SDE Standard

Technical Specification Document
Version: 2026.1

Contents

1 Motivation

Sound systems designed for typical festival stages consist of a number of loudspeaker cabinets. These cabinets are grouped in line arrays, sub arrays, fills and delays etc. each consisting of several cabinets. The positions, directions, relative levels and delays of the cabinets are usually designed with a special software in order to optimize performance for the audience. For the purpose of outdoor noise prediction, experience has shown that it is not sufficient to treat the stage or the source groups as point sources with precalculated far field directivities, instead sources have to be modelled with a complex directivity point source model (CDPS) and the calculation requires decoherence factors as described in Annex 2 (for indoor acoustic calculations the decoherence factors might be different).

To be able to transfer the data of a stage – with all the necessary properties and settings – to a noise prediction software this System Design Exchange standard (SDE) has been developed.

The SDE-standard describes the format and methodology:

- A format: how to export data of a planned sound system.
- A methodology: how to perform complex valued calculations using decoherence factors.

2 Glossary

Sound System: complete sound system with a reference point, a complete loudspeaker design, and a venue. Example: Main stage 1

Calibration Point: is a representative point in the audience (or e.g. front of house mixing position), at which the sound system delivers the required A-weighted sum-level entered by the user. The calibration point is defined in the system design / exporting software. Optionally, the spectrum of the electrical signal driving the sound system can be saved in the SDE.

Source Group: a set of loudspeaker cabinets creating a meaningful group e.g. an array. Examples: Main Left, Front fill 1.

Loudspeaker Cabinet: physical entity within a source group.

Complex Directivity Point Source: elementary source used to model the radiation within a loudspeaker cabinet.

Venue: a set of items representing audience areas, just for graphical representation.

Hierarchy: Sound System

- Calibration point
- Source Group
    - Loudspeaker Cabinet
        - Complex Directivity Point Source
- Venue

3 List of symbols and units

Table 1: List of symbols

Symbol	Description	Unit
b	bandwidth designator	
k	frequency band index ranging from k_{min} to k_{max}	
$\mathbf{f_m}$	midband frequency	Hz
ω	angular frequency	Hz
ω_m	midband angular frequency	Hz
$\mathbf{F_{ij}}$	factor to include effect of band averaging	
$\tau_{i/j}$	travel time from source i or j to receiver	s
W_{ij}	Decoherence factor due to fluctuating travel time differences	
$\sigma_{\Delta\tau_{ij}}$	Standard deviation of travel time difference from source i and source j to receiver	s
c_0	Mean sound speed	m/s
$\sigma^2_{\tau_{i/j}}$	Variance of travel time from source i or j to receiver	s^2
σ^2_c	Variance of sound speed	m^2/s^2
τ_{cor}	Correlation length	m

4 File System

The SDE format is a zip-archive of several files with the extension *.sde. The files are:

SoundSystem.xml
Main file describing location, orientation, grouping of cabinets and complex directivity point sources, their complex transfer function, level, delay and filenames to data-blobs for directivity balloons and graphic files.

***.bal**
Binary files containing the complex valued directivity (balloons) of the point sources.

Description see Annex 1.

***.obj**
Files in Blender *.obj-format, containing graphical representation of cabinets and venue.

All coordinates in these files must be given in meters.

***.enc**
File containing a symmetric key to decrypt files like the balloons and the SoundSystem.xml (optional). The symmetric key itself is encrypted with an asymmetric key specific to the exporting- and importing-software-IDs.

manifest.xml
Contains a list of all files with their encryption status as well as the exporting- and importing-software-IDs

