3D sound reproduction with “OPSODIS” and its commercial applications

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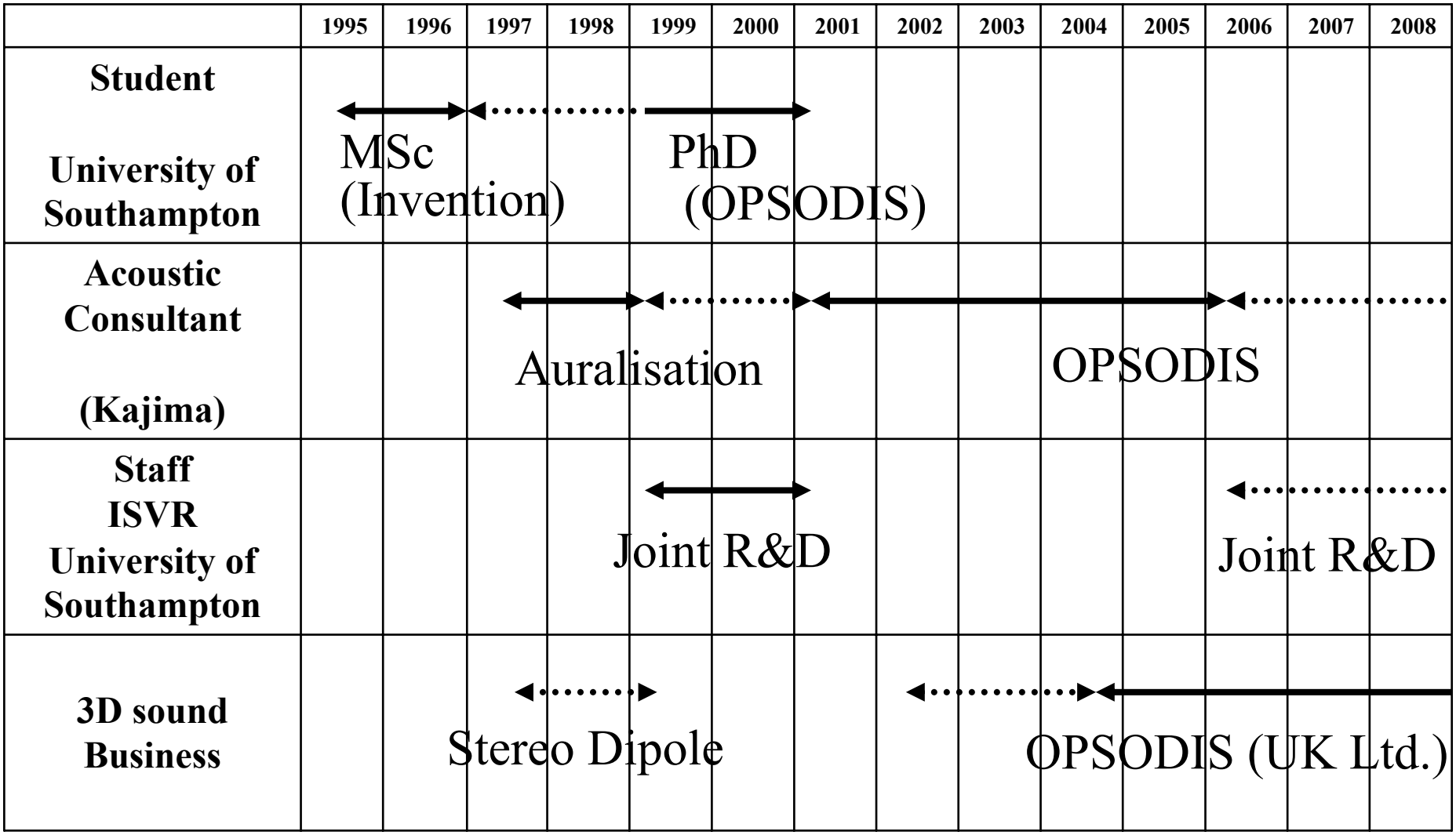
Kajima Technical Research Institute

History


1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Student
University of Southampton
MSc (Invention)
PhD (OPSODIS)
Acoustic Consultant
(Kajima)
Auralisation
OPSODIS
Staff
ISVR
University of Southampton
Joint R&D
Joint R&D
3D sound Business
Stereo Dipole
OPSODIS (UK Ltd.)

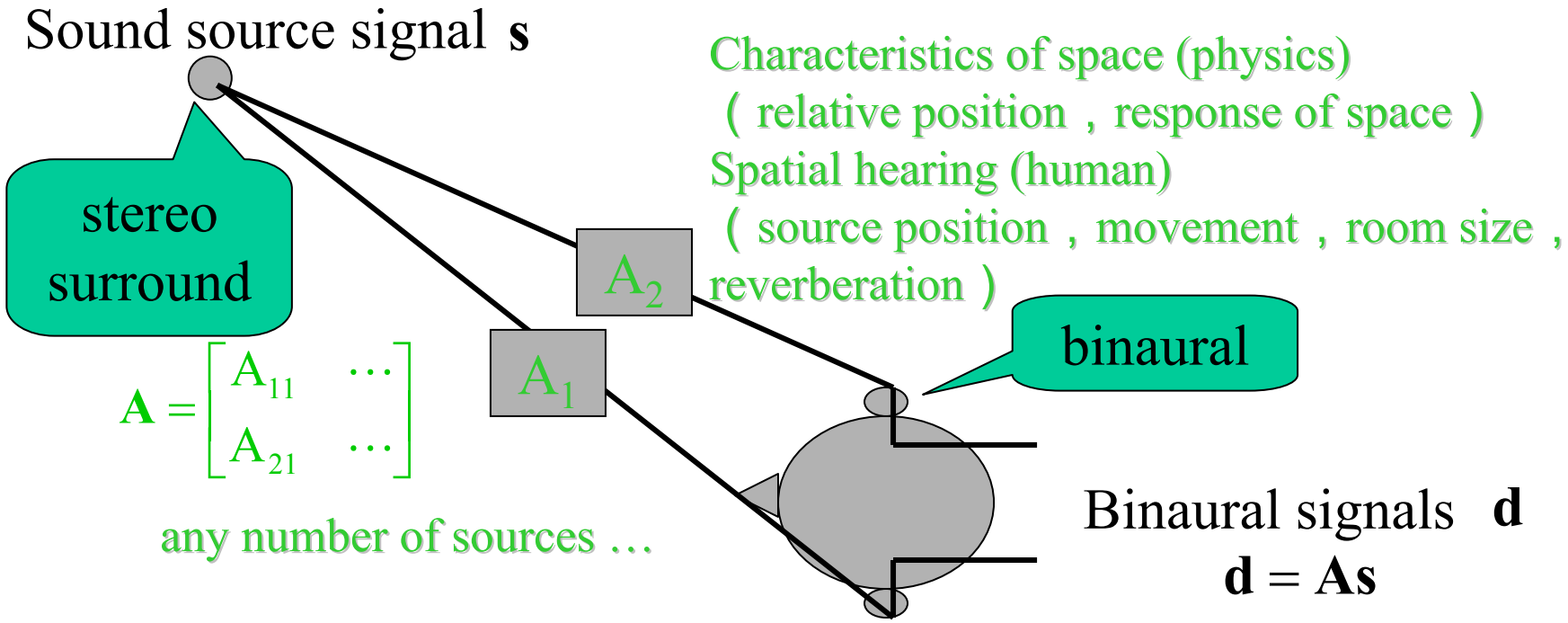
What is OPSODIS™?

Optimal **So**urce **Dis**tribution

- Principle
  - **3D sound reproduction**
  - Binaural
  - Loudspeaker reproduction
  - 2 channel system (or 3ch)
  - Stereo & Surround reproduction compatible

- What is special?
  - **Lossless crosstalk cancellation!**
  - Robust control
  - Multiple listeners

Spatial hearing and binaural signal



- Physics

  source signal ⇒ propagation ⇒ two different signal at ears

- Perception

  Separates signal and spatial information ⇐ binaural signals

Inverse filtering (crosstalk cancellation)

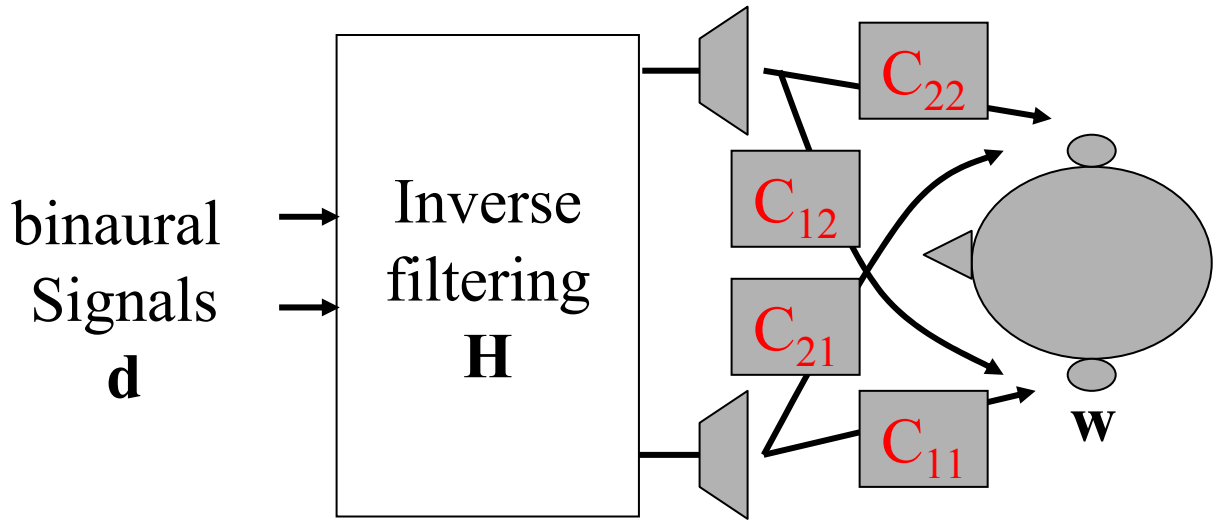
- Loudspeaker reproduction interweaves loudspeaker position

⇩

- In order to reproduce spatial information arbitrarily, independent transmission to each ear is necessary.

