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Statutory Order on noise from wind turbines

Pursuant to section 7(1), No 1, 2 and 8 section 7a(1), section 92 and section 110(3) of the Danish Environmental Protection Act, cf. Consolidation Act No 1121 of 21 September 2018, and section 33(1 and 4), section 48 (2), and section 61(1), of the Danish Act on Protection of the Marine Environment, cf., consolidated act No 1033 of 4 September 2017, the following is laid down:

Part 1

Field of application and definitions

Section 1. This statutory order shall apply to installation, modification and operation of wind turbines.

Section 2. In this statutory order understood by:

1) Small wind turbines: Single standing wind turbines with a rotary area of 200 m^2 or less and with a total height of 25 meter or less, including household wind turbines.
2) Prototype turbines: The first, non-serial produced wind turbine of a new type.
3) Series 0-turbines: First, smaller production series of a new wind turbines type. Series 0-turbines can have a temporary type certificate (B-type certificate) with unfulfilled requirements in accordance to the statutory order on Statutory Order on Technical Certification for construction, manufacturing, positioning, maintenance and service of wind turbines.
4) Experimental turbines: Series 0-turbines or wind turbines, that are prototype certified or rebuild for use in experiments according to statutory order on Statutory Order on Technical Certification for construction, manufacturing, positioning, maintenance and service of wind turbines.
5) Wind Turbine Park: A group of 3 of more wind turbines.
6) Noise impact area around experimental turbines: The largest extent of the area around the experimental turbines, where the combined noise from wind turbines is higher than 37 dB(A) at 6m/s and 39 dB(A) at 8 M/s, defined by the guidelines in annex 1 and 2.
7) Noise-sensitive land use: Areas, in-use as or in the zoning plan or the city planning statute is defined as residence-, institution-, vacation house-, camping- or allotment garden purposes , or areas, that are laid out in the zoning plan or city planning statute for noise-sensitive recreational activities.
8) Low frequency noise: Noise in the low frequency is from 10 to 160 Hz. Low frequency noise is characterized by the A-weighted level of noise in 1/3-oktav frequency bands from 10 to and including 160 Hz, calculated indoors in accordance to the method in annex 1.

Part 2

Requirements for wind turbines

Section 3. The one, who owns a wind turbine, is responsible for it being installed, operated and maintained in such a way that the provisions of this statutory order is complied with.

Section 4. The combined noise impact from wind turbines may not exceed the following limit values:

1) At the most noise-exposed point in outdoor residential areas, no more than 15 meters from the neighbouring dwelling in open countryside:

   a) 44 dB(A) at a wind speed of 8 m/s.

b) 42 dB(A) at a wind speed of 6 m/s.

2) At the most noise-exposed point in areas for noise-sensitive land use:

a) 39 dB(A) at a wind speed of 8 m/s.

b) 37 dB(A) at a wind speed of 6 m/s.

(2) The combined low frequency noise from wind turbines inside indoor dwelling, in the open land or indoor in areas dedicated to noise-sensitive land use may not exceed 20 dB at wind speeds of 8 m/s and 6 m/s.

(3) The limit values in subsection 1 and 2 do not apply to the wind turbine owners dwelling.

(4) The limit values in subsection 1 and 2 do not apply for temporary residence for refugees. Moreover, the residence is without significance for the assessment of noise from wind turbines, if the municipal council has given exemption for section 5u(1), or a permit according to section 5u(1-3) in the planning act that makes possible enabling establishment of a residence on a noise-exposed area.

Section 5. The noise impact cf. section 4 (subsection 1 and 2) is determined in accordance with the guidelines in annex 1 and 2. Moreover, is stated as the equivalent, corrected A-weighted noise level at a height of 1.5 meters at wind speeds corrected to a height of 10 meters at 6 and 8 m/s respectively at a roughness length of 0.05 meters.

Section 6. Measurements of wind turbines source strength and of the tone content in the noise, is done according to the instruction in annex 1 and 2 Environmental Measurements – External Noise, cf. statutory order on quality requirements for environmental measurements.

(2) Measurements of wind turbines, which are fitted with several generators, shall use the noise-emission from the wind turbine in operation with the generator, which causes the highest combined noise-emission, as the basis for the noise measurement.

Part 3

Experimental turbines

Section 7. Dwelling etc. that is erected or organized in existing buildings within a noise impact area around experimental turbines after the time for disclosure of suggestions for the zoning plan, that is zoning the area for positioning of experimental turbines, is without significance for the assessment of noise from experimental wind turbines, cf., subsection 2.

(2) Dwelling etc. that is erected or organized in existing buildings within a noise impact area around experimental turbines at sea after the time for publication of the environmental impact assessment (EIA), is without significance for the assessment of noise from the wind turbines.

(3) When wind turbines are to be established or changed outside an are assigned to experimental turbines on land or outside an area at sea, where the Danish Energy Agency have given permission for establishment of experimental turbines in accordance section 25 in the Danish Promotion of Sustainable Energy Act. The combined noise-emission from the experimental turbines, that is the foundation for the experimental turbines noise impact area, will be the foundation for the assessment of if the noise limits in section 4 subsection 1 and 2 are complied with. The above also applicable at the performance of oversight of these wind turbines.

Part 4

Notifications etc.

Section 8. Anyone who wishes to install or modify a wind turbine, in a way that can increase noise emissions, shall submit notification to the municipal council of this. This does not apply to the establishment or modification of wind turbines at sea.

(2) The notification shall include documentation that the wind turbines can comply with the noise limits in section 4.

(3) Documentation shall take the form of:

1) A report of the noise emission readings from one or more specimens of the notified wind turbine type. In accordance to section 6.
2) Maps of the area in which the applicant wishes to install the notified wind turbine(s). The maps shall feature a scale and North arrow as well as accurately indicate the location of the notified wind turbine(s), the location of existing wind turbines and of neighbouring dwellings and the distance to these and another noise-sensitive land use.
3) The calculation of the noise impact found at the points referred to in section 4 in accordance with the guidelines in Annex 1 and 2.

(4) For prototype turbines and series 0-turbines, there shall be measurements and calculations under section 4(1) so that the likelihood of the turbine complying with the noise limits are made probable.

Section 9. The notification is considered submitted when the municipal council has received all the information specified in section 8(3). Notification, at the earliest, can happen when there is the necessary plan basis, land zone permit and environmental impact assessment for the wind turbine. In accordance with Statutory Order on the Assessment of the Environmental Impact of Certain Public and Private Facilities.

(2) If the municipal council has not made any objections within four weeks of the date specified in subsection (1), the wind turbine may be installed or modified unless this is prevented by other legislation.

(3) Building and construction work may not commence before the expiration of this four-week deadline unless the municipal co9 uncil announces before then that it will not object to the notification.

(4) In areas which, according to municipal or district land-use planning, are reserved for the installation of several wind turbines or assigned to be wind farms and where notification of individual wind turbines takes place consecutively, the municipal council may on the basis of the calculations of the noise from the individual wind turbine set more extensive requirements for the noise contributed by the individual wind turbine than the noise limits set out in section 4. So that the total noise contribution from the wind turbines in the area can comply with the noise limits in section 4.

