Sound power level calibration of reference sound source in NMIJ

Ryuzo Horiuchi and Keisuke Yamada

National Metrology Institute of Japan
National Institute of Advanced Industrial Science and Technology, Japan

Calibration service

Reference Sound Source (RSS)

Reference Sound Source
Type 4204 (Brüel & Kjær)

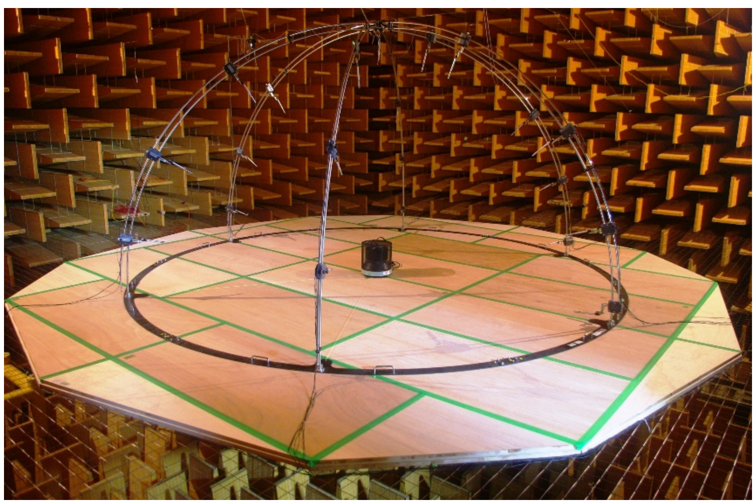
Power-supply voltage / frequency
100 V / 50 Hz
100 V / 60 Hz

Frequency range of calibration
100 Hz ~ 10 kHz
(1/3 octave band)

