Publications of the Ray W. Herrick Laboratories School of Mechanical Engineering

10-2005

"Two-Microphone" Nearfield Acoustical Holography

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"TWO-MICROPHONE" NEARFIELD ACOUSTICAL HOLOGRAPHY

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INTRODUCTION

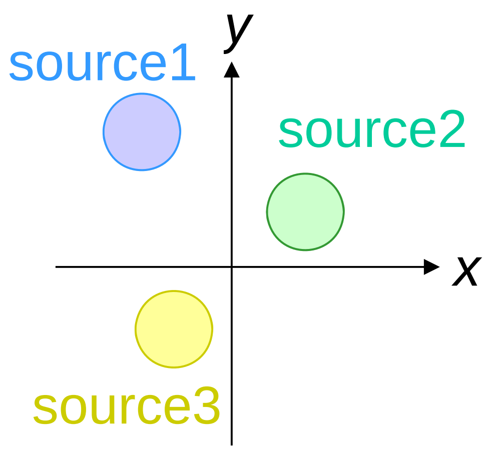
- **Conventional NAH**

  - Measurement time required for complete measurement enclosing the acoustic source may be formidable especially when the size of source is large and sound field radiated in various operating conditions is of interest.

- **Two-microphone Nearfield Acoustical Holography**

  - Only one complete measurement enclosing the acoustic source is required to estimate the sound field of acoustic source for various operating conditions.

PARTIAL FIELD DECOMPOSITION

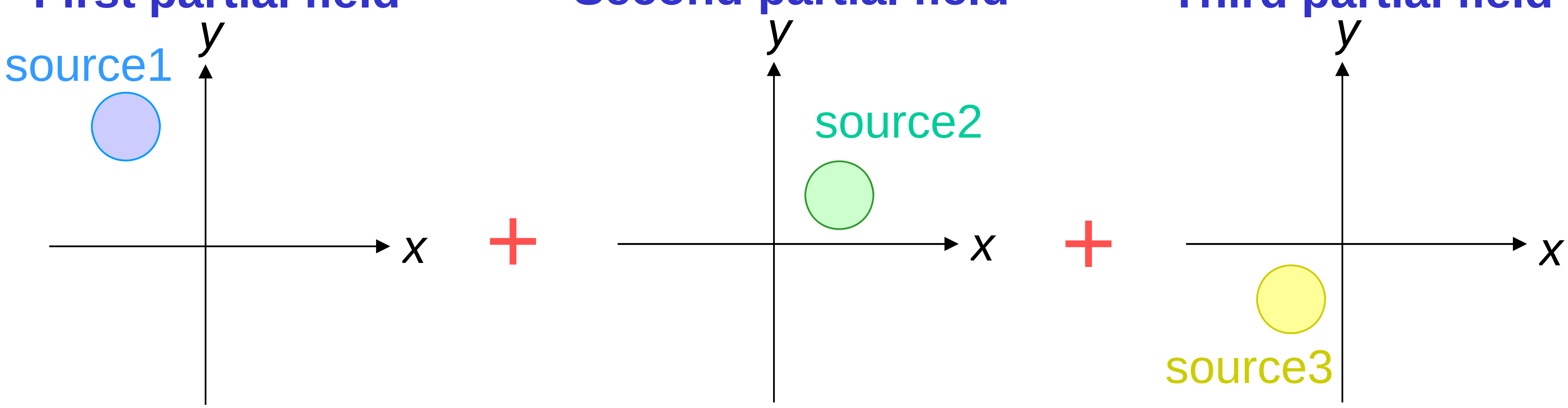


Total sound field

Consist of three incoherent sources

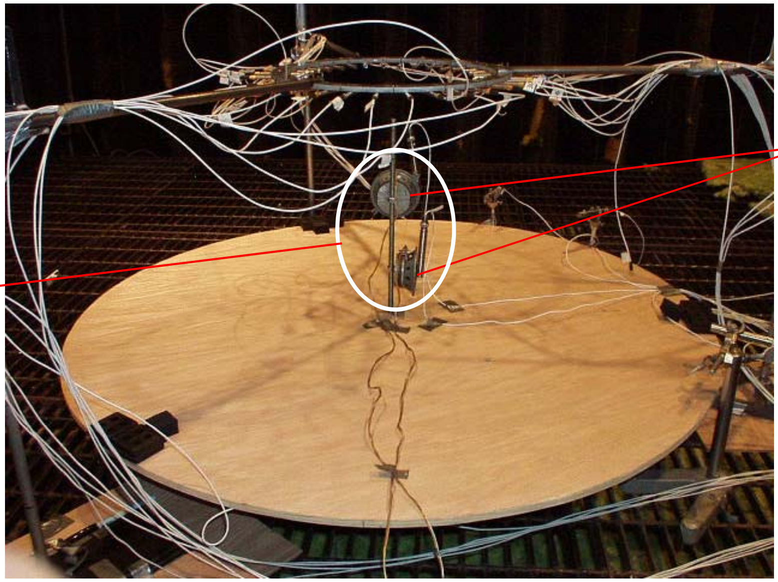
Can be decomposed to three partial fields

First partial field **Second partial field** **Third partial field**



OBJECTIVE

- Facilitate sound field measurement of the same composite acoustic source in various operating conditions.