Section 10. When a wind turbine is put into operation, or modification are put into operation, the municipal council shall be informed of this cf. section 11.

(2) If a notified wind turbine, or modifications of a wind turbine, is not put into operation within two years of the expiry of the deadline in section 9(2), a new notification containing the information specified in section 8(3) shall be submitted to the municipal council.

Part 5

Orders on noise measurements

Section 11. The municipal council have oversight over the compliance of this statutory order, cf. subsection 2.

(2) The Danish Environmental Protection Agency have oversight over the compliance of this statutory order for wind turbines at sea.

Section 12. The municipal council may order the owner of a wind turbine to carry out noise measurements and calculations at their own expense, cf. section 5 and 6:

1) When a notified wind turbine or modification is put into operation;
2) In connection with general statutory supervision, however no more than once a year; or
3) In connection with the processing of neighbours' complaints about noise, when the municipal council considers this to be necessary.

(2) The municipal council can in connection with oversight of small wind turbines, decide that noise measurements shall not be performed as Environmental Measurement – External Noise, cf. section 6 (1).

(3) For wind turbines at sea the Danish Environmental Protection Agency can impose that the owner of a wind turbine perform noise measurements and calculations at their own expense, cf. section 5 and 6.

1) When a wind turbine or modification is put into operation,

2) Related to ordinary oversight in accordance to the Marine Environment Act, however at the most 1 time a year, or
3) Related to the processing of neighbour complaints over noise emission, when the Danish Environmental Protection Agency considers this necessary.

Part 6

Appeals and penalties

Section 13. With the exception of decisions pursuant to section 12, subsection 1 and 2, and all decisions relating to municipally owned or municipally operated wind turbines, decisions taken by the municipal council can not be appealed to another administrative authority.

(2) With the exception of verdicts in accordance to section 12(3), the Danish Environmental Protection Agency decisions can not be appealed to another administrative authority.

Section 14. Unless a higher penalty is prescribed under other legislation, a fine shall be imposed on anyone who:

1) installs or modifies a wind turbine without notification and proper documentation, cf. section 8;
2) commences building and construction work or installs a wind turbine irrespective of any objections from the municipal council, cf. section 9(2) or (4);
3) commences building and construction work in contravention of section 9(3);
4) puts a wind turbine into operation in contravention of section 10; or
5) fails to comply with an order under section 12.

(2) The penalty may be increased to a prison sentence of up to two years should the infringement be committed intentionally or through gross negligence and if the infringement has

1) caused damage to the environment or resulted in the risk thereof, or
2) achieved, or was intended to achieve, financial gain for the person concerned or for others, including as a result of savings made.

(3) Criminal liability may be imposed on companies etc. (legal persons) under the rules of Part 5 of the Danish Penal Code.

Part 7

Entry into force and transitional provisions

Section 15. This statutory order shall enter into force on 13. February 2019.

(2) Statutory order no. 1736 of 21. December 2015 regarding noise from wind turbines is repealed.

(3) Section 7 finds application for experimental wind turbines, where EIA report for wind turbines at sea or suggestions for local plan, that lays out the area for installation of experimental turbines, is publicised 1. January 2012 or later.

(4) Is installation of a wind turbine or modification of a wind turbine notified before 13. February 2019, but not put into operation before 2 years after the expiration of the municipal council's objection period, then a new notification must be submitted to the municipal council in accordance to this statutory order with the specified information from section 8(3). This does not apply to wind turbines at sea.

(5) Statutory order No 304 of 14. May 1991 on noise from wind turbines continue to apply to a wind turbine, which have been notified or put into operation before 1. January 2007, cf. however subsection 9.

(6) Statutory order No 1518 of 14. December 2006 on noise from wind turbines continue to apply to a wind turbine, which have been notified or put into operation before 1. January 2012, cf. however subsection 9.

(7) Statutory order No 1736 of 21. December 2015 on noise from wind turbines continue to apply to a wind turbine on land, which have been notified or put into operation before 13. February 2019, cf. however subsection 10.

(8) Statutory order No 1736 of 21. December 2015 on noise from wind turbines continue to apply to a wind turbine at sea, which have a valid establishment permit according to the Danish Promotion of Sustainable Energy Act or put into operation before 13. February 2019, cf. however subsection 11.

(9) Regardless subsection 5 and 6 the rules of this statutory order applies to modification of a wind turbine on land, that can result in increased noise emissions, or that requires renewed certification in accordance to statutory order on technical certification scheme for wind turbines, cf. however subsection 4.

(10) Regardless subsection 7 the rules of this statutory order applies to modification of a wind turbine on land, that can result in increased noise emissions, cf. however subsection 4.

(11) Regardless subsection 8 the rules of this statutory order applies to modification of a wind turbine at sea, when the modification demands permit according to the rules on permit for essential modifications in existing facilities in the Danish Promotion of Sustainable Energy Act.

The Danish Ministry of the Environment, 7. February 2019

Jakob Ellemann-Jensen

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Annex 1

Part 1

1.1 General rules for measuring noise emission from a wind turbine

Measurement position for Land-based turbines

A turbine's noise emission (sound power level L_{WA} in 1/3 or 1/1 octave band) is measured at different levels of the electrical power produced by the turbine at a point on the leeward side of the tower. Measurements must be taken at a distance R from the base of the turbine, which must not deviate more than ±20% from the distance R_0, furthermore the deviation from the distance R_0 may not exceed ±30 meters (see figure 1). The distance R_0 is the wind turbines hub height (h) plus the rotor radius (½ d). For a wind turbine with a vertical axis R_0 is instead the height to the middle of the rotor plus the transverse dimension of the element that rotates around the vertical axis: this is not illustrated.

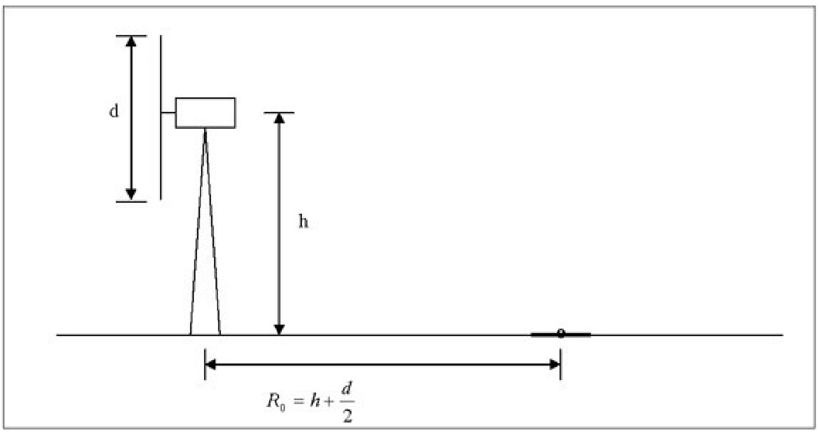

Figure 1.

During the measurement, the microphone must be positioned so that the direction from the tower of the turbine to the microphone does not deviate more than ±15° from the wind direction.

On the basis of sound measurements, A-weighted reference spectra are determined at wind speeds of 6 m/s and 8 m/s respectively.

