

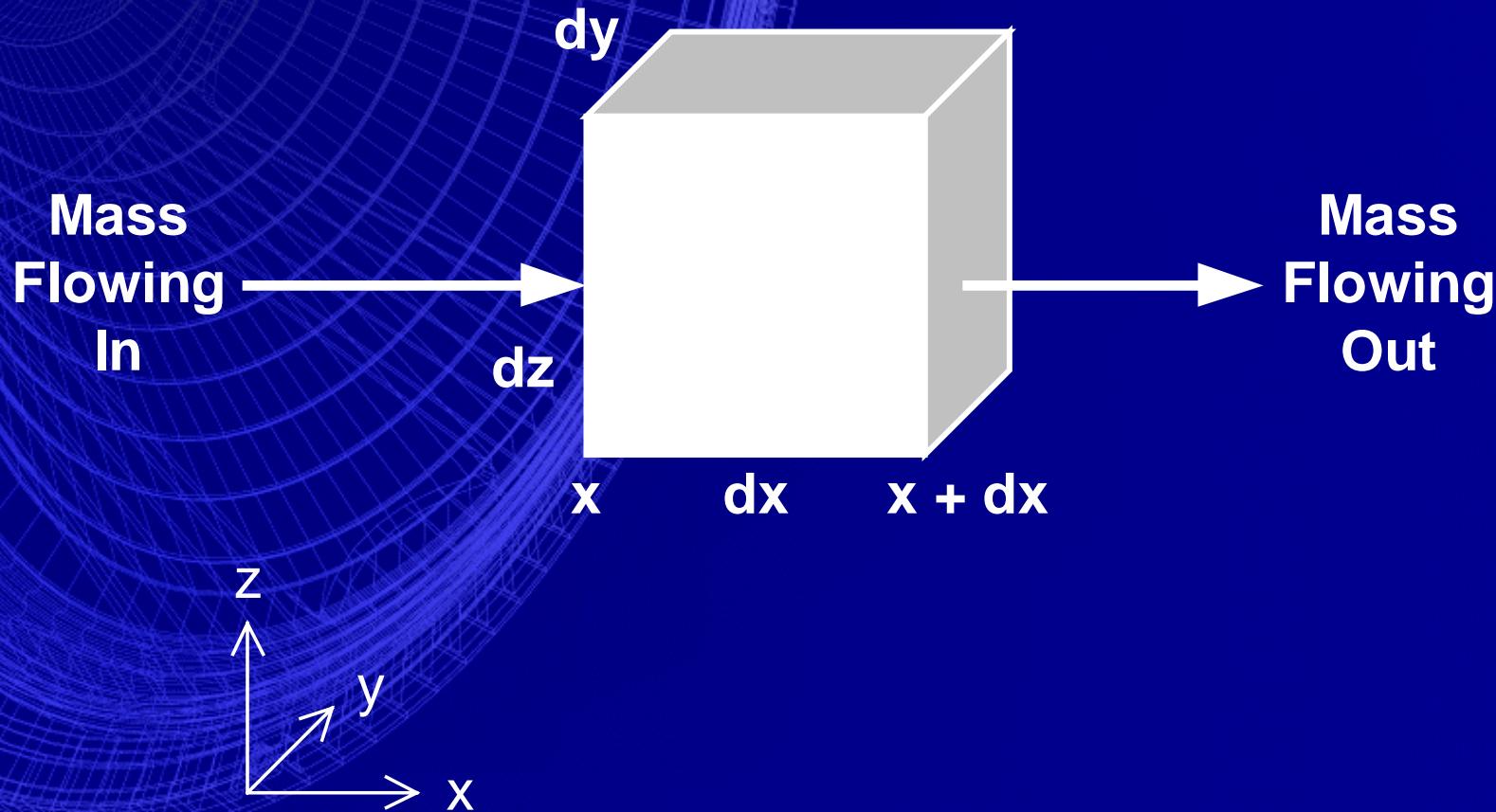
Spectral Analysis to Optimize and Predict Acoustic Response Functions

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The linear acoustic wave equation

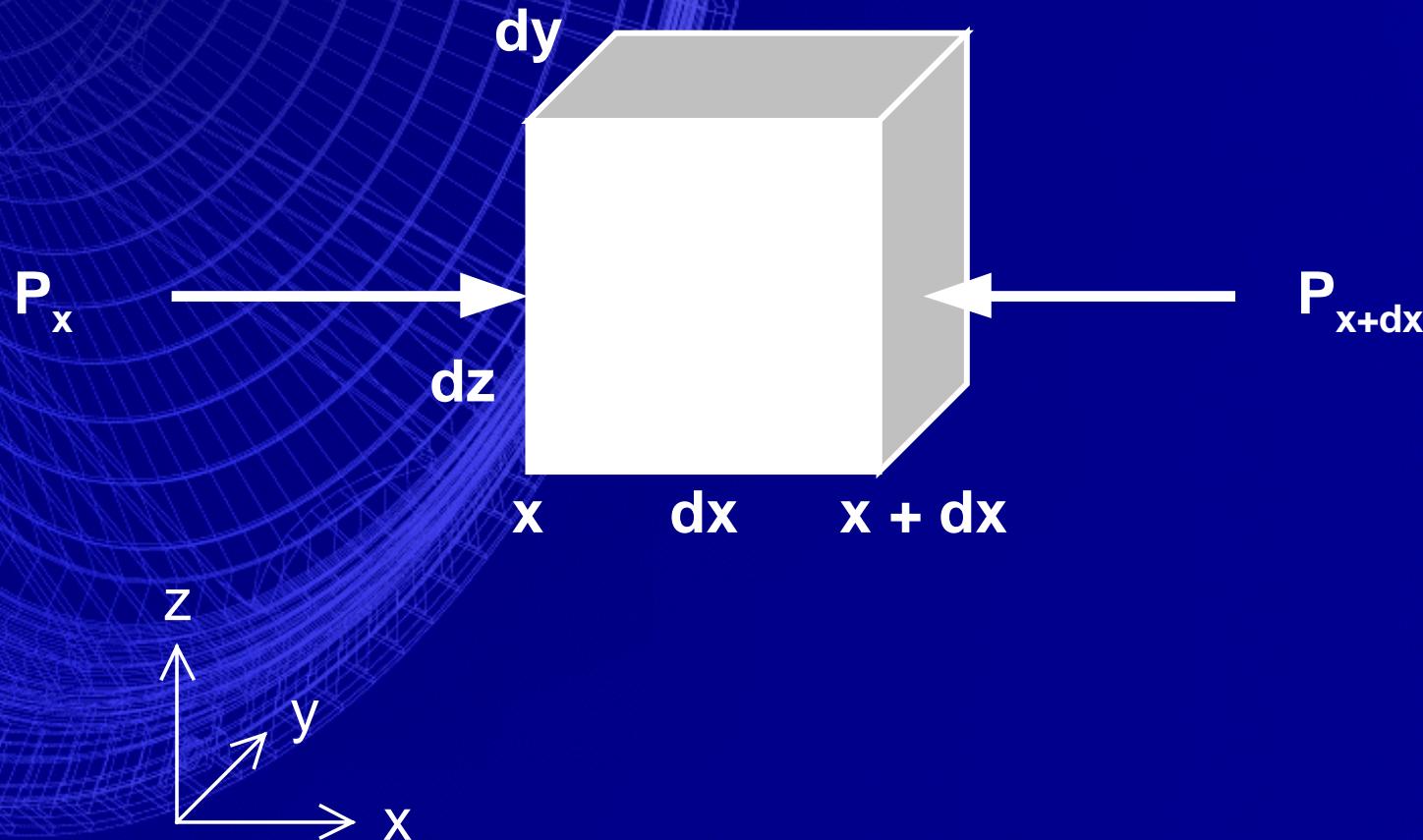
Continuity:



$$\frac{\partial m}{\partial t} = (\rho u)_x dy dz - (\rho u)_{x+dx} dy dz$$

The linear acoustic wave equation

Force:



$$\rho_0 \dot{u} = -\nabla p$$

The linear acoustic wave equation

State:

