IKO by IEM and sonible
How To Use - Software Tutorial

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https://github.com/sonible/howtoiko

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Contents

0 Quick Start Guide

Very first time IKO users probably need to grab some software packages initially:

- Download and install latest Reaper[1], ambiX[2] and mcfx[3] plugins. Check if ambiX and mcfx plugins can be loaded in Reaper.
- Download the latest IKO filter dataset and the BeamTest / Demo Reaper projects[4].

Once, this is done and works conveniently on your computer, the following guidelines might help to get IKO playing as quick as possible. We recommend taking your time for this complex device, though.

- Make sure that you have all devices together. See the required components listed in Sec. 6 on page 43.
- Set up the IKO according to the setup video tutorial[5]. Make sure to internalize the way how to (dis)-assemble the IKO.

  You will need two persons doing (dis)-assembly, since IKO is heavy and not handy for a single person!!!

  Especially IKO's disassembly might be a little bit tricky when performing it for the very first times. However, it follows a straightforward and logical convention, *(...) IKO is stored face down (...)* in the video tutorial.
- Make sure that the look at the IKO from the frontal audience axis (x-axis) matches the depiction in Fig. 15 on page 21, that might be referred to as the IKO face :-). In Fig. 16 on page 23 the corresponding top view for a typical performing situation with a half-circled reflector wall behind the IKO is depicted.
- Set up and connect the d:24 with the loudspeaker multi-core cable and the sound card. Make sure that your sound card setup realizes a 1:1 channel routing from Reaper Out to d:24 In.
- If you want to make sure that IKO is correctly set up and if you have enough time doing that, please go trough the steps described in Sections 4.3 and 4.4, from page 26. We strongly recommend to do so.

[1] https://www.reaper.fm
[2] http://www.matthiaskronlachner.com/?p=2015
[3] http://www.matthiaskronlachner.com/?p=1910
[4] https://github.com/sonible/howtoiko
[5] https://youtu.be/c0RivAnQSxE

- If you are on the fast lane, and trust that everything is performing well, directly proceed to run the Reaper project 'IKODemo1.RPP' provided in the 'IKOReaperProjects/IKODemoSuite' folder. You should see a Reaper screen similar to Fig. 25 on page 35.
- Make sure that you set up the preset folder to 'IKOFilter' (which is provided when you downloaded the IKO filter data set) in the 'mcfx_convolver24' instances which are loaded into the tracks W DECODE and HOA DECODE. You have to do this initially. Once you save the Reaper project the used folders and presets are memorized.
- The preset folder 'IKOFilter' is correctly chosen, when the 'opening a preset' action allows you to switch to the 'sonible_IKO6_September_2017' structure. Within this structure two presets should be available:

  'IKO6_September_2017'

  'IKO6_September_2017_Omni'.

  For details see Sec. 3.4 on page 18.
- Load the preset 'IKO6_September_2017' in the 'mcfx_convolver24' instance for HOA DECODE.
- Load the preset 'IKO6_September_2017_**Omni**' in the 'mcfx_convolver24' instance for W DECODE.
- Make sure that the correct sound card is set up in Reaper / Preferences / Audio / Device with 44.1 kHz sampling rate.
- Make sure that you have sufficient reflector walls in suitable positions set up and/or available.
- Make sure that the routing in IKO OUT (this is the master volume) is correctly set up for feeding the 20 amplifier channels. Un-mute the amp.
- Play the Reaper project from start. When increasing the IKO OUT fader gain slightly, IKO should be playing, if everything turned out all right.
- If not, it is time to pay more attention to the tutorial. The potential pitfalls might be looked at:

  Check if the plugins ambiX and mcfx are correctly recognized by Reaper.

  Check if the 'mcfx_convolver24' successfully loaded all IKO filters. This should look like Fig. 25, right on page 35. Please see details in Sec. 5.1.2 on page 37.

Check the different metering provided by Reaper, mcfx and the amp in the signal flow to estimate potential wrong routings. For that, it might be a good idea to internalize and check the signal flow depicted in Fig. 26.

Step back and check the test setups in Sections 4.3 and 4.4, from page 26.

- If the IKO is playing you can luckily do fancy stuff. You might play the whole Demo Suite I to get an impression on the spatial sound phenomena. If you want to modify something, you might do this in the the tracks 8-11, that contain the audio material for spatialization by the IKO. Each of these tracks has an Ambisonics encoder included. By that the beam direction and movement can be set up. Play around with the level and different beam directions of these tracks to get an idea what's going on. For own audio tracks you might copy one of the tracks and modify it to your needs.
- Fig. 23 visualizes certain beam directions meant as a top view of the IKO setup as shown in Fig. 16.
- Have fun!

1 Introduction

At the Institute for Electronic Music and Acoustics (IEM) of the University of Music and Performing Arts Graz (KUG) research on Ambisonics and 3D Audio technology is a main research focus for decades.

Spherical arrangements of loudspeakers are suitable for creating variable -directivity radiation of sound. The research at IEM about this topic has been started in Oct 2005 (...)[6]*. The IEM icosahedral loudspeaker (IKO) is a new musical instrument that has been built in 2006, originally with the idea to holographically mimic musical instruments. It consists of an icosahedral housing carrying 20 individually driven loudspeakers. IEM has been constantly working on the IKO, in order to continuously improve its quality for audio playback and playing electro-acoustical concerts. Now we are proud to announce that there is a high-quality product that just came to life in 2016*[7]: **IKO by IEM and sonible**

In 2016 sonible started to develop a ready for the market version of the IKO making the cabinet even smaller, using more powerful drivers and optimizing the mechanics, yielding the IKO by IEM and sonible cooperation. Together with sonible's d:24 power amp the **IKO system**, shown in Fig. 1, is the first commercial, compact 3rd order Ambisonics based sound emitter capable of three-dimensional beam forming for entertainment, industrial applications, art.

Figure 1: IKO system: **IKO by IEM and sonible** loudspeaker, sonible d:24 power amp, customized cabling and flight case.

[6] `https://iaem.at/Members/projekte/sphericalarrays/compact-spherical-loudspeaker-arrays`

[7] `http://iem.kug.ac.at/projects/osil/about-the-iko.html`

1.1 Enhanced Immersion with 3D Audio

A still increasing amount of loudspeakers, being set up as compact or distributed loudspeaker arrays, is nowadays utilized for 3D audio, such as in medical and engineering research and in (home)-entertainment in order to enhance the auditory perception of (reproduced or synthesized) spatial sound phenomena, often referred to as audio immersion. (...) Virtual acoustic reality is a special application for enhanced audio immersion, creating a simulation that is technical identical or perceptually convincing to a spatial sound phenomenon under reference [1].

Besides headphone-based so called binaural reproduction—to generate the two ear-signals, that have all spatial information encoded to provide audio immersion—massive-multichannel loudspeaker usage for 3D audio is popular for larger audiences.

It is common agreement that an audience-surrounding loudspeaker array with appropriate individual control of all loudspeakers can enhance the degree of immersion within a reproduced auditory scene considerably. Most important for this achievement is a convincing localization and timbre of virtual sources, as well as a convincing envelopment by the whole scene, cf. [2].

While for home entertainment this is typically approached with not more than 9 loudspeaker channels for surround formats, cinema entertainment meanwhile utilizes more than 10 loudspeakers, still increasing. In the last years so called height channels (i.e. elevated loudspeaker) were introduced into the formats and became realized setups since this is mainly considered to improve envelopment.

Different approaches (channel- and object based scene coding) and reproduction methods, i.e. algorithms how to decode a virtual scene to the given loudspeaker setup coexist for different requirements, applications and also due to competition.

1.2 Beamforming with Ambisonics

One method to encode and decode a sound field to be used for enhanced immersion is so called Ambisonics, cf. [3]. In general this method is just the continuation of the simple idea to superimpose the radiation patterns of a monopole and dipole in different directions and with different weightings to create e.g.the very useful different types of cardioid microphones or cardioid subwoofers. The continuation considers higher order (theoretically infinite, but countable) patterns that get increasingly complex in all directions, cf. Fig. 2. Summing these patterns

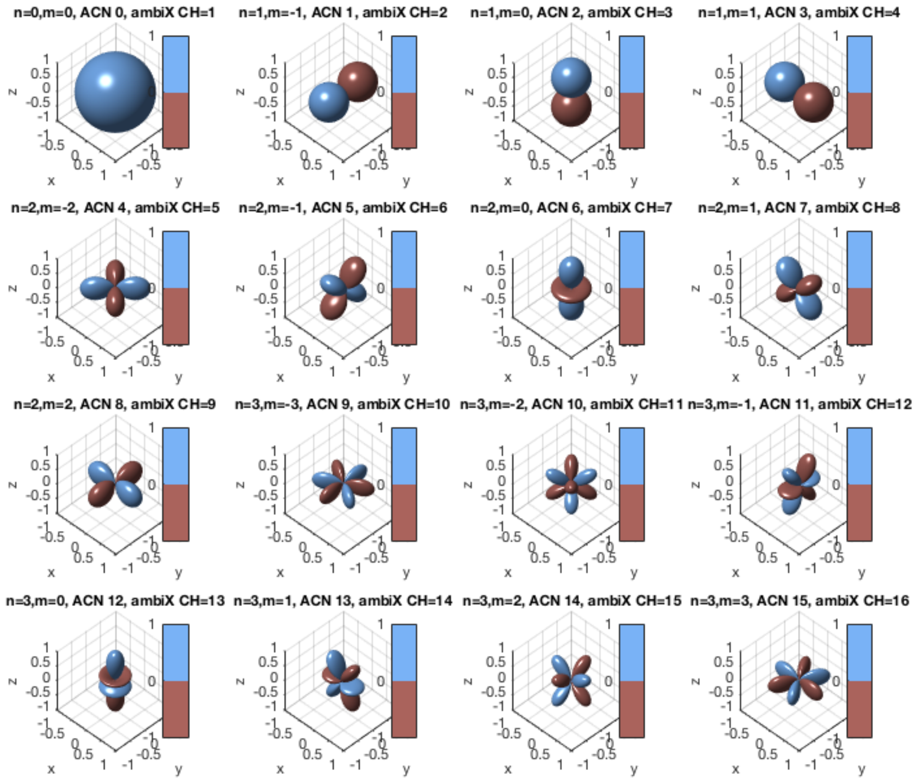

Figure 2: First 16 spherical harmonics according to the chosen IKO coordinate system convention and ambiX encoder handling, see Fig. 16, 21 and 23. These spherical harmonics can be for up to 3rd order Ambisonics beamforming by suitable (weighted) superposition.

in weighted manner (known for a long time, sometimes referred to as Laplace Series) we can realize arbitrary functional courses along a spherical surface. Vice versa, arbitrary functional courses can be decomposed into these patterns, then the weights will be found. In practices we can only capture and reproduce a limited number of these patterns, which is known as limited spatial resolution.

This is approached in Ambisonics recording and reproduction. Trying to put it very, very simple: special spherical microphone arrays capture a sound field at a certain position and the pattern's weights will be found (known as Ambisonics encoding). With spherical loudspeaker arrays, that surround the audience, these weights will be utilized to derive individual loudspeaker control signals (Ambisonics decoding) in order to re-create the captured sound field in the middle of the sphere. Depending on the used resolution, the 'middle' exhibits different, frequency dependent, spatial extent, ideally as large as the desired listening area.

In theoretical chemistry and physics, and thus acoustics the method behind Ambisonics is known as (de)-composition into eigenmodes / harmonics, here the spherical domain, and thus called spherical harmonics.