Calibration method

Absolute method in hemi-free field

Calibration of RSS of NMIJ



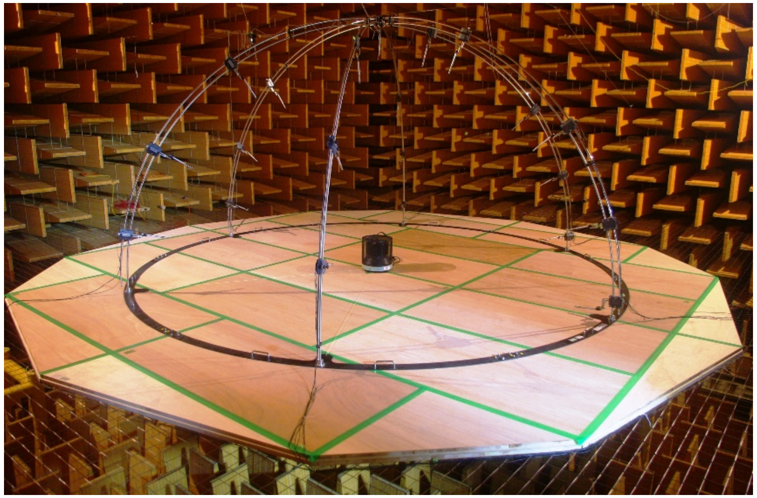
Calibration system for absolute method

Comparison method in diffuse sound field

Calibration of RSSs of clients

Calibration system for comparison method

Absolute method in hemi-free field



Calibration system for absolute method

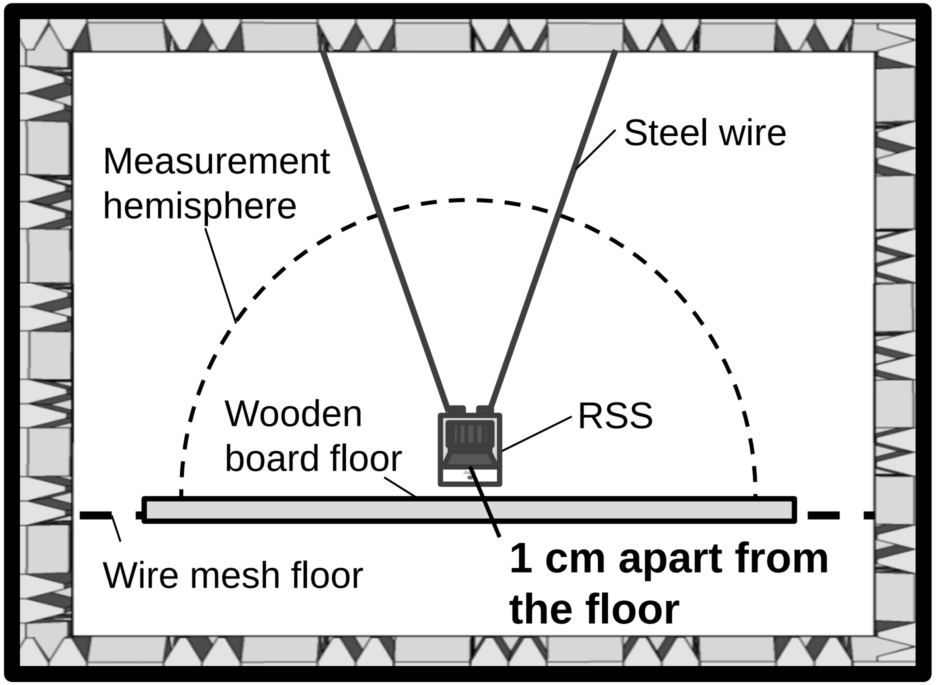
Absolute method in hemi-free field according to ISO 6926 and ISO 3745

Fixed microphone array (20 points)
Radius of measurement hemisphere: 2.0 m

Size of anechoic room :
W 9.5 m × D 8.0 m × H 7.2 m
(H 5.6 m from floor)
Surface density of floor :
15.0 kg/m^2

Hemi-anechoic environment is realized by laying down wooden boards on a wire meshed floor of the anechoic room

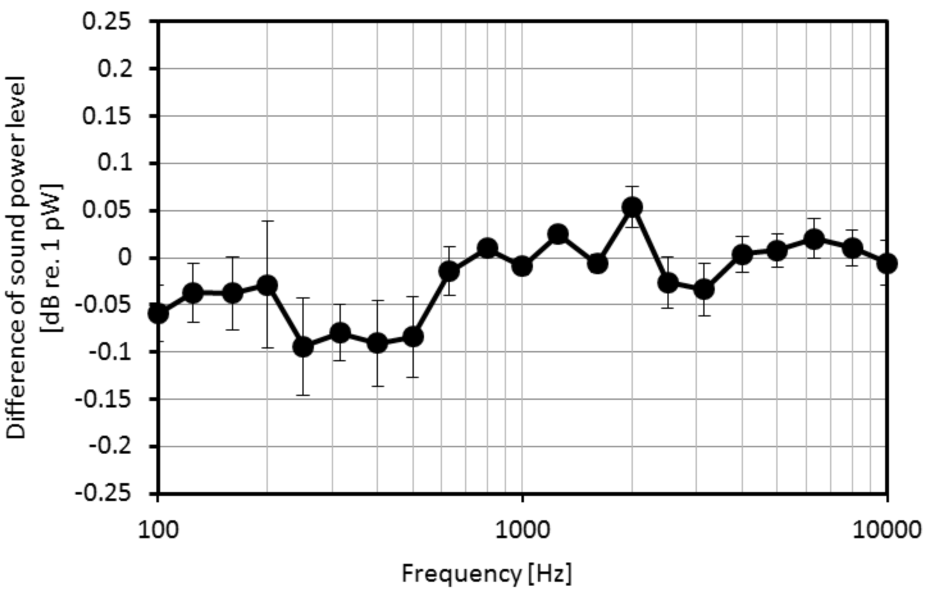
Influence of Floor Vibration caused by RSS Operation



Schematic view of the measurement

RSS was isolated from the floor by hanging the RSS from the ceiling of the anechoic room

Influence of Floor Vibration caused by RSS Operation



Difference of sound power level between with/without hanging. Error bars represent standard deviations.

