Microphone array techniques and wind instruments

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Possibilities of Acoustic Holography and Microphone Arrays

- Transient and static sound field measurement
- Measurement of vibration of structures and air columns by backpropagation of sound field variables
- Description of radiation of instrument in space using backpropagated sound field
- Source detection
- Surface description
- Binaural calculation of diffusion of musical instruments
- Determination of psychoacoustic parameters of musical instrument sound field radiation

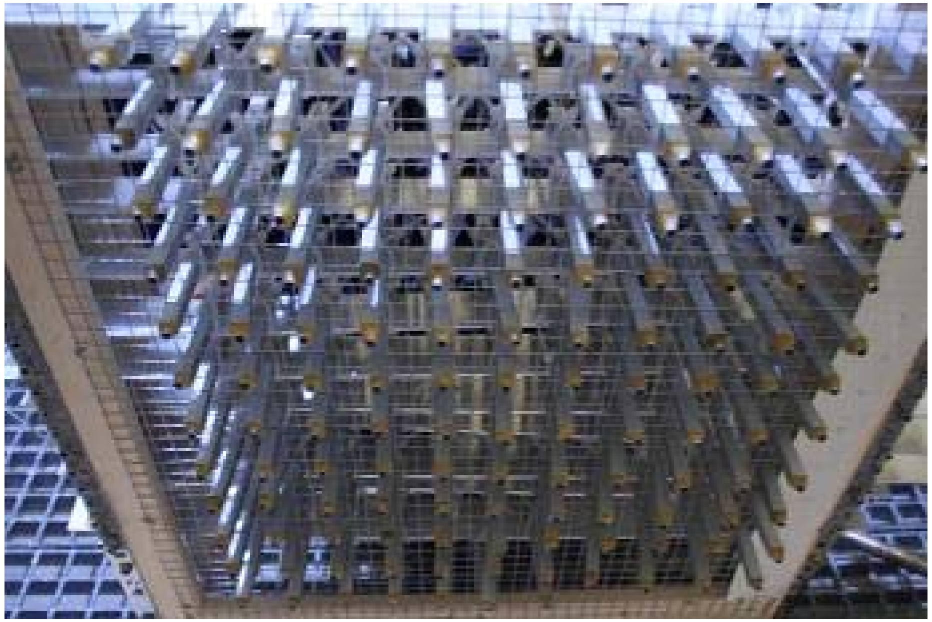
Aims of Acoustic Holography

- Detection of decisive parameters for musical instrument sounds
- Psychoacoustic relation between sound and tone quality depending upon musical instrument radiation behaviour
- Suggestions of simplified models for instrument and music performance in terms of
- loudspeakers
- room acoustis
- instrument building

Methods of Acoustic Holography

- Nearfield Acoustic Holography (NAH) and Statistical Optimized Nearfield Acoustic Holography (SONAH)
- Beam forming
- Helmholtz-Least-Square method (HELS)
- Multipole-Radiators (Equivalent Source Techniques)
- Minimum Energy method (used here)

Microphone Array



128 electret microphones in an array of 11 x 11 lines for nearfield recording of structures in a distance of 3 cm – 10 cm. Estimation possible for surface description and radiation character differences of different surface points, location of far-field sources, diffusion estimation and of course radiation measurements.

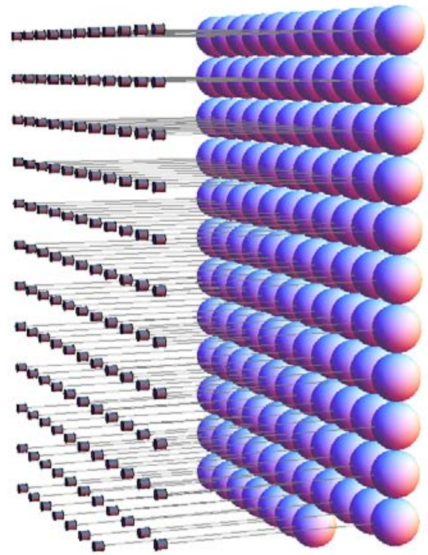
Minimum Energy method

Basic equation: sound pressure p measured at place x is the sum of pressures p_g radiated at geometry point p_g with radiation characteristic R^i

$$\mathrm{p}(\mathbf{x}) = \sum_{i=1}^{N} \mathrm{p}_g^i \ \mathrm{R}^i$$

Radiation characteristic R^i: complex propagation vector using phase and amplitude from x to x_g with wave vector k and amplitude drop Γ^i.

$$\mathrm{R}^i = \frac{1}{\Gamma^i} e^{\imath k (\mathbf{x}_g^i - \mathbf{x})}$$



Bader, R.: Reconstruction of Radiating Sound Fields using Minimum Energy Method. *J. Acoust. Soc. Am.* 2010 (in print).

Minimum Energy Method

Amplitude drop $\Gamma_0^{ij}(\alpha)$ depends on β^{ij} and α

$$\Gamma_0^{ij}(\alpha) = r^{ij}(1 + \alpha(1 - \beta^{ij}))$$

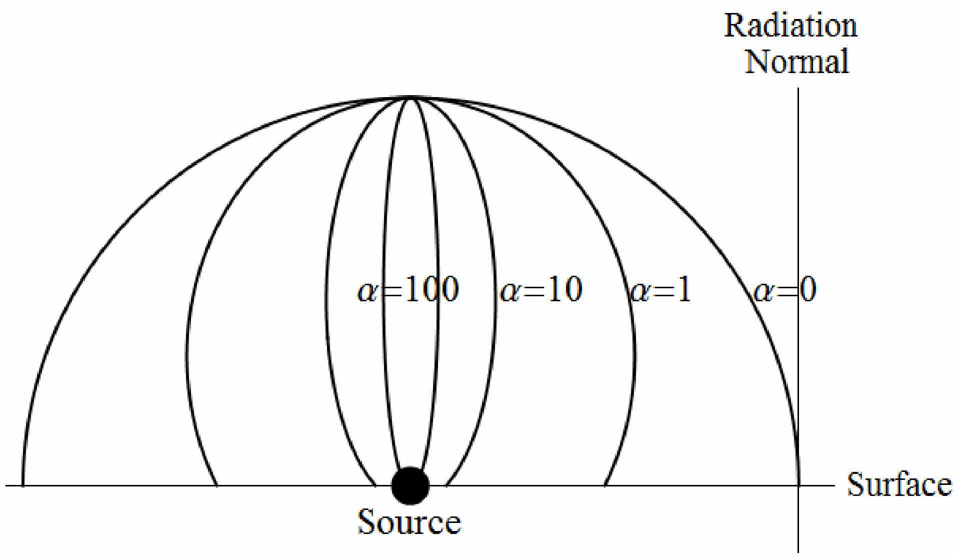
using the scalar product of normal vector $\mathbf{n}^i$ on geometry and distances.

