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NEW TECHNIQUES IN NOISE PREDICTION

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Noise prediction methods must include the mathematical description of many physical phenomena influencing sound propagation. More scientific based methods approximate the solution of the wave equation with given boundary conditions, while the engineering methods simulate the wave propagation by geometrically defined rays. The first mentioned scientifically based methods are powerful to investigate certain effects as propagation in a layered atmosphere or diffraction over a complex barrier in a simple and clear defined environment. The engineering methods are, however, clearly superior in real scenarios of high complexity like industrial facilities or built-up areas in cities with thousands of traffic sources. The techniques applied have been improved in the last years and the most important of these improvements are discussed.

1. Introduction

The assessment of noise impact in the vicinity of industrial installations is an important planning task which may lead to additional noise reduction measures at existing sites and to a different design or layout at new sites. The calculations applied in this assessment make use of algorithms laid down in standards and guidelines. These coded national and international procedures on how to calculate the noise propagation by point sources, extended line or area sources have been transferred into software packages for noise prediction [1]. It is a work package for its own to assemble these more or less complex and often extended real source structures by using the abovementioned basic source types.

For the noise prediction of industrial sources the standard ISO 9613-2 is applied in most countries [2]. It calculates the sound propagation in octave band width, but can also be used with A-weighted levels when no spectral data is available. The method is simple, but nevertheless detailed enough to predict the SPL in the vicinity of complex sources like power plants or extended factory sites. Besides the geometrical divergence the standard considers athmospheric damping, the attenuation due to the ground ("ground absorption"), and the screening effect by obstacles (e.g. by barriers, buildings). In case of special meteorological conditions, the correction term C_{met} enables to correct for wind situations diverging from the moderate downwind situation assessed by default. The attenuation due to foliage can be included, but it is not a normative part of ISO 9613-2.

Though of known limitations of the ray tracing approach used by ISO 9613-2 and by numerous other national and international standards and guidelines, the basic concept has proven to be correct even in complex situations and with large scenarios [3, 4]. On the other hand, some points in the usage of ISO 9613-2 can be improved for industrial noise modelling not being covered in sufficient detail by the standard.

2. Emission estimated from technical parameters

A basic problem is to decide about the emission values like sound power levels for all kinds of sources. In some cases these emission data are declared by the manufacturer of a device or unit, but in many cases the emission data must be taken from technical literature or even be estimated using experience from similar cases. The software tool SET [5] is an expert system that provides information about the sound emission of about 150 technical sources and can replace a lot of literature to be collected and studied otherwise. The SET-database (**S**ound **E**mission and **T**ransmission) is a compilation of noise emission data depending on the mostly well-known technical parameters of sources (e.g. pressure difference and volume flow of a pump). In addition, this dataset shortens the procedure of setting up of such a noise models of an industrial facility or site.

Figure 1 shows the principle arrangement of a software module in the SET-software. Based on this structure the data of about 150 technical sources has been implemented enabling the user to create his own models of complex technical sources. The module has 9 input ports (IN1..9) and 9 output ports (OUT1..9). Via those ports spectra can be linked from/to pre- or succeeding devices (e.g. from a pipe on the suction side of a pump, via the pump itself, and to a pipe on the pressurized side). Furthermore, there are 10 ports available for parameters (a to j) while a single port represents the sound radiation from the source (RAD). The input and output ports can be connected to other modules. A SET-source is a software that generates the radiated and transmitted spectra from the specified technical parameters.