Difference of sound power level

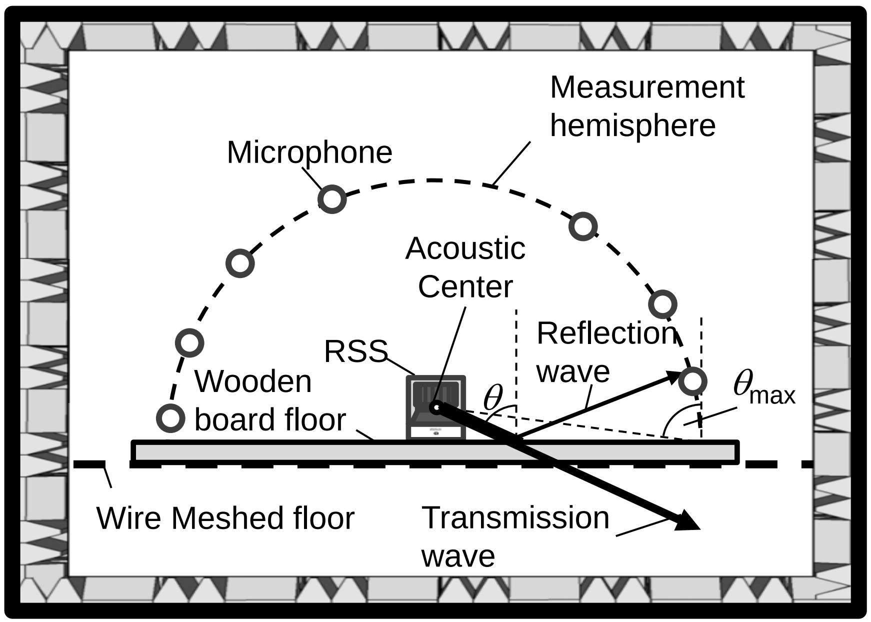
$$\Delta L_W = L_{W\_\mathrm{hang}} - L_{W\_\mathrm{on}}$$

L_{W_hang}:
Sound power level with hanging RSS

L_{W_on} :
Sound power level with RSS on the floor

- Differences are less than 0.1 dB
- Influence of floor vibration is not significant

Influence of Sound Power Transmission through Floor



Schematic view of sound incident in calibration system

- Transmission coefficient of sound power for sound incident angle θ [rad]

$$\tau_\theta(f,m) = \frac{1}{1+\left(\frac{fm}{Z}\cos\theta\right)^2}$$

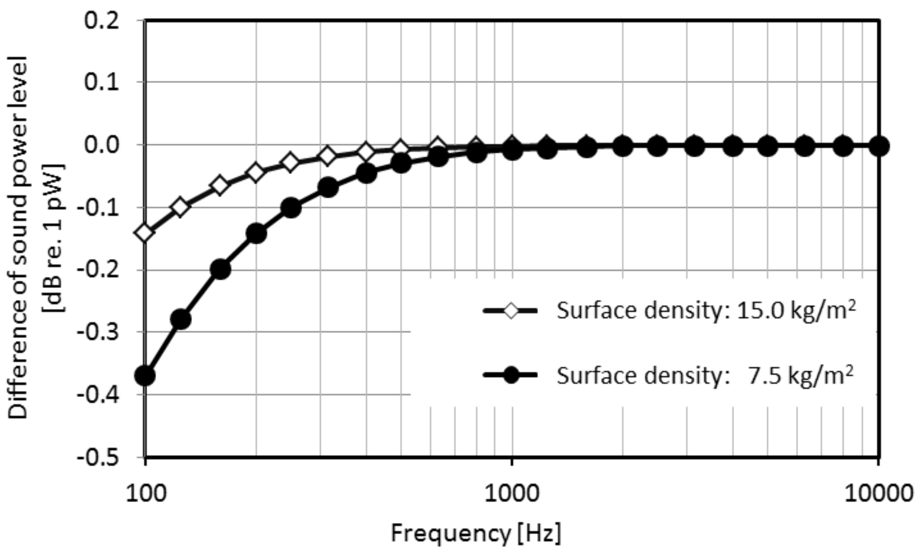
f [Hz]: Sound frequency
m [kg/m^2]: Surface density of floor
Z [kg/m^{2}s]: Acoustic impedance of air