$$\beta^{ij} = \left| \, \| \mathbf{r}^{ij} \| \otimes \mathbf{n}^i \, \right|$$

1) $\alpha = 0$: perfect sphere
2) $\alpha > 0$ and $\beta = 1$: maximum radiation (in normal direction)
3) $\alpha > 0$ and $\beta = 0$: minimum radiation (in orthonormal direction)

Minimum Energy Method

$$\Gamma_0^{ij}(\alpha) = r^{ij}(1 + \alpha(1 - \beta^{ij}))$$



Isobars for different values of α over

0 <= β <= 1

Radiation matrix:

$$\mathrm{R}_0^{ij}(\alpha) = e^{\imath kr} \frac{1}{r^{ij}(1 + \alpha(1 - \beta^{ij}))}$$

Miniumum Energy Method

Linear equation system for propagation of pressures at microphone positions to pressures of surface.

$$\mathbf{R}_0(\alpha)\ \mathbf{p}_g = \mathbf{p}_m$$

Reconstruction of sound field

$$\mathrm{p}(\mathbf{x}) = \sum_{i=1}^{N} \mathrm{p}_g^i \ \mathrm{R}^i$$

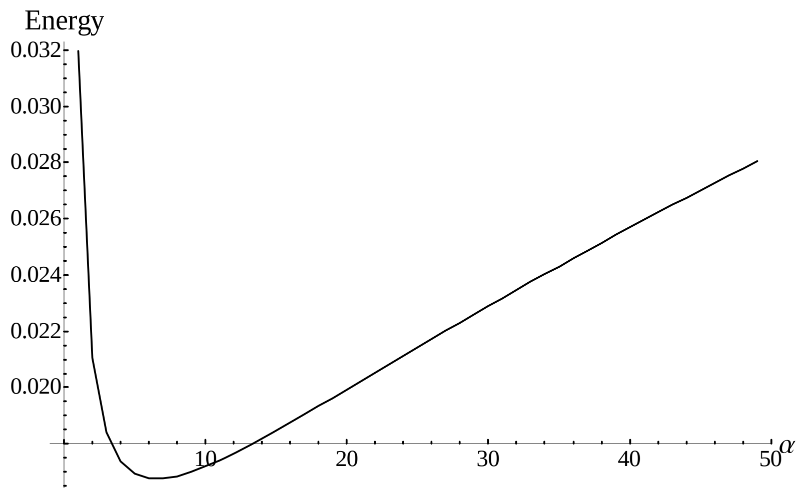
$$\mathrm{R}^i = \frac{1}{\Gamma^i} e^{\imath k (\mathbf{x}_g^i - \mathbf{x})}$$

$$\Gamma^i(\alpha) = \mid \mathbf{x}_g^i - \mathbf{x} \mid (1 + \alpha(1 - \mid \| \mathbf{x}_g^i - \mathbf{x} \| \otimes \mathbf{n}^i \mid))$$

Radiation Characteristic

For the correct radiation characteristic value α the reconstruction energy E is a minimum.

$$\mathrm{E} = \sum_i |\, \mathbf{p}_g^i \,|^2 = \mathrm{Min}$$



If α is too big (right side): reconstruction = radiation. Therefore the energy is too high as the radiation points need to fully deterrmine the microphone pressures.

If α is too small (left side): Radiation points far away from the microphone are additionally made responsible for the recorded microphone pressures. Therefore the linear system solver reconstructs the influences in a way to balance these overestimated influences. These balancing leads very fast to extremely high reconstruction energies.

Flutes

Membrane

Blowing hole

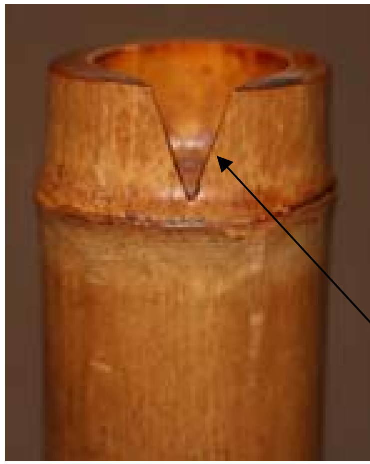
Dizi (China)

Shakuhatchi (Japan)

Suling (Bali)

