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on
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Investigation into the influence of windscreens during sound emission measurements in accordance with IEC 61400-11 ed. 3.0

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1. Acknowledgements

Senvion SE would like to thank Microtech Gefell GmbH and windtest grevenbroich gmbh for providing their own secondary windscreens. Thank you also to Siemens Industry Software NV for providing the DELTA secondary windscreen.

We at Senvion SE would like to thank Brüel & Kjær, Microtech Gefell GmbH, DELTA and windtest grevenbroich gmbh for allowing us to reference their companies in connection with the primary or secondary windscreens during this report.

We at Senvion SE would also like to take this opportunity to thank Müller-BBM VibroAkustik Systeme GmbH for providing the semi-anechoic room and for their outstanding support during the investigations.

*The contact information for these companies can be found in the Annex under "**C. Company contact details**".*

Over the course of this investigation, the exact product names will not used in the text and graphics for practical reasons (often there are no product names available). Instead, the various windscreens will be labelled with the full or abbreviated company name in brackets: Brüel & Kjær (B&K), DELTA, DNV GL, Microtech Gefell GmbH (MTG), windtest grevenbroich gmbh (WTG).

2. Summary

In this comparative study of windscreens, the following conclusions could be drawn:

1. The series dispersion of a sample windscreen (here *DNV GL*) is relatively small when comparing the average values of the insertion loss (**Figure 19**). Not every example of the same windscreen type must thus be measured again. The standard deviation may differ, in particular at higher frequencies (**Figure 18**).
2. Depending on the windscreen type, the insertion loss and standard deviation differ considerably (**Figures 21+22+49**). The differences in the third-octave bands have a big impact on the total sound power level (**Table 6**, up to 1 dB). A correction in accordance with the standard is mandatory.
3. The angle of incidence has a reproducible impact on the insertion loss (**Figures 23+24**). A distance-based correction of the insertion loss must be discussed.
4. A wet windscreen changes the insertion loss at higher frequencies (**Figure 25**). The deviations in the third-octave bands, however, only have a very small influence on the total sound power level (**Table 6**).
5. A windscreen shifted out of place by the wind leads to varying insertion losses (**Figure 26**). The deviations in the third-octave bands do not have a clear positive or negative influence on the total sound power level (**Table 6**).

6. A rubber band used to hold the windscreen in place slightly changes the insertion loss (**Figure 28**). The deviations in the third-octave bands, however, only have a very small impact on the total sound power level (**Table 6**).
7. The stretchy loudspeaker cover on the *DNV GL* windscreen has a significant impact on the insertion loss (**Figure 30**), standard deviation (**Figure 31**) and on the total sound power level (**Table 6**).
8. The results from the tested primary windscreen, when compared to the manufacturer's data, lie as far as possible within the dispersion of various windscreens of the same type (**Figures 35+36**). The primary windscreen leads to a small increase (0.15 dB) of the total sound power level (**Table 6**).
9. The assembly on the boundary surface and the height of the cut for the primary windscreen have a clear impact on the insertion loss at high frequencies (**Figure 38**). This slightly reduces the increase of the total sound power level (**Table 6**).
10. The similar insertion losses determined for the same windscreen types in two different tests (at least in the anechoic rooms) represent a relatively good reproducibility of the procedure described in the standard (**Figures 45+46**).
11. The differences in the standard deviations illustrated in **Figure 49** (u_{B4} uncertainty) lead, in a sample comparison in a sound emission measurement (**Figure 50**), to significantly increased overall uncertainties of 0.4 dB for the *Delta* windscreen only (combined standard uncertainty u_C).
12. The impact on the results of the tonal analysis is below 2000 Hz for all windscreens in a range of +/- 0.2 dB (**Figure 59**). As frequency-dependent positive and negative deviations appear for every windscreen, however, it is questionable whether a correction would make sense here. Over several tonal analyses of wind turbine generator measurements at different frequencies, the sometimes positive and sometimes negative impact would probably average out. A correction would therefore not be very productive.

3. Introduction

Wind turbine measurements differ from typical noise measurement setups as they have to be performed with operating turbines. This implies high wind speeds during the measurement which tend to lower the quality of recording by the microphone. To improve the signal to noise ratio, especially in the lower frequency bands at wind speeds above 8 m/s, a secondary windscreen is usually applied for noise emission tests. Although quite commonly used, a detailed investigation of the acoustic influence of secondary windscreens has not yet taken place. The measurements and evaluations carried out by *Senvion SE* and *DNV GL* aim to improve knowledge about the acoustic influence of different secondary windscreen types (under working conditions). Furthermore, recommendations for correct use and considerations on the noise attenuation will be illustrated.

4. Requirements from the standard

a. General

"The windscreen to be used with the ground-mounted microphone shall consist of a primary and, where necessary, a secondary windscreen."

"A secondary wind screen can be used when measurements are made at high wind speeds and at low frequencies. The secondary wind screen improves the signal to noise ratio at the lowest and highest frequencies by reducing wind induced noise in the microphone."

"If the secondary windscreen is used, the influence of the secondary windscreen on the frequency response shall be documented and corrected for in 1/3-octave bands." [1]

b. Primary windscreen design

"The primary windscreen shall consist of one half of an open cell foam sphere with a diameter of approximately 90 mm, which is centred around the diaphragm of the microphone" [1]

c. Secondary windscreen design

"The secondary windscreen can be designed in different ways. For example, it could consist of a wire frame of approximate hemispherical shape which is covered with a 13 mm to 25 mm layer of open cell foam with a porosity of 4 to 8 pores per 10 mm or different types of textile. The secondary hemispherical windscreen shall be placed symmetrically over the smaller primary windscreen. The diameter of the wind screen shall be at least 450 mm." [1]

d. Measurement procedure

- A calibration procedure for determining the insertion loss is specified.
- When determining insertion loss, the humidity and moisture should vary to the extent at which the windscreen is used in practice.
- The measurement setup is the same as that for wind turbine generator acoustic measurements.
- A loudspeaker and pink noise (1 - 2 min) should be used.
- The loudspeaker should be attached at a height of 4 m and the insertion loss determined at three distances: 4.8 m ($\Phi 1$ = 39.8°), 6.0 m ($\Phi 2$ = 33.7°) and 7.2 m ($\Phi 3$ = 29.1°).
- A reference microphone should be placed beside the microphone used for the measurements. This is used to monitor the noise radiated from the loudspeaker for sound emission fluctuations during the measurements.
- Half a primary windscreen should be attached to both microphones.
- Three measurements, with and without a secondary windscreen, are carried out at each position. The secondary windscreen is attached and removed respectively for this purpose. 18 measurements are thus carried out altogether.
- The background noise is determined before and after these 18 measurements.
- The insertion loss (difference between the results with and without the windscreen) should be determined in one-third octave bands over the arithmetic mean of 9 measurements with and without the windscreen.
- The standard deviation must be determined. The uncertainty of the secondary windscreen u_{B4} per third-octave band is incorporated into the overall uncertainty per third-octave band.
- As a slight difference between the high sound pressure levels results, the level difference should be standardised with the level difference between the corresponding measurements of the reference microphone.
- The background noise in each third-octave band should be at least 3 dB below the value when the loudspeaker is switched on. Otherwise, these third-octave bands cannot be used.

e. Acoustic properties

"At frequencies below 100 Hz the insertion loss can be assumed equal to the insertion loss at 125 Hz if background noise has prevented measurements."
"The insertion loss should be measured down to at least 100 Hz. Below 100 Hz the insertion loss can be equalled to 0 for most secondary wind screens."
"The values of the insertion loss shall be within -1.0 dB to 3.0 dB for any one-third octave

band.
The difference in insertion loss between 2 neighbouring 1/3-octave bands shall not exceed 2 dB to prevent a distortion of the FFT-spectra, where it is not possible to correct for the secondary wind screen." [1]

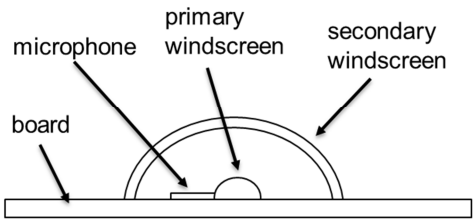


Figure 1: Measurement setup (vertical section)

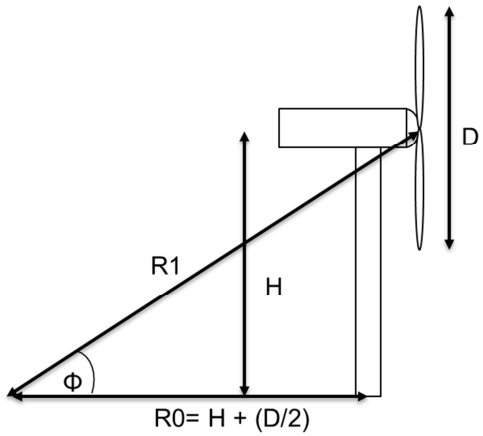


Figure 2: Definition of R0, R1 and Φ

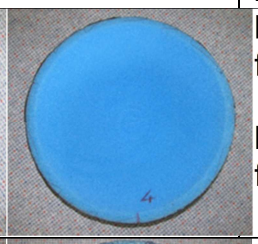
5. Investigations by Senvion

a. Secondary windscreen test items

The test items are listed in **Table 1**. There are four test items from *DNV GL* and one test item for each of the three other windscreen types. For a subsequent comparison of the results, the windscreen dimensions have been converted into the corresponding frequency using the sound velocity in the third and fourth column (**formula (1)**).

$$f = \frac{c}{\lambda}, with\ c = 340\frac{m}{s} \quad (1)$$

All four windscreen types have been designed differently.

Type	Top	Bottom	Height & Frequency	Diameter & Frequency	Description
DNV GL 4 sc.			h_i = 22 cm f_{hi} = 1545 Hz h_o = 25 cm f_{ho} = 1360 Hz	d_i = 46 cm f_{di} = 739 Hz d_o = 52 cm f_{do} = 654 Hz	Double-layer design. Stretchy loudspeaker cover and thick porous foam sewn together, foam moulded from one piece
WTG 1 sc.			h_i = 23.5 cm f_{hi} = 1447 Hz h_o = 25 cm f_{ho} = 1360 Hz	d_i = 52 cm f_{di} = 654 Hz d_o = 55 cm f_{do} = 618 Hz	Double-layer design. Very thin netting and thin porous foam that is stuck together

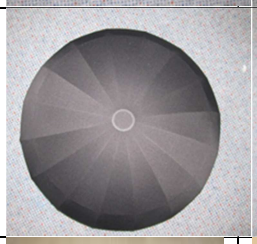
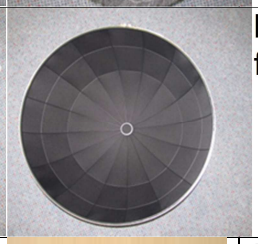
Delta type H 1 sc.		h = 25 cm f_h = 1360 Hz	d = 45 cm f_d = 756 Hz	Double-layer design. Textile fleece, “furry” material + wire frame
MTG GFM 920.1 1 sc.	 	h = 38 cm f_h = 895 Hz	d = 74 cm f_d = 459 Hz	Single-layer design. Very thin stretchy loudspeaker cover + wire frame
B&K UA-0237 3 sc.		h = 4.5 cm f_h = 7556 Hz	d = 9 cm f_d = 3778 Hz	One half of an UA-0237, open-pored polyurethane foam, straight cut
B&K UA-0237 2 sc.		h = 5.5 cm	d = 9 cm f_d = 3778 Hz	More than one half of an open cell foam sphere, uneven free-hand cut

Table 1: Overview of tested windscreen types

Two of the windscreens use a porous foam (no wire frame required). The porosity of the *DNV GL* windscreens appears to be finer (8 pores per 10 mm, ppi20) than the *WTG* windscreen (number of pores unknown). The *DNV GL* windscreen has been moulded from an entire foam block and is thus almost perfectly symmetrical. With the *WTG* windscreen, various foam parts have been combined. The material is denser where these parts meet. The thickness of the foam for the *WTG* windscreen (1.5 cm) is thinner than the foam for *DNV GL* (2.5 cm).

Both windscreens have a weather-proof cover over the foam. With the *DNV GL* windscreen, a stretchy loudspeaker cover is used and, for *WTG*, a very thin netting. The principal task of the foam for both windscreens is to reduce wind speed. The outer weather-proof cover is used to protect the windscreen against environmental influences (raindrops should roll off and should not penetrate the foam) and against dirt. The stretchy cover, in addition to the foam, also reduces wind speed.

The *DNV GL* windscreen has lead weights sewn into the bottom of the outside material in order to prevent the windscreen from shifting out of place in the wind. In practice, the *DNV GL* and *WTG* windscreens are usually also fixed into place using a rubber band (the rubber band slightly compresses the surface of the windscreen).

Both windscreens have the same external height. The diameter of the *WTG* windscreen is slightly larger than the *DNV GL* windscreen. The ratio of external height to diameter for the *DNV GL* windscreen is 2.08 and for the *WTG* windscreen 2.20 (the flattest in the field in terms of ratio). The sound incidence angle at standard distance R0 (**Figure 3**) is approx. 94° for *DNV GL* and 96° for *WTG*. These values are determined using the assumed ratio of D/2 (here 1) to H (here 2) using the **Formula (2)** and **(3)**. The angle changes according to the ratio of D/2 to H. A sound incidence angle of 90° on the windscreen represents the best possible scenario, as the sound waves then meet the material vertically and take the shortest route through the material. This route, however, also depends on the thickness of the material.

The *MTG* windscreen comprises a wire frame and a very thin stretch loudspeaker cover. The wind speed is reduced by this windscreen using the loudspeaker cover alone (single-layer design). Among the four windscreen types tested, the windscreen from *MTG* has by far the largest dimensions. It is not possible for this windscreen to be moved by the wind as it is fixed to a specially adapted base plate, positioned in a groove. When comparing the windscreens during this investigation, however, the measurements were carried out on this windscreen without the baseplate. The ratio of height to diameter is 1.95 and the sound incidence angle 93°.

The *Delta* windscreen (product name "DELTA type H", H=hemispherical) comprises a wire frame which is covered by a textile fleece, in turn covered by a "furry" material (*Delta* describes this as "Reinhardt cloth" [2]). This "fur" layer reaches as far as the ground and spreads out slightly. This overlapping is used to prevent the wind from penetrating the gap between the windscreen and the base plate. The *Delta* windscreen cannot be moved by the wind as the wire frame is very heavy. This windscreen has a height to diameter ratio of 1.8 (the highest in the field in terms of ratio) and a sound incidence angle of 87°.

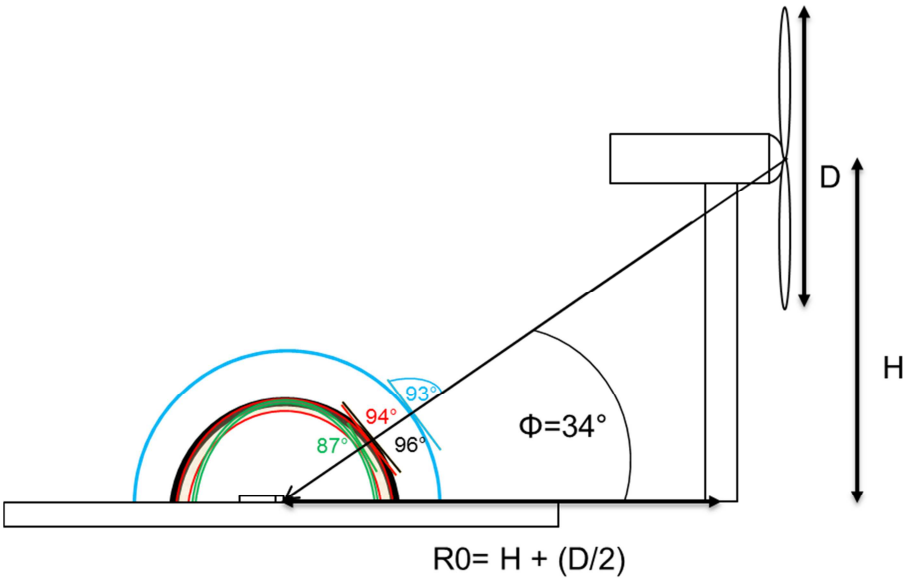


Figure 3: Sectional view of tested windscreens: Red - DNV GL, Black - WTG, Green - Delta, Blue - MTG. At the standard distance R0, the sound from the centre of the hub meets, for example, the windscreens below the angle given. The ratio of D/2 to H is assumed here in accordance with the measurement requirements for the windscreens [1] with 1 (D/2) to 2 (H).

$$c = \sqrt{H^2 + R0^2} \tag{2}$$

$$\Phi = \left(\arcsin\left(\frac{H}{c}\right)\right) * \left(\frac{180}{Pi}\right) \tag{3}$$

b. Measurement setup and procedure

Together with *Müller-BBM VibroAkustik Systeme GmbH* (Planegg, Germany), *Senvion* carried out the windscreen testing in a semi-anechoic room on 23 April 2014. The test room is a room-in-room construction with an elastic support and a very high level of sound insulation from inside the room to the outside. The lower limit frequency given is 125 Hz. The typical noise

level (background noise) is an average of 5 dB(A) during the day. The background noise present during the measurements is illustrated in **Figure 13**.