⇩

- Minimum of two independent (real) sound source necessary



$$\mathbf{C} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix}$$

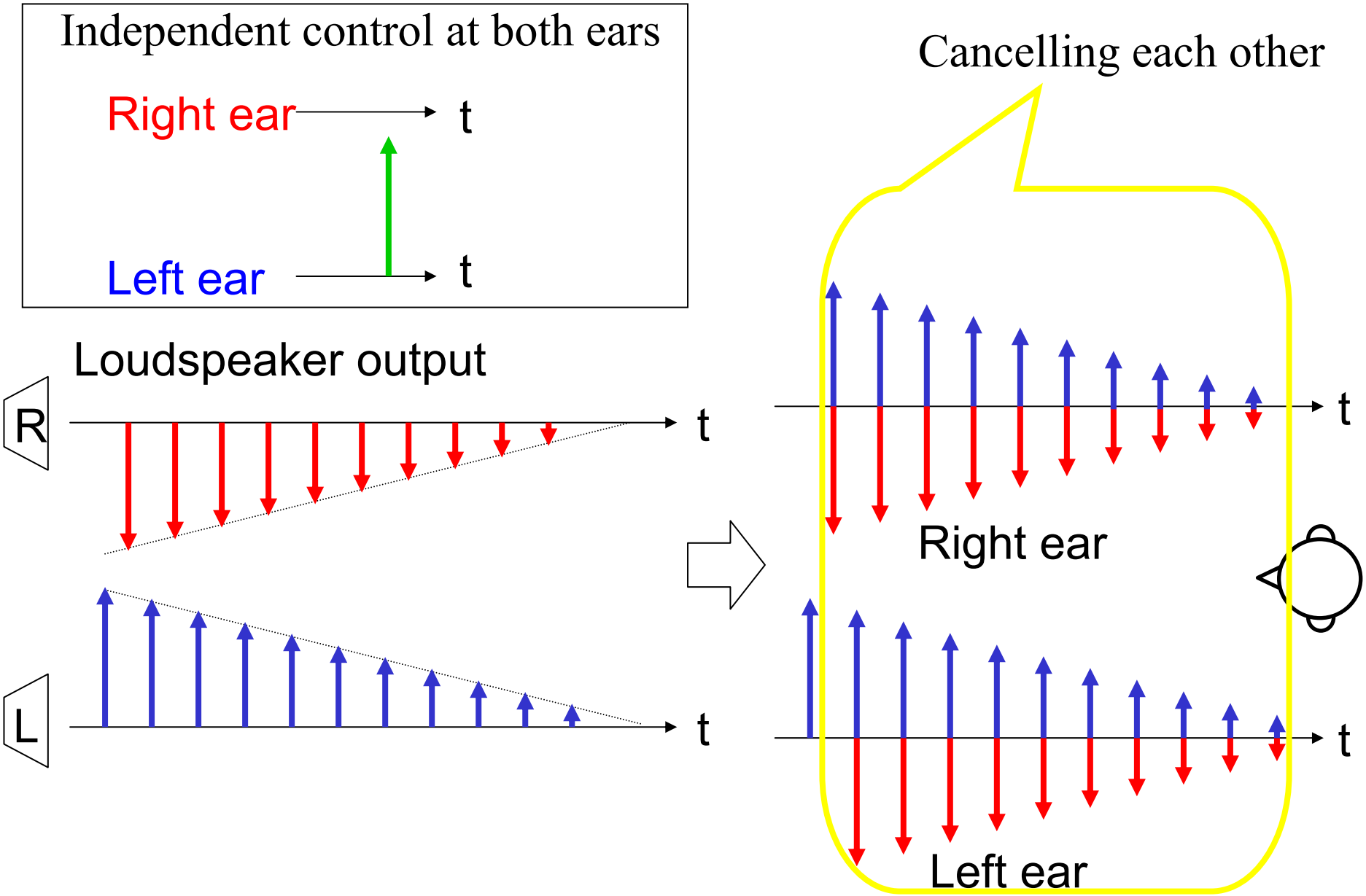
Synthesised binaural signals

$\mathbf{w} = \mathbf{CHd}$

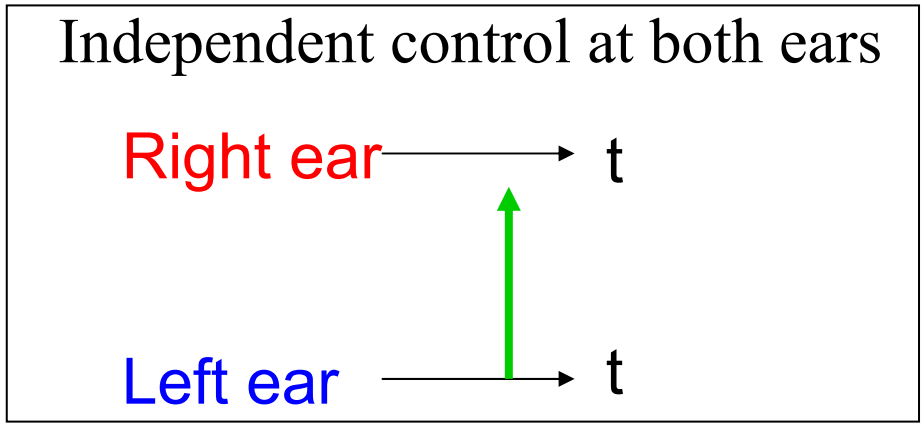
⇩

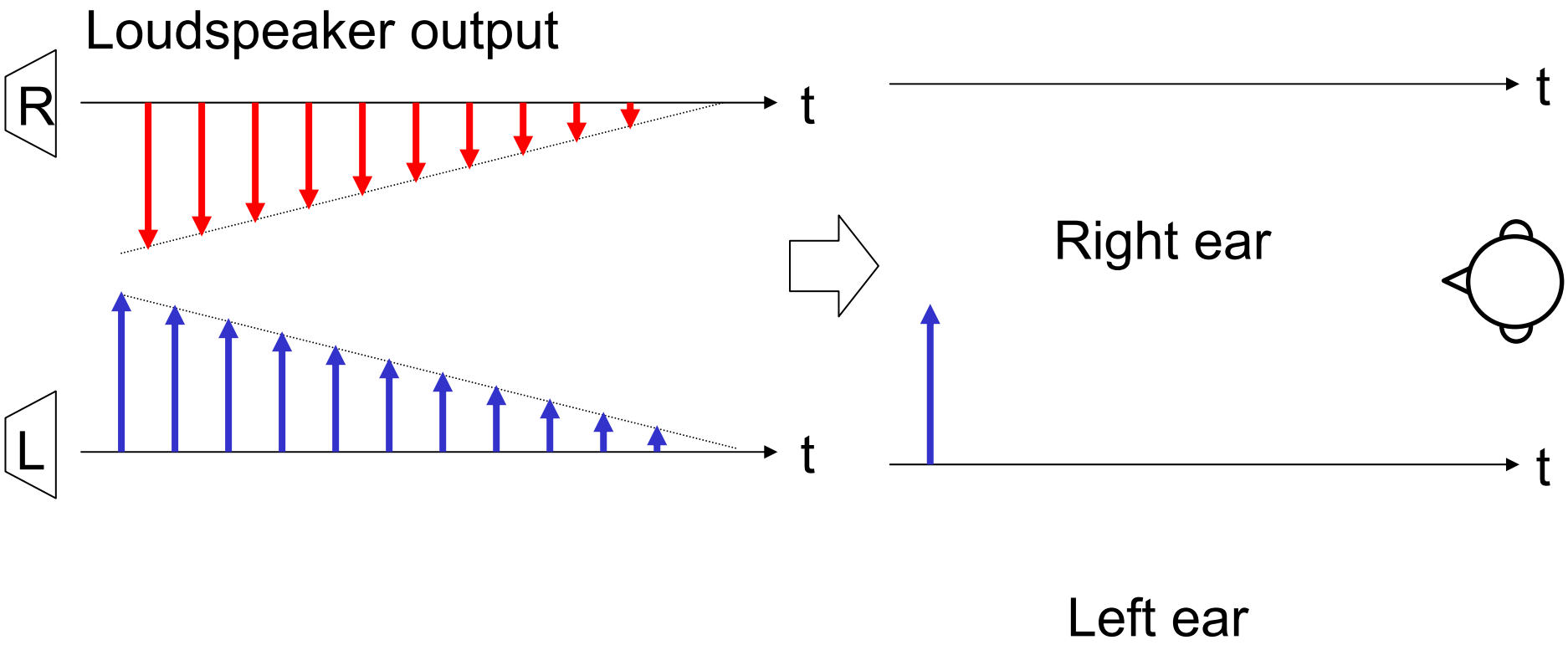
$\mathbf{w} \approx \mathbf{d}$

Conventional cross-talk cancellation

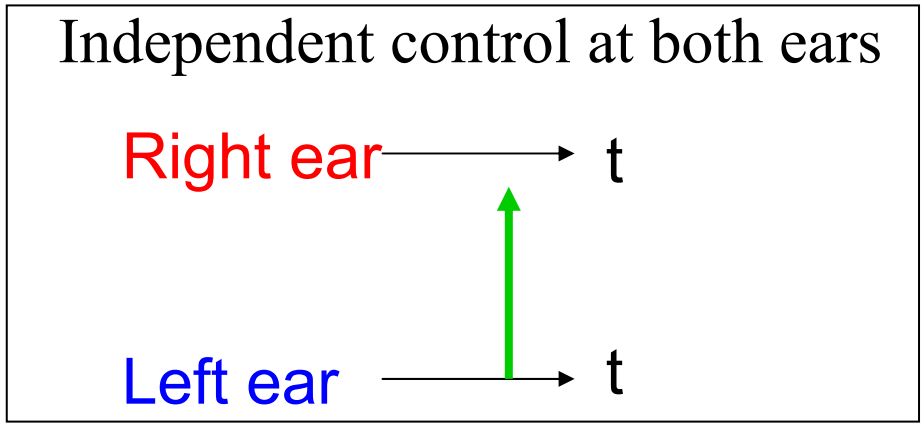


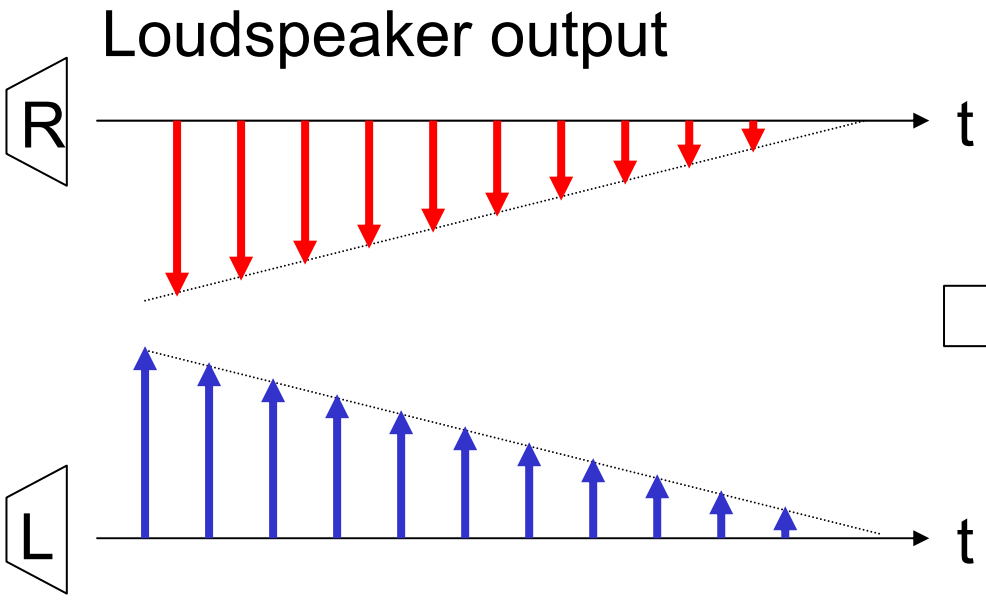
Conventional cross-talk cancellation





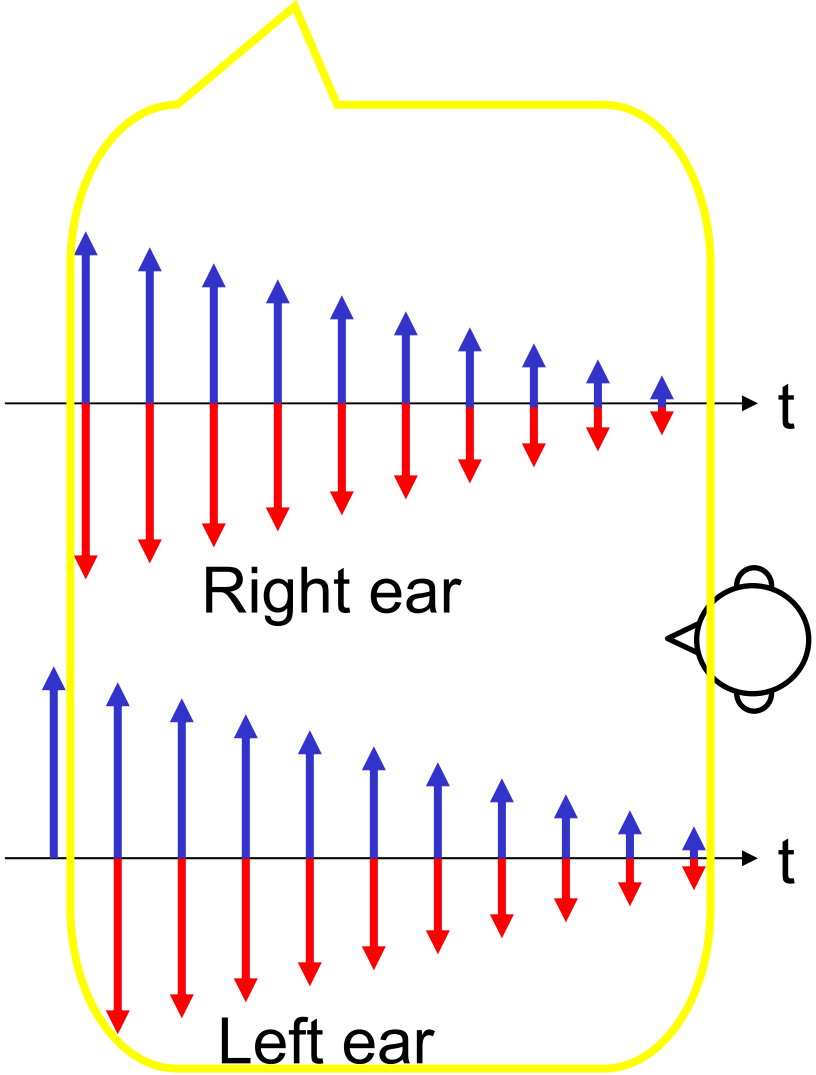
Conventional cross-talk cancellation



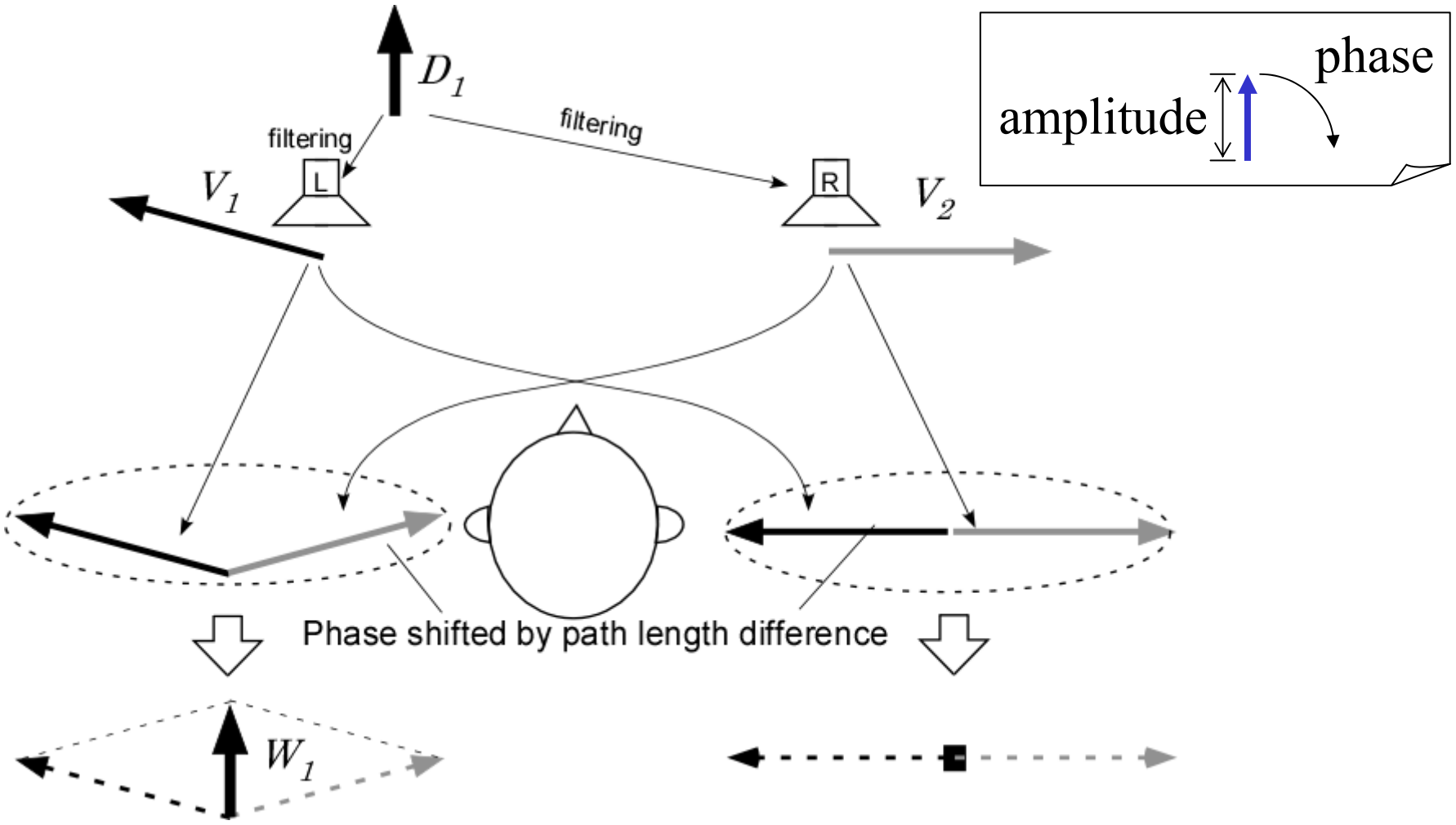


Repetitive delay = Large output
(Frequency dependent)

Massive destructive interference



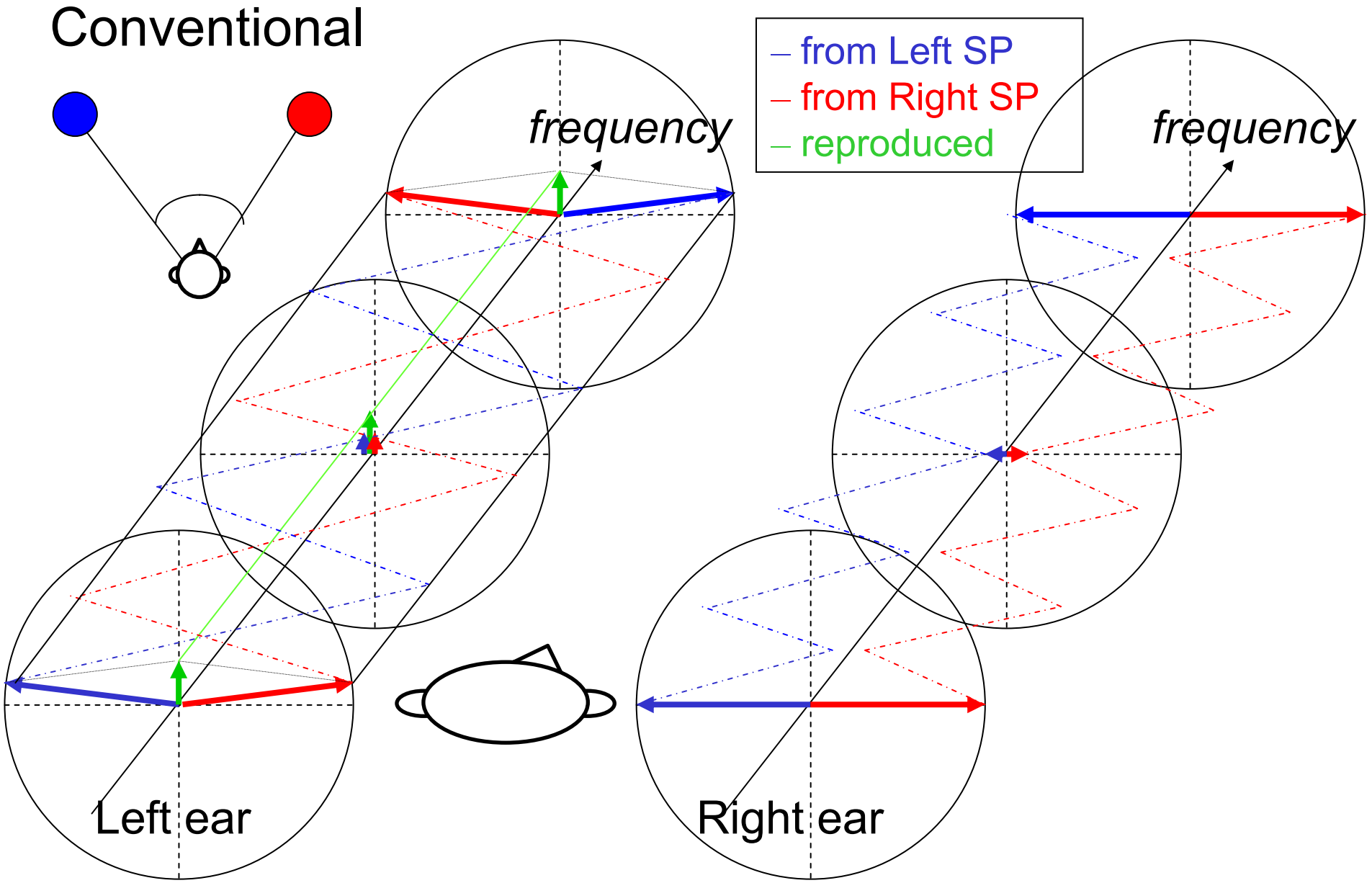
Crosstalk cancellation (frequency)



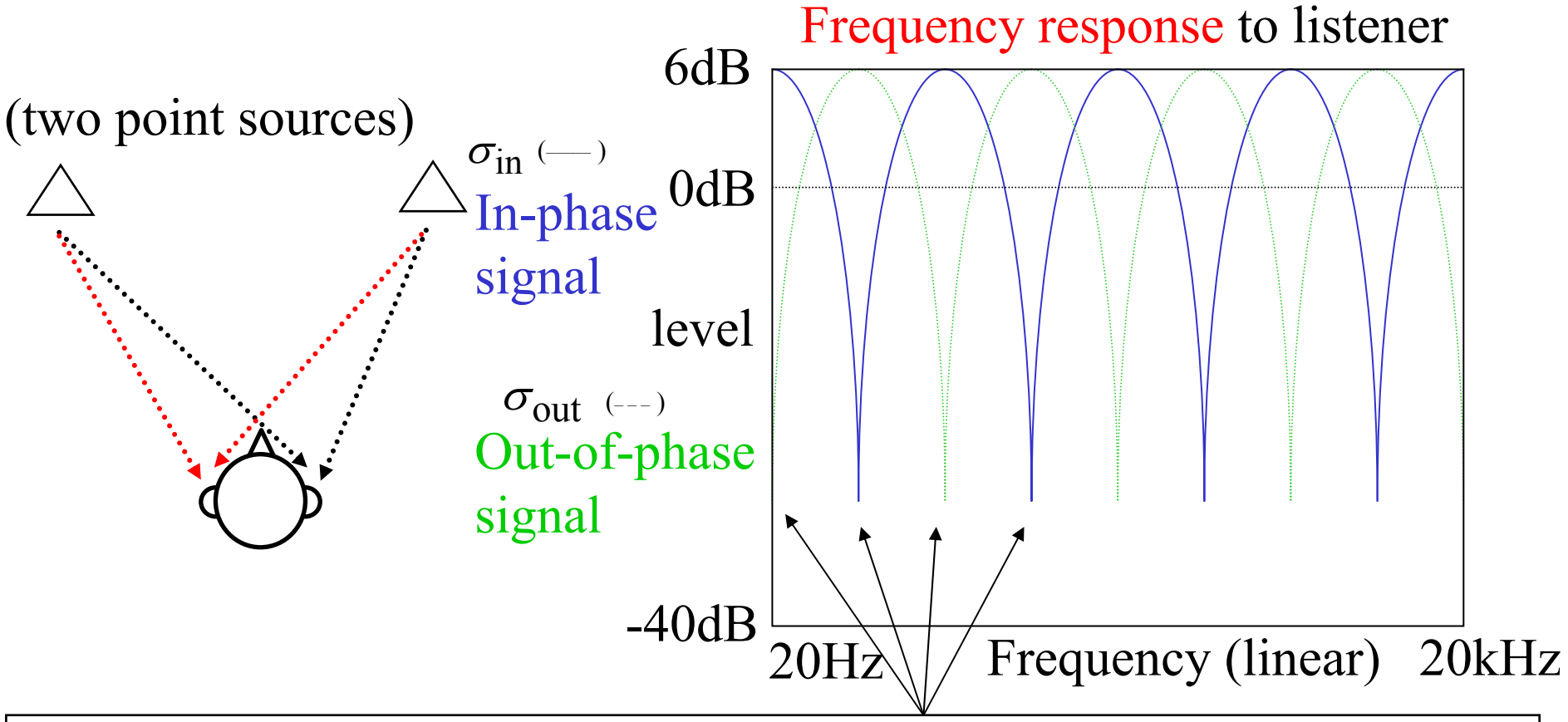
Destructive interference at both ears.

Inefficient, quality loss, sensitive to errors.

Frequency dependency



Why have 3D systems not performed well so far?



Sound emitted by loudspeakers do not reach listener's ears at certain frequencies.