Half a windscreen is affixed to the microphone, which is positioned directly above a reflective plate on the ground in order to eliminate wind noise in the microphone as much as possible. The plate must not be smaller than one metre in any direction. When measuring noise emissions at low frequencies the wind may provide a too powerful background noise. This can be counteracted by using a secondary windscreen, that is half circle shaped, between 40 and 50 cm in diameter or greater, and is placed concentric above the microphone and primary windscreen. When using a secondary windscreen there must be a correction for the dampening of the noise that the wind protector causes. The correction must be made in 1/3-oktave band.

Measurements of sound spectra and wind speed.

The noise from the turbine is measured as a number of A-weighted sound spectra pr. 1/3- octave in a frequency area, which at least encompasses the octave bands from 20 to 10000 Hz. A number of sound spectra is measured in periods, the periods shall be between 10 and 60 seconds, and where there in the same period is registered both the wind turbines produced electric mean power, the wind speed measured with the wind turbines built-in anemometer in hub height, and furthermore with a anemometer placed in a minimum height of at least 10 meters near the wind turbine on a location, where neither the wind turbine nor the objects in the terrain is estimated to influence the wind measurement.

The wind speed v_h at the wind turbines hub height is calculated based on the turbines power curve. In the calculation, there is alone used segments of the power curve, that including insecurities on the power have a positive slope. In the calculation piecewise, linear interpolation between the points is used in the specified wind speed bins on the power curve. For segments of the power curve, there have no positive slope; the wind speed is decided by the wind turbines built-in anemometer in hub height. Used in this context is an insecurity of 2% of the turbines nominal power.

The wind speed V_{ref} at a height of 10 meters under reference conditions may then be determined by using Equation 1.1.1. At higher electrical output the wind speed V_h at hub height is determined instead by using the built-in anemometer in the wind turbine at hub height, and the wind speed $V_r$ef is determined by using Equation 1.1.1. If in exceptional cases the power curve of the wind turbine is not known, or when the wind turbine has been parked due to background noise being measured, the wind speed is determined by using the anemometer erected at a height of at least 10 meters. The wind speed V_{ref} is then determined by using Equation 1.1.2.

Based on all measurements while the wind turbine is in operation with an average power of less than 0.95 times nominal power, the correlation between the three different wind speed measurements is established as follows: For each measurement period of 10 or 60 seconds the ratio between the wind speed based on the power curve of the wind turbine and the two separately measured wind speeds is determined, and finally the average value of all ratios for each of the two anemometers is determined. These averaged ratios must be multiplied with the readings from the built-in anemometer in the wind turbine at hub height when the average power produced is more than 0.95 times nominal power and with the reading on the anemometer erected at a height of at least 10 meters when the wind turbine has been parked and background noise is measured. This Constitutes an *in situ* calibration of the built-in anemometer in the wind turbine and the erected anemometer. Because the power curve of the wind turbine is used to establish the correlation between the power produced and the wind speed, a copy of the power curve must form part of the report on source strength measurements.

For an averaging period of 10 seconds a minimum of 30 spectra must be measured at average electrical power equivalent to the wind speed V_{ref} at a height of 10 meters under reference conditions falling within a range of 5.5 m/s ≤ V_{ref} ≤ 6.5 m/s and a minimum of 30 spectra where V_{ref} similarly falls within a range of 7.5 m/s ≤ V_{ref} ≤ 8.5 m/s. For an averaging period of 60 seconds, proportionally fewer spectra may be measured in each of the two ranges. Of the above, a minimum of 12 of the spectra (for a period of 10 seconds) must fall within the following four ranges for V_{ref}:

5.5 m/s ≤ v_{ref} < 6.0 m/s

6.0 m/s ≤ v_{ref} < 6.5 m/s

7.5 m/s ≤ v_{ref} < 8.0 m/s

8.0 m/s ≤ v_{ref} < 8.5 m/s

The A-weighted reference spectrum at 6 m/s and 8 m/s respectively for each 1/3 octave bands (or 1/1 octave bands) is then determined as the average energy value of the measured sound pressure spectra for V_{ref} within the specified ranges at around 6 m/s and 8 m/s respectively.

$$v_{ref} = v_h \cdot \frac{\ln \frac{z_{ref}}{z_{0ref}}}{\ln \frac{h}{z_{0ref}}}$$

where:
h = turbine hub height (in metres)
z_{0ref} = reference roughness 0.05 metres (fixed value)
z_{ref} = reference height 10 metres (fixed value)

Equation 1.1.1. Correction of wind speed measured at hub height to a height of 10 meters.

If the wind speed is measured at height z, the correlation between V_{ref} and V_z is shown in Equation 1.1.2.

$$v_{ref} = v_z \cdot \frac{\ln \frac{z_{ref}}{z_{0ref}} \cdot \ln \frac{h}{z_0}}{\ln \frac{h}{z_{0ref}} \cdot \ln \frac{z}{z_0}}$$

where:
z = height of the erected anemometer (in metres)
z_0 is the roughness of the terrain at the measurement location. The roughness of the terrain z_0 is estimated based on Table 1.1.

Equation 1.1.2. Correction of wind speed measured by erected anemometer at height z to 10 meters.

Type of terrain	Roughness z_0 [metres]
Water, snow, sand	0,0001
Open, flat land, bare soil, mown grass	0,01
Farmland with some vegetation	0,05
Residential areas, small towns, areas with dense, tall vegetation	0,3

Table 1.1: Roughness for different types of terrain

Correction for background noise, determination of sound power level

With the turbine stopped, the background noise is measured as an equivalent number of sound spectra and within the same wind speed ranges as indicated above. The wind speed is measured using an anemometer erected at a height of at least 10 meters, and the wind speed V_{ref} is calculated using Equation 1.1.2.

The average energy value of the measured background noise spectra is determined at 6 and 8 m/s respectively and used to correct the wind turbine's reference spectrum by correcting the sound pressure levels $L_{A,ref}$ in each 1/3 octave band (or 1/1 octave band) in the reference spectrum by use of Equation 1.1.3. If the sound pressure level in the reference spectrum is not at least 3 dB higher than the sound pressure level of the background noise, the correction for background noise must be limited to 3 dB. The total level L_{Aeq} of the averaged background noise must be at least 6 dB lower than the total level L_{Aeq} of the wind turbine noise. If this is not the case, a new measurement must be carried out when the background noise is lower. However, for inspection of noise impact, measurements may be used where the different between total noise and background noise is less than 6 dB provided the calculated noise level after correction for a background noise of -1.3 dB is no higher than the limit values.

$$L_{A,ref,k} = 10 \cdot \log(10^{\frac{L_{A,ref}}{10}} \div 10^{\frac{L_{A,b}}{10}})$$

where:
$L_{A,\,ref,\,k}$ = the corrected reference sound pressure level in 1/3 octave bands (or 1/1 octave bands)
$L_{A,\,b}$ = the sound pressure level of the averaged background noise in 1/3 octave bands (or 1/1 octave bands)

Equation 1.1.3. Correction for background noise

The wind turbine's sound power level $L_{WA,ref}$ in 1/3 octave bands (or 1/1 octave bands) can then be calculated using Equation 1.1.4.

$$L_{WA,ref} = L_{A,ref,k} + 10 \cdot \log 4\pi(R^2 + h^2) \div 6dB$$

6 dB is a correction due to measuring close to a reflective board on the ground
R = the current measuring distances between the microphone and the base of the wind turbine.