- Transmitted sound power

$$W_{\mathrm{trans}} = \int_S \tau_\theta(f,m)\boldsymbol{I}\cdot\boldsymbol{n}dS$$
$$= \frac{W_0}{2}\int_0^{\theta_{\max}} \tau_\theta(f,m)\sin\theta\, d\theta$$

$\boldsymbol{I}$ [W/m^2]: Sound intensity on *dS*
$\boldsymbol{n}$: Normal vector of *dS*
W_0 [W]: Total sound power emitted from RSS

Influence of Sound Power Transmission through Floor



Theologically estimated decrease of sound power level.
Surface density of floor was set to 7.5 kg/m^2 ,15.0 kg/m^2

- Estimated decrease of sound power level with surface density m

$$\Delta L_W(m) = L_{W_{\mathrm{measure}}}(m) - L_{W_0}$$

L_{W_meausre} [dB]: Measurable sound power level

L_{W0} [dB]: Sound power level of RSS

With our calibration system (surface density: 15.0 kg/m^2),
the estimated decrease of sound power level is within 0.15 dB

Experimental evaluation of sound power transmission

Sound power level measurements with two surface densities (15.0 kg/m² and 7.5 kg/m²)

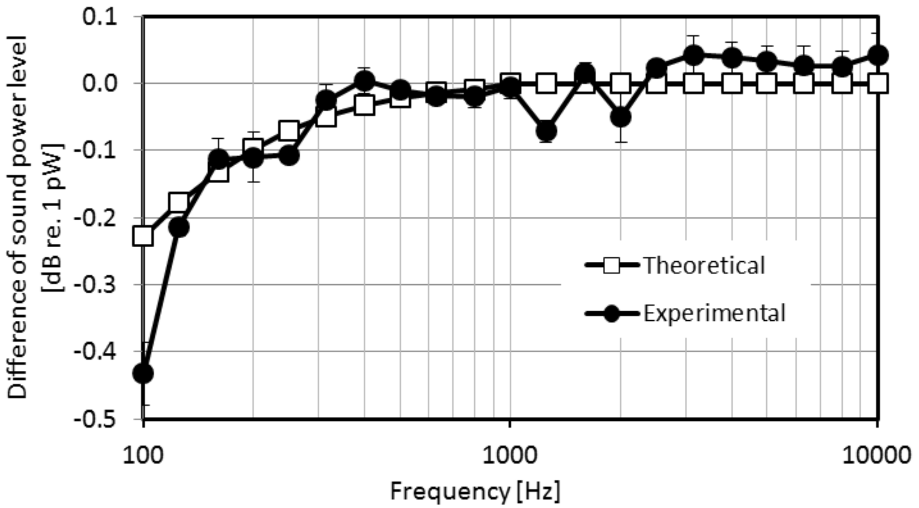
Experimental difference

$$L_{W\_\mathrm{measure}}|_{7.5} - L_{W\_\mathrm{measure}}|_{15.0}$$

⇕ Compare

Theoretical difference

$$\Delta L_w(7.5) - \Delta L_w(15.0)$$



Theoretical and experimental result. Error bars represent standard deviations of experimental difference.

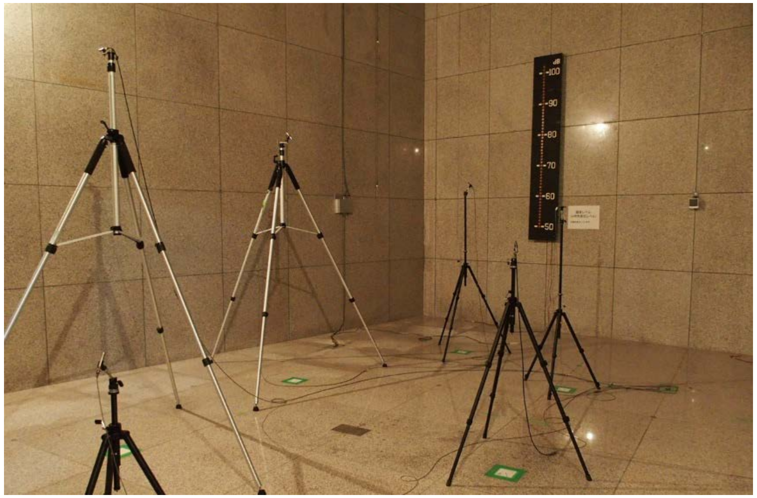
The experimental and the theoretical results showed good agreement

