Universität Rostock

Traditio et Innovatio

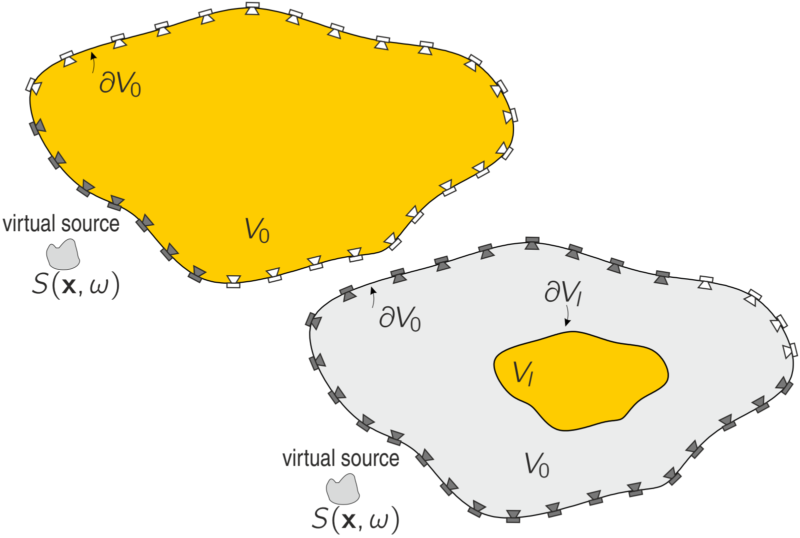
Physical Properties of Local Wave Field Synthesis using Linear Loudspeaker Arrays

Fiete Winter and Sascha Spors

University of Rostock
Institute of Communications Engineering

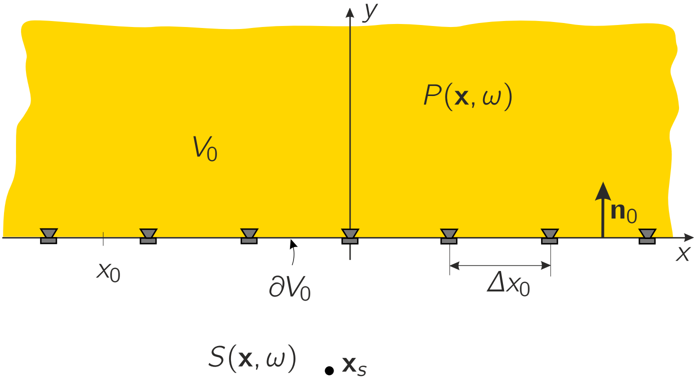
AES 138th Convention
10.05.2015, Warsaw

Sound Field Synthesis vs. Local Sound Field Synthesis



Wave Field Synthesis

2D Rayleigh-Integral

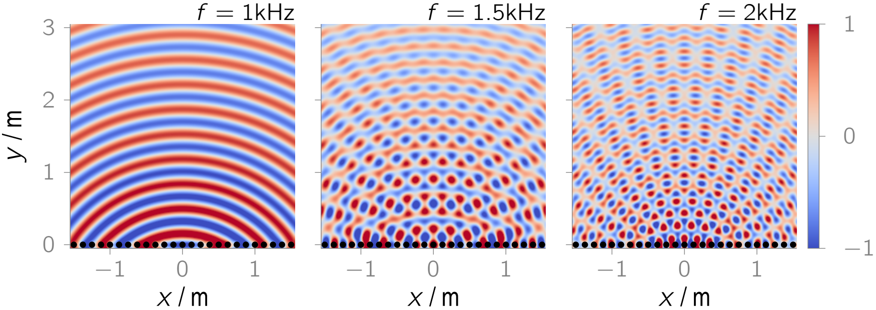


$$P(\mathbf{x},\omega) = -\int_{-\infty}^{\infty} \underbrace{\frac{\partial S(\mathbf{x}_0,\omega)}{\partial \mathbf{n}_0}}_{D_0(x_0,\omega)} G_0\left(\mathbf{x}-\mathbf{x}_0,\omega\right) \mathrm{d}x_0 = S(\mathbf{x},\omega) \text{ for } x \in V_0$$