The IKO utilizes Ambisonics en- and decoding as well—with the first 16 eigenmodes / spherical harmonics depicted in Fig. 2. Here, only the compact loudspeaker array is radiating outwards (just like a transmitting antenna) and the audience is away from the loudspeaker array (just like a receiving antenna). This case might even be more intuitive than the inward sound field reproduction problem above, because we just need to think about radiating a sound beam tow a certain direction in the far-field case.

For that we generate desired beam patterns from superposition of weighted spherical harmonics and we can orientate these beams in any direction—since the spherical shape exhibits no preferred direction—by individual electronic control (filtering) of the speakers. That's what the IKO is basically doing. How simple can it be?!

It took over ten years of university research and development to finally make this feasible; and another two years of streamlining the outstanding approach towards a manageable product. And we are still in initial states doing that.

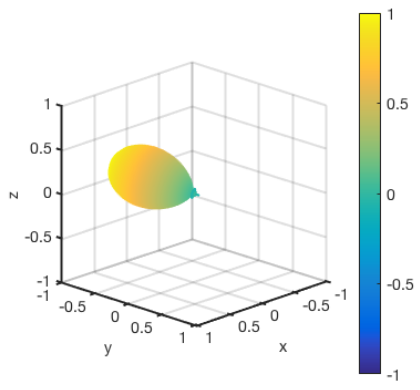

Figure 3: 3rd order Ambisonics beamforming using max-$\mathbf{r}_E$ weighting. IKO Eigen-Beam #10 (cf. page 25) with $\phi = 288\,\text{deg}$ and $\theta = 79.2\,\text{deg}$ is shown.

The story is rather long, why using an icosahedral chassis, why using these radii, why using these driver sizes, and why using max-$\mathbf{r}_E$ weighting for the desired beam pattern depicted in Fig. 3. We do not want to bother you here, but it's just the best compromise from technical and perceptual aspects at the moment for the intended applications in mind. If you want to go into detail, [3–5] and the above mentioned links of the IEM/KUG are good starting points.

1.3 Sound Scapes by Beams and Wall Reflections

From technical viewpoint the achievements for IKO are outstanding, however the initial dream of synthesizing arbitrary radiation patterns over the full audio bandwidth remains, since the required technical effort is not feasible at the moment. Thus, IKO has found its way to other applications, such as being a musical instrument in contemporary computer music and acting as research tool for generating plastic sound objects, cf. page 35. Furthermore the IKO is powerful enough to be used as a compact acoustic emitter for room acoustics measurements.

For the mentioned applications the excitation of room reflections is mandatory. If there is anything that IKO is outstandingly capable of, then this: generat-

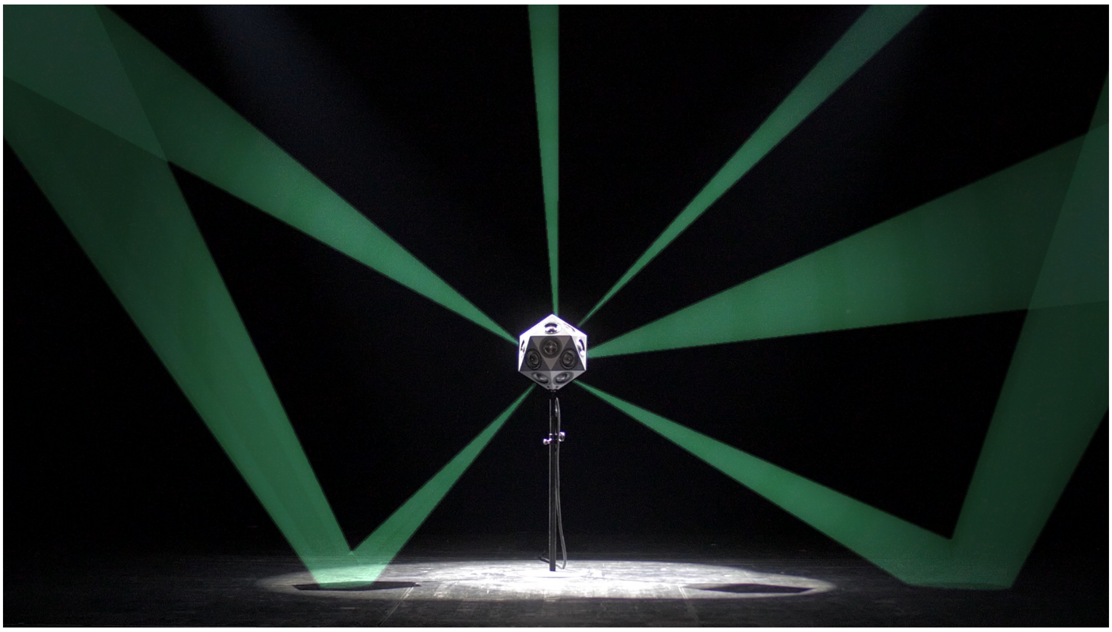

Figure 4: Schematic depiction of the IKO radiating six sound beams to different directions. Two floor reflections are visible for the beams steered downwards.

ing multiple, differently shaped beam patterns into freely selectable directions to excite different room reflections, cf. Fig. 4.

By that complex room excitation can be realized that is hardly achievable with other technologies. Perhaps, most likely you might compare this with the results that can be realized with sophisticated home-entertainment sound bars that are not fully 3D capable, though. The resulting sound fields in the room can be perceived as spatial sound phenomena with a very high degree of sonic immersion. *Experiencing the IKO (...), first-time listeners describe sculptural sound phenomena that they have not been able to imagine before and even specialists in the field experience spatial events that are hardly describable by common terminology* [1].

2 General Audio Routing and Busses

In this section we shortly describe what kind of audios signals and audio busses we have to deal with when producing with and for the IKO. In Fig. 5 the general IKO signal processing flow is given.

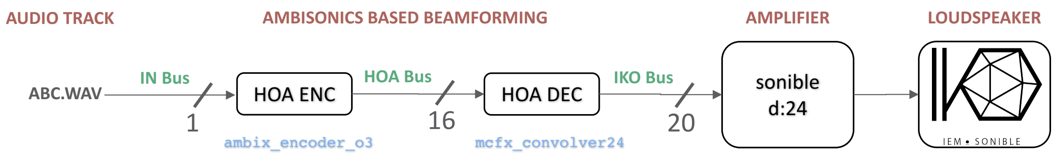

Figure 5: IKO specific signal flow for single input channel 3rd order Ambisonics encoding to a certain beam direction (HOA ENC) and Ambisonics decoding (HOA DEC) to the 20 IKO drivers.

2.1 Input Audio Channels / IN Bus (1x/2x)

Typically, audio material that is to be spatialized stems from a mono track and is then Ambisonics encoded to a single IKO beam. Sometimes, stereo files are set up to a dual IKO beam with certain opening angle between the two beam directions.

2.2 Ambisonics Channels / HOA Bus (16x)

The IKO works with 3rd order Higher Order Ambisonics (HOA) max-$\mathbf{r}_E$ weights beamforming [3, 5]. Thus we have to deal with (HOA-order + 1)^2 = 16 channel busses (in Reaper: tracks) for embedding the HOA channels also called as Ambisonics channels. Each of the 16 HOA channels exhibits one input audio signal that is encoded following the so called ACN ordering scheme. The ACN ordering scheme is given in table 6 and links the encoded signals in the HOA channel to the corresponding eigenmodes in Fig. 2.

2.3 Loudspeaker Channels / IKO Bus (20x)

Unsurprisingly due to its designation, the IKO exhibits the icosahedral shape of the 5th platonic solid and thus has twenty equilateral, triangular surfaces each embedding one loudspeaker driver. For playback to the IKO thus we have to deal with a 20 channel bus/track either as master out from a digital audio work

ACN	ambiX CH	n	m
0	1	0	0
1	2	1	-1
2	3	1	0
3	4	1	-1
4	5	2	-2
5	6	2	-1
6	7	2	0
7	8	2	1
8	9	2	2
9	10	3	-3
10	11	3	-2
11	12	3	-1
12	13	3	0
13	14	3	1
14	15	3	2
15	16	3	3

Figure 6: ACN ordering scheme used in the ambiX plugins, cf. Fig. 2 for the connection to the corresponding spherical eigenmodes.

station (DAW) or as multi-track stream. The numbering directly follows the scheme described in Sec. 4.2.

For Ambisonics based beamforming the HOA bus (16 channels) is decoded to the IKO Bus (20 loudspeaker channels), as described later.

3 Software Components

In order to work with the IKO system, it is proposed to utilize the following software packages: Reaper, Matthias Kronlachner's plugin suites *mcfx* and *ambiX*, as well as proprietary IKO filter datasets[8]. These are discussed in detail in the following subsections.

3.1 Digital Audio Workstation Reaper

We propose to use the digital audio workstation (DAW) Reaper[9] for productions with the IKO system. Although many other DAW manufacturers just recognized the importance of massive multichannel capable send and aux busses and implementing it at the moment, Reaper initially provided this feature from the very beginning, making it the perfect choice to work within the Ambisonics domain.

> We did not test other environments, yet. However, Ableton Live together with MaxMSP seems to be a convincing way of doing things with the IKO. We will check this out in near future. If you have another preferred production environment, let us know, in order we can think about it.

3.2 Ambisonics PlugIns ambiX o3

The ambiX plugin suite realizes Ambisonics based en-/decoding as well as signal processing within the Ambisonics domain. The IKO utilizes 3rd Ambisonics. Ambisonics decoding is realized with the proprietary IKO filter dataset described in Sec. 3.4. Thus, for simplest IKO beamforming only the ambiX 3rd order encoder, depicted in Fig. 7 is required.

The tutorial uses the 3rd order ambiX plugins of version v0.2.7 for VST under a MAC OSX 10.11.6. This configuration was extensively used and tested while working with the IKO and behaves robust and stable. You might download the source code of this version tag at [10]. Pre-compiled VST plugins for different OS might be downloaded at [11].

[8] `https://github.com/sonible/howtoiko`
[9] `https://www.reaper.fm`
[10] `https://github.com/kronihias/ambix`
[11] `http://www.matthiaskronlachner.com/?p=2015`

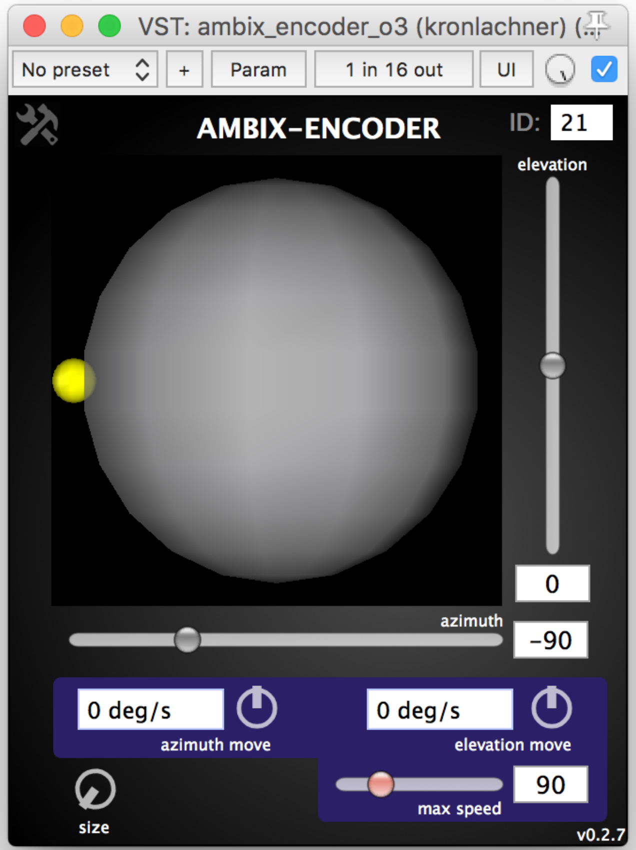

Figure 7: ambiX_encoder_o3.