Correction for sound power transmission

Additional correction for sound power transmission

$$\underbrace{L_W = \overline{L_p} + 10\log_{10}\left(\frac{S_1}{S_0}\right) + C_1 + C_2 + C_3}_{\text{Sound power level calculation in ISO 3745}} \boxed{+ C_4}$$

Comparison method in diffuse field



Calibration system for comparison method

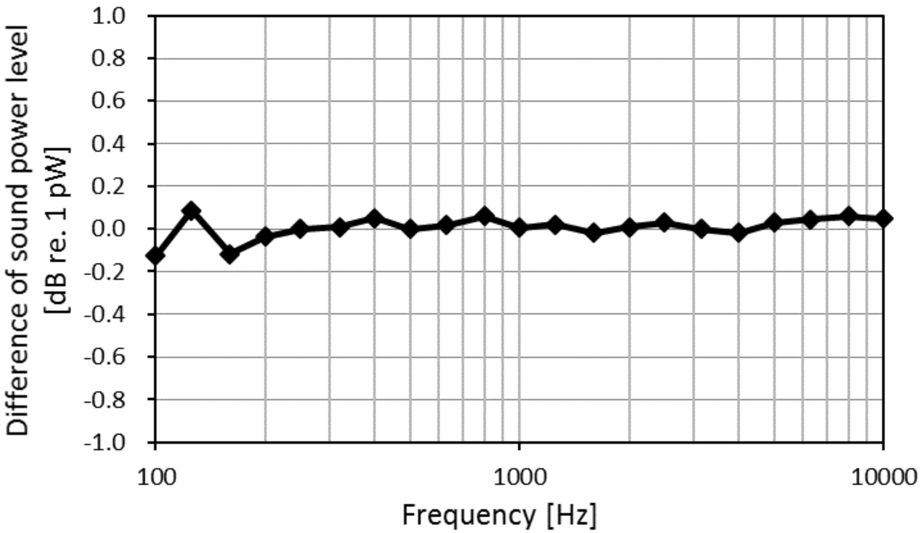
Comparison method in hemi-free field according to ISO 3745

Fixed microphone array (6 points)

Volume of reverberation room : 350 m^3
Reverberation time: 10 s (at 1000 Hz)

Comparison method using RSS calibrated by absolute method in hemi-free field as reference

Equivalency between absolute method and comparison method



Difference of sound power level measured by absolute method and comparison method is within 0.2 dB

Calibration uncertainty

Expanded uncertainty of RSS calibration with comparison method

Frequency	Uncertainty (k = 2)
100 Hz	0.8 dB
125 Hz	0.6 dB
160 Hz, 200 Hz	0.5 dB
250 Hz ≤ f ≤ 2.5 kHz	0.4 dB
3.15 kHz ≤ f ≤ 5.0 kHz	0.5 dB
6.3 kHz, 8.0 kHz	0.6 dB
10 kHz	0.9 dB

