signal contains multiple, artistically controlled delivery formats: an Auro-compatible format (e.g. Auro 9.1 or Auro 11.1), Surround and an additional Stereo version. Since the Surround carrier is a standard PCM signal, it can be played back on any existing digital audio system, even when no Auro-Codec® Decoder is present in the playback device (BD-player, AV-system, etc.). If the playback device is equipped with the Auro-Codec® Decoder it will decode the original AURO-3D® mix.
- **Studio-grade Sound Quality:** The audio quality remains at the highest standards, as originally created in the studio by the audio professionals. There are no audible artefacts since the Auro-Codec® does not use any perceptual coding techniques as used in all lossy codecs, while still providing better compression ratios than lossless codecs. The Auro-Codec® does not use any matrix encoding nor does it rely on correlation between the encoded channels - all channels are discrete with 100% separation.
- **Artistic Control:** Instead of relying on automatic algorithms, each version provided by the Auro-Codec® – AURO-3D®, Surround or Stereo – can be entirely controlled by the producer.

The following picture shows how the different formats can be combined into an Auro-Codec® encoded carrier.

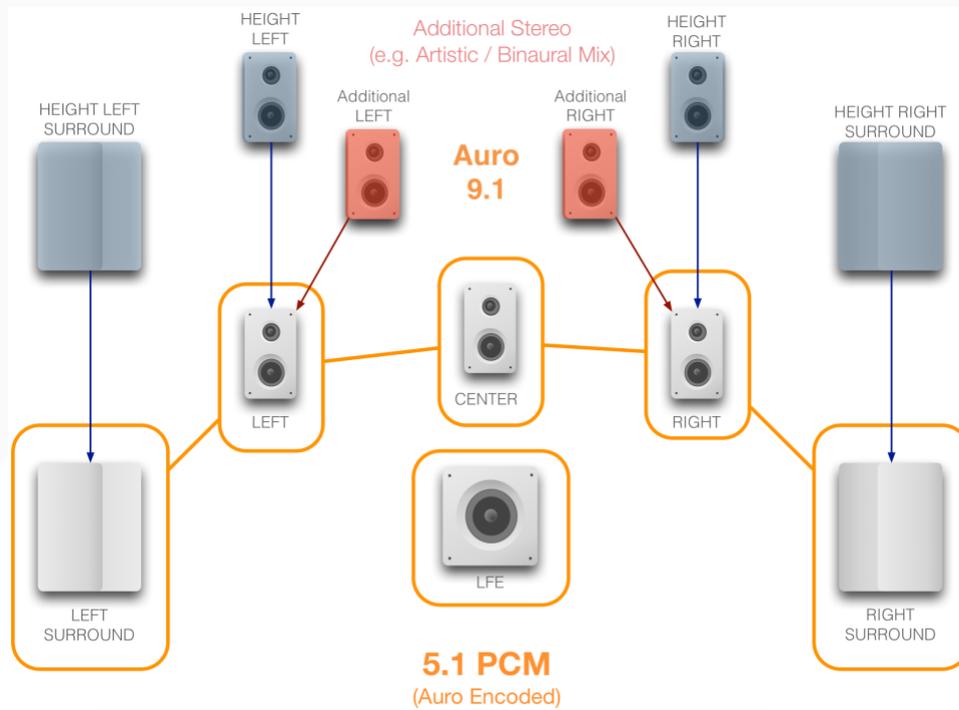


Figure 8 - AURO-3D® in a 5.1 Surround carrier

For more info on the Auro-Codec®, please see the white paper on the Octopus codec (<https://www.auro-3d.com>).

3.2 Auro-Matic®

The groundbreaking Auro-Matic® upmixing technology is used to convert any legacy content (i.e., not Auro-encoded) from Mono, Stereo and Surround into an AURO-3D® format as illustrated below:

