2.5D higher-order Ambisonics for a sound field described by angular spectrum coefficients

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1. Introduction
- Analytical approaches to sound field recording and reproduction
  - Recording stage: Spherical harmonics expansion
  - Reproduction stage: Higher order Ambisonics (HOA)
- Flexible sound field recording and reproduction: WFS for SHE
- Proposed approach: Spectrum division method (SDM)
- Angular spectrum

2. Analytical conversion of sound field representation
- Sound field represented by angular spectrum coefficients
  - $P(x, y, \omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \tilde{P}(k_x, \omega)e^{-j\sqrt{k_x^2+k_y^2}y}e^{-jk_zz}dk_x$ 
  - Spatial inverse Fourier transform
- Circular harmonics expansion of plane wave
  - $e^{-jk_r\cos(\phi-\phi_0)} = \sum_{m=-\infty}^{\infty} (-j)^m J_m(kr)e^{j\pi m(\phi-\phi_0)}$
- Analytical conversion of sound field representation from angular spectrum to circular harmonics expansion
  - Coordinate system is transformed as $[x, y] \rightarrow [r, \phi]$, $k_x \rightarrow k\cos(\phi_0)$
- Analytical solution for 2D sound field
  - $\tilde{P}_{2D,m}(r, \omega) = \frac{k(-j)^m J_m(kr)}{2\pi} \int_{0}^{\pi} \tilde{P}(\phi_0, \omega) e^{j\pi m(\phi-\phi_0)}d\phi_0$

3. Proposed formulation
- Sound field recorded by linear receiver (Spatial Fourier transform)
  - $\hat{P}(\phi_0, \omega) = \hat{P}(k_x, \omega) = \int_{-\infty}^{\infty} P(x, 0, \omega)e^{jkr_x}dx = \int_{-\infty}^{\infty} P(x, 0, \omega)e^{j\cos(\phi_0)x}dx$
- 2.5D HOA for circular secondary sources (J. Ahrens et al. 2008.)
  - $\hat{D}_{2.5D,m}(r = 0, r_0, \omega) = \frac{1}{2\pi r_0} \cdot \frac{\hat{P}_{m}[m](\omega)}{-jkh^2[m](kr_0)}Y^m[(\pi/2, 0)^*]$ Integrated with
  - Plane wave: $\hat{P}_{m}[m](\phi, \omega) = 4\pi(-j)^m Y^m(m/2, \phi_k)^*$
  - Point source: $\hat{P}_{m}[m](r_s, \omega) = -jkh^2[m](kr_s)Y^m[(\pi/2, \phi_k)^*$

4. Computer simulations
- Reproduced sound field and reproduction error
  - $L_{mic} = L_{sp} = 64$ ch, $\Delta x = 0.05$ m, $r_0 = 2.0$ m, $x_s = [1, -5, 0]^T$

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