- Reduce cost of acoustic measurement and allow more detailed investigation of acoustic sources in various operating conditions.

TWO-MICROPHONE HOLOGRAPHY

- **Key assumption**

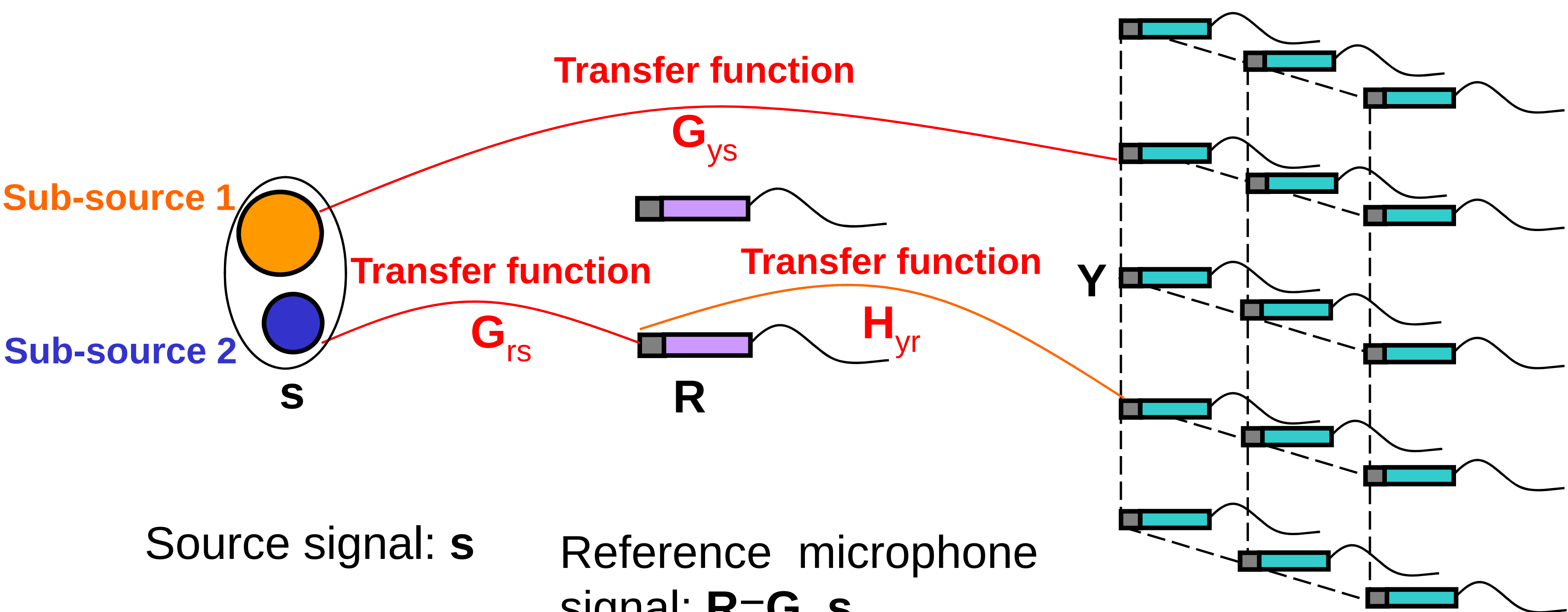
  Transfer function between reference and field microphones is assumed to be remain identical for various combinations of source level or operating conditions – true if directivity of sub-sources is independent of level.

- **Benefit**

  Partial fields for different operating conditions can then be estimated from a measurement of the reference spectral matrix alone.

TWO-MICROPHONE HOLOGRAPHY

Sound sources | Reference microphones | Field microphones



Source signal: **s**

Reference microphone signal: $\mathbf{R}=\mathbf{G}_{rs}\mathbf{s}$

Field microphone signal: $\mathbf{Y}=\mathbf{G}_{ys}\mathbf{s}$

TWO-MICROPHONE HOLOGRAPHY

$\mathbf{R}=\mathbf{G}_{rs}\mathbf{s},$

$\mathbf{Y}=\mathbf{G}_{ys}\mathbf{s},$

$\mathbf{S}_{ry}=E\{\mathbf{R}\mathbf{Y}^H\}=\mathbf{G}_{rs}\mathbf{S}_{ss}\mathbf{G}_{ys}^H$ or $\mathbf{S}_{ry}^H=\mathbf{G}_{ys}\mathbf{S}_{ss}\mathbf{G}_{rs}^H,$

$\mathbf{S}_{rr}=E\{\mathbf{R}\mathbf{R}^H\}=\mathbf{G}_{rs}\mathbf{S}_{ss}\mathbf{G}_{rs}^H,$

Transfer function between reference and field microphones:

$$\mathbf{H}_{yr}=\mathbf{Y}\mathbf{R}^{-1}=\mathbf{G}_{ys}\mathbf{G}_{rs}^{-1}=\mathbf{S}_{ry}^H\,\mathbf{S}_{rr}^{-1}$$

is independent of sub-source level combination (i.e., operating condition), so long as directivity of component sub-sources is independent of level.