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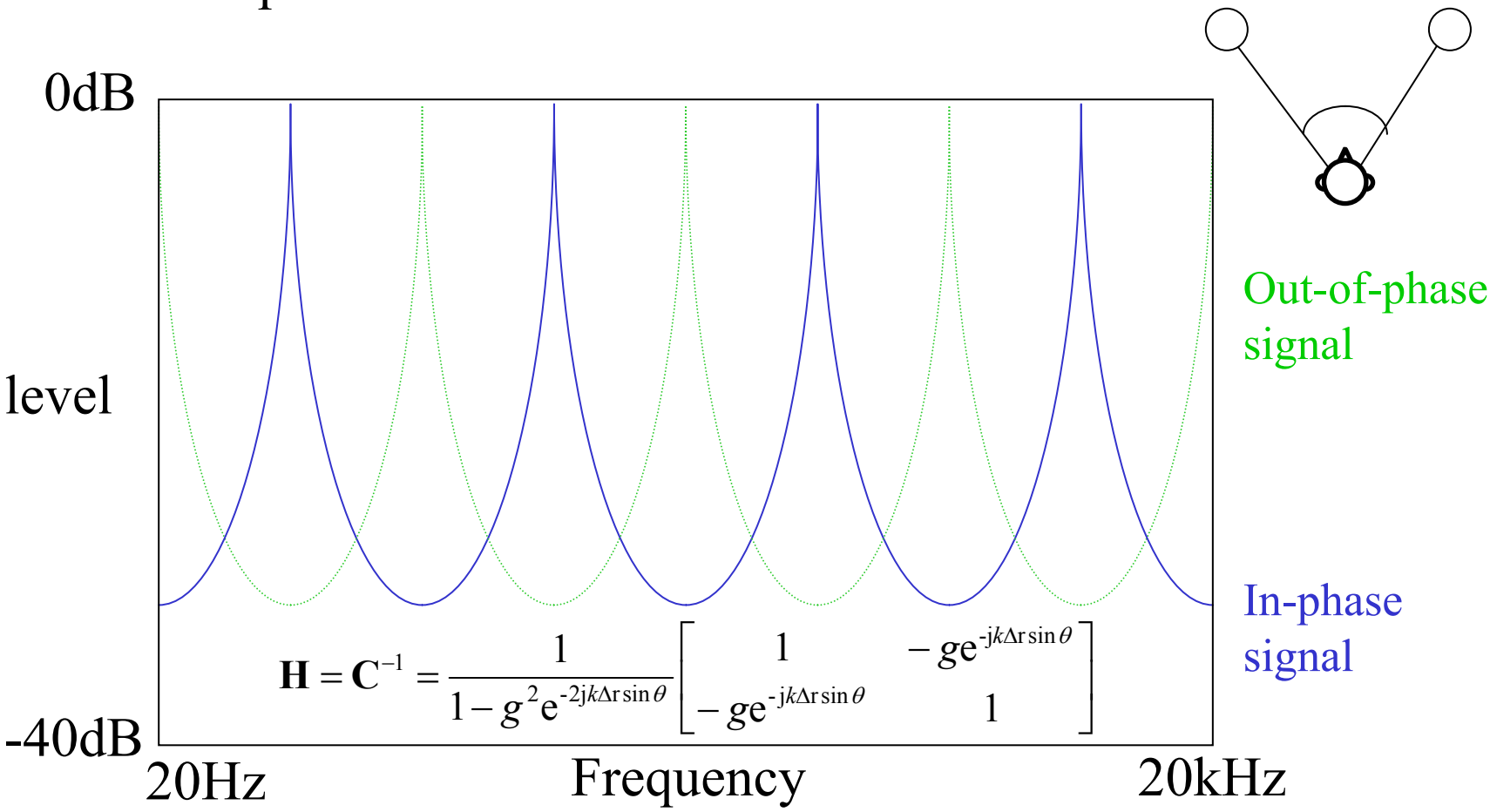
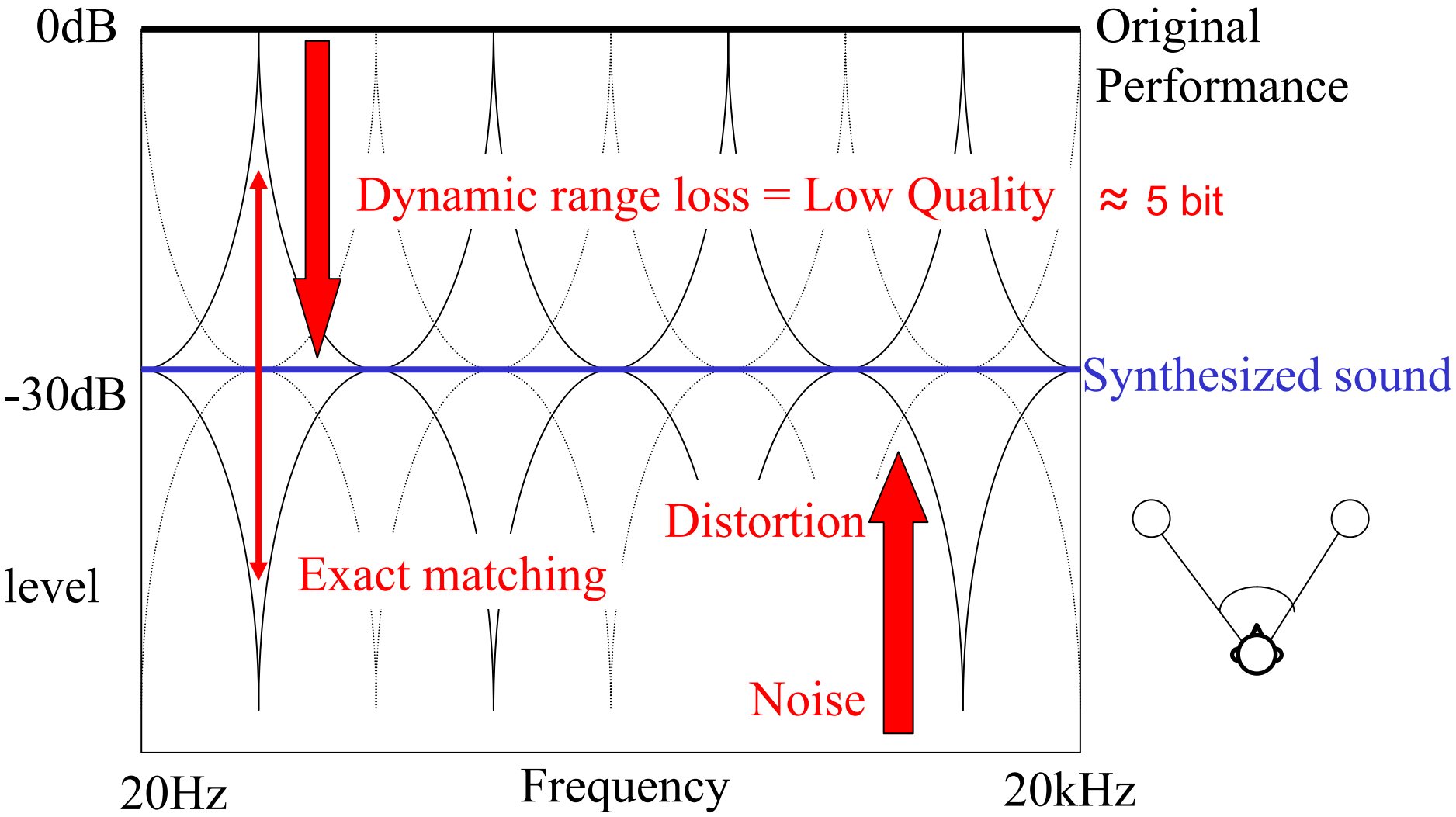
Large output required to compensate it.

Loss of performance through cross-talk cancellation process

- Typical frequency response of the inverse filters for 3D reproduction.

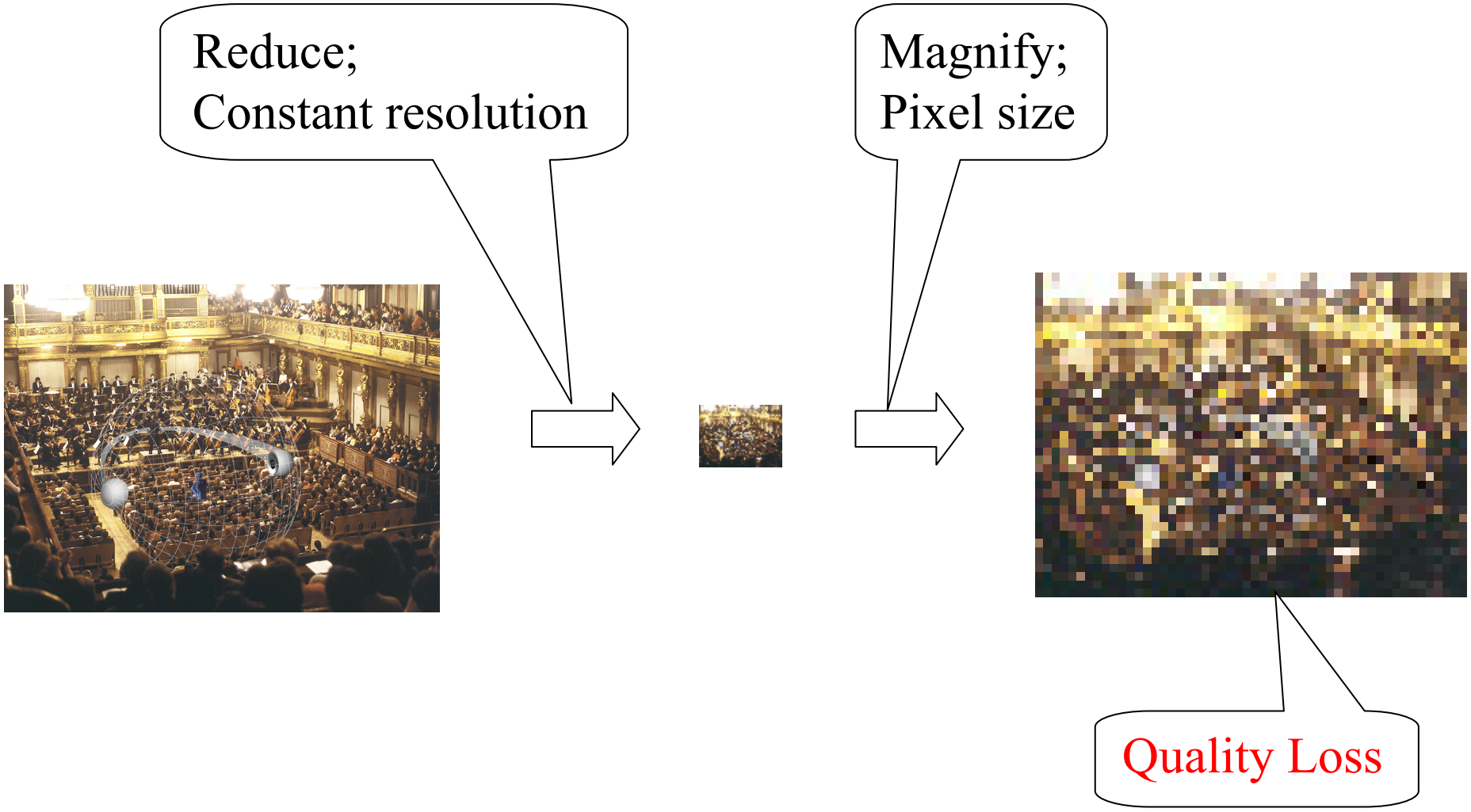


Loss of performance through cross-talk cancellation process

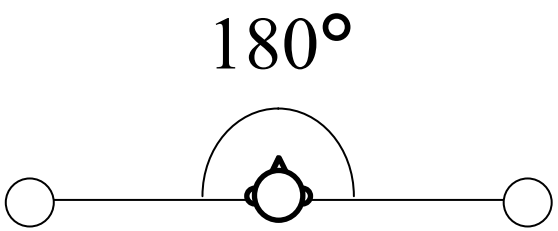


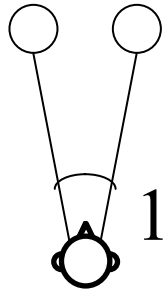
Cross-talk cancellation degrades performance severely.

Analogy to picture quality

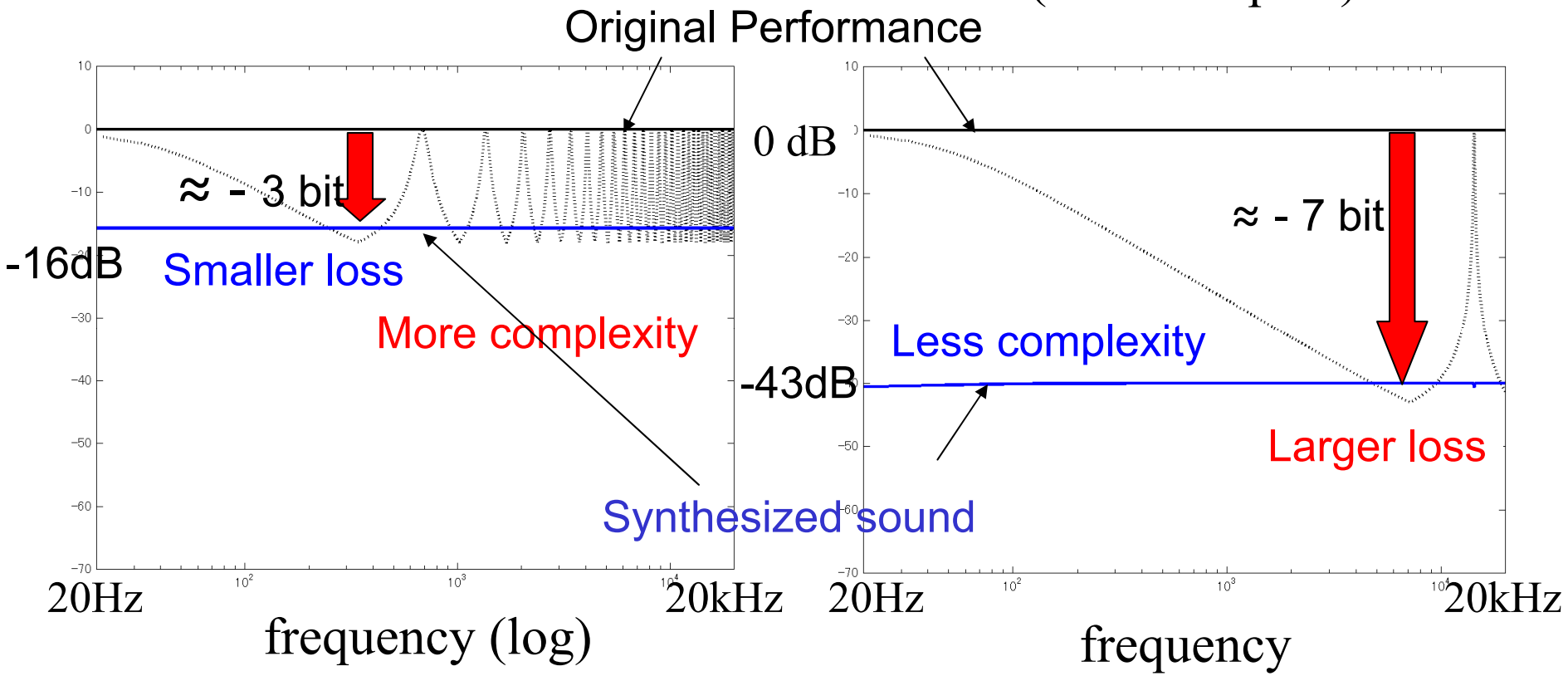


Loudspeaker span

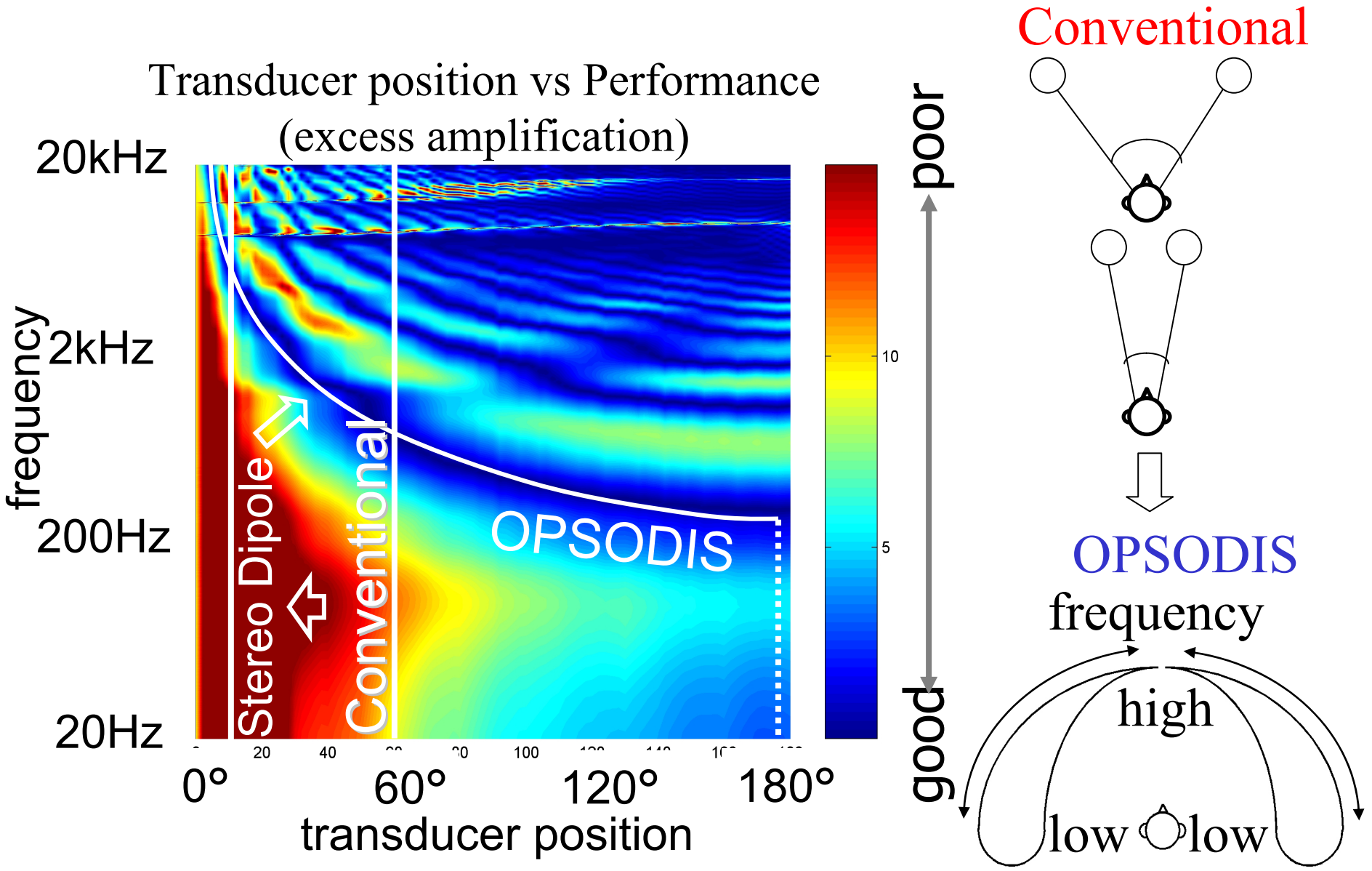




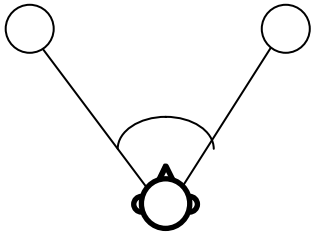
(Stereo Dipole)