$$PV = nRT$$

$$P - P_0 = B \frac{\rho - \rho_0}{\rho_0}$$

The linear acoustic wave equation

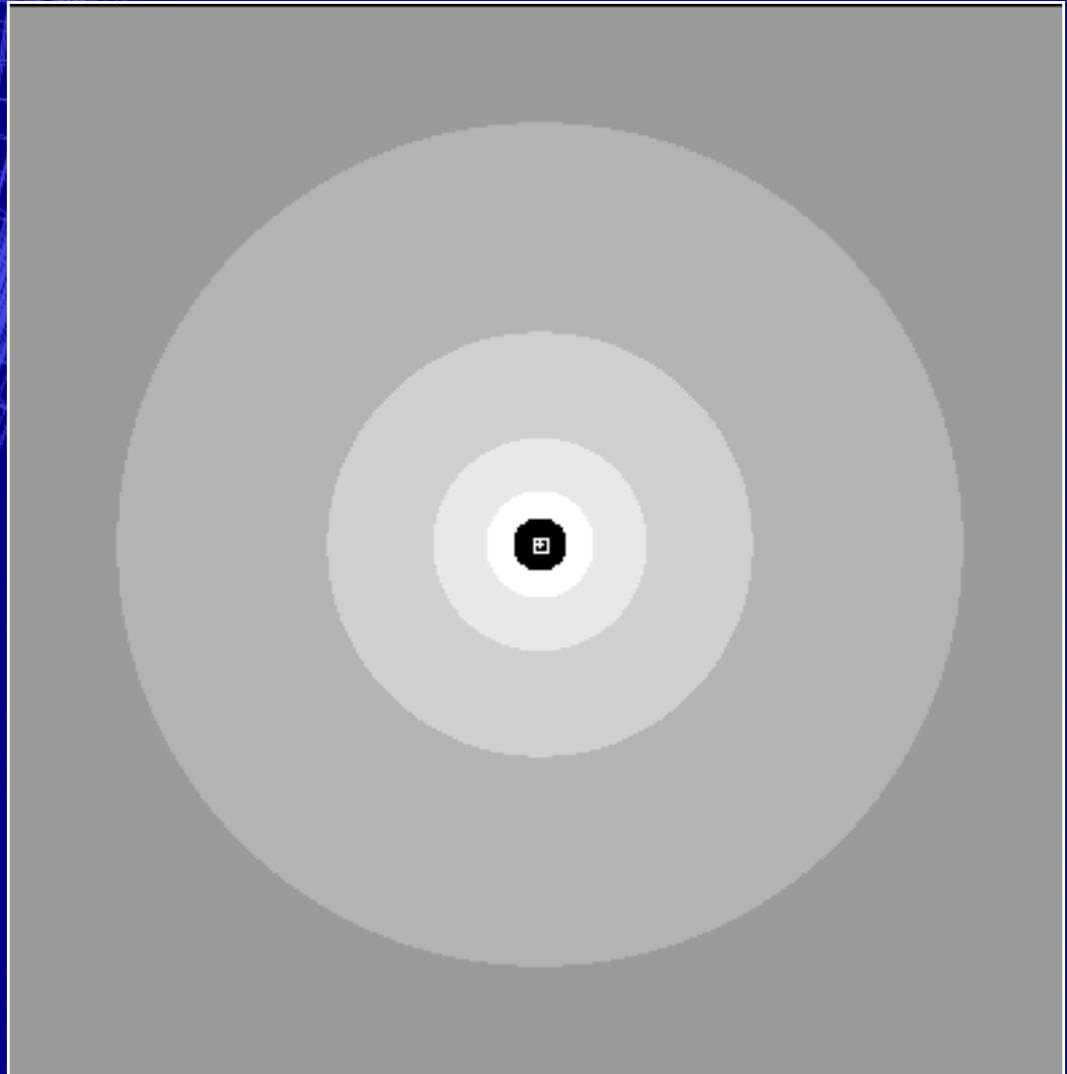
$$\nabla^2 p = \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2}$$

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

Sound radiation

Omnidirectional
Source

$$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{2}{r} \frac{\partial}{\partial r}$$



Sound radiation

$$\nabla^2 = \frac{\partial^2}{\partial r^2} + \frac{2}{r} \frac{\partial}{\partial r}$$

$$\frac{\partial^2 p}{\partial r^2} + \frac{2}{r} \frac{\partial p}{\partial r} = \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2}$$

$$\frac{\partial^2 (rp)}{\partial r^2} = \frac{1}{c^2} \frac{\partial^2 (rp)}{\partial t^2}$$

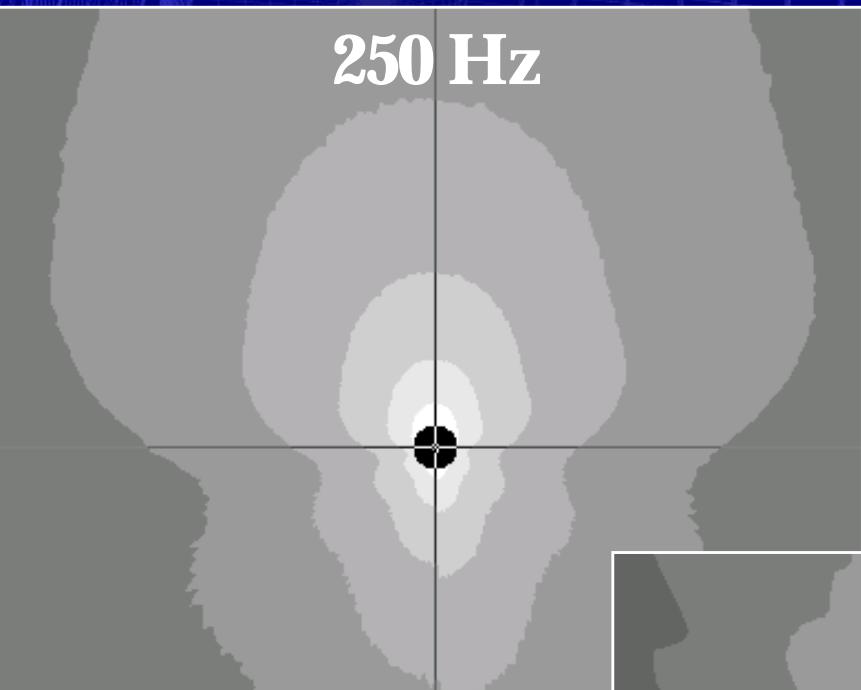
$$p = \frac{A}{r} e^{j(\omega t - kr)}$$