If you want to use other Ambisonics encoder plugins, please ensure and validate that your chosen encoding process is equivalent to the ambiX convention [6], most important following the ACN and SN3D handling. Furthermore, it is very important to check which azimuth, elevation and spherical coordinate system convention is chosen in your preferred Ambisonics encoder. You very likely will end up with other values for Table 1 and based on the spherical visualization of the encoder GUI you might reconsider what you see and what beam directions you get. For example, the Blue Ripple Sound O3A Panners (i.e. 3rd order Ambisonics encoder) work also with ACN and SN3D handling, but exhibit different convention for azimuth. While, the elevation remains the same, the azimuth has an inverted sign compared to the ambiX convention from Table 1.

The plugins **ambix_converter_o3** (cf. Fig. 8), **ambiX_mirror_o3** (cf. Fig. 9) might help to adapt differently derived HOA streams to the IKO conventions. **If you use the ambiX encoder with the IKO system you will not need these sophisticated plugins, but only the ambiX_encoder_o3 in the first instance.** The proprietary decoder then handles the required SN3D to N3D normalization and mirroring to adapt to IKO convention.

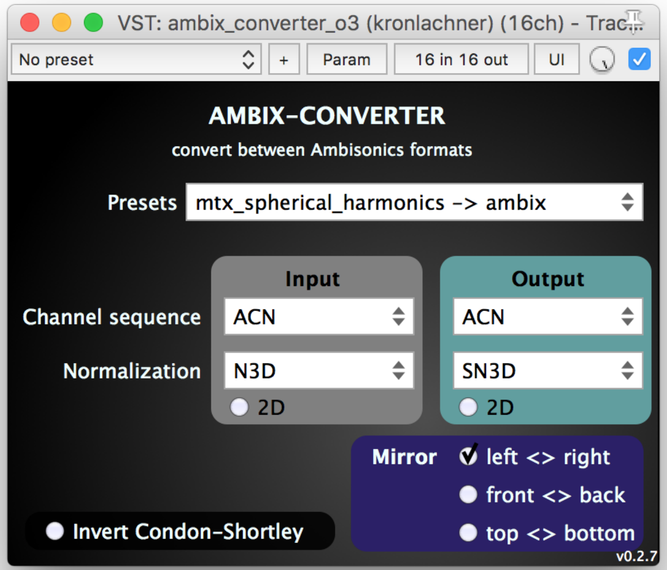

Figure 8: ambiX_converter_o3.

A useful plugin within the ambiX suite is the **ambiX_rotator_o3**, cf. Fig. 10. By that a whole HOA stream, and thus a 3D audio scene, can be easily rotated, here the 3rd-order HOA stream. Further signal processing within the Ambisonics domain can be realized with the plugins **ambiX_warp**, **ambiX_directional_loudness**, **ambiX_widening** [7].

A practical feature of the **ambiX_encoder_o3** is the 'size' parameter located left / bottom in the GUI. With that the HOA order can be continuously faded from 3rd order (size=0, default case, resulting in a beam shape depicted in Fig. 3) to 0th order (size=1, monopole, Fig. 2 top/left). The fading curve features pure 2nd order HOA for size=0.5 and pure 1st order HOA (also known as First

Figure 9: ambiX_mirror_o3.

Order Ambisonics, FOA) for size=0.6.

3.3 DSP PlugIns mcfx

The mcfx plugin suite realizes different standard signal processing algorithms, such as delay, gain, IIR / FIR filtering and metering. mcfx has outstanding features that fit to the Ambisonics based signal processing, such as multichannel processing and low-computational 'filter and sum'-convolution. The tutorial uses the mcfx plugins of version v0.5.3 for VST under a MAC OSX 10.11.6. This configuration was extensively used and tested while working with the IKO and is robust and stable. You might download the source code of this version tag at [12]. Pre-compiled VST plugins for different OS might be downloaded at [13].

[12]https://github.com/kronihias/mcfx
[13]http://www.matthiaskronlachner.com/?p=1910

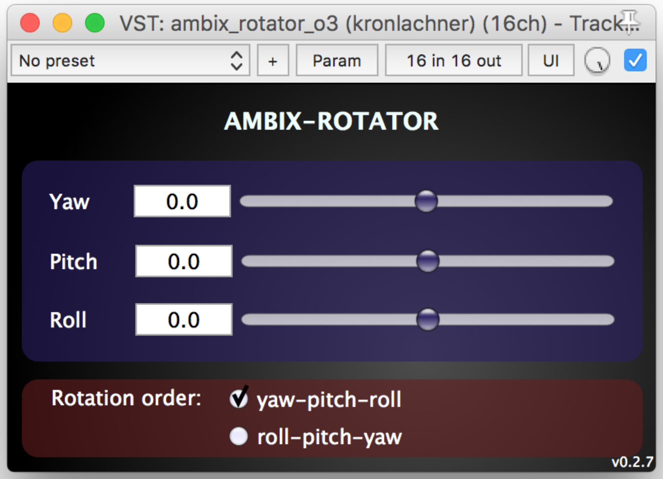

Figure 10: ambiX_rotator_o3.

mcfx_gain_delay24, cf. Fig. 11 is a very handy insert FX allowing to adapt gain, mute, polarity and delay of the individual signals of a bus (here with 24 signals). Furthermore, test signals from a signal generator can be utilized on individual channels with an automated step through option. With this plugin insert into the master output and into the Ambisonics bus, individual signals in these bus domains can be easily accessed. Please, ensure that the plugin behaves transparent or is bypassed if you want to use IKO in normal operation mode.

A further very convenient plugin is the **mcfx_meter24**, depicted in Fig. 12 to monitor levels on busses. Typically, we use this to check the master out levels and the HOA bus levels, both pre fader.

The plugin **mcfx_filter2** realizes an infinite impulse response (IIR) filter bank of a series cascade consisting of low cut, low shelf, 2x bell, high shelf, high cut filters, cf. Fig. 13. For the specified bus-width all signals will be filtered with the same filter parameters.

The most important tool for working with the IKO is the excellent plugin **mcfx_convolver24**. It realizes 'fast convolution and summing' operations for virtually arbitrary input/output configurations. These are controlled by *.conf file-structures [14]. For playing the IKO this plugin is used to handle the Ambison-

[14] `https://github.com/kronihias/mcfx/blob/master/CONVOLVER_CONFIG_HOWTO.txt`

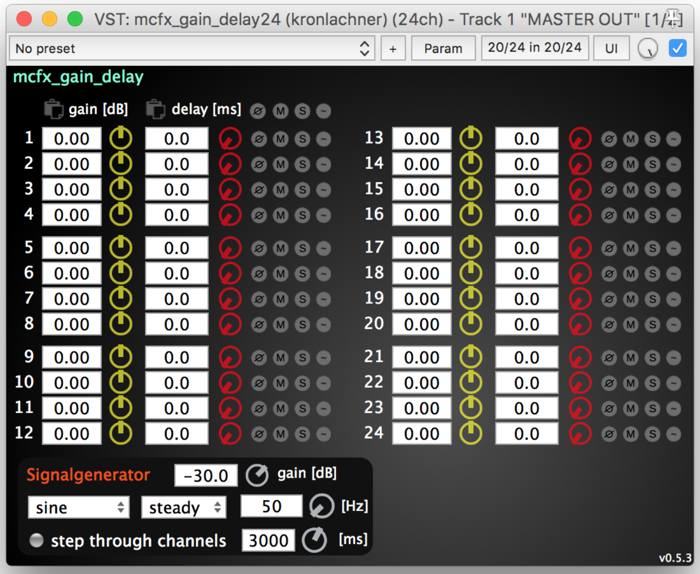

Figure 11: mcfx_gain_delay24.

ics decoder together with loudspeaker linearization in a single signal processing step.

3.4 IKO Filter Dataset

The provided folder 'IKOFilter' includes filter sets for the 5-inch driver equipped IKO (IKO5) and the 6-inch driver equipped IKO (IKO6). The filter design is straightforwardly based upon [8] using dedicated measurements of IKO5 and IKO6. The sampling rate for these filter sets is 44.1 kHz. For the 6-inch IKO, the current filter set version is from September 2017. Thus, the actually required filter set is located in the folder
'**sonible_IKO6_September_2017**' and consists of

- file 'IKO6_September_2017.conf' (this appears also as the preset name in mcfx_convolver24)
- file 'IKO6_September_2017_Omni.conf' (this appears also as the preset name in mcfx_convolver24)
- subfolder 'wav' with 320 wav-files each including a finite impulse response (FIR) with the naming convention 'IKO_Filter_i_o.wav' with $i = 1, 2...16$

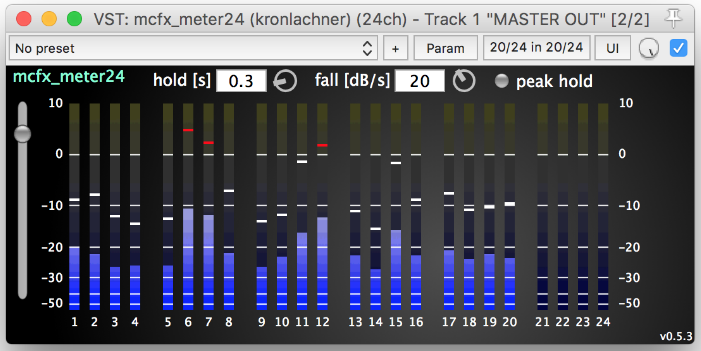

Figure 12: mcfx_meter24.

(Ambisonics ACN mode) and $o = 1, 2, ...20$ (IKO loudspeaker)

These FIR filters are instantiated by the plugin **mcfx_convolver24** via the corresponding *.conf files.

With 'IKO6_September_2017.conf' the full 3rd-order Ambisonics decoding is realized. With 'IKO6_September_2017_Omni.conf' only the first eigenmode (omnidirectional radiation, point source) is decoded, and thus actually only the FIR 'IKO_Filter_i_o.wav' for $i = 1$ are used. The multichannel filtering realizes the max-$\mathbf{r}_E$ weights [3,5] Ambisonics decoding [16 (full 3rd HOA) or 1 (omni only) Ambisonics modes decoded to 20 loudspeakers], as well as on-axis frequency

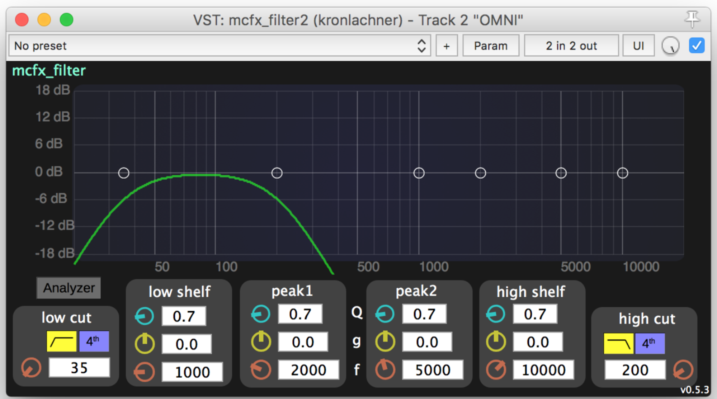

Figure 13: mcfx_filter2 realizing a bandpass.