TWO-MICROPHONE HOLOGRAPHY

$$\mathbf{S}_{\mathbf{yy}}=\mathbf{E}\{\mathbf{YY}^{\mathbf{H}}\}=\mathbf{G}_{\mathbf{ys}}\mathbf{S}_{\mathbf{ss}}\mathbf{G}_{\mathbf{ys}}^{\mathbf{H}}=\mathbf{H}_{\mathrm{yr}}\mathbf{G}_{\mathrm{rs}}\mathbf{S}_{\mathbf{ss}}\mathbf{G}_{\mathbf{ys}}^{\mathbf{H}}=\mathbf{H}_{\mathrm{yr}}\mathbf{S}_{\mathrm{ry}}$$

$$=\mathbf{S}_{\mathrm{ry}}^{\mathrm{H}}\,\mathbf{S}_{\mathrm{rr}}^{-1}\mathbf{S}_{\mathrm{ry}}=\mathbf{P}\mathbf{P}^{\mathbf{H}}$$

Hence the partial field matrix, **P**, is,

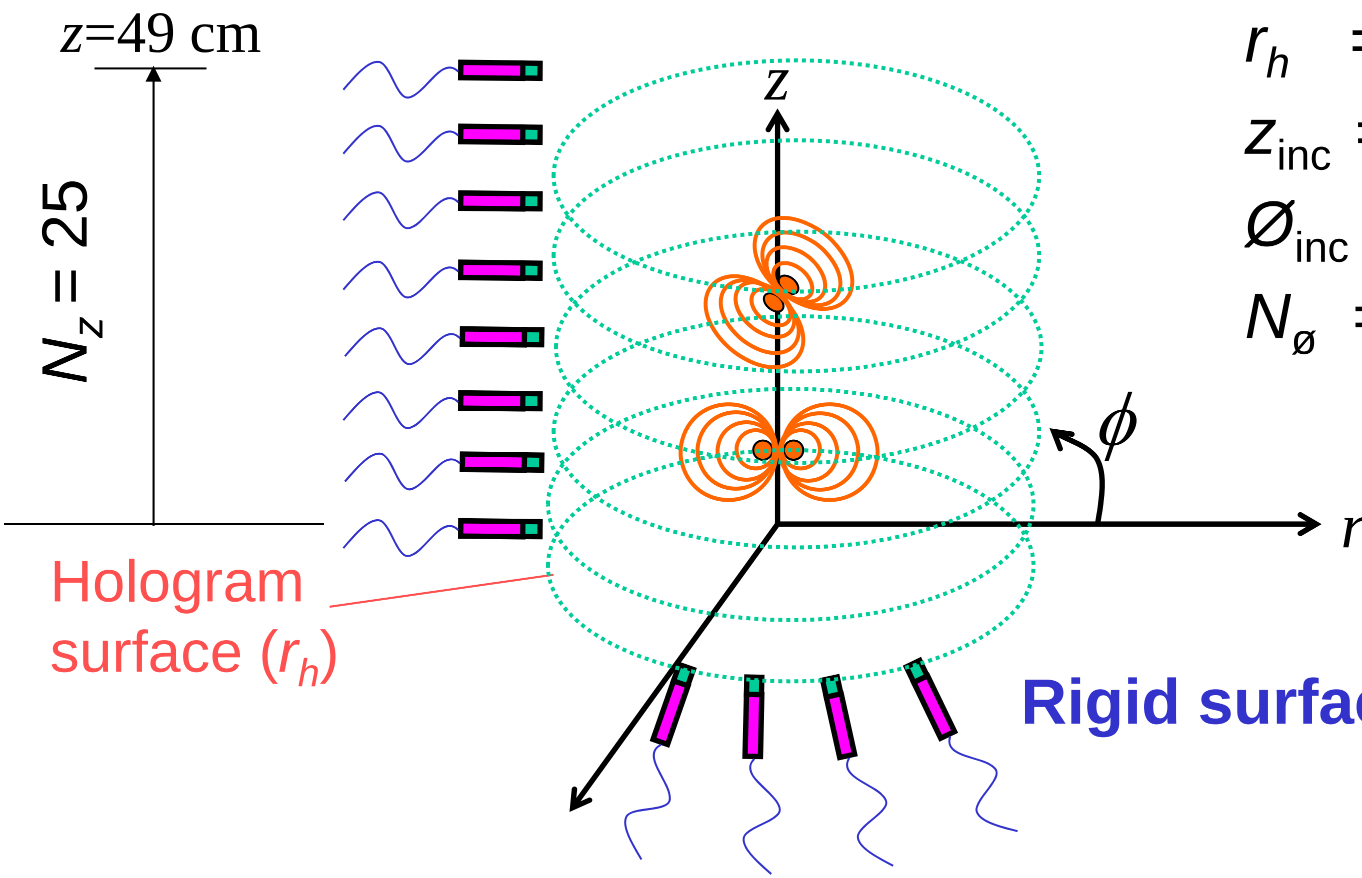
$$\mathbf{P}=\mathbf{S}_{\mathrm{ry}}^{\mathrm{H}}\,\mathbf{S}_{\mathrm{rr}}^{-1/2}=\mathbf{H}_{\mathrm{yr}}\,\mathbf{S}_{\mathrm{rr}}^{1/2}$$

Partial fields for the *n*th operating condition can then be estimated from a measurement of the *n*th reference spectral matrix $\mathbf{S}_{\mathrm{rr},n}$ alone when $\mathbf{H}_{\mathrm{yr},}$ is known from measurement in *m*th operating condition: i.e.,

$$\mathbf{P}_n=\mathbf{H}_{\mathrm{yr},n}\,\mathbf{S}_{\mathrm{rr},n}^{1/2}=\mathbf{H}_{\mathrm{yr}}\mathbf{S}_{\mathrm{rr},n}^{1/2}$$