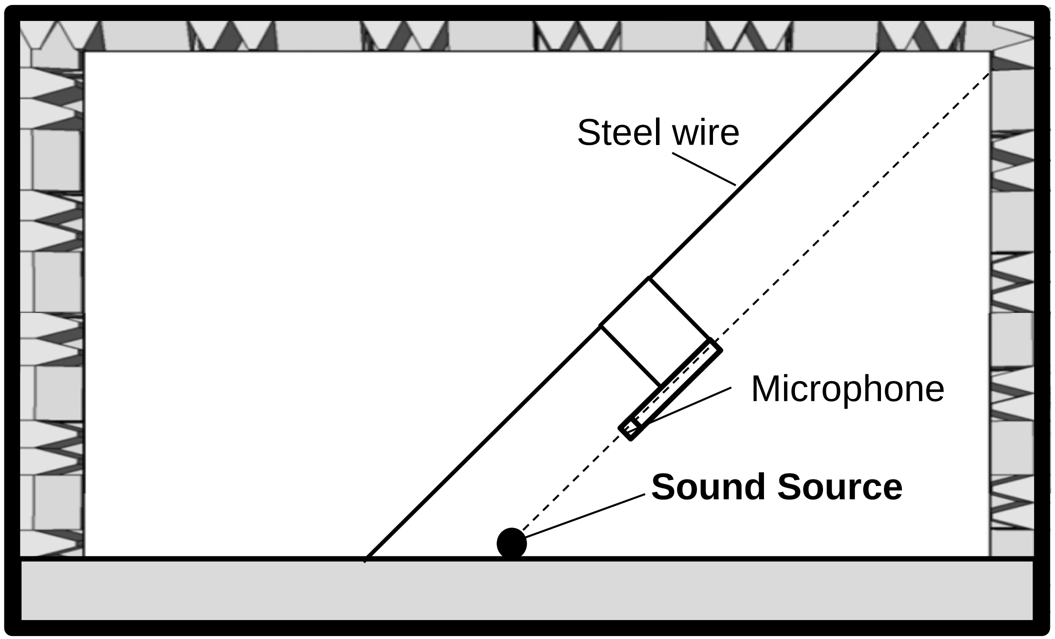
Request from RSS users

What kind of sound source is suitable for the room evaluation based on ISO 3745?

ISO 3745:
Precise method to determine the sound power level in an anechoic or hemi-anechoic room

Annex A of ISO 3745:
Procedure to qualify the performances of anechoic and hemi-anechoic room by estimating the deviation of the sound pressure level from the inverse-square law.

Measurement of inverse square law



Schematic view of measurement of inverse square law

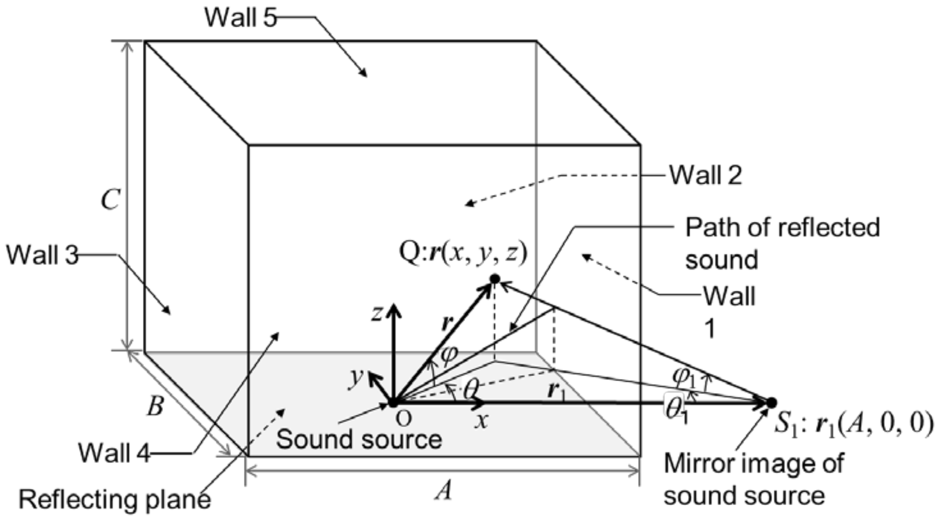
Sound pressure levels were measured along straight paths from the sound source to the room walls.

ISO 3745 requires almost omnidirectional sound source for the measurement

Commercially available loudspeakers usually do not satisfy the requirement

Calculation of effect of directivity

How does the directivity of sound sources affect on the measurement of inverse square law?