5 Definitions

5.1 Coordinate system

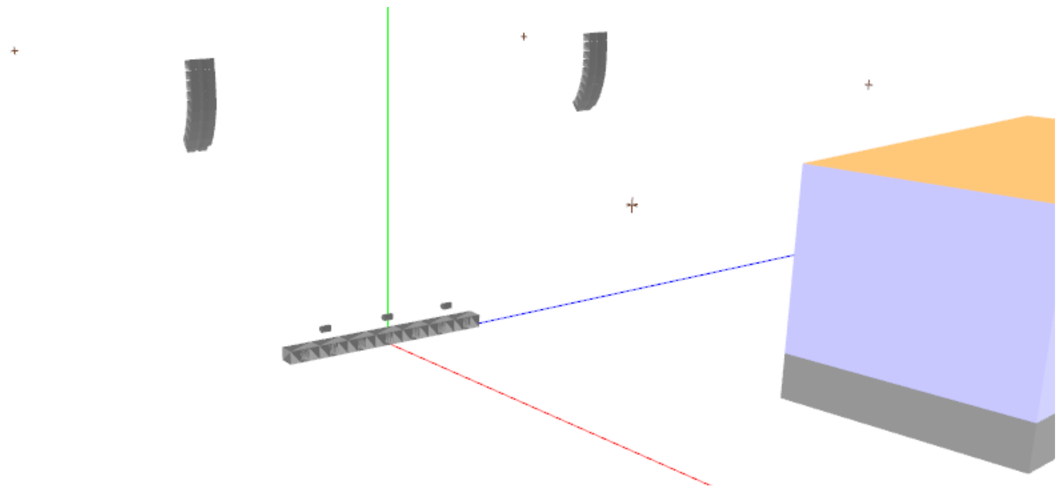


Fig. 1: Coordinate system

All coordinates given in the SoundSystem.xml file are referenced to a certain coordinate system with arbitrary origin, but usually somewhere in the middle between the main speakers. It is defined in the following way:

X: Positive direction in the main shooting direction of the stage (see Fig. 1, red axis)
Y: Positive direction to the left when you look at the audience (see Fig. 1, blue axis)
Z: Positive direction pointing to the sky (see Fig. 1, green axis)

The coordinate system is a right-handed one.

5.2 Rotations

To give the cabinets and the directivity balloons the correct orientation in the file SoundSystem.xml, rotation angles *rot1z*, *rot2y* and *rot3x* are given. Those three elemental rotations are intrinsic rotations (rotations about the rotated coordinate systems, solidary with the moving cabinets or balloons).

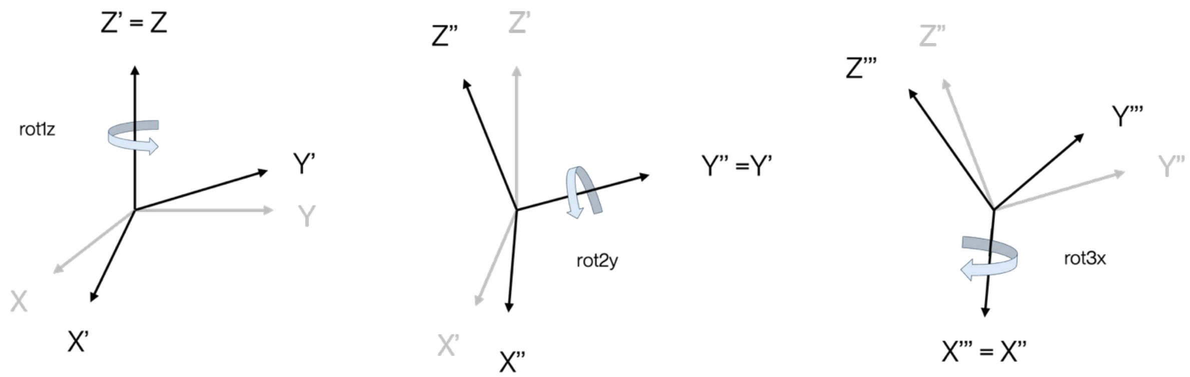


Fig. 2: Basic setting of rotation sequence and rotation mode

The rotational angles are performed in the following sequence in the mathematically positive direction of rotation (right hand rule) (see Fig. 2):

rot1z = 1st rotation about the z-axis
rot2y = 2nd rotation about the new rotated y-axis
rot3x = 3rd rotation about the new doubly rotated x-axis

5.3 Definition of frequency range ([1]; [2])

Midband frequency f_m in Hz:

$$f_m = 1000 * 10^{\frac{k3b}{10}}$$

Where b is a rational fraction that serves as the bandwidth designator (b = 1/3 for third octave bands) and k is an index. For a third octave spectrum from 20Hz to 20kHz k ranges from k_{min} = -17 to k_{max} = +13.