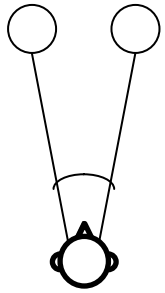


Optimal Source Distribution



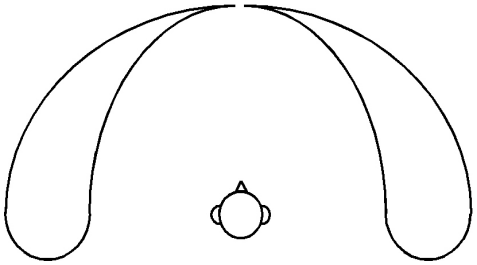
Conventional



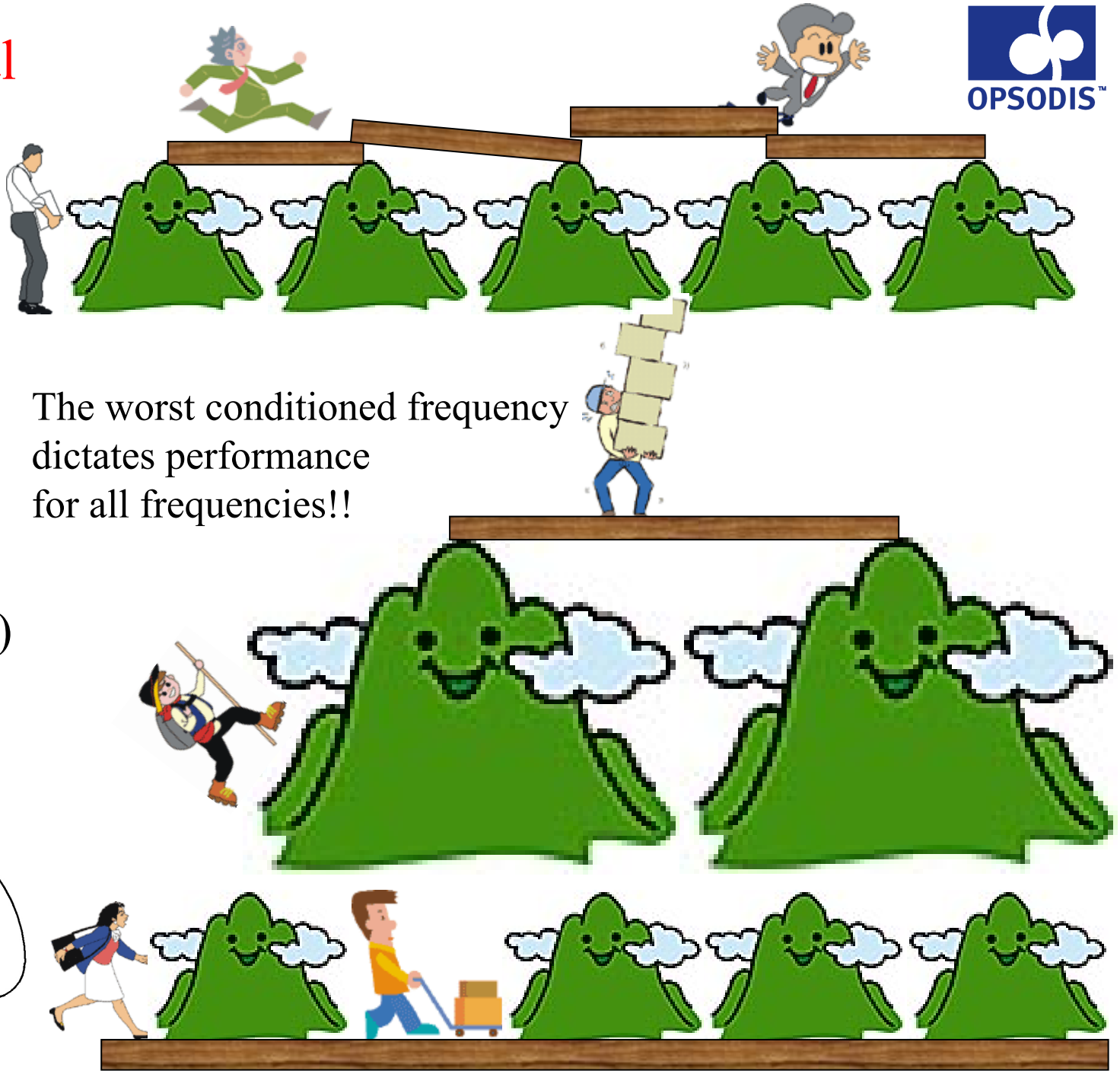


(Stereo Dipole)

OPSODIS



The worst conditioned frequency
dictates performance
for all frequencies!!

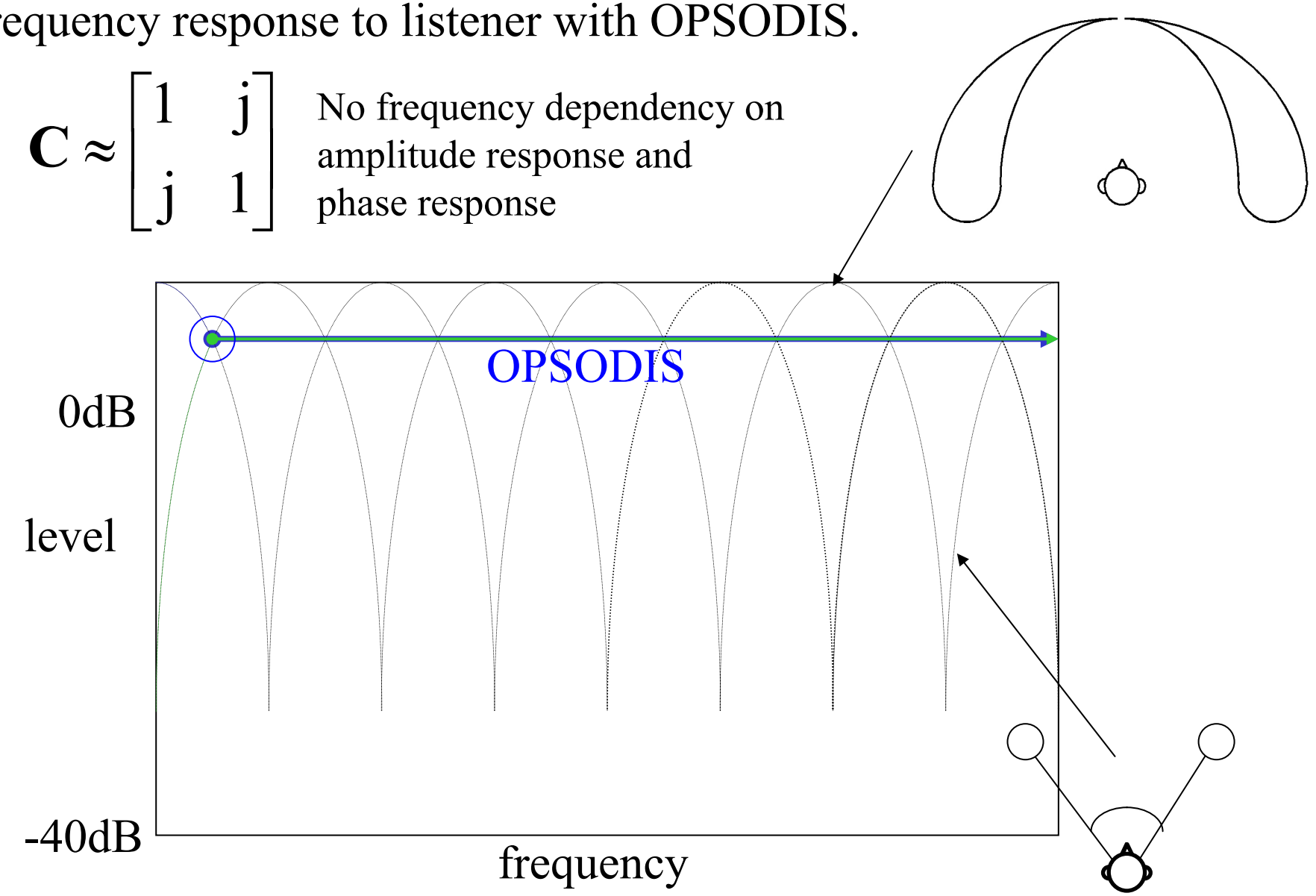


OPSODIS loudspeaker

- Frequency response to listener with OPSODIS.

$$\mathbf{C} \approx \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

No frequency dependency on amplitude response and phase response

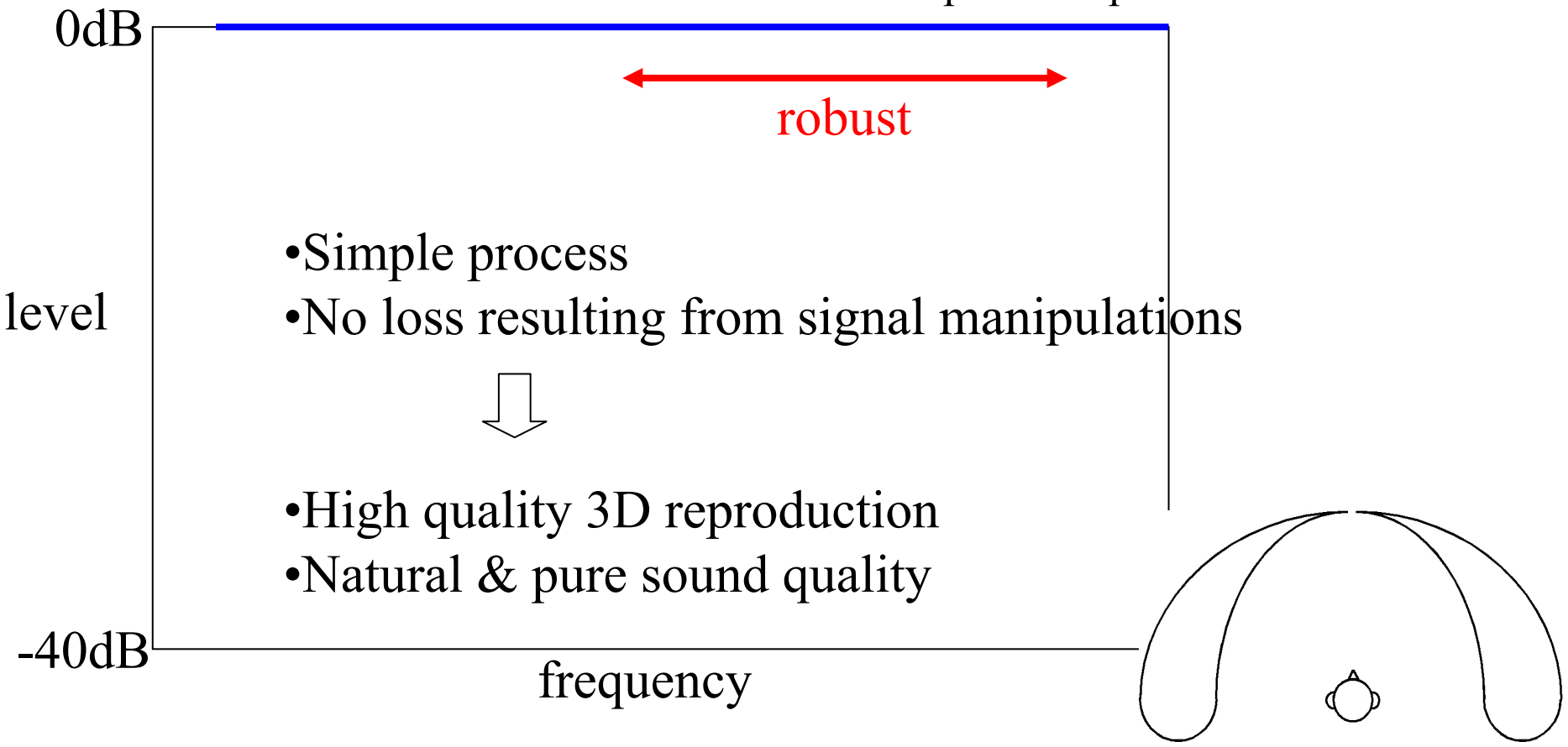


OPSODIS principle

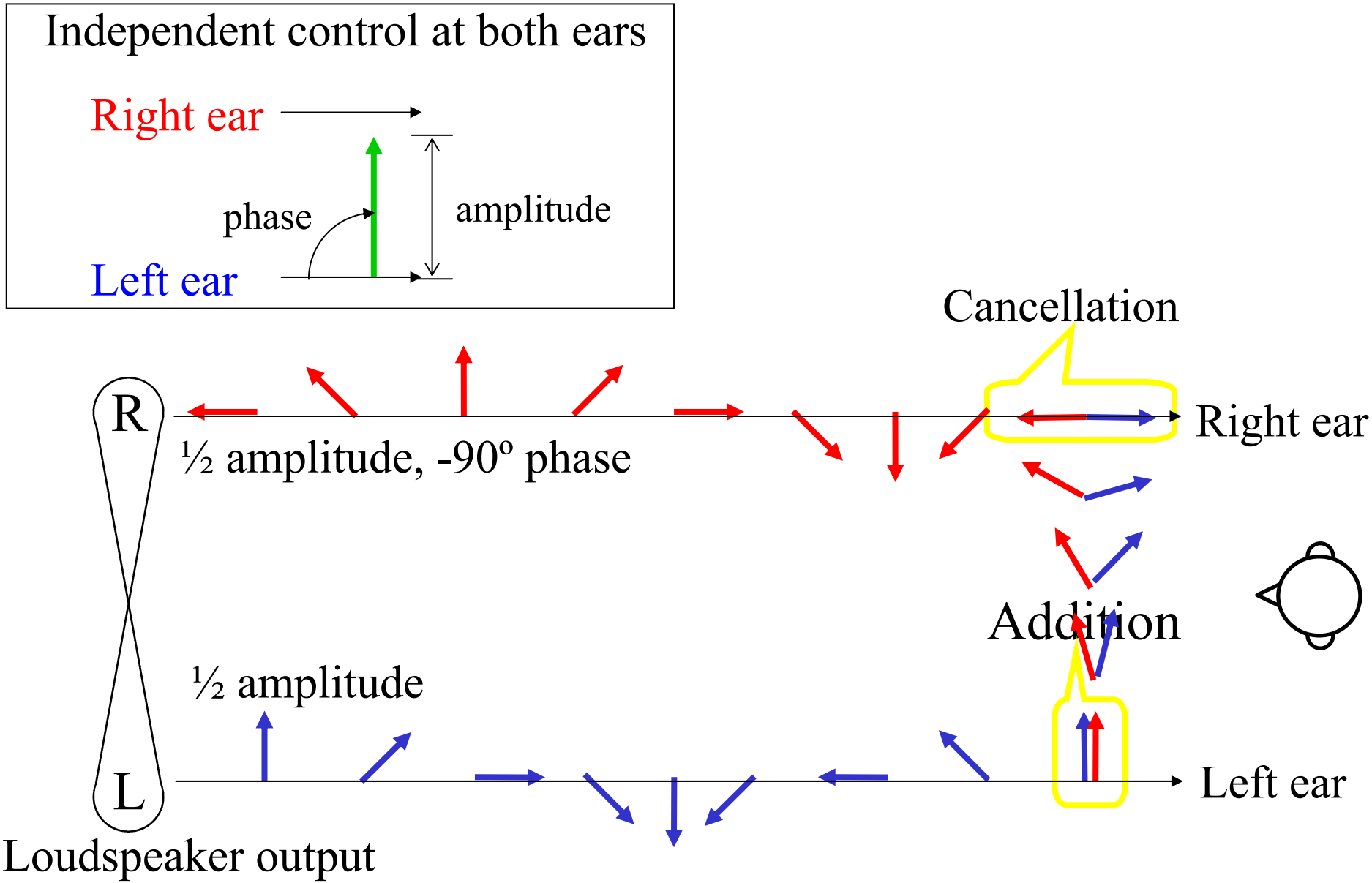
- Frequency response of the OPSODIS inverse filters.

$$\mathbf{H} = \frac{1}{1+g^2}\begin{bmatrix} 1 & -jg \\ -jg & 1 \end{bmatrix} \approx \frac{1}{2}\begin{bmatrix} 1 & -j \\ -j & 1 \end{bmatrix}$$

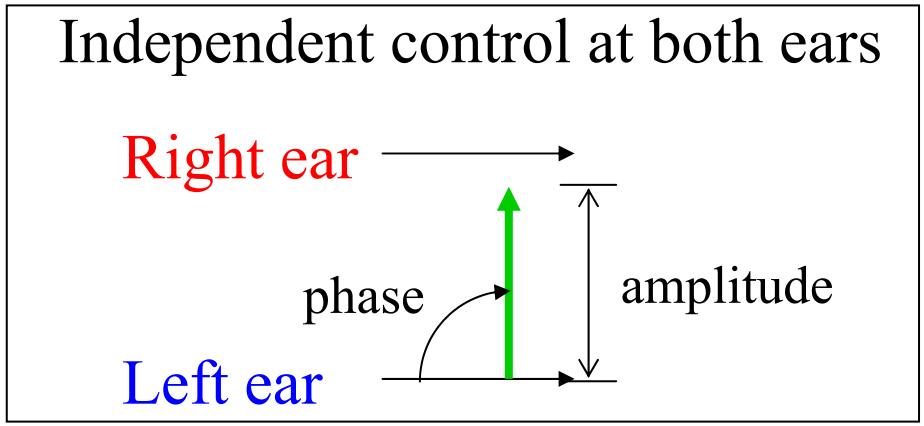
No frequency dependency on amplitude response and phase response