Schematic of a hemi-anechoic room including the coordinates of the sound source, the mirror image of the sound source.

$$p(\boldsymbol{r}) = \sqrt{p_{\mathrm{d}}(\boldsymbol{r})^2 + \sum_{i=1}^{5} p_{\mathrm{r}i}(\boldsymbol{r})^2}$$

$$= \sqrt{\left(w(\varphi,\theta)\cdot\frac{p_0}{|\boldsymbol{r}|}\right)^2 + \sum_{i=1}^{5}\left(w(\varphi_i,\theta_i)\cdot\frac{p_0\sqrt{1-\alpha}}{|\boldsymbol{r}-\boldsymbol{r}_i|}\right)^2}$$

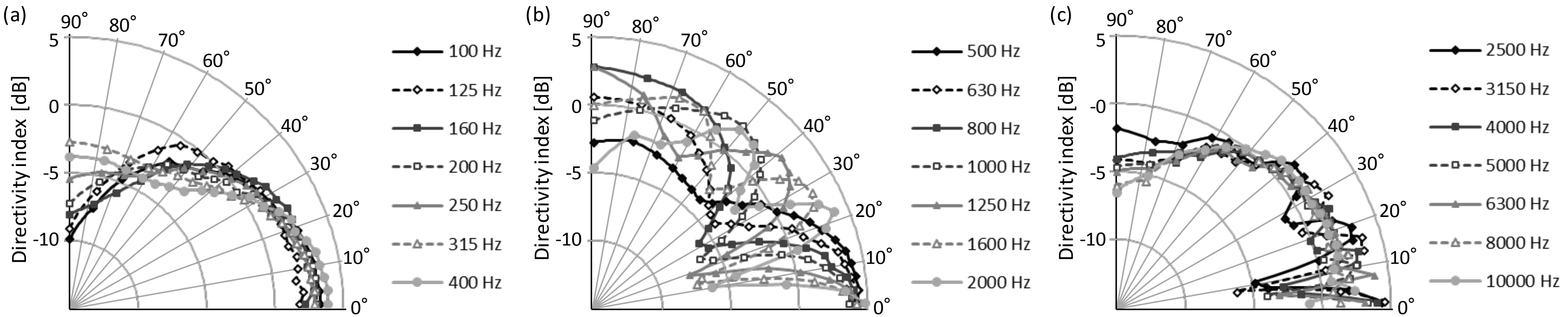
$\boldsymbol{r}$: position vector

$w(\varphi,\theta)$: weighting function representing the directivity of the sound source

p_0: sound pressure averaged over a hemisphere with a radius of unit length and enclosing the sound source

α: sound energy absorption coefficient of walls

Directivity of RSS

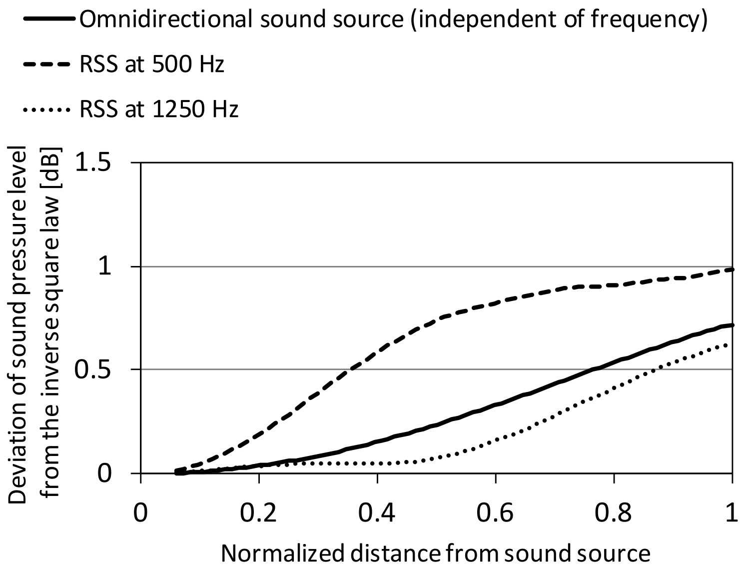


Directivity index of the RSS (Brüel & Kjær type 4202) for elevation angles from 0° to 90°
(a) 100 Hz to 400 Hz, (b) 500 Hz to 2000 Hz, and (c) 2.5 kHz to 10 kHz.