Dizi

Bamboo membrane covering hole

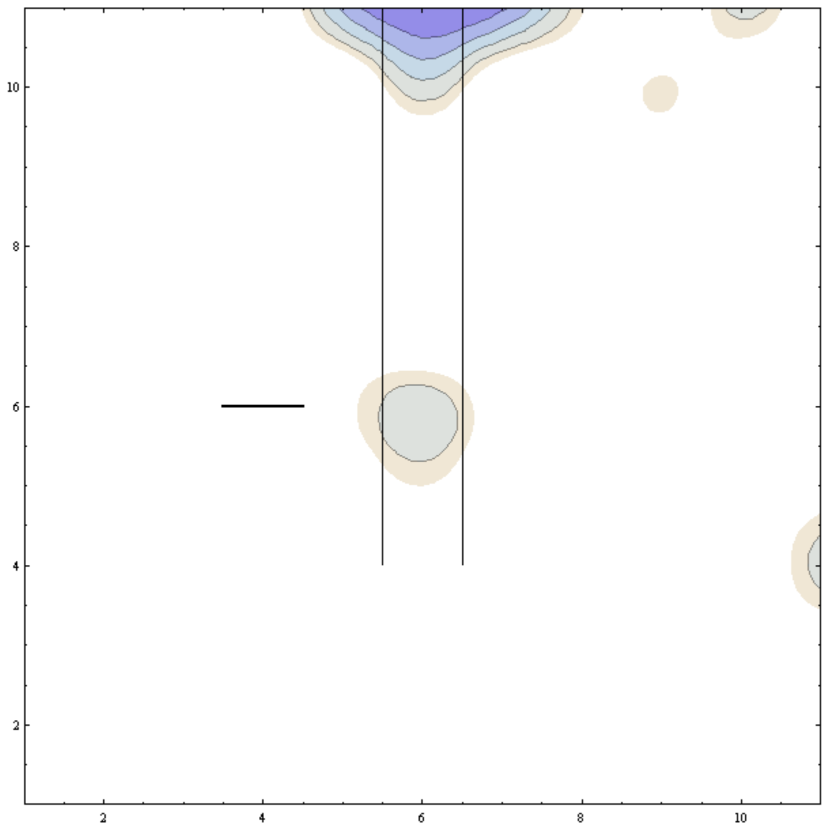


Suling

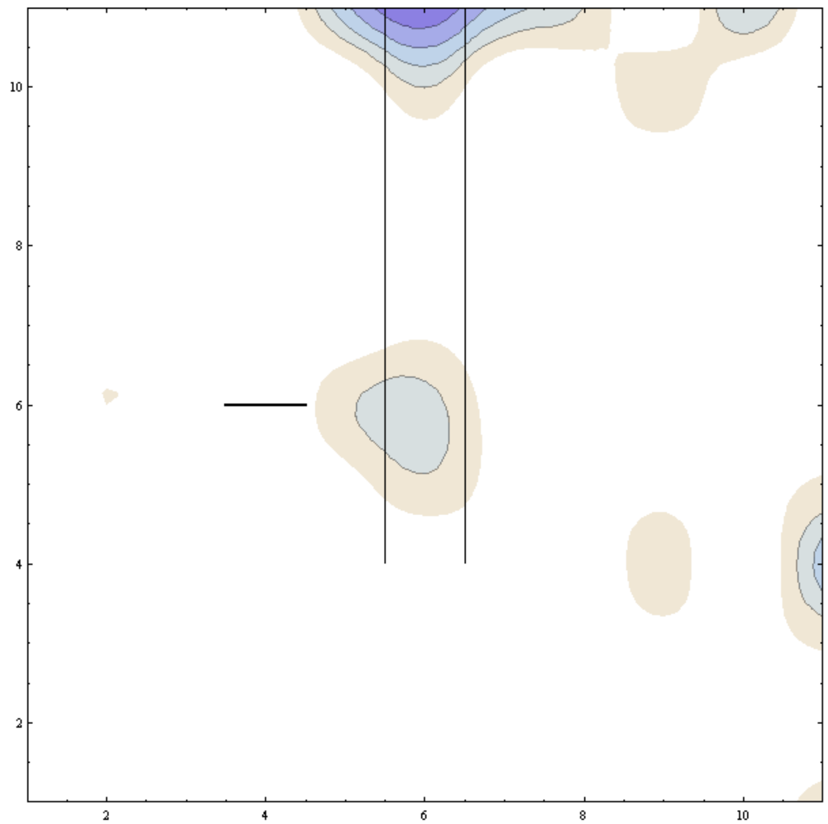
Blowing hole

Shakuhatchi Blowing edge

Suling

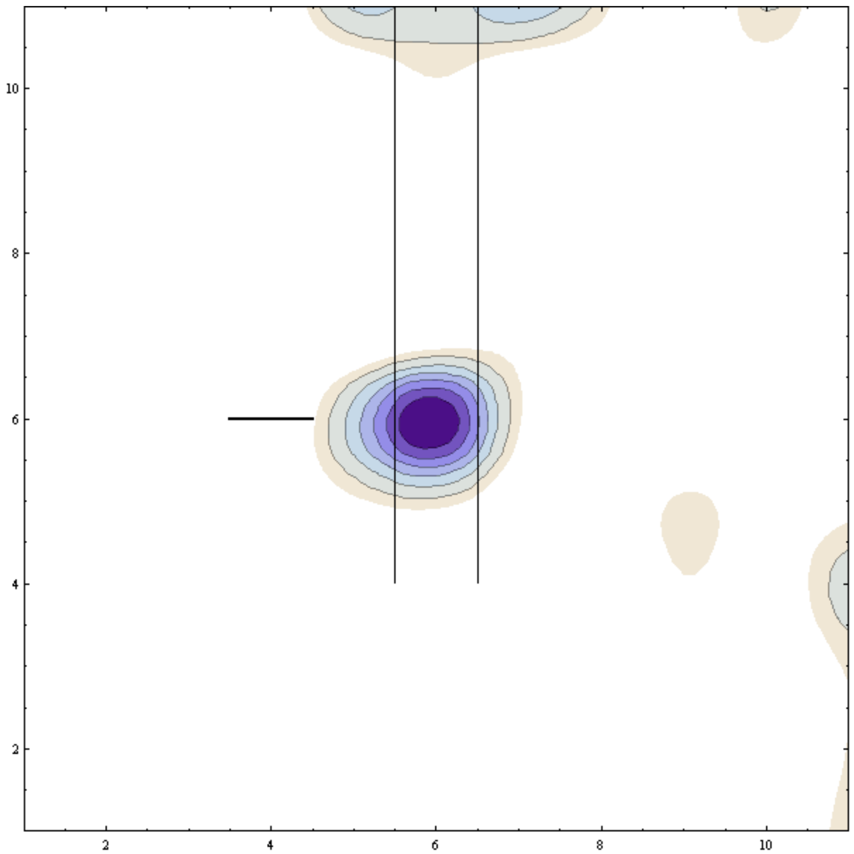


1. Partial 580 Hz

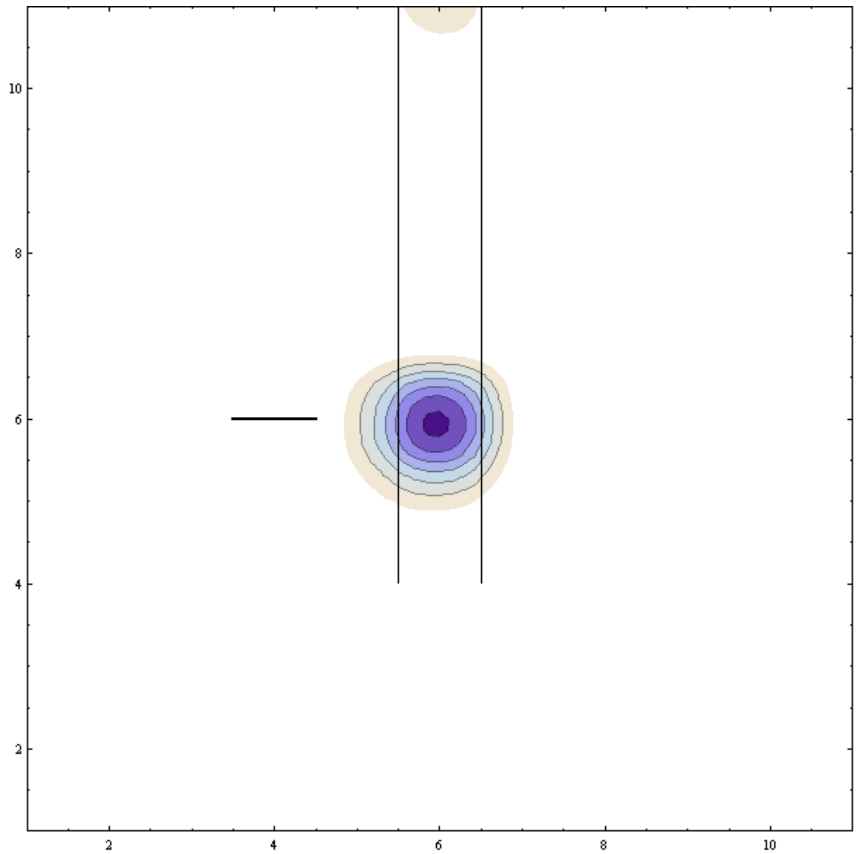


2. Partial 1160 Hz

Suling

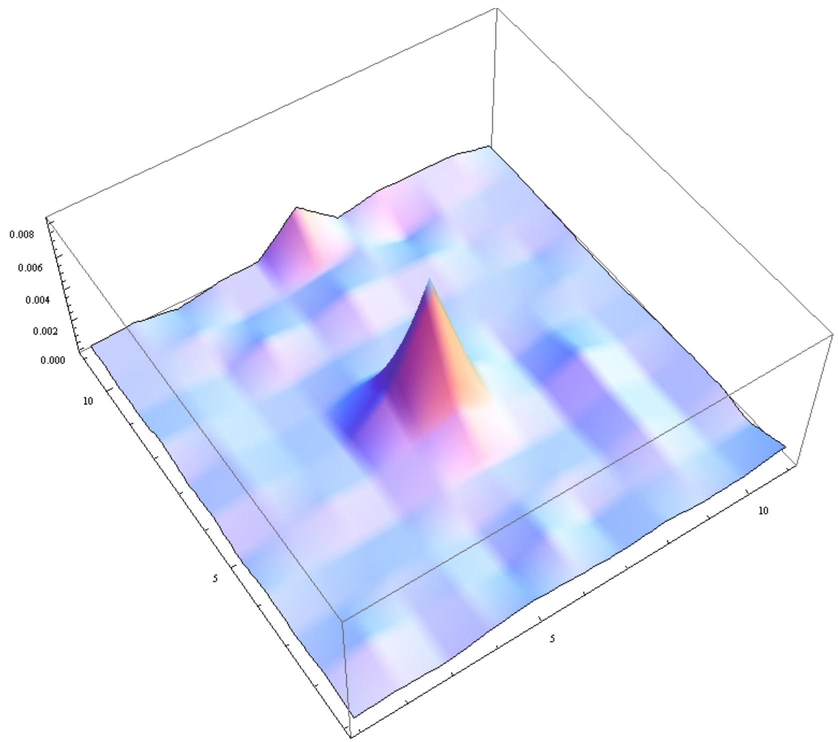


3. Partial 1770 Hz



4. Partial 2370 Hz

Suling