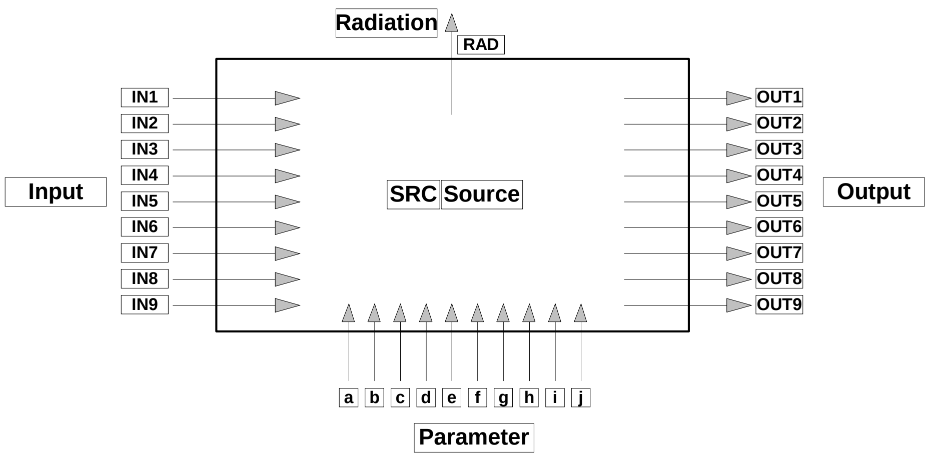

Figure 1. Structure of a software module in CadnaA-SET.

As a simple example, an electric motor is modelled by a point source. This source description is based on the SET-module "E-Motor Standard 50Hz/3000rpm" the sound emission of which is generated from the motor's electric power P in kiloWatts (kW). The emitted sound power level calculates from the formula:

$$PWL = 68.5 + s + 11.5*lg(P) \text{ in dB(A)} \quad (1)$$

where s is the spectral correction:

f (Hz)	31.5	63	125	250	500	1000	2000	4000	8000
s (dB)	-49.7	-37.7	-21.7	-11.7	-6.7	-4.7	-5.7	-10.7	-16.7

The resulting A-weighted PWL-spectrum for an electric motor of 30 kW electric power is:

f (Hz)	31.5	63	125	250	500	1000	2000	4000	8000
PWL (dBA)	35.8	47.8	63.8	73.8	78.8	80.8	79.8	74.8	68.8

which is displayed on the points source's data (Figure 2).

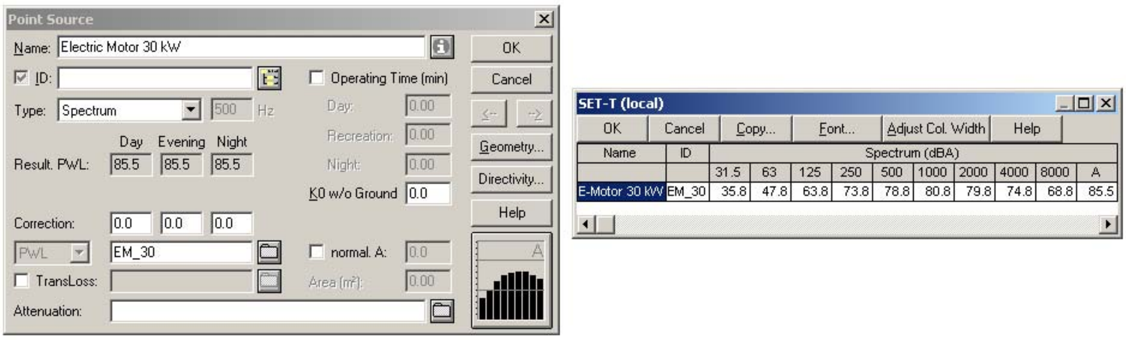

Figure 2. Emission spectrum PWL in dB(A) of an electric motor.

This structure can also be applied to model even more complex systems (i.e. a sequence of SET-modules), where the sound power is generated, partly radiated and partly transmitted to other parts of the system. An example is a hose filter used for exhaust gas cleaning where noise is generated by motor and fan, as well as by the stack, the filter casing, and a pressure release valve (Figure 3). The emission of all sub-sources is calculated automatically from the relevant parameter, here from the volume flow in cubicmeter per hour.