Loudspeakers

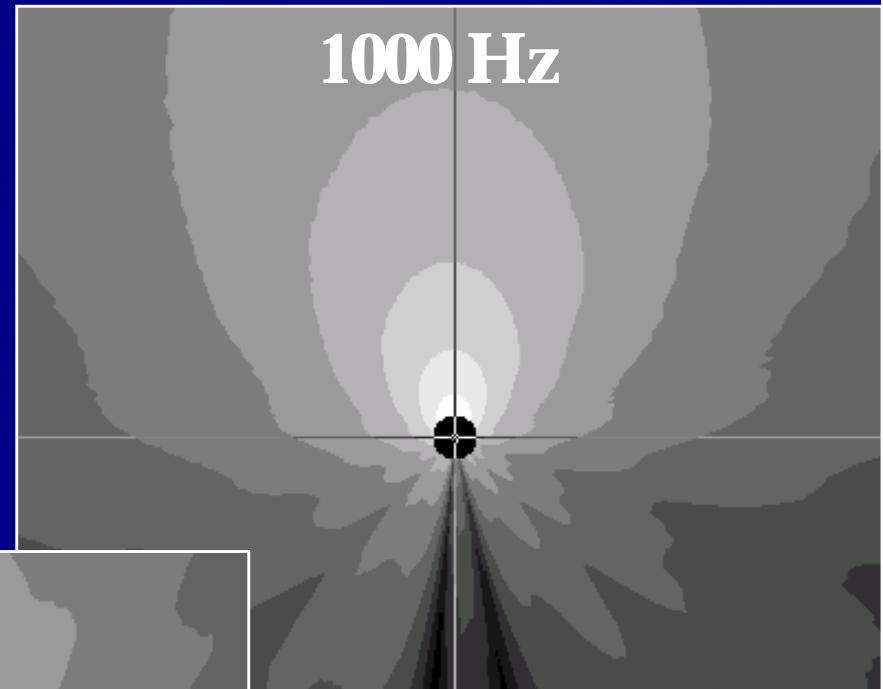


Loudspeaker Radiation Patterns

250 Hz



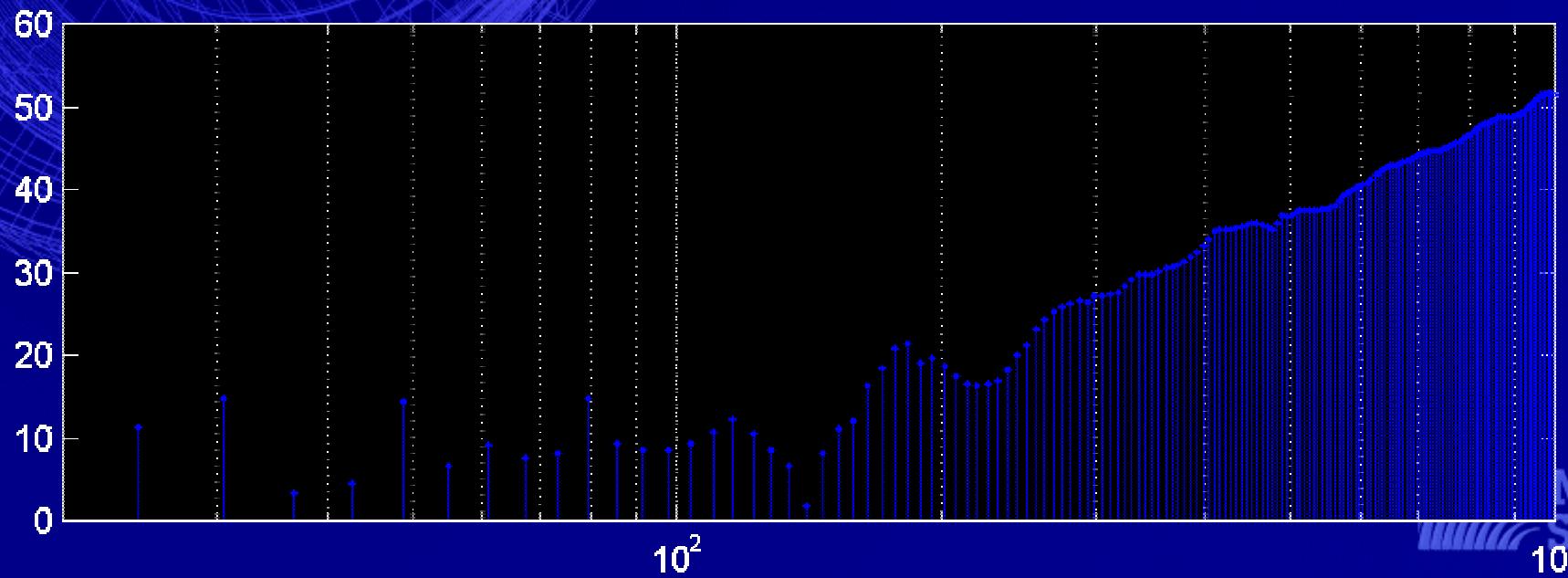
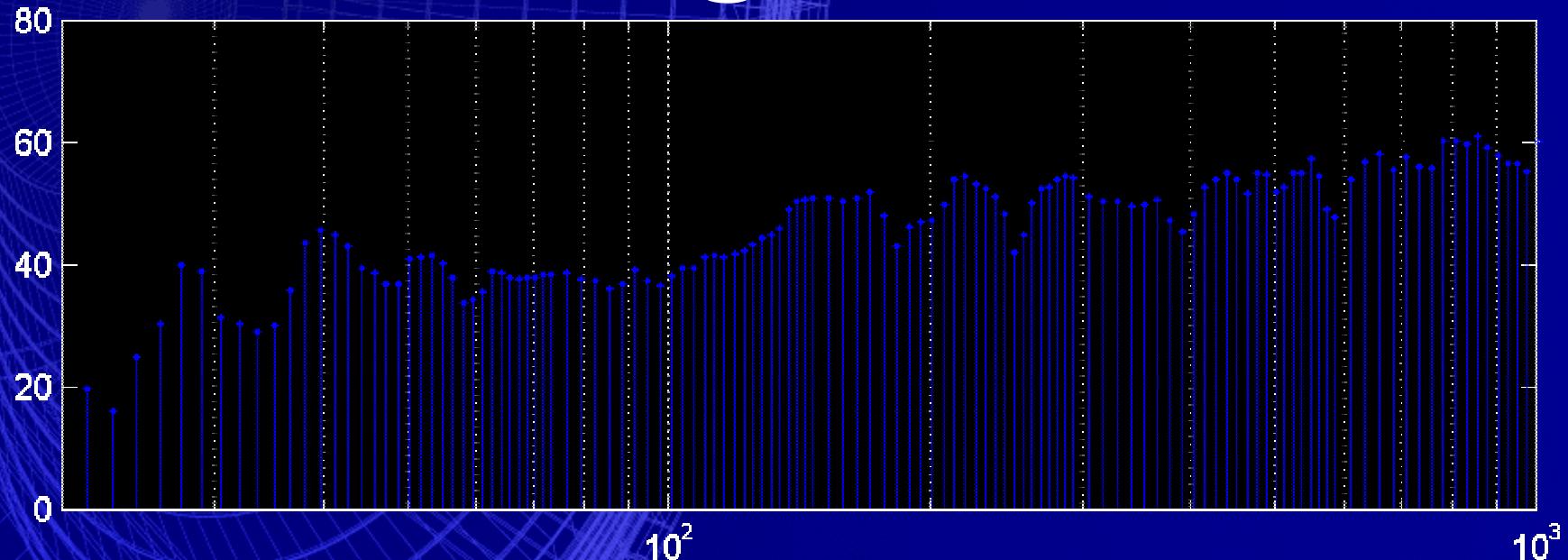
1000 Hz



