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Measurement of Outdoor Sound Propagation – Validation of Nord 2000 Prediction Models

SP Swedish National Testing and Research Institute
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Abstract

A new Nordic prediction model for sound propagation outdoors has been developed since 1996. More measurements of sound propagation simultaneously with wind at different topographies were needed for validation of parts of the model.
A SILVA wind instrument has been connected to a Bruel & Kjaer Type 9666 acoustic front end / DAT recorder combination in such a way, that wind speed and direction can be recorded during sound measurements. Voltage supervision of an existing sound source at Swedish National Testing and Research Institute, SP, has been constructed and realized. Six new locations for measurements have been found: Gässlösa, Rångedala Twin Peaks, I15 supply depot, I15 shooting gallery, I15 loading ramp and Rångedala Flat.

Software for evaluation of sound pressure and wind from measurements recorded as DAT-files has been written and modified. Sound pressure is evaluated in 1/3 octave bands. Systematic error and power spectrum estimation variance is presented. Wind is evaluated as wind speed and wind speed component in the direction of sound measurement. The equipment (hardware and software) for wind speed and direction measurement has been calibrated. Calibration curves are presented. The sound power level of the source and its standard deviation have been determined.

Measurements of sound propagation in 1/3 octave bands and wind have been done. They include flat, valley and hill cases over gravel, grass and rough soil. No measurements have been done over distances of more than 80 m. The frequency range of evaluation of measurements was 50 – 10000 Hz. The frequency range of the signal to the sound source was 150 – 10 000 Hz. A similar analogue treatment of measurements would have given a lower limit of 200 Hz. Evaluated results are presented as sound pressure levels relative free field together with background noise levels and theoretical results calculated by Mikael Ögren with a tentative version (N2000_13) of parts of the new Nordic prediction model. The frequency range of model calculations was 315 – 10000 Hz.

Key words: outdoor sound propagation, acoustics, acoustic measurement, topography, wind.

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Preface

This work is done for the Swedish National Testing and Research Institute, SP under the guidance of Michael Ögren. Examinator has been Johan Boman at the department for Environmental Physics, School of Physics and Engineering Physics, Göteborg University.
I also want to express my gratitude to:

- Hans Jonasson and Geir Andresen from SP for help with review and measurements
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- Lotta at Vasallen for cooperation with the I15 locations
- Krister Lundberg at Elfsborgsgruppen for cooperation with Gässlösa

Per Persson

Conclusions

- The correspondence between calculated and measured values is good.
- Variations in sound propagation over 30 – 60 s are not only caused by visible wind speed variations.
- The maximum measurement error of the wind speed component in direction from sound source to receiver is not greater than 0,5 m/s plus 12 % of the value.
- The maximum measurement error in wind speed is not greater than 0,5 m/s.
- The maximum systematic error in the developed evaluation software goes from 1,76 dB at 50 Hz to 0,01 dB at 10 000 Hz.
- The maximum power estimation variance in the developed evaluation software goes from 0.64 dB at 50 Hz to 0,05 dB at 10 000 Hz.
- The 95% confidence interval in sound power level of the sound source used is ±2,14 dB.

1 Introduction

A growing number of people are exposed to unwanted sound, noise. To minimize unwanted exposition without sacrificing important public activities, and to reduce the costs generated by noise and for noise protection, it is important to be able to predict noise propagation. According to [1], it has been shown that calculating noise levels by means of an established prediction model on average gives more reliable results than measurements. The reason for this is that the prediction models account accurately for important meteorological fluctuations, which are hard to cover in one measurement.

With start in the early 1970s the Nordic Council of Ministers brought about a number of Nordic prediction models for road [2], air [3] and railway [4] traffic, industrial plants [5], shooting ranges [6], motor racing circuits [7] etc. These models are now well established and have legal recognition even in courts of law. The models are separate, which means that noise levels from different models cannot be compared to each other. Furthermore, the computer and scientific progress since the 70s gives totally new opportunities to make better models.

Therefore, the Nordic Council of Ministers has decided to build up a new generation of environmental noise prediction models, based on present scientific knowledge [1]. To achieve this the Environmental Noise 2000 or shorter Nord 2000 project was initiated in 1996. The aim is to get one basic model, which can be used in many different situations, is more detailed, and can deal with more complex situations, including different weather conditions. The work is carried out jointly by DELTA Acoustics & Vibration, Denmark, SINTEF Telecom and Informatics, Acoustics, Norway and Swedish National Testing and Research Institute (SP), Sweden.

At spring/summer 1999, when the planning of this thesis started, the Nord 2000 project was almost ready regarding choice of models for sound propagation and methods for prediction. Some development and a part of the validation, evaluation and implementation remained though. A number of model measurements and some full scale measurements of simple cases had been done.

However, there was a need for full scale measurements of more cases. There also was a need of being able to measure the wind continuously during the measurement.

The aim of this work has been:

- Modification of existing equipment to be able to record wind speed and direction simultaneously with the noise.
- Finding new locations with different topologies and surfaces for full scale measurements of sound propagation.
- Development of software to handle data from measurements and to make them useful in the development and validation of the prediction model.
- To make measurements and provide data for the validation.

Chapter 2 gives a short presentation of the new Nordic prediction model, especially the parts that have a connection with this thesis, in its present state.
Chapter 3 covers modifications of existing measurement equipment and some properties of the sound source.
Chapter 4 gives a survey over some sound propagation measurements and a description of new measurement locations.

Chapter 5 describes the software created and modified for evaluation of the measurements.
Chapter 6 presents implementation and results of the measurements. In connection with these, some comparisons with calculations by Mikael Ögren using the new Nordic prediction model are shown.

2 New Nordic noise propagation prediction model

The work with a new Nordic noise prediction model started in 1996. The model is not ready yet. It is still constantly changing, even though the pace of change is slowing down. This section mostly describes the model as it has been during 1999. The complete model will be ready in a year or two.

The new Nordic noise prediction model can be divided into three basic propagation models:

- The flat terrain model.
- The valley model
- The hill model

The flat model is used for flat and moderately uneven terrain. If the surface is rough, it is approximated by an equivalent, flat terrain. Also uneven terrain with so little unevenness that it fits the definition for roughness, is approximated by an equivalent flat terrain. The valley model is used when the terrain is too uneven for the flat model, but so flat and/or convex that no screening occurs. Screening is when the difference between the direct ray length from source to receiver and the ray length via the edge of an obstacle is larger than a certain fraction of the wavelength. The hill model is used when screening occurs. As the definitions of "rough", "uneven" and "screening" is frequency dependent, a certain piece of terrain can be flat in one part of the spectrum, valley in another and hill in a third.

The base of the new Nordic prediction model is one flat, smooth segment of ground with homogenous ground impedance. If the ground impedance isn't homogenous, it is split into smaller segments until all segments are internally homogenous. If the segment isn't flat, the same principle applies until all segments are flat. Sound propagation over flat ground with homogenous impedance is a well-known subject. In the new Nordic propagation model, calculations are for the first time done made in 1/3 octave frequency bands with the actual algorithms from ray theory instead of with approximate or empirical solutions.

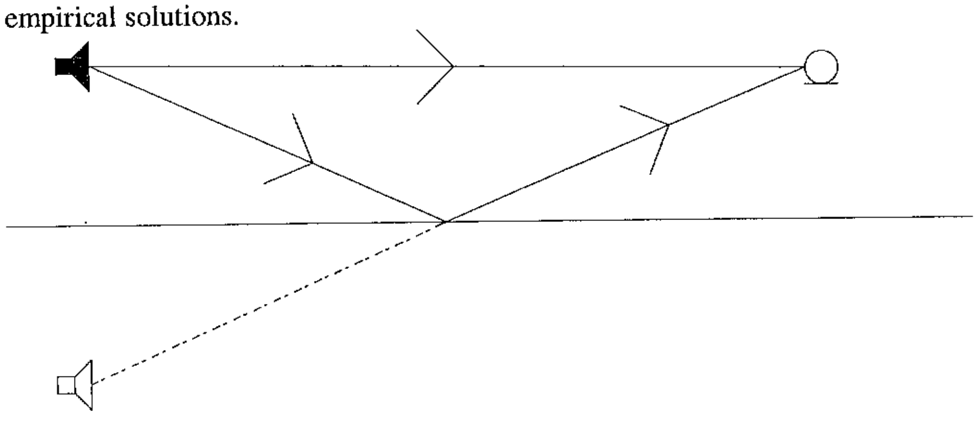


Figure 1
When sound propagates from a source to a receiver, one part goes directly and another bounces via the ground. To model this, an image source below the ground is introduced.

From a point source, sound radiates in different directions. Of the sound that reaches a receiver, one part goes directly from source to receiver. Another part bounces via the ground and is influenced by the ground impedance. To model this, an image source below the ground is introduced (Figure 1). If the ground is perfectly hard, like frozen soil, this only means that we have got two rays to calculate instead of one. If not, we have to model the sound reflecting properties of the ground. In the new Nordic prediction model, this is done with the ground impedance, which is described with a one parameter model. From this and the geometry, a spherical reflection coefficient, Q, is calculated. Then the calculation is made with (1).

$$p = p_A\left(\frac{e^{ikR_1}}{R_1} + Q\frac{e^{ikR_2}}{R_2}\right)e^{-i\omega t} \qquad (1)$$

Where

- p - acoustic pressure [Pa]
- p_A - sound source amplitude [Pa]
- k - wavenumber = ω/c [m^{-1}]
- ω - angular frequency [rad/s]
- R_1 - length of ray from direct source [m].
- R_2 - length of ray from image source [m].
- Q - spherical reflection coefficient.

A detailed description with references can be found in [8].

To calculate the ground effect for a number of terrain segments, two segments are calculated first. When two segments are calculated, the results are merged with Fresnel zone interpolation [9]. This merged result is then merged to the result from the next calculated segment in the same way, this merged result is then merged to the result from the next calculated segment… and so on until all segments are merged.

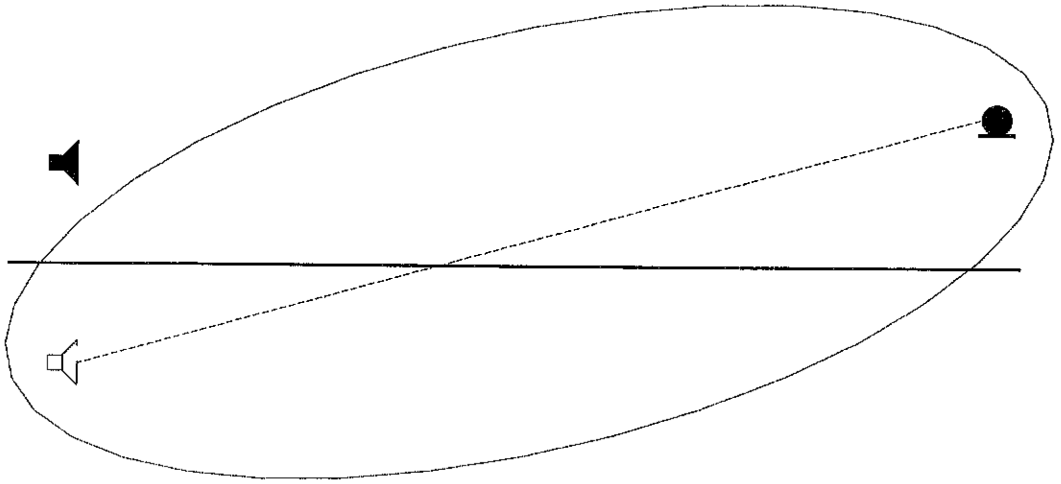


Figure 2

The Fresnel zone is an ellipse with the image source in one focus and the receiver in the other.

The Fresnel zone is the ellipse which is limited by the points on the ground for which the sum of the distances to the image source and receiver does not exceed the direct distance with more than a certain fraction of the wavelength (figure 2). The fraction of each ground surface in the Fresnel-zone is used to determine the weighing factor, r, used for interpolation between the ground effects of each surface type. In principle the method is described by (2).

$$20\log(|p_{TOT}|) = r20\log(|p_S|) + (1-r)20\log(|p_R|) \quad (2)$$

p_{TOT} = the solution with the impedance discontinuity

p_S = the solution with the source impedance over the whole area

p_R = the solution with the receiver impedance over the whole area

r = weighting factor.

In the Valley model the terrain is divided into flat segments, but with angles in between. Then a modified form of Fresnel zone interpolation is used, where the result is modified depending on the angle between the segments.

In the Hill model, the first two screens are handled in one way and the third and following screens (if any) in another. If the ground profile contains one or two screens high enough for diffraction to occur, a combination of diffraction and ground effect will be used.

If we have a source, a screen, and a receiver that can't be reached by direct sound from the source, the first step is to imagine a receiver at the top of the screen. This image receiver will be reached by the same sound that the receiver in Figure 1. This is calculated with (1) as usual. Next step is to place an image source at the top of the screen.