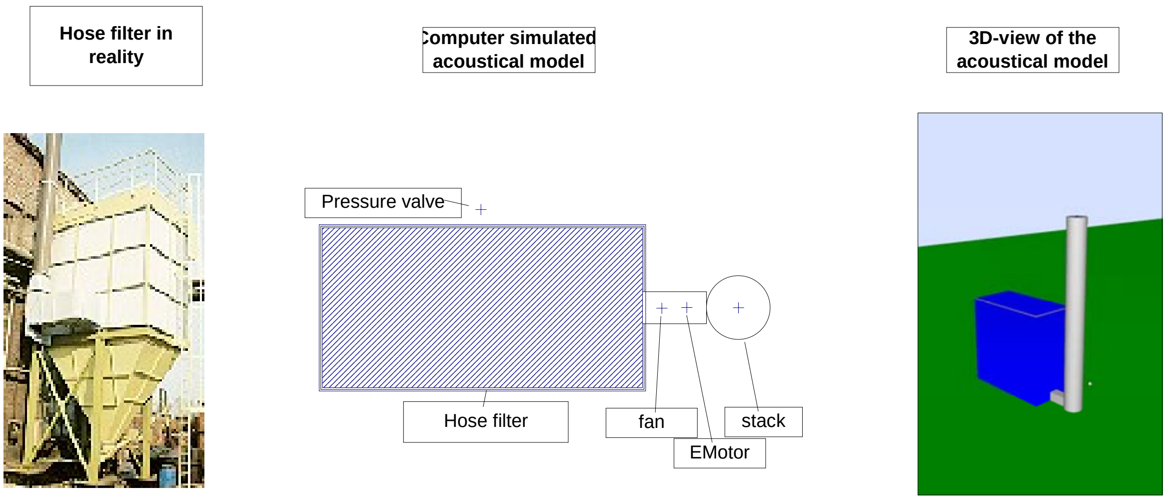

Figure 3. Detailed modelling of a hose filter used for exhaust gas cleaning.

3. Special objects used for industrial noise modelling

3.1 Reflection at chimneys and stacks

ISO 9613-2 describes how to calculate reflected and diffracted sound in general. A cylinder can act as a reflector, but the standard does not state a procedure to calculate the reflected sound at cylinders for all possible positions of source and receiver. When a sound ray is reflected according to the well known image source method even parallel inciding rays cause a widening of the angle after reflection (from a1 to a2), depending on the curvature of the cylinder (Figure 4 and Figure 5).

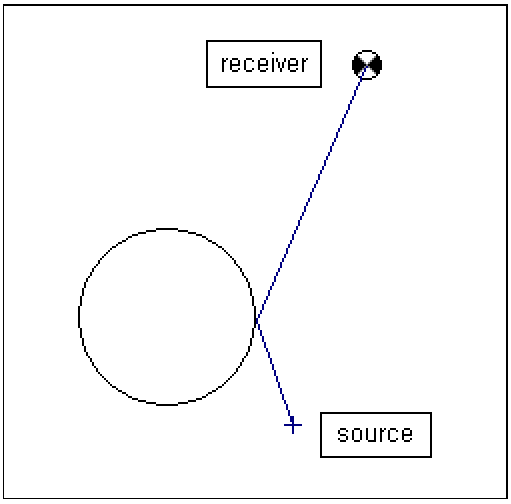

Figure 4. Reflection with equal angles for incident and reflected ray.

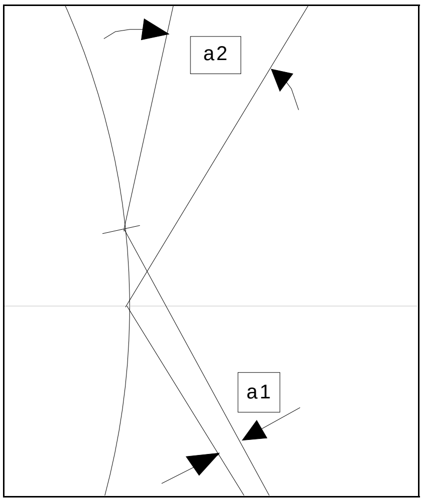

Figure 5. Additional attenuation by widening of the reflected ray.

New algorithms have been developed to calculate the reflection at the source side of the cylinder by taking into account the additional attenuation caused by its curvature. At the backside attenuation by diffraction is included. This allows to include such a cylinder in models of any complexity even when calculating noise maps (Figure 6 and Figure 7).