The measurement setup is illustrated in **Figures 4-10** and **Figures 14-17**. The distances specified in the standard had to be scaled down to correspond with the dimensions of the room. Each measurement took 1 minute. The dodecahedron radiated pink noise. The excellent signal to noise ratio is illustrated in **Figure 13**. Any external distortions of the measurement results could thus be ruled out.

Although three microphones were positioned on the ground for all measurements, only one windscreen at one position (R0-20% or R0 or R0+20%) was ever measured in the room. This was done to prevent the windscreens from influencing each other in the sound field.

Each windscreen was marked with 0°. For the first measurement, the 0° marking showed the direction of the noise source and after every measurement (three per windscreen and position) the windscreen was rotated 90°. The windscreens were rotated to average out any differences between the different sides of the windscreen.

Measurements were consistently taken without the windscreens throughout the overall investigation. This was done, on the one hand, to check for a constant excitation. On the other, to calculate the difference between the measurement average with and without the windscreen at the respective distance (**Figure 11**, black curve). The maximum fluctuation was 0.6 dB by microphone 2 in the 8 kHz third-octave band. All other bands displayed significantly smaller fluctuations. Microphone 1 and 2 displayed values below 0.6 dB in every third-octave band. The largest fluctuations appeared with very low (100 Hz, 125 Hz, here the room was pushed to its limits) and very high frequencies (6.3-10 kHz).

As the dodecahedron is not a perfect spherical source of sound for all frequencies and the sound is not evenly dispersed to the microphones due to the directional pattern of the dodecahedron (with various lobes), each microphone was assigned its own correction curve. Furthermore, the three microphones used do not have the exact same frequency response. This uncertainty is also eliminated by the individual corrections for each position. The curves illustrated in **Figure 12** show the average value at each position for five 1 minute measurements.

During this investigation, the secondary and primary windscreens were measured separately.

The investigations were carried out using measurement technology from *Müller-BBM VibroAkustik Systeme GmbH* and *Brüel & Kjær Sound & Vibration Measurement A/S* (see **B List of test equipment**).

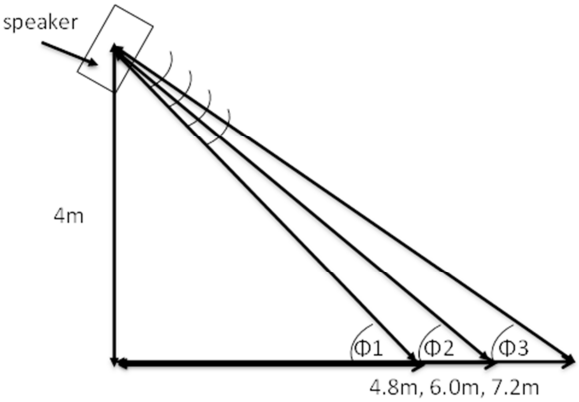


Figure 4: Measurement setup according to Annex E in the standard for the "Characterisation of a secondary windscreen" [1]

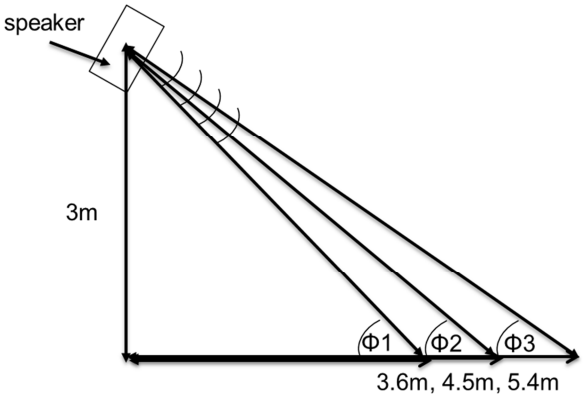


Figure 5: Measurement setup in semi-anechoic room

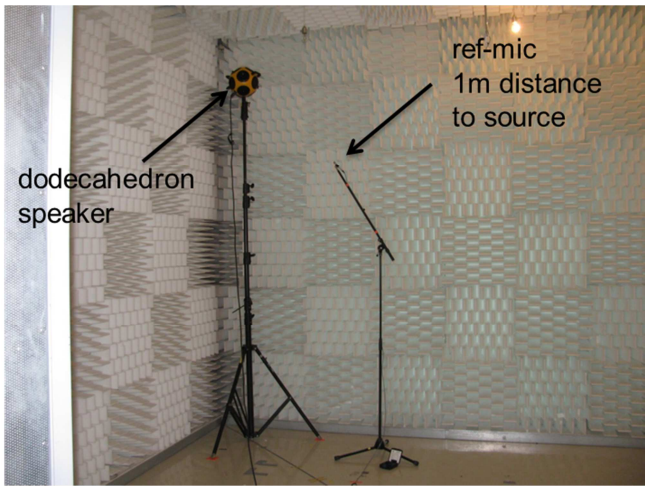


Figure 6: Placement of dodecahedron and reference microphone

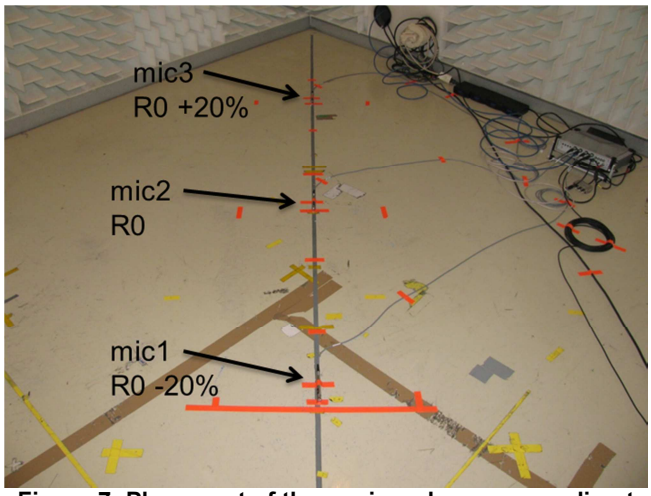


Figure 7: Placement of three microphones according to standard specification +/-20% of R0

Figure 8: Close-up of microphone 1

Figure 9: Close-up of microphone 2

Figure 10: Close-up of microphone 3

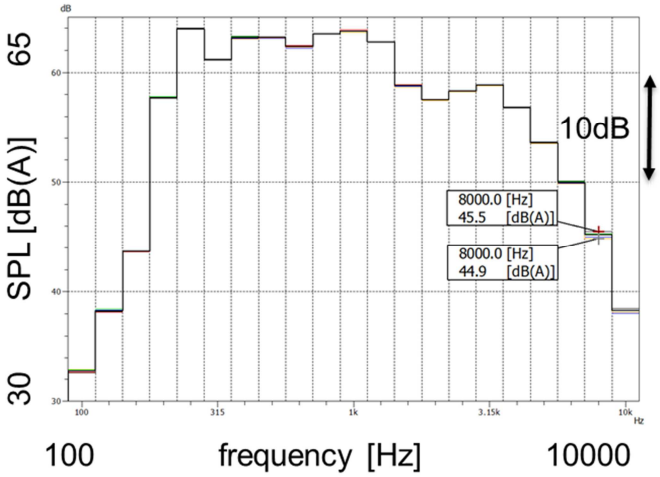


Figure 11: Third-octave spectrum variance for microphone 2. Five measurements, each lasting 1 minute. Pink noise distributed throughout the day. Maximum deviation 0.6 dB at 8 kHz.

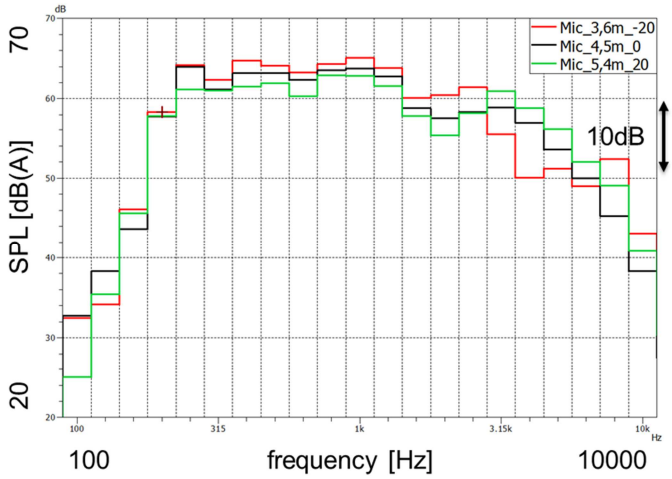


Figure 12: Correction curves per microphone. Five measurements, each lasting 1 minute. Pink noise distributed throughout the day.

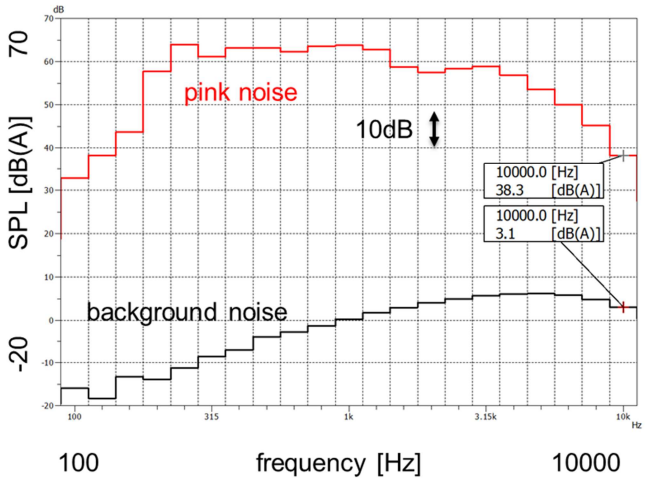


Figure 13: The signal to noise ratio is between 100 Hz and 10 kHz below 35 dB at no third octave

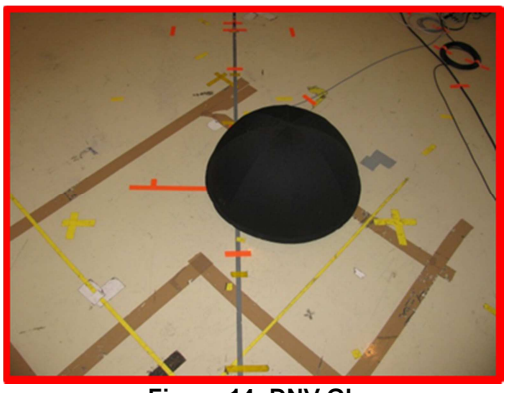


Figure 14: DNV GL

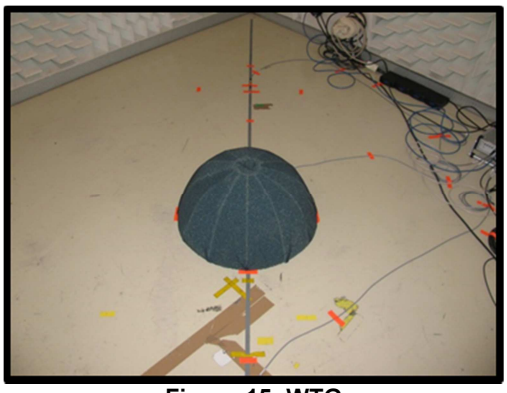


Figure 15: WTG

Figure 16: Delta

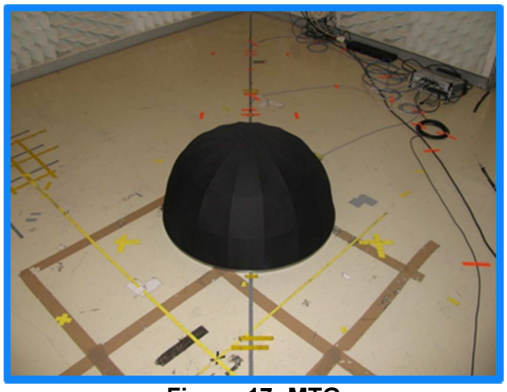


Figure 17: MTG

c. Measurement results

i. Deviation in the series production of a windscreen using four structurally identical windscreens

The results of the four *DNV GL* windscreens tested are shown in **Figure 18**. The prominent peaks of the insertion losses in the third-octave bands 630 Hz (561 Hz - 707 Hz), 800 Hz (713 Hz - 898 Hz), 1600 Hz (1425 Hz - 1796 Hz) roughly match the dimensions of the *DNV GL* windscreen (see **Table 1**, f_{do} = 654 Hz, f_{di} = 739 Hz, f_{ho} = 1360 Hz, f_{hi} = 1545 Hz). A correlation with the dimensions of the windscreens is presumed here.

Figure 19 shows a relatively small series dispersion of the four *DNV GL* windscreens. The average value for the four windscreens shown in **Figure 19** will be used in the following for comparing with the other windscreens.
Figure 20 shows a standard deviation sharply increasing under 100 Hz. This was to be expected due to the lower limit frequency specification of 125 Hz for the semi-anechoic room.

All results from 100 Hz are shown in the following.

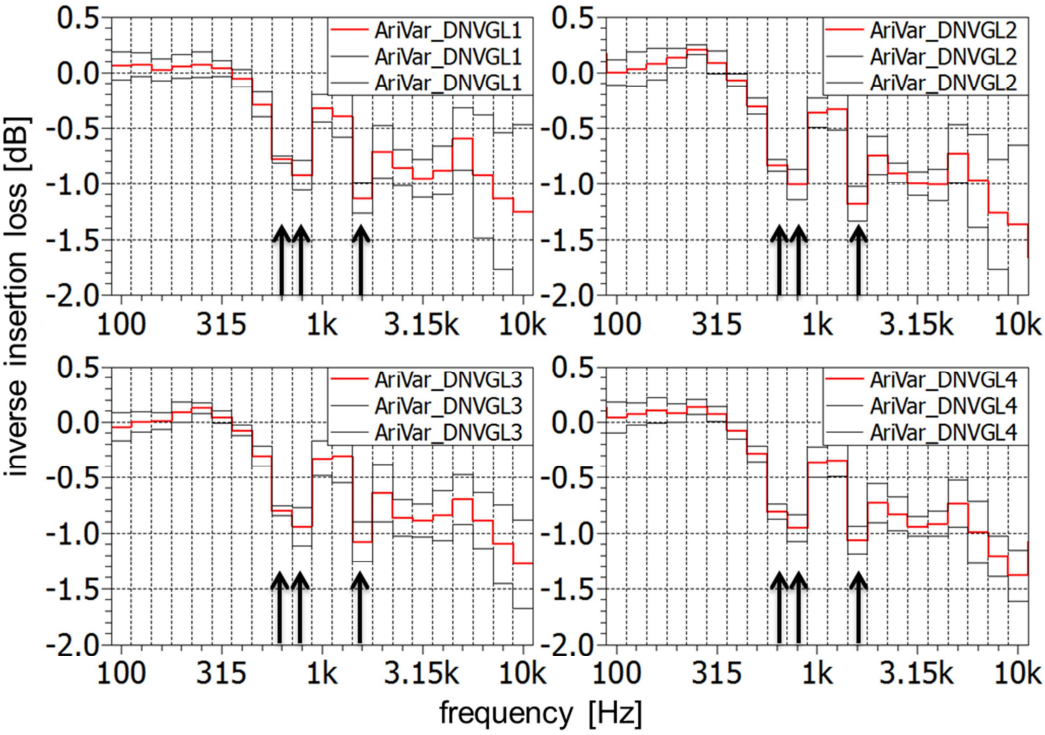


Figure 18: Red curves: Inverse insertion loss, Black curves: Standard deviation. Insertion loss peaks are marked with arrows.