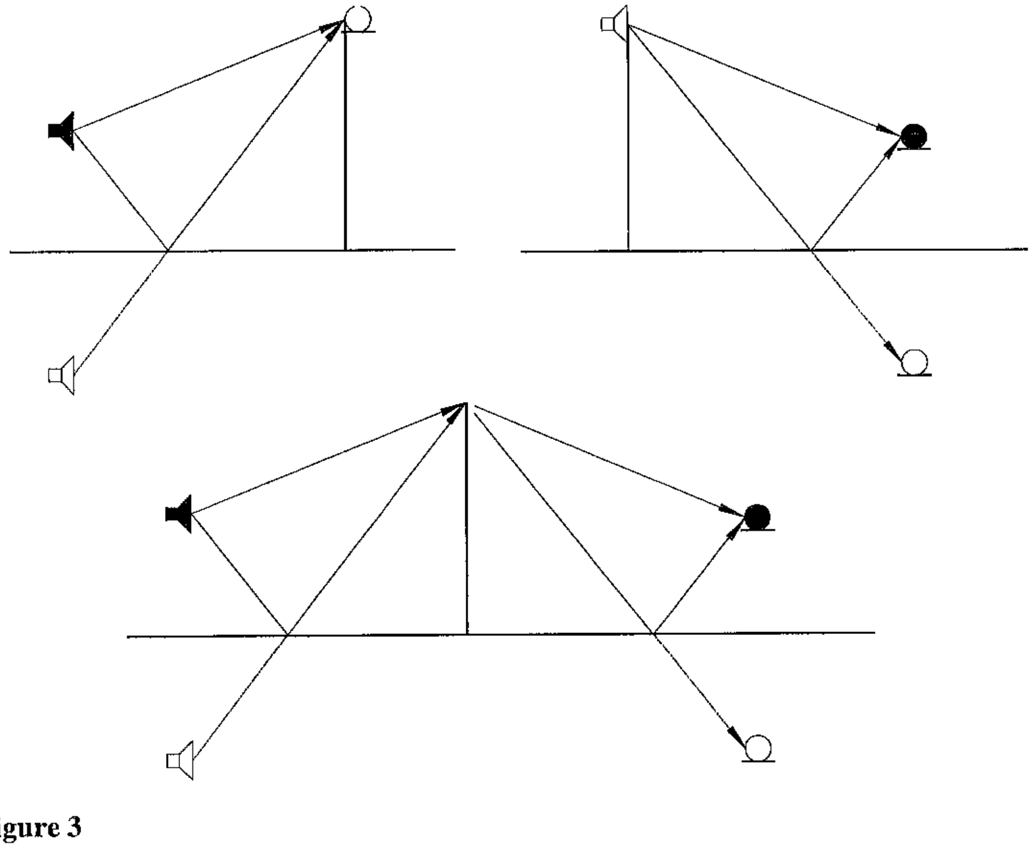


Figure 3
One direct and one reflected propagation path before the screen and the same after gives a total of four.

Reflection and ground effect will affect the sound from this "image" source in the same way. This is solved in a similar way with an "image" receiver (Figure 3, upper right). In this way we will get four paths from source to receiver (Figure 3, lower). We also get a method to calculate the propagation in steps. If we have two screens we will get eight paths. In the prediction method the biggest screen is selected and the sound field at the top is calculated. Then the screen is replaced by a sound source, the second largest screen is selected and the procedure is repeated. A diffraction coefficient is calculated for each screen with an image source on the screen before and an image receiver on the screen after. These coefficients are then combined into a single diffraction coefficient.

If there are more than two screens, the rest of the screens are regarded as reflecting surfaces and sound propagation is calculated with a slightly modified valley method.

The sound absorption in the air is calculated according to ISO 9613-1[10]. Air turbulence scattering is included in two ways. One is scattering of sound energy into shadow zones. It is calculated as a simple addition of energy in the shadow zone. The other is a "smoothing" effect on interference patterns generally. Both these effects have little or no influence on low and middle frequencies. (The model is intended for a total frequency range of 25 – 10000 Hz).

As Fresnel zone interpolation, surface and turbulence scattering affects the coherence information in the calculations, the model in divided in coherent and incoherent parts. The results from these parts are weighted together with coherence coefficients.

3 Modification of the equipment

In spring 1999, Forssén and Ögren measured sound reduction in presence of wind and turbulence at Brämhult [11]. They used equipment from Swedish National Testing and Research Institute, SP. This equipment was only able to measure the average wind speed for the time of a whole measurement. The measurement time with this equipment is usually around 60 s. Suspicions that the wind could shift considerably during such a period arose. There even were indications that there is a connection between wind speed in general and the amount of turbulence. Therefore, it was decided to make it possible to measure the wind simultaneously with the sound propagation. The modifications on the SP equipment to achieve this are described in section 3.1.

A little Poff! in the driver used as sound source for the propagation measurements initiated modifications for voltage supervision described in section 3.2.

3.1 Modification for simultaneous wind and sound data collection.

The existing wind speed instrument is partly described in 3.1.1 and [12]. It measures wind speed and direction simultaneously with good accuracy. A telephone call to SILVA and a check with oscilloscope (figure 4) made it clear that it was possible to store both wind speed and directional data on one channel of a DAT-recorder [13]used in the sound propagation measurements (chapter 6).

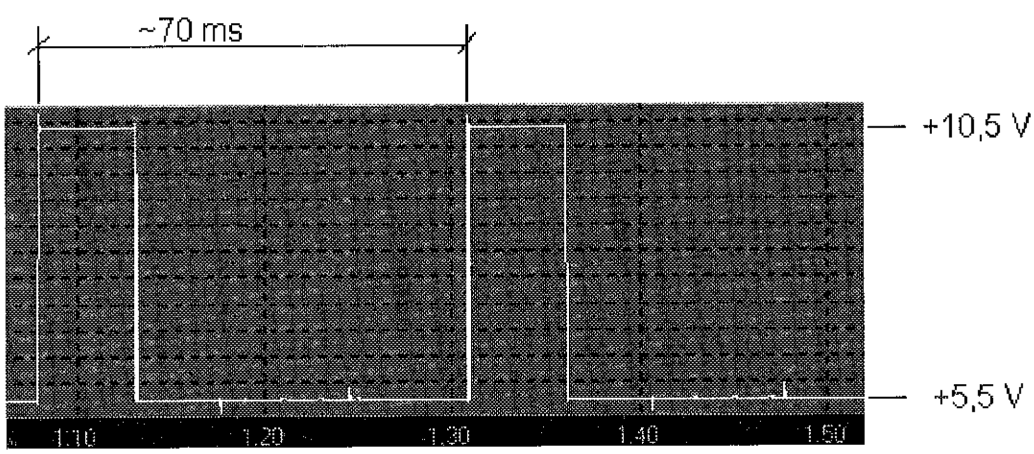


Figure 4
At around 4,4 m/s the signal from the wind gauge varied between +5 and +10 V with a period of 70 ms. Picture dumped from Sony PC scan mkII. [14].

In this way it would be possible to compare the amount of turbulence (~ total wind speed) and the wind speed component in the direction from source to receiver.

Other possible methods to collect wind data simultaneously are for example hotwire anemometer instruments or MLS (maximum length sequence). A hotwire anemometer is described in [8]. It was used at the measurements in Brämhult [8] to measure turbulence. It is very fast but not equally sensitive in all directions and it can't measure wind direction. It's more suited to measure random turbulence than wind speed and direction during a measurement. The anemometer is also shaky and hard to trim.

The use of MLS is described in [25] and the theory is described in [15] and [16]. In brief, the travel time of a sound pulse is used to determine the wind speed. The MLS method can give the wind component along the sound propagation path with sufficient accuracy and can also increase the signal to noise ratio. This can reduce problems with background noise level. However, MLS can't tell if the sound is refracted, diffracted, reflected or scattered by turbulence. The aim of the measurements was to provide data for the validation of a prediction model. In a prediction model we have to use the wind measured with for example meteorological instruments over a whole area and can't predict the sound propagation path in detail. This makes MLS less appropriate for our purpose.

The conclusion of this was to modify the existing SILVA wind instrument to be able to connect it to the DAT-recorder.

3.1.1 Wind gauge

The wind gauge is a part of a SILVA 40 wind instrument [12]. The instrument consists of a wind gauge connected to a central box with a display instrument and power supply. The gauge is connected to the central box with a 4-conductor cable. Each pair of conductors lead one square pulse signal. The frequency of the pulses is proportional to the wind speed and the positive pulse width is proportional to the direction of the wind (figure 5). The signal in one pair of conductors is dislocated 90 degrees (a quarter of a period) in relation to the signal in the other pair.

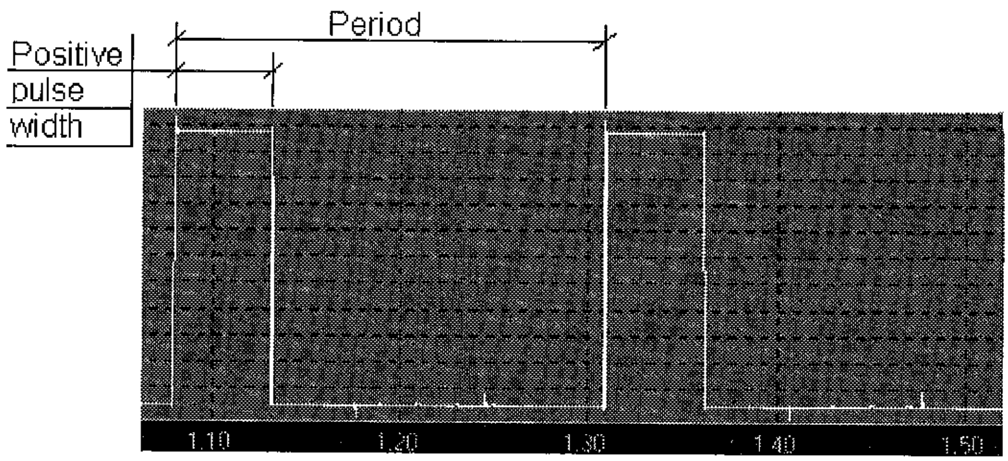


Figure 5

One of the two square pulse signals from the wind gauge at a wind direction of 30 degrees. Picture dumped from Sony PC scan mkII. [14]

The wind gauge cable is connected to the central box with a panel mounted female connector. To get access to one of the signals, two single conductors was soldered from the wind gauge connector to a BNC-connector, witch was mounted in the front panel. This made it possible to connect the wind gauge to the DAT-recorder. In this way the wind gauge could still be connected to the central box and get its power supply that way.

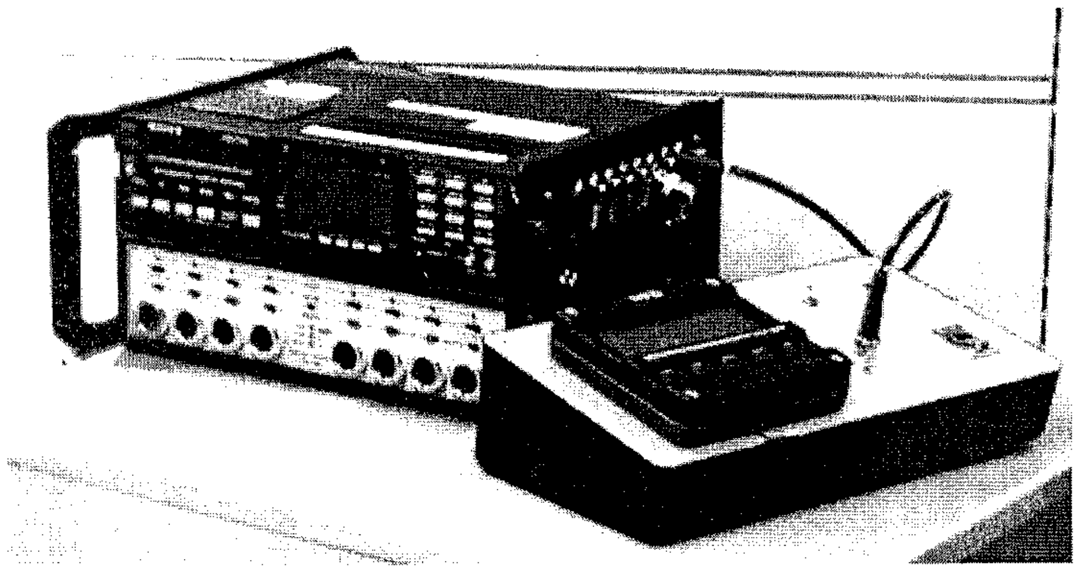


Figure 6
Central box of wind instrument connected to DAT recorder bypassing acoustic front end [17].