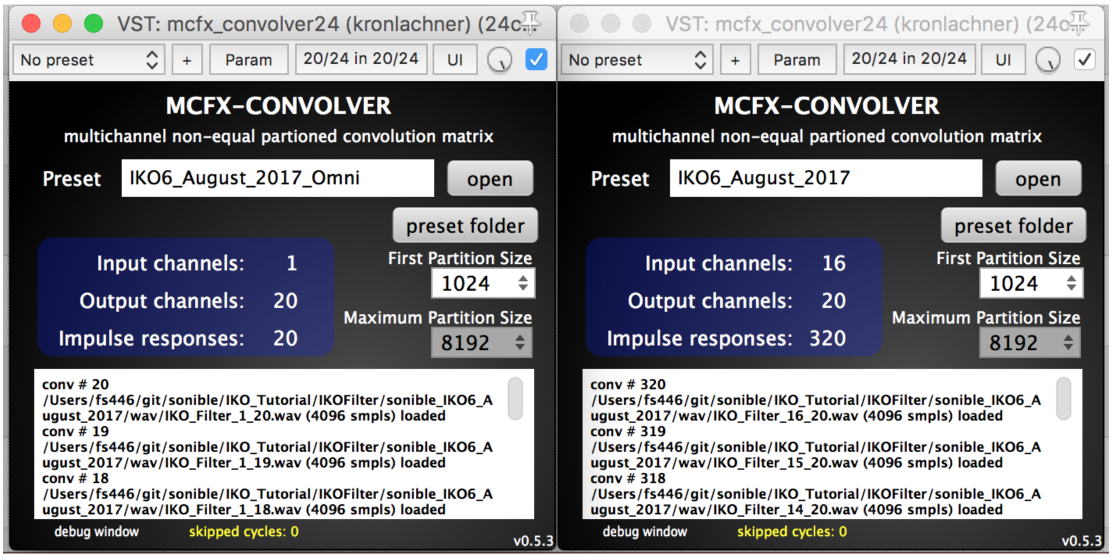

Figure 14: mcfx_convolver24 with IKO6 presets loaded as of August 2017, left decoding for pure omni-directional radiation in W DECODE, right full 3rd-order Ambisonics decoding for beamforming in HOA DECODE. You might use both decodings at the same time routed to the same IKO output bus. Then, by using a bandpass in the Omni decoding, the low frequency content of the the W channel can be easily leveled in the final mix.

response equalization of the loudspeakers and additionally crosstalk cancellation between the loudspeakers. In Fig. 14 the mcfx_convolver24 plugins loaded with the two mentioned presets are depicted. Please, always make sure that you utilize the correct filter set (pay special attention to: IKO 5/6, Omni vs. Full).

3.5 vIKO Filter Dataset

TBD[15]

[15]please see `http://iaem.at/projekte/osil/vikocall.zip`

4 IKO Test Suite

Figure 15: Look at the IKO from the frontal listening axis, cf. Fig. 17 top/left. Loudspeaker 6 is facing towards the frontal listener, loudspeaker 11 is indicated by the gray 'IKO by IEM and sonible'-badge.

In this section we provide information on how to set up the IKO system, which geometric conventions and mindsets are proposed concerning this matter, and how to test proper functionality. Please realize that validation and verification of proper technical operation is very important for the IKO system. Since the IKO utilizes complex beamforming even a single channel failure or deviation from normal and expected behavior (by wrong routing, muted, inverted amp/speaker, delay and so on) can result in severe mis-operation. And even having this checked, the degrees of freedom are numerous that weird things can happen. Please save yourself hours of puzzling over unexpected spatial sound phenomena (which in principle is a very nice and desirable experience) at least for the mentioned technical issues that require careful check.

Think of the IKO as a musical instrument [1] that has to be maintained and practiced to create outstanding spatial performances, rather than setting up a fancy looking loudspeaker.

4.1 Geometrical and Electrical Setup

First, we need to consider the mechanical and electrical setup of the IKO system. For this, please have a look at the **setup video tutorial** at:

```
https://youtu.be/cORivAnQSxE
```

Make sure that the look at the IKO from the frontal audience axis matches the depiction in Fig. 15, i.e. looking at what might be designated as 'IKO face'.

We propose to work with the right-hand Cartesian coordinate system convention depicted in Fig. 16 and Fig. 17, assuming that the IKO origin matches the origin of the coordinate system. For the radius $0 \leq r < \infty$, the azimuth $0 \leq \phi < 2\pi$ (AZ) and the elevation $0 \leq \theta \leq \pi$ (EL) a point in space is given with [9, eq. (1.5.16)]

$$x = r\,\sin(\theta)\,\cos(\phi) \qquad y = r\,\sin(\theta)\,\sin(\phi) \qquad z = r\,\cos(\theta). \tag{1}$$

For typical stage-based IKO performances the audience is located at positions $x > 0$ and the reflectors on the stage stand roughly at positions $x < 0$.

The frontal axis of the IKO is considered along the positive x-axis. Thus, a beam into positive x-axis directly radiates towards a frontal listener, a beam into negative x-axis directly radiates away from a frontal listener (under free-field conditions, when not considering reflections). Furthermore, for this frontal listening position and looking at the IKO, the **positive** / negative y-axis indicate beams towards **right** / left direction and the **positive** / negative z-axis indicate beams directly **upwards (to ceiling)** / downwards (to floor), respectively.

4.2 Loudspeaker Numbering and EigenBeam Convention using the ambiX Encoder

Agreeing on this coordinate system convention, the Ambisonics en- and decoding process as well as the IKO positioning should match.

Thus, the IKO loudspeaker exhibits a specific loudspeaker (LS) numbering scheme that is depicted in Fig. 17 and conveniently as net view in Fig. 18. The proposed Ambisonics processing is strictly related to that scheme. Make sure that you have the depictions of the IKO numbering scheme at hand, when going though the next statements.

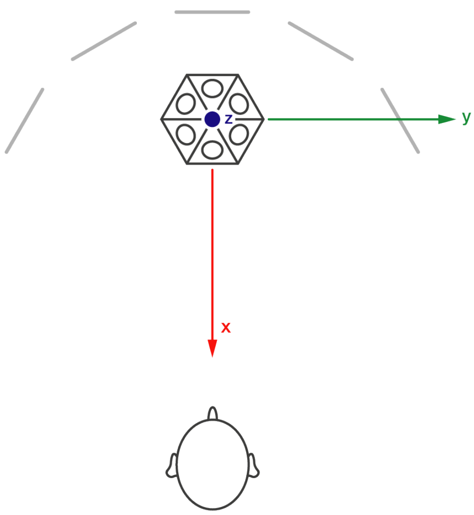

Figure 16: Typical IKO setup (not to scale and shape) and coordinate system convention, top view. Direct frontal listening is considered along the x-axis. The coordinate system origin coincides with the IKO origin.

With four important rules the IKO numbering scheme can be deduced. The first three rules are, cf. Fig. 17 top/left, Fig. 15 and Fig. 18:

(i) The triangle with the IKO logo badge corresponds to loudspeaker #**11**.

(ii) The adjacent upper/left triangle corresponds to loudspeaker #**6**, which is facing to the frontal listening position.

(iii) From #**6** the adjacent upper triangle, facing also into frontal listening position, corresponds to loudspeaker #**1**.

Based on these rules, the upper spherical cap (i.e. theses triangles of which the outward normals exhibit the same elevation angle 37.4 deg) is numbered from #1 to #5 in mathematical positive angle increments. The next five loudspeakers with elevation angle 79.2 deg are numbered from #6 to #10, again in mathematical positive angle increments. This part can be referred to as the upper horizontal band. Then, the next five loudspeakers with elevation angle 100.8 deg are numbered #11 to #15, and are referred to as the lower horizontal band. It is worth noting that loudspeaker #13 is facing backwards the frontal listening position. To finish with the lower spherical cap we need to introduce the final rule

(iv) Adjacent triangles between the upper spherical cap and the upper horizontal band or the lower horizontal band and the lower spherical cap exhibit a numbering offset of 5, cf. Fig. 18.

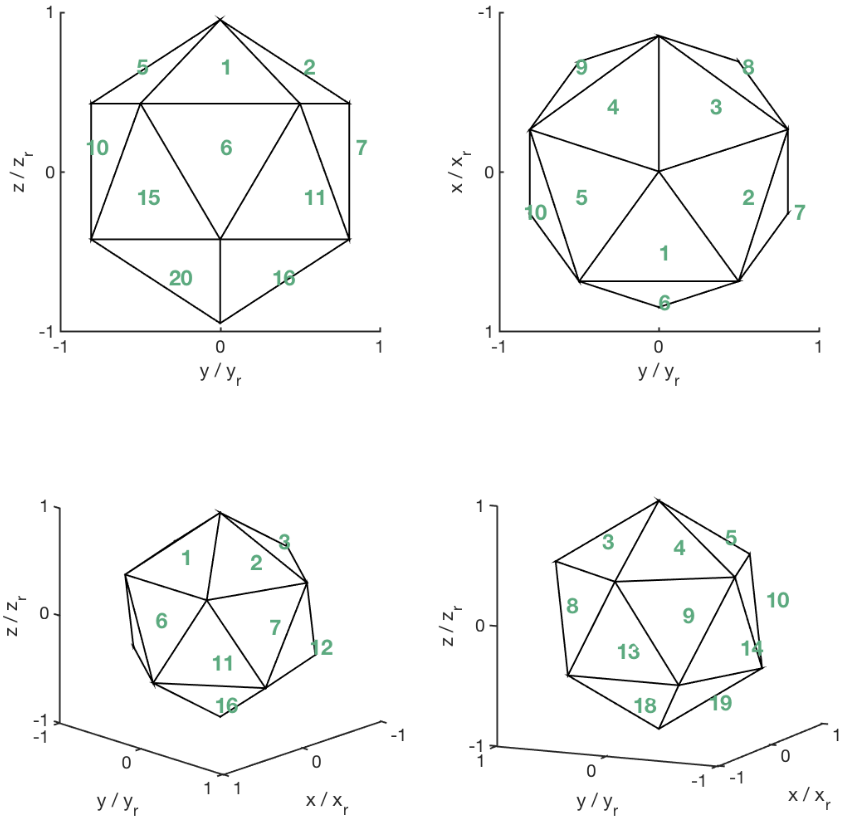

Figure 17: IKO loudspeaker and EigenBeam numbering in the used coordinate system convention. Top/left: frontal view (same as Fig. 15, this is the 'IKO face'), top right: top view (same as Fig. 16), bottom/left: triangles 1 and 6 facing to front, **triangle 11** includes the **IEM logo badge** (same as Fig. 19), bottom/right: 13 facing backwards.

Therefore, once loudspeaker position #11 is determined by the IKO logo badge, you can find the loudspeaker #16 on the triangle directly below. Another example following this rule are #6 and #7 on the upper horizontal band which are directly connected by triangles #1 and #2 of the upper spherical cap. In Fig. 19 this is clarified with a further IKO photo. With rule (iv) the lower spherical cap is then given with #16 to #20 with the triangles of the same elevation angle 142.6 deg.