Wave Field Synthesis

Finite Spacing of Loudspeakers - Spatial Sampling

$$\mathbf{x}_s = [0, -1, 0]^T$$

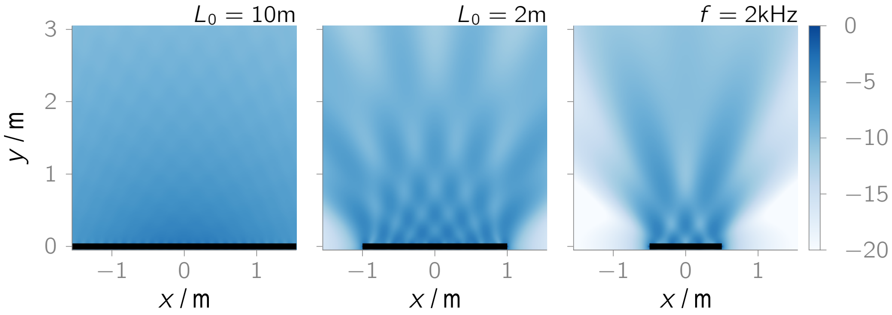


$$D_0^S(x_0, \omega) = D_0(x_0, \omega) \cdot \Delta x_0 \sum_{\mu=-\infty}^{\infty} \delta(x - \mu \Delta x_0)$$

Wave Field Synthesis

Finite Length of Array - Spatial Truncation

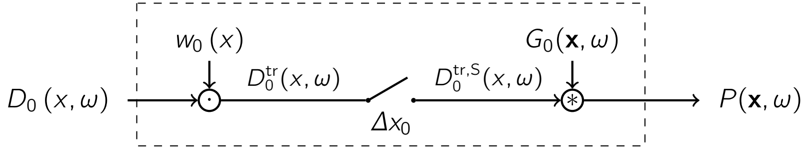
$$\mathbf{x}_s = [0, -1, 0]^T, f = 1\text{kHz}$$



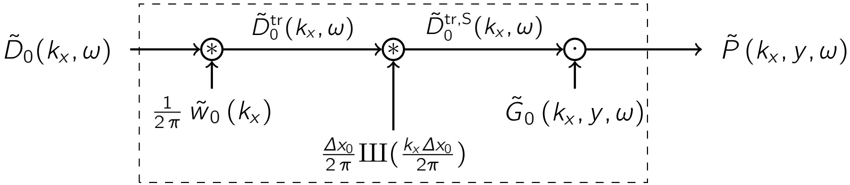
$$D_0^{\text{tr}}(x_0, \omega) = D_0(x_0, \omega) \cdot w_0(x_0)$$

Wave Field Synthesis

Systemtheoretic View

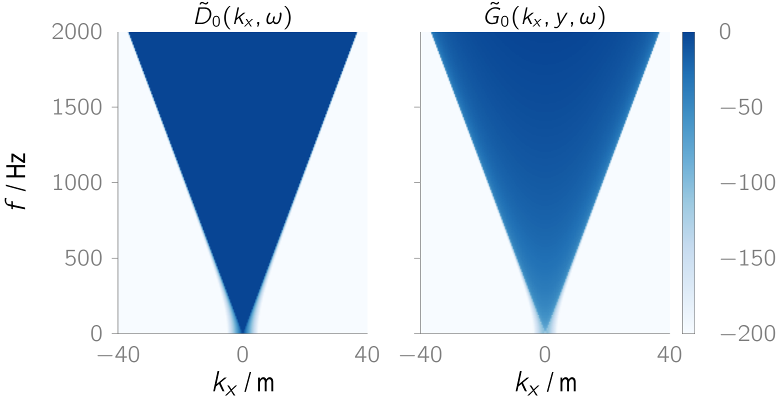


$$\tilde{F}(k_x, \omega) = \int_{-\infty}^{\infty} F(x, \omega) e^{j k_x x} \, \mathrm{d}x$$