3.1.2 Calibration of wind speed signal

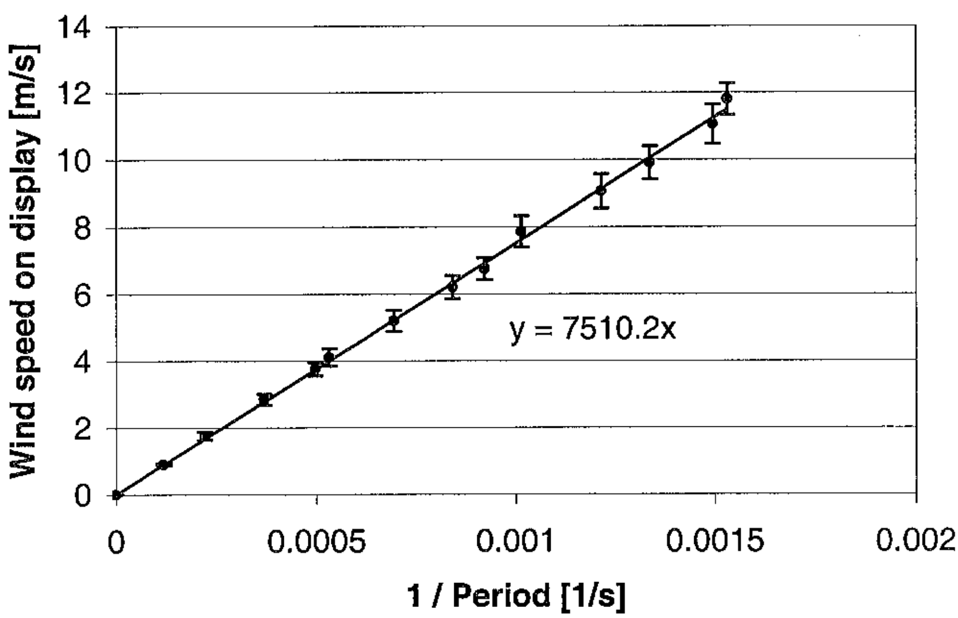


Figure 7
Calibration curve for wind signal. The regression line is made by Excel [18] with least sqare method. Error bars indicate uncertainty in wind reading on display plus 4% from the accuracy of the instrument [12]. Data on CD-Rom (Annex 5).

To check the wind speed signal, DAT-files were recorded at 13 different wind speeds. The wind was an airstream artificially created in the fan system usually used to test ventilation noise at SP. The period of the square pulse signal (Figure 5) was calculated for the different wind speeds and a linearisation was made in Microsoft Excel 97 [18] (Figure 7). Excel 97 uses the least square method for such a calculation. The proportional factor from Figure 7 was then used in the software for evaluation of wind speed (5.1.3 "utv.m").

At some points the wind speed fluctuated, probably due to turbulence in the ventilation channels. The deviations of the max and minimum values from the mean value plus the maximum error of the instrument are shown as error bars in Figure 7. The accuracy of the speed in the wind instrument is ± 4 %[12].

3.1.3 Calibration of wind direction signal

To check the wind direction, 12 DAT-files were recorded with the wind gauge rotated from 0 to 330 degrees in 30-degree steps. The angle to the direction of the air channel was measured with a protractor. The air speed was chosen to minimize the wobble in the wind gauge.

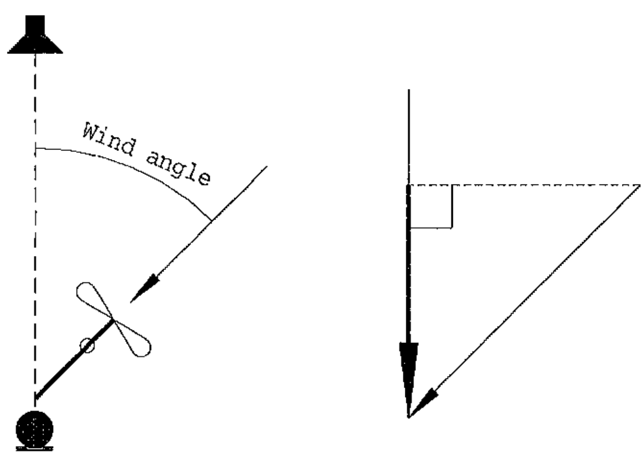


Figure 8
Left: The wind angle is the angle between the measurement direction source –> receiver and the direction of the wind. Right: The interesting component of the wind is the one that is parallel to the sound measurement direction.

The part of the wind that affects sound propagation is the component of the wind in the direction sound source – microphone (figure 8). The relation of this component to the absolute wind speed is the same as the relation of the positive pulsewidth to the period in Figure 5. The wind component in the measurement direction, cos(wind angle), is shown on the Y-axis of Figure 9. The positive pulse / period ratio is shown on the X-axis. The calibration line in the diagram is done in Excel with least square method. The accuracy of the wind instrument is ± 2°[12].

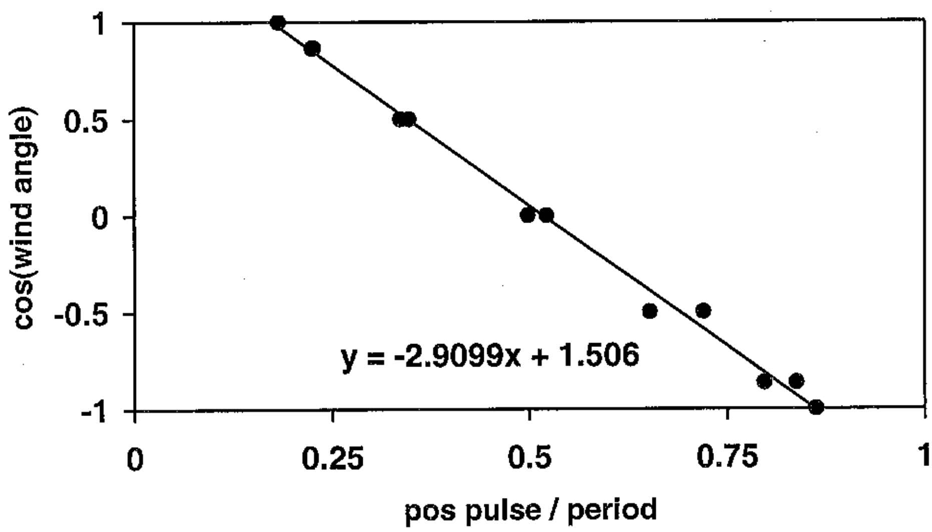


Figure 9
Calibration curve for wind direction. Linearisation made with least square method.

3.1.4 Result and discussion

Figure 7 shows that the error between the calculated value and the displayed value on the wind instrument is well below 0,5 m/s. In figure 9 the largest residual of the pos pulse/period value calculated with Curve Expert [19] is 0,12 at cos(wind angle) = -0,5. This corresponds to an error of 12%.

The wind is interesting for two reasons. Firstly, the component of the wind in the direction from sound source to receiver affects sound propagation and refraction. The maximum error is not greater than 0,5 m/s plus 12% of the wind speed.

Secondly, the absolute value of the wind speed can have a relationship with the amount of turbulence. The maximum error in wind speed is not greater than 0,5 m/s.

3.2 Supervision of voltage at driver

One part of the sound source in the sound propagation measurements is a JBL 2447 driver shown in figure 10. The complete sound source is described in section 6.2 "Equipment". The rated impedance of the 2447 compression driver is 8 ohms [20]. With the resistance of 50 m cable approximately equal to this we adjusted the amplifier output to 29,3 V RMS. The pink noise used was also high pass filtered from 150 Hz to avoid low frequency currents that the driver could not convert to sound anyway.

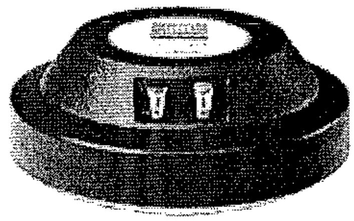


Figure 10
JBL 2447 compression driver. Picture from [21].

On one occasion the voice coil of the driver was overloaded. This can have been caused by for example exchanging the cable from the amplifier for another one with less resistance. To prevent this from happening again, a new cable drum with a 4-conductor cable was built, where two conductors could be used to monitor the voltage at the driver. To be able to calculate a better voltage for the amplifier output the impedance of the driver was measured with MLSSA [22].

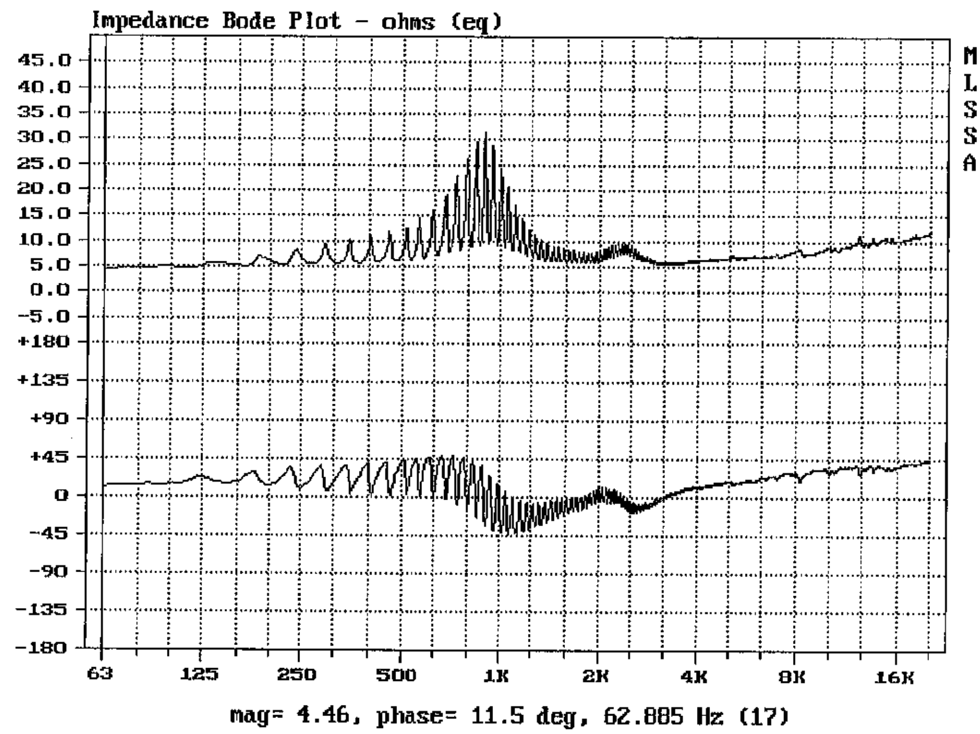


Figure 11
Impedance of the sound source. Picture dumped from MLSSA [22].

The impedance of the driver in the setup used for measurements shows a peak around 1 kHz due to membrane resonance and a ripple due to resonances in the hose (figure 11). The lowest impedance was found to be approximately 5 ohms. The driver is rated 100 W continuous program power above 500 Hz [20]. Continuous program power in this case means 3 dB greater than continuous pink noise. As we use continuous pink noise we thus have to limit the power to 50 W. This gives a voltage of U ≈15,8 V across the poles of the driver (Figure 12).

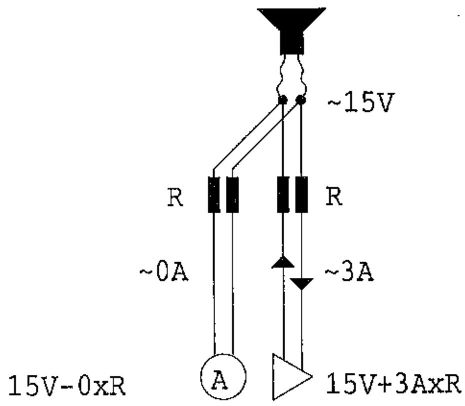


Figure 12
Equivalent scheme over voltage supervision and some approximate voltages. "A" is a FLUKE 12 [23] RMS instrument.

As the two conductors used to monitor the voltage leads to an instrument with high input impedance, they are almost free of current and the voltage is roughly the same as on the poles. During all measurements with this cable drum, an instrument able to measure RMS (FLUKE 12 [23]) was used to supervise the voltage across the driver.

3.2.1 Discussion

Current supervision could have been an alternative to protect the coil of the driver. This would have eliminated the need for a new cable drum. However, use of different cable drums would have acquired adjustments of the amplifier at each change. With the voltage supervision solution the voltage didn't have to be adjusted one single time, although it was supervised all the time. The new cable drum was different enough from others to avoid confusions. Another advantage with voltage supervision is that the supervision instrument can be attached and detached without breaking the circuit.

4 New locations for sound propagation measurements

4.1 Literature survey of sound propagation measurements.

Measurements have been made before the Nord 2000 project started and in the project. To see what had been measured a survey of measurements was made (table 1).

Table 1

Some sound propagation measurements. Sp - Spectrum, 1/1 – octave band. 1/3 – third octave band, 1/10 - tenth octave band. A - A-weighted.