The inverse octave band fraction 1/b and the k_{min}/k_{max} – values in the referenced balloon file must be identical as given in the <Frequencies> section of the SoundSystem.xml-file.

6 Definition of balloons as binary file

6.1 Definition of angles

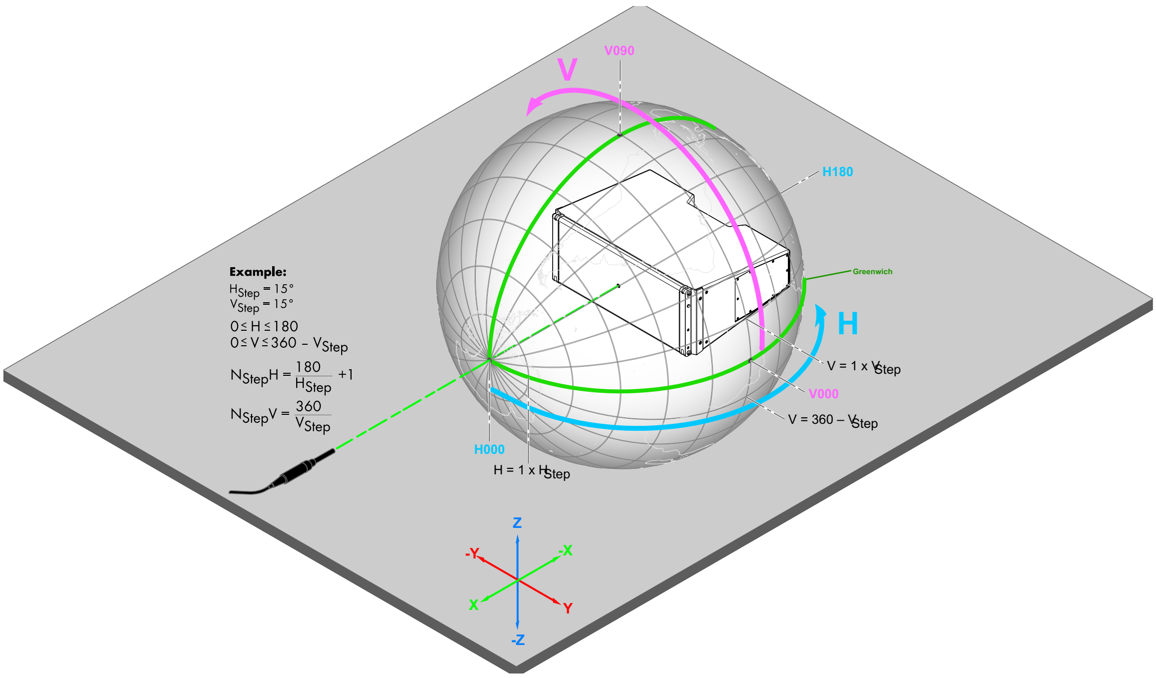


Fig 3 Definition of angles

The positive X-axis is the H000-direction. The positive Y-axis is the V000-direction and the positive Z-axis is the V090-direction.

6.2 Symmetries

You can have the following symmetries:

Enum	Description	Angle range V in deg	Angle range H in deg
0	none	0<=V<=360-VStep	0<=H<=180
1	vertical	0<=V<=180	
2	horizontal	270<=V<=360-VStep and 0<=V<=90	
3	vertical and horizontal	0<=V<=90	
4	radial	N/A	

6.3 Definition of balloons as binary file

Header

Variable	Offset in bytes	Width in bytes	Data structure	Example
Magic number	0	4	Unsigned integer	'SDEF' (0x53444546)
Version	4	2	Unsigned short	1
1/b	6	2	Unsigned short	3
kmin	8	2	Signed short	-17
kmax	10	2	Signed short	13
NStepH	12	2	Unsigned short	73 (corresponds to angle step of 2.5°)
NStepV	14	2	Unsigned short	144 (corresponds to angle step of 2.5°)
Symmetry flag	16	2	Unsigned short 0: none 1: vertical 2: horizontal 3: vertical and horizontal 4: radial	0

Rem: NStepH and NStepV do not depend on symmetry!