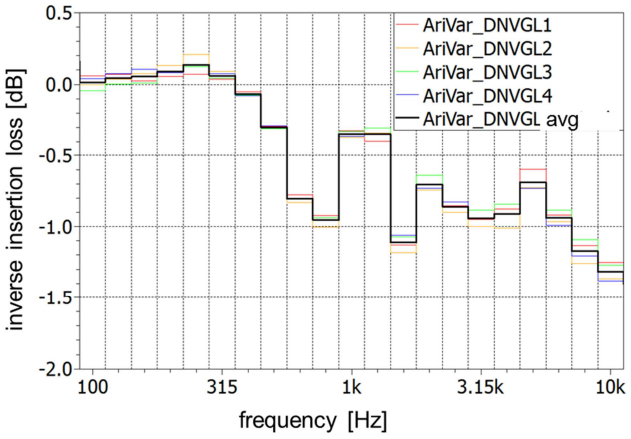


Figure 19: Inverse insertion losses for all four individual *DNV GL* windscreens and their average value

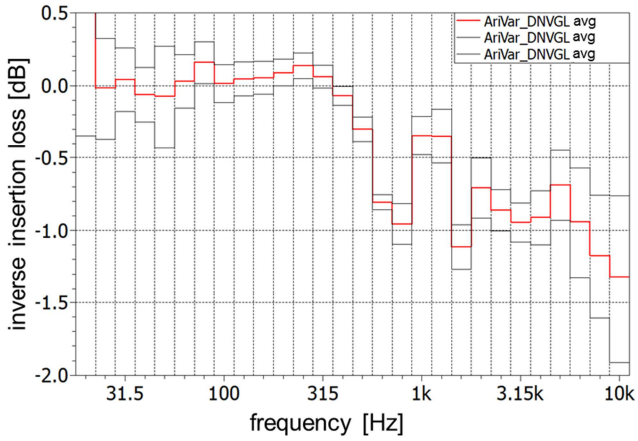


Figure 20: Average of inverse insertion loss (red) and standard deviation (black) for *DNV GL* windscreens

ii. Results from all tested secondary windscreen types

All windscreen types behave in a similar way at low frequencies (**Figure 21+22, Table 2**). Apart from the *MTG* windscreen, all other windscreens tend to have a slight increase. The previously described peaks then subsequently develop. The prominent peaks of the insertion losses in the third-octave bands 630 Hz (561 Hz - 707 Hz), 800 Hz (713 Hz - 898 Hz), 1600 Hz (1425 Hz - 1796 Hz) once again match very well with the dimensions of the windscreens (**Table 1**). Only the frequency to height ratio for the *Delta* windscreen (1360 Hz) does not entirely fit the 1600 Hz third-octave band. The *MTG* windscreen displays peaks at lower third-octave bands due to its larger dimensions. The positions of the peaks again coincide with the dimensions.
The remainder of the third-octave spectrum is characterised by the absorbing properties of the materials used. The *Delta* windscreen in particular has a very marked broadband insertion loss. The *WTG* and *MTG* versions have the least insertion loss. The *DNV GL* windscreen is about average in this comparison. Due to its strong influence on the total sound power level of wind turbine generators, special mention is given here to the relatively high values of the *Delta*

windscreen in the third-octave bands 500 Hz, 630 Hz and 800 Hz (**Table 6**). The third-octave bands 630 Hz and 800 Hz for the *DNV GL* windscreen also draw attention.

Overall, the *WTG* windscreen has the smallest standard deviations. The *MTG* windscreen has similarly small values up to 2 kHz. There is a sharp rise in the standard deviation for the *MTG* windscreen as the frequencies increase. Compared with the other windscreen types, *DNV GL* is also middle of the field when it comes to the standard deviation. The *Delta* windscreen has the greatest standard deviations.

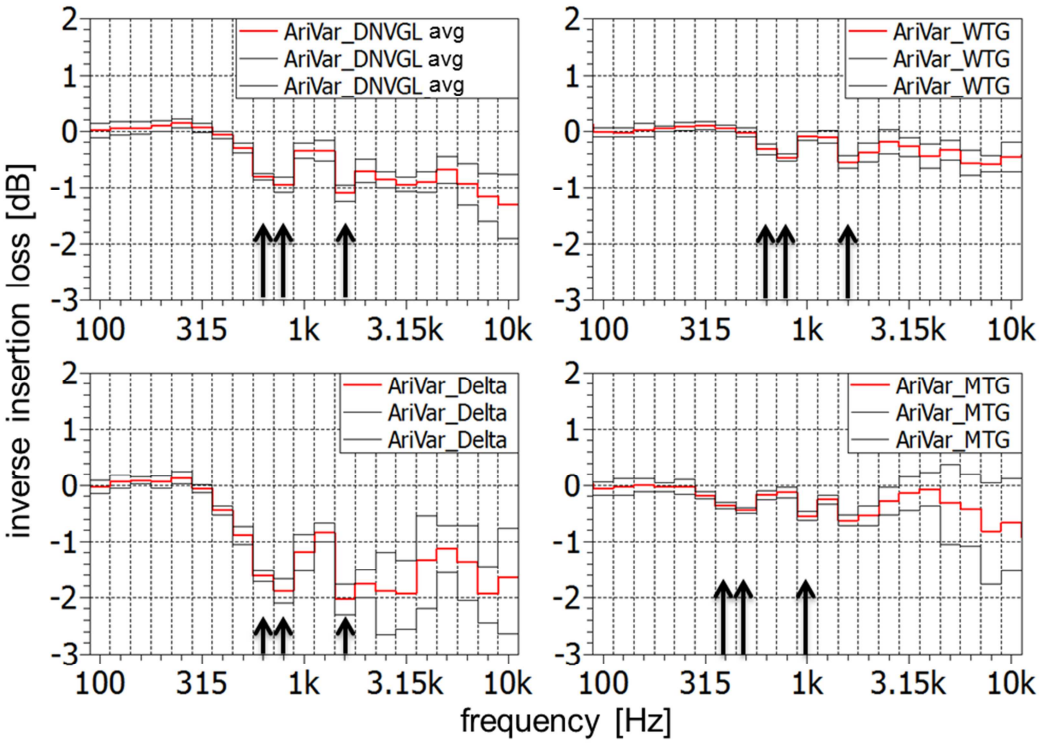


Figure 21: Inverse insertion loss (red) and standard deviation (black) for all tested secondary windscreens.

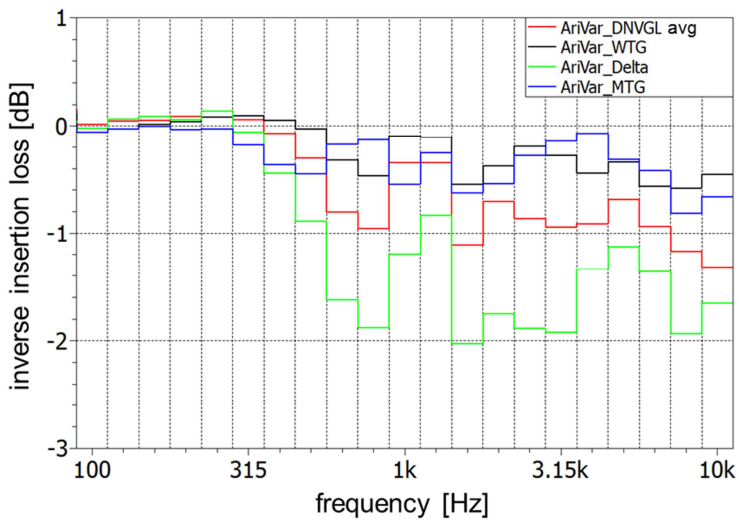


Figure 22: Inverse insertion loss for all tested windscreens

	DNV GL (average, four screens)		WTG		Delta		MTG	
1/3 Octave band [Hz]	Insertion loss [dB]	Standard deviation [dB]	Insertion loss [dB]	Standard deviation [dB]	Insertion loss [dB]	Standard deviation [dB]	Insertion loss [dB]	Standard deviation [dB]
63	-0.03	0.37	-0.02	0.33	-0.03	0.36	0.00	0.27
80	-0.16	0.29	-0.12	0.31	-0.06	0.21	-0.03	0.28
100	-0.01	0.26	0.02	0.17	0.02	0.23	0.06	0.25
125	-0.05	0.23	0.02	0.17	-0.06	0.24	0.03	0.31
160	-0.05	0.23	-0.02	0.22	-0.09	0.13	0.00	0.24
200	-0.09	0.18	-0.04	0.10	-0.06	0.21	0.03	0.16
250	-0.14	0.17	-0.08	0.15	-0.14	0.21	0.02	0.27
315	-0.06	0.16	-0.09	0.14	0.05	0.14	0.18	0.12
400	0.07	0.13	-0.05	0.11	0.44	0.16	0.37	0.11
500	0.30	0.17	0.03	0.15	0.89	0.33	0.45	0.09
630	0.81	0.10	0.32	0.19	1.62	0.19	0.17	0.16
800	0.95	0.28	0.47	0.14	1.88	0.43	0.13	0.20
1000	0.34	0.27	0.09	0.16	1.19	0.65	0.54	0.14
1250	0.35	0.37	0.11	0.23	0.83	0.33	0.25	0.16
1600	1.11	0.31	0.55	0.22	2.03	0.54	0.62	0.19
2000	0.71	0.41	0.38	0.33	1.75	0.49	0.54	0.35
2500	0.86	0.28	0.19	0.42	1.89	1.46	0.28	0.50
3150	0.94	0.27	0.28	0.33	1.92	1.22	0.14	0.61
4000	0.91	0.37	0.44	0.43	1.33	1.65	0.07	0.60
5000	0.69	0.48	0.34	0.34	1.13	0.85	0.31	1.43
6300	0.94	0.75	0.56	0.44	1.36	1.33	0.42	1.29
8000	1.17	0.85	0.58	0.28	1.93	1.01	0.81	1.81
10000	1.32	1.15	0.45	0.53	1.65	1.87	0.66	1.64

Table 2: Inverse insertion loss for all tested windscreens. The third-octave bands 63 Hz and 80 Hz are only given to highlight the increasing standard deviation at low frequencies by the free-field conditions no longer in place.

iii. Influence of direction of sound incidence

The angle at which the sound meets the windscreen depends on the distance of the microphone from the wind turbine generator. The angle Φ (**Figure 2+3, Formula (2)+(3)**) is, for example, as follows for the case described in the standard:

R0-20% → Φ1 = 39.8°
R0 → Φ2 = 33.7°
R0+20% → Φ3 = 29.1°

The maximum change to the sound incidence angle on the windscreen is thus 10.7°. Both **Figure 23** and **Figure 24** show the average value of the inverse insertion loss per measurement distance and windscreen. With the different *DNV GL* windscreens, the course and the arrangement according to distance can be reproduced very easily. A variation of the sound incidence angle by almost 11° thus appears to have a reproducible impact on the insertion loss. Similar differences are also seen in the results for the other three windscreen types (**Figure 24**).

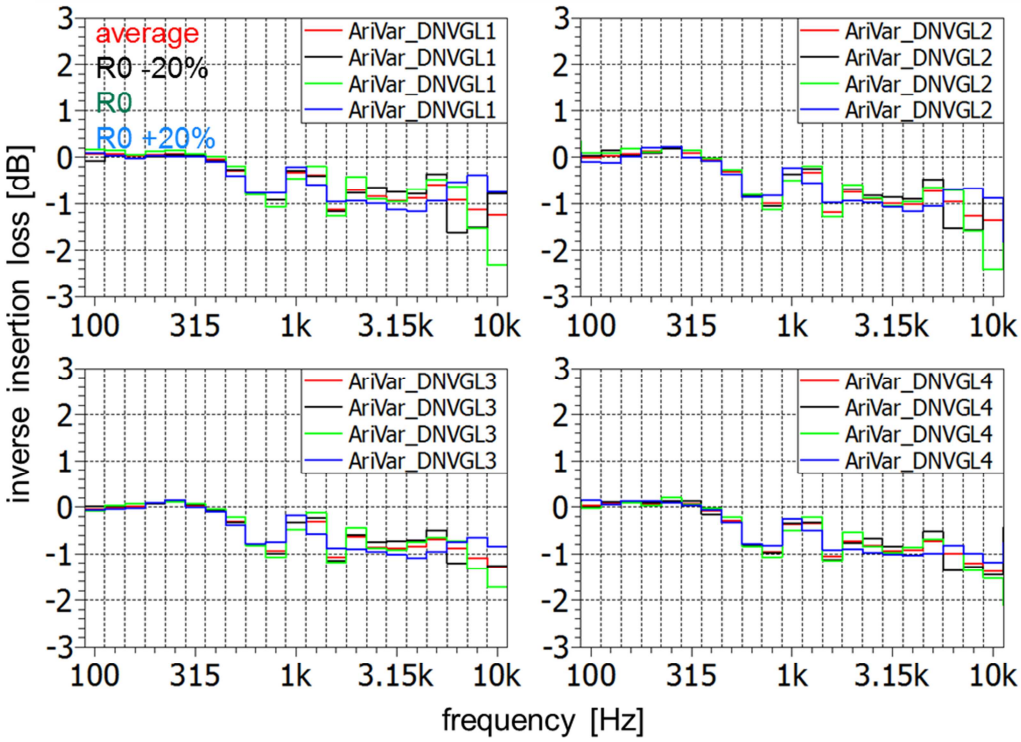


Figure 23: Insertion loss for all four *DNV GL* windscreens split up according to microphone position or sound incidence angle

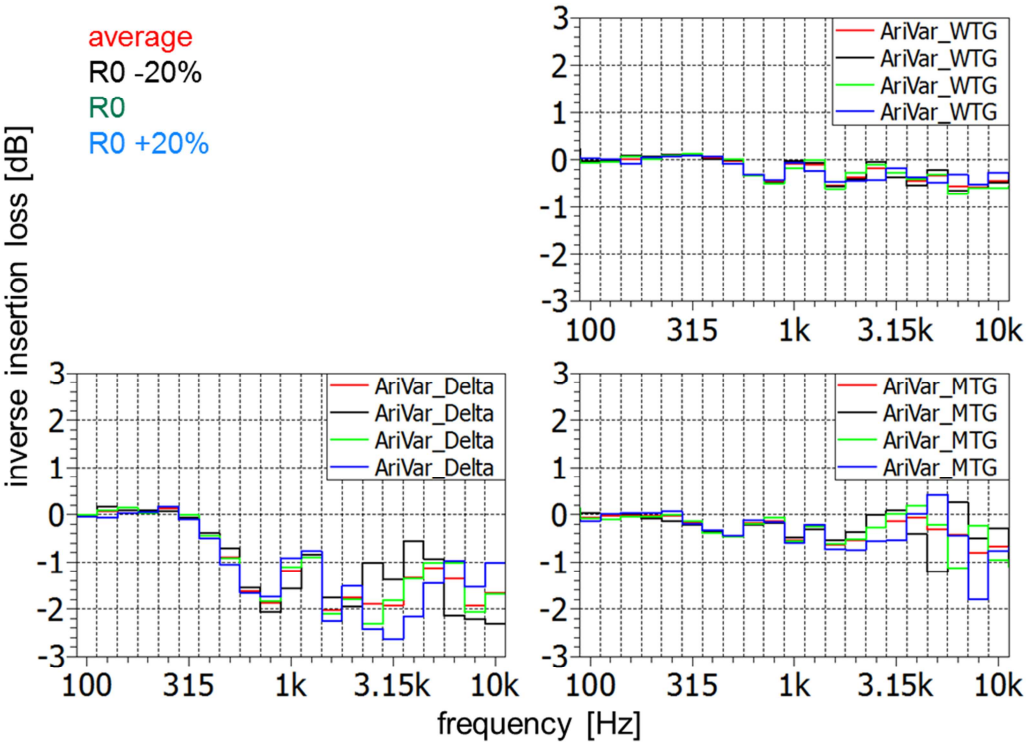


Figure 24: Insertion loss for *Delta*, *WTG* and *MTG* windscreens split up according to microphone position or sound incidence angle

iv. Wet windscreen

As sound emission testing can often take the whole day, the probability that it may rain at some stage over the course of the measurements is quite high. For this reason, a test was carried out here with a very wet windscreen. The degree of wetness is comparable with a shower of rain.