Wave Field Synthesis

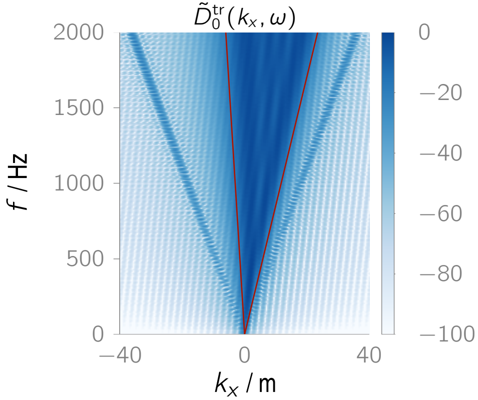
Wavenumber-Spectrum

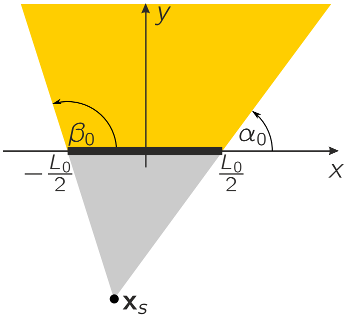


- propagating for $|k_x| \leq \frac{\omega}{c}$, evanescent for $|k_x| > \frac{\omega}{c}, \omega = 2\pi f$

Wave Field Synthesis

Truncation - Geometric Approximation and Spectrum

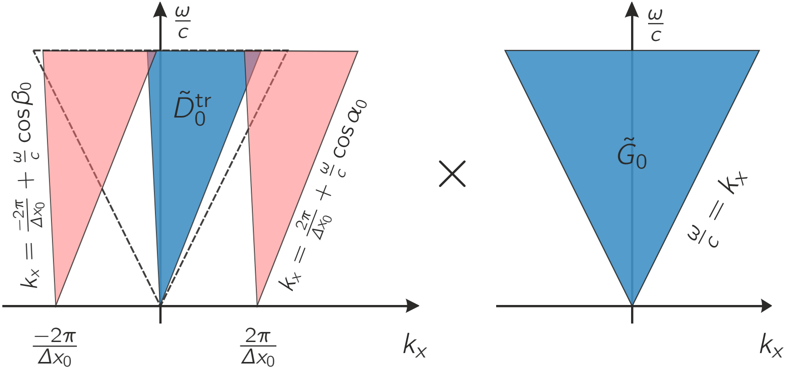




- energy concentrated between $k_x = \frac{\omega}{c}\cos\beta_0$ and $k_x = \frac{\omega}{c}\cos\alpha_0$

Wave Field Synthesis

Spatial Aliasing - Qualitative Illustration

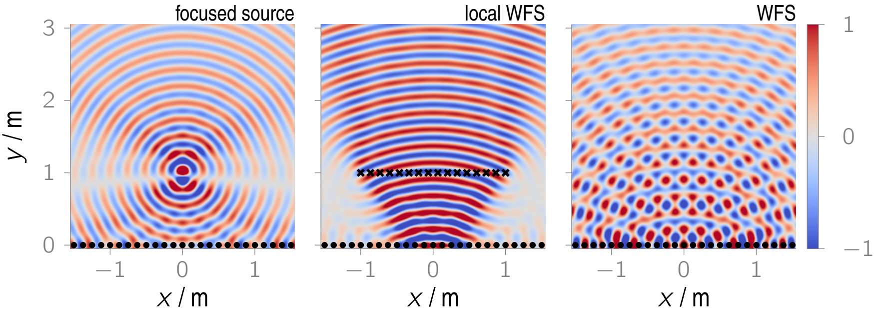


- Aliasing frequency inside the listening area: $f_0^{\text{al}} = \dfrac{c}{\Delta x_0(\cos\alpha_0 - \cos\beta_0)}$
- **Truncation increases aliasing frequency**