The angle steps in deg are calculated as following:

$$HStep = \frac{180}{NStepH - 1}$$

$$VStep = \frac{360}{NStepV}$$

Now follows a block of data for each frequency (kmin...kmax)

Variable	Width in bytes	Data structure
Amplitudes in dB	NStepH*NStepV*4	Array of 4 byte signed float
Phases in rad	NStepH*NStepV*4	Array of 4 byte signed float

The values for each array for Amplitudes and Phases have the following order:

(*H*=0 ; *V*=0), (*H*= H$Step$; *V*=0), …, (*H*=180; *V*=0)
(*H*=0; *V*=$VStep$), (*H*= $HStep$; *V*= $VStep$) , …, (*H*=180; *V*= $VStep$)
…
(*H*=0 ; *V*=$360 - VStep$), (*H*= $HStep$; *V*= $360 - VStep$) , …, (*H*=180; *V*= $360 - VStep$)

In case of a certain symmetry the redundant values are omitted, reducing the data size.
For vertical symmetry:

(*H*=0 ; *V*=0), (*H*= H$Step$; *V*=0), …, (*H*=180; *V*=0)
(*H*=0; *V*=$VStep$), (*H*= $HStep$; *V*= $VStep$) , …, (*H*=180; *V*= $VStep$)
…
(*H*=0 ; *V*<=180), (*H*= $HStep$; *V*<=180) , …, (*H*=180; *V*<=180)

The total size of the file for the given example values would be (10 + 31 * 2 * 73*144 * 4) bytes = 2606986 bytes

7 Description of proposed calculation procedure

7.1 Calculation

Complex summation of the contributions **of all source points of a sound system** / one stage (CDPS, elementary source) **to the receiver points, but:**

1. **Differences of path travel times** due to **statistical fluctuations**
   standard deviation of wind weakens the correlation (micro turbulences in air)
2. **Energy-bandwidth averaging**
   obligatory when showing 3rd octave (or octave) band-levels

No complex summation between sound systems of different stages because the signals (content) are not correlated. (The exception of emergency announcements is not relevant for noise impact.)

Complex summation and decoherence factors

When calculating a complex directivity point source for a given receiver position, we assign a complex valued pressure contribution to the receiver:

$$p = A \cdot e^{j\omega\tau}$$

Where A is derived from (square root of) the intensity level calculated according to a certain standard (e.g. ISO 9613-2 or Nord2000). τ is the delay time:

$$\tau = dt + \frac{r}{c_0} + \frac{\theta}{\omega}$$

Where:

dt: Delay for the CDPS (as given in the SDE-file)
r: Travel distance between source and receiver
c_0: Mean sound speed
θ: Phase shift from balloon

When summing up the contributions of all N coherent point sources one can show that the total intensity level is:

$$\left|\sum_{i=1}^{N} pi\right|^2 = \sum_{i=1}^{N} Ai^2 + \sum_{i=1}^{N}\sum_{j=i+1}^{N} 2Ai\,Aj\cos\left(\omega(\tau i - \tau j)\right) = \sum_{i=1}^{N} Ai^2 + \sum_{i=1}^{N}\sum_{j=i+1}^{N} 2Ai\,Aj\cos\left(\omega\Delta\tau_{ij}\right)$$

With:

$$\Delta\tau_{ij} = \tau i - \tau j$$

Mirror sources by reflections on building facades, noise barriers etc. could be treated in a similar way, but, due their minor significance and to reduce the computational load, these contributions are summed up purely incoherently.