From approx. 1600 Hz, significant differences between the wet and dry windscreens become apparent (**Figure 25**).

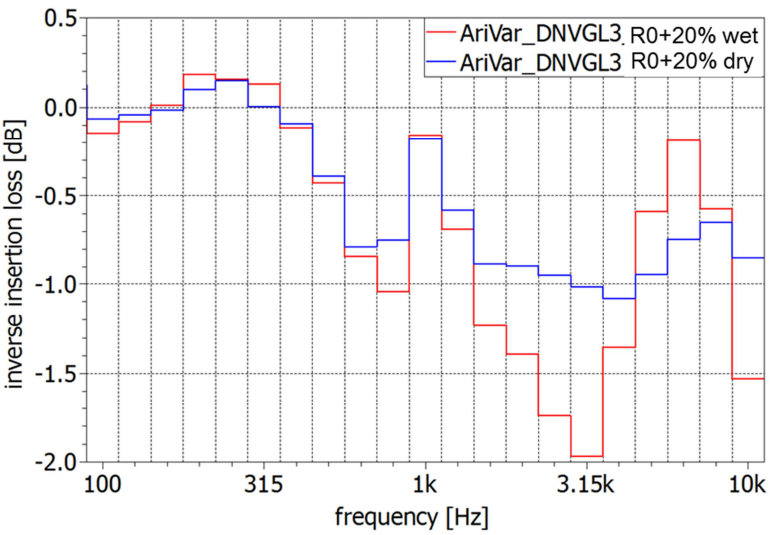


Figure 25: Comparison of dry and wet secondary *DNV GL3* windscreen

v. Shifted windscreen

There is a greater risk of windscreens without a wire frame being moved in high winds due to their lesser weight. Therefore, when measuring with these models in practice, a rubber band was used to fix them in place (see **vi.**).

In extreme cases, the secondary windscreen shifts out of place until it collides with the primary windscreen. Due to its position against the primary windscreen, loud scratching noises thus emerge when the screen moves in the wind and the insertion loss changes when the windscreen is no longer centrally placed over the microphone diaphragm.

The worst-case scenario (resting against primary windscreen) is shown in **Figure 26**. The average value from the three measurements at R0-20% is illustrated for comparison. The importance of centrally placing the windscreen can be seen from the relatively small dispersion of the individual measurements (**Figure 27**) compared with the influence of a shift in position (**Figure 26**).

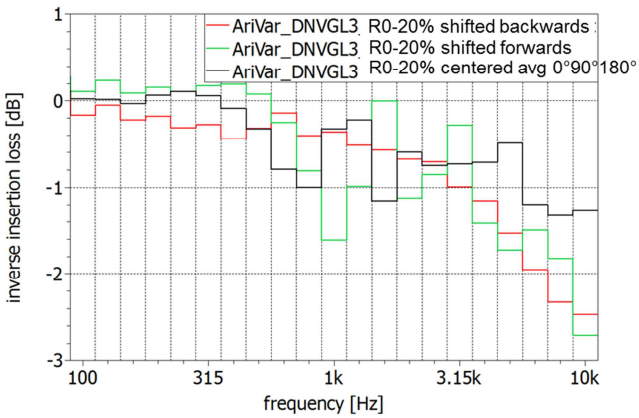


Figure 26: Influence of secondary windscreen that is not centrally positioned. The windscreen has almost shifted the maximum distance forward and back here.

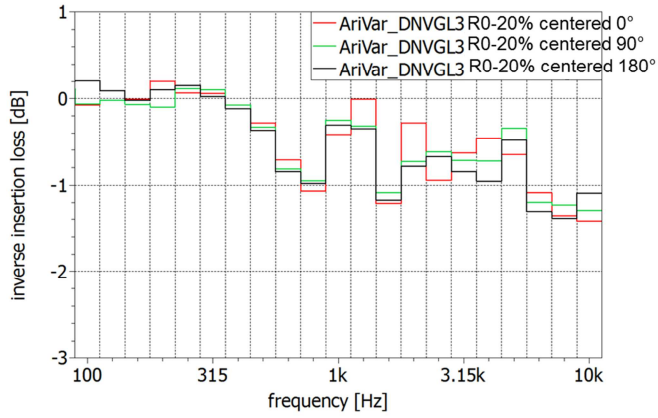


Figure 27: Variation of three measurements with same distance to source.

vi. Windscreen suppressed using rubber band

In practice, models without a wire frame are often fixed into place using a rubber band (**Figure 29**). In the sound emission reports from the various measurement institutes, it can be seen from the photos of the windscreens that the rubber bands used sometimes leave a clear indentation on the windscreens. The impact of this indentation on the windscreen is shown in **Figure 28**. Differences when compared with windscreens without indentations become apparent from approx. 1 kHz.

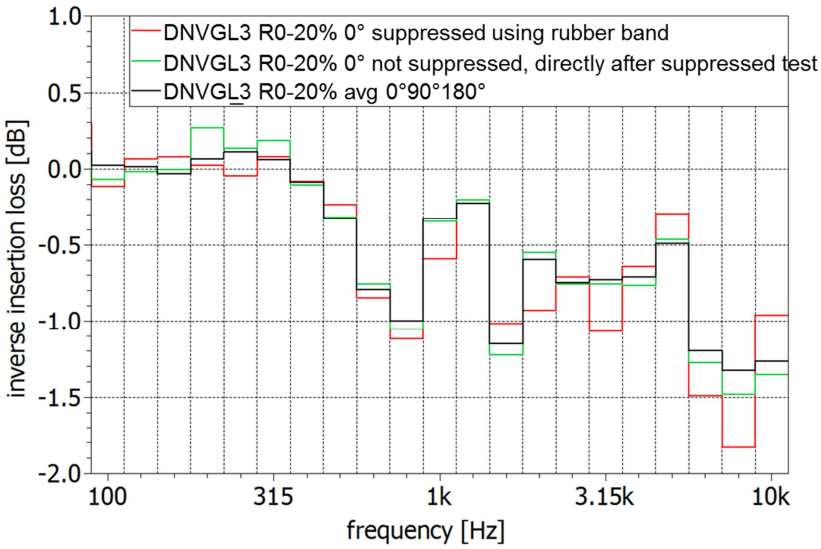


Figure 28: Influence of indentation on windscreen *DNV GL3* when using a rubber band to secure its position during high wind speeds

Figure 29: The *DNV GL3* windscreen secured with a rubber band

vii. Windscreen DNV GL without stretchy loudspeaker cover

In **Figure 32**, considerably higher standard deviations were determined for the entire *DNV GL2* windscreen when compared with the *DNV GL2* windscreen without the stretchy loudspeaker cover (**Figure 31**). Reproducibility is thus considerably improved when only foam is used. This has the effect of reducing the overall uncertainty (**b. Impact on the combined standard uncertainty**).

DNV GL has only been using this type of foam, without the stretchy loudspeaker cover, since around the summer of 2014. The question that remains unanswered, however, is to what extent the sole use of foam negatively influences the wind induced noise when compared to the

additional use of a loudspeaker cover. From approx. 400 Hz, the insertion loss is significantly lower without the loudspeaker cover (**Figure 30**).

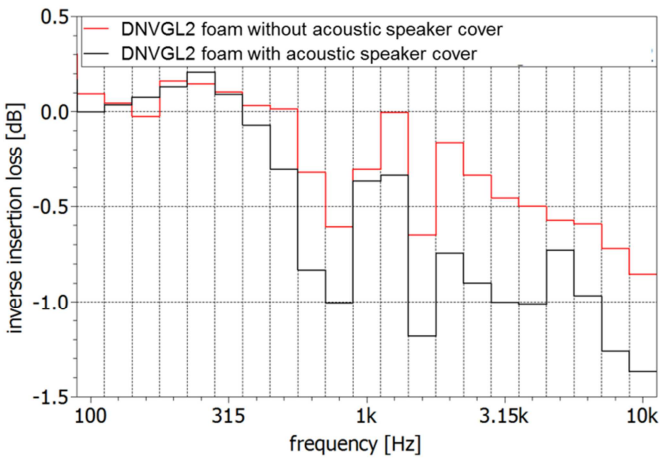


Figure 30: Influence of stretchy loudspeaker cover on insertion loss for *DNV GL2*

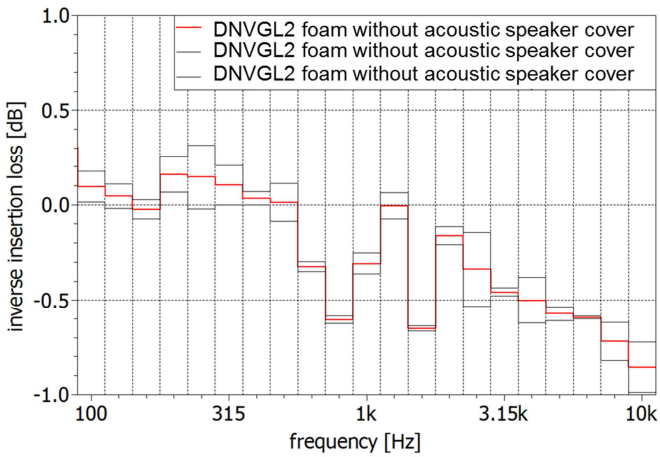


Figure 31: Insertion loss and standard deviation of *DNV GL2* without stretchy loudspeaker cover

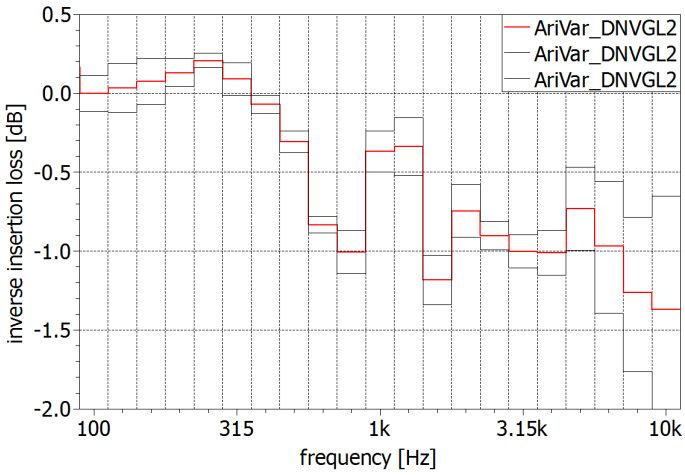


Figure 32: Insertion loss and standard deviation of the entire *DNV GL2*

Figure 33: DNV GL2 without stretchy loudspeaker cover

viii. Primary windscreen results

Table 1 shows the *UA-0237* windscreen from *Brüel & Kjær*. This has been cut straight through the middle (top image of primary windscreens in **Table 1**). The advantage to this cut is that there is no excess foam material that needs to be suppressed and the microphone can be placed flat on the surface. This has the disadvantage, however, that it is possible for air to enter under the windscreen and directly meet the microphone diaphragm. The bottom image in **Table 1** shows a free-hand cut made below the centre line, which is often the case during measurements. The advantage to this version is that air is prevented from meeting the microphone diaphragm. The disadvantage lies in the assembly, as the microphone is not positioned flat on the surface.

In **Figures 34 + 36**, the results from three different *UA-0237* windscreens cut through the centre are shown. The standard deviation runs a similar course for all three windscreens. From approx. 500 Hz, the insertion loss starts to increase until the maximum is reached (2500 Hz). The curve then drops again after this. At 5 kHz and 6.3 kHz, the values remain almost identical. The third windscreen differs considerably from the first and second windscreens (**Figure 36**). Windscreens one and two come from the same overall windscreen. The numerical values for the results determined are shown in **Table 3**.

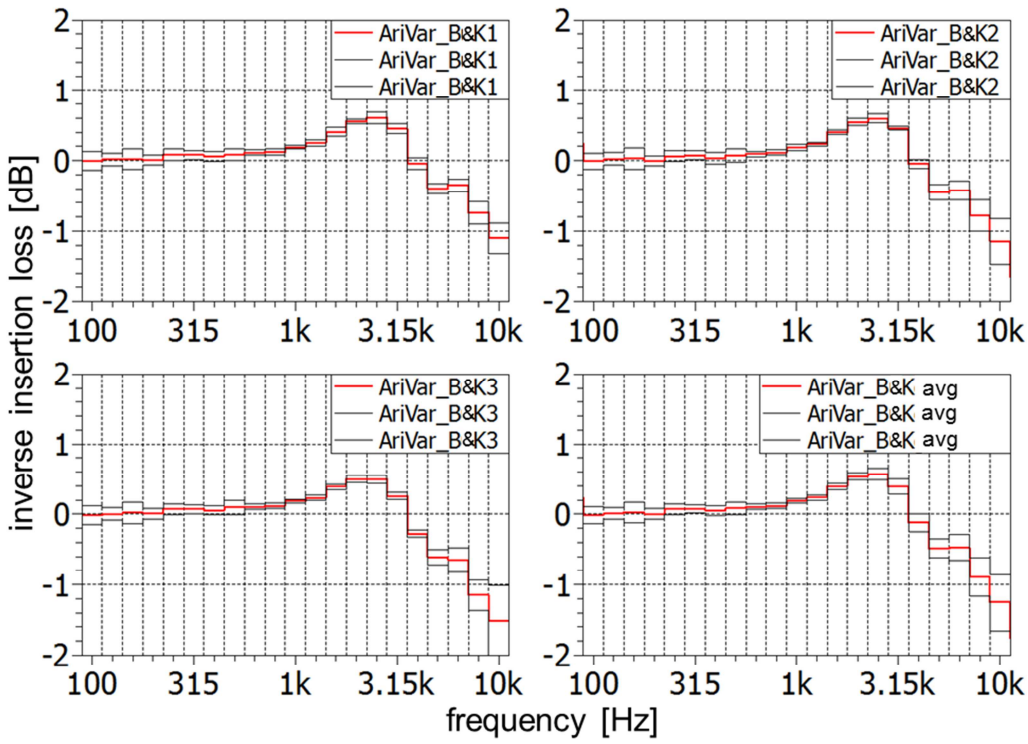


Figure 34: Insertion loss and standard deviation for three *Brüel & Kjær* UA-0237 centre-cut windscreens, together with their average value. Windscreens one and two come from the same overall windscreen.

One-third octave band [Hz]	Insertion loss [dB]	Standard deviation [dB]
63	-0.12	0.31
80	-0.23	0.22
100	0.01	0.24
125	-0.01	0.17
160	-0.02	0.28
200	0.00	0.14
250	-0.07	0.15
315	-0.07	0.12
400	-0.05	0.14
500	-0.08	0.18
630	-0.10	0.08
800	-0.12	0.08
1000	-0.18	0.06
1250	-0.24	0.07
1600	-0.39	0.09
2000	-0.53	0.10
2500	-0.56	0.17
3150	-0.39	0.21
4000	0.12	0.26
5000	0.49	0.26
6300	0.47	0.37
8000	0.89	0.54
10000	1.25	0.80

Table 3: Average value of insertion loss and standard deviation of three *Brüel & Kjær* UA-0237 centre-cut windscreens.

The course of the halved UA-0237 windscreen resembles the manufacturer's data [3] for an entire windscreen with an incidence angle of 30° (**Figure 35**). The extent of the differences in **Figure 35** is similar to the extent of the differences between two different windscreens within the UA-0237 series (**Figure 36**). In order to provide statistically correct statements, more whole and half windscreens needed to be measured.

The measurement room could have an influence on the results. In semi free-field conditions, direct sound and one reflection by the windscreen would influence the measurement of an entire windscreen (double impact). In a free-field or anechoic room, only the direct sound flows through the windscreen (single impact). The design of the measurement room at *Brüel & Kjær* is unknown.