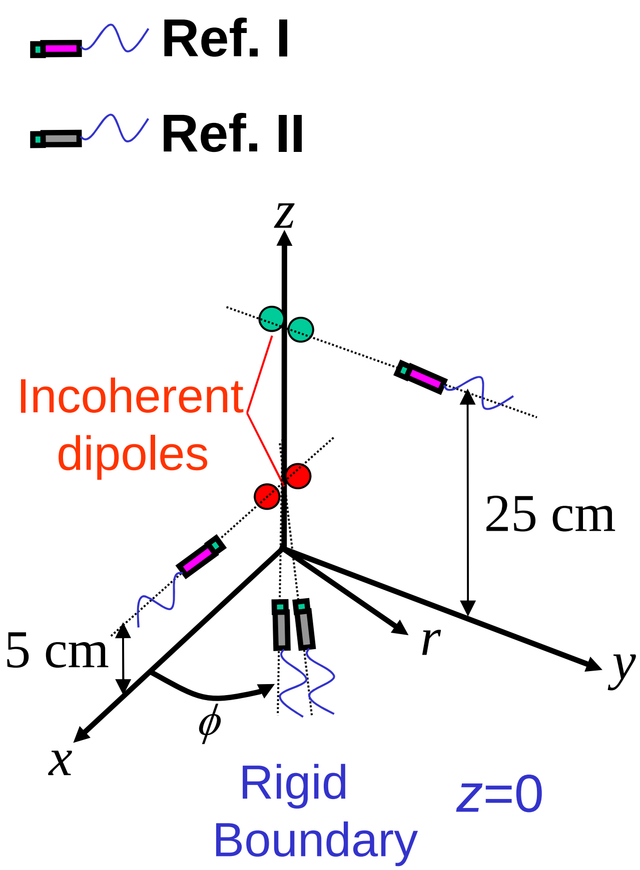
DIPOLE NUMERICAL SIMULATION

- Dipole axes in *ø*=0, *z*=5 cm and *ø*= 90º, *z*=25 cm



r_h = 14.15 cm
z_{inc} = 2 cm
$Ø_{inc}$ = 11.25º
$N_ø$ = 32

DIPOLE NUMERICAL SIMULATION

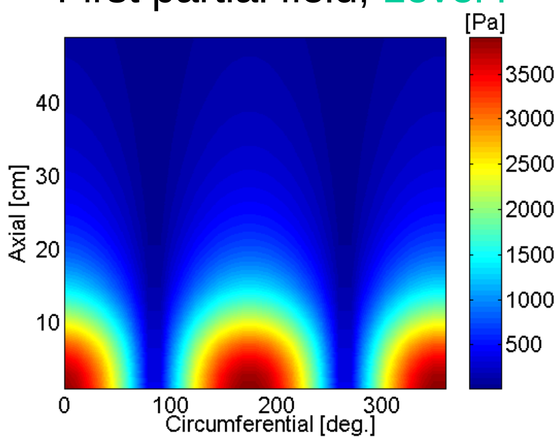


Cases		Source Amplitude		Ref. Mic. Position (r =10 cm)			
		A	B	$\varnothing_1$ (deg)	z_1 (cm)	$\varnothing_2$ (deg)	z_2 (cm)
Ref. I	Level I	1	1	0	5	90	25
	Level II	0.5	1.5				
Ref. II	Level I	1	1	40	5	50	5
	Level II	0.5	1.5				

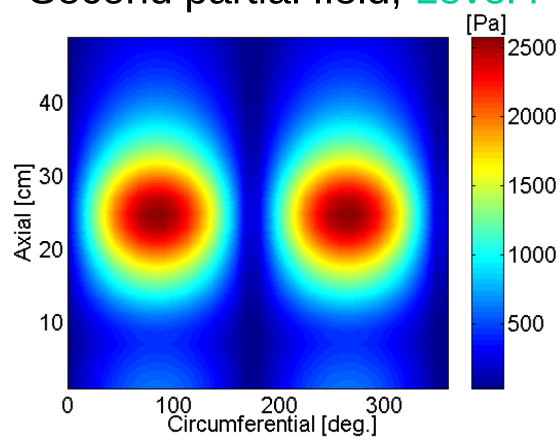
DIPOLE NUMERICAL SIMULATION

Sound fields from direct measurement (1000 Hz)

