2018 IEEE International Conference on Acoustics, Speech and Signal Processing

INFLUENCE OF THE NUMBER OF LOUDSPEAKERS ON THE TIMBRE IN MIXED-ORDER AMBISONICS REPRODUTION

Haiming Mai, Bosun Xie, Jianliang Jiang*
Acoustic Laboratory, School of Physics and Optoelectronics, South China University of Technology, Guangzhou, 510641, China; phbsxie@scut.edu.cn

♦ Introduction

● **Ambisonics:**

--- spatial sound reproduction systems;

--- region size & high-frequency

increase with increasing order

--- the required number of loudspeakers;

--- mixed-order Ambisonics (MOA)

horizontal → higher
vertical → lower

● **Timbre:**

--- an important perceptual quality;

--- Moore's revised loudness model

● **Aim of present work:**

--- the influence of the number of loudspeakers on the timbre in MOA reproduction

♦ Mixed-order Ambisonics

● **Spherical coordinate:**

--- (r, θ, ϕ), $\Omega = (\theta, \phi)$

● **The target sound pressure:**

$$P(r,\Omega,\Omega_S,f) = 4\pi \sum_{l=0}^{L_{3D}} \sum_{m=0}^{l} \sum_{\sigma=\pm1} j^l j_l(kr) S_{lm}^{\sigma} Y_{lm}^{\sigma}(\Omega) + 4\pi \sum_{l=L_{3D}+1}^{L_{2D}} \sum_{\sigma=\pm1} j^l j_l(kr) S_{ll}^{\sigma} Y_{ll}^{\sigma}(\Omega)$$

● **The reproduced sound pressure:**

$$P'(r,\Omega,\Omega_S,f) = 4\pi \sum_{i=1}^{M} \sum_{l=0}^{L_{3D}} \sum_{m=0}^{l} \sum_{\sigma=\pm1} j^l j_l(kr) E_i(\Omega_S) Y_{lm}^{\sigma}(\Omega_i) Y_{lm}^{\sigma}(\Omega) + 4\pi \sum_{i=1}^{M} \sum_{l=L_{3D}+1}^{L_{2D}} \sum_{\sigma=\pm1} j^l j_l(kr) E_i(\Omega_S) Y_{ll}^{\sigma}(\Omega_i) Y_{ll}^{\sigma}(\Omega)$$

● **When $P' = P$:**

$$\sum_{i=1}^{M} E_i(\Omega_S) Y_{lm}^{\sigma}(\Omega_i) = S_{lm}^{\sigma} \quad \Rightarrow \quad \boldsymbol{S} = \boldsymbol{Y}_M \boldsymbol{E}$$

$(K \times 1)$

$$\boldsymbol{S} = [S_{00}^{1}(\Omega_S), S_{10}^{1}(\Omega_S), \cdots, S_{L_{2D}L_{2D}}^{-1}(\Omega_S)]^{\mathrm{T}}$$

$(M \times 1)$

$$\boldsymbol{E} = [E_1(\Omega_S), E_2(\Omega_S), \cdots, E_M(\Omega_S)]^{\mathrm{T}}$$

$\boldsymbol{Y}_M$ is the $K \times M$ matrix composed of SHFs of loudspeaker directions

$$\boldsymbol{Y}_M = \begin{bmatrix} Y_{00}^{1}(\Omega_1) & Y_{00}^{1}(\Omega_2) & \cdots & Y_{00}^{1}(\Omega_M) \\ Y_{10}^{1}(\Omega_1) & Y_{10}^{1}(\Omega_2) & \cdots & Y_{10}^{1}(\Omega_M) \\ Y_{11}^{1}(\Omega_1) & Y_{11}^{1}(\Omega_2) & \cdots & Y_{11}^{1}(\Omega_M) \\ Y_{11}^{-1}(\Omega_1) & Y_{11}^{-1}(\Omega_2) & \cdots & Y_{11}^{-1}(\Omega_M) \\ \vdots & \vdots & \vdots & \vdots \\ Y_{L_{2D}L_{2D}}^{-1}(\Omega_1) & Y_{L_{2D}L_{2D}}^{-1}(\Omega_2) & \cdots & Y_{L_{2D}L_{2D}}^{-1}(\Omega_M) \end{bmatrix}$$