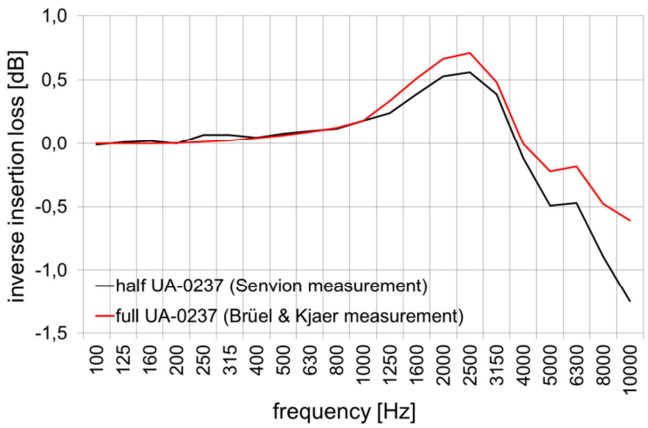


Figure 35: Insertion loss data from *Brüel & Kjær* for the entire UA-0237 windscreen with an incidence angle of 30°. The third-octave curve corresponds to the twelfth octave curve from the document [3]. Four twelfth octaves have been energetically averaged to a third-octave. Comparison with the average values determined by *Senvion* with half an *UA-0237* at a 34° angle of incidence.

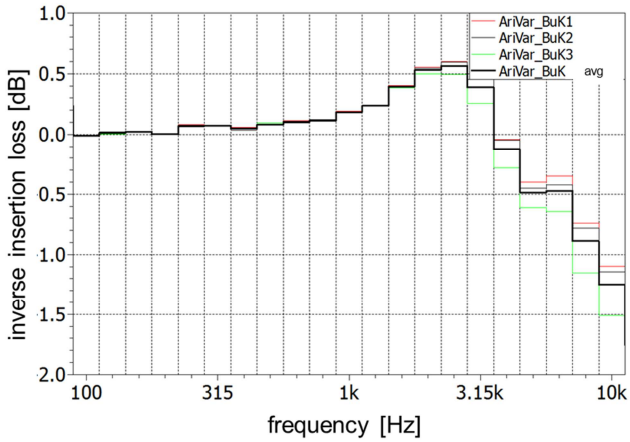


Figure 36: Insertion loss for three centre-cut *Brüel & Kjær* UA-0237 windscreens, as well as their average value. Windscreens one and two come from the same overall windscreen.

Figure 37 contains the results for two windscreens cut free-hand below the centre. Here, the microphone did not lie flush with the boundary surface. Between the underside of the microphone at the microphone diaphragm and the boundary surface, there was approx. 5 mm - 10 mm of space. The rear part of the microphone lay directly on the boundary surface (see photo in **Table 1**). Both windscreens exhibit a clear decrease from 2 kHz to higher frequencies.

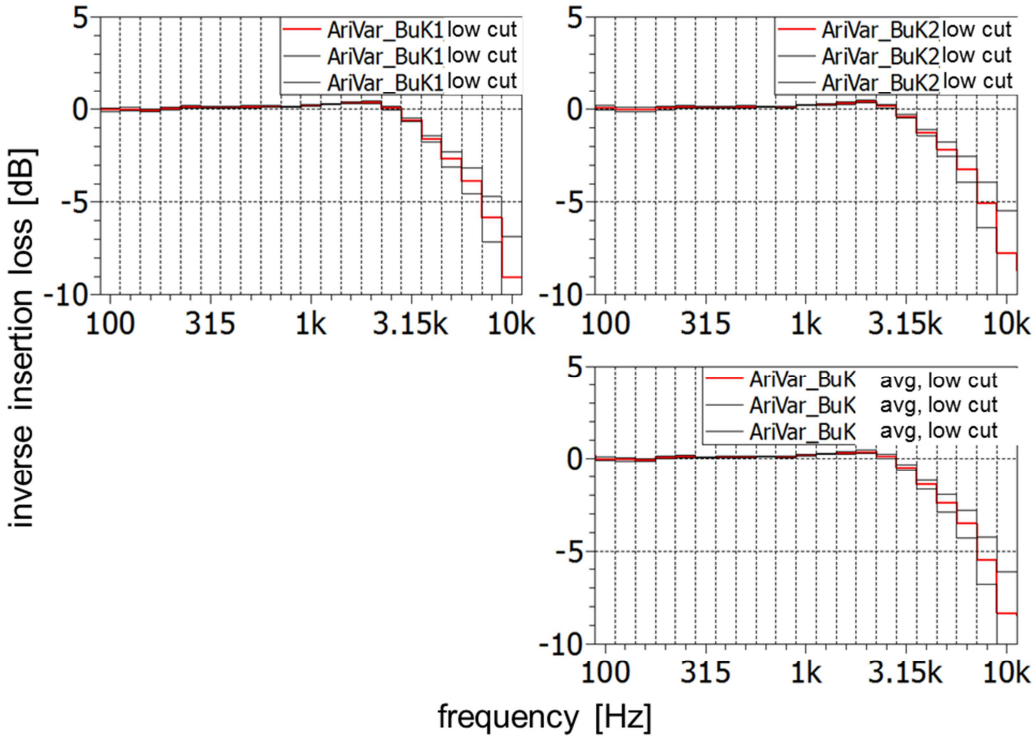


Figure 37: Insertion loss and standard deviation for two UA-0237 windscreens cut below the centre from *Brüel & Kjær*, as well as their average value. There was approx. 5 mm - 10 mm from the microphone at the microphone diaphragm to the boundary surface in each case.

Both designs (perfectly halved windscreen with microphone directly on the boundary surface compared to microphone with distance to boundary surface thanks to foam underneath, here approx. 5 mm - 10 mm) differ considerably at high frequencies (**Figure 38**). On the one hand, the coherent reflection (+ 6 dB level increase) at the boundary surface is no longer fully given and, on the other, the sound absorption of the windscreen doubles. The findings probably lie slightly below the red curve shown in **Figure 38** for everyday measurements. A cut slightly below the centre is common practice. It is unlikely that a small distance to the boundary surface can always be prevented.

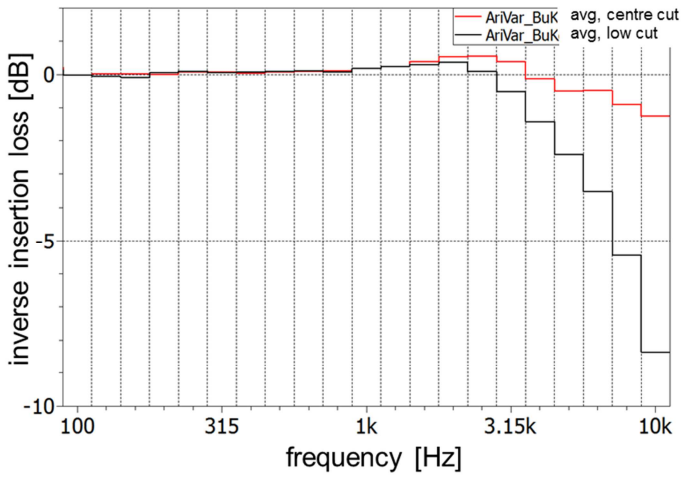


Figure 38: Insertion loss for perfectly halved windscreen with microphone directly on the boundary surface compared to the microphone at a distance to the boundary surface due to the foam underneath.

ix. Narrow band insertion loss of windscreens

The striking peaks in the third-octave bands described in "**i. Deviation in the series production of a windscreen using four structurally identical windscreens**" suggest that

the peaks are far more noticeable in a narrow-band range. **Figure 39** shows the narrow-band spectra of the insertion loss with 2 Hz line width for all four secondary windscreen types and, in **Figure 40**, for the primary centre-cut windscreen.

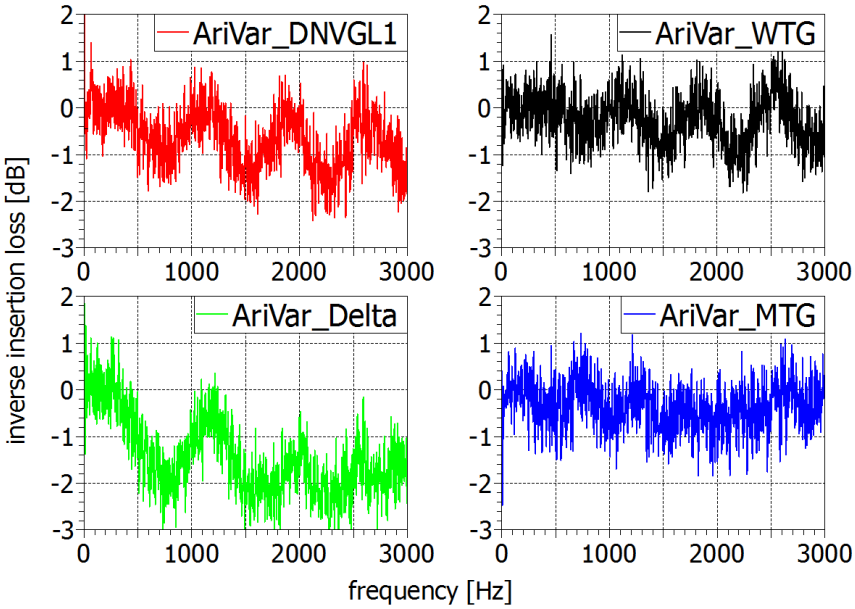


Figure 39: Narrow-band insertion loss (2 Hz line width) for four secondary windscreen types

The peaks described are very distinct. The curve progression matches the respective third-octave band spectrum in **Figures 22 + 36**. Depending on the windscreen type, the frequency range in which the windscreen is amplified is also present with a narrow-band analysis.

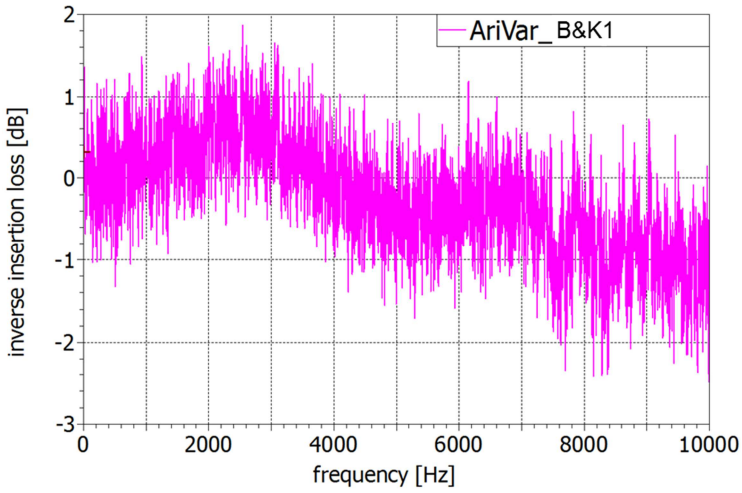


Figure 40: Narrow-band insertion loss (2 Hz line width) for primary UA-0237 windscreen (centre-cut)

6. Investigations by DNV GL

The secondary windscreens of *DNV GL* were measured externally. The external measurement was conducted by the *PTB* testing laboratory (*Physikalisch-Technische Bundesanstalt*) in Braunschweig (Germany). [4]

a. Secondary windscreen test items

The secondary *DNV GL* windscreen consists of a machined foam screen (8 pores per 10 mm, ppi20). The shape is hemispherical with an outer diameter of 52 cm. The thickness of the foam

is 25 mm. A weather protection layer may also be used. The secondary windscreen was also measured with this weather protection layer. The board is a wooden plate with rounded edges and a diameter of 1.11 m.

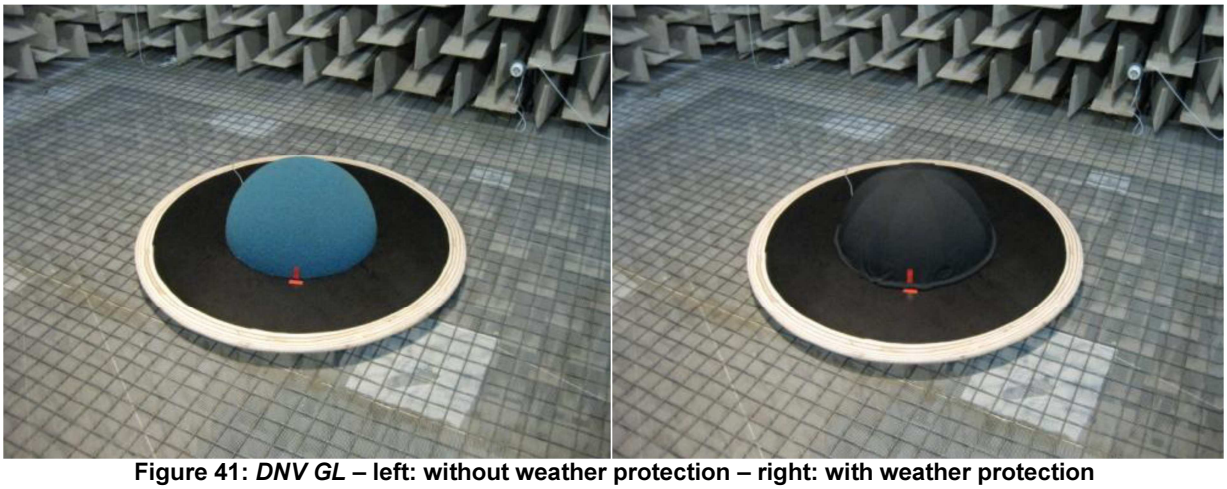


Figure 41: *DNV GL* – left: without weather protection – right: with weather protection

b. Measurement setup and procedure

PTB carried out the windscreen testing in an anechoic chamber on 23 April 2014.

Testing was carried out according to IEC 61400-11 ed. 3.0 Appendix E. [1]

In a sufficiently large anechoic chamber, a speaker that radiates pink noise was installed at a height of 4 m. The secondary windscreen was positioned at three distances: 4.8 m, 6 m and 7.2 m, from the source and measured with three repetitions at each distance. The windscreen was rotated 120° to average out any geometric irregularities. The various sound incidence angles (α = 29°, 34°, 40°) corresponded to the different measurement distances (d). **Figure 42** shows the basic structure.

The half primary windscreen was not measured as is specified in the standard. The microphone (capsule with preamp) was on the circular baseplate about 4 cm off centre and always fixed in the direction of the sound source. The secondary windscreen was centrally positioned on the plate.

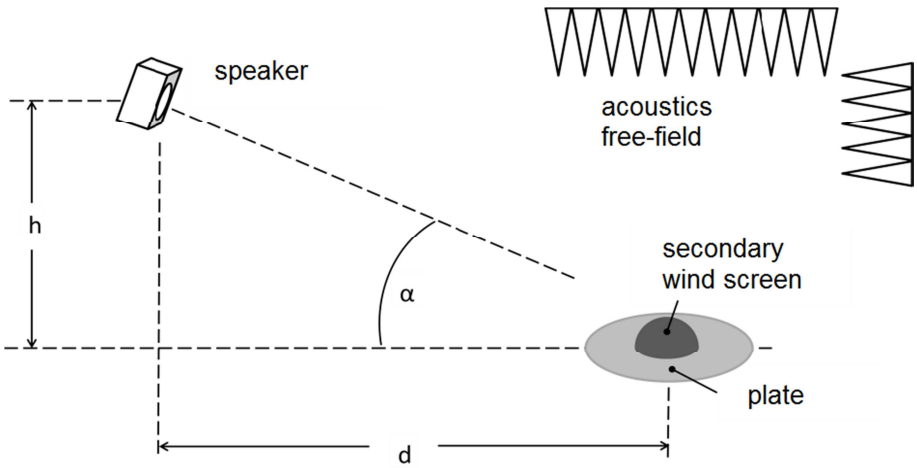


Figure 42: Sketch of the structure in the anechoic chamber

The following were measured: the acoustic background, the structure without a secondary windscreen, the structure with a secondary windscreen and the structure with a secondary

screen and weather protection layer. The equivalent continuous sound level (Lzeq) in third-octave frequency from 20 Hz to 20 kHz was evaluated for at least 3 minutes. To compensate for possible variations in the speaker level, the LZeq was recorded in third-octave frequencies with a second microphone at a fixed position away from the body and corrected on the screen microphone.
The electrode consisted of a calibrated 2-channel sound level metre (Norsonic type 840) and two measurement microphones (*Brüel & Kjaer* type 4133) on preamplifiers of *Brüel & Kjær* type 2669.
After adjusting the measurement level at the screen microphone to the fluctuation of the speaker level (three measuring distances x three repeats), calculated from the third-octave spectra of the nine individual measurements, the mean and standard deviation of the insertion loss was determined in dB:

Insertion loss = adjusted level without screen - adjusted level with screen.