Ref	Topography	Surface	Full/ model scale	Sp	Remark
[8]	Thin screen	Hard	Model	1/3	Air nozzle
[8]	Wide screen	Hard	Model	1/3	Air nozzle
[8]	Double screen	Hard	Model	1/3	Air nozzle
[24]	Flat	Grass		1/1	MLS. Upwind. Downwind. 50, 100, 200m.
[25]	Flat, uneven, valley	Grass	Full	1/1	MLS. Upwind. Downwind. No wind. 100, 200 m.
[26]	Flat	Snow etc.	Full		Max 15 m. Snow, reticulated foam
[27]	Flat	Growth	Full	1/10	Corn, hemlock, red pine, hardwood, soil. 100, 200 ft. 100 Hz - 10 kHz.
[28]	Flat, wedge	Discontinuity.	Model 1:100	1/3	Reflecting, absorbing.
[29].	Flat.	Reflecting/ absorbing Bulk reacting	Full		Gated sine wave. 300 Hz – 10 kHz.(Tone burst) 2,4 – 10 m. Plywood, concrete slabs, porous ceramic, 10 cm fiberglass.
[11]	Screen	Gravel	Full	1/3	Wind. Turbulence. 8 - 30m.
				1/1	Downwind 50, 100, 200m. 125 – 2000 Hz
[30]	Flat	Discontinuity Hard(formica) Soft(felt)			Sine wave sweep 1 - 20 kHz. Discontinuity parallel to direction source - receiver
[31]	Curved r = 2,5 m	Smooth / Rough.	Model		6, 8, 12 kHz. 0 - 160 cm
[32]	Level	Absorbing	Full	A	Oil seed rape field. 1-45 m.
[32]				A	Avon jet engine. - 1.158 km.
[33]	Flat, rough	Hard, soft, rough.	Model	1/3	Air nozzle.Wood-fibre plate. Porcelain.Corr. to 50-3150Hz
[34]	Flat	Snow	Full	1/1	1 – 100 m. 200-3200Hz

Most measurements are made on flat surfaces, with and without screens. Some model measurements of more complicated topographies and surfaces have been performed. The only full scale measurements over non flat ground are [25]. This measurement is already used in validation of prediction methods in papers with roots in the Nord 2000 projects: [35], [36].

4.1.1 What is of interest to measure?

To be of interest, the measurements have to be made on more complicated cases than flat ground and flat ground with screens. For example valley, hill, wedge, wide screen, complex screen, double screen, rough surface. Measurements with wind are of interest to be able to validate refraction and turbulence parts of the model.

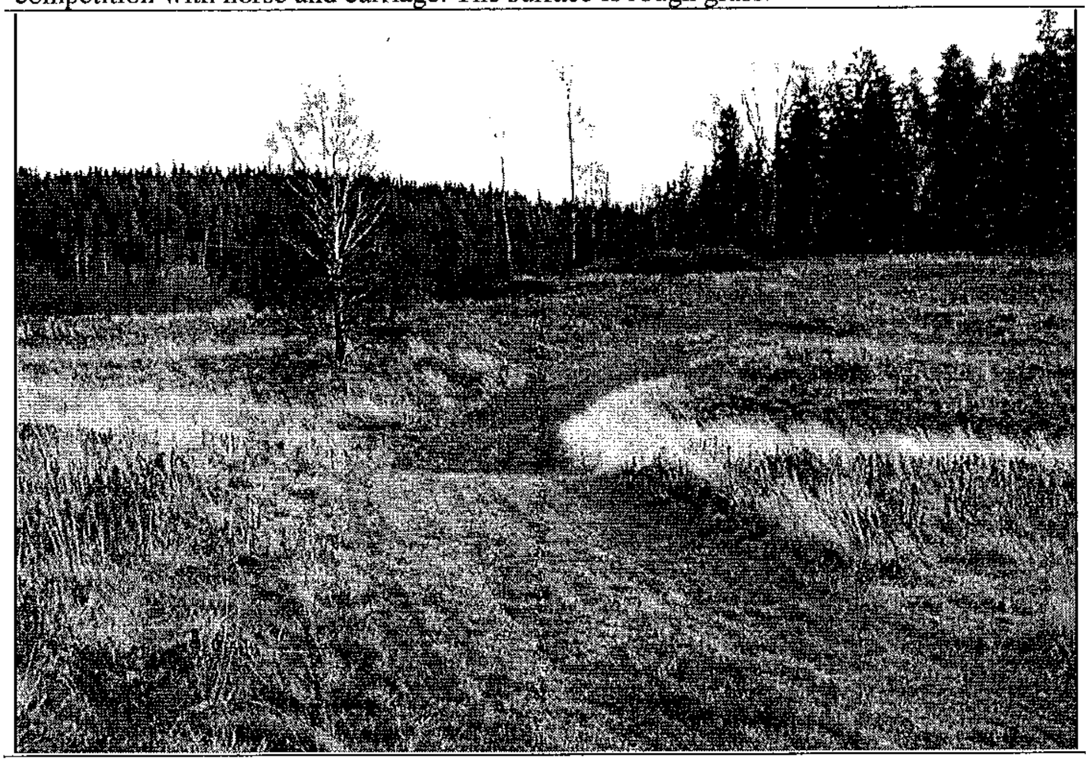
4.2 Result - new measurement sites

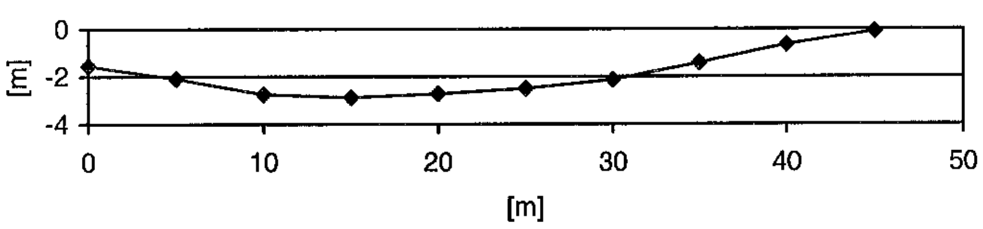
These new sites have been used in measurements for validation of the tentative Nord 2000 sound prediction models. A contact list to the respective contact persons of the sites can be found in Annex 4 (in Swedish).

No measurements have been made on anything that can be compared with a normal traffic noise screen. In one location, Bråt shooting range, some screens are found, but no measurements have been made there due to problems with access time. (The man who controls the gate has to be contacted one day in advance, and since the weather in Borås is unpredictable, one day notification and measurable weather has not been possible to combine.) Bråt shooting range is located near Gässlösa Valley.

4.2.1 Gässlösa valley

Gässlösa valley (figure 13) is located in a recreation area a little more than 2 km from a road with medium busy traffic. The trail seen in the photo is used for training and competition with horse and carriage. The surface is rough grass.





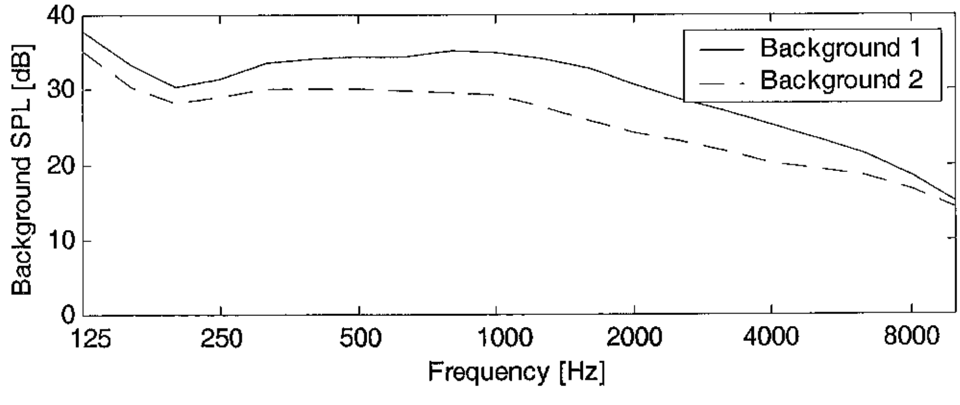


Figure 13
Gässlösa valley. Photo, ground profile and two measurements of background sound pressure level (SPL). x-coordinate value 0 is in the near side of the photo.

4.2.2 I15 supply depot

The I15 supply depot (figure 14) is located a few hundred meters from the medium busy road with some terrain obstacles and buildings in between. Depending on how the source and receiver are located, it is possible to measure both with and without screening. The surface is rough grass.

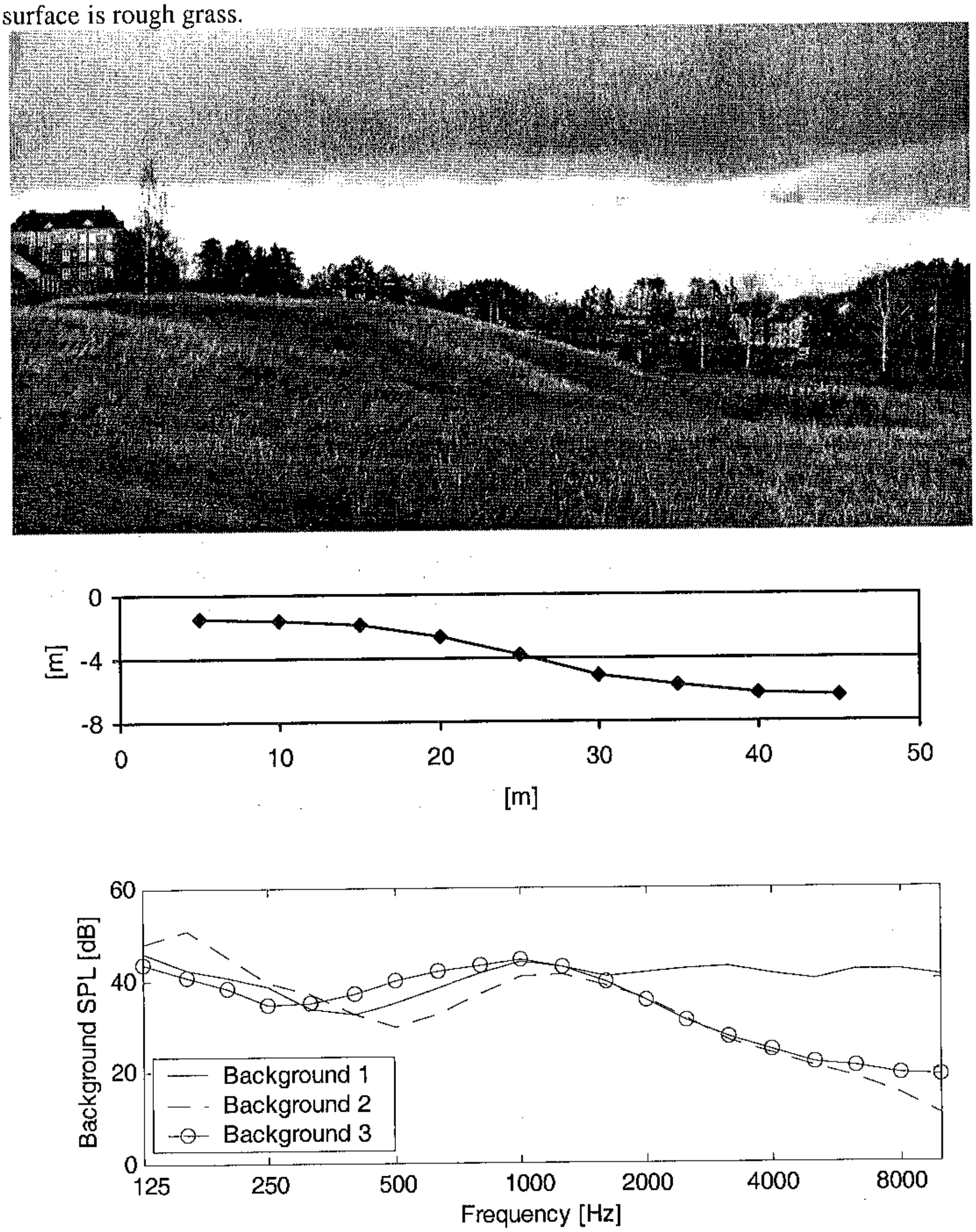
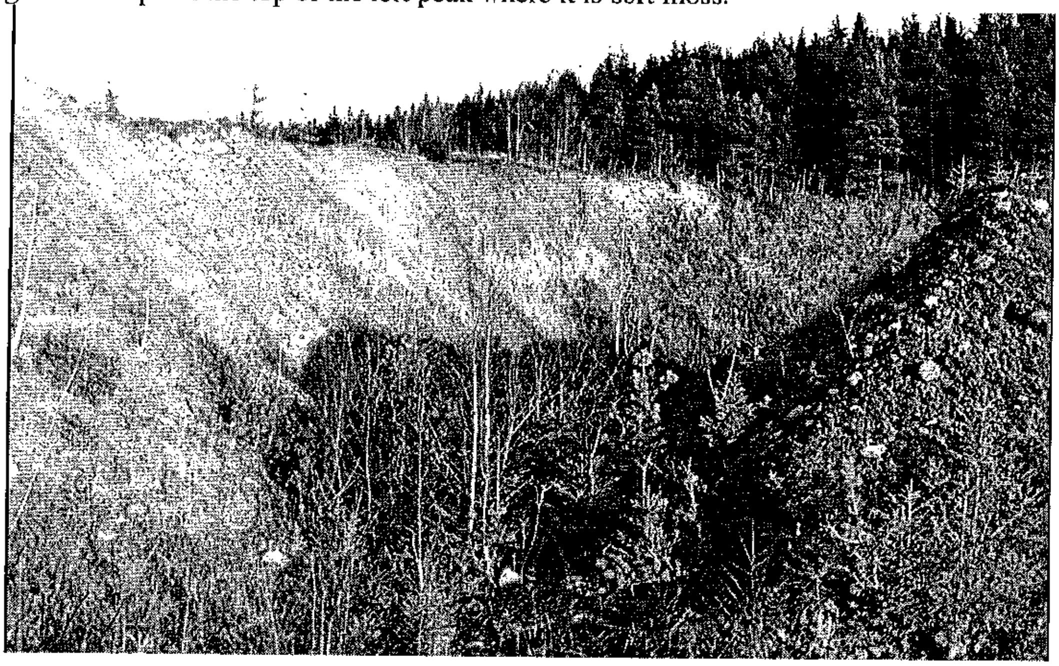
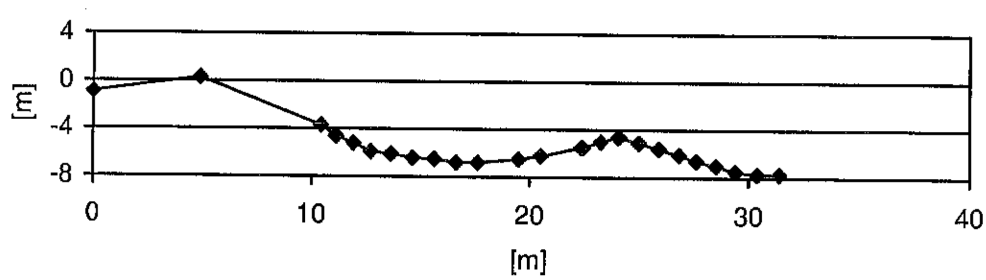