● **Loudspeaker signals:**

--- a linear combination of independent signals

$$\boldsymbol{E} = \boldsymbol{D}\boldsymbol{S}$$

Where $\boldsymbol{D}$ is the decoding matrix. When $M \geq K$, $\boldsymbol{D}$ can be solved by using the pseudo-inverse method:

$$\boldsymbol{D} = pinv(\boldsymbol{Y}_M) = \boldsymbol{Y}_M^{\mathrm{T}}(\boldsymbol{Y}_M \boldsymbol{Y}_M^{\mathrm{T}})^{-1}$$

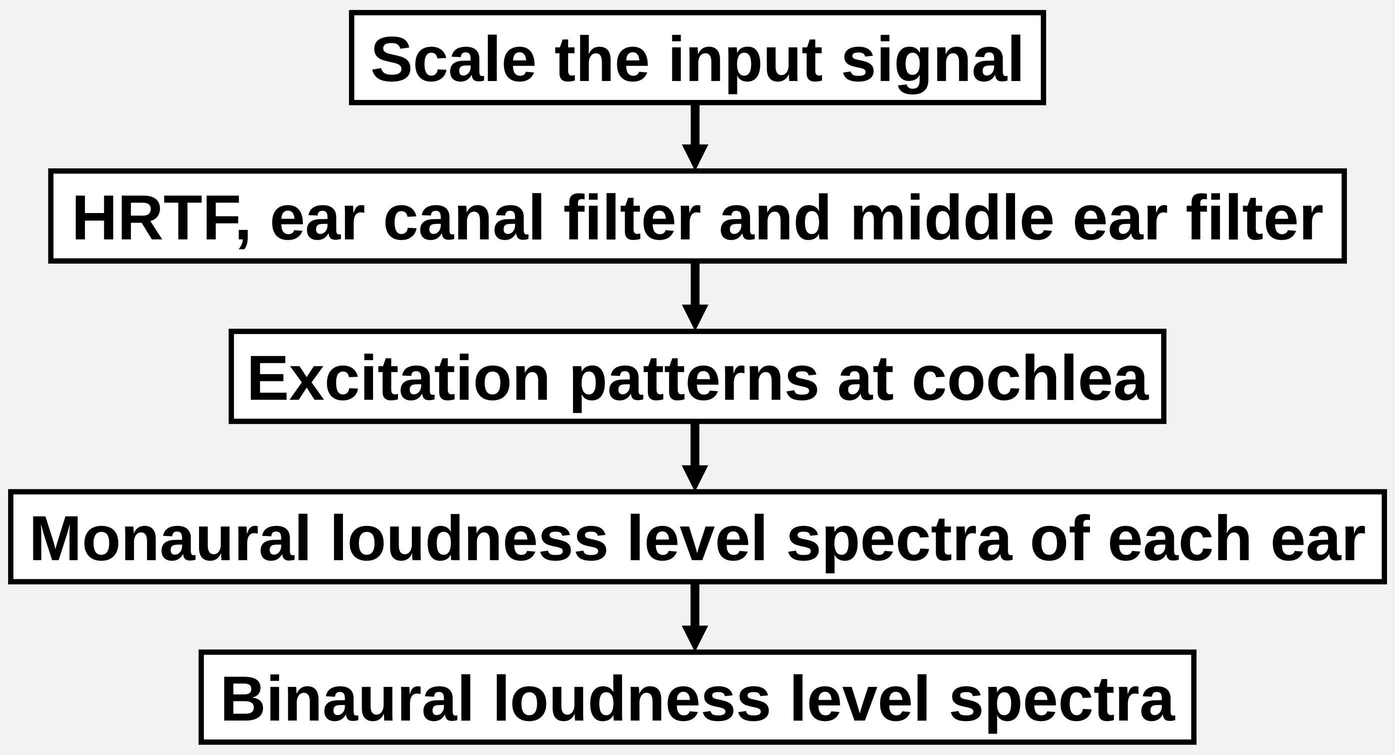
Room 301, Building 18, Wushan Rd., Tianhe District, South China University of Technology, P. R. China(http://www.scut.edu.cn/physics)
Phone: +86 20 87113191; Fax: +86 20 87114230
Email: phbsxie@scut.edu.cn