The descriptions above can be conveniently summarized in tabular form, see Table 1. The given angle pairs (azimuth/elevation) of the IKO according to eq. (1) can set up the position of a corresponding loudspeaker/triangle center for a given IKO size (i.e. with a defined radius) or define the outward normal vector of

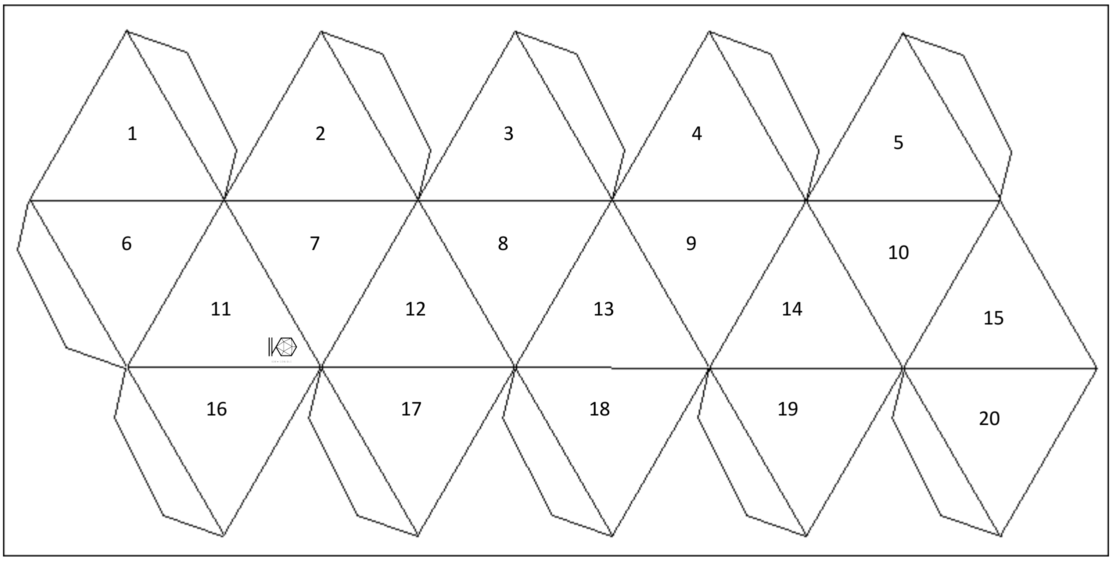

Figure 18: IKO net with chosen numbering convention indicating triangle 11 with the 'IKO by IEM and sonible'-badge.

a corresponding triangular surface.

We refer these 20 specific normal vectors to as so called **IKO EigenBeams**. The EigenBeams indicate outward radiating beam directions that are orthogonal to the IKO triangles. Then, with typical Ambisonics beam forming precisely into an EigenBeam direction, the highest playback level occurs at the corresponding loudspeaker with the same number as the EigenBeam, cf. Table 1. Second highest levels occur at loudspeakers along adjacent triangles. For EigenBeam #1 the

Figure 19: Look at the IKO directly to loudspeaker 11 with the gray 'IKO by IEM and sonible'-badge, cf. Fig. 17 left/bottom.

loudspeaker EigenBeam	azimuth eq. (1)	elevation eq. (1)	ambiX azimuth	ambiX elevation
1	0	37.4	+180	+53
2	72	37.4	+108	+53
3	144	37.4	+36	+53
4	216	37.4	-36	+53
5	288	37.4	-108	+53
6	0	79.2	+180	+11
7	72	79.2	+108	+11
8	144	79.2	+36	+11
9	216	79.2	-36	+11
10	288	79.2	-108	+11
11	36	100.8	+144	-11
12	108	100.8	+72	-11
13	180	100.8	0	-11
14	252	100.8	-72	-11
15	324	100.8	-144	-11
16	36	142.6	+144	-53
17	108	142.6	+72	-53
18	180	142.6	0	-53
19	252	142.6	-72	-53
20	324	142.6	-144	-53

Table 1: IKO 'EigenBeam' directions corresponding to the loudspeaker (LS) position with azimuth and elevation according to eq. (1) convention and according to our chosen ambiX convention (rounded). All angles in degree.

highest level occurs on loudspeaker 1 and adjacent loudspeakers 2,5 and 6 exhibit approx. 4 dB less level with the chosen Ambisonics decoding scheme.

We will later use these EigenBeams to check proper Ambisonics en- and decoding within our software system.

4.3 Discrete Loudspeaker Test

However, before utilizing Ambisonics related beam forming, we initially should make sure that all loudspeakers are correctly connected to the amplifier and our sound card playback matrix as well as the DAW project is correctly set up.

This is conveniently performed with the projects 'IKOEigenBeamTest.RPP' or 'IKOBeamTest.RPP' in Reaper using the plugins mcfx_gain_delay24 (cf. Fig. 11) and mcfx_meter24 (cf. Fig. 12). Without going into detail on the structure of these projects—this follows in the next two subsections—we only concentrate on the mcfx_gain_delay24 and mcfx_meter24, which are insert to the 20 Channel Bus MASTER OUT. This bus realizes the Reaper hardware out. Thus, depending on the used sound card, **make sure that Dante or MADI streams are routed 1:1 from the MASTER OUT as Reaper Hardware Out to the d:24 Hardware In**. With mcfx_meter24 the level can be checked pre MASTER OUT fader.

Then—with Reaper MASTER OUT to 0 dB if and only if d:24 in SOFT MUTE!—the routing can be checked with the mcfx_gain_delay24's signal generator. You might leave the settings -30 dB, sine, steady, 50 Hz as is, since they become useful in a minute. Just click on 'step through channels' and check if the active channel in mcfx_gain_delay24 and mcfx_meter24 corresponds to the active channel in the d:24 metering (relatively low level in meter, but sufficient for check).

If the routing is correctly established to the d:24, we furthermore need to check if the amp correctly feeds all loudspeakers. We do this with the same handling as above only with an UNMUTED amp, SO FOR YOUR SAFETY be absolutely sure that you NEVER playback the Reaper project (this might be bloody loud!!!), but rather only use the mcfx_gain_delay24 for doing this check. By using a low level 50 Hz sine, step through channels each 3 s, you can easily follow the loudspeaker numbering scheme from #1 to #20 when touching lightly the corresponding membrane and feeling the low frequency vibration. If all loudspeakers are set up correctly, we have ensured that the Reaper Hardware Out is discretely and appropriately connected to the IKO loudspeaker by 1:1 routing. Make sure, that no inverted channels occur in user-dependent signal processing steps in between. Afterwards we are ready for checking the Ambisonics processing. For safety put MASTER OUT to -inf dB and SOFT MUTE the d:24 for now.

4.4 EigenBeam Test

With the Reaper project 'IKOEigenBeamTest.RPP', cf. Fig. 20 the Ambisonics processing, i.e. the correct interaction of the ambiX Ambisonics encoding and the mcfx convolution based Ambisonics decoding, can be conveniently checked. Note that the 44.1 kHz sampling rate is exclusively used. The project exhibits the busses following the signal processing chain from output to input

- MASTER OUT, 20 channel receive from HOA DECODE -> 20 channel transmit to Hardware Out
- HOA DECODE, 16 channel receive from HOA BUS -> 20 channel transmit to MASTER OUT
- HOA BUS, 16 channel receive from IKO 1...20 -> 16 channel transmit to HOA DECODE
- IKO 1...20, mono channel receive from WAV playback -> 16 channel transmit to HOA BUS

with all sends post fader / post pan. See Fig. 24 for depiction of the signal flow.

The IKO 1...20 tracks each have an ambiX_encoder plugin (cf. Fig. 7) insert, precisely setting up the 1...20 EigenBeams from Table 1, all encoding the bandpass filtered noise signal 'EIA 426B 12dB Crest Noise Bandpass 44k.wav'. The media items are arranged such that the EigenBeams will be played consecutively in normal playback mode. The ambiX encoder setup for the first six EigenBeams 1...6 corresponding to Table 1 are shown in Fig. 21.

All IKO tracks send their 16 Ambisonics signals to the collecting HOA BUS. The HOA BUS has the plugins mcfx_gain_delay16 (cf. Fig. 11 for its 24 channel version) and mcfx_meter16 (cf. Fig. 12 for its 24 channel version) insert for

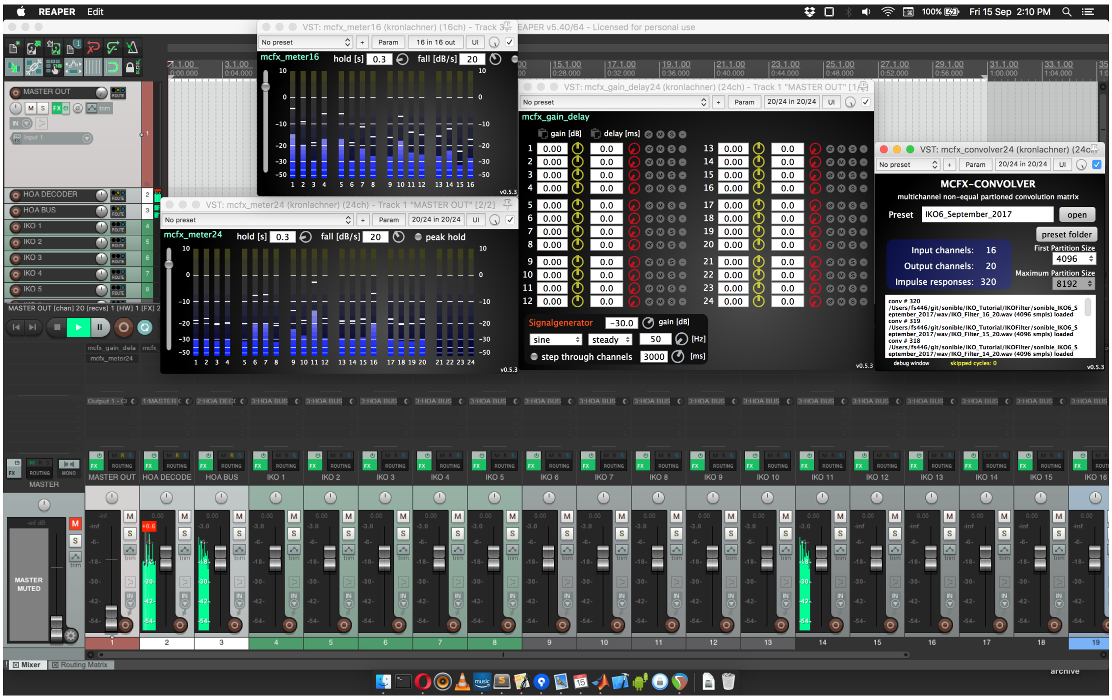

Figure 20: Screenshot of Reaper project 'IKOEigenBeamTest.RPP'.

debugging purpose. You may want to meter the Ambisonics domain or manipulate the gain/delay/polarity of individual Ambisonics modes in such cases. For normal work these plugins are not necessary. Please ensure that mcfx_gain_delay16 is doing nothing, when in normal playback mode.

The HOA BUS track send its 16 Ambisonics signals to the decoding HOA DECODE track. The insert plugin mcfx_convolver24 (cf. Fig. 14) realizes the 16×20 convolutions required for Ambisonics decoding and the final summations of all Ambisonics modes per loudspeaker channel. Make sure that the corresponding filter set is loaded (set Preset Folder to 'IKOFolder' and Open Preset 'sonible_IKO6_September_2017->IKO6_September_2017' (cf. Sec. 3.4), successful if 'conv # 320' and the correct folder appears in the notation window in the first lines). These filters at the same time not only realize Ambisonics decoding but also on-axis frequency response equalization and MIMO system crosstalk cancellation for the loudspeakers.

The HOA DECODE track sends its 20 loudspeaker ready signals to the MASTER OUT. The MASTER OUT has the plugins mcfx_gain_delay24 and mcfx_meter24 as insert FX for testing/metering purpose, cf. Sec. 4.3. This 20 channel bus is then routed directly to the connected sound card (MADI or DANTE). With the MASTER OUT fader the IKO level is controlled, BE CAREFUL HERE!