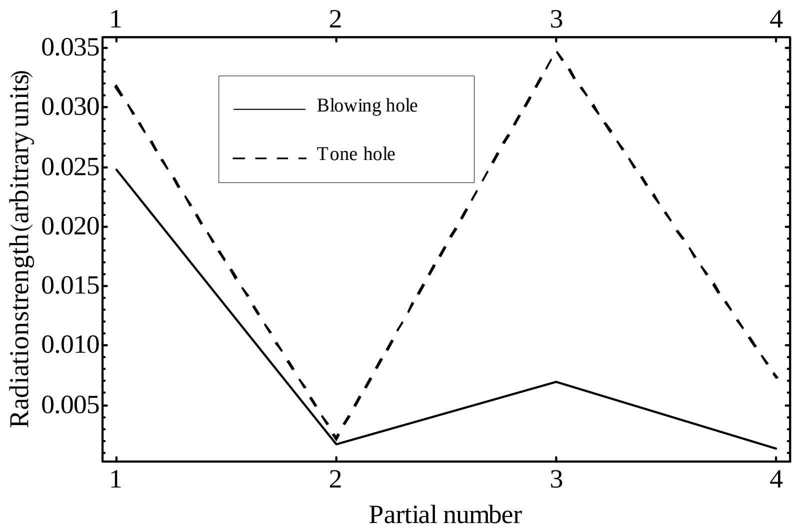
2370 Hz

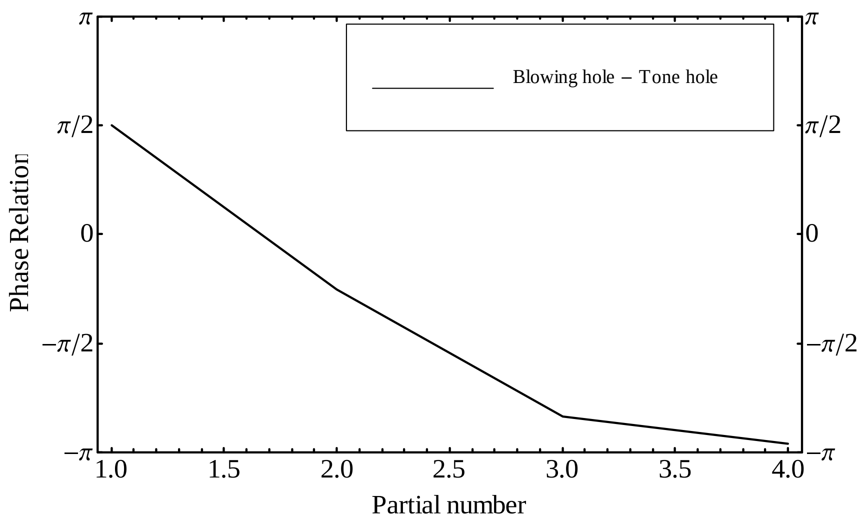
partial	alpha
1. (580 Hz)	0.1
2.(1160 Hz)	0.1
3. (1770 Hz)	0.0
4. (2370 Hz)	0.0

For comparison: alpha for tamborine modes

Frequency	194 Hz	316 Hz	326 Hz	436 Hz	444 Hz	540 Hz	566 Hz
n-pole	monopole	dipole	dipole	quadrupol	quadrupol	6-pole	6-pole
alpha (radiation characteristic)	0.8	2.2	1.8	4.8	4.8	10.0	9.0