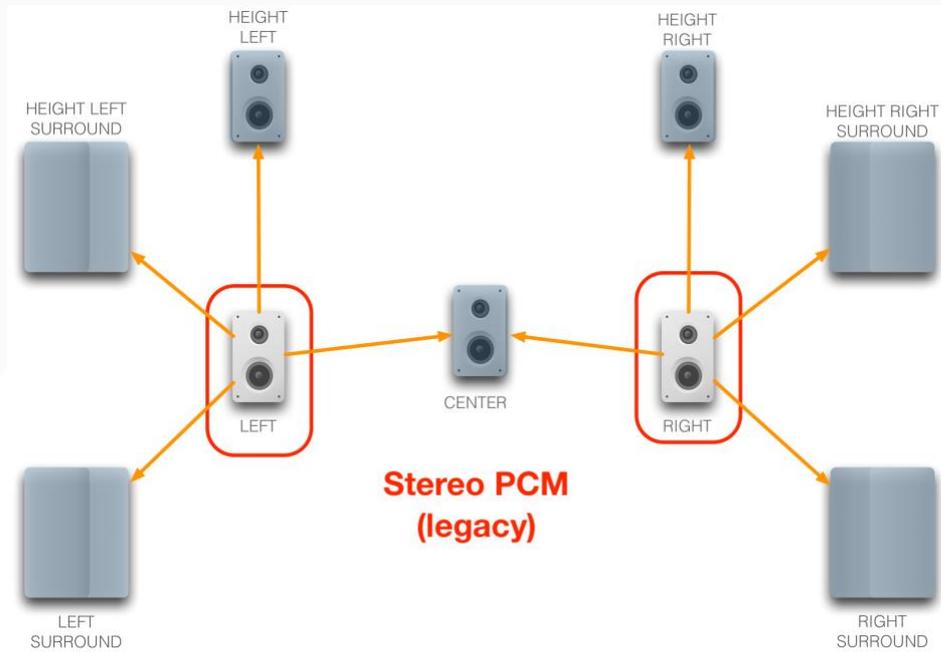


Figure 9 - Auro-Matic® upmixing from Stereo to Auro 9.1

Unlike most other upmixing technologies on the market, Auro-Matic® keeps the original channels of the input source intact instead of steering parts of it to particular speakers. The sophisticated adaptive processing rather places the original recording in a 3-dimensional environment that matches the acoustical properties of the recording, creating an immersive sound field that creates the impression of being in the same environment as where the recording was taking place.

Auro-Matic® will also further upmix AURO-3D® content in case the output configuration has more channels than present in the AURO-3D® encoded content. This is the case when some Auro 9.1 content is being played on an Auro 11.1 speaker setup, for instance. In its latest version, it is now also possible to further upmix alternative 3D audio signals, coming from other systems (i.e., not AURO-3D®).

Lastly, Auro-Matic® is also capable of upmixing other immersive sound formats, creating a much more natural, continuous immersive listening experience, even when the original mix does not contain much height information. This not only works for complete AURO-3D® speaker layouts that include Height Center and Top speakers not present in other systems, but also when the target layout is already compatible with the original rendering (e.g., 5.1.4 in → 5.1.4 out).

The Auro-3D® Engine provides different controls to adjust the results to the type of content as well as the listener's taste for a maximum of flexibility. These controls include a **Strength** setting and a **Preset** selection. Each Preset (**Small-Medium-Large**) defines a different set of parameters for the analysis of the input content and emphasizes a different characteristic of the experience. **Large** is ideal for content typically recorded in large spaces, such as orchestral recordings, while **Small** will be preferred for a more cosy experience, being

perfectly suited for programs such as chamber music. As for the **Medium** preset, it will be a great fit for most music, movies and TV shows and is thus set as default. The two additional **Speech** and **Movie** presets are dedicated to news/broadcast and large cinema experience respectively.

3.3 Auro®-Scene™

With Auro®-Scene™, the Auro-3D® Engine includes a best-in-class virtualization technology used to generate a virtual immersive soundfield from any compatible device, including soundbars, smart speakers and multi-channel speaker systems. To do so, Auro®-Scene™ optimally uses the acoustic characteristics of the reproduction device and combines them with cutting-edge sound processing technologies developed by the NEWAURO R&D center. In soundbars and smart speakers, up-firing and side-firing speakers can be used to beam the sound towards the ceiling and walls. It is thus critical to fully control the audio signal sent to those speakers to allow the sound waves to optimally reflect off the ceiling and walls to generate virtual sound source all around and above the audience. Auro®-Scene™ does this in combination with powerful sound processing techniques to also generate virtual sound sources from front-firing speakers.