Figure 14
I15 supply depot. Photo, ground profile and three measurements of background sound pressure level (SPL).

4.2.3 Rångedala twin peaks

Rångedala twin peaks (figure 15) is located some km from a road with heavy traffic (R40). The terrain between the road and the location is rough and hilly with some forest. Rångedala twin peaks is a "natural" (its in a gravel pit) double screen. The surface is gravel except on the top of the left peak where it is soft moss.





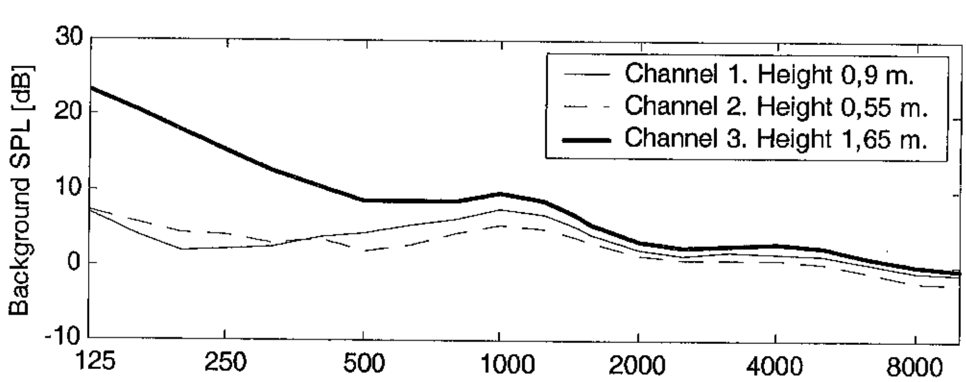


Figure 15

Rångedala twin peaks. Photo, ground profile and measurements of background sound pressure level (SPL) at three microphone positions.

4.2.4 I15 shooting gallery

The I15 shooting gallery (figure 16) is located near the supply depot with a few hundred meters to a medium busy road with some terrain obstacles and buildings in between. It should be useful for measurement of broad screen and multi edge screening. The surface is gravel. The house and roof is covered with corrugated sheet metal.

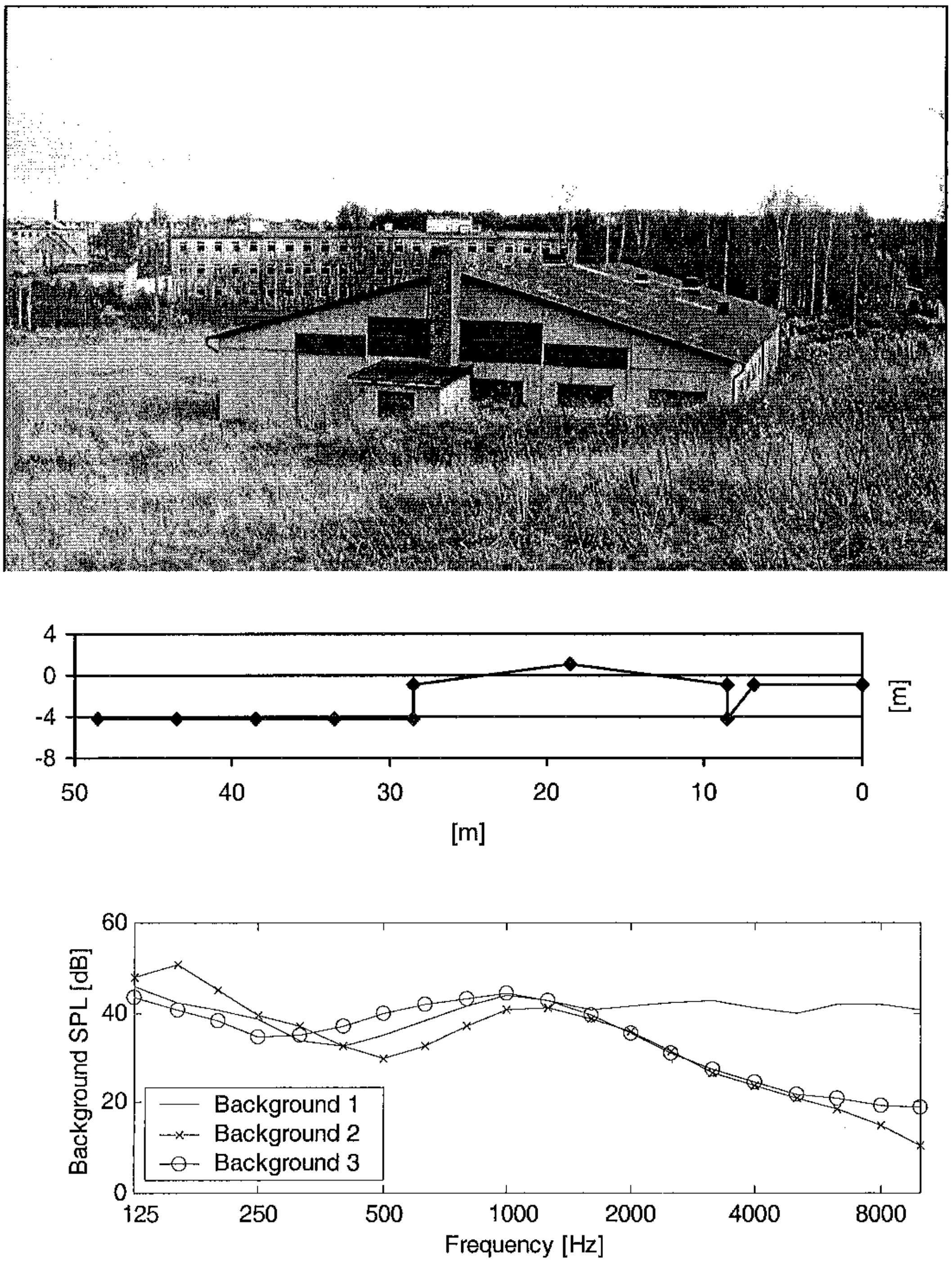
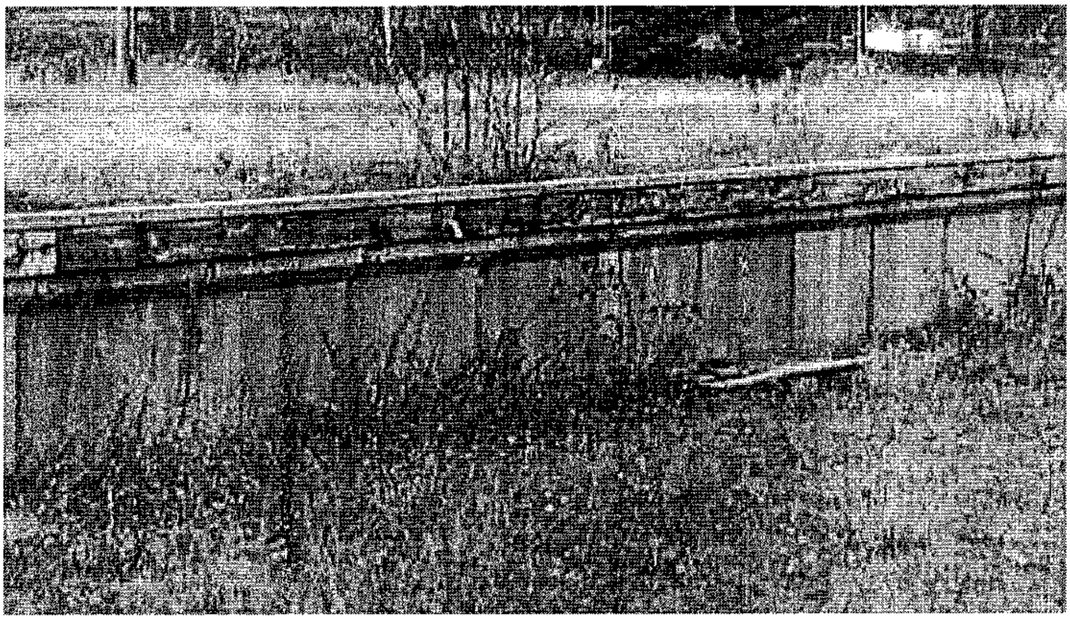
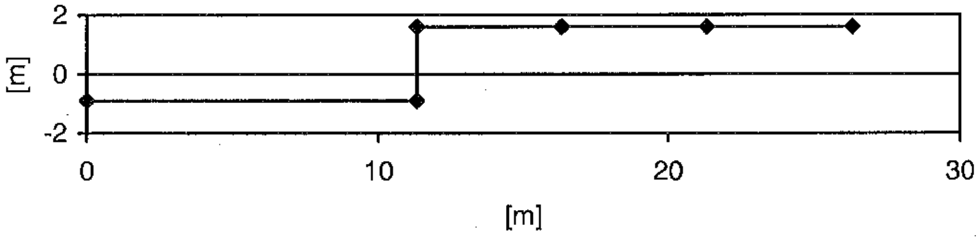


Figure 16
I15 shooting gallery. Photo, ground profile and three measurements of background sound pressure level (SPL).

4.2.5 I15 loading ramp

The I15 loading ramp (figure 17) is located near the shooting gallery. It has a steep, perpendicular vertical part. The horizontal parts of the surface are gravel and the vertical part concrete.





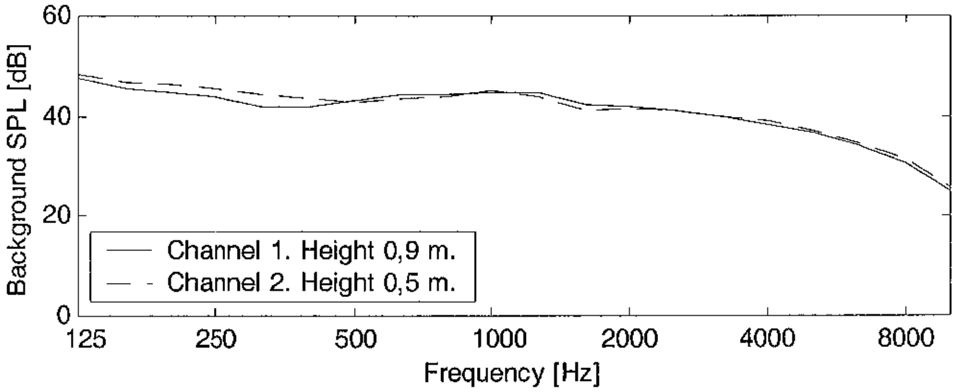


Figure 17
I15 loading ramp. Photo, ground profile and measurements of background sound pressure level (SPL) at two microphone positions.

4.2.6 Rångedala flat

Rångedala flat (figure 18) is located in an old gravel pit some km from a road with heavy traffic. Rångedala flat has an unusually low background noise level. The surface was rough soil/gravel.