- **Spatial Nyquist frequency - reproduction**

$$f < f_{max,H} = \frac{Lc}{2\pi a}$$

♦ Moore's loudness model

- **BLLS calculation:**



- **The target binaural pressures:**

$$P_\alpha(\Omega_S, f) = H_\alpha(\Omega_S, f)S_0(f)$$

- **The reconstructed binaural pressures:**

$$P'_\alpha(\Omega_S, f) = \sum_{i=1}^{M} H_\alpha(\Omega_i, f)E_i(\Omega_S, f)$$

♦ Results

- **The reference loudspeaker layout:**

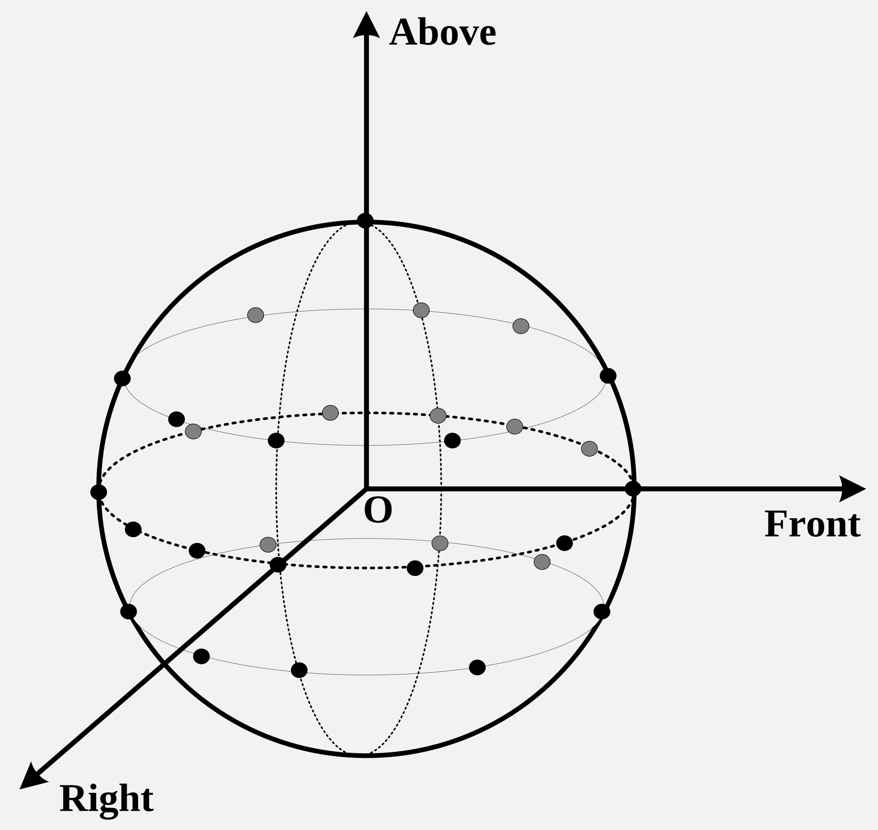


Fig.1. 28+1 layer-wise loudspeaker layout

- **Stability:**

Table.1. The condition number of loudspeaker position matrix

L_{3D}/L_{2D} \ M	29 (Hor-12)	41 (Hor-24)	53 (Hor-36)	89 (Hor-72)
3/3	2.51	3.24	3.92	5.50
3/5	2.51	3.24	3.92	5.50
3/11	10^{16}	3.77	4.58	6.44
3/17	10^{16}	10^{16}	5.08	7.13
3/35	10^{16}	10^{16}	10^{15}	8.50