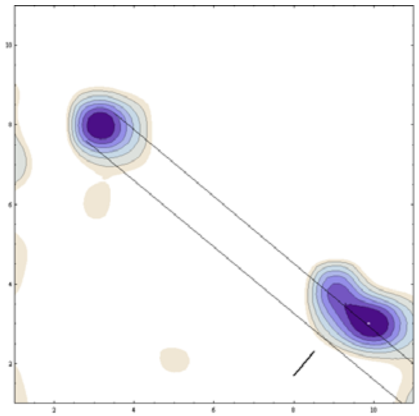
Suling
Amplitude and Phase relations



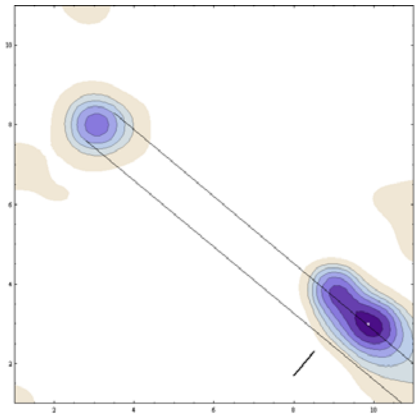


Shakuhatchi

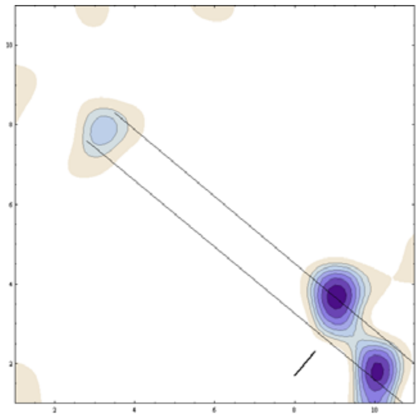
Normal tone



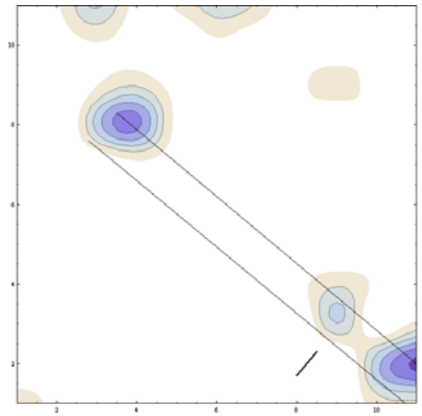
1. Partial 396 Hz



2. Partial 795 Hz

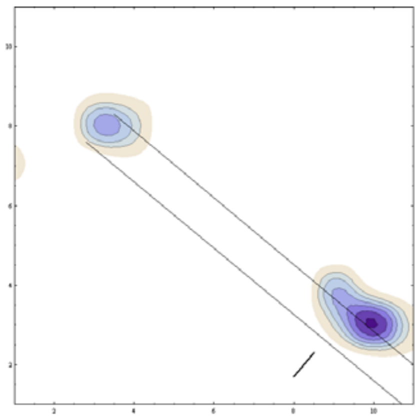


3. Partial 1180 Hz

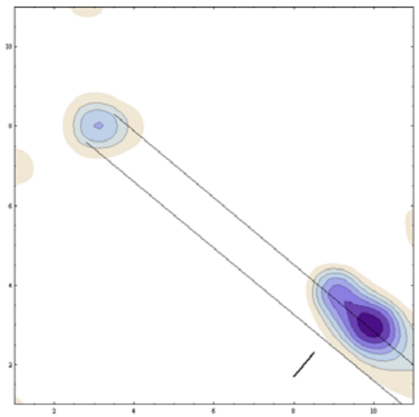


4. Partial 1570

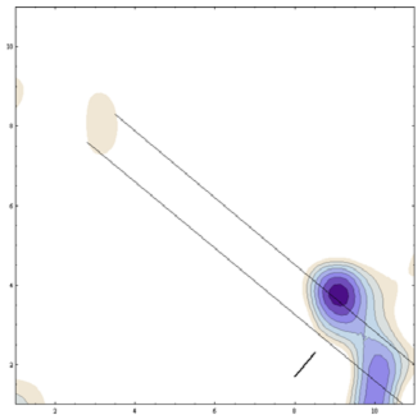
Overblown