The effect of band averaging is represented by a factor F_{ij}.

To include the effects of statistical fluctuations of sound speed the decoherence factor W_{ij} is introduced.

So finally, we get:

$$\left\langle\left|\sum_{i=1}^{N} \boldsymbol{pi}\right|^2\right\rangle = \sum_{i=1}^{N} \boldsymbol{Ai^2} + \sum_{i=1}^{N}\sum_{j=i+1}^{N} \boldsymbol{2F_{ij}W_{ij}Ai\,Aj\cos\left(\omega_m\Delta\tau_{ij}\right)}$$

The band averaging factor F_{ij} is described in Annex A. The decoherence factor for statistical fluctuations W_{ij} is described in Annex B

7.2 Calibration of the Sound System

General description

A pre-calculation is used to calibrate the sound system and to ensure a required A-weighted sound level at a representative point in the audience in the importing software.

Details

- The exporting software
  - must provide a calibration point
    - at a representative place in the audience area (e.g. front of house)
    - in the same coordinate system as the complex directivity point sources
    - to ensure an A-weighted sum-level, which the user defines in the importing software
  - can provide the spectral distribution of a “drive” signal (program material, “mix”) going into the sound system (into the amplifiers, “before the transfer-functions”)
    - unweighted **3rd** octave $\boldsymbol{L_{eq3rd}}$ levels
- The importing software
  - provides a set of spectral distributions of “drive” signals (program material, “mix”) going into the sound system (into the amplifiers, “before the transfer functions”) ideally including
    - the spectrum from the exported SDE when available
    - spectra from the IEC60268 and EIA426B standards
    - genre and/or application specific spectra (pronounced and/or extended bass, sport)
  - performs the calibration
    - performs a pre-calculation of the propagation to the calibration point using

- the spectral distribution of the user selected drive signal
- data of the source points: position, orientation, transfer functions, balloons

- the calibration level equals the difference between the user entered, required A-weighted sum-level and the resulting A-weighted sum-level of the pre-calculation:
  $\Delta L_{A,calibration} = L_{A,required} - L_{A,precalculation}$
- the calibration level is added to the resulting levels of the main calculation

Note

All relative levels between all sources are maintained and remain as adjusted in the exporting software before exporting the SDE. They are not affected by the calibration, pre- or main calculation.

The resulting spectrum at any receiver / grid point is a combination of the spectral distribution of the drive signal (the “mix”, program material), the complex transfer functions and balloons of each source (including any filters, effectively the “system curve”) and the result of the propagation calculation to that receiver / grid point.

Only the sum-level is shifted in order to achieve the user entered required A-weighted sum-level at the calibration point.

8 Annex A: Band Averaging

When performing band averaging, we get:

$$\left\langle \left| \sum_{i=1}^{N} pi \right|^2 \right\rangle = \frac{1}{\Delta\omega} \int_{\omega_m - \frac{\Delta\omega}{2}}^{\omega_m + \frac{\Delta\omega}{2}} \left| \sum_{i=1}^{N} pi \right|^2 d\omega = \sum_{i=1}^{N} Ai^2 + \sum_{i=1}^{N} \sum_{j=i+1}^{N} 2F_{ij} Ai\, Aj \cos\left(\omega_m \Delta\tau_{ij}\right)$$

With the band averaging decoherence factor:

$$F_{ij} = \frac{\sin\left(\frac{\Delta\omega\Delta\tau_{ij}}{2}\right)}{\left(\frac{\Delta\omega\Delta\tau_{ij}}{2}\right)}$$

If $\omega_m$is the midband frequency of a third octave band then $\Delta\omega/2 = 0.115 * \omega_m$.