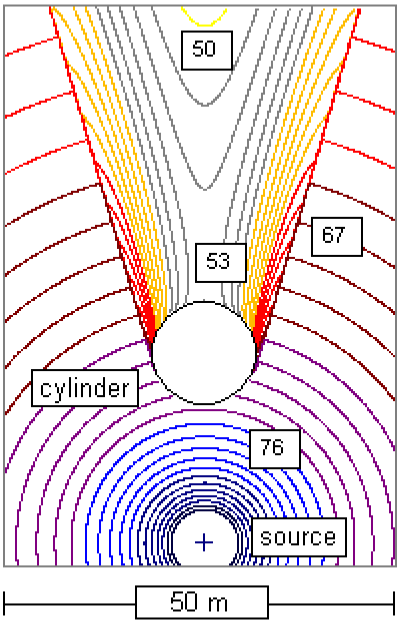

Figure 6. Screening without reflection at cylinder.

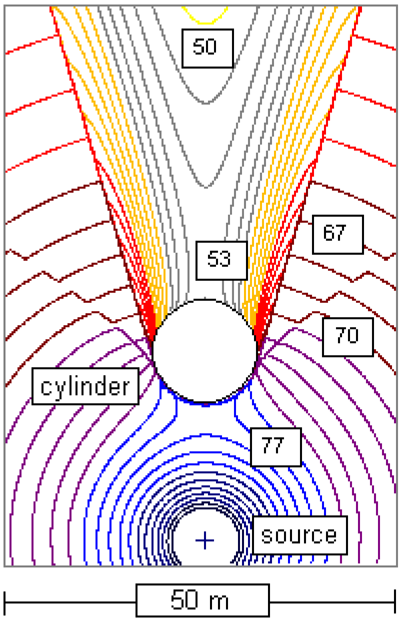

Figure 7. Screening and reflection at cylinder.

3.2 Semi-transparent structures

In industrial plants, structures exist which could be considered as partially reflecting and partially transmitting objects. Examples are found in refineries or chemical plants like pipe racks, tanks or ovens forming blocks like buildings that are partially reflecting and partially open to noise transmission (Figure 8). In a calculation model it would be a hard job to model all details by using the objects being available, for instance a complex arrangement of cylindrical tanks (Figure 9). Even when doing so, the result from this arrangement of objects as far as reflection and screening is concerned is unclear as all relevant effects inside such an arrangement cannot be modelled or are unknown, not talking about the increase in calculation time.

Figure 8. Acoustically semi-transparent structures in a refinery.

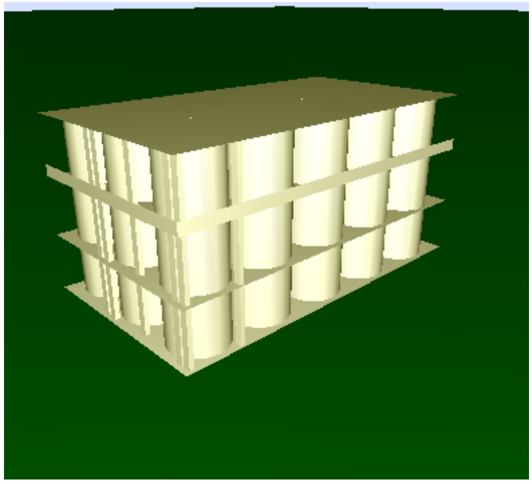

Figure 9. Layout of tanks where gaps allow for transmission of sound.

In order to simplify the approach, such an arrangement of objects can be modelled by a single building specifying the "acoustical transparency" in % (i.e. the portion of transmitted sound energy). Only the sound energy that is not transmitted directly is included in the screening calculation (with transmission factor $\tau = Transparency\% / 100$):

$$E_{screened} = E_{dir}(1-\tau) \qquad (2)$$

The direct path for a single building with transparency results from:

$$E_{transmitted} = E_{dir} * \tau \qquad (3)$$

The transmission factor for the direct path of n objects with transmission factor τ_i results from:

$$\tau_{tot} = \prod_{i=1}^{n} \tau_i \qquad (4)$$

3.3 Extended roofs & porches

By default, the calculation procedure in ISO 9613-2 does not allow for any screening objects or reflectors in z-direction besides the ground. In conjunction with the fact that the ground absorption is combined with the ground reflection, while the latter is accounted for by not using the image source method, any arrangements of sources screened by a roof or similar right above or aside of their location cannot be modelled using the basic ISO-method. In the other hand, such situations are encountered rather frequently in real life. To enable these kind of arrangements the screening calculation using the so-called "ribbon-band method" has been extended to horizontal surfaces extending as the cantilevered part of the object "Barrier". The porch shown in Figure 10 would not produce any screening effect upwards by the default ISO-screening model. Applying the calculation of path length difference not just in xy-plane, but also in z-direction provides a screening effect across the entire space showing also the 1st and the 2nd screening edge (Figure 11). This tool is a flexible extension of the ISO-screening model allowing for new fields of application.