- **Scale the input signal: 70dB**

- **BLLSD:**

--- the deviation between the BLLS of reproduction and target

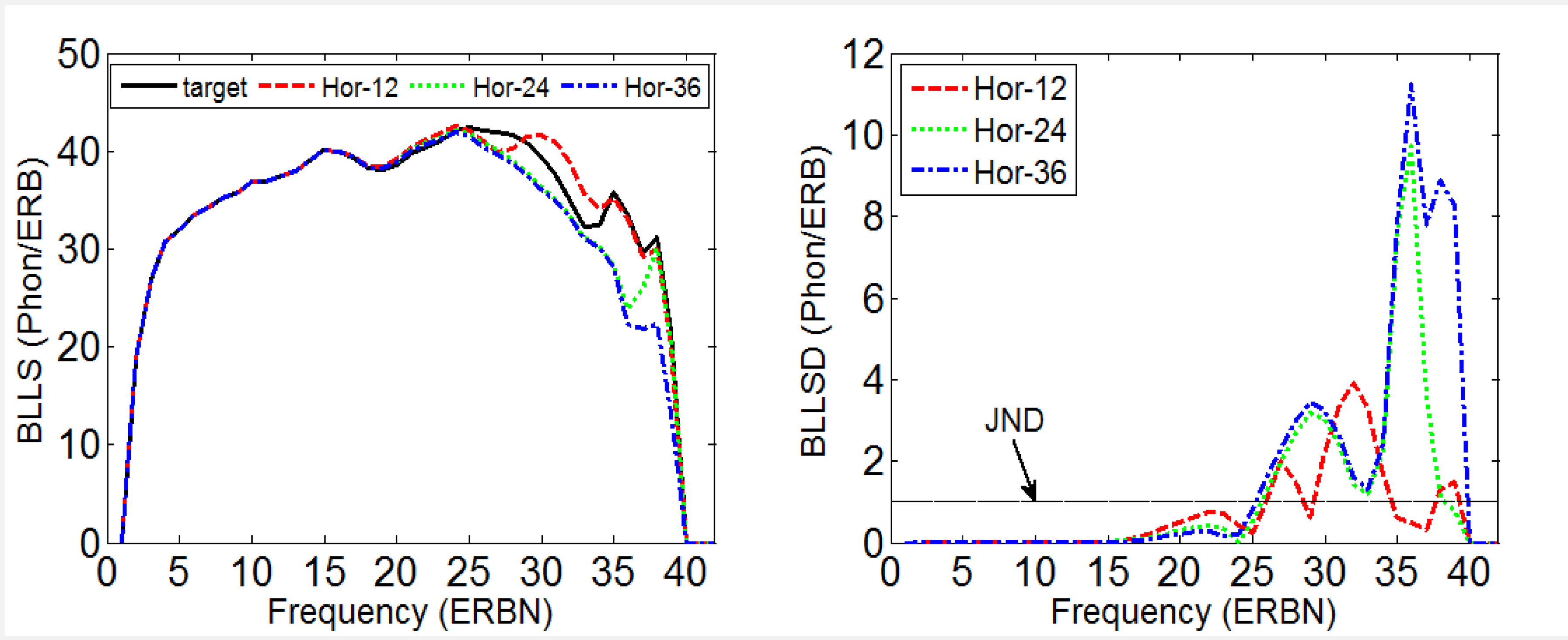


Fig.2. 3/5 order MOA reproduction, (θ_S, ϕ_S) = (15°, 0°)