9 Annex B: Statistical fluctuations

Due to fluctuations in wind and temperature $\Delta\tau_{ij}$ is also randomly changing. Supposing random fluctuations with a Gaussian distribution with a standard deviation $\sigma_{\Delta\tau_{ij}}$ and a mean $\overline{\Delta\tau_{ij}}$ we get:

$$\left|\sum_{i=1}^{N} pi\right|^2 = \sum_{i=1}^{N} Ai^2 + \sum_{i=1}^{N}\sum_{j=i+1}^{N} 2Ai\,Aj \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_{\Delta\tau_{ij}}} e^{-\frac{(\overline{\Delta\tau_{ij}}-\Delta\tau_{ij})}{2\sigma_{\Delta\tau}^2}} \cos(\omega\Delta\tau_{ij})\, d\Delta\tau_{ij}$$

$$\left|\sum_{i=1}^{N} pi\right|^2 = \sum_{i=1}^{N} Ai^2 + \sum_{i=1}^{N}\sum_{j=i+1}^{N} 2Ai\,Aj\, exp\left(-\frac{\omega^2\sigma_{\Delta\tau_{ij}}^2}{2}\right)\cos\,(\omega\overline{\Delta\tau_{ij}})$$

Here

$$W_{ij} = exp\left(-\frac{\omega^2\sigma_{\Delta\tau_{ij}}^2}{2}\right)$$

is the decoherence factor due to fluctuating travel time differences.

Unfortunately, Wij never gets zero, which would be advisable in order to reduce calculation time, therefore Wij can be replaced by the following

Let

$$x = -\frac{\omega^2\sigma_{\Delta\tau_{ij}}^2}{2}$$

then

$$W_{ij} = \begin{cases} \exp(x) & -1 \le x \le 0 \\ (2+x)\exp(-1) & -1 < x < -2 \\ 0 & x \le -2 \end{cases}$$

9.1 Derivation of standard deviation $\sigma_{\Delta\tau_{ij}}$:

$$\sigma_{\Delta\tau_{ij}}^2 = \langle\Delta\tau_{ij}^2\rangle - \langle\Delta\tau_{ij}\rangle^2 = \langle(\tau_i-\tau_j)^2\rangle - \langle\tau_i-\tau_j\rangle^2 = \langle(\tau_i-\tau_j)^2\rangle - (\langle\tau_i\rangle - \langle\tau_j\rangle)^2$$

$$\sigma_{\Delta\tau_{ij}}^2 = \langle\tau_i^2\rangle - \langle\tau_i\rangle^2 + \langle\tau_j^2\rangle - \langle\tau_j\rangle^2 + 2\langle\tau_i\rangle\langle\tau_j\rangle - 2\langle\tau_i\tau_j\rangle$$

$$\sigma_{\Delta\tau_{ij}}^2 = \sigma_{\tau_i}^2 + \sigma_{\tau_j}^2 + 2\langle\tau_i\rangle\langle\tau_j\rangle - 2\langle\tau_i\tau_j\rangle$$

Derivation of standard deviation $\sigma_{\tau_i}^2 or\ \sigma_{\tau_j}^2$:

$$\tau_{i/j} = \int_0^{s_{i/j}} \frac{1}{c(\vec{r})} ds$$

$$\langle\tau_{i/j}\rangle = \frac{s_{i/j}}{c_0} \qquad (1)$$

$$\sigma_{\tau_{i/j}}^2 = \langle{\tau_{i/j}}^2\rangle - \langle\tau_{i/j}\rangle^2 \qquad (2)$$

Calculating $\langle {\tau_{i/j}}^2 \rangle$

$$\langle {\tau_{i/j}}^2 \rangle = \langle \int_0^{s_{i/j}} \frac{1}{c(\vec{r}(s))} ds \int_0^{s_{i/j}} \frac{1}{c(\vec{r}(s'))} ds' \rangle$$

$$\langle {\tau_{i/j}}^2 \rangle = \int_0^{s_{i/j}} \int_0^{s_{i/j}} \langle \frac{1}{c(\vec{r}(s))} \frac{1}{c(\vec{r}(s'))} \rangle \, ds ds'$$