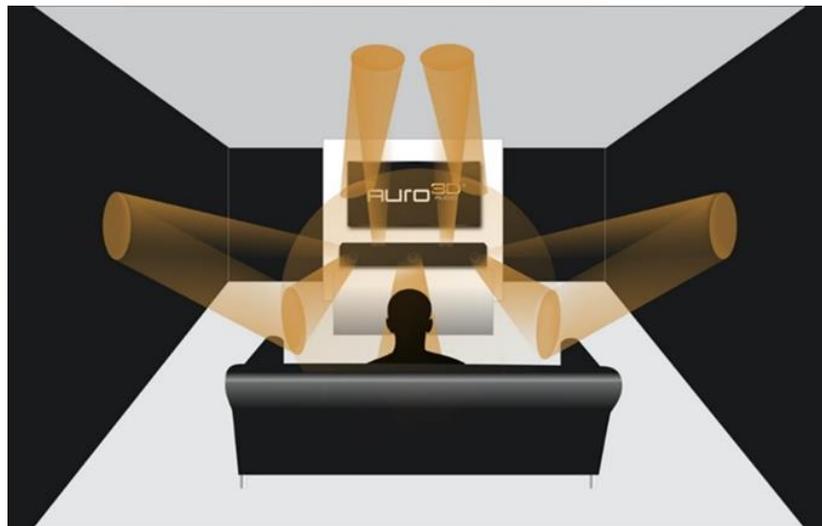


Figure 10 - Virtualization on a 5.1.2 soundbar

This challenging task aims to considerably improve the immersion of the audience in soundbar and smart speaker modes and even enable the generation of virtual speakers in AVRs. Virtual side and height soundfields can indeed be experienced with standard stereo and multi-channel systems up to 7.1.2. Larger speaker configurations already contain a sufficient number of Surround and Height speakers, eliminating the need for further virtualization.

To make all of this possible, a number of core processing technologies are used in very specific ways to generate the breathtaking 3D immersive sound as intended by the AURO-3D® format, including:

- **Cross-talk Cancellation filters** to reproduce binaurally processed audio through loudspeakers. Binaural processing creates localization cues designed to enable the AURO-3D® sound experience such that sound events can be perceived from all directions around the listener.

- **Virtual Height/Surround filters** to allow sound to be perceived as coming from overhead and all around the listener.
- **Decorrelation algorithms** to increase the differences between audio signals and thus spatially enhance the experience, significantly improving the perception of all three dimensions of the sound stage, i.e. Width, Height, and Depth.
- **Center extraction** to process centrally positioned signals separately from the rest of the content being virtualized.

Further equalization filters are also used to reduce to the absolute minimum the global sound coloration inherently introduced by the virtualization processing.

3.4 Auro®-Headphones™ Binaural processing

Starting from v3.2, the Auro-3D® Engine includes binaural rendering technology to reproduce an immersive soundfield on a standard pair of headphones or earbuds.

The Auro®-Headphones™ technology itself can handle up to 14 input sources. Typically, these will represent a virtual version of the AURO-3D® speaker configurations.

The binaural processing is based on Head-Related Transfer Functions (HRTF) in combination with high-quality algorithmic room simulation to enhance the realism of the virtual soundfield.

As it is well-known that binaural listening is highly dependent on individual physiomy, multiple HRTF filter banks are provided as presets to allow the listener to select a filter bank that provides the most natural experience for timbre and spatial positioning. An additional ITD Offset (Inter-aural Time Difference) control then optionally allows the user to further adjust the processing for more accurate positioning of the sources.

Room simulation is a critical element of the binaural processing, creating reflections in 3D space that increase the realism and source position accuracy. The Auro®-Headphones™ processing provides 4 Room Presets that can be selected by the user according to taste:

- **Home Cinema** (default)
- **Lounge**
- **Cinema Theater**
- **Concert Hall**

While the Auro®-Headphones™ processing has been designed to be as efficient as possible, it might still be quite CPU intensive for some implementations. However, a 'Quality' control is provided to decrease the CPU load at the expense of reduced precision and externalization without introducing artefacts.