8000 Hz

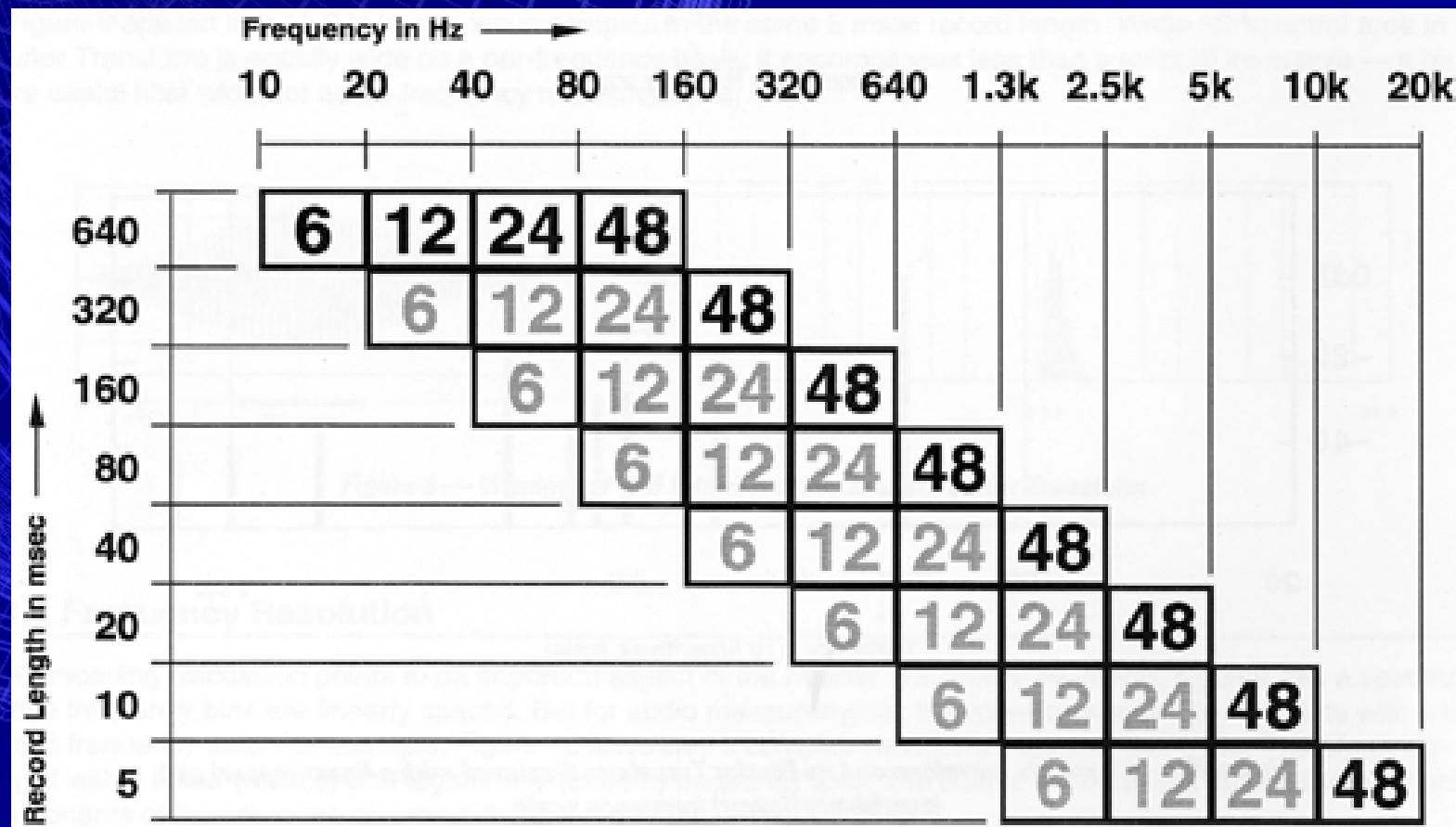


Linear vs. Logarithmic Data



Meyer
Sound

SIM Frequency Resolution



Acoustic transfer function measurements

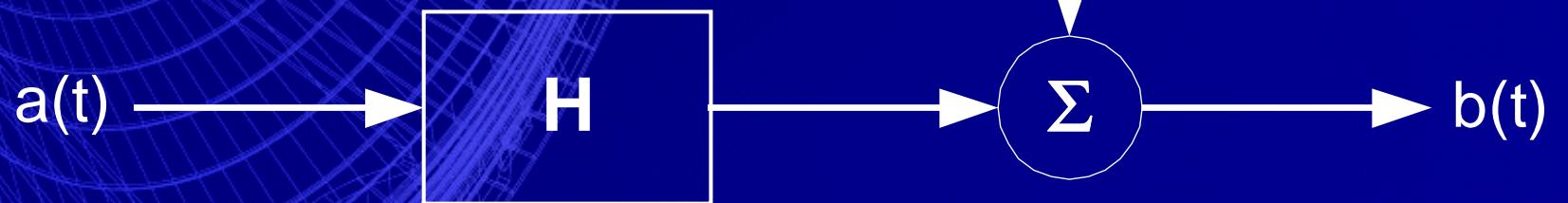


$$b(t) = a(t) * h(t)$$

$$H(f) = \frac{B(f)}{A(f)}$$

Acoustic transfer function measurements

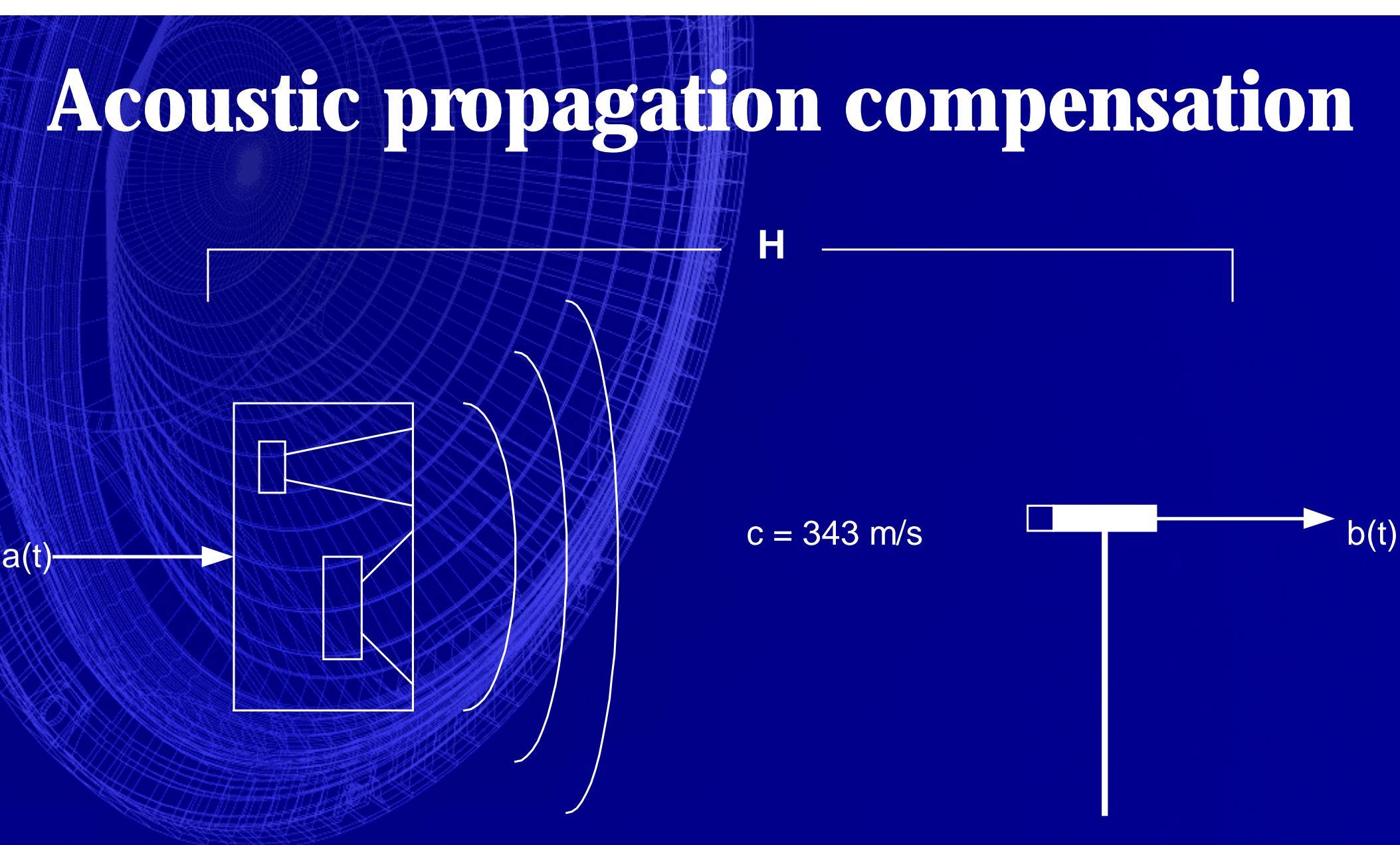
$$H(k) = \frac{G_{ab}}{G_{aa}} = \frac{B(k)\tilde{A}(k)}{A(k)\tilde{A}(k)}$$