Using the two-point correlation function for a stationary stochastic process T(x)

$$\langle T(x)T(y) \rangle = \langle T \rangle^2 + \sigma_T^2 \exp\left(-\frac{|x-y|}{\tau_{cor}}\right)$$

and substituting $s' = s + \rho; d\rho = ds'$ we get

$$\langle {\tau_{i/j}}^2 \rangle = \int_0^{s_{i/j}} \int_{-s}^{s_{i/j}-s} \langle \frac{1}{c(\vec{r}(s))} \frac{1}{c(\vec{r}(s+\rho))} \rangle \, ds d\rho$$

Where:

$$T(x) = \frac{1}{c(\vec{r}(x))}$$

$$\langle T(x) \rangle = \frac{1}{c_0}$$

$$\sigma_T^2 = \frac{\sigma_c^2}{c_0^4} \text{ for } \sigma_c \ll c_0$$

$$\langle {\tau_{i/j}}^2 \rangle = \int_0^{s_{i/j}} \int_{-s}^{s_{i/j}-s} \left[\frac{1}{c_0^2} + \sigma_T^2 \exp\left(-\frac{|\rho|}{\tau_{cor}}\right)\right] ds d\rho$$

$$\langle {\tau_{i/j}}^2 \rangle = \frac{s_{i/j}^2}{c_0^2} + \sigma_T^2 \int_0^{s_{i/j}} \int_{-s}^{s_{i/j}-s} \exp\left(-\frac{|\rho|}{\tau_{cor}}\right) ds d\rho$$

Solving the integral:

$$\langle {\tau_{i/j}}^2 \rangle = \frac{s_{i/j}^2}{c_0^2} + 2\sigma_T^2 \tau_{cor} \left(s_{i/j} + \tau_{cor}\left[\exp\left(-\frac{s_{i/j}}{\tau_{cor}}\right) - 1\right]\right)$$

With (1) we get for $\langle \tau_{i/j} \rangle^2$

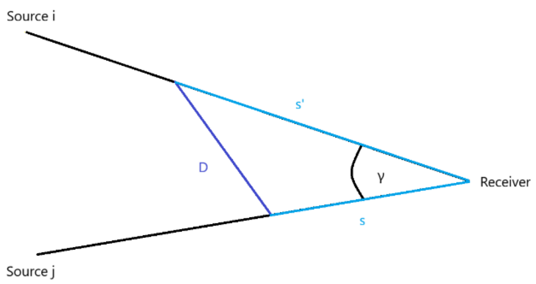
$$\langle \tau_{i/j} \rangle^2 = \left(\frac{s_{i/j}}{c_0}\right)^2$$

With (2) we finally get for $\sigma_{\tau_{i/j}}^2$

$$\boldsymbol{\sigma_{\tau_{i/j}}^2 = 2\sigma_T^2 \tau_{cor} \left(s_{i/j} + \tau_{cor}\left[\exp\left(-\frac{s_{i/j}}{\tau_{cor}}\right) - 1\right]\right)}$$

Calculating $\langle \tau_i \tau_j \rangle$

$$\langle \tau_i \tau_j \rangle = \frac{s_i s_j}{c_0^2} + \sigma_T^2 \int_0^{s_i} \int_0^{s_j} \exp\left(-\frac{D(s, s', \cos(\gamma))}{\tau_{cor}}\right) ds ds'$$



$$D(s, s', \cos(\gamma)) = \sqrt{s^2 + s'^2 - 2ss'\cos(\gamma)}$$

$$\sigma_{\Delta\tau_{ij}}^2 = \sigma_{\tau_i}^2 + \sigma_{\tau_j}^2 + 2\langle \tau_i \rangle \langle \tau_j \rangle - 2\langle \tau_i \tau_j \rangle$$

$$\sigma_{\Delta\tau_{ij}}^2 = \sigma_{\tau_i}^2 + \sigma_{\tau_j}^2 + \frac{2 s_i s_j}{c_0^2} - 2\left(\frac{s_i s_j}{c_0^2} + \sigma_T^2 \int_0^{s_i} \int_0^{s_j} \exp\left(-\frac{D(s, s', \cos(\gamma))}{\tau_{cor}}\right) ds ds'\right)$$