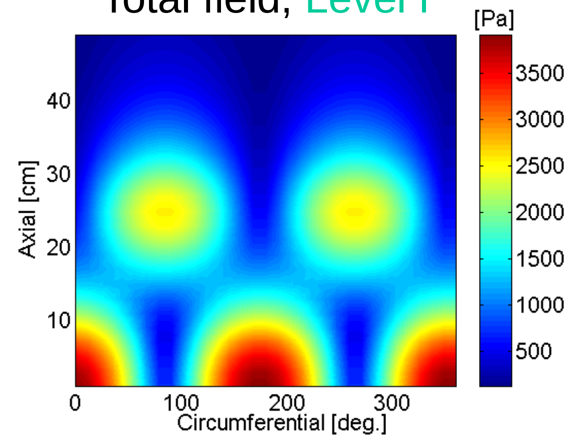
First partial field, Level I



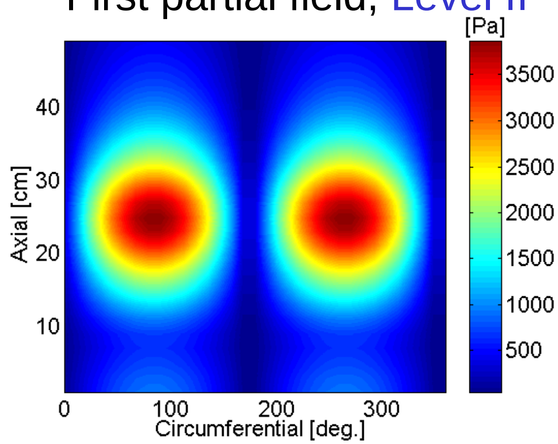
Second partial field, Level I



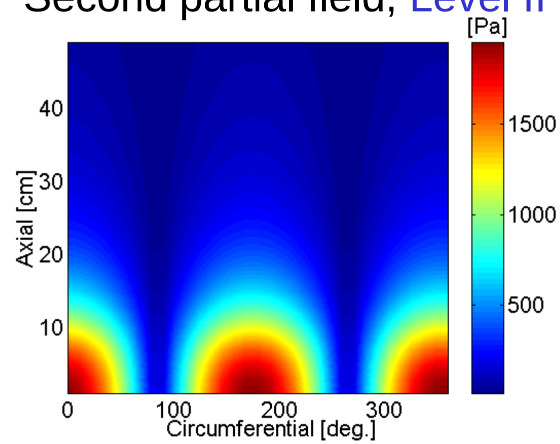
Total field, Level I



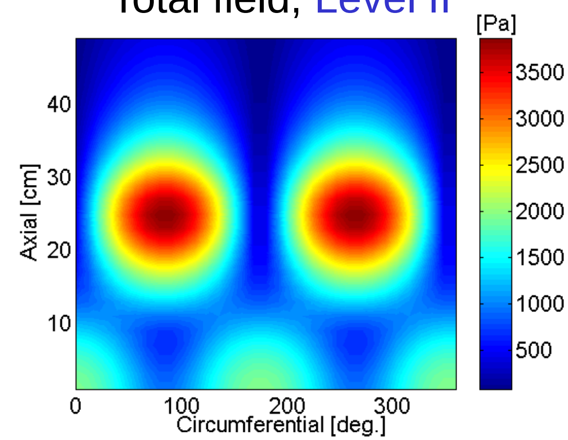
First partial field, Level II



Second partial field, Level II



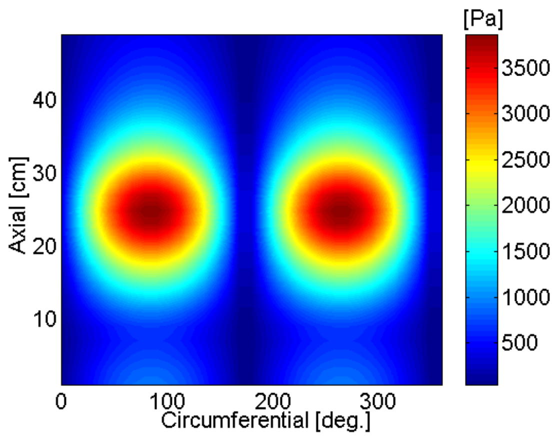
Total field, Level II



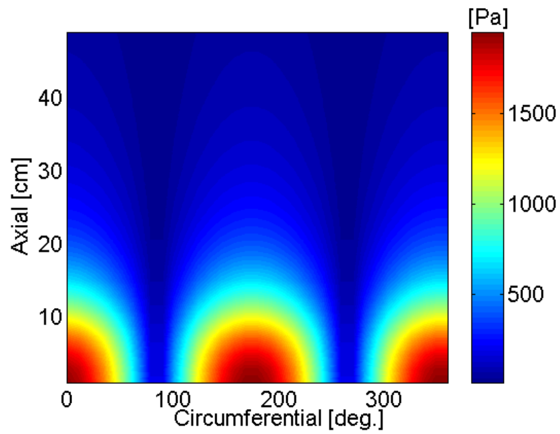
DIPOLE NUMERICAL SIMULATION

Estimated sound fields for source level II (based on source level I H_{yr})