A damping effect on the screen thus leads to a positive insertion loss value, a reinforcing effect to a negative value.

The ambient conditions during the tests were as follows:

Air temperature:	23.7°C ± 1°C
Relative humidity:	46% ± 15%
Air pressure:	100.2 kPa ± 3 kPa

The signal-to-noise ratio was greater than the prescribed standard minimum value of 3 dB at the two microphones during each measurement in all specified third octave bands:

- 20 Hz Signal-to-noise ratio > 3 dB
- 25 Hz to 63 Hz Signal-to-noise ratio > 15 dB
- 80 Hz to 5 kHz Signal-to-noise ratio > 60 dB
- 6.3 kHz to 16 kHz Signal-to-noise ratio > 15 dB
- 20 kHz Signal-to-noise ratio > 3 dB

c. Results

The determined insertion losses of the secondary windscreen are shown in **Tables 4 + 5** and graphically in **Figures 43 + 44**.

	d = 4,80m		d = 6,00m		d = 7,20m		avarage	
frequency	avarage value	standard deviation	avarage value	standard deviation	avarage value	standard deviation	avarage value	standard deviation
[Hz]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]
20.00	-0.13	0.15	0.10	0.00	-0.03	0.15	-0.02	0.15
25.00	-0.07	0.06	0.00	0.00	-0.03	0.06	-0.03	0.05
31.50	0.00	0.00	0.03	0.12	0.03	0.06	0.02	0.07
40.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.05
50.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.05
63.00	0.00	0.00	-0.03	0.06	0.00	0.00	-0.01	0.03
80.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.05
100.00	0.00	0.00	0.00	0.00	-0.07	0.06	-0.02	0.04
125.00	0.00	0.00	-0.03	0.06	0.00	0.00	-0.01	0.03
160.00	0.00	0.00	-0.03	0.06	0.00	0.00	-0.01	0.03
200.00	-0.10	0.00	-0.07	0.06	0.00	0.00	-0.06	0.05
250.00	-0.10	0.00	0.00	0.00	0.00	0.00	-0.03	0.05
315.00	0.00	0.00	-0.07	0.06	0.00	0.00	-0.02	0.04
400.00	-0.07	0.06	-0.13	0.06	0.00	0.00	-0.07	0.07
500.00	0.10	0.00	0.17	0.15	0.20	0.00	0.16	0.09
630.00	0.37	0.06	0.40	0.00	0.33	0.06	0.37	0.05
800.00	0.40	0.00	0.40	0.00	0.33	0.06	0.38	0.04
1000.00	0.00	0.00	0.00	0.00	0.03	0.06	0.01	0.03
1250.00	0.23	0.06	0.30	0.00	0.33	0.06	0.29	0.06
1600.00	0.20	0.10	0.20	0.00	0.23	0.06	0.21	0.06
2000.00	0.27	0.06	0.37	0.06	0.43	0.06	0.36	0.09
2500.00	0.30	0.00	0.37	0.06	0.43	0.06	0.37	0.07
3150.00	0.23	0.06	0.37	0.06	0.33	0.06	0.31	0.08
4000.00	0.40	0.00	0.37	0.06	0.37	0.06	0.38	0.04
5000.00	0.43	0.06	0.43	0.06	0.37	0.06	0.41	0.06
6300.00	0.43	0.06	0.53	0.12	0.50	0.00	0.49	0.08
8000.00	0.60	0.00	0.63	0.12	0.67	0.12	0.63	0.09
10000.00	0.63	0.06	0.83	0.12	0.73	0.06	0.73	0.11
12500.00	0.67	0.06	0.87	0.12	0.93	0.06	0.82	0.14
16000.00	0.80	0.00	0.83	0.21	1.13	0.35	0.92	0.26
20000.00	0.30	0.00	0.67	0.32	0.87	0.06	0.61	0.30

Table 4: Insertion loss of the secondary windscreen EWS-12A-01 without optional weather protection as average and standard deviation

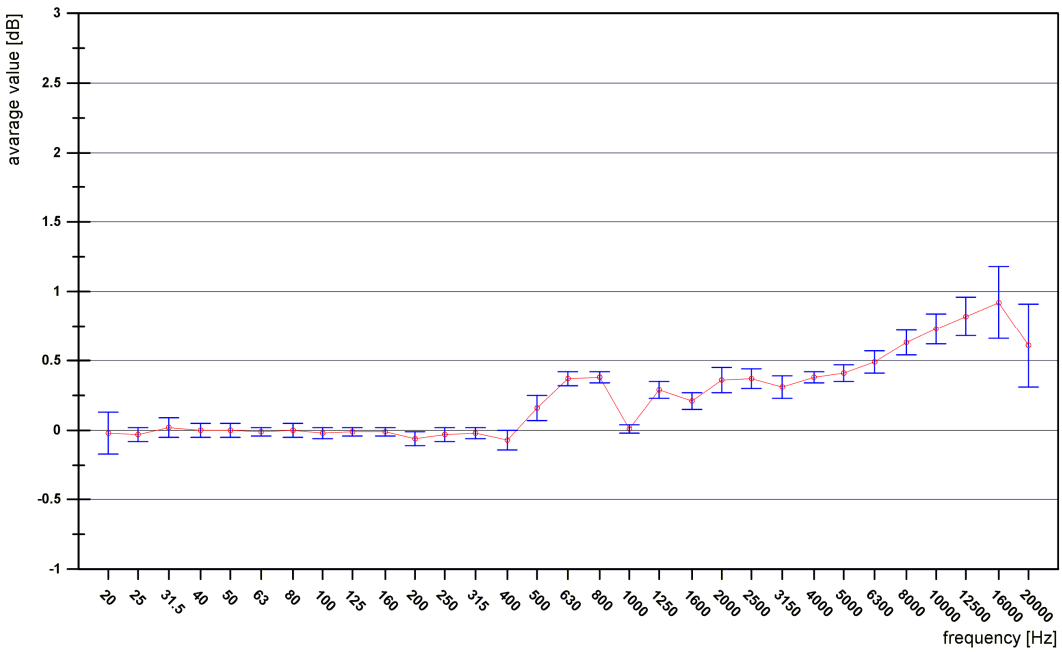


Figure 43: Insertion loss of the secondary windscreen EWS-12A-01 without optional weather protection as average and standard deviation

	d = 4,80m		d = 6,00m		d = 7,20m		avarage	
frequency	avarage value	standard deviation	avarage value	standard deviation	avarage value	standard deviation	avarage value	standard deviation
[Hz]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]	[dB]
20.00	0.00	0.20	0.07	0.21	0.13	0.06	0.07	0.16
25.00	0.03	0.06	0.00	0.00	0.07	0.12	0.03	0.07
31.50	0.00	0.00	0.10	0.10	0.03	0.06	0.04	0.07
40.00	0.00	0.00	0.07	0.06	0.00	0.00	0.02	0.04
50.00	0.00	0.00	0.07	0.06	0.00	0.00	0.02	0.04
63.00	0.07	0.06	0.07	0.06	0.00	0.00	0.04	0.05
80.00	0.00	0.00	0.03	0.06	-0.03	0.06	0.00	0.05
100.00	0.00	0.00	0.00	0.00	-0.07	0.06	-0.02	0.04
125.00	0.00	0.00	0.03	0.06	-0.10	0.00	-0.02	0.07
160.00	0.00	0.00	-0.03	0.06	-0.03	0.06	-0.02	0.04
200.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250.00	-0.10	0.00	0.00	0.00	0.00	0.00	-0.03	0.05
315.00	0.10	0.00	-0.03	0.06	0.07	0.06	0.04	0.07
400.00	0.13	0.06	0.10	0.00	0.10	0.00	0.11	0.03
500.00	0.50	0.00	0.53	0.06	0.43	0.06	0.49	0.06
630.00	0.80	0.00	0.80	0.00	0.60	0.17	0.73	0.13
800.00	0.53	0.06	0.60	0.00	0.30	0.20	0.48	0.17
1000.00	0.10	0.00	0.10	0.00	0.13	0.06	0.11	0.03
1250.00	1.00	0.00	0.87	0.06	0.60	0.17	0.82	0.20
1600.00	0.57	0.12	0.50	0.00	0.30	0.10	0.46	0.14
2000.00	1.23	0.06	1.00	0.10	0.63	0.23	0.96	0.29
2500.00	1.03	0.06	1.23	0.06	0.77	0.29	1.01	0.25
3150.00	0.53	0.06	1.37	0.06	1.20	0.36	1.03	0.42
4000.00	0.57	0.06	1.37	0.12	1.53	0.32	1.16	0.48
5000.00	0.40	0.00	1.13	0.23	1.67	0.21	1.07	0.57
6300.00	0.30	0.17	0.40	0.00	0.90	0.10	0.53	0.30
8000.00	1.43	0.40	0.20	0.26	0.17	0.29	0.60	0.69
10000.00	2.13	0.64	0.93	0.06	-0.33	0.21	0.91	1.12
12500.00	0.50	0.35	3.33	0.42	0.17	0.47	1.33	1.55
16000.00	1.50	0.69	2.37	0.32	1.57	0.81	1.81	0.70
20000.00	-0.23	0.06	0.07	0.42	2.07	0.50	0.63	1.13

Table 5: Insertion loss of the secondary windscreen EWS-12A-01 including optional weather protection as average and standard deviation

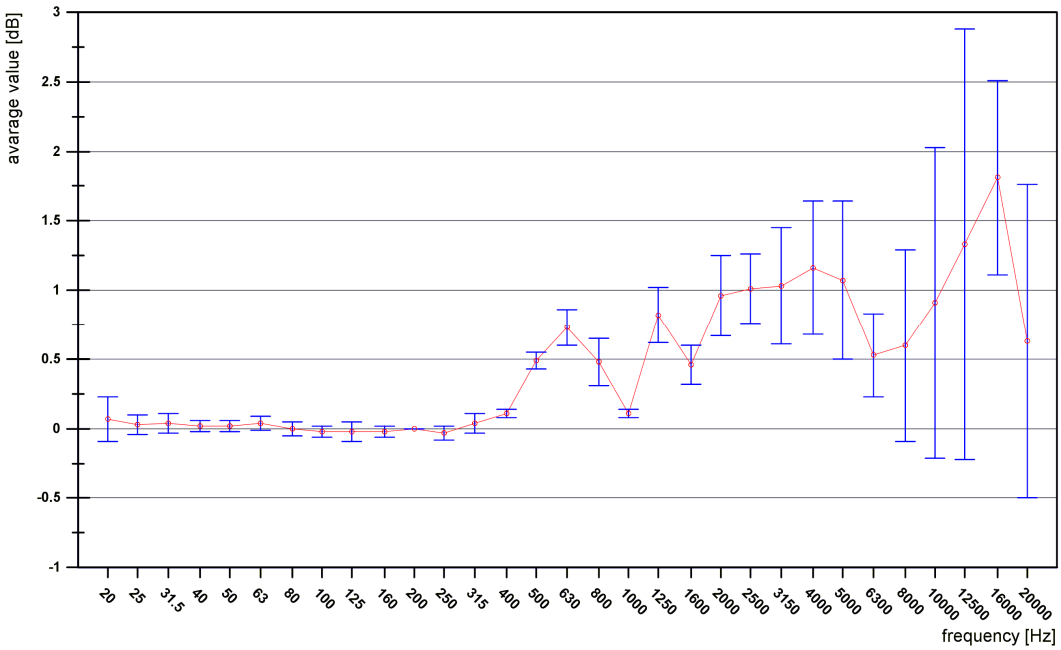


Figure 44: Insertion loss of the secondary windscreen EWS-12A-01 including optional weather protection as average and standard deviation

7. Comparison of measurement results from windscreen investigations carried out by *Senvion* and *DNV GL*

The results from **Figures 20 + 30** and **Figures 43 + 44** are compared in **Figures 45 + 46** for the secondary *DNV GL* windscreen. The average values deviate by up to 400 Hz within the series dispersion from **Figure 19**. The differences are greater than expected from approx. 500 Hz. With lower frequencies in particular, the standard deviations from the *PTB* tests are considerably smaller than those from *Senvion* (**Figure 45**). When comparing without the stretchy loudspeaker cover, the *PTB* standard deviation is lower across the entire range (**Figure 46**).

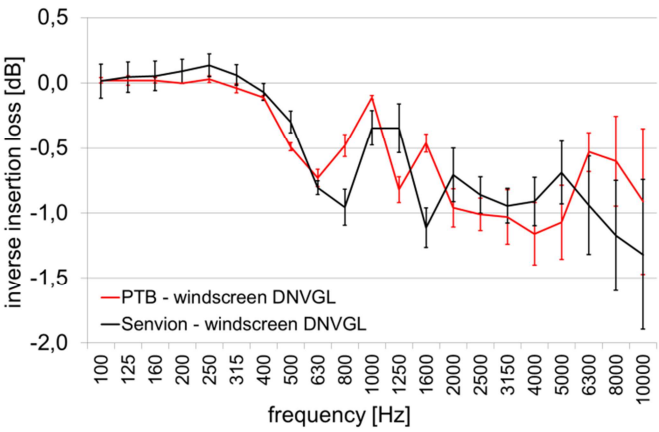


Figure 45: Insertion loss and standard deviation for two separate tests carried out on the same *DNV GL* windscreen types

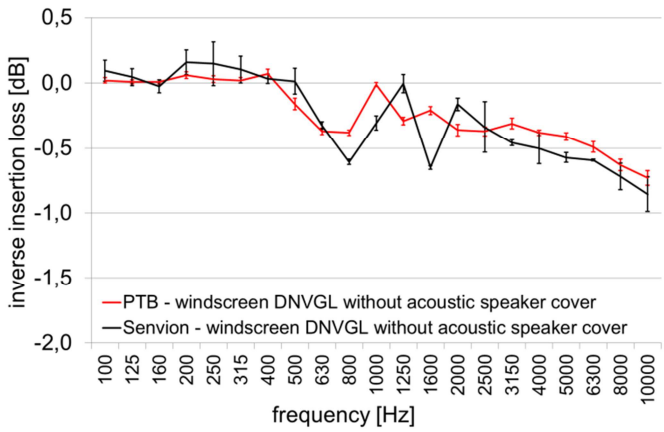


Figure 46: Insertion loss and standard deviation for two separate tests carried out on the same *DNV GL* windscreen types without a stretchy loudspeaker cover

There are a number of possible reasons for the differences:

- During the investigations carried out by *Senvion* in the semi-anechoic room at *Müller BBM*, the microphone and the windscreen were placed directly on the ground. At *PTB*, the microphone and the windscreen were placed on the wooden baseplate used for emission measurements. This should not normally have any impact on the measurement results as, in both cases, corrections are made with the corresponding output measurement minus the windscreen.
- The windscreen that was measured by *PTB* is described in the test report as “bleached and what appears to be a slightly older model” [4]. The *DNV GL* windscreens tested by *Senvion* were almost brand new. It may have been the case that small dust particles were present in the windscreen tested by *PTB* which would have, to some extent, blocked the pores of the stretchy loudspeaker cover and the foam. This would have had an influence on higher frequencies.
- At *PTB*, the three repeated measurements were carried out one after the other, the windscreen rotated by 120° after each measurement. The output position at 0° was centred between two seams of the stretchy loudspeaker cover (see schematic diagram in **Figure 47** or photo in **Table 1**). The measurements at 120° and 240° took place when positioned slightly beside the seams. At *Senvion*, the windscreens were rotated by 90° after every measurement. As the output position was either directly at the seam or very close to it, all three measurements were made near to or at seams (in retrospect, maybe not the best idea).There is thus a possibility that the differences in the average value in **Figure 45** have something to do with the orientation around the axis of the windscreen.