Equation 1.1.4. The sound power level of the wind turbine

The method described complies with IEC 61400-11, and measurements carried out in accordance with this standard may be used as a basis for the determination of $L_{WA,ref}$.

1.2. Determination of sound pressure level L_{pA}

At a point, e.g. by the nearest neighbor, the wind turbine's sound pressure level in 1/3 octave bands (or 1/1 octave bands) at a height of 1.5 meters can be determined using Equation 1.2.1.

$$L_{pA} = L_{WA,ref} \div 10 \cdot \log(l^2 + h^2) \div 11dB + \Delta L_g \div \Delta L_a$$

where:
l = the distance from the base of the turbine to the calculation point
11 dB = correction for distance, 10 x log 4π
ΔL_g = correction for ground effect (1.5 dB for onshore turbines and 3 dB for offshore turbines)
ΔL_a = air absorption, ($\alpha_a \times \sqrt{l^2 + h^2}$) where the absorption coefficient α_a is shown in Tables 1.2 and 1.3.

Equation 1.2.1. Calculation of sound pressure level in 1/3 octave bands (or 1/1 octave bands)

Terrain correction for wind turbines at sea is valid when calculating the sound pressure level at a building near the coast. If the noise must be calculated for a building, that when looking at the direction of the wind turbines is more than 200 meters from the coastline, then terrain correction for land placed wind turbines is used. For buildings that are within 0 and 200 meters from the coast a linear interpolation between the 2 values is made for the terrain correction.

Calculations are carried out for 1/3 octave bands 50-10,000 Hz or 1/1 octave bands 63-8,000 Hz.

An optional safety margin can be added, so that the calculations are using a higher value for the source strength $L_{WA,ref}$, than it is evident from the target report.

Octave band centre frequency in Hz	63	125	250	500	1000	2000	4000	8000
α_a in dB/km	0,11	0,38	1,02	2,0	3,6	8,8	29,0	104,5

Table 1.2: Air absorption coefficients per 1/1 octave at a relative air humidity of 80% and an air temperature of 10º C

1/3 octave centre frequency in Hz	50	63	80	100	125	160	200	250	315
α_a in dB/km	0,07	0,11	0,17	0,26	0,38	0,55	0,77	1,02	1,3

1/3 octave centre frequency in Hz	400	500	630	800	1000	1250	1600	2000
α_a in dB/km	1,6	2,0	2,4	2,9	3,6	4,6	6,3	8,8

1/3 octave centre frequency in Hz	2500	3150	4000	5000	6300	8000	10000
α_a in dB/km	12,6	18,8	29,0	43,7	67,2	105	157

Table 1.3: Air absorption coefficients per 1/3 octave at a relative air humidity of 80% and an air temperature of 10º C

Correction for multiple reflections for wind turbines at sea

The threshold distance, l_0, for multiple reflections is determined for V_{ref} = 6 m/s and V_{ref} = 8 m/s by Equation 1.2.2.

$$l_0 = 2000 \cdot \frac{h}{30} \cdot \sqrt{\frac{6}{v_{ref}}}$$

Equation 1.2.2. Threshold distance for multiple reflections

The normed distance, l', between the wind turbine and the coat in the direction of the calculation point is determined with Equation 1.2.3.

$$l' = \frac{l_k}{l_0}$$

Where L_k is the distance between the wind turbine and the coast in the direction of the calculation point.

Equation 1.2.3. Normed distance between the wind turbine and the coast.

Correction for multiple reflections, ΔL_m, is henceforth calculated by Equation 1.2.4.

$$\Delta L_m = \begin{cases} 0 \;\; for\; l' \leq 1 \\ 10 \cdot \log l' \;\; for\; 1 < l' < 2{,}512 \\ N \cdot \log \frac{l'}{2{,}512} + 4 \; for\; 2{,}512 \;\leq\; l' \;\leq 5 \\ 10 \cdot \log l' + (N-10) \cdot \log \frac{5}{2{,}512} \;\; for\; l' > 5 \end{cases}$$

Where N is a frequency dependant scaling factor, that can be seen in tabel 1.3.2.

Equation 1.2.4. Calculation of correction for multiple reflections.

1/3-Octaveband center frequency in Hz	**<400**	**500**	**630**	**>800**
N	20	16,8	13,4	10

Table 1.3.2. Scaling factor N for the determination of correction for multiple reflections

The total A-weighted sound pressure level $L_{pA,tot}$ at the point is then found by adding the sound pressure levels $L_{pA,i}$ in each 1/3 octave band (or 1/1 octave band), cf. Equation 1.2.5.

$$L_{pA,tot} = 10 \cdot \log \sum 10^{\frac{L_{pA,i}}{10}}$$

Equation 1.2.5. Combined noise pressure level.

The uncertainty of the calculated sound pressure level L_{pA}, tot by use of this method is ±2 dB.

1.3. Determination of tones and noise exposure level L_r

In order to determine the noise exposure level L_r (noise impact) at a given point, the content of clearly audible tones in the noise is measured.

If a frequency analysis, conducted according to annex 2, of the turbine noise measured close to the wind turbine as described in the procedures for measurement of the A-weighted sound power level, shows there should be no penalty for clearly audible tones near the wind turbine, there will be no tones in the noise at dwellings, and a separate analysis hereof is not necessary.

If the measurement near the wind turbine indicates a penalty, the measurement is taken at the dwelling or those dwellings, where the combined noise exposure, with or without an eventual tone penalty, is greatest, and where the exceedance of a noise limit may occur. The noise measurement must be carried out at a representative point close to the nearest dwelling, 1.5 meters above ground and selected in such a way that the wind noise has as little effect as possible on the measurement results[1)]. The chosen measuring point or points are documented by photos.

There must be a downwind of ± 45° from the wind turbine towards the measurement position. In this context, there are no requirements for temperature gradient or cloud cover. The wind speed measured at 10 meters above ground, decided according to the power curve, for that wind turbine that can cause tone content in the noise at the neighbors, must be between 5 and 9 m/s. For small wind turbines, where there is no power curve available, the wind speed is determined by a measurement 10 meters above terrain.

Measurements should last at least 1 hour under those operation circumstances where the tone is the clearest. Objective analyzes of the tonal content is made according to the guidelines in section 3. And in such a way that there is at least 5 spectra (averaging time 60 seconds) in each of the wind speed intervals 5,5 m/s – 7 m/s (at least one spectrum at a wind speed under 6,0 m/s) and 7 m/s – 8,5 m/s (at least one spectrum at wind speed over 8,0 m/s). The tonal penalty K_T, in dB, is determined for each of the measured spectra as indicated in annex 2, section 2.4, equation 2.4.2.

The noise exposure L_r for 6 and 8 m/s is determined on the basis of the highest value of K_T for each of the corresponding wind speed intervals as specified in equation 1.3.1.

$$L_r = L_{pA,tot} + K_T$$

Equation 1.3.1. Determination of noise exposure level L_r with penalty of clearly audible tones.

When processing a notification, the tone content may be determined on the basis of a measurement on the downwind side of an equivalent turbine at a distance corresponding to the distance to the neighboring point.