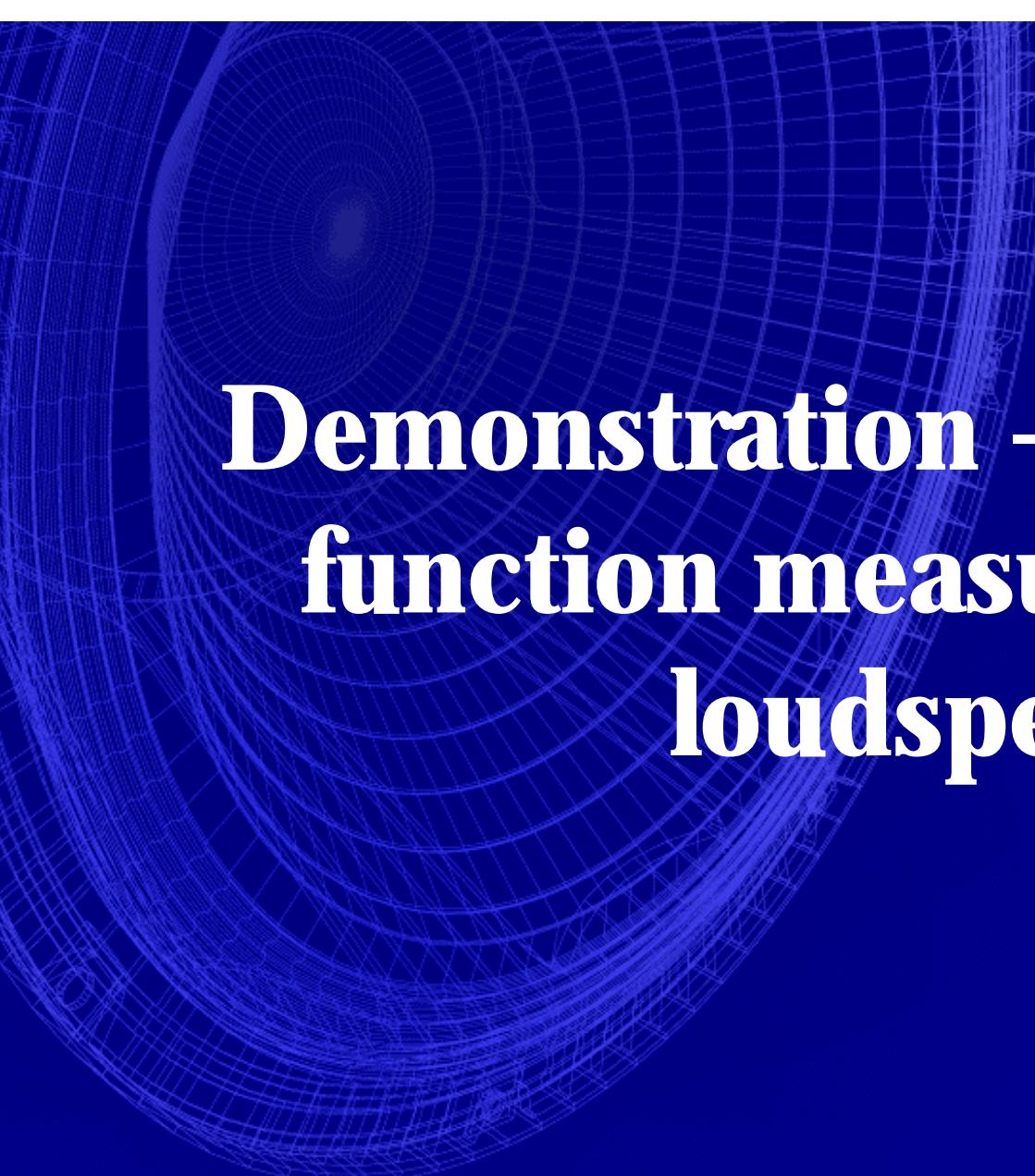


$$|H(k)| = \sqrt{\operatorname{Re} H(k)^2 + \operatorname{Im} H(k)^2}$$

$$\phi(k) = \tan^{-1} \frac{\operatorname{Im} H(k)}{\operatorname{Re} H(k)}$$

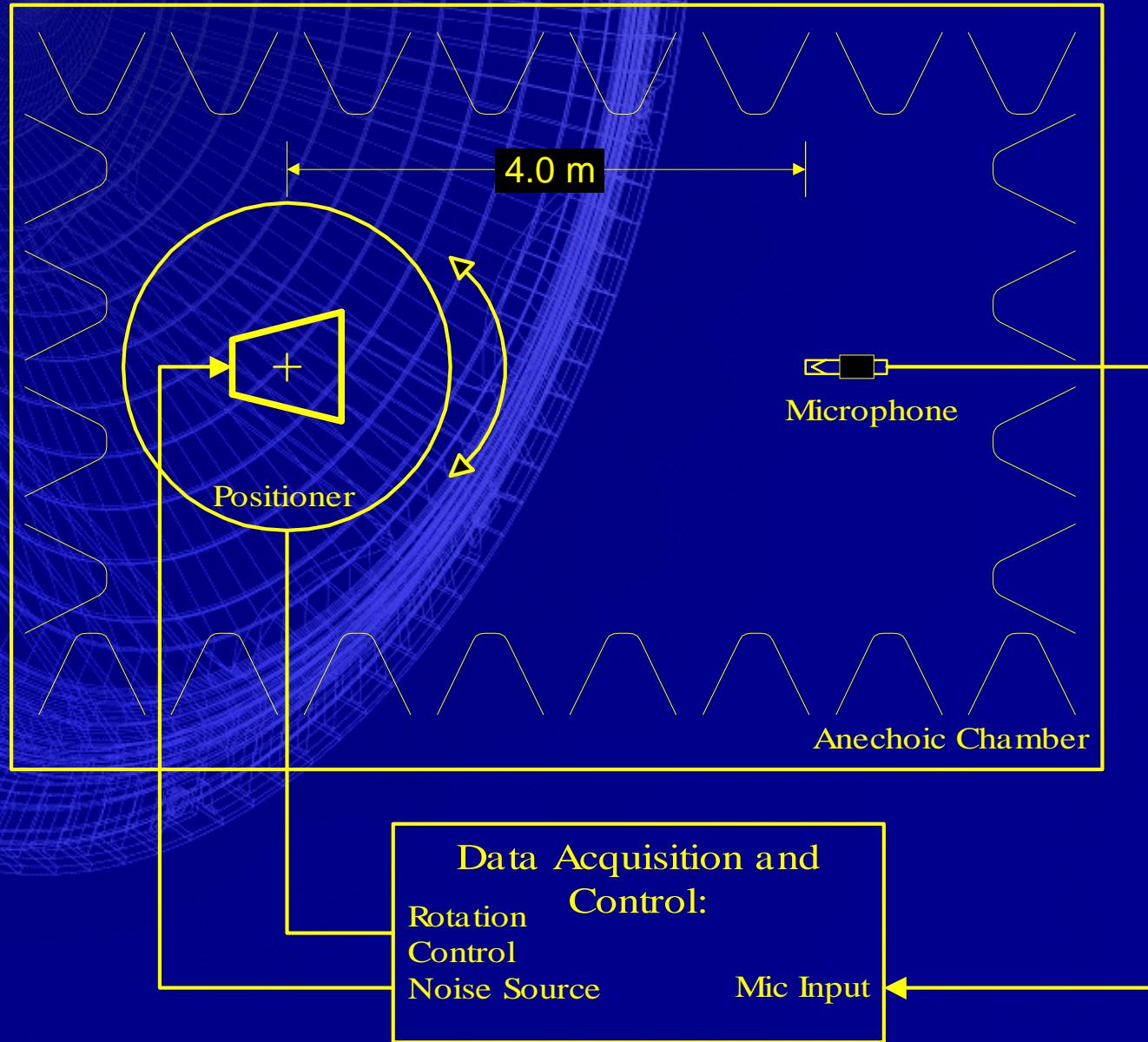
Acoustic propagation compensation





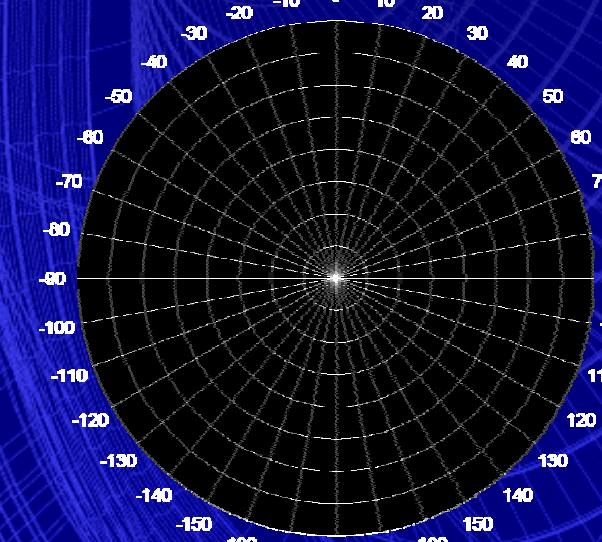
Demonstration – Live transfer function measurement of a loudspeaker