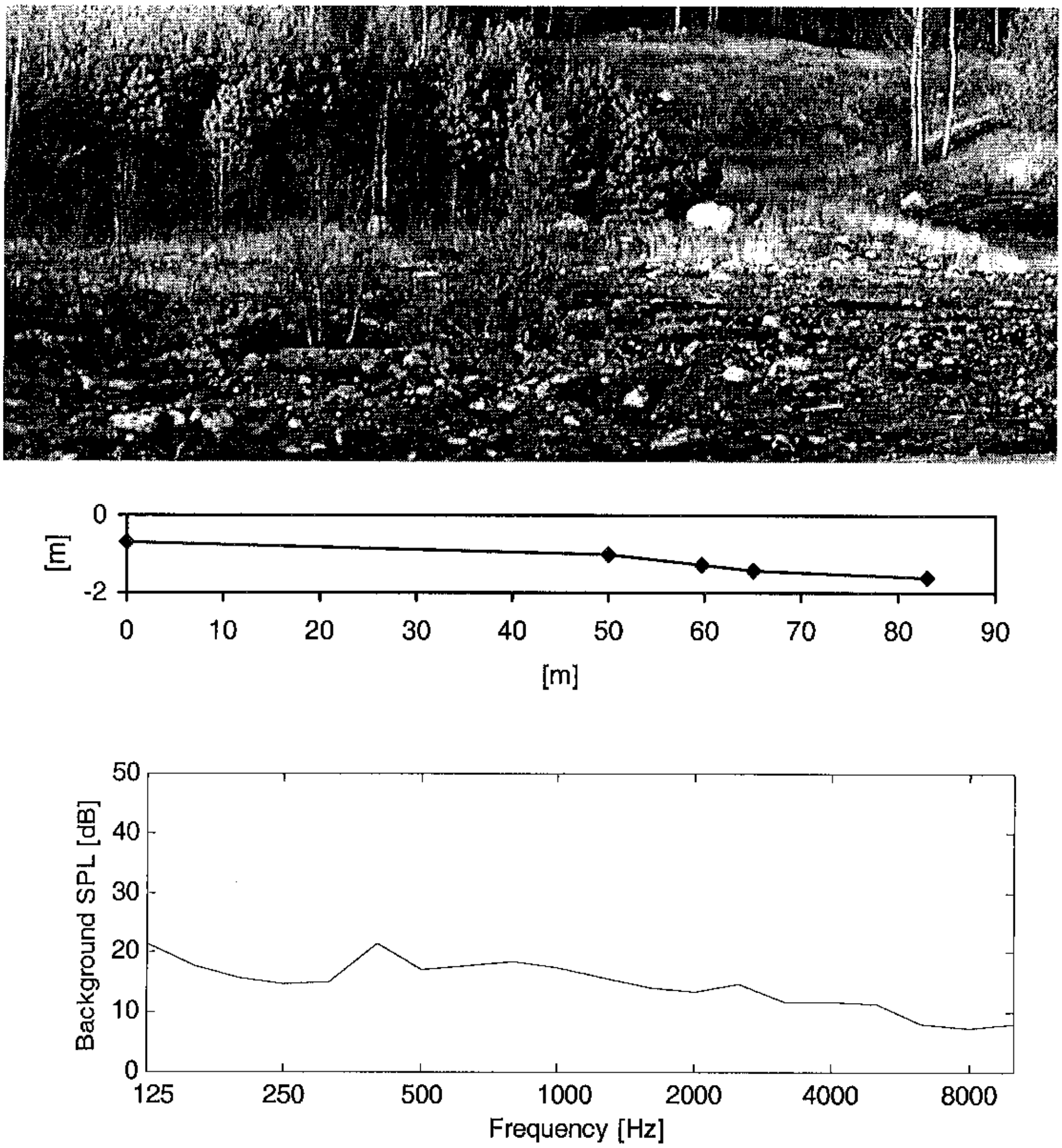


Figure 18

Rångedala flat. Photo, ground profile and measurements of background sound pressure level (SPL). The picture lies a little due to telescopic lens. The distance to the white rock in the middle is just under 100 m. Low x-coordinate on the near side.

4.3 Discussion

The locations found represent a variety of topographies. They can be used for validation measurements of both flat, valley and hill terrain. Natural and multi edge screens and a natural double screen have been found. The ground surfaces are mostly gravel, but also grass, soil and small spots of soft moss and corrugated sheet metal. One location with rough surface has been found.

Background noise measurement at Rångedala flat was well under 30 dB (A). This means that measurements over longer ranges can be done. However, the size of the site limits the possible distances to somewhere between 150 – 200 m. Both Rångedala sites are gravel pits not in use at the moment, and with assistance from a Caterpillar or a wheel loader a wide variety of rough surfaces and small to medium terrain ondulations can be created. Bråt shooting range has some interesting topographies, but is of questionable value as it is a little complcated to get access to.

5 Software for evaluation of sound propagation measurements

The software described in this section is used from the moment the measured data is placed on the hard disc in binary form as a DAT-file.

A measurement is originally analog from the microphones all the way into the DAT-recorder and digitized there (16-bit, 24000 sample / s). In the DAT and from the DAT to the hard disc the data is handled by hard [37] and software [14]from SONY. This equipment is described in section 6.2."Equipment".

To evaluate a measurement session it is necessary to specify the filenames of the DAT-files used for calibration, calculation of source power and measurements. For each DAT-file the range switch setting for each channel used has to be given. A commented template example file showing this is given on CD-rom (Annex 5). Figure 19 shows the principal flow between the programs involved.

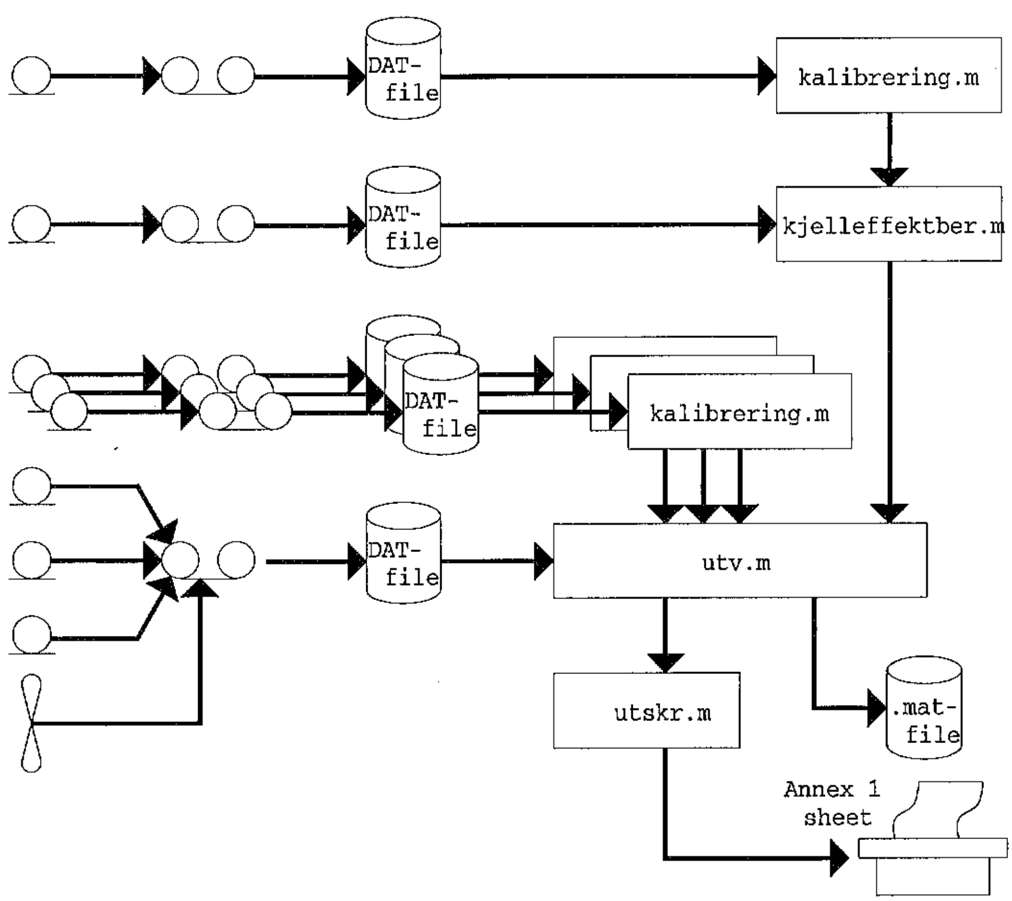


Figure 19

The sound signal comes from the microphone(s) and is digitized and saved in the DAT tape recorder. From the DAT it is transferred to the hard disc of a PC. The different matlab programs then read measurement data from the hard disc.

In the Nord 2000 project all algorithms are developed as Matlab .m-files [38]. In this thesis Matlab [39] is used to make scripts and functions for evaluation of the measurements.

All matlab .m files have been provided with help texts which describe name, date, parameters and outfile, if any. The program "utvhelp.m" prints the helptexts for programs involved in a usual evaluation of a measurement. All source code and some examples can be found on CD – R (Annex 5).

5.1 Software developed

5.1.1 kalibrering.m

Usually, a calibration signal is used to set the amplification of the instrument. In this case with evaluation made in software, the calibration signal measurement is used to calculate a calibration factor. This is done every time the measurement chain (microphone, cable, acoustic front end, DAT-recorder) is put together after having been taken apart, for example at the beginning of each measurement occasion. The function "kalibrering.m" calculates the calibration factor from a calibration file.

Name:	kalibrering.m
Data in:	File name, channel number, range setting on the acoustic front end [17].
Data out:	Calibration factor.

5.1.2 kjelleffektber.m

To determine the characteristics of the sound source, a sound source pressure level file is recorded. The function kjelleffektber.m evaluates such a file, compensates for distance and eventual reflection, and returns a vector with sound power level at each 1/3 octave band.

Name:	kjelleffektber.m
Data in:	File name, distance, channel number, calibration factor, range setting on the front end, reflection effect.
Data out:	Sound power level at each 1/3 octave band.

5.1.3 utv.m

The function "utv.m" evaluates one measurement file. A measurement file is a matrix of four rows and a number of columns. One column per sample. The first three rows are sound data. The last row is wind data.

The wind data row from a measurement contains voltage level data. The voltages from the wind gauge are in one of two levels, 5 or 10 V (figure 4). Strength and direction of the wind are encoded in the frequency and the ratio of the positive pulse to the period (figure 5). To find theese a threshold is set and the result is differentiated to find the flanks. Positive and negative flanks are kept apart. A two row matrix is created with flanks in one row and the matching time (actually, the number of the sample in which the flank was found) in the other. The period is the time between a flank and the next flank of the same sign. The positive pulse width is the time between a positive flank and next flank of the different sign.

The relative size of the wind component in the measurement direction is computed from the positive pulse width and the period. Then its put in a row of a "wind shift" - matrix. The wind force is calculated from the period, the wind factor from 3.1.2 "Calibration of wind speed signal" and the wind component and put in the next row of the "wind shift" - matrix. The third row of the "wind shift" - matrix is the time of the flank.

A sound data row from a measurement has columns with data. These data are 16 bit voltage levels from the microphone. A whole row can be regarded as a wave. To calculate the frequency content of the wave, it is analyzed using Fast Fourier Transform (FFT). FFT is done with an algoritm presented by Welch in [40]. The result of the FFT is delivered in narrow bands with equal bandwidth over the spectrum covered. Conversion of these to 1/3 octave bands, which have logarithmic bandwidths, is made by the function "tersband.m" (5.1.4). The sound pressure of each channel is put in a row vector.

To obtain the sound pressure level relative free field the sound source power is subtracted from the sound pressure curve and a compensation for the distance source - receiver is made. The sound pressure relative free field of each channel are put in a row vector.

The wind component and speed for the time of each FFT window is taken from the "wind shift" matrix and put in row vectors. The time of each FFT is calculated from the column number and the sampling frequency and put in a row vector.

To reduce the amount of data, the averages of ten columns of these vectors are written to an matlab .mat file. For sound pressures the averaging is done with "emean.m". The output file is completed with a label vector produced by "vacker_f_ber.m"

Name:	utv.m
Data in:	filename for in and outfile, head for outfile, distance, sound power level curve, calibration factor/s, range setting/s on the front end.
Data out:	.mat file with head, sound pressure level/s (average of 10), sound pressure level/s relative free field (average of 10), wind (average of 10), wind component (average of 10), time (for the 5^{th} column of 10), label vector for neat scaling of axles.

5.1.4 tersband.m

The function "tersband.m" summarizes sound data in narrow bands to 1/3 octave bands according to IEC 1260 [41]. The frequency range is limited to 50 - 10000 Hz.

Name:	tersband.m
Data in:	sound power level in narrow bands, narrow band frequencies.
Data out:	sound pressure level in 1/3 octave bands

5.1.5 emean.m

The function "emean.m" takes 10 sound pressure levels, calculates the quadratic sound pressures, averages over 10 points and calculates the sound pressure level for the average.