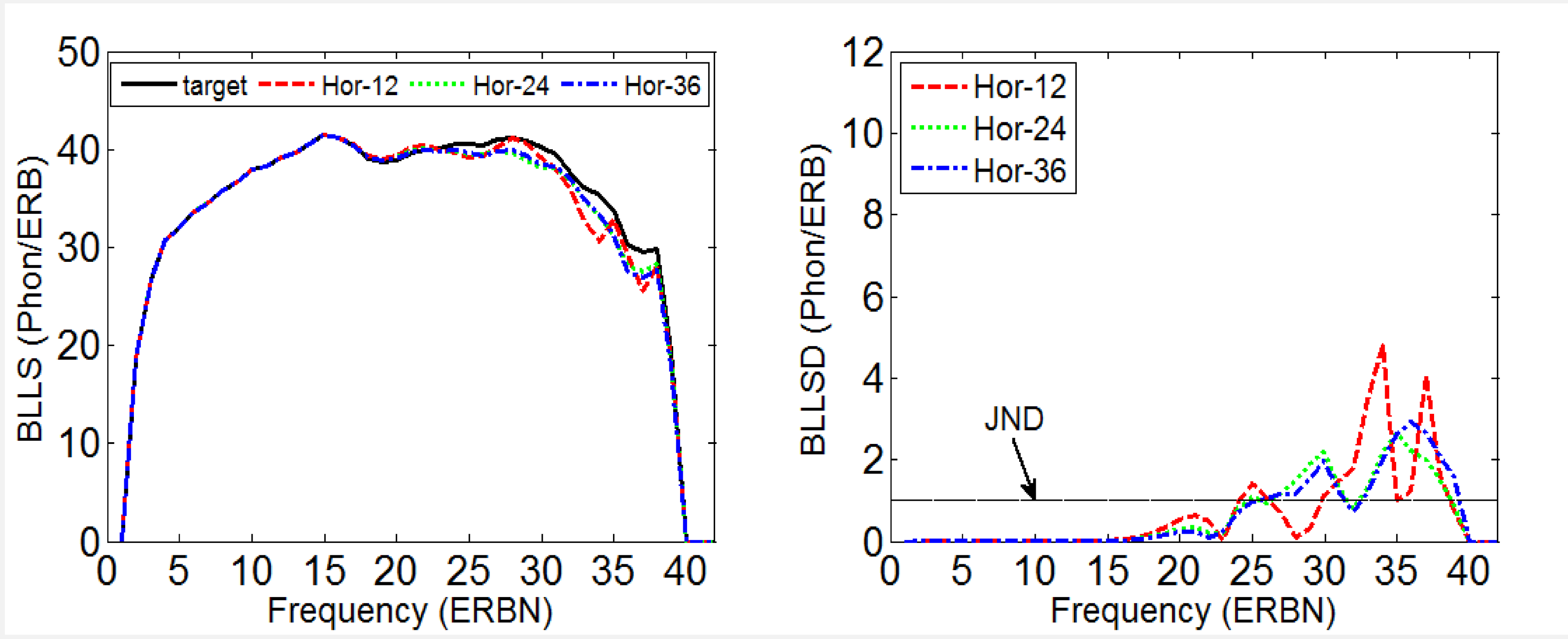


Fig.3. 3/5 order MOA reproduction, (θ_S, ϕ_S) = (75°, 0°)