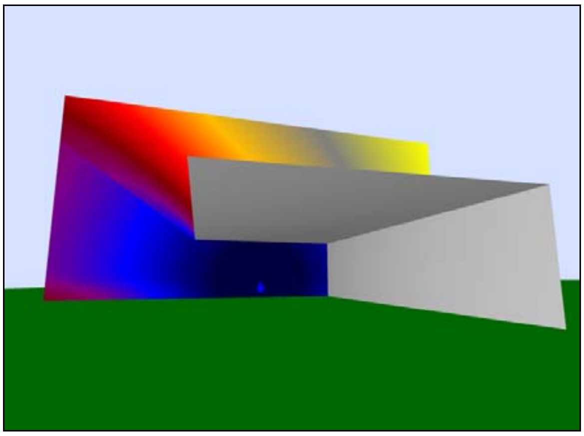

Figure 10. Barrier with horizontal cantilever forming a porch in front of a building.

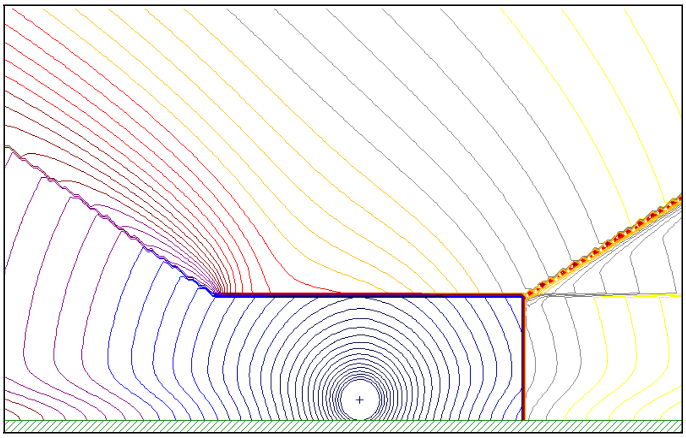

Figure 11. Vertical grid perpendicular to the barrier's edge.

3.4 Horizontal tanks above ground

By default, the diffraction model of ISO 9613-2 requires that all screening objects are raising from the ground. The screening calculation procedure just treats the diffraction across the top edge of obstacles (barriers and buildings), adjusted to consider the lateral diffraction around the vertical edges of an object or an arrangement of objects. In case of an arrangement of objects, the so-called "outer envelope" is used. In order to model horizontal tanks above the ground a so-called "floating barrier" can be defined the lower edge of which is lifted above ground (Figure 12). This model can be used to obtain correct screening results across and around such an object, while no screening around the lower edge (i.e. upwards) occurs (Figure 13). This restriction is due to the non-existant diffraction algorithm for lower edges in ISO 9613-2. A general solution to the screening effect around a lower edge of an obstacle must consider the interference of the diffracted sound with the reflected sound from the ground.

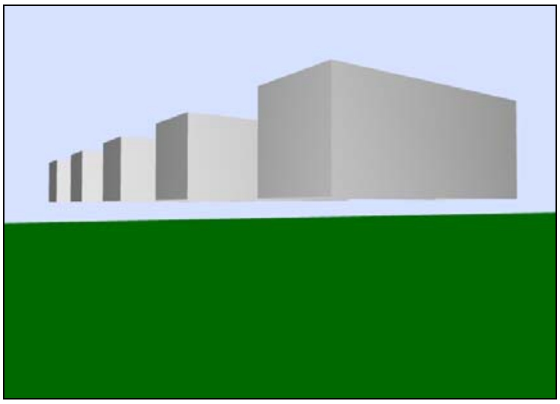

Figure 12. Arrangement of five horizontal tanks modelled from barriers.