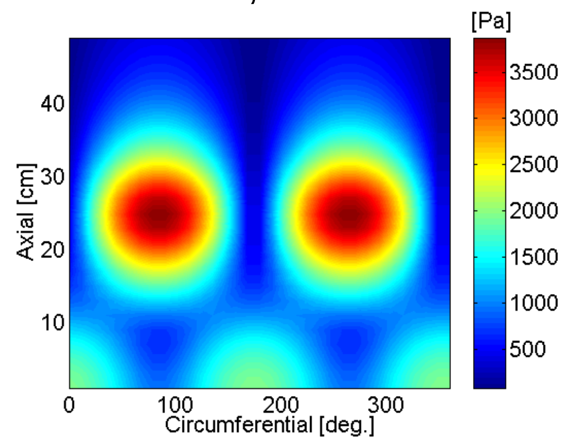
First partial field, Ref. I



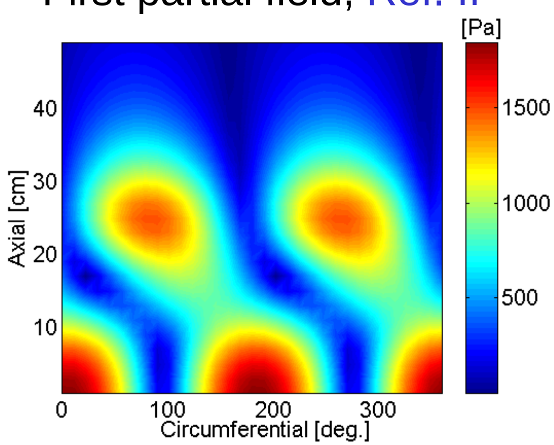
Second partial field, Ref. I



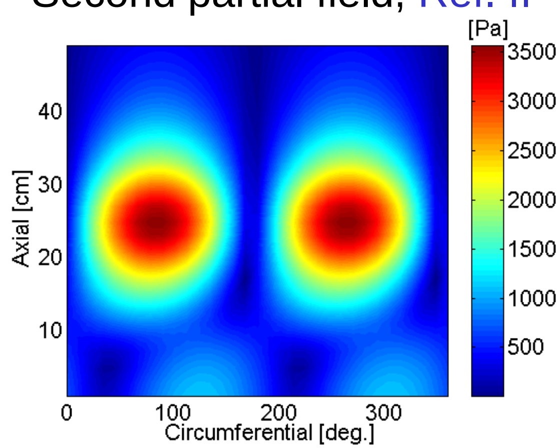
Total field, Ref. I



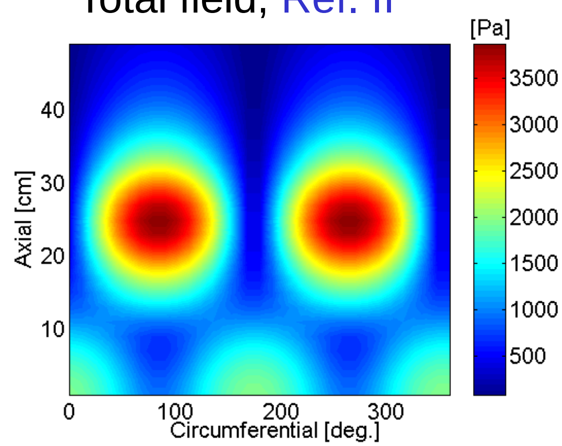
First partial field, Ref. II



Second partial field, Ref. II

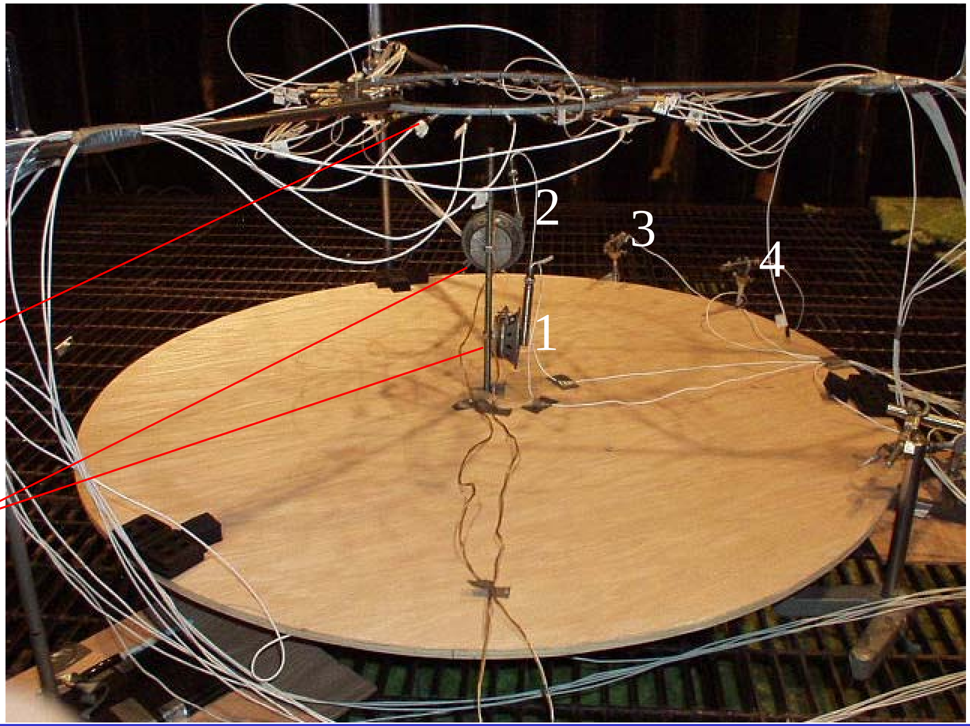


Total field, Ref. II



LOUDSPEAKER MEASUREMENT

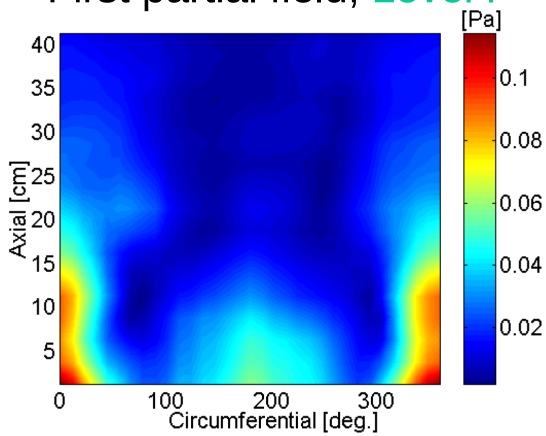
- Number of field microphones : $N_{\varnothing} = 32$ ($\varnothing_{inc} = 11.25^{o}$)
- Microphone spacing in *z* direction : $z_{inc} = 2.5$ cm
- Radius of hologram : $r_h = 13$ cm
- Total aperture size : 42.5 cm ($N_z = 17$)
- Total number of measurement : 544