3.5 Listening modes

The Auro-3D® Engine provides the ability for the end-user to select a preferred listening experience amongst up to 4 listening modes. They essentially depend on the user's personal taste, the type of content being played back and the reproduction device, and provide a different experience ranging from stereo (1D) to full immersive sound (3D) described as follows:



Figure 11 - Main listening modes

1. **Stereo:** All content will be played back as a stereo version. This thus means that stereo content will remain untouched, while Surround and AURO-3D® signals will be downmixed to a 2-channel version. For soundbars and smart speakers, the Auro®-Scene™ processing is still active in this Listening Mode and will therefore still create a wider soundstage than without the processing.
2. **Surround:** The Auro-3D® Engine creates a full Surround experience on all available speakers in the Surround plane or through virtualization on soundbars and smart speakers, regardless of the provided input signal. It will NOT create any Height or Top signals. This means Surround content encoded with the Auro-Codec® will be decoded (and further upmixed if needed) and all other content will be upmixed to the available surround (typically 5.1 or 7.1) speaker configuration or virtual equivalent.
3. **AURO-3D:** The Auro-3D® Engine creates a full 3D immersive experience on all available speakers by applying virtualization if needed, regardless of the provided input signal. This means Auro-3D® encoded content will be decoded (and further upmixed if needed) and all other content will be upmixed to the selected physical or equivalent virtual speaker configuration.
4. **Native:** This extra Listening Mode is introduced to provide the listener with the experience as close to the original content created by the artist as possible. In this mode, the Auro-3D® Engine will only perform decoding and/or downmixing, but never upmixing, depending on the combination of the input and output configurations. Stereo input signals will therefore be played back as a stereo output, 5.1 Surround as 5.1 outputs, Auro 9.1 as Auro 9.1, etc..., even if more speakers are available. For Soundbars and Smart Speakers, the Auro®-Scene™ processing will then only virtualize the available signals and will be disabled for the AVR configuration.

4 IMMERSIVE SOUND WITHOUT ANY COMPROMISE

4.1 Range of applications

The Auro-3D® Engine has been designed to be integrated in a large range of audio products dedicated to immersive sound at home for three different type of applications summarized below:

<p style="text-align: center;">AVR SYSTEMS</p> <p style="text-align: center;">Auro-3D® Engine integrated into an AV-Receiver or an AV-processor Supporting setup from Stereo to 13.1 Auro-3D®</p>  <p style="text-align: center;">AURO 10.1 CONFIGURATION</p>
<p style="text-align: center;">SOUNDBARS</p> <p style="text-align: center;">Auro-3D® Engine integrated in the soundbar embedded electronics Supporting setup from 2.0 to 5.1.2 with an extra pair of surround/height satellites</p>  <p style="text-align: center;">5.1.2 SOUNDBAR WITH FRONT HEIGHT SATELLITES</p>
<p style="text-align: center;">SMART SPEAKERS</p> <p style="text-align: center;">Auro-3D® Engine integrated in the smart speaker embedded electronics Supporting only 3.1.1 setup for convincing immersive soundfield from a small device</p>
<p style="text-align: center;">HEADPHONES</p> <p style="text-align: center;">Auro-3D® Engine integrated in media player applications, in mobile devices</p>

4.2 Most flexible and performant solution

When enabled, the Auro-3D® Engine will take any incoming PCM audio stream, analyze it and automatically select the correct process to create the optimal output, based on the selected listening mode, and take full advantage of the available speaker configuration.

It combines the best-in-class Auro-Codec® decoder, Auro-Matic® upmixer, Auro®-Scene™ virtualization and Auro®-Headphones™ technology with other processes to create a highly flexible and performant solution dedicated to immersive sound at home. Without doing any compromise on quality, it results in a complete and powerful audio DSP product, offering optimized latency, typically around 1152 samples, that will be perfectly suitable for processors with strong specifications. A large number of target platforms are currently supported for the Auro-3D® Engine implementation, including:

- ADI DSP: Griffin Lite (ADSP-SC573), Griffin Ultra-Lite (ADSP-21569), Griffin Lite XP (ADSP-21593)
- TI C66xx, C67xx DSP
- ARM-based SoC: NXP i.MX8M, Qualcomm QCS405, ARM v7A Android9, ARM aarch64 apple iOS
- Linux OS x86_64

Moreover, for even more flexibility, the Auro-3D® Engine also supports a Low Latency mode in which the Auro-Codec® decoder and format detection are disabled, resulting in a much lower inherent latency of the Auro-3D® Engine, typically between 0 and 32 samples, depending on which processing (upmixing, virtualization, sample rate conversion) is enabled. This is particularly interesting when applying Auro-Matic® and/or Auro®-Scene™ on regular stereo and surround sources from non-lossless audio codecs or to enable the implementation of a 'split engine' scenario in which the decoder and post-processing parts of the Engine are implemented on separate processing engines.

For more info, please contact info@auro-3d.com.