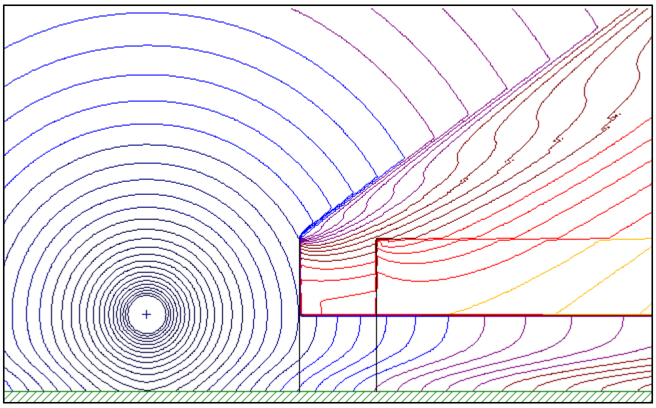

Figure 13. Vertical grid at a single elevated tank lifted from the ground.

Figure 13 illustrates that at a height below the lower edge free propagation occurs, while no upward diffraction happens to the right of the object's lower edge. The diffraction around the top edge applies the conventional ISO-approach where the level "inside" the barrier is irrelevant.

3.5 Screening and reflecting plane in free space

A screening and reflecting plate-shaped object which can be arbitrarily placed in 3D-space is not treated in ISO 9613-2. As the screening formulas just hold for screening edges (top & side edges) being straight and parallel to the ground the numerics cannot be adopted easily. There are acoustical theories describing the interaction of sound waves at more complex shaped bodies, but these theories based on wave-approach cannot be combined with the other objects assessed by ray-tracing method. In order to allow for such an object the following steps are used:

- generation of an even plane by minimizing the least mean square of height deviations,
- generation of an image source & evaluation of the penetration point of the reflected ray,
- calculation of the screening effect accounting for 3 paths: shortest direct & two lateral paths perpendicular to the shortest direct path,
- the path difference results from the nearest diffracting edge of all reflector edges,
- the lateral diffraction result from the path difference perpendicular to the latter path.

In conjunction with all other screening obstacles the screening effect (A_{bar}) is calculated for all objects individually. The final screening effect for this ray results from the obstacle with the highest individual A_{bar}. This rule is used to prevent from excessive screening effects due to arbitrarily increasing path length differences in conjunction with the use of 3D-reflectors.

4. Determining the uncertainty of noise predictions

The emission values of sources are measured or taken from technical literature. The uncertainty of the emission value (sound power level PWL) of a source n is characterized by the standard deviation σ_n . When L_n is the sound pressure level caused by this source at the receiver the uncertainty of the receiver level caused by all sources is [6]:

$$\sigma = \frac{\sqrt{\sum\left(\sigma_n \cdot 10^{0.1 \cdot L_n}\right)^2}}{\sum 10^{0.1 \cdot L_n}} \tag{5}$$

This method has been implemented into the noise prediction software CadnaA. The sources are not characterized only by a sound power level PWL, but also by the standard deviation σ. The finally calculated sound pressure level at a receiver L is, in addition, characterized by the uncertainty of this value, the standard deviation σ . This enables to calculate the receiver level for a distinct level of confidence, e.g. at a level 95% meaning that the respective SPL is not exceeded at a probality level of 95%.

A simple example with two sources in a distance of 100 m is shown in Figure 14. Source Q1 radiates with a PWL=110 dB(A) with an uncertainty σ=4 dB, while source Q2 radiates with a PWL=100 dB(A) with an uncertainty of σ=3 dB.