Name:	emean.m
Data in:	vector with sound pressure levels.
Data out:	10 times shorter vector with sound pressure levels.

5.1.6 vacker_f_ber.m

The program "vacker_f_ber.m" creates a vector with labels from 50 – 10000 Hz according to ISO 1260, Annex A, table A.1 [41] for neat scaling of the frequency axis in a diagram.

Namn:	vacker_f_ber.m
Data in:	none.
Data out:	vacker_f.mat

5.1.7 utskr.m

"utskr.m" prints two diagrams. One shows wind data during a measurements and the other shows mean sound propagation during the measurement in 1/3 octave bands.

Namn:	utskr.m.
Data in:	One file from utv.m.
Data out:	Two diagrams. See Annex 1.

5.1.8 Template for evaluation

The file "helutvmall.m" is a template for evaluation of one measurement occasion, including calibrations, source sound power curve and evaluation of measurements (also see 6.1.3 "Measurements").

5.2 Storage of raw data

The raw data is kept:
1. On the original DAT-tapes labeled "Vind1" – "Vind4".
2. As unprocessed binary data files on CD-R discs (Annex 5). Scans of notes taken during the measurements are also saved on CD-R.

5.3 Discussion

At the moment the whole measurement chain except the software fulfills applicable parts of IEC 651 as sound level meter type I [42]. A natural extension would be to validate the whole chain as sound level meter type I. If this is to be done, some way to ensure the function of the software used arises.

5.3.1 Software identity

An important question here is: Which is the software? As Matlab is an interpreting language, the source code of the program modules (the .m files described in section 5.1) is the same as the object code. This means that open distribution of the source code, which is preferred from an academic point of view, will enable anyone to tamper with the code, thereby jeopardizing the reliability of the evaluation. In this thesis I have given all software modules version numbers and dates. This reduces the risk for confusion, but gives no protection against deliberate changes. If some kind of compiling language is used, we can separate the source and object codes and reduce the risk for mistakes. It would still be possible to change the source code and produce new object code, though.

One alternative is not to distribute the source code, but open distribution is to prefer. For use of software in officially calibrated equipment an alternative is to calculated some kind of electronic signature for each tested program module and attach the signatures to the calibration protocol. This will work for both interpreting and compiling software. The use of electronic signatures have recently been given legal status in the European Community.

5.3.2 Accuracy of FFT evaluated measurements.

One of the purposes of these measurements was to be able to follow wind fluctuations. To achieve this the window of the FFT was set to 4096 samples. With a sample frequency of 24000 samples / s this gives a window length of 0,170 s. This is believed to be short enough for the wind to be stable and the turbulence to be "frozen". With this window length we also can regard the measured signal as stationary, which is necessary to be able to use FFT at all.

The result from the FFT is delivered in narrow bands. The conversion to 1/3 octave bands is done by summing the narrow bands which have center frequencies between the min and max frequencies for each 1/3 octave band. In the lower end of the spectrum, the spacing between the narrow band frequencies approaches the spacing of the 1/3 octave bands. This means that the result is affected by a random factor, depending on how many narrow bands that fall in the 1/3 octave band. This gives a systematic error that is of different size for every combination of narrow and 1/3 octave bands. In the case the level of all bands are equal the error is exactly computable. If the levels differ, the total sound energy of the signal will still be correct, differences only occur in the distribution between adjacent bands.

A simpler approach is to presume that the maximum deviation is one narrow band in each 1/3 octave band. If so, the error will be:

$$b_f = 10\log\left(\frac{1+h}{h}\right) \qquad (3)$$

where

b_f - systematic (bias) error [dB]

h - number of narrow band center frequencies that falls within the 1/3 octave band.

In Table 2, b_f for 1/3 octave bands is shown.

In this case, 50 % overlap is used in the FFT. The variance of the data in each narrow band will then, according to [43] be given by:

$$\delta_f = \frac{9}{8L} g^2(f) \qquad (4)$$

Where

δ - variance

L - number of windows (in this case 10)

g(f) - the sound pressure in each band

and for all narrow bands with center frequencies in the same 1/3 octave band:

$$\delta_f = \frac{9}{8L\sqrt{h}} g^2(f) \qquad (5)$$

This gives a confidence interval of:

$C_f = \pm 10\log(1+2\delta)$ (actually, $1{,}96\delta$ for 95% confidence) (6)

Where

C_f - confidence interval in [dB]

Table 2

Systematic error and confidence interval of 1/3 octave bands.

Frecuency label Of 1/3 octave band	b_f	C_f
[Hz]	[dB]	[dB]
50	1,76	0,64
63	1,25	0,53
80	1,25	0,53
100	0,97	0,46
125	0,79	0,42
160	0,67	0,38
200	0,51	0,33
250	0,41	0,30
315	0,35	0,27
400	0,26	0,24
500	0,22	0,22
630	0,17	0,19
800	0,13	0,17
1000	0,11	0,15
1250	0,09	0,14
1600	0,07	0,12
2000	0,05	0,11
2500	0,04	0,10
3150	0,03	0,09
4000	0,03	0,08
5000	0,02	0,07
6300	0,02	0,06
8000	0,01	0,05
10000	0,01	0,05

If we want to compare with a similar analogue measurement, the condition for an error smaller than ± 0,5 dB with 95% confidence is:

$$f = \frac{300}{1{,}70L} \approx 200 \text{ Hz} \qquad (7)$$

Where

300 is a constant and 0,170 is the measurement time for 10 measurements.

6 Sound propagation measurements

The overall purpose of these measurements is to provide sound propagation data for validation of a new noise propagation prediction model developed in the Nord 2000 project. To fulfill this optimally, the measurements have to be made in 1/3 octave bands from 25 Hz – 10 kHz over a distance range of 0,5 m – 1 km [44]. At the specification of this thesis, the distance range was limited to 20 – 100 m by my tutor. The topography has to be more complicated than flat ground, or flat with one screen. Wind speed and direction must be recorded during the measurements.

Calculations with different models for comparison with measured data falls out of the aim of my thesis. The model calculations in this section have been made by Mikael Ögren, SP, with applicable parts of a tentative Nordic noise prediction model (N2000-13) as it was in autumn 1999. It is briefly described in chapter 2. For a deeper description see [45] with modifications in [46]. The result of all measurements, even those not used for model calculations, can be found in Annex 1 and on CD-R (Annex 5).

6.1 Method, procedure

6.1.1 Calibration of sound power level

The sound source driver was investigated in two measurements. The first measurement was made at 4 m with sound source and microphone lying flat on the floor in a hemi anechoic room. The second was made with source and microphone in eye height, distance 1 m and sound absorbing material on the floor of the same room to create "free field" conditions.

6.1.2 Calibration of wind signal.

The wind speed was investigated by recording files at 13 wind speeds. The direction by recording 12 files in angles with 30 degrees spacing. A more detailed description of this can be found in sections 3.1.2 and 3.1.3.

6.1.3 Measurements

At each measurement, the topography was measured. Positions of sound source and micophone(s) were measured. A calibrator was used to give a signal for calibration of the chain from microphone to computed result. The first measurement(s) at each location was one or more background(s). Then a number of measurements with the sound source active was performed at various distances, heights and settings on the equipment. At SP after the measurements, the measured files were transferred to computer hard disc. These files were then evaluated with the software developed in this work.

In the measurements the equipment consisted of sound source, sound data collection device and wind gauge. The topography was checked with surveying tools. The measured data was transferred to a computer with an interface adapter. No analyzer is used, as the evaluation of measured data is done totally in the PC with software coded in Matlab

6.2 Equipment

The sound source consists of a driver with attached hose, an amplifier, the cable between driver and the amplifier, a portable CD-player, and a CD with pink noise. At some measurements a FLUKE12 [23] instrument was used for voltage supervision of the signal.

The driver is a JBL 1 ½" compression driver [21] with a 3,15 m long plastic hose (figure 20). To provide a hold for the hose an aluminum plate is attached. In the other end of the hose an aluminum nozzle is mounted to prevent the end of from vibrating at high sound pressures. A sketch over the plate and the nozzle is found in Annex 3. The driver is connected to a power amplifier JBL GTS300 [47].
A CD-player Sony Discman ESP model D-E301 [48] is connected to the amplifier via line outlet. In the player a CD - R with a noise track on resides. The noise used is pink noise, high pass filtered from 150 Hz. The noise track is fabricated with Matlab.

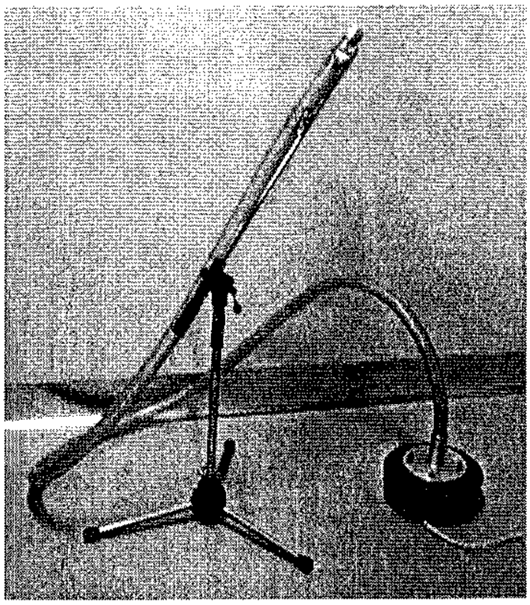


Figure 20
Sound source. Driver with hose.

All measurements but one was calibrated with Bruel & Kjaer 4231 [49]. At the measurement of source soundpower curve after modification for voltage supervision (section 6.3.1) a Bruel & Kjaer 4230 was used. Bruel & Kjaer 4231 fulfills IEC 942 [50] as sound calibrator class I.
Microphones: Larsson Davis 2541 [51].
Preamplifiers: Norsonic 1201 [37].
DAT-recorder: Sony PC208A [13] equipped with Bruel & Kjaer Acoustic Front End Type 5966 [52]. This combination is sold under the name Bruel & Kjaer Type 9666 [53].

To transmit data from the DAT recorder to a PC, a digital interface adapter Sony PCIF-5 with cables PCDK22, PCDK30 and PCCK24 was used. The control software was Sony PCIF 260 [14] series **PCscan mkII**, version 2.00.

All equipment used is regularly calibrated in its normal operation at SP, but no calibration or validation of the whole chain in the design used in these measurements has been done. The sound measurement equipment in the chain from microphone to DAT-recorder fulfills applicable parts of IEC 651 as sound level meter type I [42].

A surveying protractor Carl Zeiss Jena NI50 with tripod, a surveying scale, a measuring tape with a length of 50 m and a folding rule was used. The measurements were evaluated with the software described in chapter 5.

6.3 Preparatory measurements

6.3.1 Source sound pressure

The source sound pressure level was measured once before the first field measurements started (figure 21, left) and the sound power level calculated from it. After introducing the new voltage supervision cable drum (section 3.2) and changing the setting of the amplifier, the measurement and calculation was made again (figure 21 right). Both measurements were made in the hemi anechoic chamber at SP. The input signal was filtered pink noise described in section 3.2 "Supervision of voltage at driver".

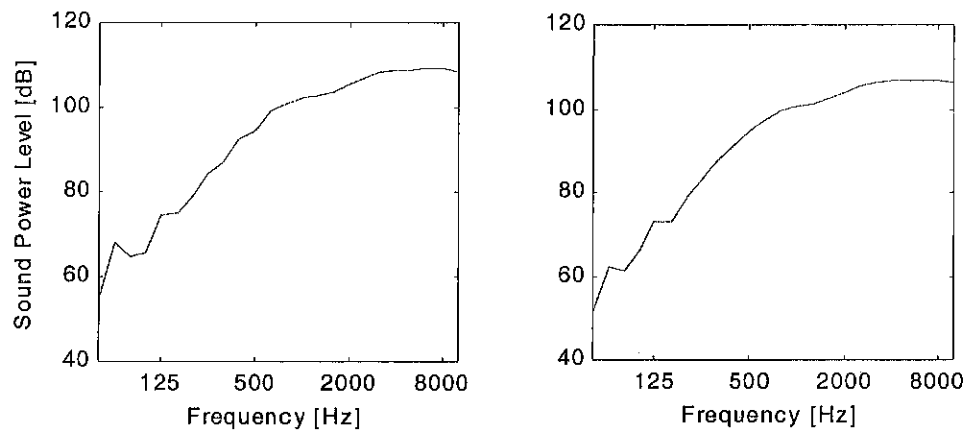


Figure 21
Source sound power level curve calculated from sound pressure measured before (left), and after (right) the new voltage supervision cable drum was introduced (section 3.2).

6.3.2 Source sound pressure fluctuations

When measuring the source sound pressure the first time, time dependant variations in sound power was discovered. Therefore, when doing the measurement again due to altered amplifier setting, ten measurements, each approximately one minute long were made. The standard deviations of all source measurements are shown in table 3. All measurements were made at 1000 Hz.