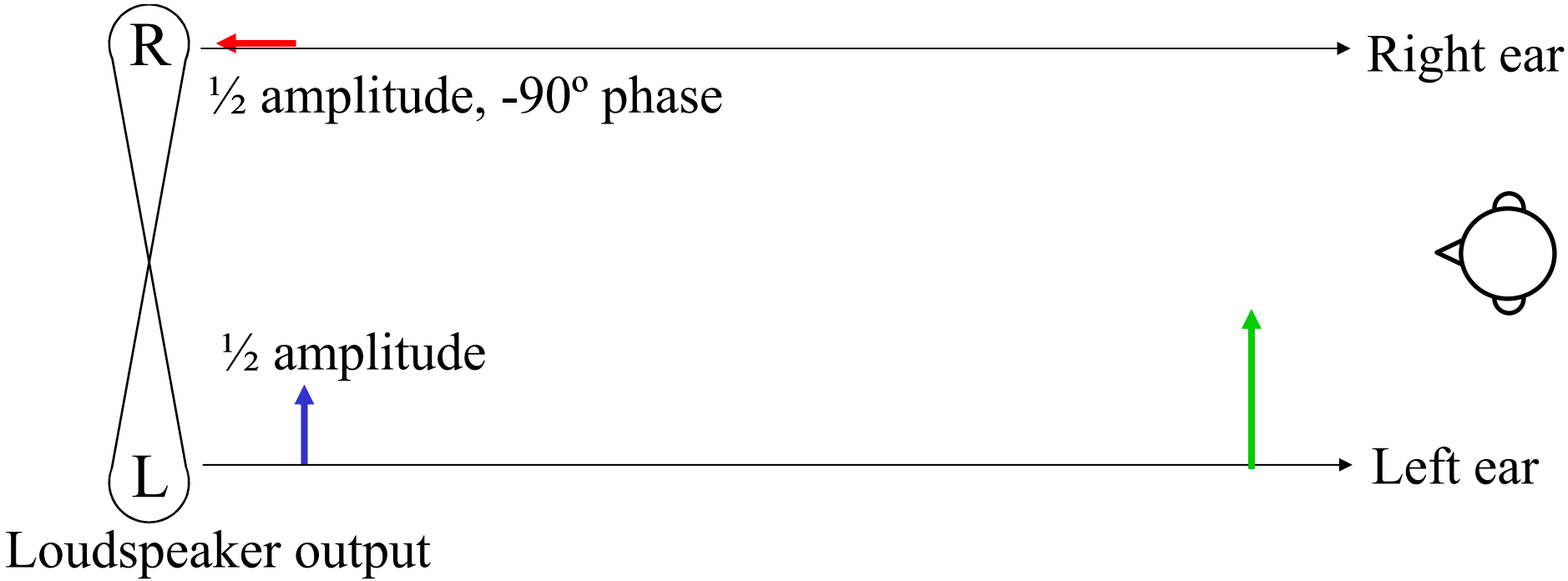


Crosstalk cancellation of OPSODIS

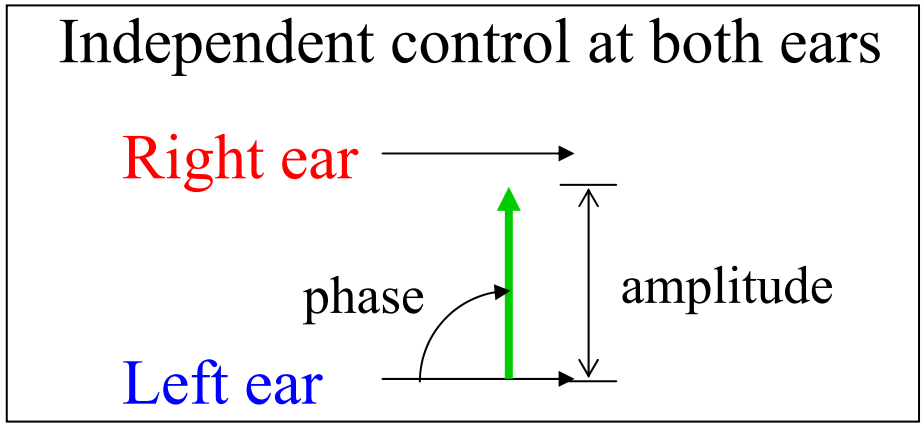


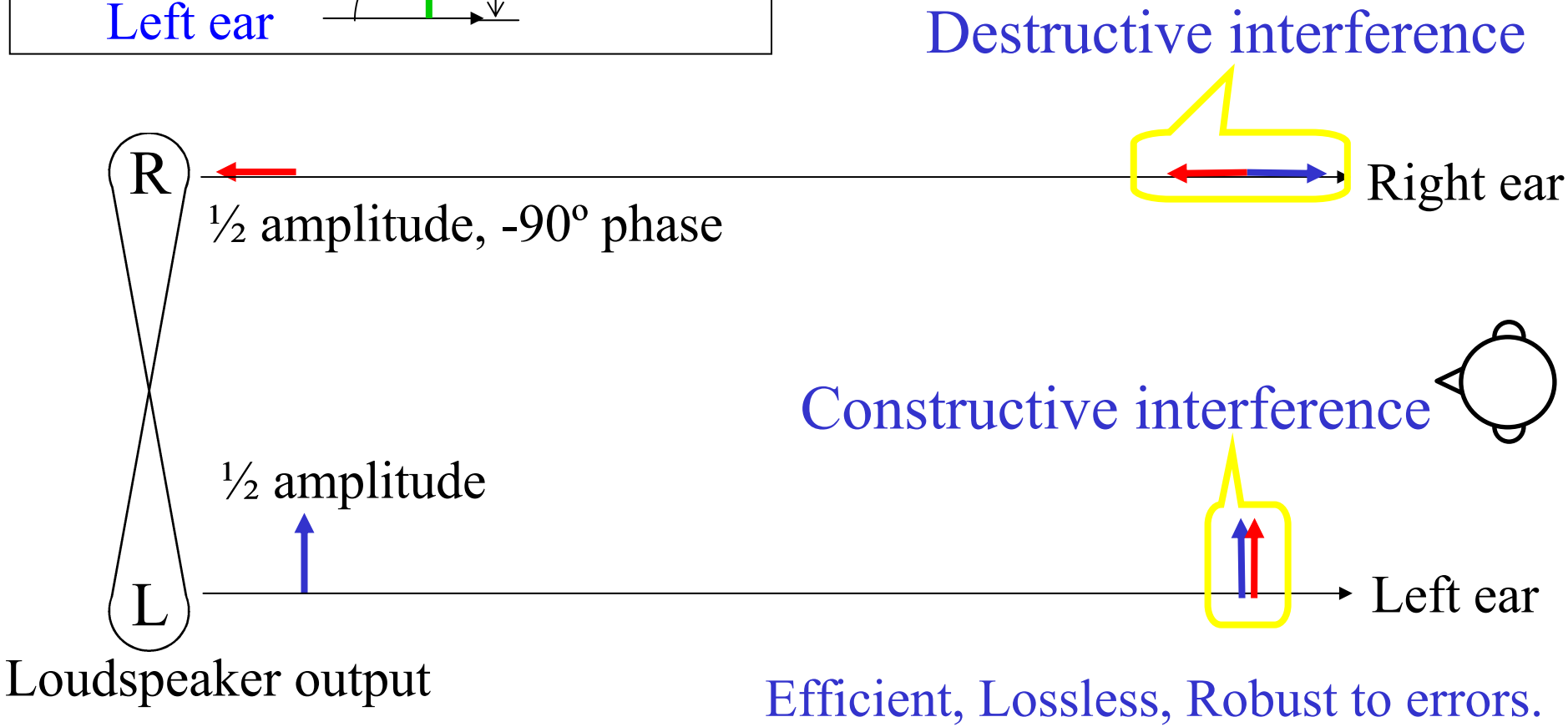
Crosstalk cancellation of OPSODIS





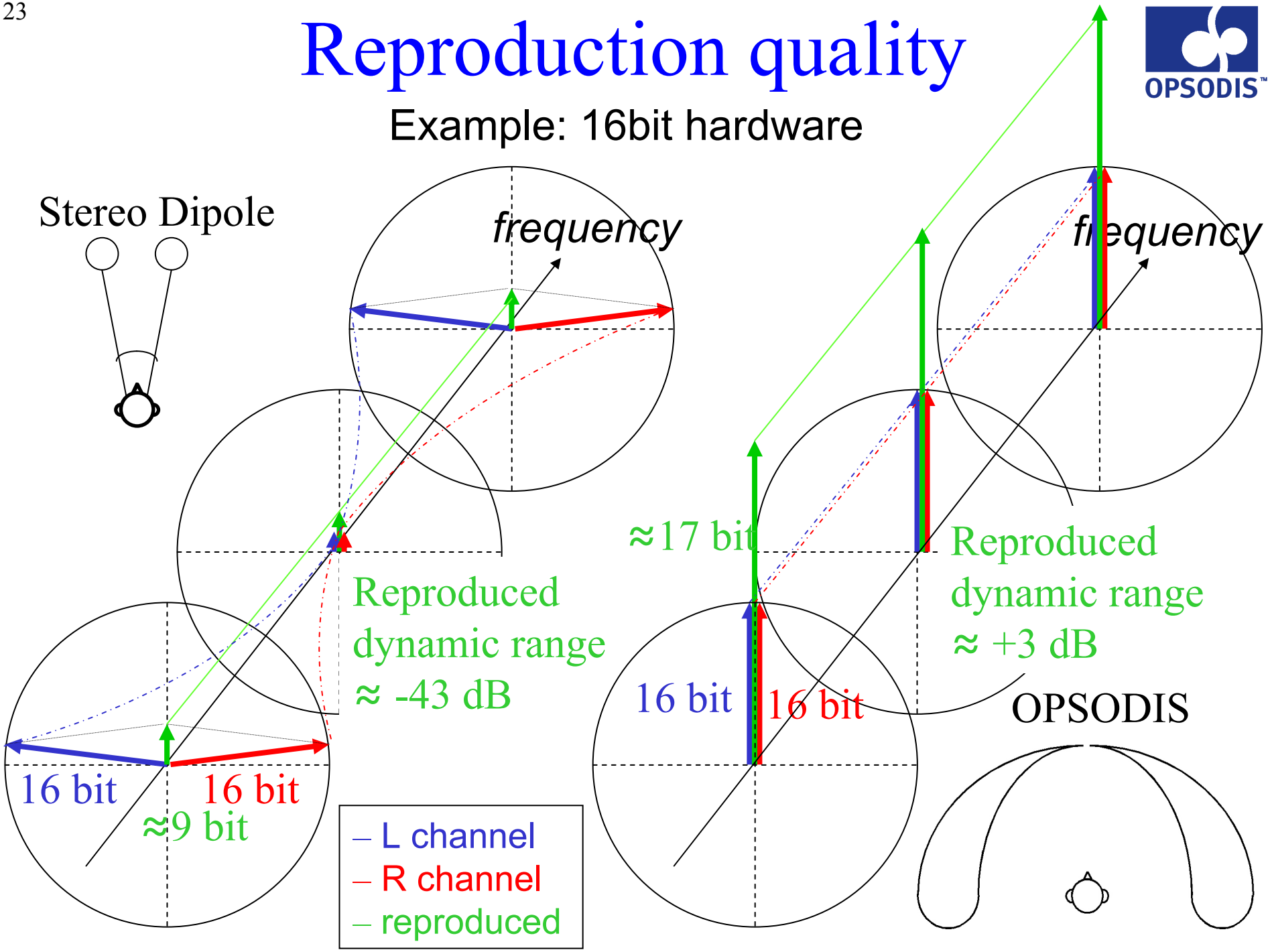
Crosstalk cancellation of OPSODIS





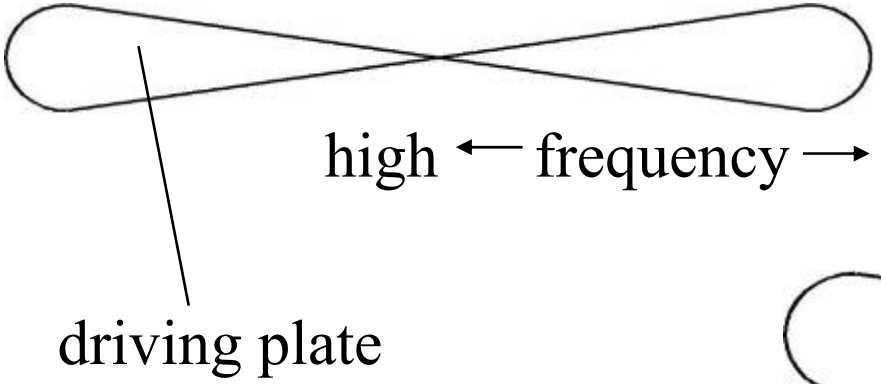
Reproduction quality

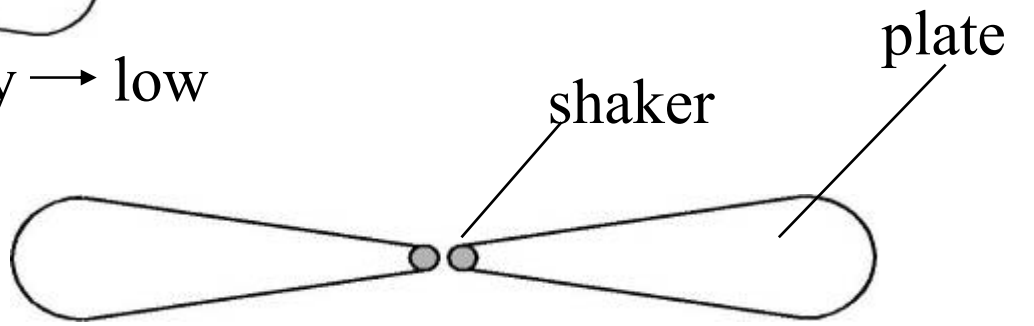
Example: 16bit hardware



Electro-acoustic transducer for OPSODIS

•Flat panel loudspeakers



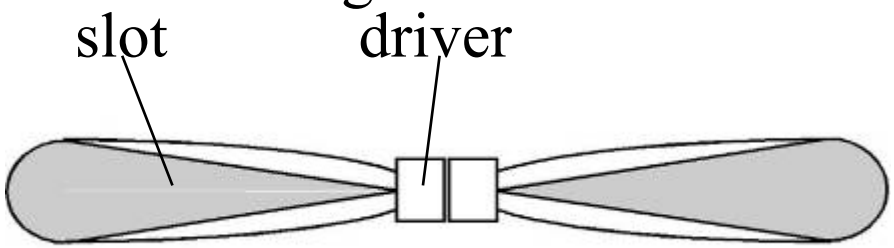


narrow ← width → wide

large ← stiffness → small

high ← frequency → low

•Acoustic waveguide

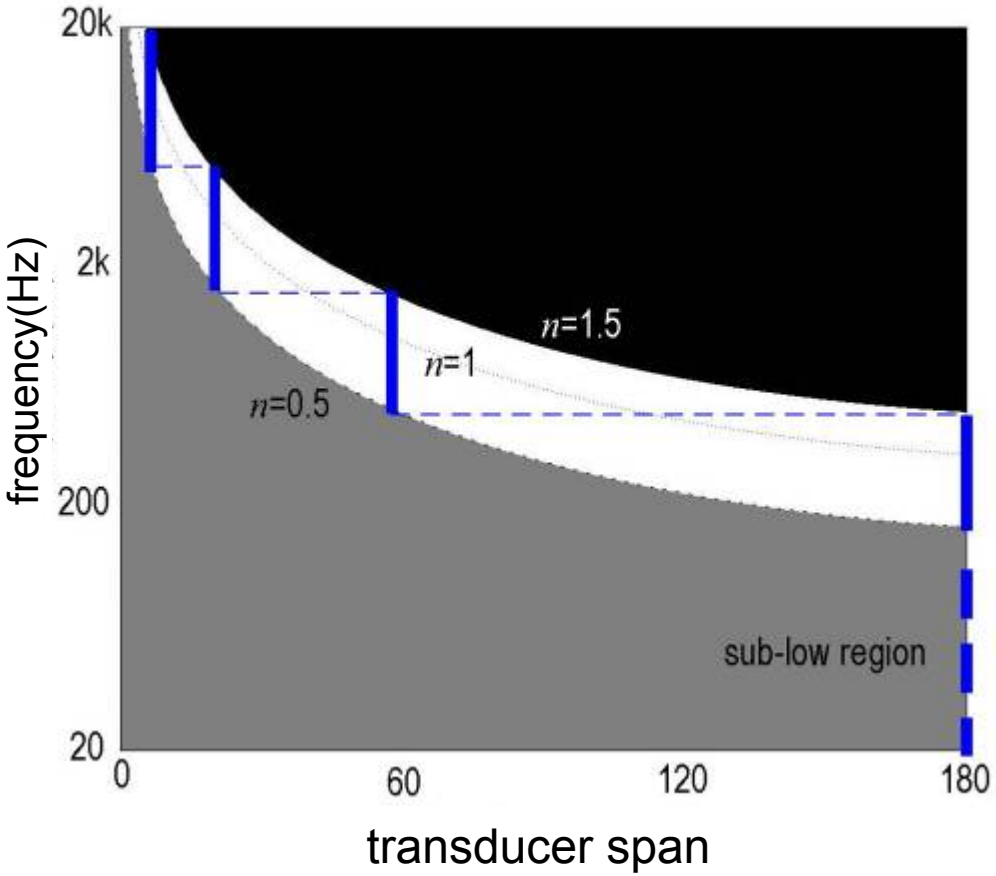


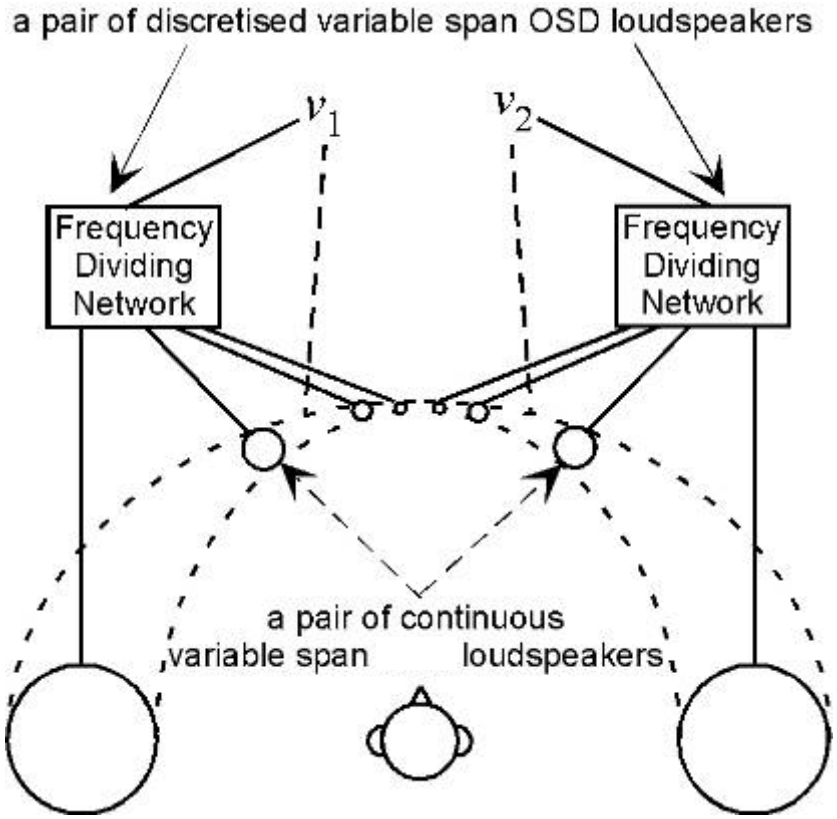
narrow ← slot → wide

high ← frequency → low

Variation in excited frequency and radiation impedance

Discrete system





- Width of n enables discretisation

$$n = 1 \rightarrow 1 - \nu \leq n \leq 1 + \nu$$

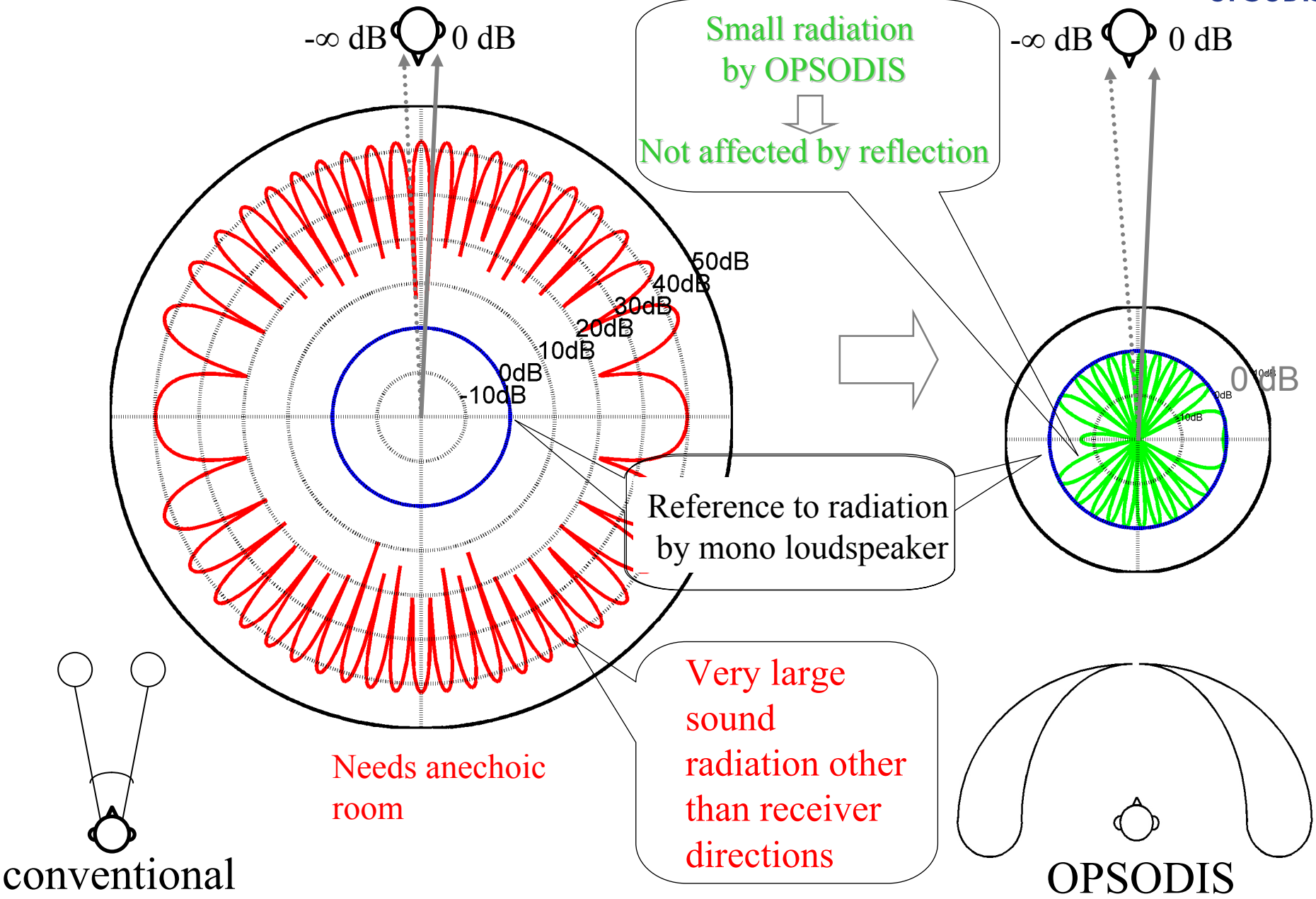