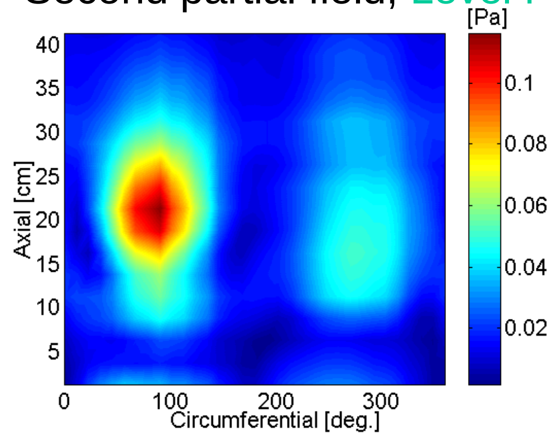
LOUDSPEAKER MEASUREMENT

Sound fields from direct measurement, reference 1 and 2 (2000 Hz)

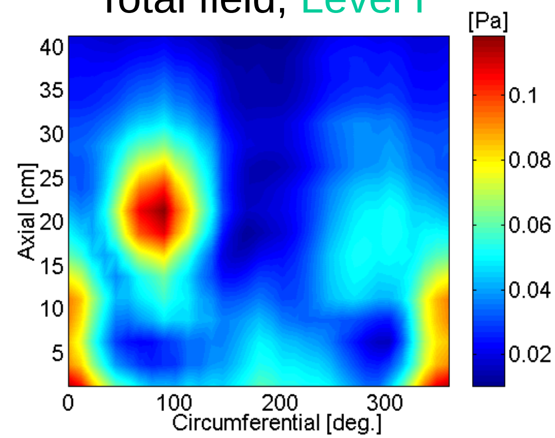
First partial field, Level I



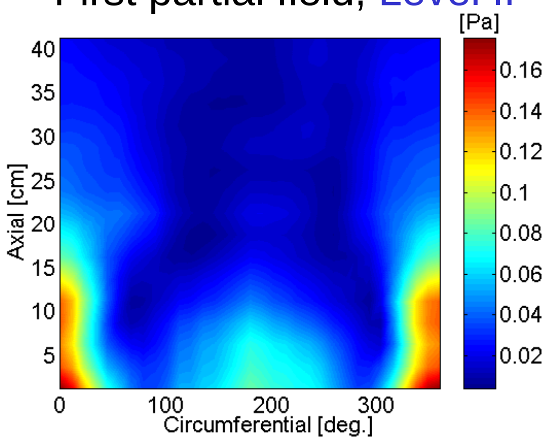
Second partial field, Level I



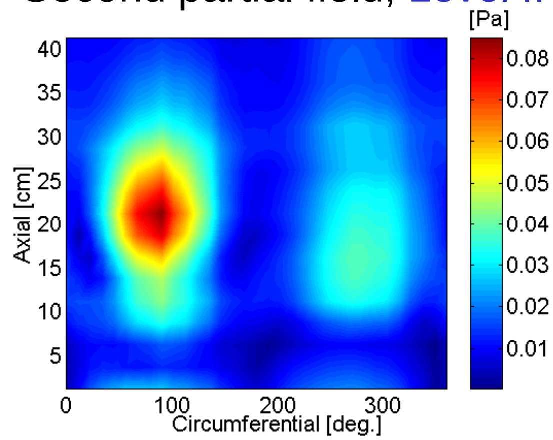
Total field, Level I



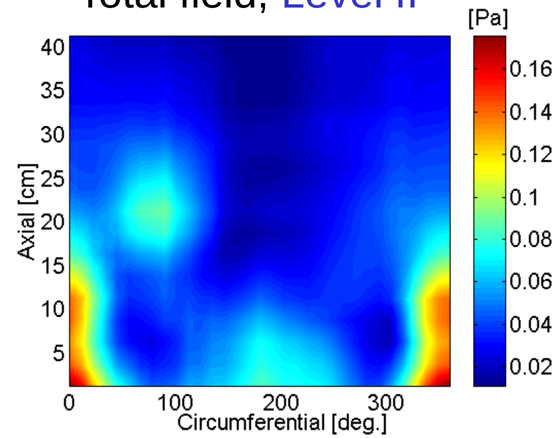
First partial field, Level II



Second partial field, Level II



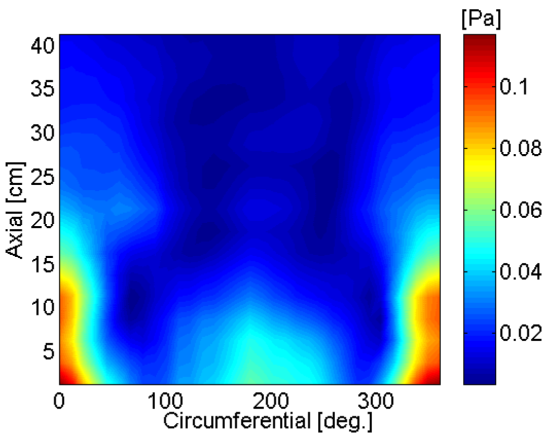
Total field, Level II



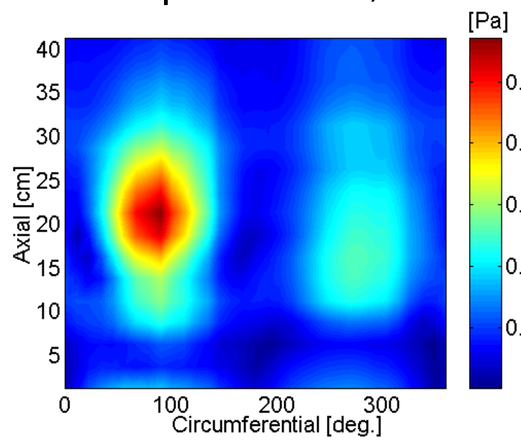
LOUDSPEAKER MEASUREMENT

Estimated sound fields from source level I (based on source level II H_{yr})

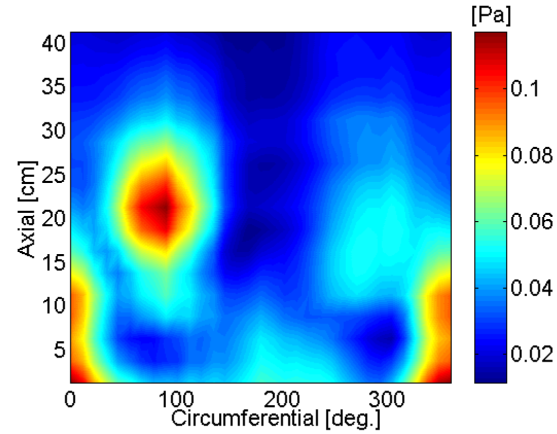
First partial field, ref. 1 & 2



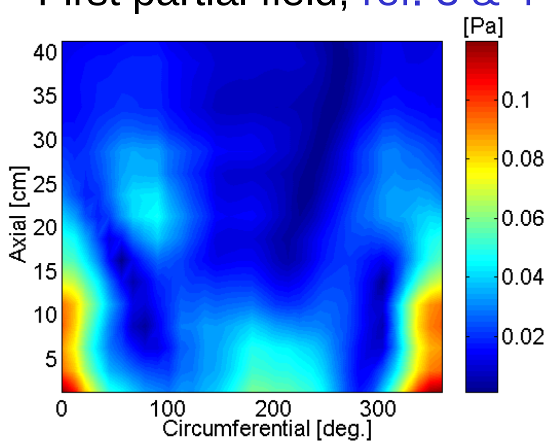
Second partial field, ref. 1 & 2



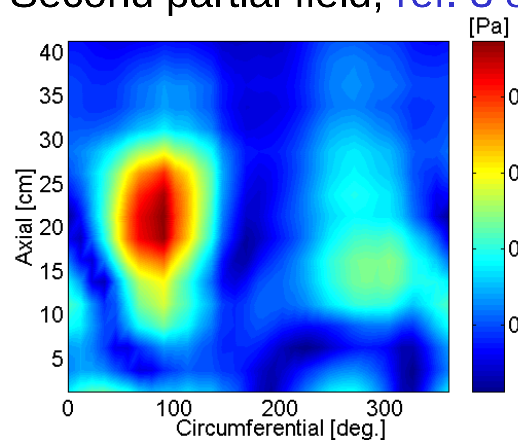