Loudspeaker polar response acquisition

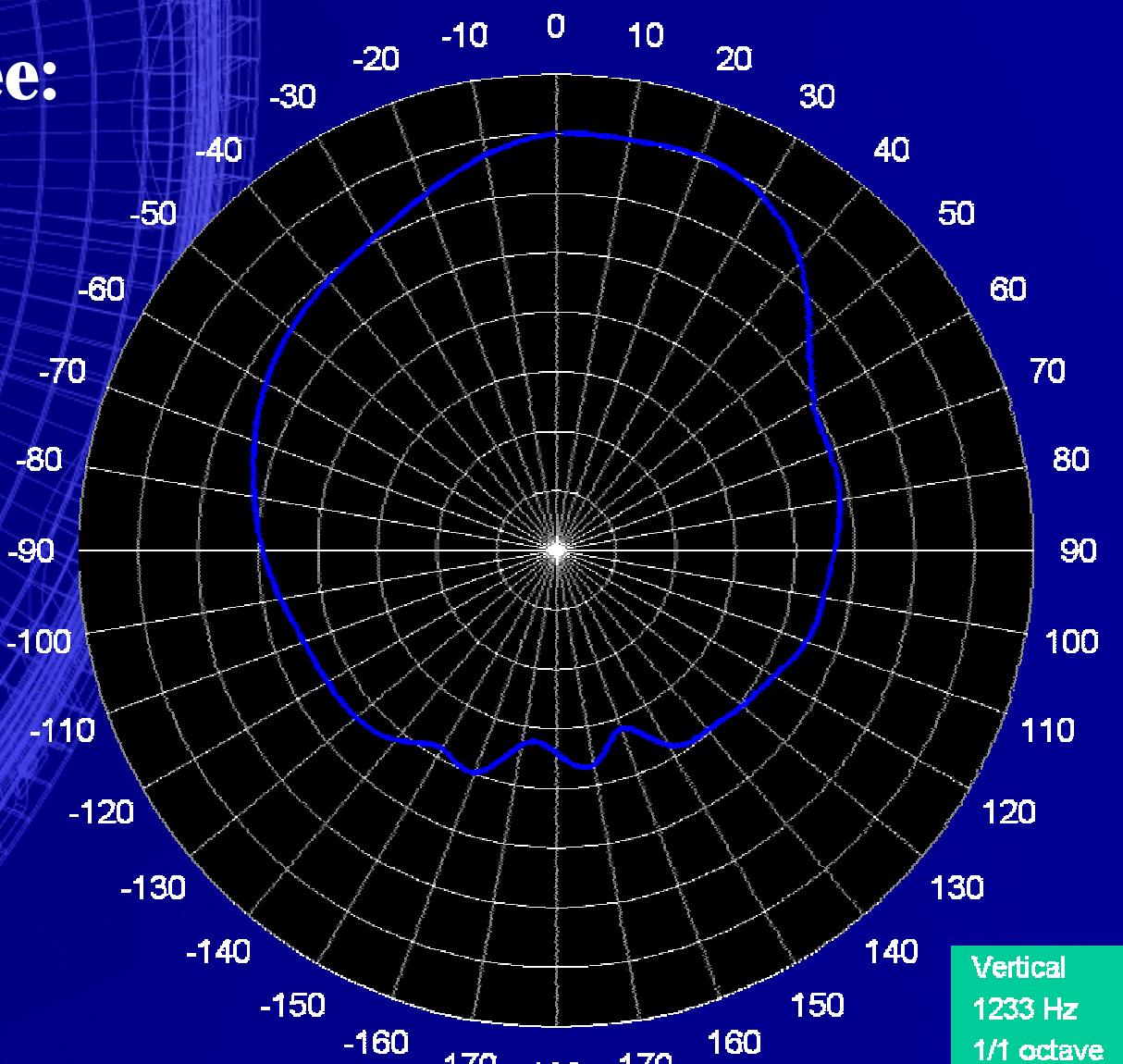
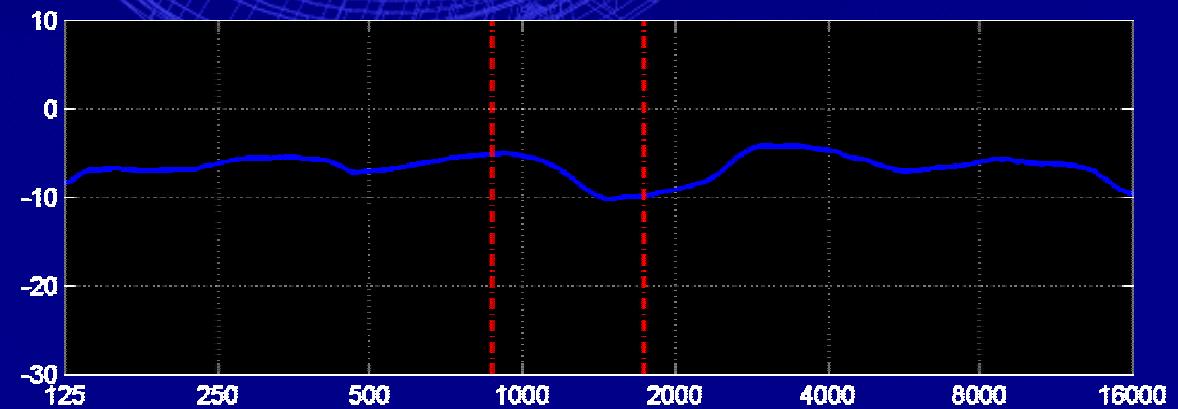


One Octave, Ten-Degree:

Angular Resolution:

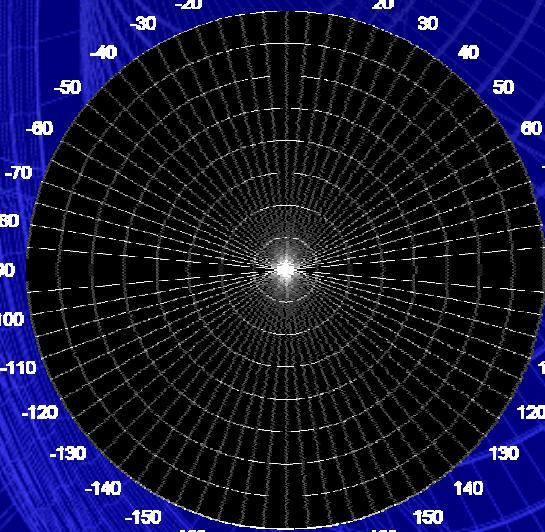


Frequency Resolution:

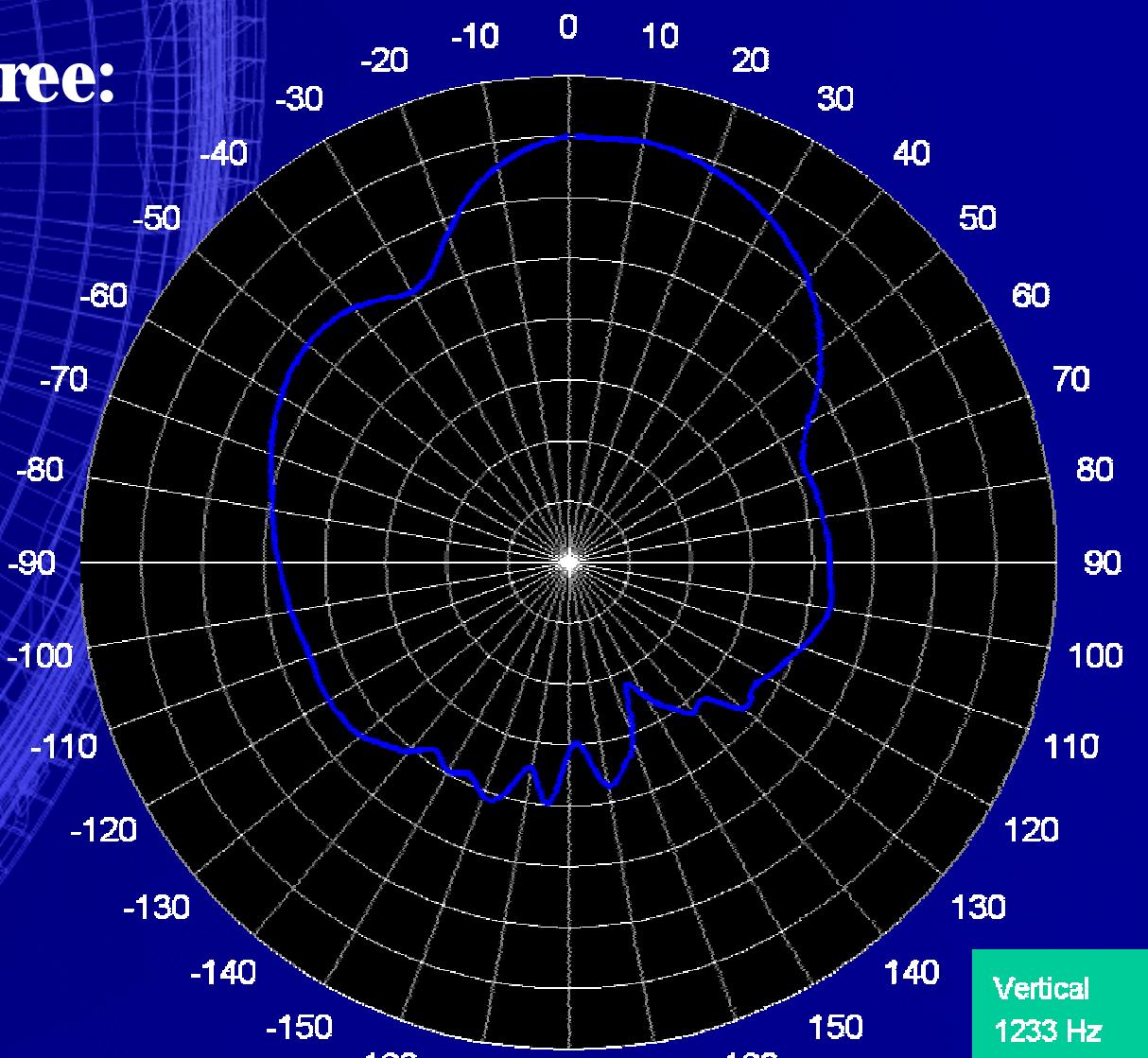
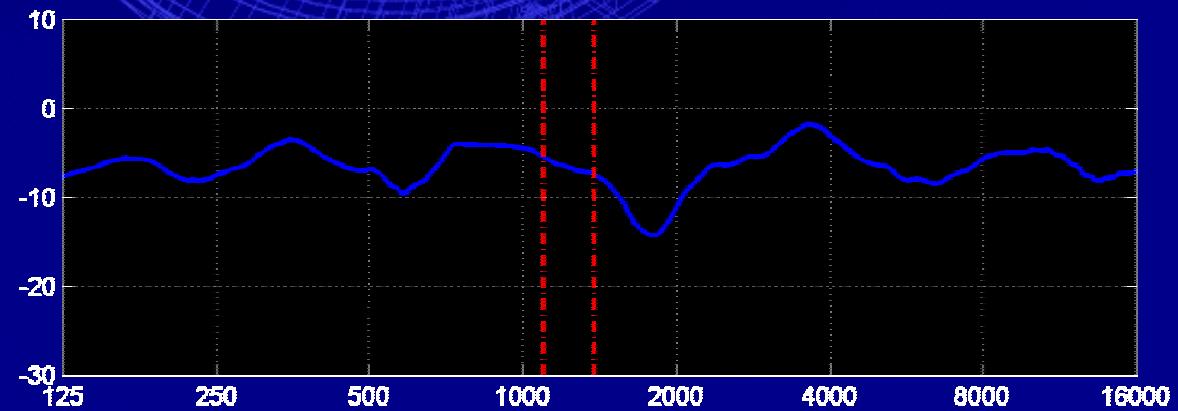