Playing back from start, the project consecutively follows the EigenBeam numbering scheme of Table 1. You may follow this with very moderate levels (MASTER OUT -40...-30 dB is sufficient) near the IKO by checking that the loudest loudspeaker directly corresponds to the actual EigenBeam. A wiping hand motion in front of the corresponding loudspeaker clearly indicates a quite likely correct setup. It might be a good idea having the IKO numbering scheme memorized for this task.

Put MASTER OUT to -inf dB when validating correct beams has been finished. We can then proceed with beam forming in certain directions that especially give meaningful auditory perception when being in a frontal listening position.

4.5 Left/Right/Front/Back/Up/Down Beam Test

With the Reaper project 'IKOBeamTest.RPP', cf. Fig. 22 the Ambisonics processing, i.e. the correct interaction of the ambiX Ambisonics encoding and the mcfx convolution based Ambisonics decoding, can be again conveniently checked and finally validated from a perceptual perspective far away from the IKO.

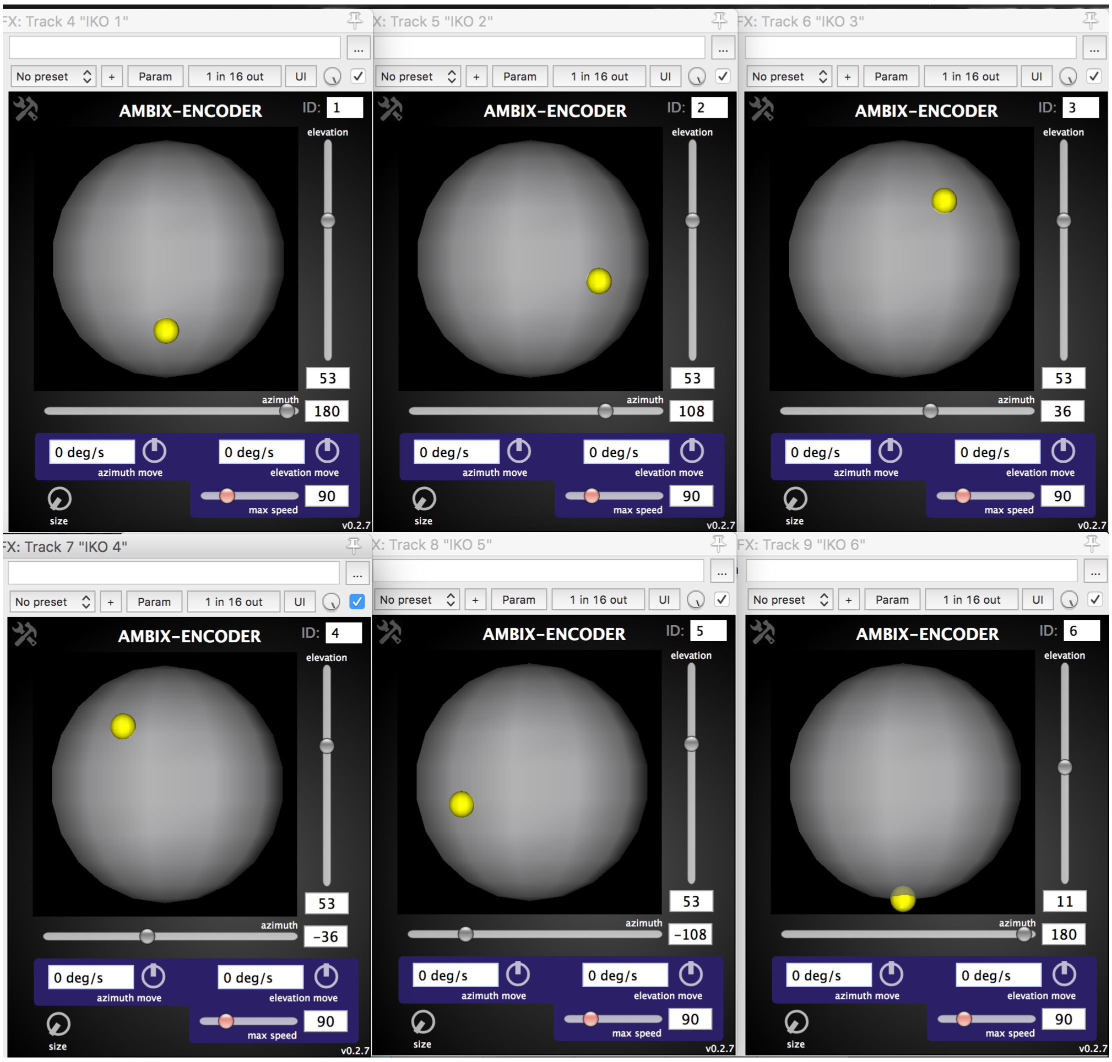

Figure 21: ambiX encoder convention for IKO EigenBeams #1, #2,...,#6 depicted from left/top to right/bottom. The spherical visualization and beam direction into direction of the yellow circle correspond to the top view of Fig. 16 and Fig. 17 top/right, cf. the Reaper project 'IKOEigenBeamTest.RPP'.

This project is similar to the already discussed 'IKOEigenBeamTest.RPP', but encodes less beams with other beam directions. The signal flow for this project is also visualized with Fig. 24 as well as for the EigenBeam test. The project includes six tracks with bandpass noise for beams to the left, right, front, back, up and down direction with regard to the frontal listening axis as discussed above. These beams directions can be clearly distinguished some meters away the IKO. The remaining HOA and OUT busses are precisely identical to 'IKOEigenBeamTest.RPP'. The

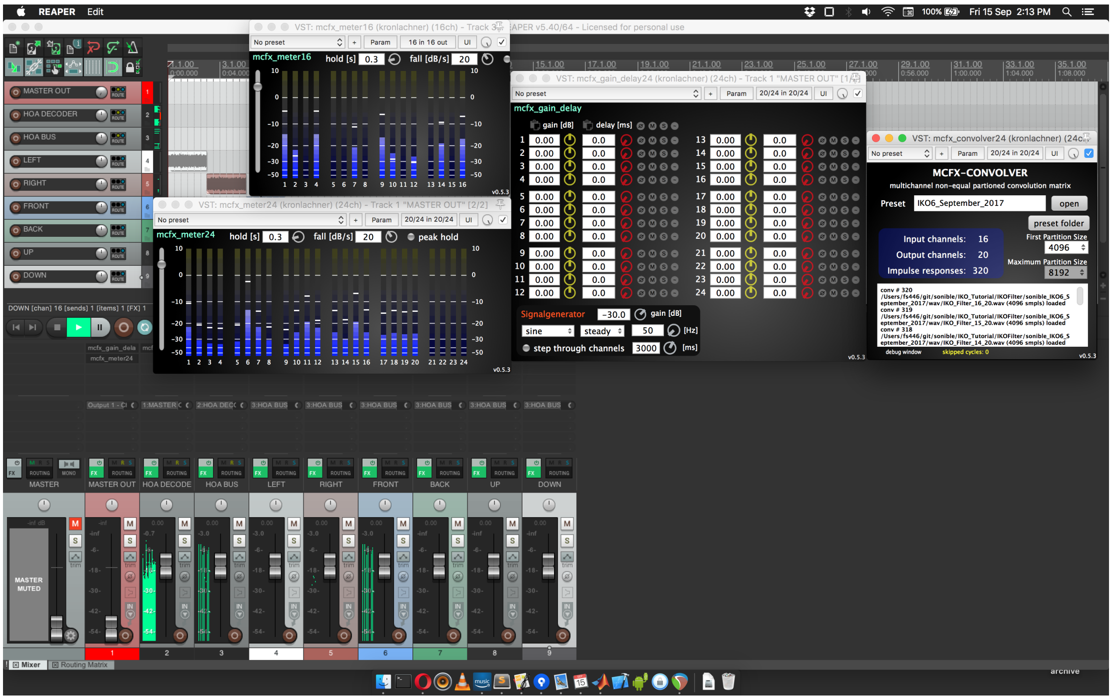

Figure 22: Screenshot of Reaper project 'IKOBeamTest.RPP'.

ambiX encoding is shown is Fig. 23.

This test is meaningful for IKO setups that utilize the half circled reflector wall behind the IKO, cf. Fig. 16. In a frontal listening position along the x-axis some meters away from the IKO, then a left/right, front/back, up/down beam scenario can be easily checked for its validity with appropriate MASTER OUT level.

The Reaper project 'IKOBeamTest.RPP' can furthermore be used as a simple initial project for your own future IKO projects.

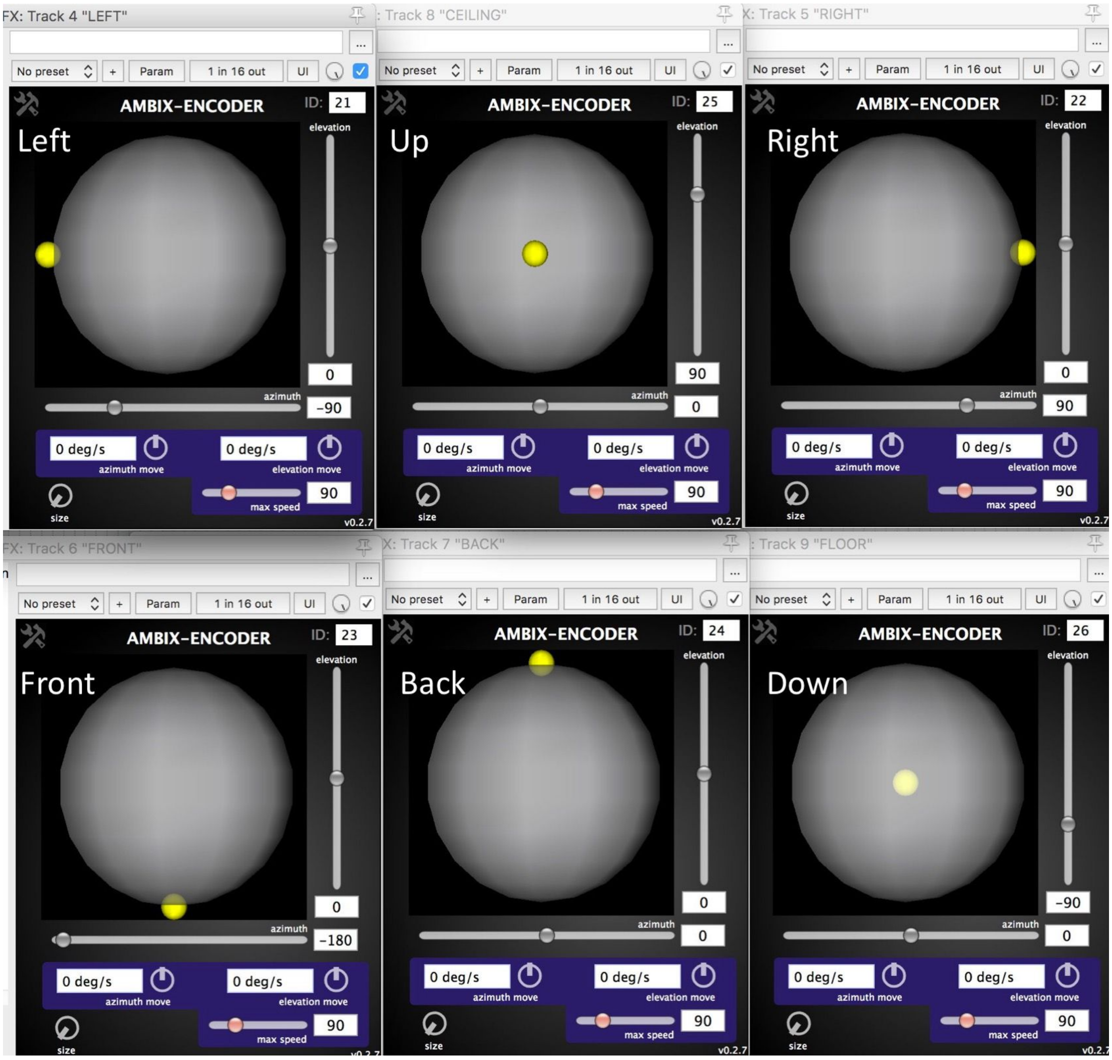

Figure 23: ambiX encoder convention for IKO beams to left, upwards to the ceiling, to right, to front, to back and downwards to the floor depicted from left/top to right/bottom. The spherical visualization and beam direction into direction of the yellow circle correspond to the top view of Fig. 16 and Fig. 17 top/right, cf. the Reaper project 'IKOBeamTest.RPP'.