- U-shaped valley

⇩

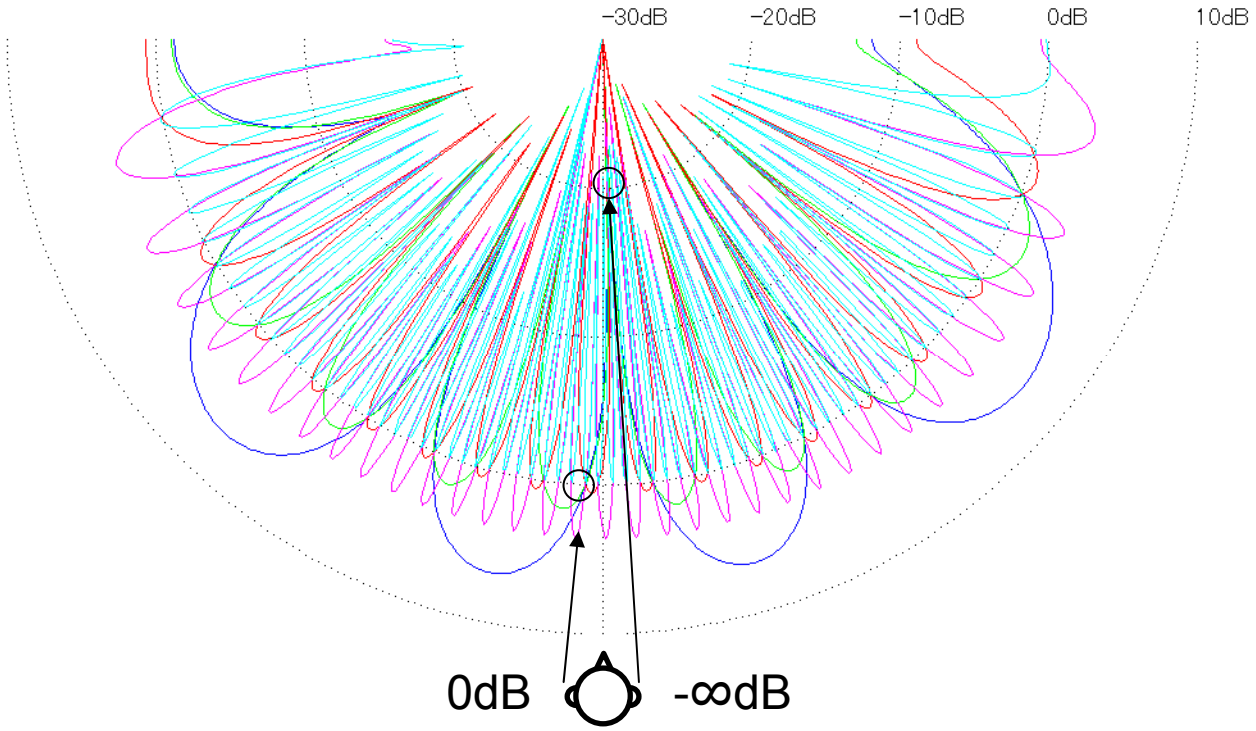
Small performance loss

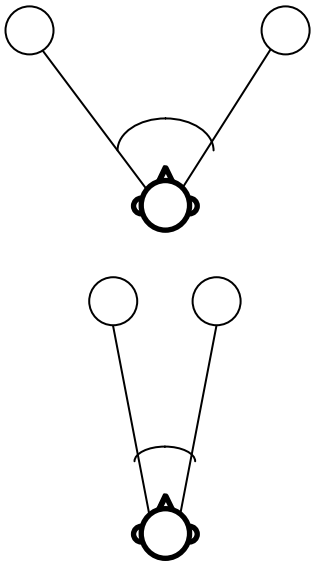
- 2 channel, multi-way system
  - Use of conventional transducers
  - Wide frequency range

Effects of room reflection (sound radiation)



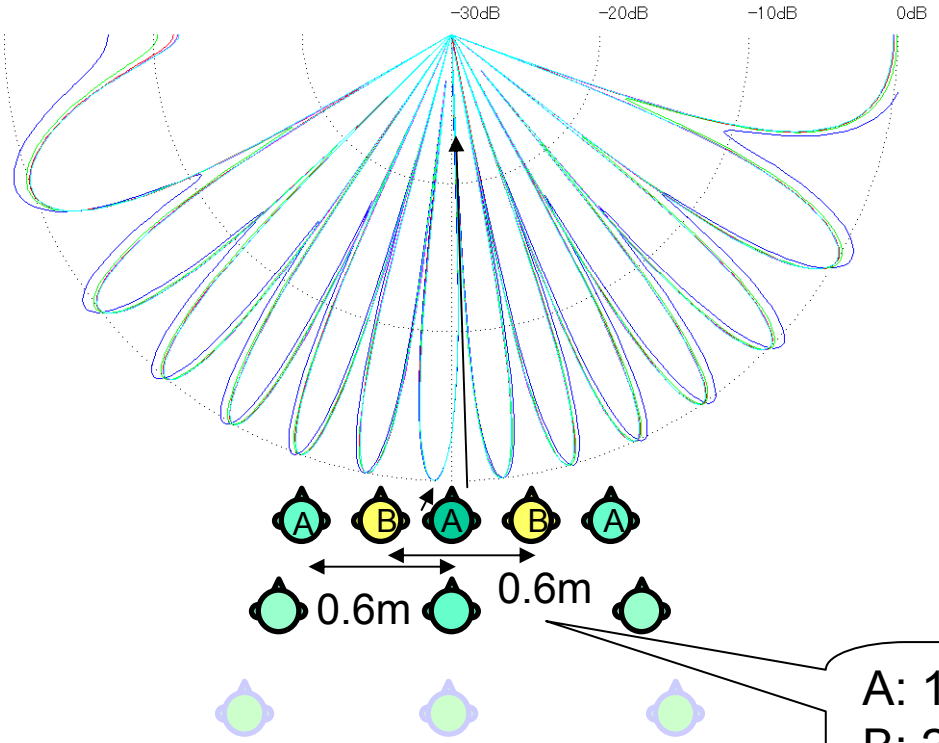
Radiation pattern of Conventional

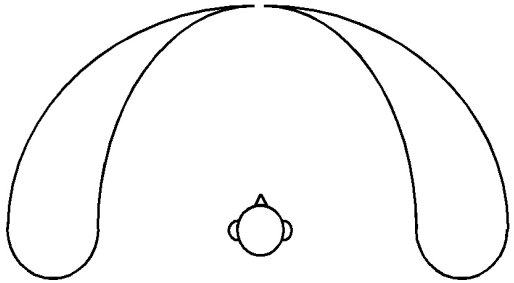




- Radiation pattern is different depending on the frequency.
- Single listener .
- Very small sweet area.

Radiation pattern of OPSODIS

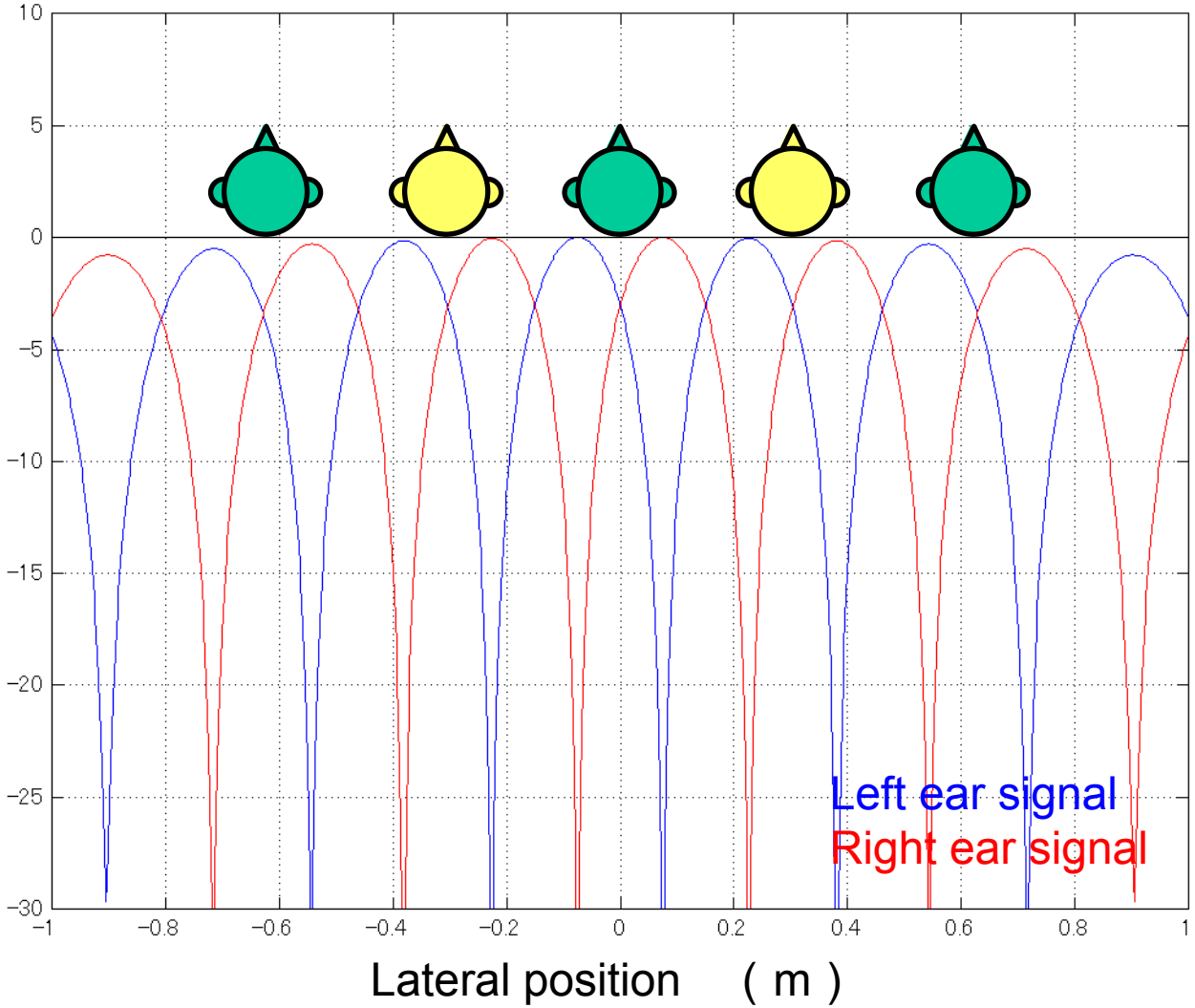




- Radiation pattern is constant regardless the frequency; Large sweet area
- No spectral change; elevation works everywhere.
- Multiple listener listening with a little performance loss.
- The interval of L-R cross-talk cancellation is about 0.3m; Alternative seating positions.

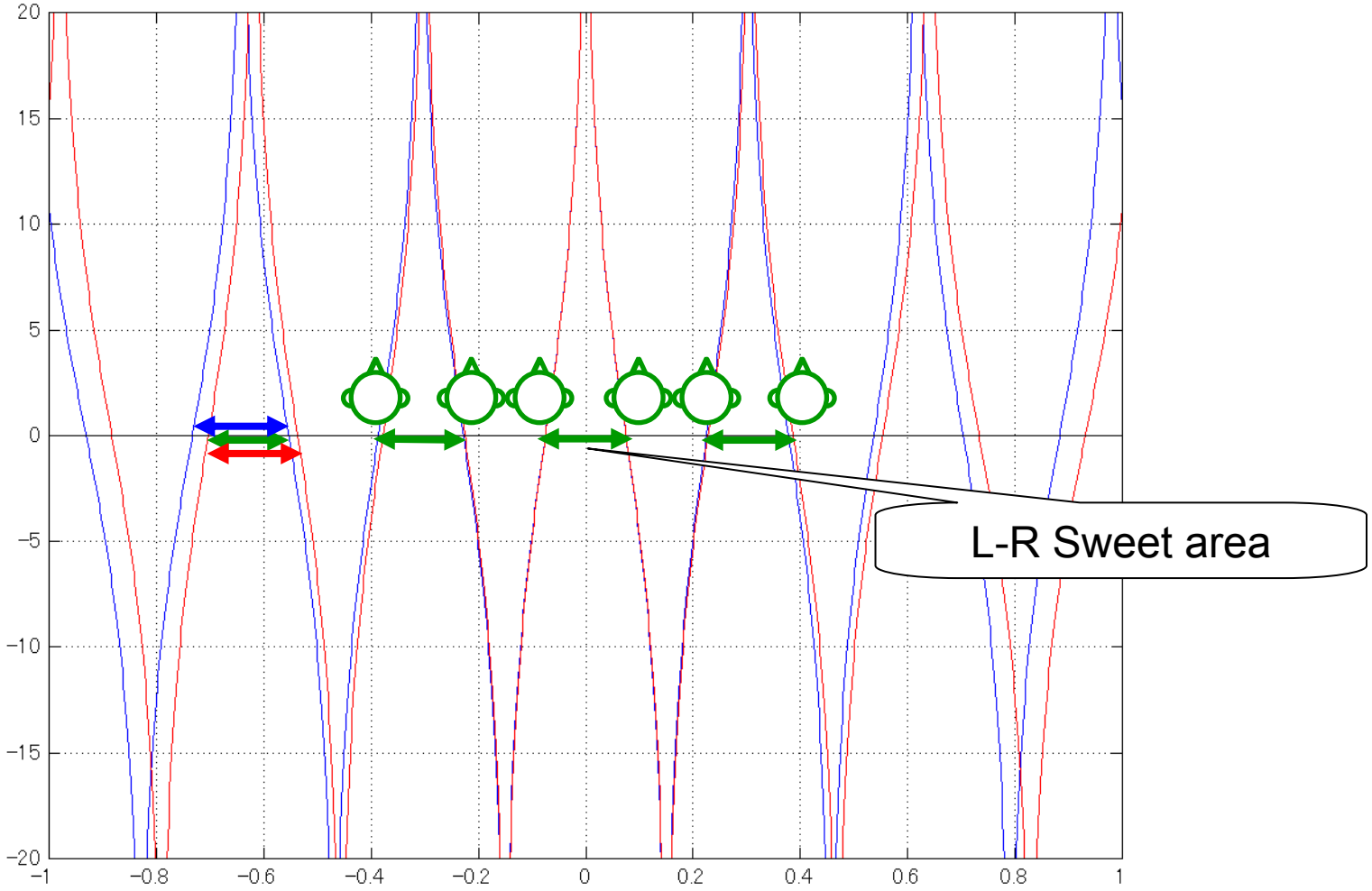
Reproduced sound level (lateral position)