Third Octave, Five-Degree:

Angular Resolution:



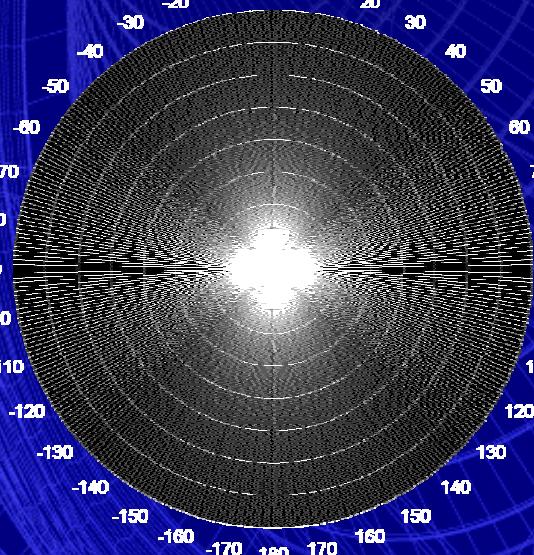
Frequency Resolution:



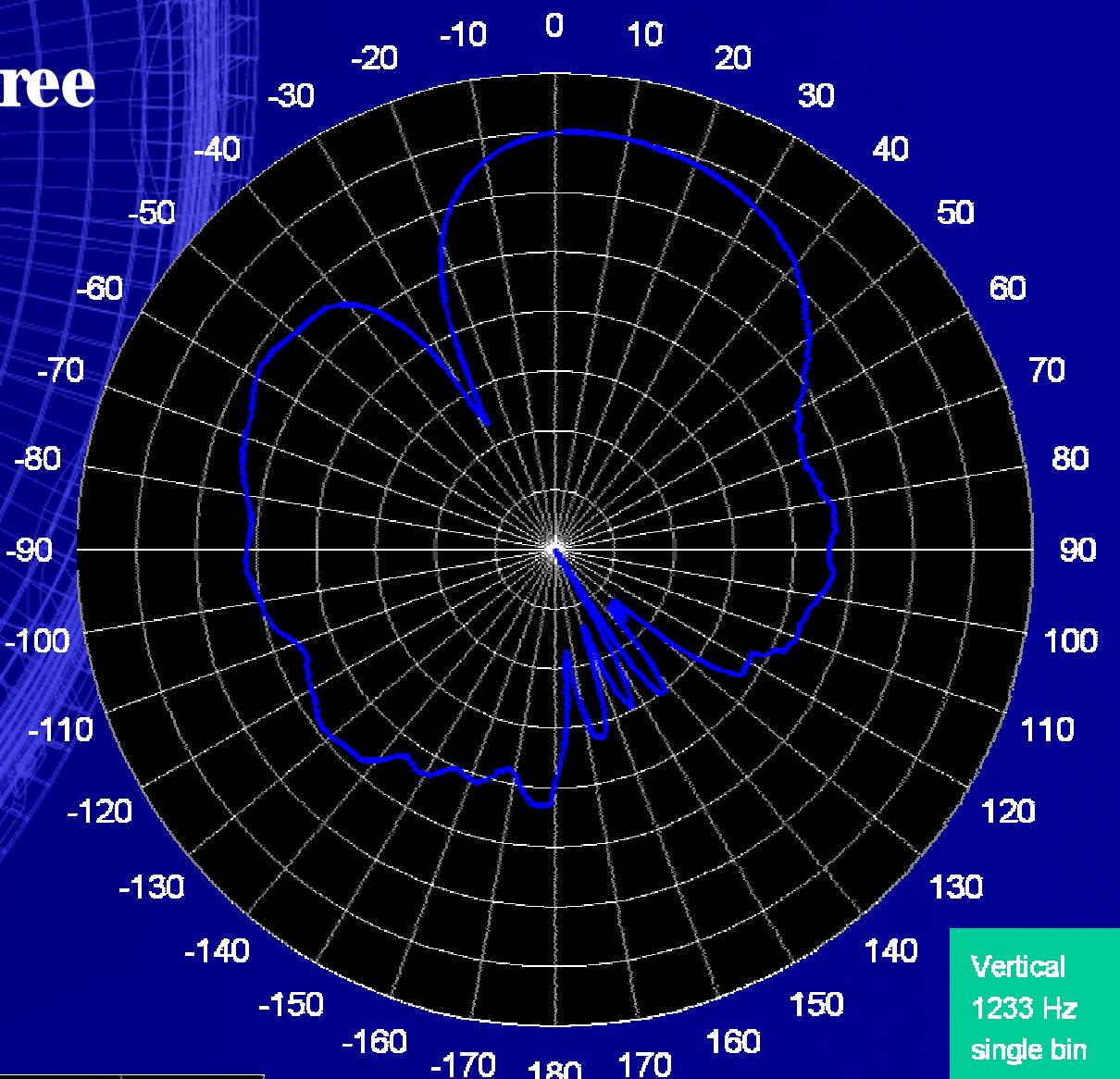
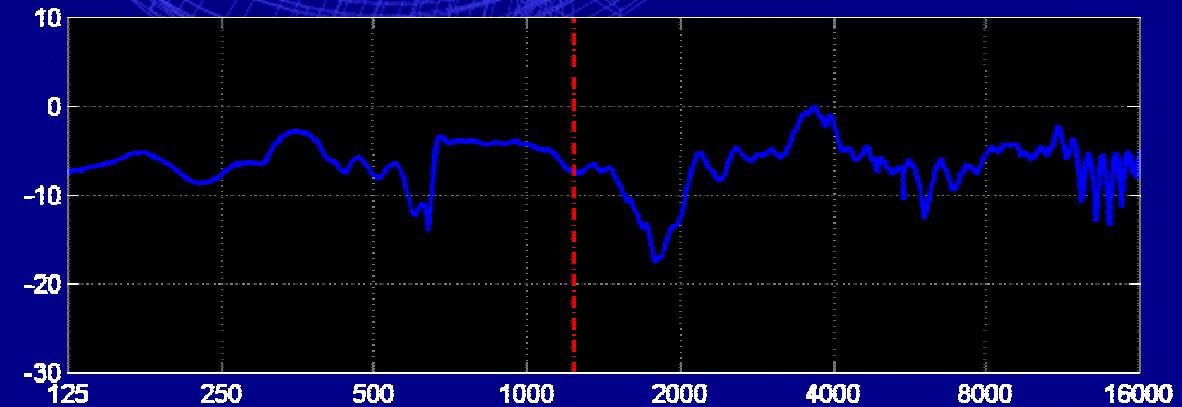
Vertical
1233 Hz
1/3 octave
5 degree(s)