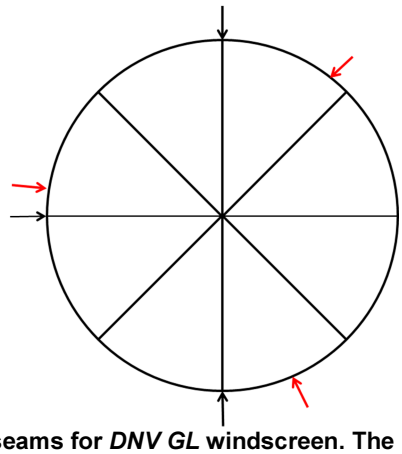


Figure 47: Schematic representation of seams for *DNV GL* windscreen. The black arrows mark the direction of sound incidence during the *Senvion* measurement and the red ones the direction during the *PTB* measurement.

8. Impact of windscreen measurement results on wind turbine generator measurement results

a. Impact on the total sound power level

The standard [1] requires a correction of the measured wind turbine generator third-octave spectra with the determined windscreen insertion losses. If the total energy is calculated from all the non-corrected third-octave spectra, and the total energy of the corrected third-octave spectra subtracted from this, the result is the impact on the total sound power level (ΔL). This ΔL is listed for all the different windscreens in **Table 6** (lines 1-7).

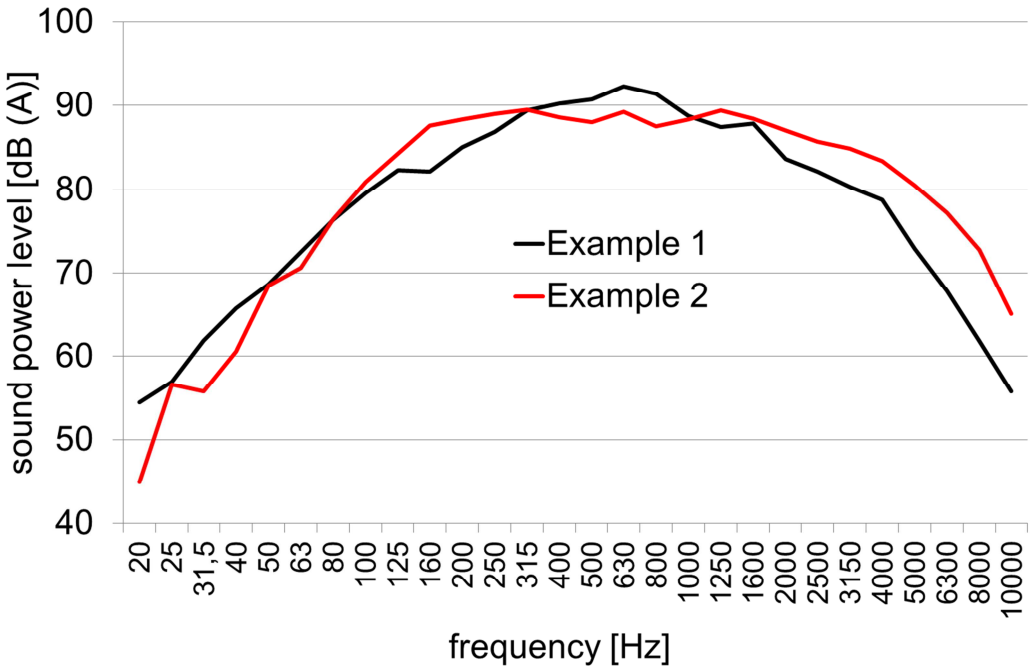


Figure 48: Two sample third-octave spectra from wind turbine generators

In lines 8-11 of **Table 6**, the difference between two states is respectively listed. For example, the result -0.09 dB for "*DNV GL3* wet - dry" means that in the wet state the total sound power level is additionally reduced by 0.09 dB for example 1 when compared to the dry state. For the calculations, two sample third-octave distributions were used as dummy wind turbine generator noise (see **Figure 48**). Other third-octave distributions also lead to slightly different results.

Therefore, the impact on the total sound power level determined in **Table 6** is only to be taken as a guide.
The secondary windscreens in lines 1-5 must be corrected as standard according to [1] (the primary windscreen is included in the standard test procedure). Lines 7-11 demonstrate the impact that can be avoided with a corresponding measurement setup (lines 7 and 9-11) or when carrying out a measurement (line 8, timely covering of windscreen before rain starts).

According to the impact on the total sound power level, the secondary windscreens can be ranked as follows:

1. Delta
2. DNV GL average
3. MTG
4. WTG and DNV GL2 without stretchy loudspeaker cover

Not correcting the *Delta* windscreen reduces the total sound power level by almost 1 dB. At the lower end are both foam versions (*WTG* and *DNV GL2* without stretchy loudspeaker cover) with a relatively small impact of less than 0.2 dB.

The primary windscreen leads to a small increase of the total sound power level of approx. 0.15 dB.

The third-octave spectra for lines 8 and 9 are shown in **Figures 25 + 28**. As the major differences refer to high third-octaves of less important levels, the impact on the total sound power level is thus fairly low. Lines 10 and 11 shown in **Figure 26** are variable influences on the overall frequency range. The impact on the total sound power level is thus not always positive or negative (Example 1 vs. Example 2).

No.	Test items	ΔL Example 1 [dB]	ΔL Example 2 [dB]
1	*DNV GL* average	-0.44	-0.36
2	*DNV GL2* without stretchy loudspeaker cover	-0.18	-0.14
3	*WTG*	-0.16	-0.14
4	*Delta*	-0.98	-0.81
5	*MTG*	-0.27	-0.25
6	*B&K* centre cut, average	0.13	0.15
7	*B&K* low cut, average	0.10	0.03
8	*DNV GL3* wet – dry	-0.09	-0.10
9	*DNV GL3* suppressed – unsuppressed	-0.04	-0.04
10	*DNV GL3* shifted backwards – centred	0.08	-0.07
11	*DNV GL3* shifted forwards – centred	0.14	0.03

Table 6: Influence of insertion loss determined for the various windscreens on the total sound power level for two sample third-octave spectra. Furthermore, various states are compared with each other (Lines 8-11).

b. Impact on the combined standard uncertainty

The differences in the standard deviations illustrated in **Figure 49** (u_{B4} uncertainty) lead, in a sample comparison in a sound emission measurement (**Figure 50**), to significantly increased overall uncertainties of 0.4 dB with the *Delta* windscreen only (combined standard uncertainty u_C).

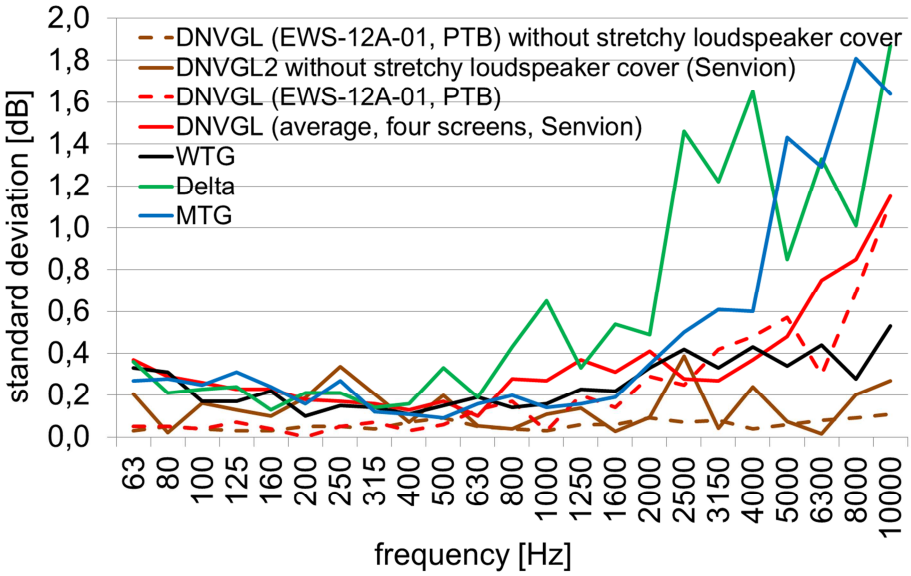


Figure 49: Standard deviations for the secondary windscreens measured by *PTB* and *Senvion*

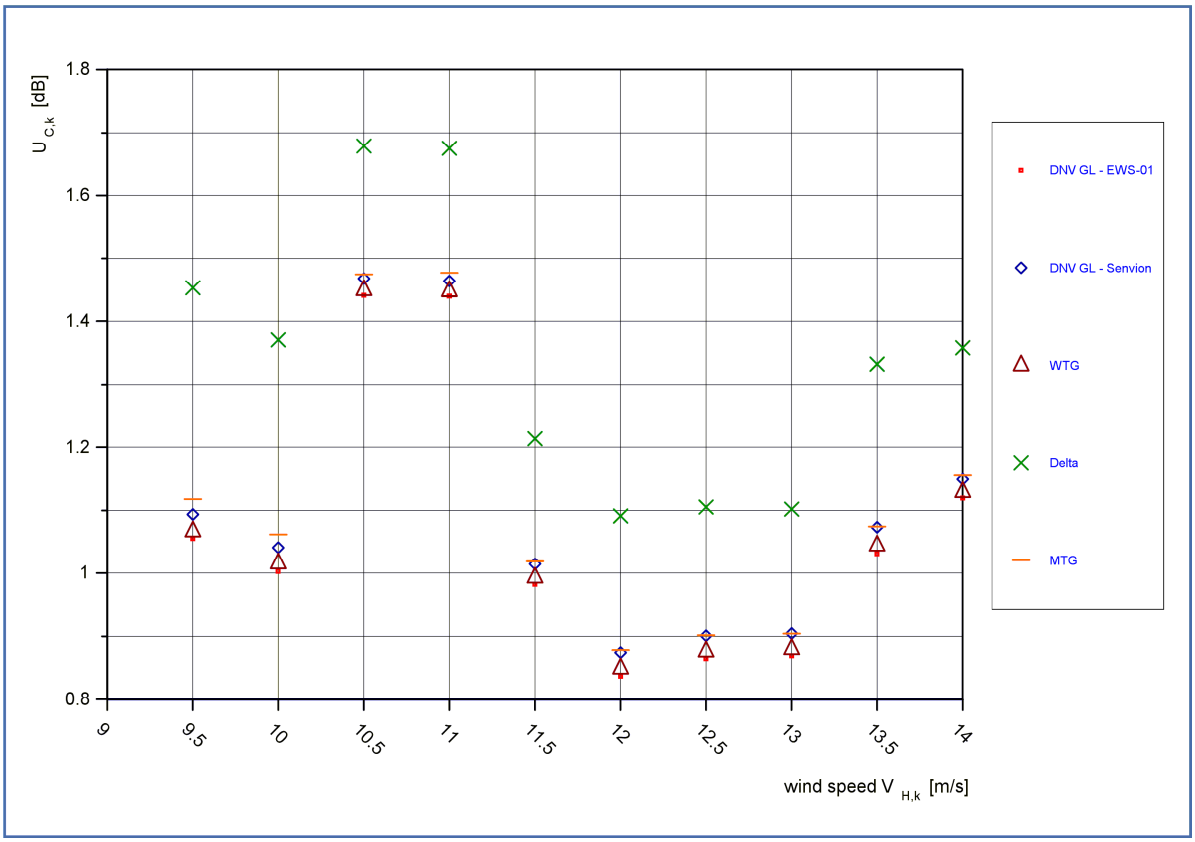


Figure 50: Representation of the total uncertainties U_C according to IEC 61400-11 Ed.3.0 using various windscreens

c. Impact on the results of the tonal analysis

The narrow-band insertion loss illustrated in **Figure 39+40** lead us to assume there has been an influence on the results of the tonal analysis. The impact of the windscreens on tonality has thus been investigated here. Here, synthetic sounds were added to a real wind turbine generator signal at various frequencies (see **Figure 56**). The tonal analysis was calculated once without any correction to the windscreen and, subsequently, separately for all five windscreens. In **Figure 58**, the differences in tonality (with vs. without the windscreen) for the

untreated narrow-band insertion loss are represented. Due to the large fluctuations in the narrow-band insertion loss within the respectively critical bandwidth, the results are very unclear and often random. A smoothed averaging of the narrow-band insertion loss was thus subsequently carried out (red curves in **Figure 51-55**). In doing so, it was possible to considerably reduce the fluctuations in the narrow-band insertion loss. The results in **Figure 58** appear more plausible than those in **Figure 59**.

The impact on the results of the tonal analysis is below 2000 Hz for all windscreens in a range of +/- 0.2 dB (**Figure 59**). As frequency-dependent positive and negative deviations appear for every windscreen, however, it is questionable whether a correction would make sense here. Over several tonal analyses of wind turbine generator measurements at different frequencies, the sometimes positive and sometimes negative impact would probably average out. A correction would therefore not be very productive.

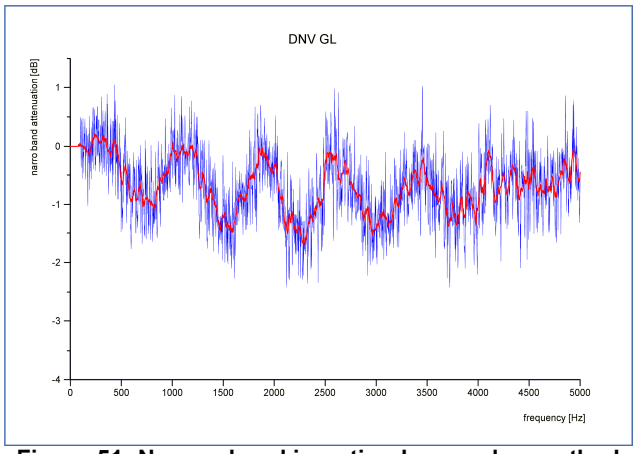


Figure 51: Narrow-band insertion loss and smoothed secondary windscreen *DNV GL*

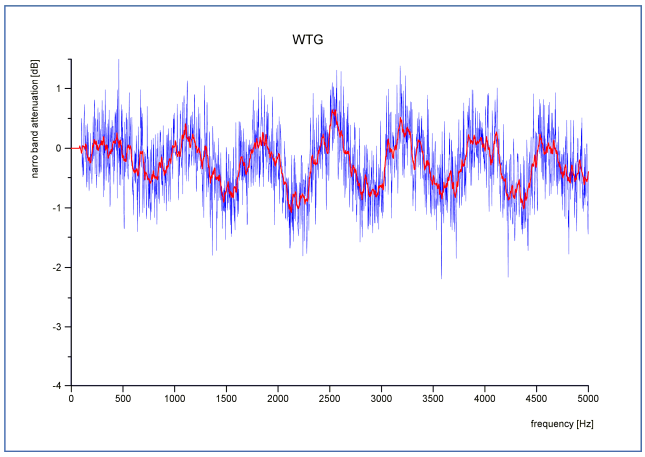


Figure 52: Narrow-band insertion loss and smoothed secondary windscreen *WTG*.

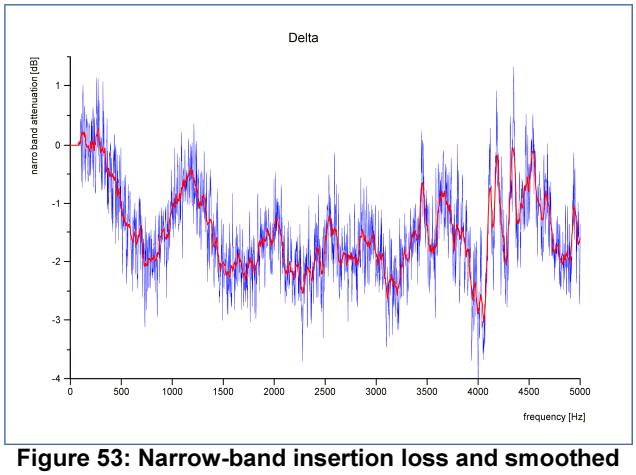


Figure 53: Narrow-band insertion loss and smoothed secondary windscreen *Delta*.