Allowable deviation in directivity of the sound source (hemi-free field)

1/3 octave band frequency	Allowable deviation in directivity
≤ 630 Hz	±2.0 dB
800 Hz to 5 kHz	±2.5 dB
6.3 kHz to 10 kHz	±3.0 dB
> 10 kHz	±5.0 dB

Deviation from inverse square law

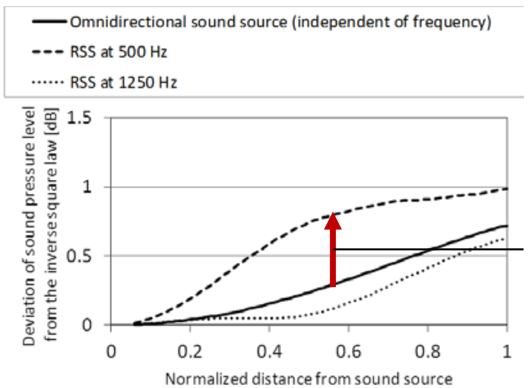


Calculated deviation of the sound pressure level from the inverse-square law for the RSS and for the omnidirectional sound source. The sound energy absorption coefficient of walls: 0.95.

Allowable deviation from inverse square law (hemi-free field)

1/3 octave band frequency	Allowable deviation in directivity
≤ 630 Hz	±2.5 dB
800 Hz to 5 kHz	±2.0 dB
> 6.3 kHz	±3.0 dB

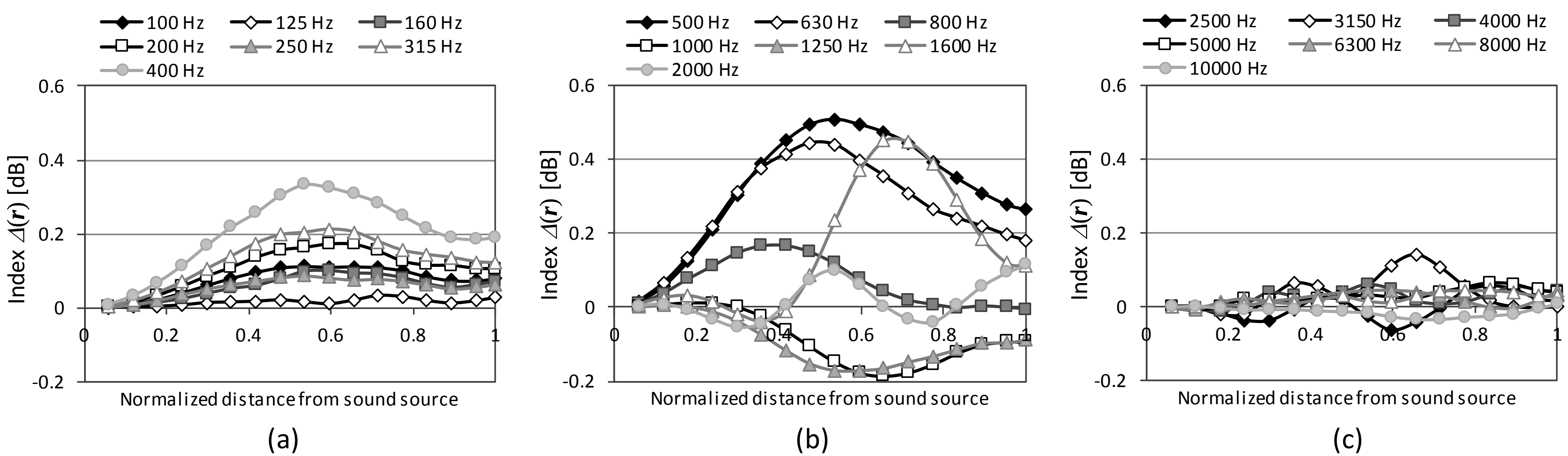
Influence of directivity of RSS



Influence of directivity

Allowable deviation from inverse square law (hemi-free field)

1/3 octave band frequency	Allowable deviation in directivity
≤ 630 Hz 800 Hz to 5 kHz > 6.3 kHz	±2.5 dB ±2.0 dB ±3.0 dB



Influence of directivity of RSS
(a) 100 Hz to 400 Hz, (b) 500 Hz to 2000 Hz and (c) 2.5 kHz to 10 kHz.

Conclusion

The analytical results by the proposed method showed that the commercially available RSS can be used for qualifying hemi-anechoic rooms

Further studies will aim to examine individual differences of directional characteristics between RSSs of the same type