1/36th Octave, One-Degree

Angular Resolution:

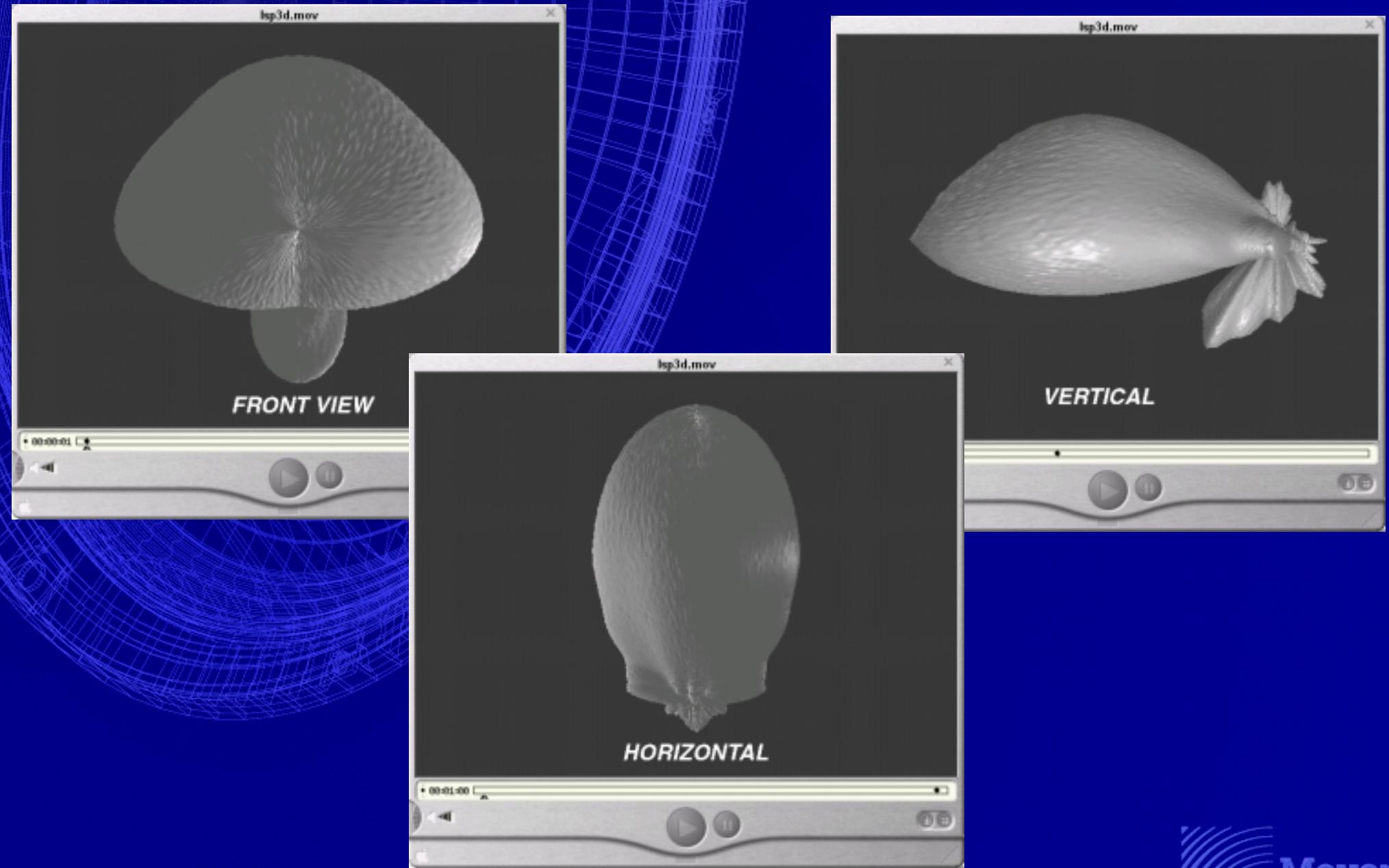


Frequency Resolution:

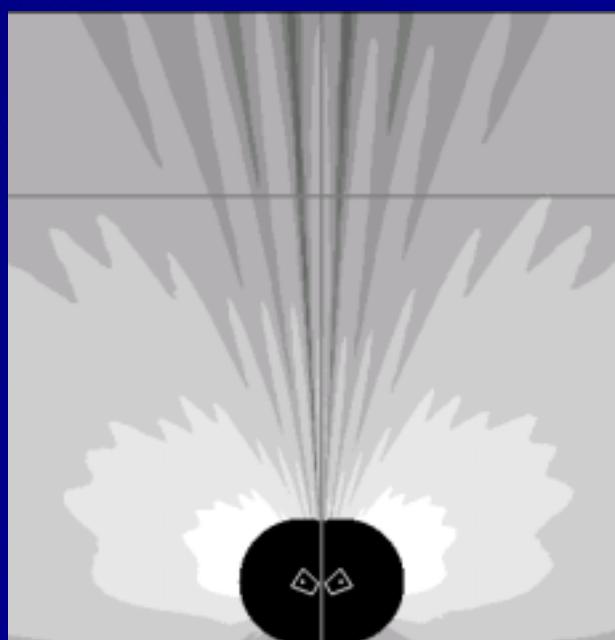
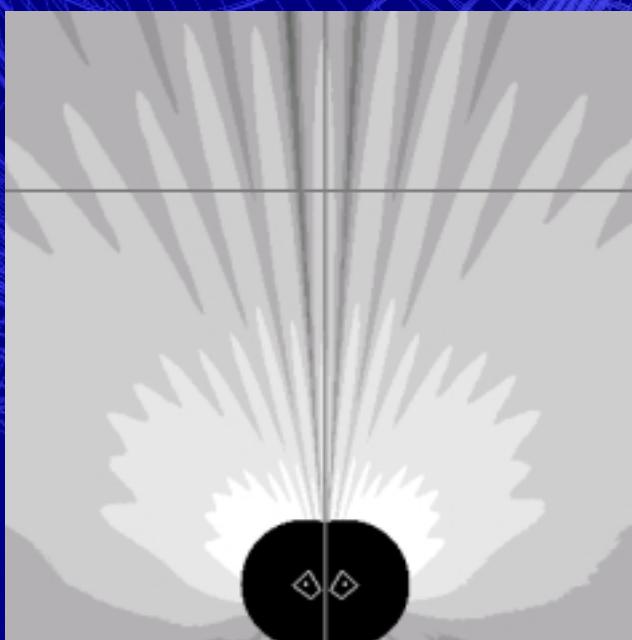
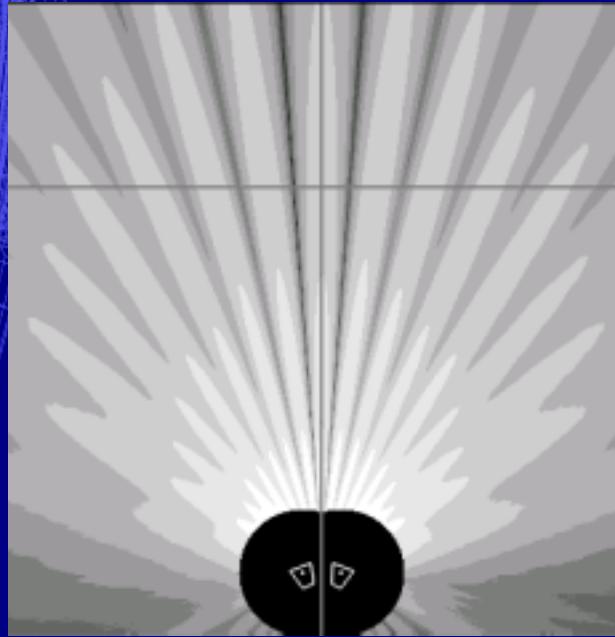


Vertical
1233 Hz
single bin
1 degree(s)

Three-dimensional polar visualization



Prediction of soundfields



Further Demonstration