Total field, ref. 1 & 2



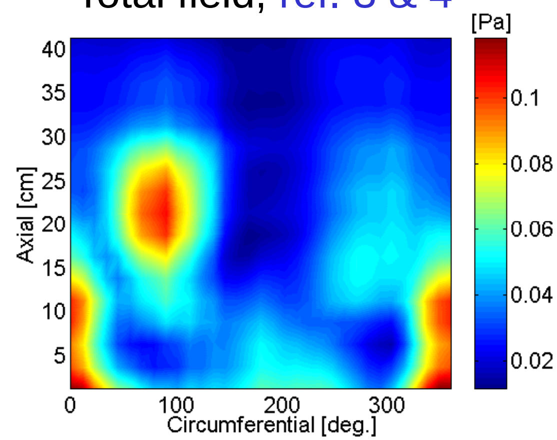
First partial field, ref. 3 & 4



Second partial field, ref. 3 & 4



Total field, ref. 3 & 4



CONCLUSIONS

- Once the transfer functions between the reference and field microphones were found, entire sound field for any operating condition could be reconstructed based on reference measurements alone.
- Accurate total fields were obtained even when the reference microphones were placed an unrealistically large distance from the sources and even when partial fields included contribution from both sources.
- This approach can facilitate more detailed investigation of acoustic sources in various operating conditions.
- Potential quality control application to check the total radiated sound fields of many “similar” devices based on reference measurements.