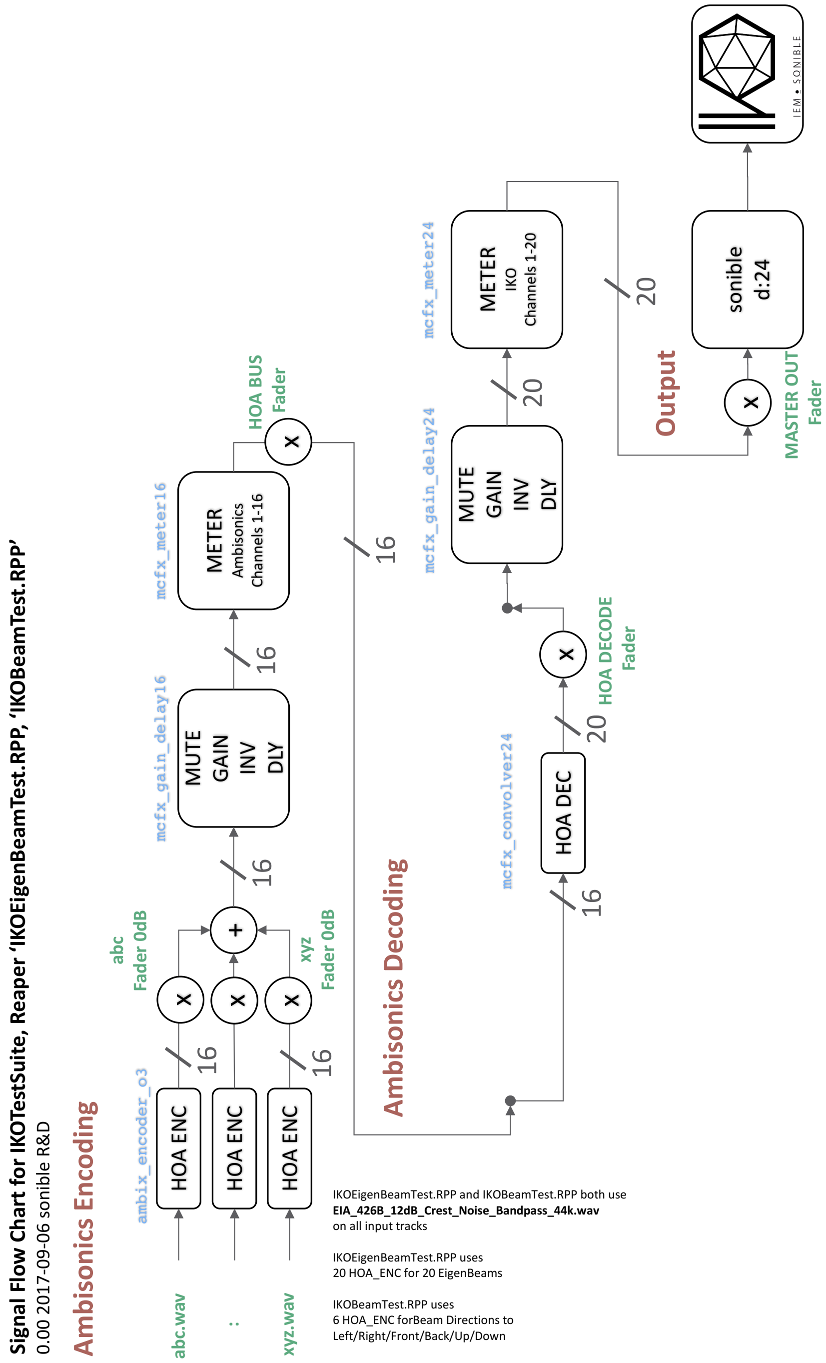

Figure 24: Signal Flow for Test Suites in Reaper 'IKO(Eigen)BeamTest.RPP'.

5 IKO Demo Suite

In this section we provide information on how to create simple 3D sound scapes with the IKO system. For your own projects and compositions you initially might get inspiration from the miniatures that were composed for the IKO to research the composing process, the perception and the verbalization of plastic sound objects that occur when IKO excites room reflections. This research was performed within the artistic research project "**Orchestrating Space by Icosahedral Loudspeaker**" (OSIL, PEEK AR-328-G21 funded by the Austrian Research Promotion Agency), supervised by Franz Zotter, and constitutes the **origin** of the **IKO by IEM and sonible** cooperation. Composing spatial sound phenomena for and with the IKO was initially pursued by Gerriet K. Sharma. In his dissertation [10][16] the composition of plastic sound objects with the IKO, also designated as sound sculptures is thoroughly discussed. In [10] the mentioned set of composed miniatures is discussed[17]. A single miniature demonstrates a certain entity for creating an intended plastic spatial sound phenomenon. The miniatures 29, 35 and 38 became especially inspiring to create the Demo I.

Figure 25: Demo Suite I in Reaper 'IKODemo1.RPP'.

[16]`https://iem.kug.ac.at/fileadmin/media/osil/gksh_dissertation.pdf`
[17]`www.gksh.net/downloads/Indx_Miniaturen.zip` - ca. 1GB.

5.1 Demo I

The Reaper project 'IKODemo1.RPP', cf. the screenshot in Fig. 25 is designated as Demo I in this tutorial. It discusses the Reaper handling for the required tracks and busses and the usage of audio material to create a 3D sound scape, cf. the signal flow in Fig. 26. Note that again the 44.1 kHz sampling rate is exclusively used.

The project is slightly more complicated than the beam test projects and exhibits

- IKO OUT, 20 channel receive from HOA DECODE and from W DECODE -> 20 channel send to Hardware Out
- **for vIKO**: vIKO OUT, 2 channel receive from L/R DECODE -> 2 channel send to Hardware Out
- W DECODE, 1 channel receive (i.e. the 1st signal) from HOA BUS -> 20 channel send to IKO OUT
- HOA DECODE, 16 channel receive from HOA BUS -> 20 channel send to IKO OUT
- **for vIKO**: IKOtoEM32, 16 channel receive from HOA BUS -> 25 channel send to L/R DECODE
- **for vIKO**: L/R DECODE, 25 channel receive from IKOtoEM32 -> 2 channels send to vIKO OUT
- HOA BUS, 16 channel receive from the tracks Drone, GrainHD, GrainLD, Rhythm & FM -> 16 channel send to HOA DECODE and IKOtoEM32, 1st channel send to W DECODE
- tracks Drone (Drone.wav), GrainHD (grainHighDens.wav), GrainLD (grainLowDens.wav), Rhythm & FM (RhythmBass.wav, SineFM.wav), single channel receive from WAV playback -> 16 channel transmit to HOA BUS

with all sends post fader / post pan.

If you are familiar with the test projects you will recognize the differences compared to this demo project as:

- IKO OUT=MASTER OUT, use this bus and fader to control the playing level of the IKO
- there are additional tracks and busses for the **vIKO**, which are briefly explained below

- there is an additional W DECODE track, which is explained below
- instead of test signals such as sine and noise, we use more sensational audio material, such as grains, bass pulses, AM/FM modulated noise and tones to be spatialized for an immersive sound scape

The IKO specific signal flow within the project is sketched in Fig. 26. The vIKO specific signal flow is TBD.

5.1.1 Ambisonics Encoding & Ambisonics Bus

Mono/Stereo tracks of real time input or audio files are encoded with the 3rd order Ambisonics encoder plugins ambix_encoder_o3 / ambix_encoder_i2_o3, already used in the test beam projects. Multiple inputs signals encoded into the Ambisonics domain are then summed to the HOA BUS. The encoding and summing is sketched in the signal flow chart in Fig. 26, cf. the Ambisonics encoding stage. The HOA BUS fader controls the signal level prior to the Ambisonics decoding stage.

For the Demo I we use fixed beam directions as well as time-changing ones. The latter can be conveniently realized with the azimuth and elevation move (in deg/s) and a max speed (deg/s) parameter.

5.1.2 Ambisonics Decoding to IKO

Other than in the beam test projects the Ambisonics decoding process is somewhat enhanced for artistic purpose, cf. the Ambisonics decoding stage in Fig. 26. There are two decodings involved:

- the decoding of only the **Ambisonics W channel** (i.e. the omni-directional radiation pattern). For that the 'mcfx_convolver24' decoder preset

  'IKO6_September_2017_**Omni**.conf' is deployed in the W DECODE track (1 receive -> 20 sends).
- the **full 3rd order Ambisonics** decoding. For that the decoder preset 'IKO6_September_2017.conf' is deployed in the HOA DECODE track (16 receive -> 20 sends).

Both decodings are then summed to the IKO OUT bus, which includes the usual mcfx_gain_delay24 and mcfx_meter24. Additionally to the different decodings each channel has an IIR filter bank insert. In the W DECODE track only the W channel is filtered with the mcfx_filter2 plugin, in the HOA DECODE track 16 channels are equally filtered with the mcfx_filter16 plugin.

Then, by applying a lowpass (high cut) filter (e.g. between 80-130 Hz) and a security highpass (lowcut) filter (e.g. 35 Hz) in the W DECODE, the decoding realizes pure omni-directional radiation in this frequency range, cf. the screenshot in Fig. 25. These signal components can now be leveled against the fullrange 3rd order Ambisonics signal components in HOA DECODE in order to enhance the control of low frequencies. You even might realize a frequency crossover between W DECODE and HOA DECODE (using 4th order filters with the same cut frequency, then a 6 dB level loss is realized at the cut frequency and correct amplitude summation of the two frequency bands is achieved).

However, note that these two strategies differ. While the first approach adds pure W channel components to the fullrange HOA components (adding more omni-directional bass), the second approach strictly separates the frequency range into a pure W channel below the chosen cut frequency and pure HOA channels above the cut frequency (control of more or less omni-directional bass). It might also help to utilize the low shelf filter of the mcfx_filter16 plugin in the HOA DECODE track to control more or less bass.

Depending on the room situation and the IKO/reflectors setup you might play a little bit around to find a suitable configuration.

If you do not want to use this enhanced option, simply mute the W DECODE track. This yields the 'classical' decoding, already used in the beam test projects. For that additionally make sure that the mcfx_filter16 filter curve is flat.

5.1.3 Binaural Decoding to vIKO

The vIKO [11], abbreviation for virtual icosahedral loudspeaker array, is a research output of OSIL, pursued by Markus Zaunschirm. At the moment we do not yet provide a designated vIKO dataset for the IKO by IEM and sonible. That's why we also do not get into detail on this topic for now, please cf. [11].