$$\sigma_{\Delta\tau_{ij}}^2 = \sigma_{\tau_i}^2 + \sigma_{\tau_j}^2 - 2\sigma_T^2 \int_0^{s_i} \int_0^{s_j} \exp\left(-\frac{D(s, s', \cos(\gamma))}{\tau_{cor}}\right) ds ds'$$

$$\boldsymbol{\sigma_{\Delta\tau_{ij}}^2 = \sigma_{\tau_i}^2 + \sigma_{\tau_j}^2 - 2\frac{\sigma_c^2}{c_0^4} \int_0^{s_i} \int_0^{s_j} \exp\left(-\frac{D(s, s', \cos(\gamma))}{\tau_{cor}}\right) ds ds'}$$

$$\boldsymbol{D(s, s', \cos(\gamma)) = \sqrt{s^2 + s'^2 - 2ss'\cos(\gamma)}}$$

Substituting s -> s/$\boldsymbol{\tau_{cor}}$; s' -> s'/$\boldsymbol{\tau_{cor}}$

$$\boldsymbol{\int_0^{s_i} \int_0^{s_j} \exp\left(-\frac{D(s, s', \cos(\gamma))}{\tau_{cor}}\right) ds ds' = \tau_{cor}{}^2 \int_0^{s_i/\tau_{cor}} \int_0^{s_j/\tau_{cor}} \exp(-D(x, y, \cos(\gamma)))\, dxdy}$$
$$\boldsymbol{= \tau_{cor}{}^2 I\left(\frac{s_i}{\tau_{cor}}, \frac{s_j}{\tau_{cor}}, \cos(\gamma)\right)}$$

$$\boldsymbol{\sigma_{\Delta\tau_{ij}}^2 = 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}\left(s_i + \tau_{cor}\left[\exp\left(-\frac{s_i}{\tau_{cor}}\right) - 1\right]\right) + 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}\left(s_j + \tau_{cor}\left[\exp\left(-\frac{s_j}{\tau_{cor}}\right) - 1\right]\right)}$$
$$\boldsymbol{- 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}{}^2 I\left(\frac{s_i}{\tau_{cor}}, \frac{s_j}{\tau_{cor}}, \cos(\gamma)\right)}$$

$$\boldsymbol{\sigma_{\Delta\tau_{ij}}^2 = 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}(s_i + s_j) + 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}{}^2\left\{\left[\exp\left(-\frac{s_i}{\tau_{cor}}\right) - 1\right] + \left[\exp\left(-\frac{s_j}{\tau_{cor}}\right) - 1\right] - I\left(\frac{s_i}{\tau_{cor}}, \frac{s_j}{\tau_{cor}}, \cos(\gamma)\right)\right\}}$$

$$\boldsymbol{\sigma_{\Delta\tau_{ij}}^2 = 2\frac{\sigma_c^2}{c_0^4}\tau_{cor}{}^2\left\{\left[\frac{s_i}{\tau_{cor}} + \frac{s_j}{\tau_{cor}}\right] + \left[\exp\left(-\frac{s_i}{\tau_{cor}}\right) - 1\right] + \left[\exp\left(-\frac{s_j}{\tau_{cor}}\right) - 1\right] - I\left(\frac{s_i}{\tau_{cor}}, \frac{s_j}{\tau_{cor}}, \cos(\gamma)\right)\right\}}$$

The expression {..} can be precalculated and stored as 3-dimensional matrix, where I(..) can be solved numerically. Intermediate values could then be calculated by bilinear interpolation, but so far, the approximate solution given in [3] has been found sufficient.

10 Bibliography

[1] ISO 266:1997: Acoustics — Preferred frequencies

[2] ISO 9613-1:1993: Acoustics — Attenuation of sound during propagation outdoors — Part 1: Calculation of the absorption of sound by the atmosphere

[3] Stefan Feistel: *Modeling the Radiation of Modern Sound Reinforcement Systems in High Resolution*, ISBN 978-3-8325-3710-4, Logos Verlag Berlin GmbH 2014