1.4. Determination of low-frequency noise from wind turbines

The level of low-frequency noise, e.g. in the nearest dwelling, is determined by use of Equation 1.4.1.

$$L_{pALF} = L_{WA,ref} - 10 \cdot \log(l^2 + h^2) - 11dB + \Delta L_{gLF} - \Delta L_\sigma - \Delta L_a$$

where:
l = the distance from the base of the wind turbine to the calculation point
11 dB = correction for distance, 10 x log 4π
ΔL_{gLF} = correction for ground effect at low frequencies (Table 1.4)

ΔL_σ = sound insulation at low frequencies (Table 1.4)

ΔL_a = air absorption, ($\alpha_a \times \sqrt{l^2 + h^2}$) where the absorption coefficient α_a is shown in Table 1.4.

ΔL_m = correction for multiple reflections (0 dB for land based wind turbines, for sea based wind turbines see equation 1.2.4)

Equation 1.4.1. Calculation of low-frequency noise from wind turbines in 1/3 octave bands

1/3 octave center frequency in Hz	**10**	**12,5**	**16**	**20**	**25**	**31,5**	**40**
ΔL_{gLF}: ground correction, onshore wind turbine (dB)	6,0	6,0	5,8	5,6	5,4	5,2	5,0
ΔL_{gLF}: ground correction, offshore wind turbine (dB)	6,0	6,0	6,0	6,0	6,0	5,9	5,9
ΔL_σ: sound insulation (level difference) (dB)	4,9	5,9	4,6	6,6	8,4	10,8	11,4
α_a in dB/km	0,0	0,0	0,0	0,0	0,02	0,03	0,05

1/3 octave center frequency in Hz	**50**	**63**	**80**	**100**	**125**	**160**
ΔL_{gLF}: ground correction, onshore wind turbine (dB)	4,7	4,3	3,7	3,0	1,8	0,0
ΔL_{gLF}: ground correction, offshore wind turbine (dB)	5,8	5,7	5,5	5,2	4,7	4,0
ΔL_σ: sound insulation (level difference) (dB)	13,0	16,6	19,7	21,2	20,2	21,2
α_a in dB/km	0,07	0,11	0,17	0,26	0,38	0,55

Table 1.4: Terrain correction for low-frequency noise for wind turbines location onshore and offshore respectively, sound insulation (level difference) and air absorption coefficients per 1/3 octave at a relative air humidity of 80% and an air temperature of 10º C

Ground correction for offshore wind turbines is valid for calculation of low-frequency noise in a building close to the coast. If noise is to be calculated in a building which, seen in the direction of the wind turbines, is more than 200 meters inland, the terrain correction for onshore wind turbines is used instead. For buildings located between 0 and 200 meters from the coast linear interpolation between the two values for terrain correction is made.

The total sound pressure level of the low-frequency noise $L_{pALF, tot}$ in the dwelling is then found by adding the sound pressure levels $L_{pALF,i}$ in each 1/3 octave band, cf. equation 1.4.2.

$$L_{pALF,tot} = 10 \cdot \log \sum 10^{\frac{L_{pA,i}}{10}}$$

Equation 1.4.2. Total sound pressure level

The uncertainty of the calculated sound pressure level $L_{pALF,tot}$ by use of this method is ±2 dB.

Part 2

Special rules

2.1 Determination of noise from wind farms

In this statutory order, a wind farm means a cluster of three or more identical wind turbines irrespective of whether these are erected onshore or offshore.

The sound power level $L_{WA, ref}$ in 1/3 octave bands or 1/1 octave bands is determined by measurements of at least three randomly selected wind turbines of the same type. For the other wind farm turbines the average energy value of the three (or more) measured sound power levels is used. Wind turbines with different noise modes is considered wind turbines of different types in this setting.

The erected anemometer must, if it is located on the downwind side of one of the other wind turbines, have a distance to this wind turbine of at least ten times the rotor diameter (d) of the turbine. See Figure 1.

The sound pressure level in 1/3 octave bands or 1/1 octave bands at a point is found by adding the noise contribution from each wind turbine calculated using Equation 1.2.1, as shown in Equation 2.1.

$$L_{total} = 10 \cdot \log(10^{\frac{L_p 1}{10}} + 10^{\frac{L_p 2}{10}} + \ldots)$$

Equation 2.1. Total sound pressure level form multiple wind turbines

The same formula is used when the contribution from a new wind turbine needs to be added to the sound pressure level produced by the existing wind turbines around the dwelling concerned.

The total A-weighted sound pressure level $L_{pA,tot}$ at the point is then found by using Equation 1.2.5.

Correction for multiple reflections for offshore wind turbine parks

Calculations of ΔL_m is completed at each individual wind turbine to determine the threshold distance, l_0, on the basis of the downwind component in the direction from wind turbine to calculation point in relation to one fixed wind direction, which is the direction from the turbine, that is nearest the calculation point, to the calculation point. The tail wind component $v_{ref,k,i}$ for wind turbine "i" in the park is determined by equation 2.2:

$V_{ref,k,i} = v_{ref} \cdot \cos \theta_i$

Where:
θ_i is the angle between the direction from the calculation point to the nearest wind turbine and the direction from

Equation 2.2. Calculation of downwind component.

Cos θ_i can be found with equation 2.3:

$$Cos\ \theta_i = \frac{l_1^2 + l_i^2 - l_m^2}{2 \cdot l_1 \cdot l_i}$$

Where:
l_1 = the distance from calculation point to the nearest wind turbine in the park
l_i = the distance from calculation point to the wind turbine "i"
l_m = the distance between wind turbine "i" and the wind turbine nearest the calculation point.

Equation 2.3. Calculation of cos θ_i

Threshold distance $l_{0,i}$ for wind turbine "i" in the wind turbine park can be found hereafter by inserting $V_{ref,k,i}$ into equation 1.2.2.

2.2 Measurement of noise emission from offshore wind turbines

A. Microphone mounted on a reflective board on the ship

Compared to measurements for onshore wind turbines, the measurement method is changed so that the reflective board on to which the microphone is placed is affixed to the roof of the pilothouse on the measuring vessel or on a correspondingly large surface with an unobstructed view to the wind turbine from the location of the microphone. The roof or board must be no smaller than four meters in any direction.

Otherwise, the instructions set out in Chapter 1, Section 1, apply.

B. The microphone mounted off the side of the ship

If the microphone cannot be mounted as specified under Heading A, the microphone must be positioned 3-5 meters above sea level, free from reflective surfaces, etc. and 1-2 meters away from the side of the measurement vessel with an unobstructed view to the wind turbine. A primary windscreen must be affixed to the microphone, and the microphone axis must point in the direction of the hub of the wind turbine.

The noise from the wind turbine is measured as A-weighted spectra for a number of periods in accordance with the guidelines set out in Chapter 1, Section 1 for onshore wind turbines, with simultaneous recording of the power produced by the wind turbine, the wind speed at hub height measured by the built-in anemometer in the wind turbine and the wind speed v_z at a height of at least 10 meters above sea level with the anemometer placed on the same vessel as the microphone. Due to the low roughness value of the surface of the sea, $v_z = v_{ref}$.

If the background noise is too high, its effect may be reduced by increasing the height of the microphone to 5 meters and reducing the measuring distance.