OPSODIS™



L-R Crosstalk cancellation

(target signal – crosstalk signal)



Lateral displacement (m)

Left = Left - Right

Right = Right - Left

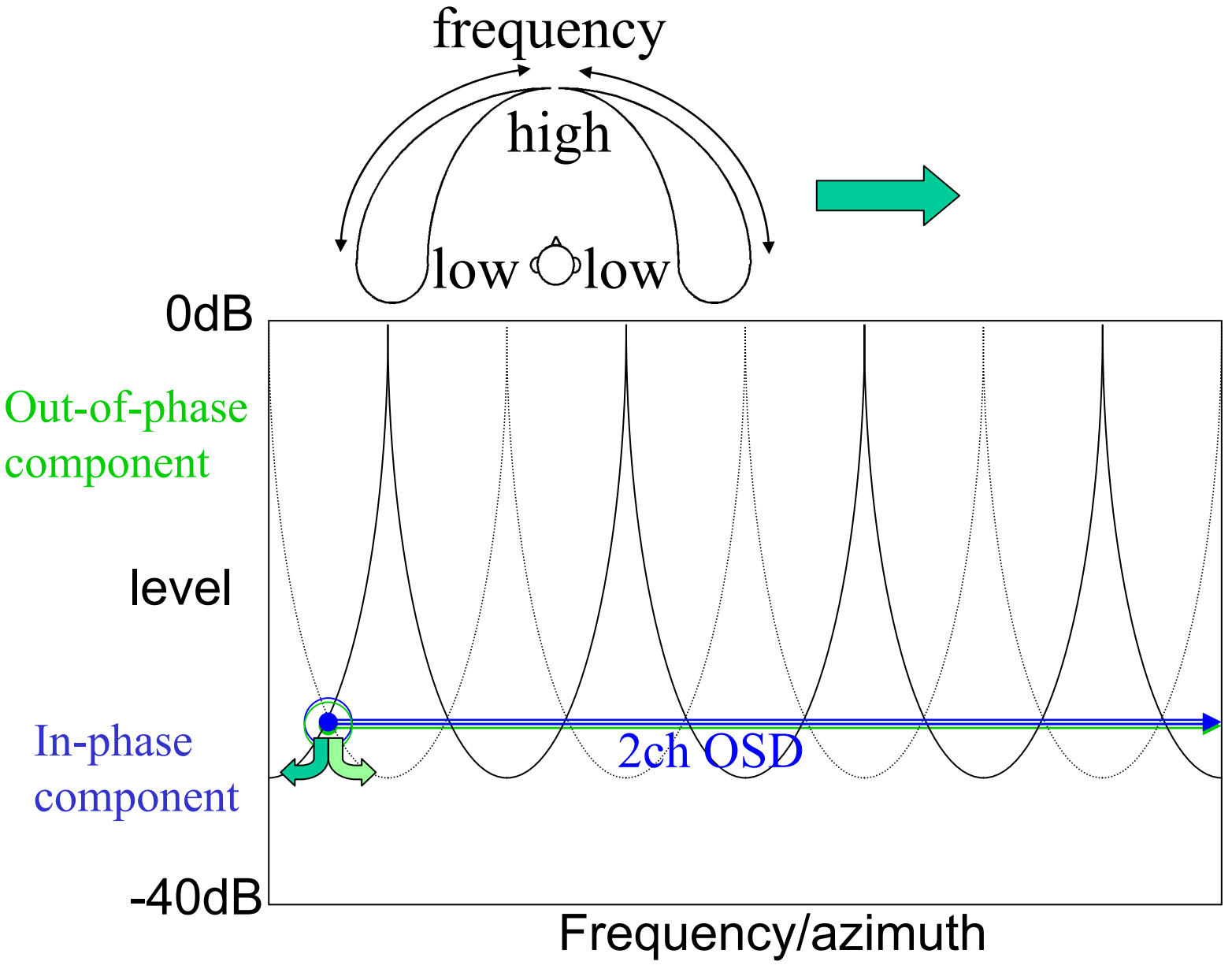
Aspects of the "OPSODIS"

- No dynamic range loss
  - Quality (Lossless)
  - Good S/N
  - No distortion
  - Reduced transducer fatigue
- Robust to errors in **plants** and **filters**
  - Robust to individual difference in HRTFs
  - Generic inverse filters
- Flat amplitude response of inverse **filters**
  - No colouration at any location
- Small sound radiation other than receiver directions
  - Robust to room reflections
- Consistent radiation over frequency
  - Multiple listener listening