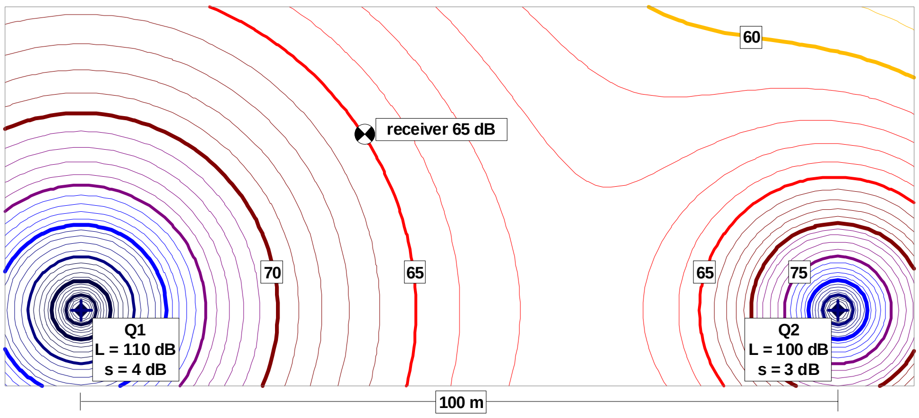

Figure 14. Noise map calculated with the method ISO 9613-2.

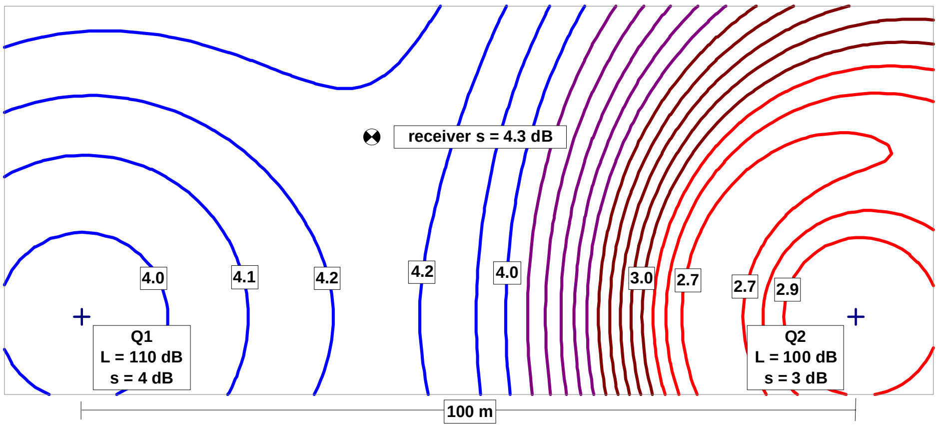

Figure 15. Total uncertainty (standard deviation) of the predicted receiver level and spatial distribution.

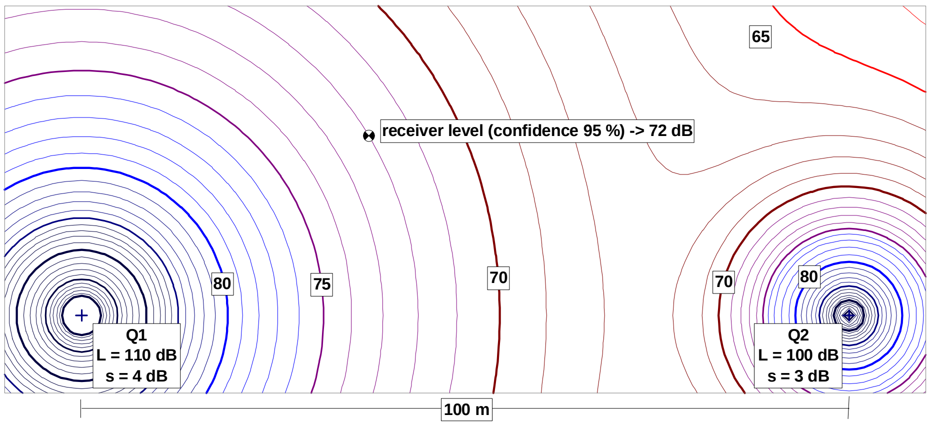

Figure 16. Map of noise levels not exceeded with 95%-confidence level.

Figure 14 shows the distribution of sound presented as noise map with lines of 1 dB spacing. Based on the abovementioned method the uncertainty of the calculated level for each grid point is determined and presented as "uncertainty map" (Figure 15). Multiplying the standard deviations in Figure 15 by 1.65 and adding them up with the level grid, results in a noise map showing the distribution of levels at a confidence level of 95% (Figure 16). Especially with industry noise when emission values must be derived from single measurements or even be estimated such considerations are extremely helpful in critical situations, where limiting values may be exceeded.

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