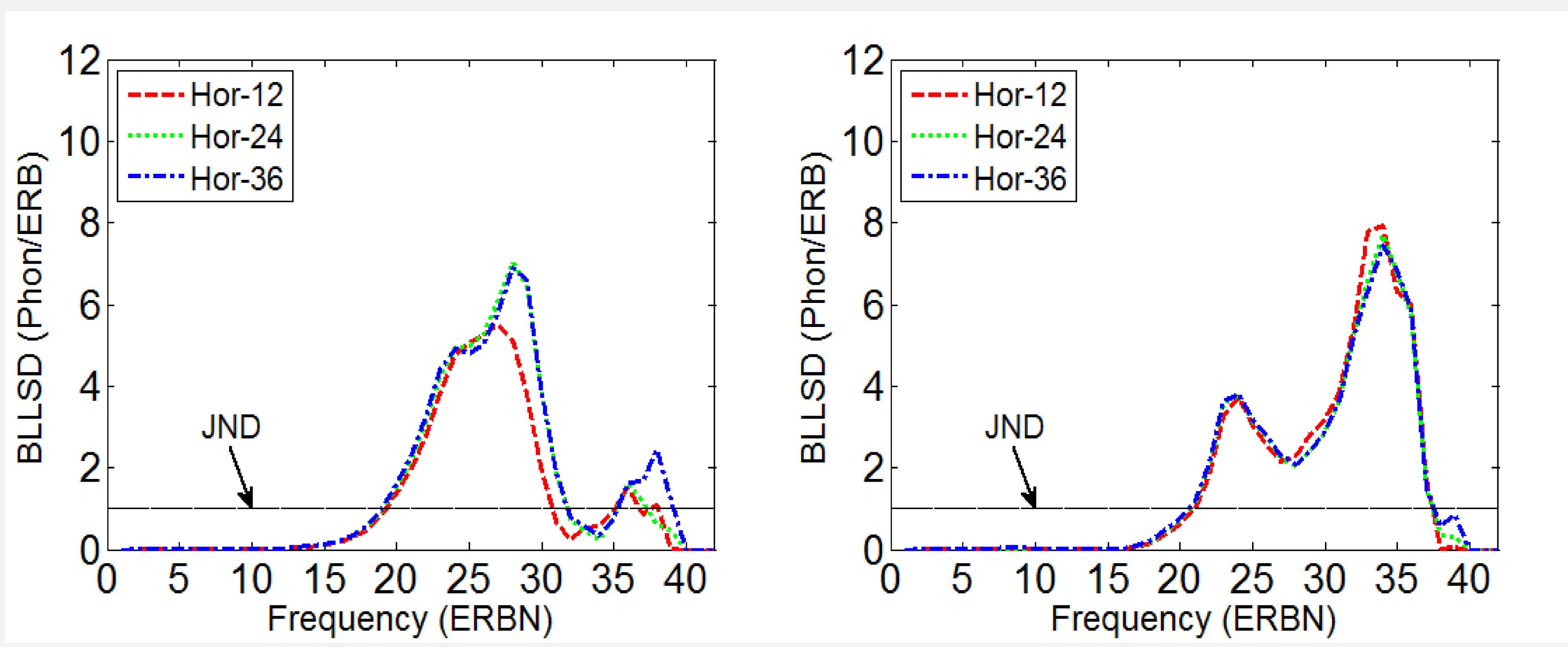


Fig.4. 3/5 order MOA reproduction, BLLSD
Left: (θ_S, ϕ_S) = (15°, 45°); Right: (θ_S, ϕ_S) = (75°, 45°)

♦ Conclusions

- **L_{2D}↑, $f_{max,H}$ ↑ for horz. virtual source**
- **≤ $f_{max,H}$: no perceivable timbre change**
- **> $f_{max,H}$: i. number of loudspeakers**
  ii. target source direction

--- M_{hor}↑: BLLSD↓ for lateral directions
BLLSD↑ for frontal and back

- **Influence(M_{hor})↓: depart from horz. plane**

Room 301, Building 18, Wushan Rd., Tianhe District, South China University of Technology, P. R. China(http://www.scut.edu.cn/physics)
Phone: +86 20 87113191; Fax: +86 20 87114230
Email: phbsxie@scut.edu.cn

物理与光电学院
SCHOOL OF PHYSICS