The turbine's sound power level $_{LWA,ref}$ in 1/3 octave bands (or 1/1 octave bands) is then determined as indicated in 2.4.

$$L_{WA,ref} = L_{A,ref,k} + 10 \cdot \log 4\pi (R^2 + h^2) \div 3dB$$

Equation 2.2. Sound power level for offshore wind turbines

The instructions above for the measurement of the noise impact of wind farms also apply to the measurement of the noise impact of offshore wind farms.

2.3 Measurement of noise emission from small wind turbines

For small wind turbines, including domestic turbines, the source strength is determined in accordance with the principles in the method specified in 1.1 with the option of the following deviation:

- During measurement, the microphone must be positioned in such a way that the direction from the tower of the turbine to the microphone does not deviate more than ±45° from the wind direction.

Small wind turbines usually do not provide the option of direct reading of the power produced in short time ranges, and the correlation between the noise emission of the wind turbine and the wind speed is, therefore, based on measurements by an anemometer erected at a height of at least 10 meters near the wind turbine in a position where neither the wind turbine nor other objects in the area are deemed to affect the wind measurement.

Annex 2

Objective method for determination of the clarity of tones in noise

Part 1

The method[2)] includes procedures for stationary and for varying tones, for narrowband noise as well as low frequency tones, and the result is a graduated tonal penalty between 0 and 6 dB[3)].

Part 2 Objective method

2.1. In general

The method has three steps:
1. Narrowband frequency analysis (FFT-analysis).
2. Determination of average sound pressure levels for the tone or tones and masking noise within a critical band around the tone/tones.
3. Calculation of the tones clarity ΔL_{ta} and the penalty, K_T.

2.2. Frequency analysis

Every A-weighted narrowband spectrum is determined by linear averaging for one minute (long-term averaging).

The effective analysis bandwidth must be smaller than 5% of the width of the critical band with tone components. The width of the critical band is given in Table 1. As a starting point, it is recommended to use 3 Hz frequency resolution equivalent to an effective analysis bandwidth at 4,5 Hz.

The frequency analyser must be calibrated in dB re 20 µPa, and Hanning weighting is used as window function.

Notes:
1) With the use of Hanning time-window, the effective analysis bandwidth is 1,5 times the frequency resolution. The frequency resolution is the distance between the lines of the spectra.
2) With an effective analysis bandwidth of 5% of a critical band will just audible tones normally be seen as local maxima of at least 8 dB above the surrounding noise in the averaged spectra.
3) In rare circumstances with a complex of many close tones, a finer resolution (lesser bandwidth) can be necessary to determine the level of the masked noise correctly.
4) If the frequency of the audible tones within the averaging time varies more than 10% of the width of the actual critical band, it can be necessary to subdivide the long-term averaging in a number of averages with a shorter duration. In this case, the combined Leq for the tone is calculated according to the same principle as described in the Danish environmental agency's guidance no. 6/1984 section 8.

2.3. Determination of sound pressure levels

2.3.1. Sound pressure level of tones, L_{pt}

The tones are identified by visual inspection of the narrowband spectrum, and the sound pressure levels of the tones is determined based on the spectrum.

All local maxima with a 3 dB-bandwidth, which is less than 10% of the bandwidth of the actual critical band, are regarded as a tone.

The levels, L_{pti}, of all tones, no. i, within the same critical band shall be added on an energy basis to give the total tone level in this band, L_{pt}:

$$L_{pt} = 10 \log \sum 10^{\frac{L_{pti}}{10}}$$

Equation 2.3.1. The total tone level in a critical band.
Notes:

1) If a "tone" is actually narrowband noise, or if the frequency of the tone is varying, then the tone will show itself as a number of lines in the averaged spectrum. In these cases L_{pti} the energy sum of all lines with levels within 6 dB of the local maxima, corrected for the influence of the used window-function (for the Hanning-window this is the energy sum subtracted 1,8 dB).

2) In cases, where tones occur at low frequencies, it is advisable to investigate the tones unweighted level in relation to the hearing threshold (see DS/EN ISO 387-7). Tones with levels 10 dB or more below the hearing threshold they are disregarded.

2.3.2. Bandwidth and center frequency for critical bands

The bandwidths of critical bands are shown in Table 2.1.

Center frequency, fc [Hz]	50-500	Above 500
Bandwidth [Hz]	100	20% of f_c

Table 2.1. The width of critical bands.

If there is only one tone in a critical band, place it with center frequency, fc, equal to the tone frequency, however in such a way that fc is greater than 50 Hz.

If the spectrum contains multiple tones, the critical band is placed around the most significant tones so that:

1) As many possible significant tones are included in the critical band, and
2) In such a manner, that the difference in the total tone-level, L_{pt}, and the level of the masking noise, L_{pn}, (see section 2.3.3.) becomes the greatest possible. This point is crucial in relation to point 1.
3) When the relevant tones are selected, the critical band is placed symmetrical around the selected significant tones in that band.

For the purpose of determination of the center frequency of the critical band, f_c, only tones within 10 dB of the tone with the highest level are regarded as significant.

Note:

The center frequency of the critical bands, f_c, can vary continuously within the relevant frequency area. The lowest critical band is 0 Hz - 100 Hz.

2.3.3. Sound pressure level of the masking noise in a critical band, L_{pn}

The average sound pressure level in a critical band, $L_{pn,avg}$, can be found by a visual averaging of the spectrums "noise lines" within an area between ±0,5 and ±1 times the width of the critical band around the center frequency, f_c. The "noise lines" are found by disregarding all maxima in the spectrum, which are due to tones and any of their sidebands in the concerned area.

The total sound pressure level of the masking noise in a critical band, L_{pn}, is calculated based on the average noise level in the same critical bands, $L_{pn,avg}$, as indicated in equation 2.3.2.:

$$L_{pn} = L_{pn,avg} + 10 \log (\text{bandwidth of critical band / effective analysis bandwidth})$$

Equation 2.3.2. The total sound pressure level of the masking noise in a critical band

2.4. Calculation of the tones clarity, ΔL_{ta}, and the penalty, K_T

The tones clarity, ΔL_{ta}, is expressed in dB above the masking threshold, MT, see Figure 2. The penalty, K_T, is the value that is added to L_{Aeq} for a period of time to get the tone corrected noise exposure in this period of time. From the difference between the level of tone and noise in a critical band, $L_{pt} - L_{pn}$, both ΔL_{ta} and K_T can be determined with the help of Figure 2.

A given center frequency, f_c, of the critical band and a given level difference $L_{pt} - L_{pn}$ determines a point in Figure 2. ΔL_{ta} is determined as the difference between $L_{pt} - L_{pn}$ and the masking threshold, which is shown on the figure. K_T is read by interpolating between the lines marked with different values of K_T in the figure. Alternatively, ΔL_{ta} can be calculated by equation 2.4.1., and K_T can be calculated by equation 2.4.2.