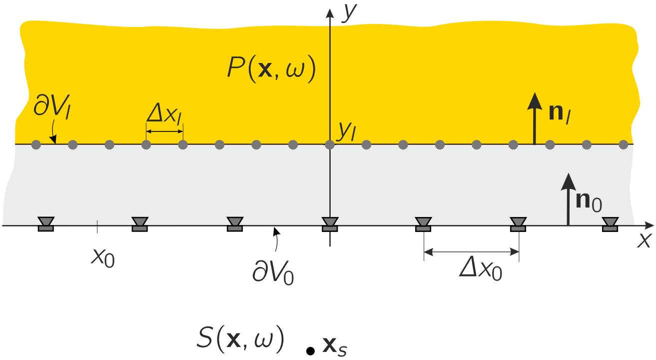
Local Wave Field Synthesis

Basic Principle

$$\mathbf{x}_s = [0, -1, 0]^T, f = 1.5\text{kHz}, L_0 = 10\text{m}$$



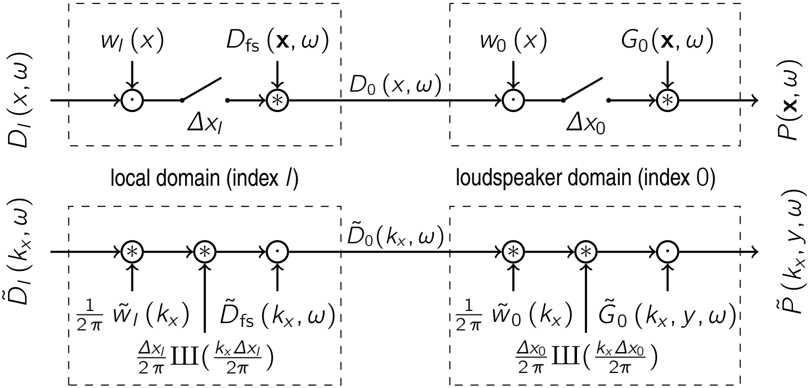
Local Wave Field Synthesis



$$P(\mathbf{x},\omega) = \int_{-\infty}^{\infty} \underbrace{\int_{-\infty}^{\infty} \overbrace{\frac{\partial S(\mathbf{x}_l,\omega)}{\partial \mathbf{n}_l}}^{D_l(x_l,\omega)} D_{\text{fs}}\left(\mathbf{x}_0 - \mathbf{x}_l,\omega\right) \mathrm{d}x_l}_{D_0(x_0,\omega)} G_0\left(\mathbf{x} - \mathbf{x}_0,\omega\right) \mathrm{d}x_0$$

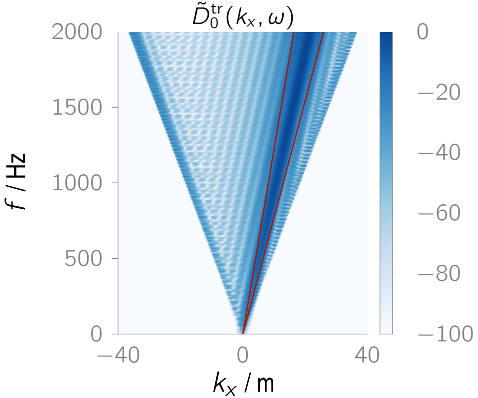
Local Wave Field Synthesis

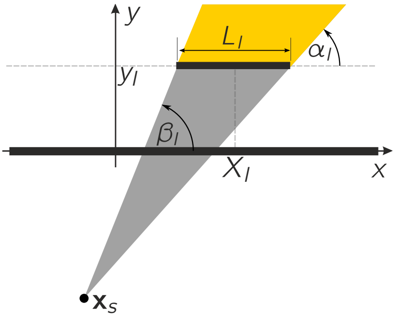
Systemtheoretic View



Local Wave Field Synthesis

Truncation in Local Domain

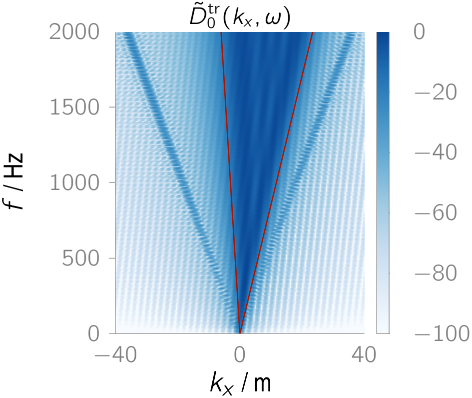


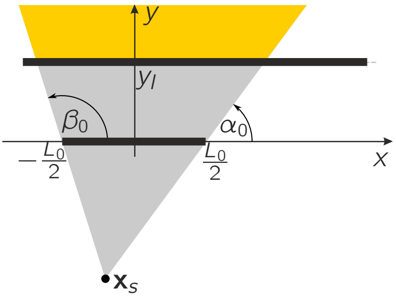


- energy concentrated between $k_x = \frac{\omega}{c}\cos\beta_l$ and $k_x = \frac{\omega}{c}\cos\alpha_l$