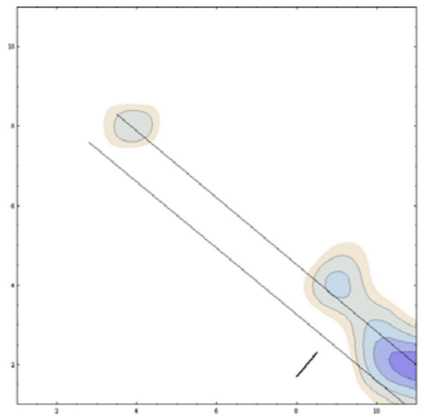
1. Partial 395 Hz



2. Partial 802 Hz



3. Partial 1180 Hz



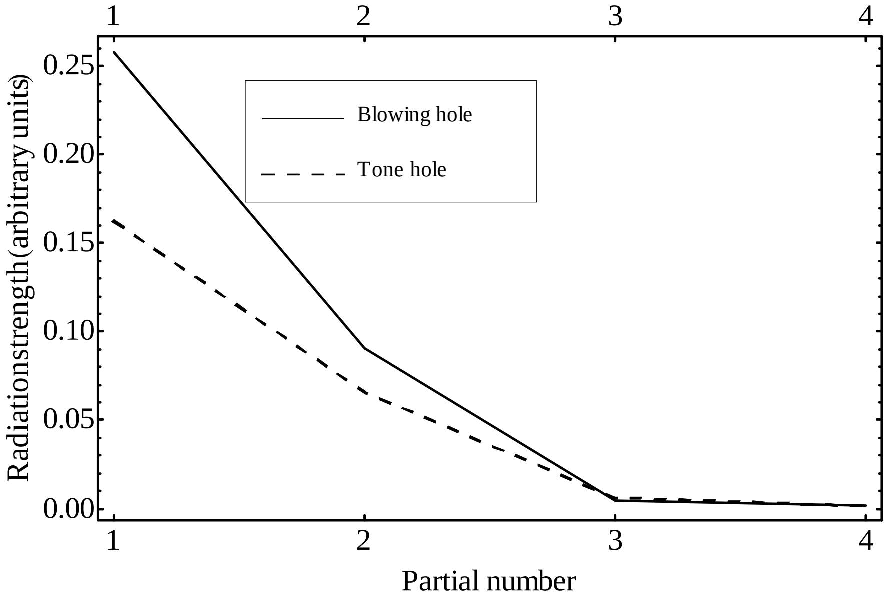
4. Partial 1580

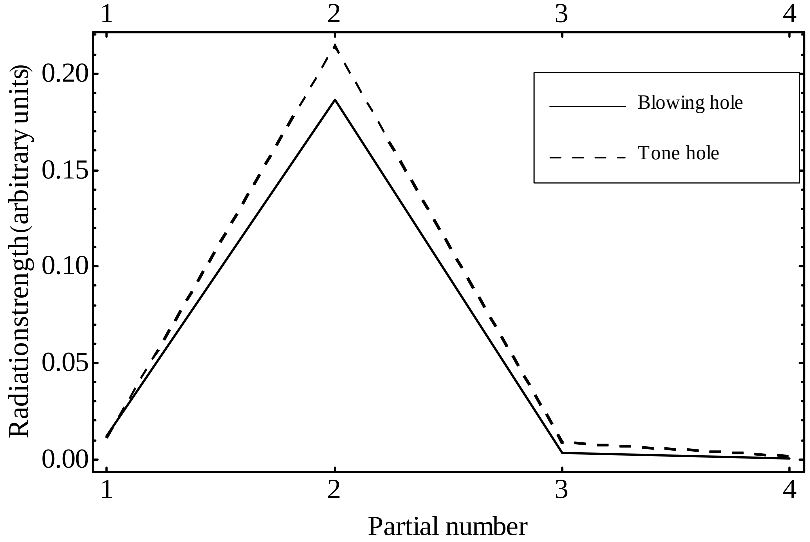
Shakuhatchi

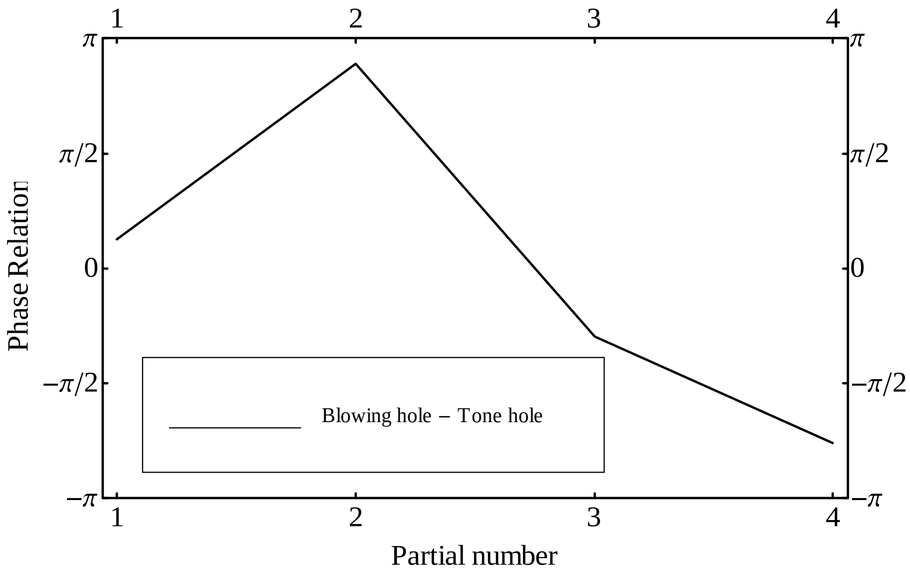
Normal	alpha	Over-blown	alpha
396 Hz	0.2	395 Hz	0.2
795 Hz	0.2	802 Hz	0.2
1180 Hz	0.2	1180 Hz	0.4
1570 Hz	0.2	1580 Hz	0.0

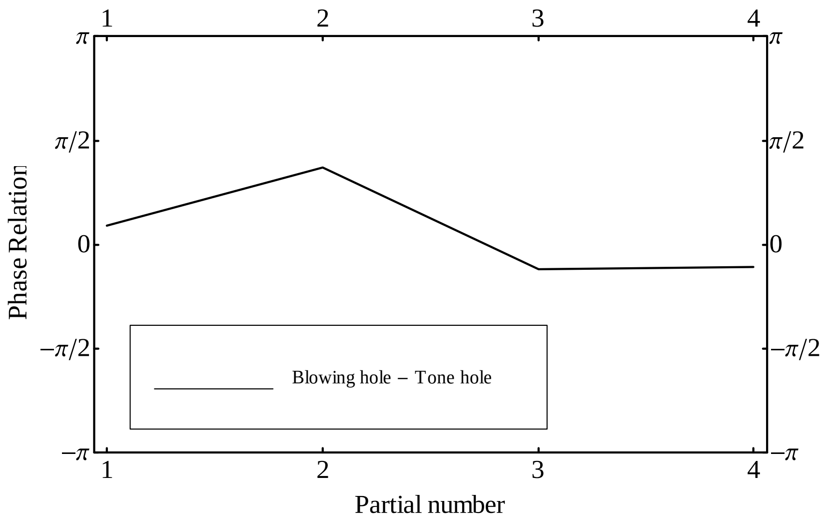
Shakuhatchi
Amplitude and Phase relations