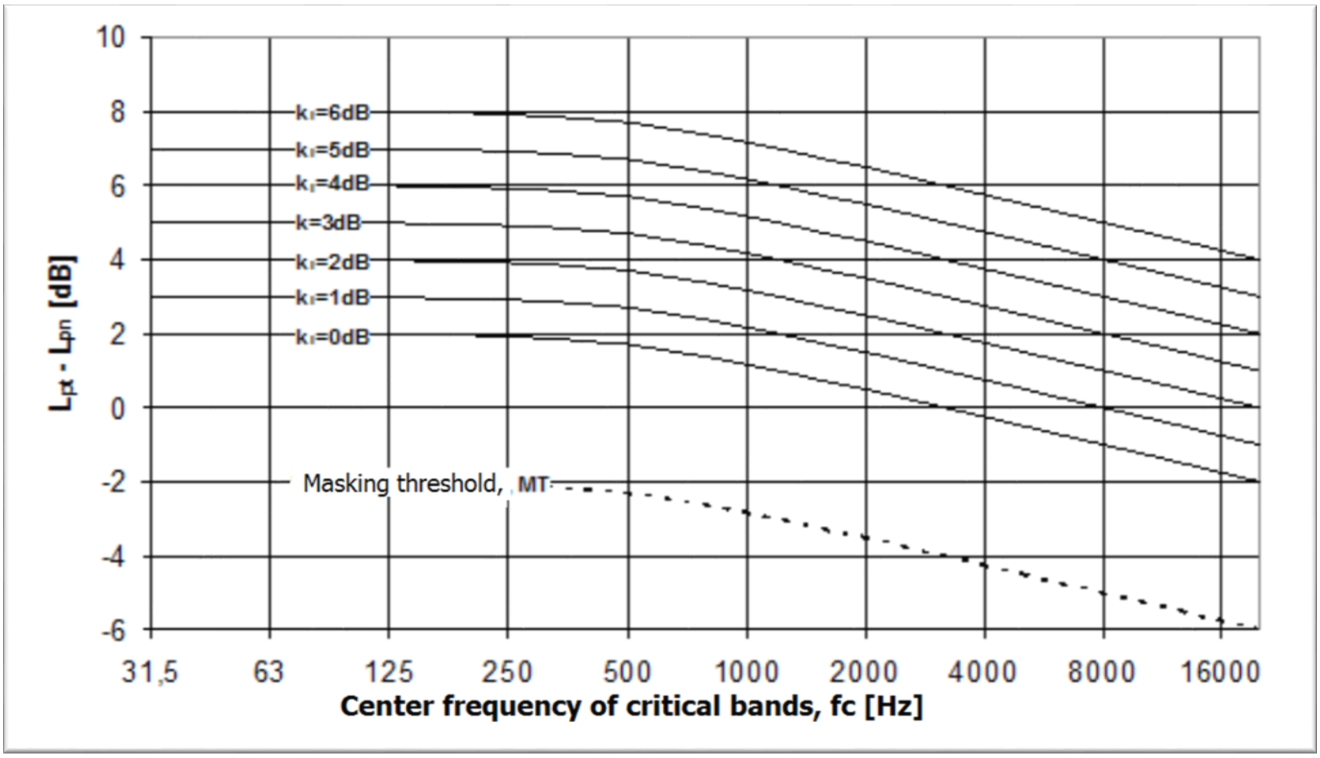

Figure 2.
The masking threshold, MT, and curves for determination of the penalty, K_T. L_{pt} is the total sound pressure level of the tones in a critical band, and L_{pn} is the total sound pressure level of the masking noise in the same band.

The clarity of the tones in a critical band can be calculated with the help of equation 2.4.1.:

$$\Delta L_{ta} = L_{pt} - L_{pn} + 2 + \log\left(1 + (f_c / 502)^{2,5}\right) \text{ dB re MT,}$$

Where

L_{pt} is the total sound pressure level of the tones in the critical band,

L_{pn} is the total sound pressure level of the masking noise in the critical band, and

f_c is the center frequency in Hz of the critical band.

Equation 2.4.1. Clarity of tones in a critical band.

The penalty, K_T, in dB can be determined by equation 2.4.2.:

10 dB < ΔL_t: K_T = 6 dB 4 dB ≤ ΔL_{ta} ≤ 10 dB: $K_T = \Delta L_{ta}$ - 4 dB ΔL_{ta} ≤ 4 dB: K_T = 0 dB Note: K_T is not limited to integer values.

Equation 2.4.2 the penalty K_T.

If multiple tones (or groups of tones) occur in the same spectrum within different critical bands, separate calculations must be made for each of these bands. The critical band, containing the clearest tone or tones (i.e. the one or ones with the highest value of ΔL_{ta}), is essential for ΔL_{ta} and for the penalty, K_T, based upon this spectrum.

Part 3 Documentation

The tone analysis must be documented by the following:

3.1. The frequency analysis

- Measurement period, number of spectra/averaging time and effective analysis bandwidth.
- Time period (e.g. Hanning), tone weighting (Lin) and frequency weighting (A).
- A typical spectrum with indication of the location of the determining critical band and the average noise level in that band.

3.2. Calculation in the determining critical band

- Specify if the result are reached by visual averaging or by automatic calculation.
- Frequencies and levels of the tones and the total tone level, L_{pti}, in dB re 20 μPa.
- The level of the masking noise in the critical band, L_{pn}, in dB re 20 μPa.
- Clarity of the tone(s), $\Delta L_{ta,}$ in dB above the listening threshold.
- The value of the penalty, K_T, in dB.

Tones in other critical bands, that can trigger a penalty, must be stated at least by their frequency.

Part 4 Clarifying definitions of tone- and noise levels

Especially for the purpose of computer implementation of the method is there in this part given a more clarifying definition of tones and noise.