Local Wave Field Synthesis

Truncation in Loudspeaker Domain

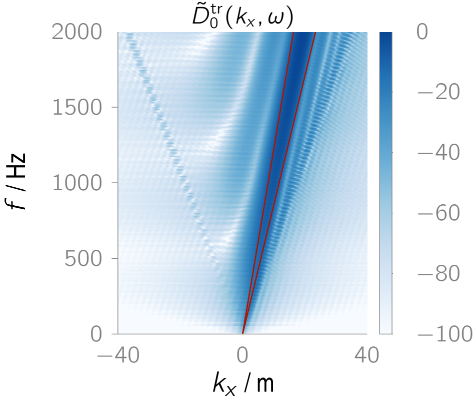


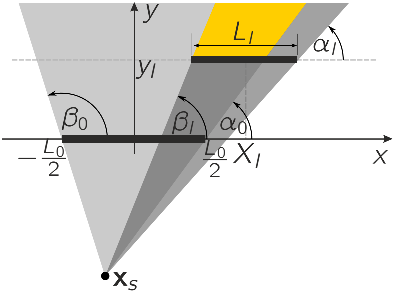


- energy concentrated between $k_x = \frac{\omega}{c} \cos \beta_0$ and $k_x = \frac{\omega}{c} \cos \alpha_0$

Local Wave Field Synthesis

Truncation in Both Domains

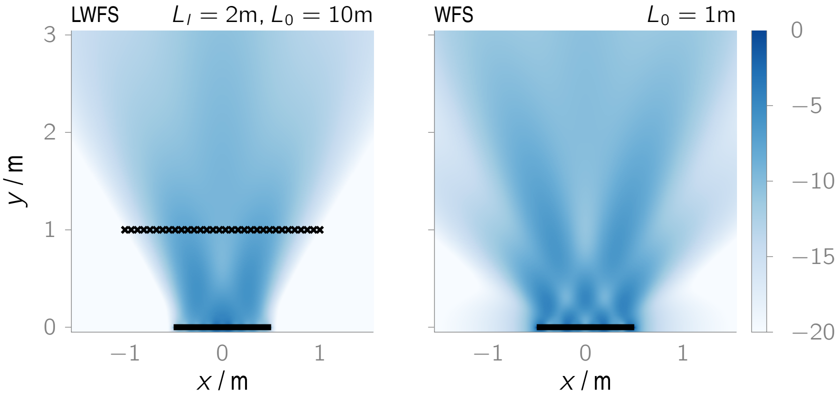




- energy concentrated between
  $k_x = \frac{\omega}{c} \cos(\max(\alpha_0, \alpha_l))$ and $k_x = \frac{\omega}{c} \cos(\min(\beta_0, \beta_l))$

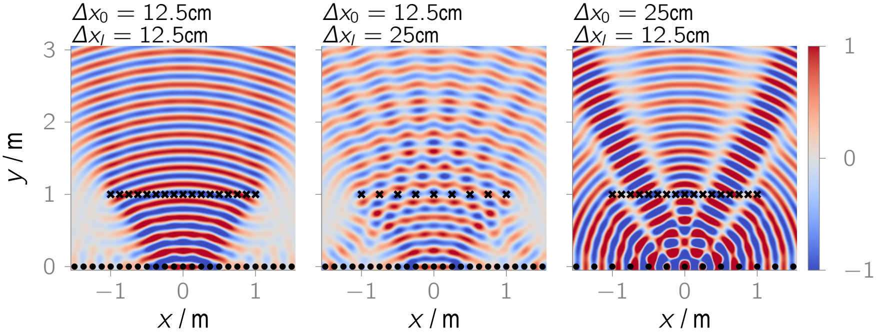
Local Wave Field Synthesis

Smoothing of Truncation Artifacts



Local Wave Field Synthesis

Sampling



- spatial sampling has to be sufficient in local domain to avoid additional aliasing
- aliasing frequency inside the listening area:

$$f_0^{\mathrm{al}} = \frac{c}{\Delta x_0 (\cos(\max(\alpha_0, \alpha_l)) - \cos(\min(\beta_0, \beta_l)))}$$

Conlusion

- local WFS defines a smaller listening area surrounded by focused sources
- aliasing frequency can be increased by shrinking the listening area
- number of focused sources has to be sufficient to avoid additional spatial aliasing

Outlook

- close connection between spatial aliasing frequency of WFS systems and perceived coloration [Wierstorf2014]
- perceptual experiments comparing coloration in WFS, LWFS and NFC-HOA

[Wierstorf2014, Perceptual Assessment of Sound Field Synthesis, PhD thesis]

This research has been supported by EU FET grant TWO!EARS, ICT-618075.