Normal | Overblown

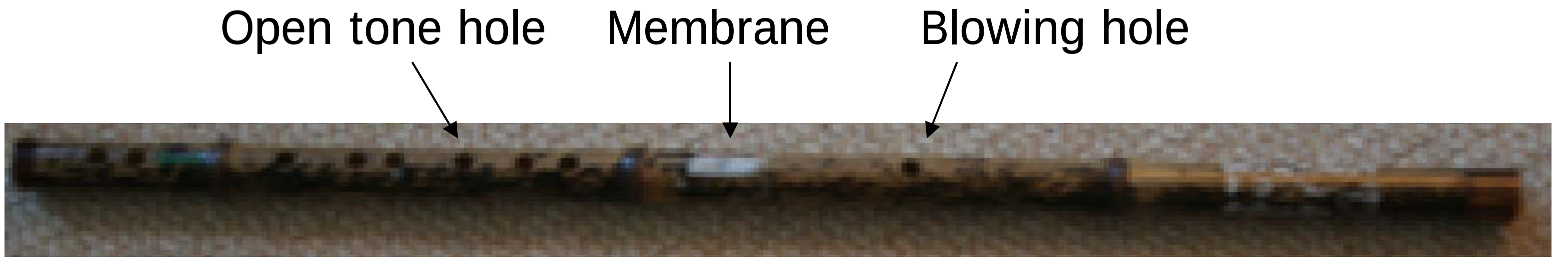






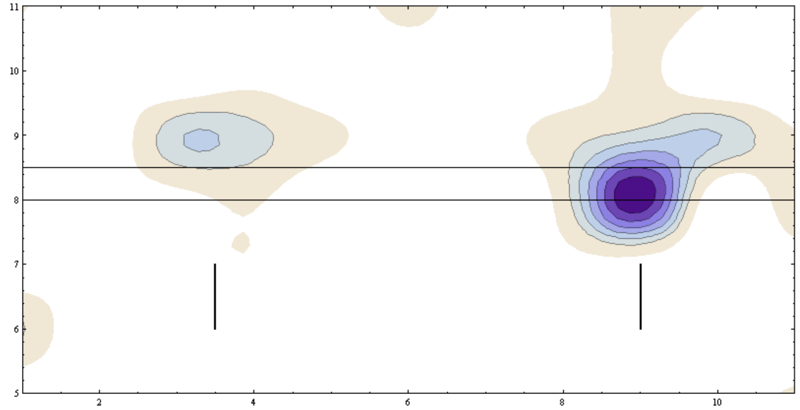


Dizi



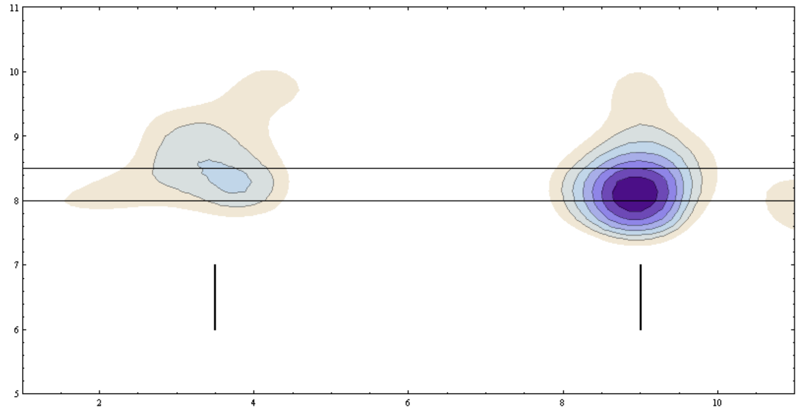
1. Partial

571 Hz



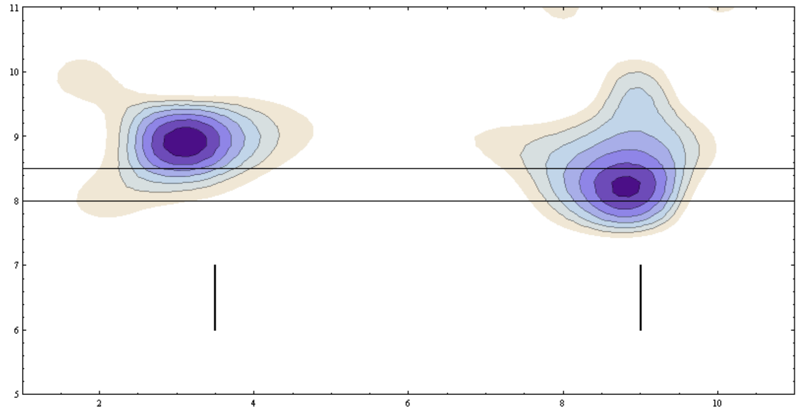
2. Partial

1140 Hz

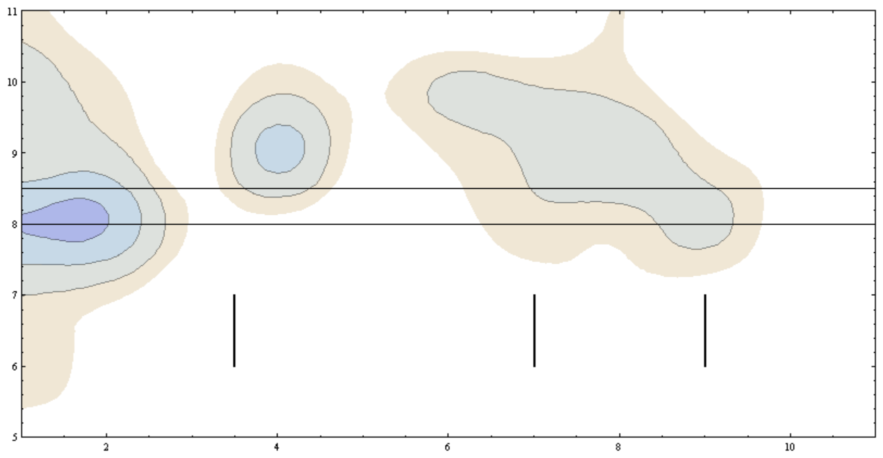


3. Partial

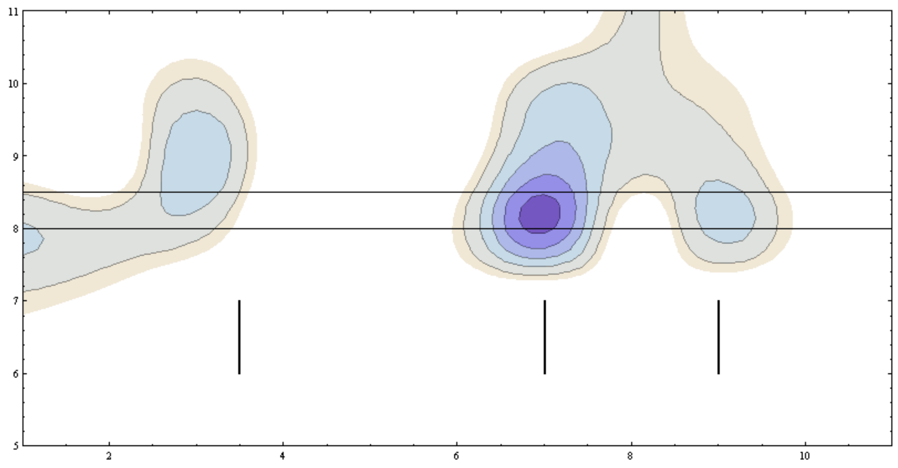
1720 Hz



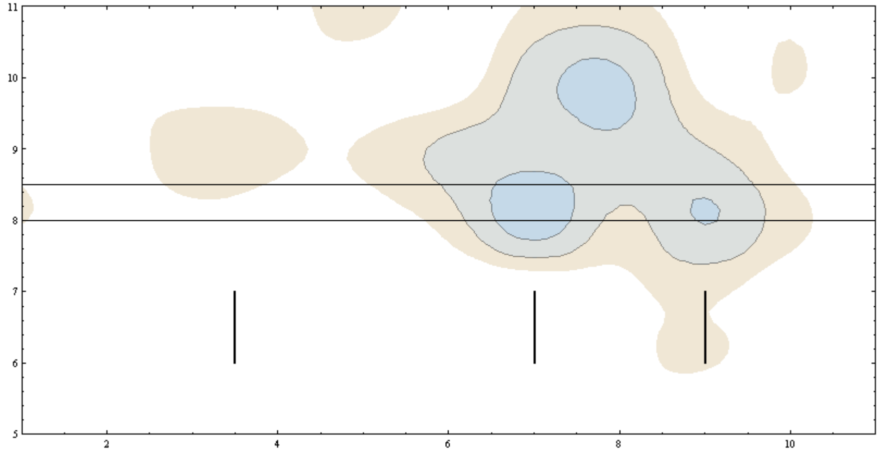
4. Partial 2290 Hz



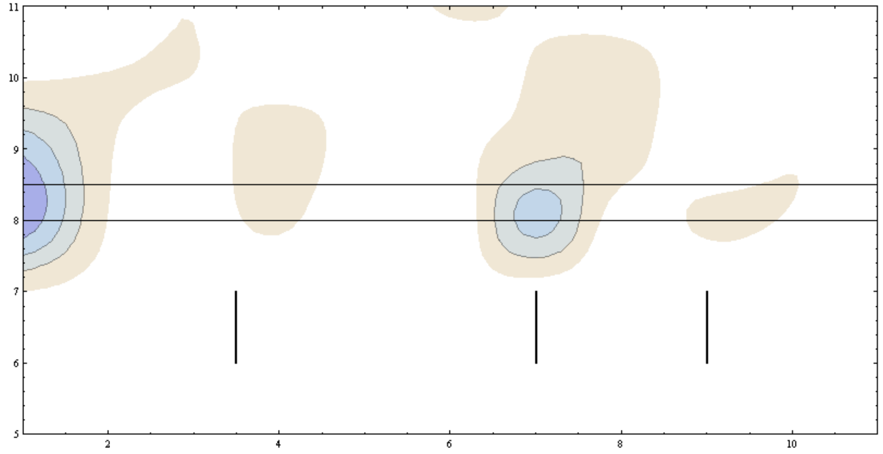
6. Partial 3435 Hz



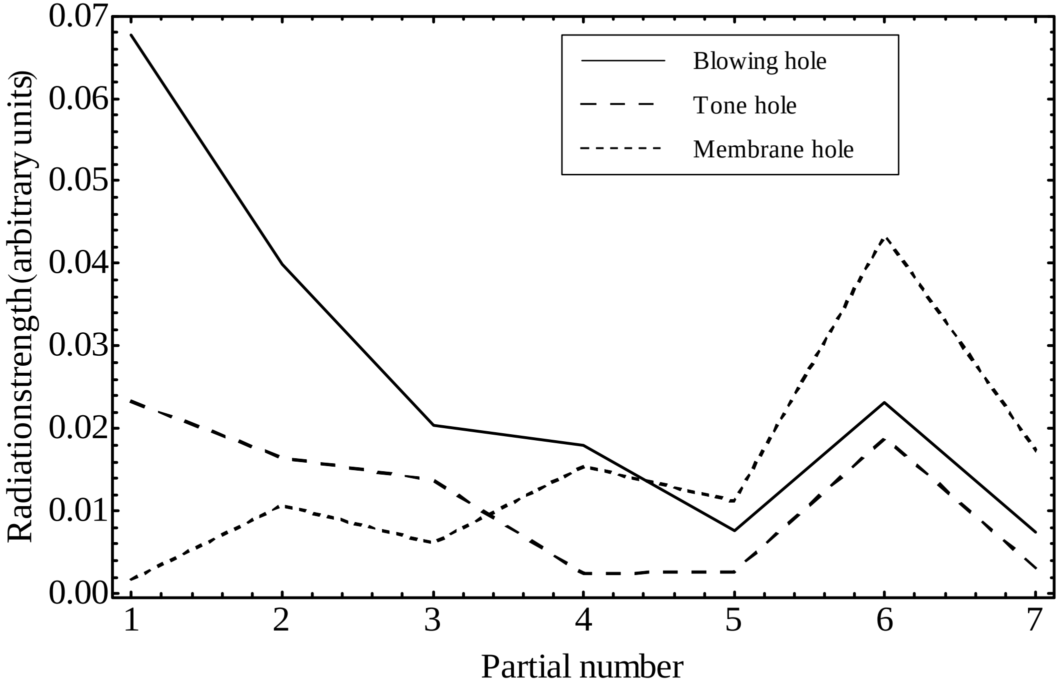
5. Partial 2860 Hz