4.1. In general

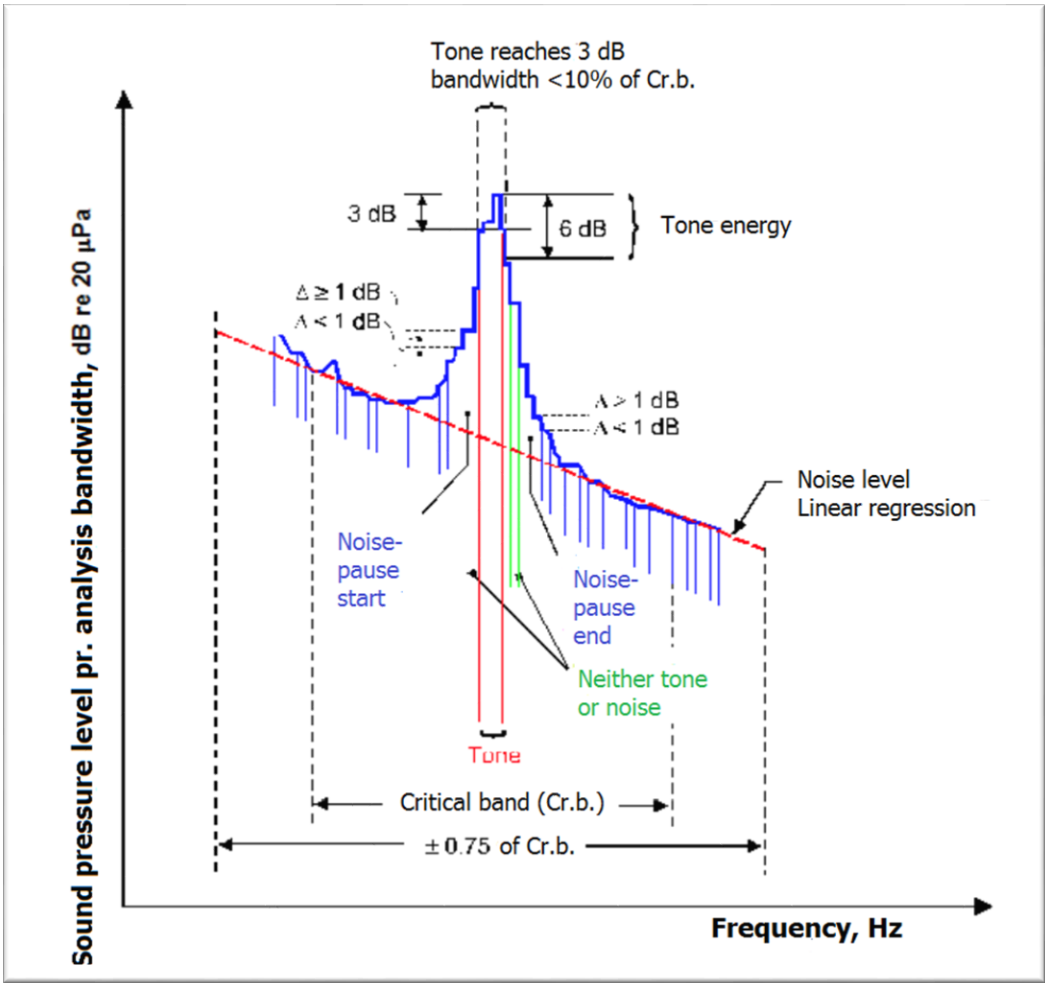

Figure 3
Definitions of tones (red lines), noise (blue lines) and noise pauses (neither tones nor noise, green lines). Δ is the tone search criterion and is usually selected to 1 dB.

Note:

It is important, those software implementations makes visual inspections of the results possible. As a minimum a spectrum is needed, where it is indicated, what lines that are defined as tones, along with a marking of the surrounding critical band with associated regression line for the noise. Moreover, it will be a help with an indication of, which lines that are characterized as noise, noise pauses and tones. This can e.g. be indicated by the use of different colours for the spectrums lines as seen in Figure 3.

4.2. Noise pauses

Noise pauses are local maxima in the spectrum with possible occurrence of tones. The noise pauses are defined and found based on the following principle:

The start if a noise pause is found on the positive (left) flank of a local maximum as the line, s, where the following conditions are met:

$L_s - L_{s-1} \geq \Delta$ dB and

$L_{s-1} - L_{s-2} < \Delta$ dB,

Where L_s is the level of line no. s and L_{s-1} is the level of line no. s-1, etc. Δ is the tone search criterion, which is usually selected to 1 dB.

For normal and even spectrums, the tone search criterion Δ = 1 dB works without problems. For irregular spectra (ex. spectrums measured with a short averaging time as mentioned in section 4.3.) values op to 3 or 4 dB can give correct results. It is recommended, that this parameter is user defined in software implementations of the method.

The end of the noise pause is determined on the negative (right) flank of the local maximum as the line: e, where the following conditions are met:

$L_e - L_{e-1} \geq \Delta$ dB and

$L_{e-1} - L_{e-2} < \Delta$ dB,

All the lines from and including s to and including e are defined as belonging to a temporary noise pause.

The search for the next noise pause begins with line no. e+1.

A noise pause can only contain one noise pause start and one noise pause end. A procedure equivalent to the above must be supplementary implemented by examining the lines in the spectrum from high towards low frequencies (backwards procedure).

Resulting noise pauses are lines, which are defined as associated temporary noise pauses at both the mentioned "forwards" and "backwards" procedures.

4.3. Tones

Tones are found within the noise pauses. There may be a tone, when the level of a line within the noise pause is 6 dB or more above the level for the lines no. s-1 and e+1.

Tones are defined in section 2.3.1. The definition includes both tones and narrow noise bands. The bandwidth of the local maximum is defined as the 3 dB bandwidth from the highest line in the noise pause.

When the 3 dB bandwidth is less than 10% of the critical bandwidth, all the lines within 6 dB from the local maximum are classified as a tone. The tone frequency is determined from the frequency of the line with the highest level within the noise pause.

Note:

When the 3 dB-bandwidth is greater than 10% of the critical bandwidth, the lines are regarded neither as tones nor as narrow band noise. There is no penalty for such a phenomenon, unless it is caused by a tone with a varying frequency. In that case, it is necessary to implement the analysis with a shorter averaging time.

Tones with a varying frequency can appear in the long time averaged spectrum as wide maxima. The width of these are dependant of the variation area for the tone frequency and the averaging time. When the frequency of a tone varies more than 10% of the width of the surrounding critical band within the averaging time, the 10% bandwidth rule must be disregarded (see section 2.3.1.), and either all lines within the wide maximum must be classified as tones, or there must be performed sub-analyses with shorter averaging times, however, still in such a way that the combined averaging time becomes 60 seconds.

4.4. Masking noise

All lines, which are not characterized as belonging to noise pauses, are defined as masking noise and are designated "noise lines" in section 2.3.3.

The level of the masking noise within a critical band is determined by 1st order linear regression between the level of all lines, which are defined as noise, and the frequency. The area for regression is usually chosen as ±0,75 critical bandwidth around the center frequency of the critical band.

For irregular spectres or for spectres with a wide noise pause the area for the linear regression can be extended to ± 1 or 2 critical bands, if this provides better compliance with the general noise floor. It is recommended, that the area for linear regression is user defined in software implementations of the method.

Each spectral line I the critical band is attributed to the level, L_n, by the regression line. The total sound pressure level of the masking noise in the critical band, L_{pn}, is determined as the sum of energy of the attributed levels, L_n, for all spectral lines in the critical band, corrected for the influence of the used window function:

$$L_{pn} = 10\log\sum 10^{\frac{L_n}{10}} + 10\log\frac{\text{Frequency resolution}}{\text{Efficient analysis bandwidth}}$$

Equation 4.4.1. The total sound pressure level of the masking noise.

Official notes

[1)] Guidance on this can be found in the conclusion in "Vurdering af toneindhold i vindmøllestøj hos naboer" Rapport no. 28 from the Danish Environmental Agency's reference laboratory for noise-measurements RL 17/15.

[2)] The method is the same as described in Orientation from the Reference-laboratory no. 31, 2001: "Forslag til revideret objektiv metode til bestemmelse af tydeligheden af toner i støj" and is reproduced in DS/ISO 1996-2, 2nd edition, 2007-06-20: "Akustik – Måling, beskrivelse og vurdering af ekstern støj – Del 2: Bestemmelse af eksterne støjniveauer" Annex C (informative) and in British Standard BS 4142:2014: "Methods for rating and assessing industrial and commercial sound" Annex D (normative) Objective method for assessing the audibility of tones in sound: Reference method.

[3)] The clarity of tones, which was on the criteria curve for the fixed penalty 5 dB for the measured noise level in the method previously used, will after the present method give rise to an penalty of 2,5 dB. Much clearer tones will get a penalty of 6 dB.