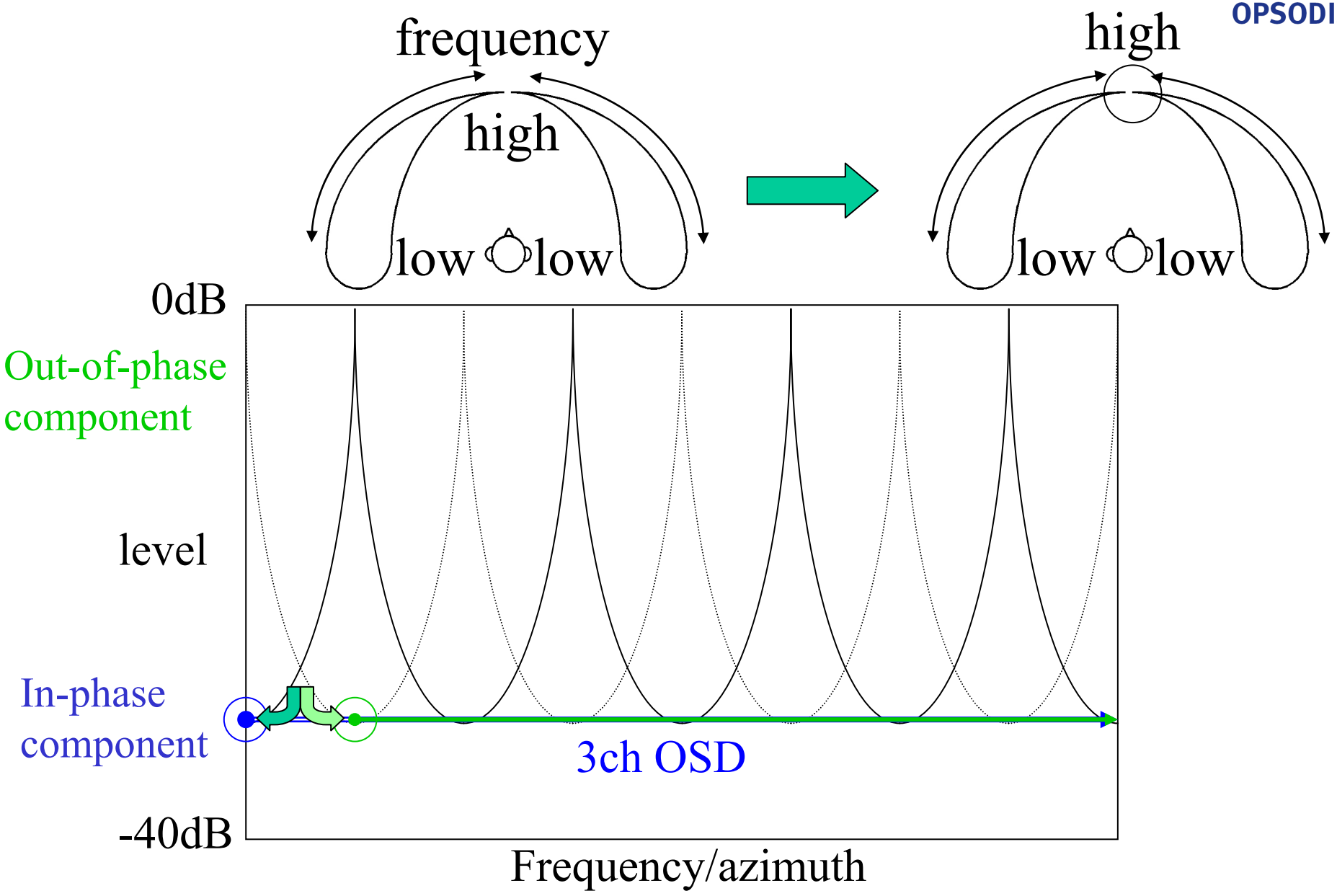
OPSODIS™

3 channel OPSODIS

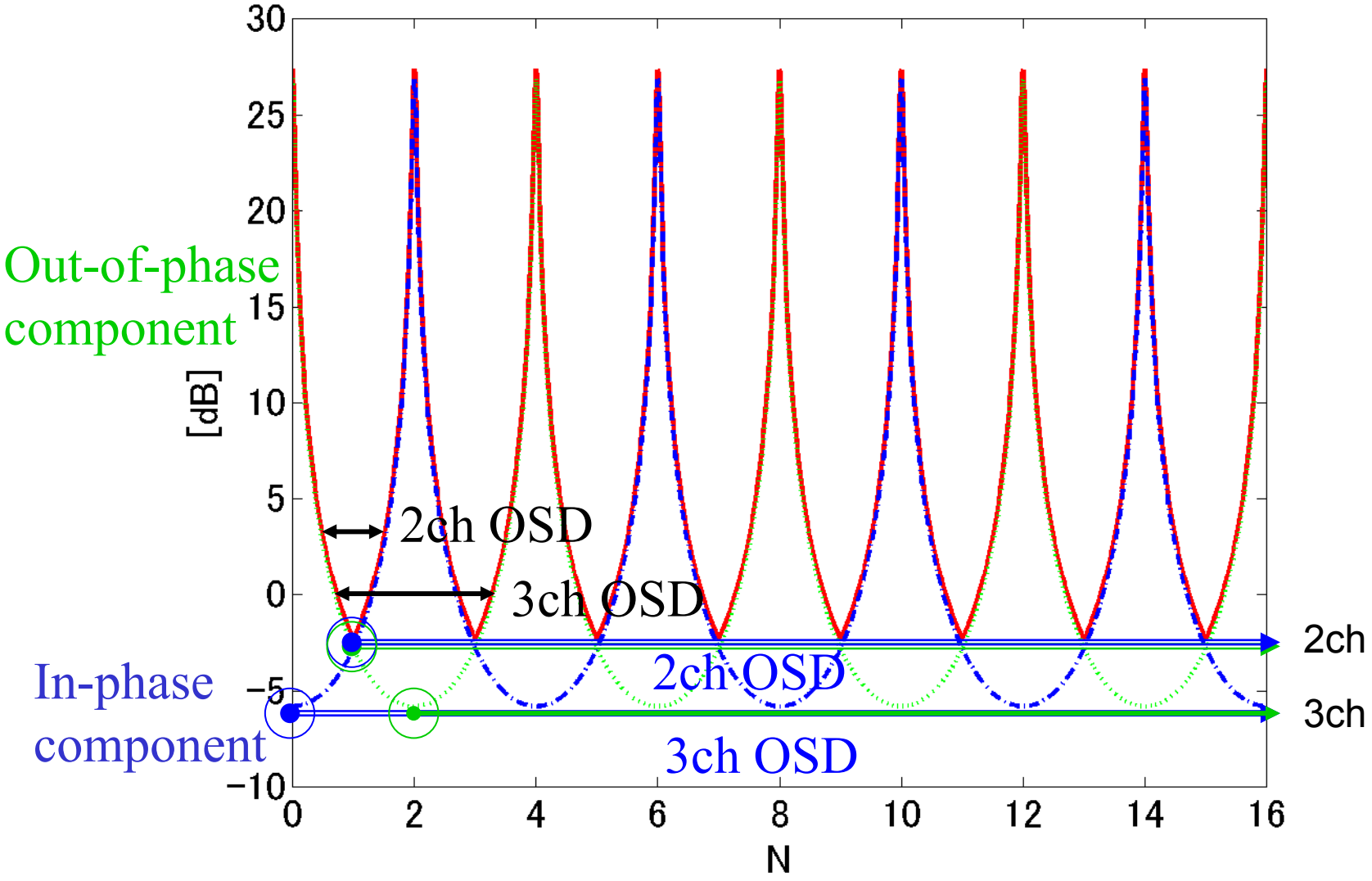
Inverse filter ~ 2 channel OSD



Inverse filter ~ 3 channel OSD

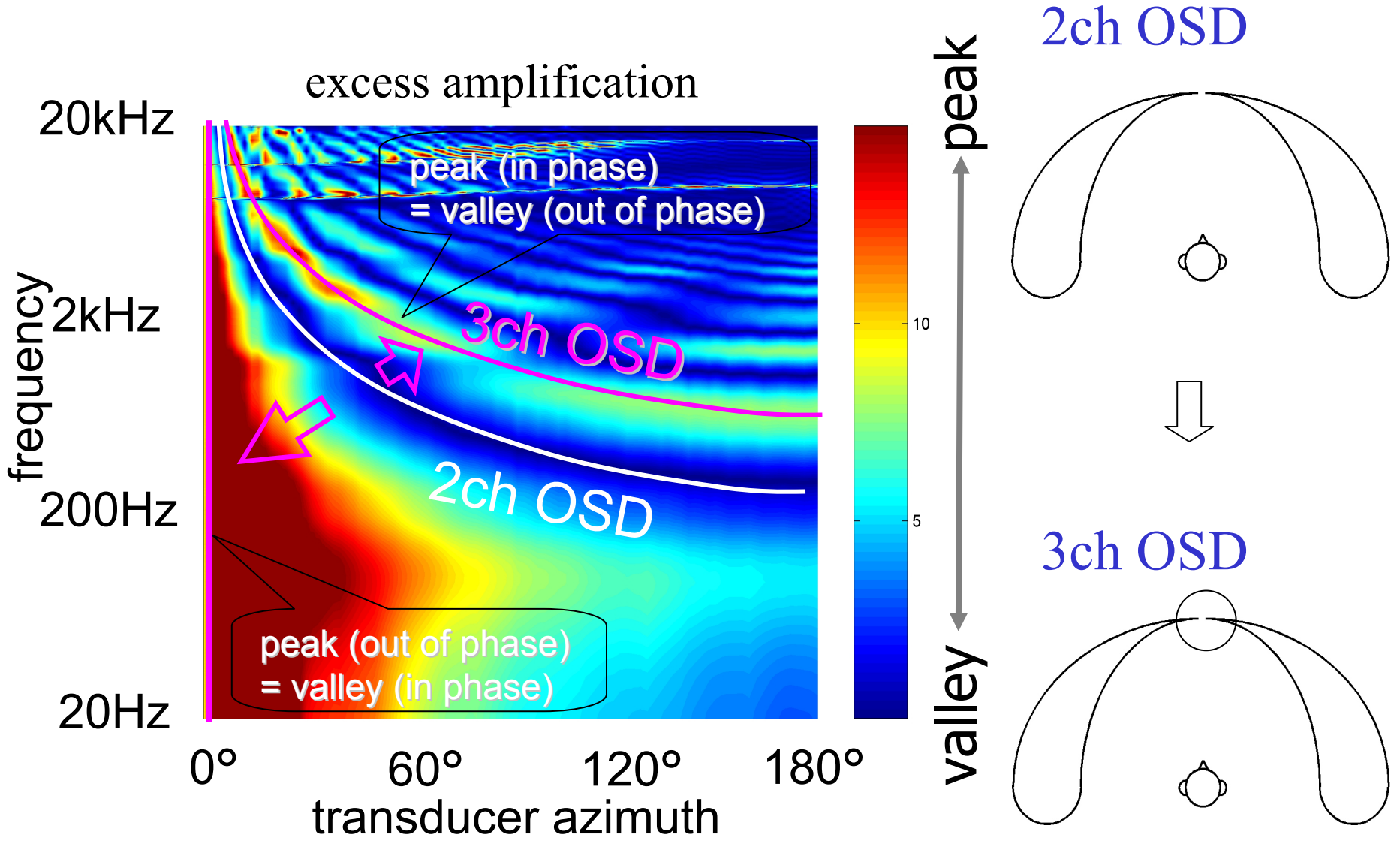


Extension to 3 channel

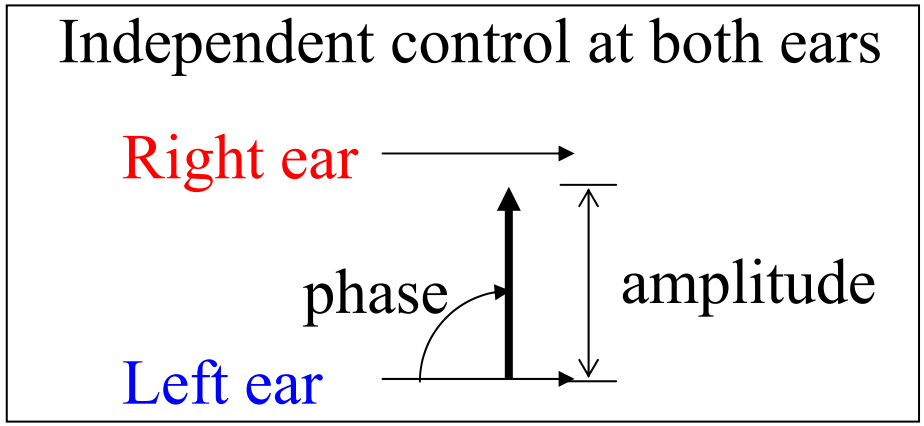


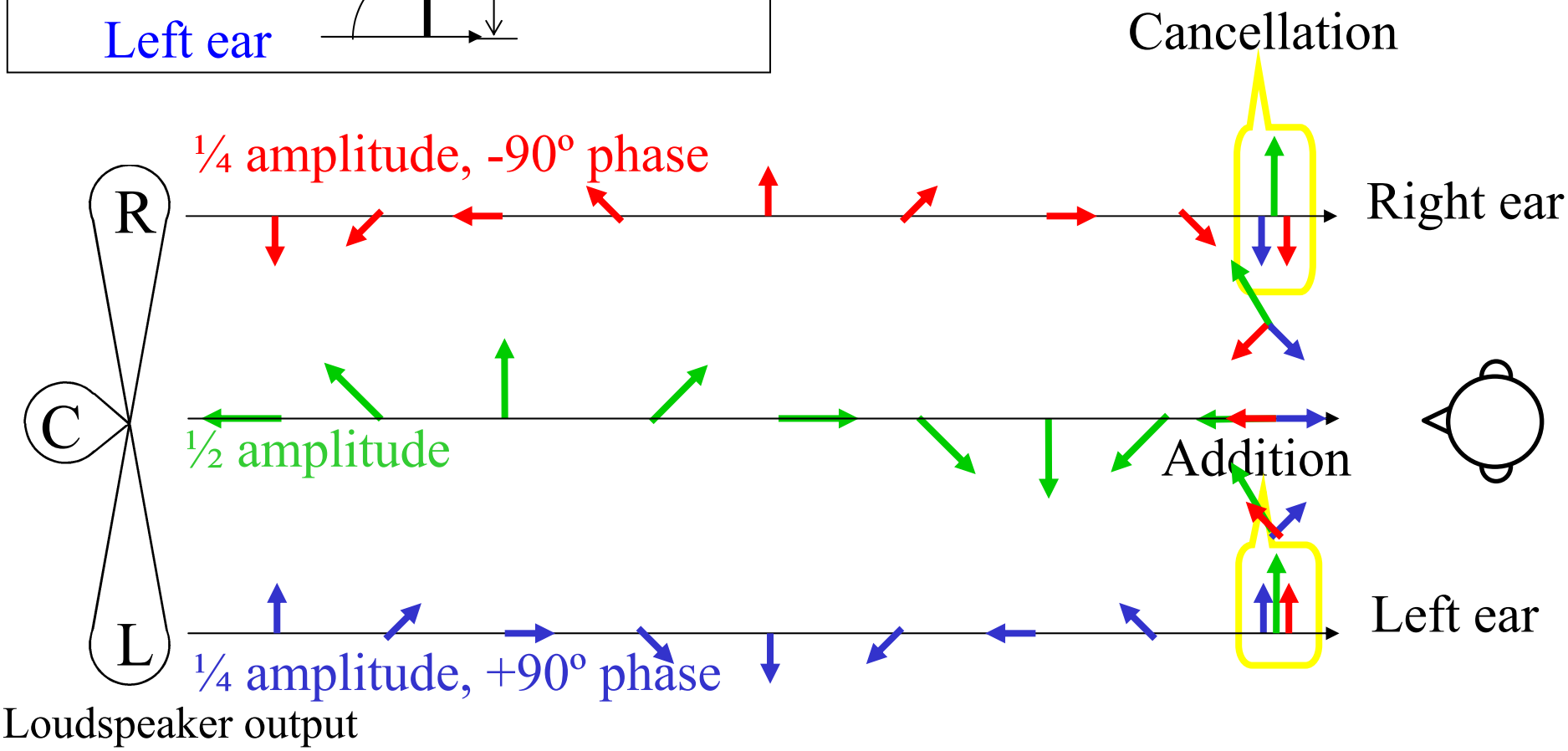
Singular values of the inverse filter matrix **H**

3 channel OSD

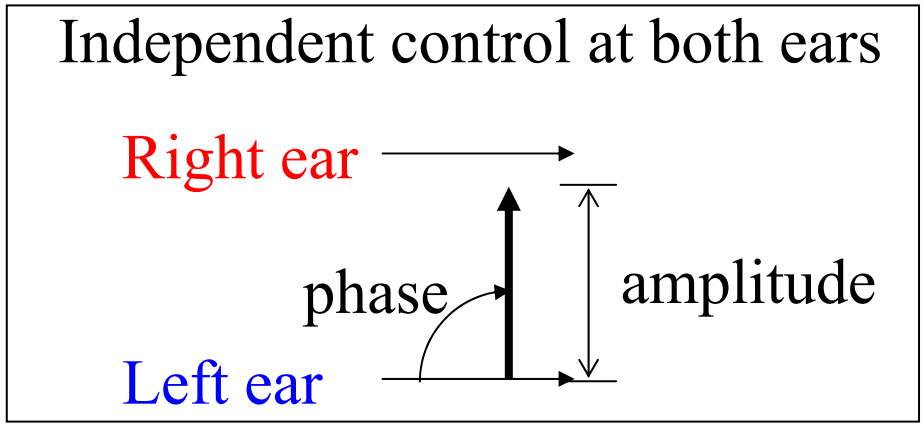


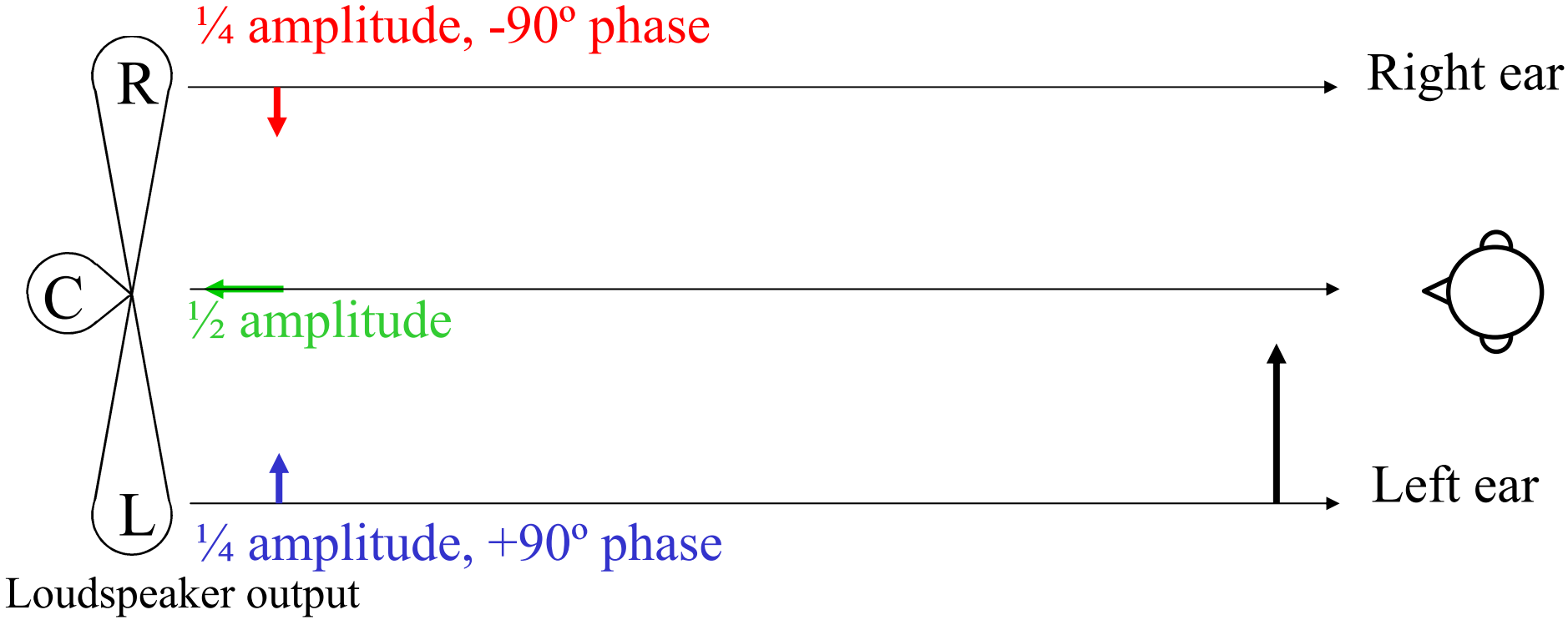
Crosstalk cancellation of 3ch OPSODIS



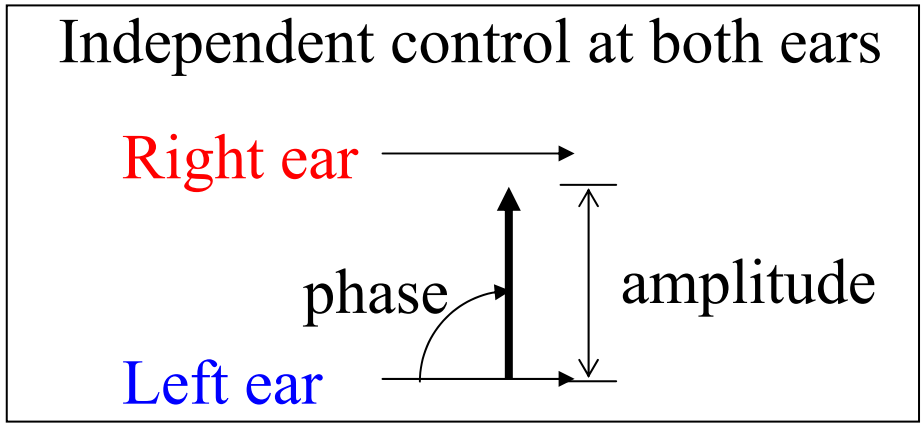


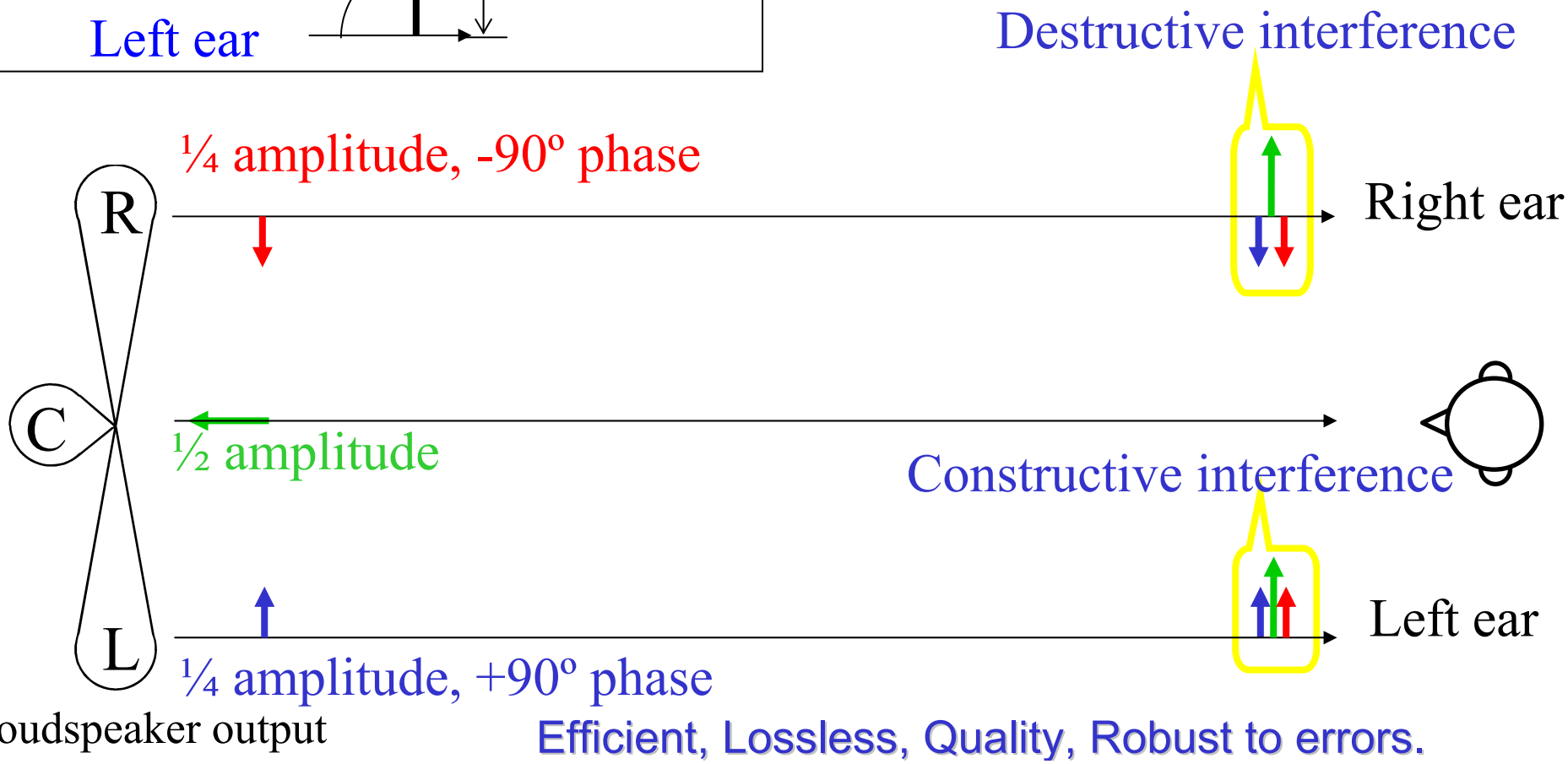
Crosstalk cancellation of 3ch OPSODIS





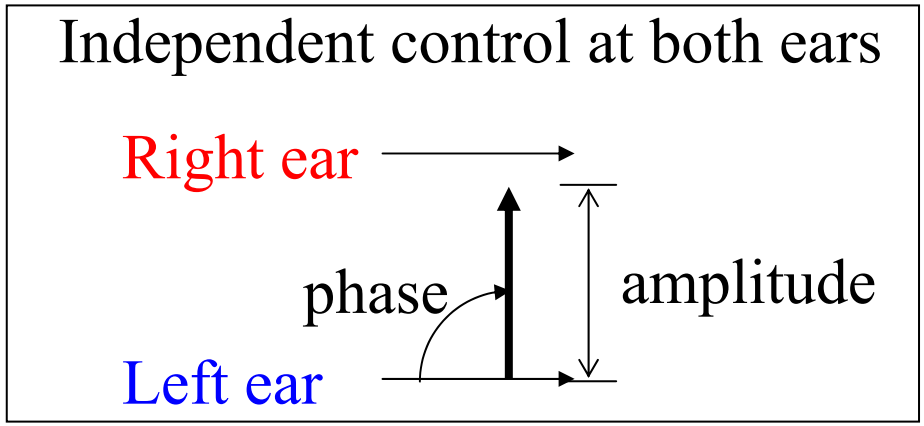
Crosstalk cancellation of 3ch OPSODIS

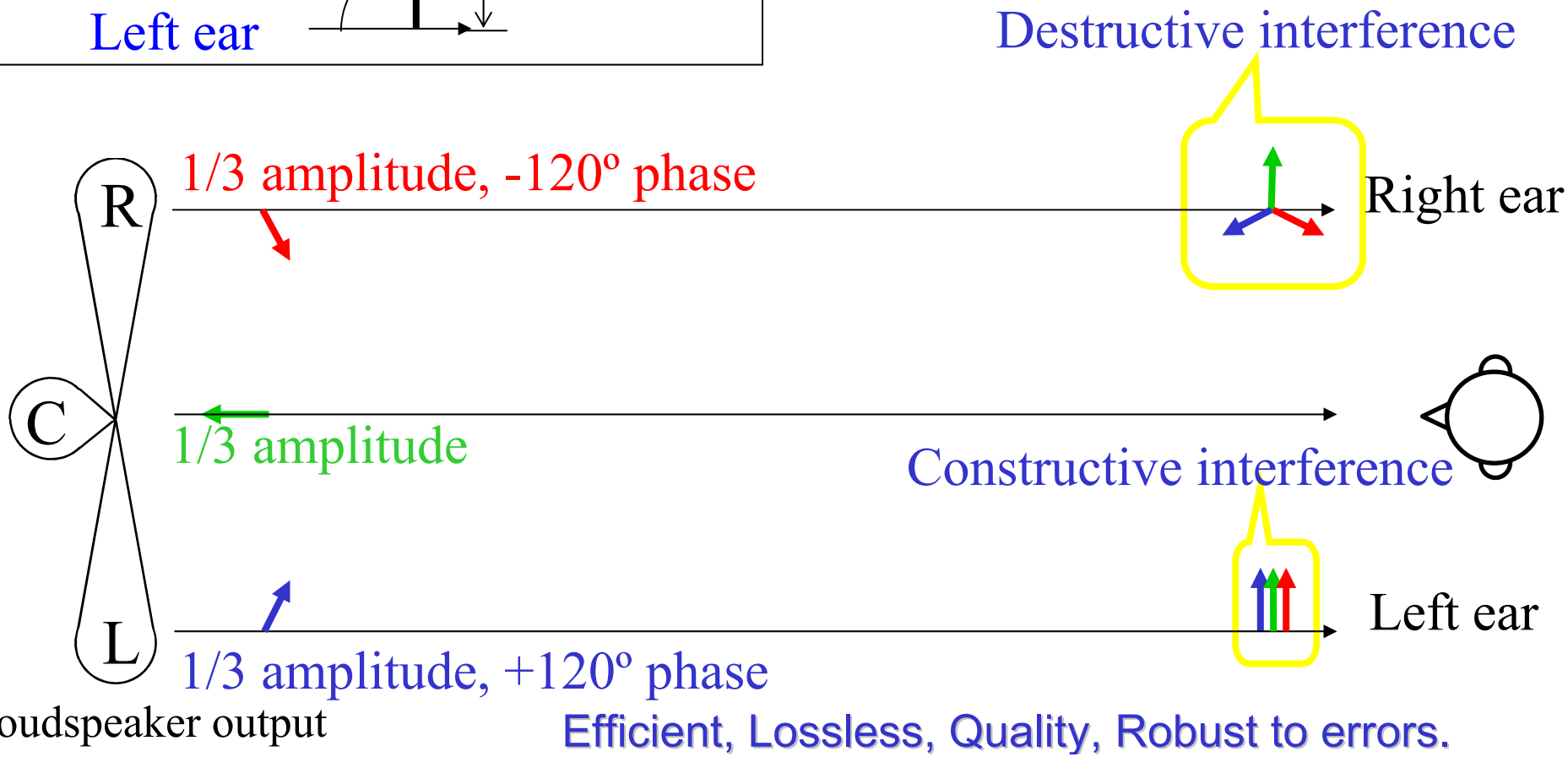




Efficient, Lossless, Quality, Robust to errors.

Crosstalk cancellation of 3ch OPSODIS





Efficient, Lossless, Quality, Robust to errors.

- OPSODIS
  - Enabling high definition 3D sound reproduction with 2 channel (or 3ch) loudspeakers
  - Natural sound quality without distortion
  - Natural sound at any location
  - Effective in any room
  - Compatible with surround reproduction