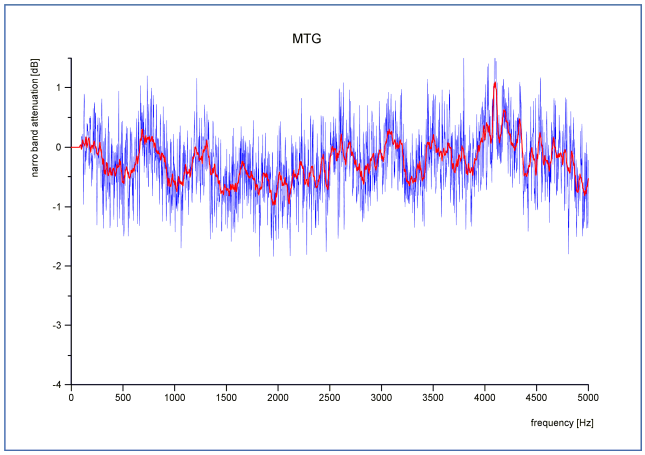


Figure 54: Narrow-band insertion loss and smoothed secondary windscreen *MTG*.

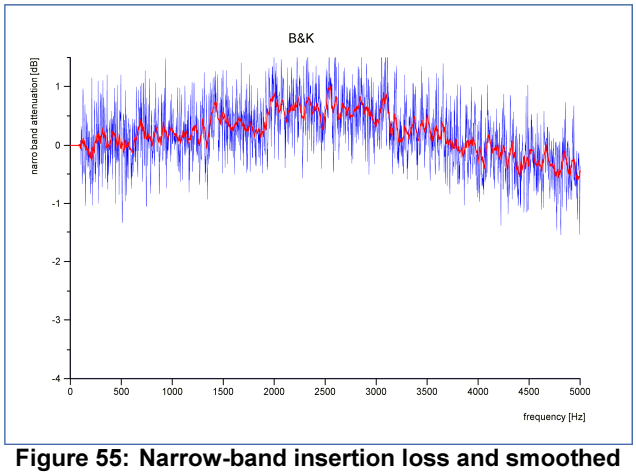


Figure 55: Narrow-band insertion loss and smoothed primary windscreen *B&K*.

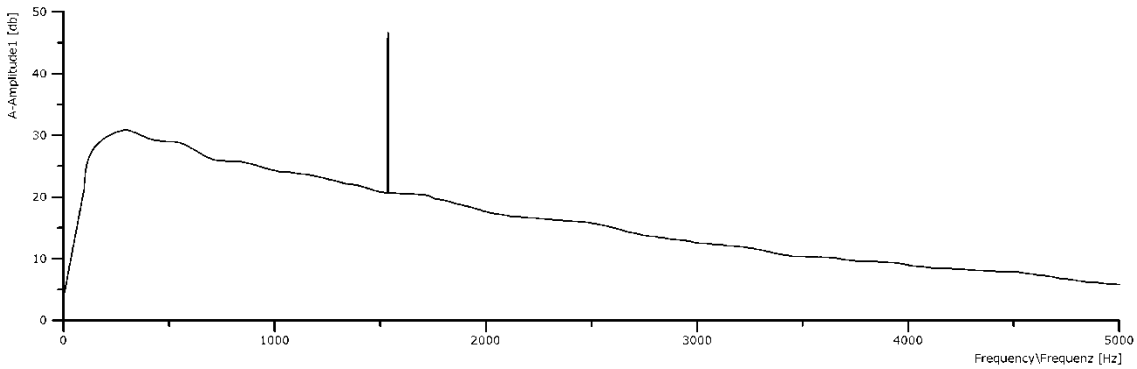


Figure 56: Example - narrowband input data for tonality analysis

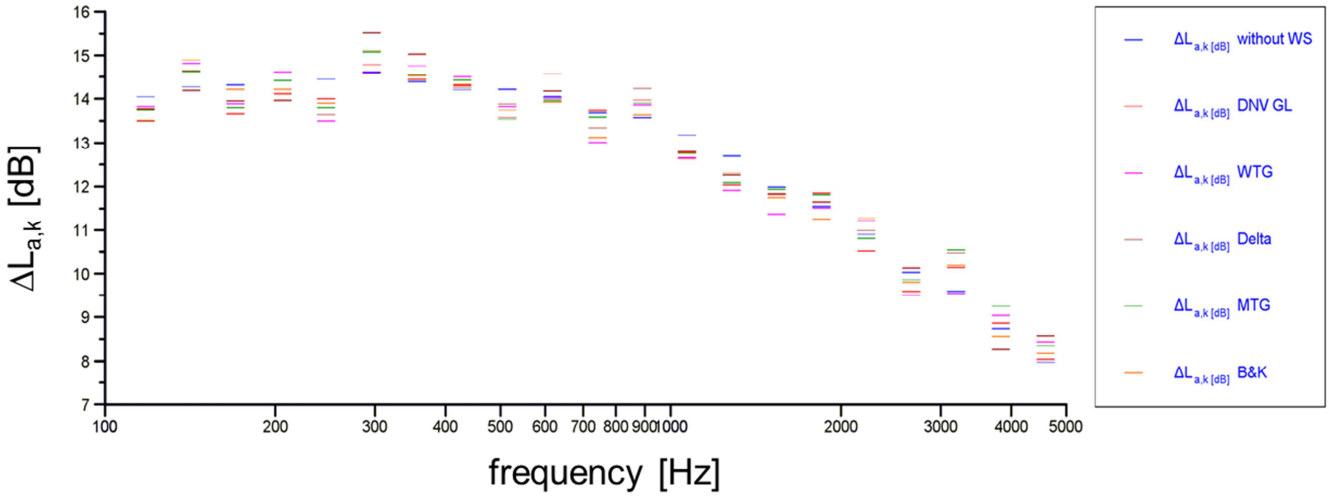


Figure 57: Different tonality $\Delta L_{a,k}$ when using narrow band insertion loss

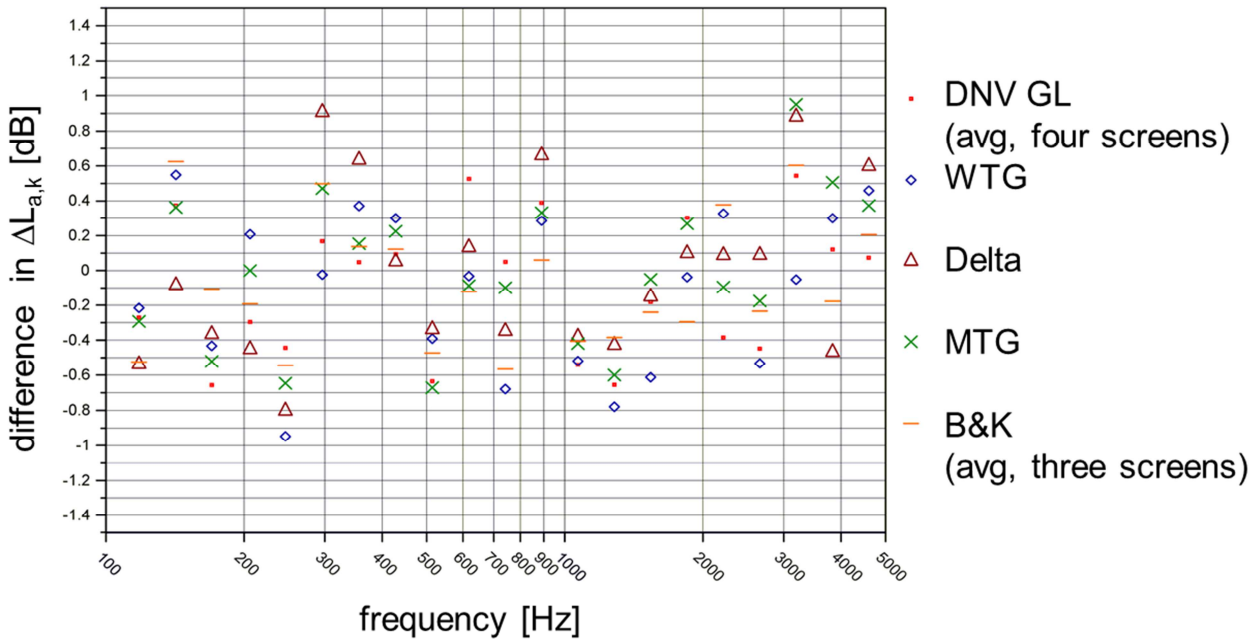


Figure 58: Different tonality $\Delta L_{a,k}$ when using narrow band insertion loss

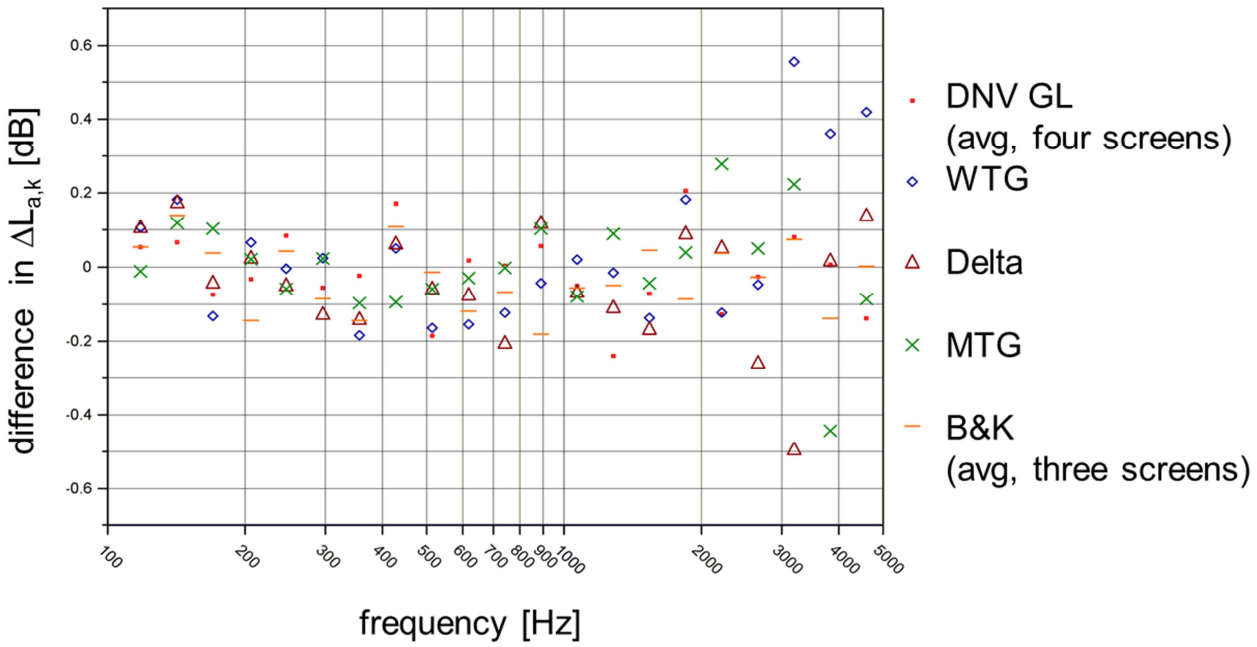


Figure 59: Different tonality $\Delta L_{a,k}$ when using smoothed narrow band insertion loss

9. Conclusion

In addition to the correctly determined insertion loss and standard deviation taken into consideration during evaluation, the user on site makes a considerable contribution to the unwanted impact on measurement results when working with windscreens. Just like any other element of the measurement chain, the windscreen must also be correctly used (protection against wet and dirt, as well as the correct positioning).

10. Outlook

In addition to correcting the insertion loss, the quality of the various windscreens is an important factor in the reduction of wind speed. The better the reduction of the wind speed, the better the reduction of the wind-induced noise. This topic has become more important when it comes to reducing the lowest frequency to be evaluated (IEC 61400 ed. 2.1 → 50Hz, IEC 61400-11 ed. 3.0 → 20Hz) as the wind has a particularly strong impact on low-frequency third-octave bands. Thus every windscreen, depending on the quality of the reduction of the wind speed, contributes to the result at lower frequencies (or whether a result can even be determined by adhering to the minimum permitted signal-noise distance). If measurement results from various wind turbine generators are compared, it is inevitable that these results will be influenced by the different windscreen types used. This may explain part of the pronounced dispersion at low frequencies when comparing results from the various wind turbine generators.

Rotating the microphone 180° during noise emission measurements is another way to further reduce wind-induced noise. In this position, the remaining wind does not meet the microphone diaphragm head on. As the directional pattern of the microphone is not a perfect spherical shape for all frequencies, the influence of the sound incidence direction from 0° to 180° must be considered during evaluation (see **Figure 60**).

Both points described here should be further explored in the future.

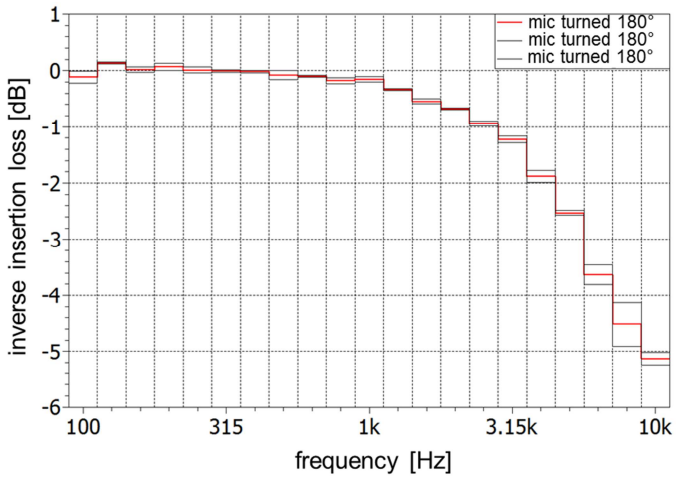


Figure 60: Influence of a 180° microphone rotation compared with 0° with a Φ=34° angle of incidence.

A. References

[1] "IEC 61400-11 ed. 3.0: Wind turbine - Part 11: Acoustic noise measurement techniques", *International Electrotechnical Commission*, 2012-11

[2] Søndergaaard B., Ryom C., AV 135/08, „ Project Report, EFP-06 project, Low Frequency Noise from Large Wind Turbines, Sound Power Measurement Method", DELTA, 2008-04

[3] "Product Data: Accessories for Falcon Range Microphones", *Brüel & Kjær*, http://www.bksv.com/doc/bp1650.pdf

[4] Bork I., Kling C., „Test Report 16149 PTB 14", *Physikalisch-Technische Bundesanstalt* (*PTB*), 2014-06

B. List of test equipment *Senvion*

Description	Manufacturer	Type	Series No.
Dodecahedron	*Müller-BBM VAS*	DOD250A	324716
Front-end	*Müller-BBM VAS*	MKII 2-Slot	
Measurement software	*Müller-BBM VAS*	PAK 5.7 SR7b	
Evaluation software	*Müller-BBM VAS*	PAK 5.7 SR7b PAK 5.8 SR4	
½-inch free-field microphone R0-20%	*Brüel & Kjær*	4190-B-001	2803237
½-inch free-field microphone R0	*Brüel & Kjær*	4190-B-001	2728097
½-inch free-field microphone R0+20%	*Brüel & Kjær*	4190-B-001	2728098
½-inch free-field microphone ref	*Brüel & Kjær*	4190-B-001	2803235
Secondary windscreen *WTG*	*WTG*	*WTG*	102023
Secondary windscreen *DNV GL*	*DNV GL*	*DNV GL*	1-4
Secondary windscreen *MTG*	*MTG*	GFM920.1	
Secondary windscreen *Delta*	*Delta*	Delta type H	
Primary windscreen *B&K*	*Brüel & Kjær*	UA-0237	

C. Company contact details

1. Brüel & Kjær Sound & Vibration Measurement A/S, Skodsborgvej 307, Nærum, DK-2850, www.bksv.com

2. DELTA Danish Electronics, Light & Acoustics, Venlighedsvej 4, 2970 Hørsholm, Denmark, www.madebydelta.com

3. Microtech Gefell GmbH, Georg-Neumann-Platz 1, 07926 Gefell, Germany, www.microtechgefell.de

4. Müller-BBM VibroAkustik Systeme GmbH, Robert-Koch-Straße 13, 82152 Planegg, Germany, *http://www.muellerbbm-vas.com*

5. Siemens Industry Software NV, Research Park 1237, Interleuvenlaan 68, 3001 Leuven, Belgium, www.plm.automation.siemens.com/en_us/products/lms/index.shtml

6. windtest grevenbroich gmbh, Frimmersdorfer Str.73a, 41517 Grevenbroich, Germany, www.windtest-nrw.de