7. Partial 4010 Hz

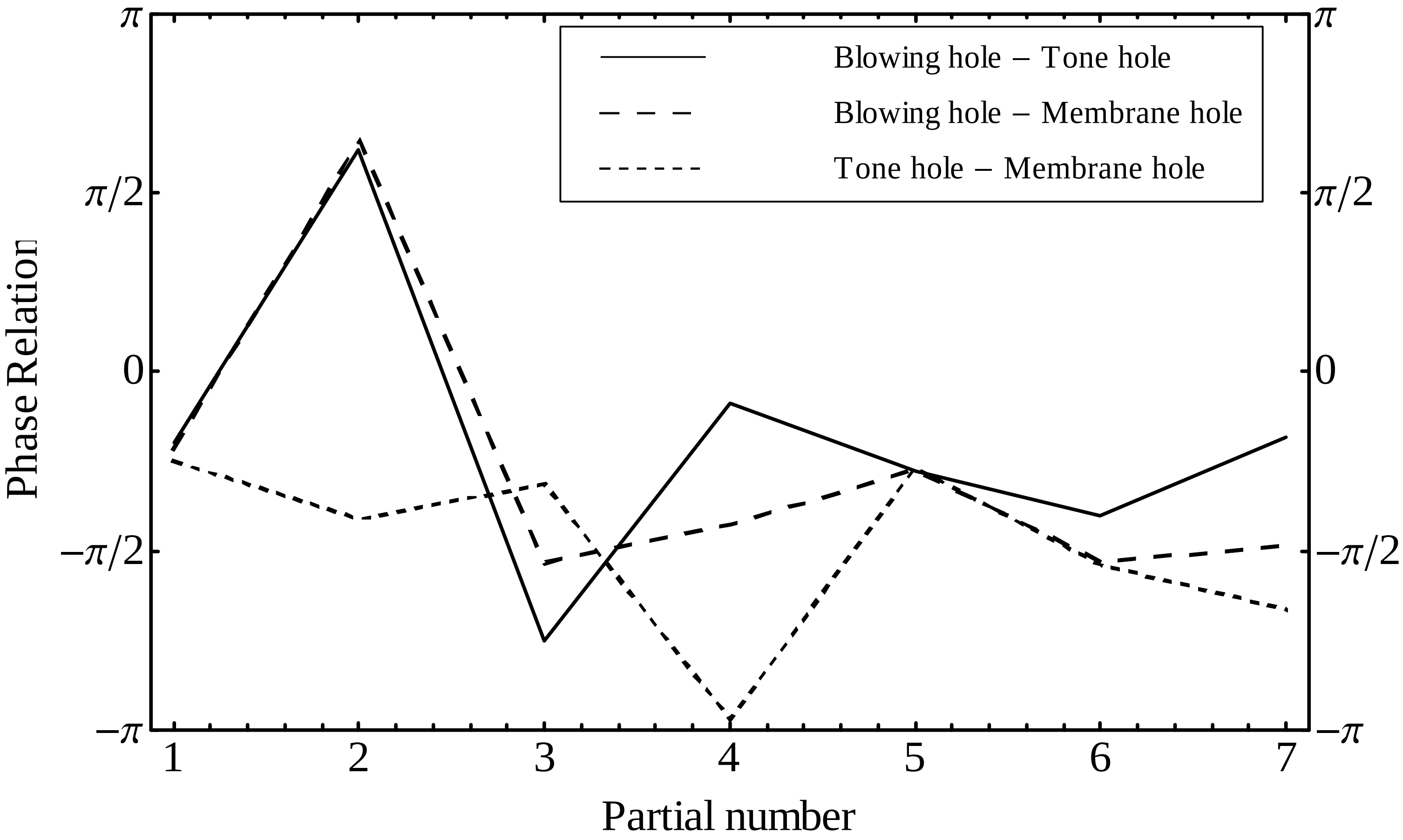


Dizi



Partial	alpha
571 Hz	0.0
1140 Hz	0.6
1720 Hz	0.0
2290 Hz	0.0
2860 Hz	0.0
3435 Hz	0.0
4010 Hz	0.3

Dizi Phase relations



Conclusions

- Higher partials radiate with tone holes rather than with blowing holes, lower partials vice versa
- Membrane of Dizi major radiator above 2.5 kHz
- Dizi blowing hole radiation shows strong turbulent influence
- Shakuhatchi turbulent sound production not measured
- Phase relations between blowing and tone holes as expected for lower frequencies