However, you might get a dataset at [18] for the very first IKO that was prototypical developed at IEM/KUG before OSIL. This dataset was provided in line with an International Call for Compositions - for and with - the IKO in spring 2017, presenting the best compositions in a concert performance at the 4th International Conference on Spatial Audio (ICSA) 2017 in Graz.

[18] `http://iaem.at/projekte/osil/vikocall.zip` see [12] in there

The provided Reaper projects from this call enable you to compose with a binaural simulation of that IKO prototype in two different room situations using HRTFs sets of different resolution of two heads. You might get familiar with the provided vIKO demo projects and then adapting the filter handling to the Demo I project. It only uses slightly different track naming. So in order you want to load the required filters, notice that 'vIKO to ambi' (in vIKO call) is equal to 'IKOtoEM32' (in Demo I)—using a mcfx_convolver32—and 'binaural ambi decoder' (in vIKO call) is equal to 'L/R DECODE' (in Demo I)—using the ambix_binaural_o5 plugin—, provided in the 5th order ambiX plugin suite[19].

Furthermore, the ambiX_rotator_z_o3 and ambiX_rotator_o5 are used in these tracks in order to rotate the scene according to the IKO conventions. The latter can furthermore be used for potential dynamic head tracking to improve the quality of the binaural synthesis.

Make sure that the routing of the vIKO OUT master out links the two desired hardware channels of your sound card, where a headphone is connected to. Make also sure, that the IKO OUT is muted or its level is set to -Inf, while playing the binaural simulation, in order to avoid potential but not intended summation onto the same output bus.

5.1.4 Creating the Demo I 3D Audio Scene

Audio material

The project exhibits four input tracks and uses five different audio stimuli, i.e. two of them are set up in the same track 'Rhythm & FM'. The track 'Drone' includes 'Drone.wav', a bandpass noise which exhibits spectral and loudness changes over time. This was realized by bell contour filtered pink noise where frequency bands around 110 Hz, 220 Hz, 440 Hz, 880 Hz and 1.1 kHz are dynamically weighted with parametric equalizers. This resembles the so called 'Drone' that was used in some of the miniatures mentioned above. The track 'GrainHD' includes 'grainHighDens.wav', i.e. grains of comparably high density and durations between 20 and 100 samples derived from white Gaussian noise. The track 'GrainLD' includes 'grainLowDens.wav', i.e. grains of comparably low density and durations between 20 and 200 samples derived from white Gaussian noise. The track 'Rhythm & FM' includes a 64 Hz sine burst with repeated ca. 1.5 s fade in and fade out windows ('RhythmBass.wav') and a bandpass filtered uniform noise

[19] http://www.matthiaskronlachner.com/?p=2015

FM modulated to a 1.705 kHz sine carrier ('SineFM.wav').

Encoding to Beams

The material of track Drone is encoded with elevation of 35 deg (upwards) and azimuthal rotation of 128 deg/s, yielding an elevated orbit with beam directions typically into the ceiling. These parameters lead to what can be perceived as spatial beating, cf. [7, p.102]. The material of track GrainHD is encoded with elevation rotation of 111 deg/s and azimuthal rotation of 243 deg/s, yielding arbitrary beam directions. The material of track GrainLD is encoded with elevation rotation of -213 deg/s and azimuthal rotation of 144 deg/s, yielding arbitrary beam directions. The material of track Rhythm & FM is encoded with a fixed beam direction into elevation of 0 deg and azimuth of $\pm$ 180 deg, which is the frontal beam direction described above.

Level Automation and Filtering

All tracks exhibit an automation of the volume envelope in order to create different spatial sound phenomena by combining the different audio materials and different beam patterns. Additionally the grain tracks include an IIR filter bank. With these filters the spectral weighting of the grains can be altered such that the grains appear at different distances from the IKO. With different levels between the tracks different spatial effects can be derived. You might play around with the provided given initial parameters. For example, play with the azimuthal rotation speed of the Drone, highpass filter the drone at ca. 100-400 Hz, alter the bass level in the W DECODE track. You will perceive very different spatial sound phenomena. The stereo file 'IKODemo1_Binaural.flac' contains a Neumann KU100 binaural recording of the scene produced in the Cube at IEM/KUG using five reflectors semi-circled ca. 4 m behind the IKO.

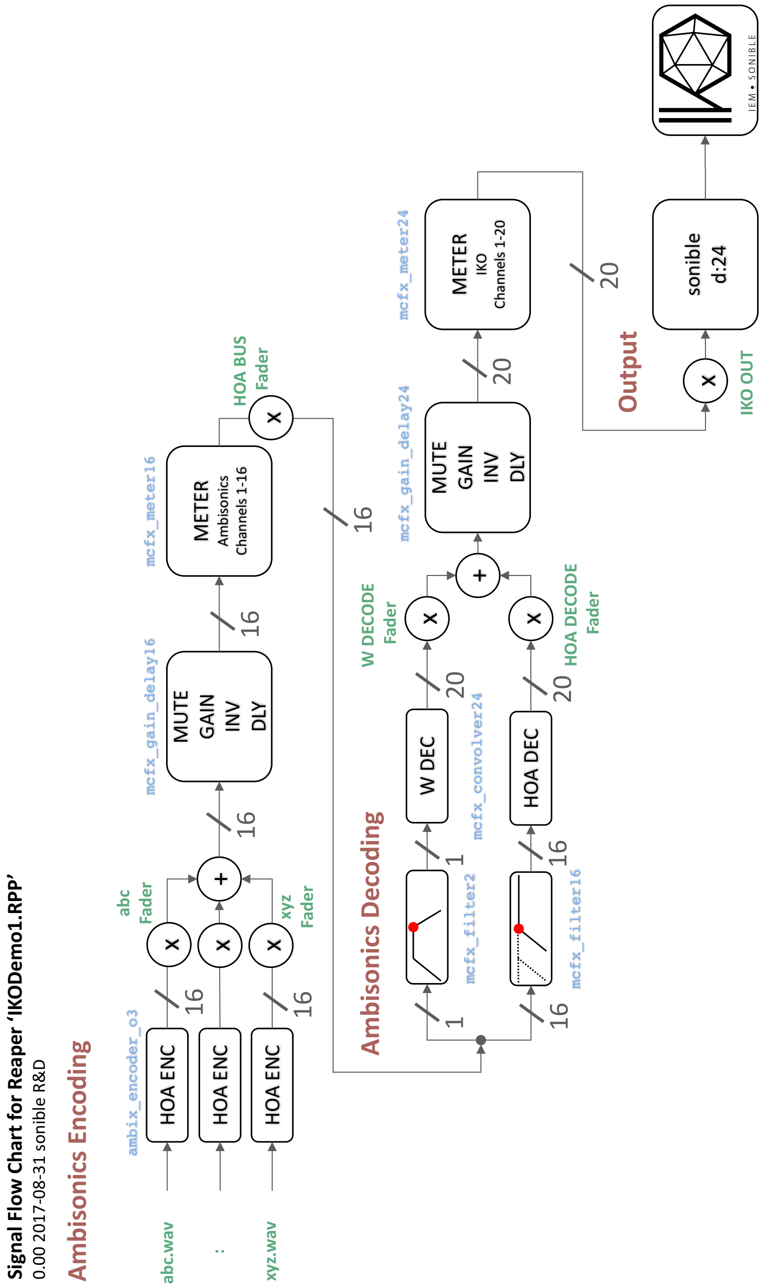

Figure 26: Signal Flow for Demo Suite I in Reaper 'IKODemo1.RPP'.

6 Hardware Component Checklist for IKO System

The IKO system **provided by sonible** comprises of

- IKO by IEM and sonible, i.e. the **loudspeaker itself** in a flightcase
- the flightcase also includes **two handles** (to be temporarily locked into the IKO housing for (dis)-assembly with the stand), a stand's **locking screw** and a customized **multicore cable** to connect the loudspeaker with the amp d:24
- a sonible **d:24** 24-channel power amplifier equipped either with **MADI** or with **DANTE** in a flightcase including a Neutrik **PowerCon connector cable**
- software kit including filters, demo projects and audio examples

Furthermore, you will need the following essential tools, which are **not provided by sonible**:

- A **heavy loudspeaker stand** with standard socket's diameter of 35 mm is used for the the standing configuration of the IKO. Please make sure, that your stand can securely handle the IKO weight of about 40 kg.
- Depending on your d:24 configuration either a **MADI capable sound card** that is connected either **coaxially** or **optically** to the d:24 and connected either by **USB** or by **Thunderbolt** to the used playback computer
- or a **DANTE Virtual sound card** in the playback computer is to be used to connect to the IKO system with suitable cabling (BNC, optical fiber with SC-DC connectors or CAT5).

Thus, make sure that you have everything (the stuff that is provided by sonible and the stuff which is not) at hand for playing with IKO.

7 Software Component Checklist for IKO System

Please, ensure that you have the folder structure and files shown in Fig. 27 stored in an IKO specific parent directory to work with.

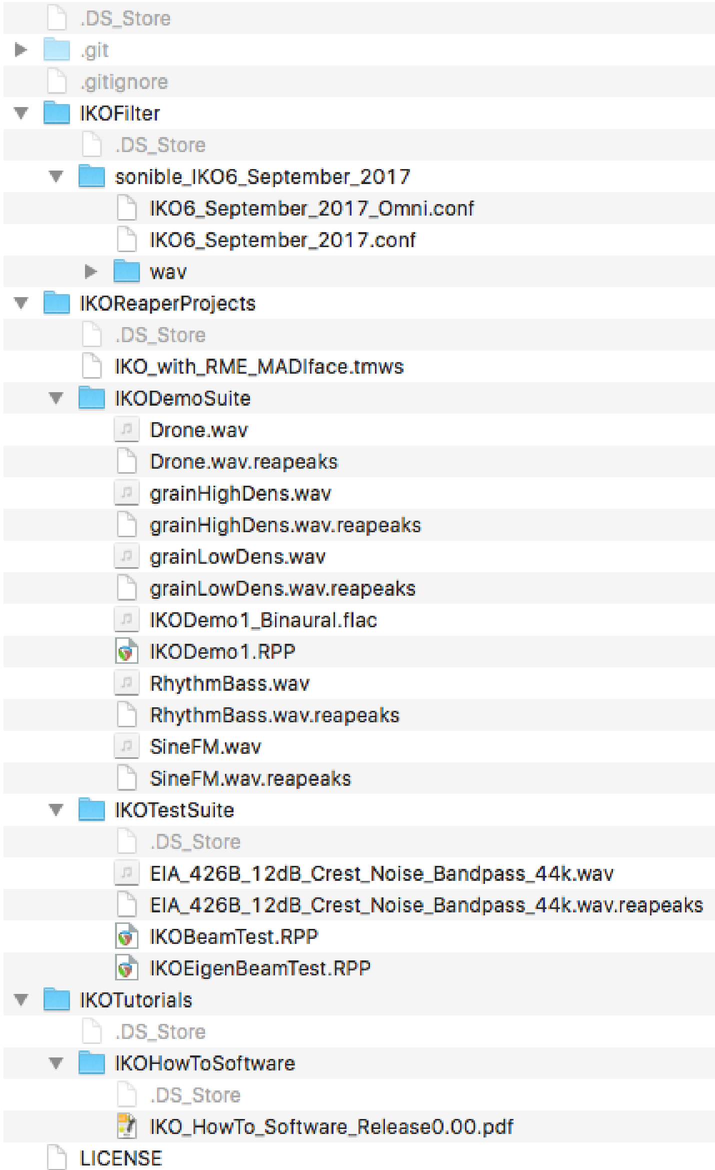

Figure 27: Provided data and folder structure for IKO tutorials.

8 Specifications & DataSheet IKO System

TBD

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