Table 3
Variations in source sound power level at 1000 Hz.

ID	Relative level [dB]	Signal
Vind1id36		29,3 V RMS at amplifier
101	61,628	15,8 V RMS at source
102	63,223	
103	61,0398	
104	62,2402	
105	60,7407	
106	62,7305	
107	61,96	
108	63,8713	
109	61,4613	
110	63,7018	
Mean	62,25966	
Standard deviation	1,09	

The relative level of ID 104 was closest to the average level of ID 101 – 110, so ID 104 was used to calculate the source sound power level for the measurements made with voltage supervision.

6.3.3 Discussion

The standard deviation of the sound power level at 1000 Hz have in 10 measurements of each 60 seconds never been larger than 1,09 dB. This gives a confidence interval of the sound power level of ± 2,14 dB at 95% confidence. The levels may be different at other frequencies, but the size of the fluctuations is probably of the same magnitude. As the variations in sound propagation we intend to measure is in the magnitude of ten decibels and more, source sound pressure level variations will probably not affect the usefulness of the measurement results.

6.4 Measurement of topography

One important part of these measurements is the uneven ground. To be able to calculate sound propagation properly, the coordinates of the topography must be measured thoroughly. The prediction mode is mainly thought to handle terrain variations in two dimensions, so the task was to measure 2D terrain coordinates.

To get a 2D terrain profile, surveying protractor, scale and a measuring tape were used. The tape was put on the ground and the height at different points was read at the surveyor scale with the protractor. If necessary, a new zero reference was taken along the way. At the I15 depot a folding rule was used to prolong the scale.

In all locations except Rångedala Twin Peak, the difference between the real x-coordinate and the value read on the tape lying on the ground was found to be so small (less than one meter on 50 m), that the value from the tape was used as x-coordinate. At Rångedala Twin Peak, a curve with the profile of the ground was constructed geometrically with a CAD-program, and the coordinates were taken from the curve.

6.5 Gässlösa Valley

6.5.1 Background

At Gässlösa, the microphone was fixed and the sound source was placed at ten different locations. Figure 22 shows one location and in the next section results of measurements and model calculations for this location are shown.

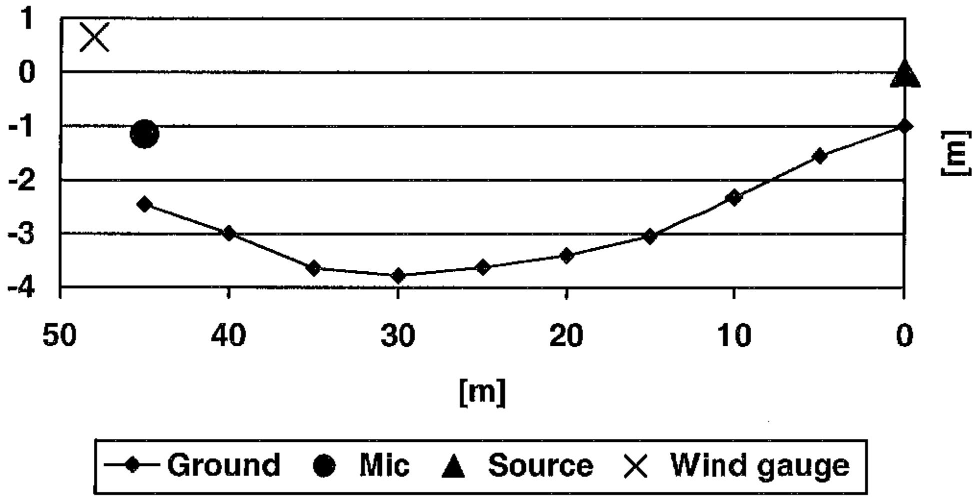


Figure 22
Dimensions at longest distance measurement in Gässlösa.

The wind gauge was placed near the microphone at a height of around 4 m and unfortunately directed 90 degrees off the line microphone – source. This causes the wind direction data to be unusable.

6.5.2 Result

The measurement over the longest distance is presented. This measurement from Gässlösa has the following data:

Surface	Rough grass
Source position	x = 0; y = 0 [m]
Microphone position	x = 45, y = -1,15 [m]
Channel	1
Tape	Vind 2
Measurement ID	13
Background ID	1 (background 1), 14 (background 2).
Calibration ID	0
Ground impedance class at calculation	400 kPas/m^2

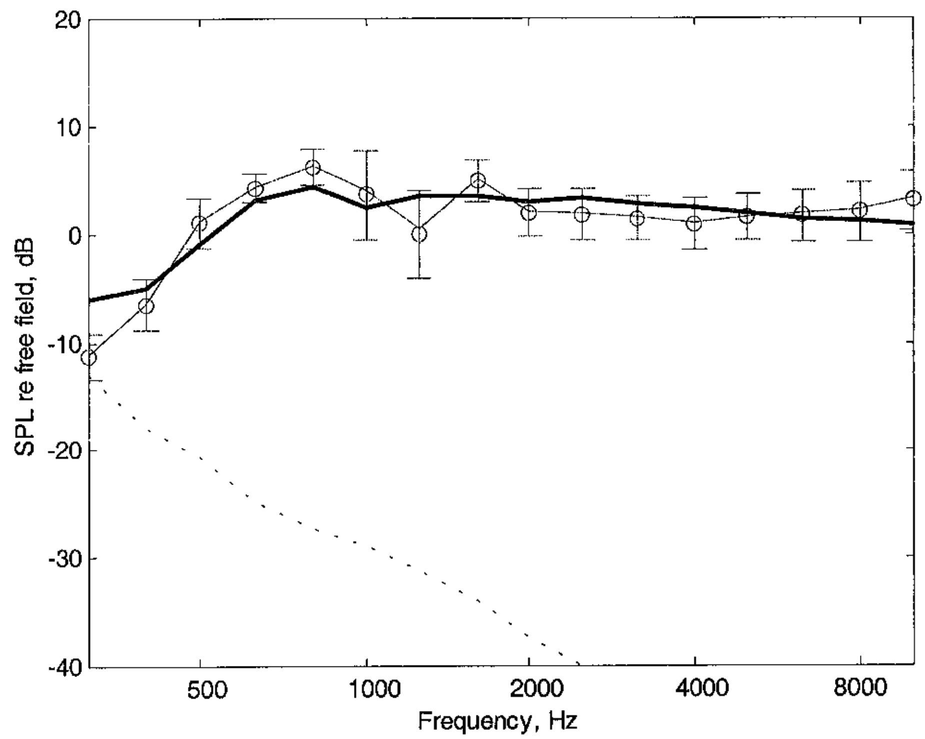


Figure 23
Sound propagation at Gässlösa. Model calculation: Thick line. Measurement result: thin, with rings. The error bars indicate 95% confidence in propagation variations during the measurement. Broken line: Background noise "relative free field". This curve is calculated so that the difference between sound pressure level in the background measurement and in the actual measurement is calculated. This difference is then subtracted from the sound power level relative free field to indicate the importance of the background noise.

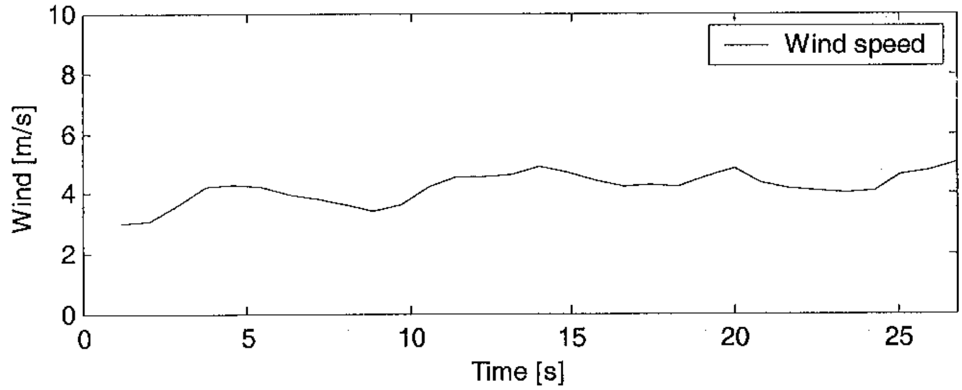


Figure 24
Wind during the measurement at Gässlösa Twin Peaks.

6.6 I15 supply depot

6.6.1 Background

At the I15 depot, the sound source was fixed and two microphones were placed in six different locations.

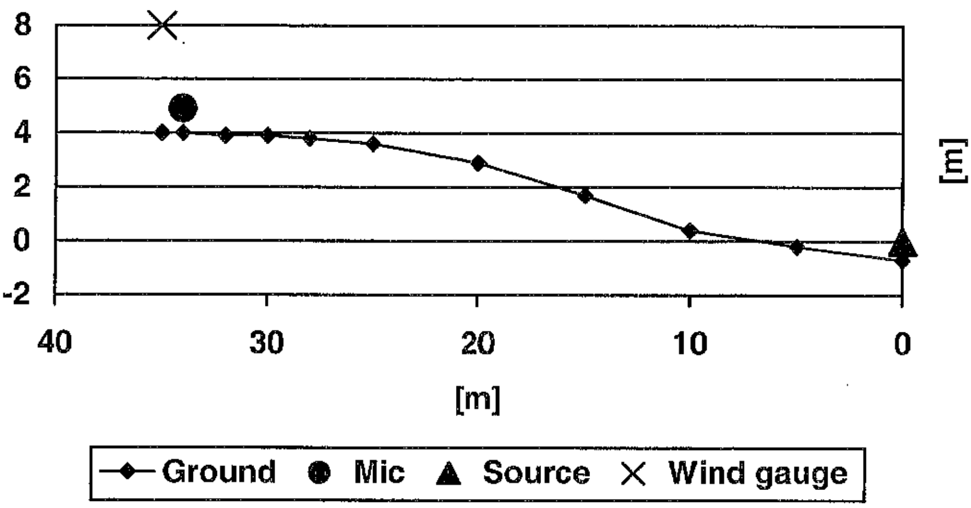


Figure 25
Dimensions for the presented measurement at I15 depot.

The wind gauge was at distance 0 and at a height of around 4 m above the ground.

6.6.2 Result

The presented measurement from I15 depot have the following data:

Surface	Grass
Source position	x = 0; y = 0 [m]
Microphone position	x = 34, y = 4,9 [m]
Channel	1
Tape	Vind 3
Measurement ID	11
Background ID	Background 1: 3. Background 2: 12. Background 3: 14.
Calibration ID	0
Ground impedance class at calculation	100 kPas/m^2

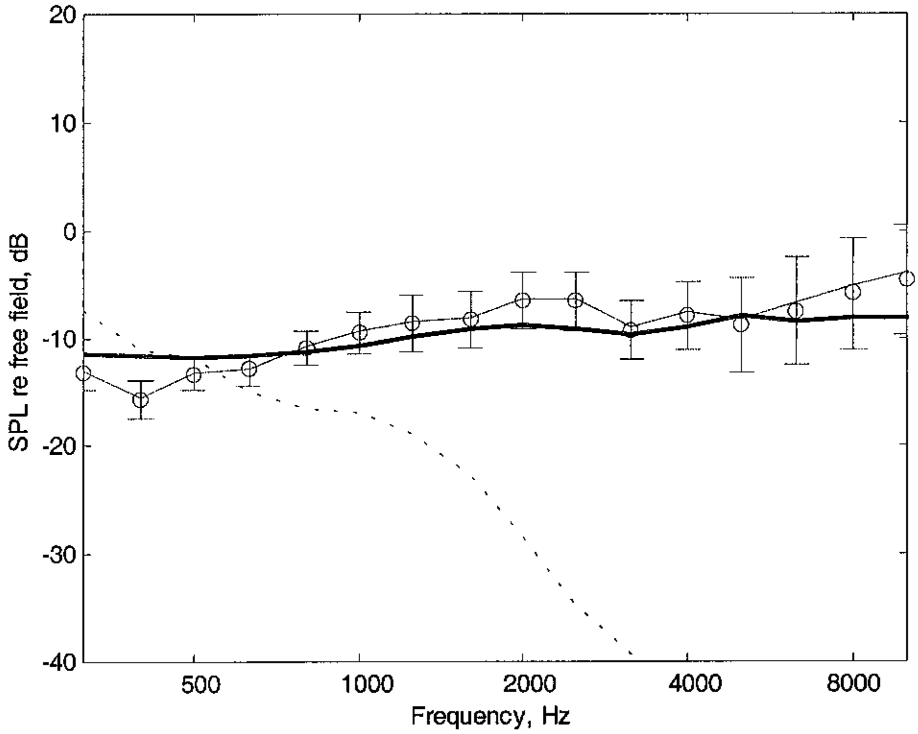


Figure 26
Upper: Sound propagation at I15 supply depot. For legend see description of figure 23.

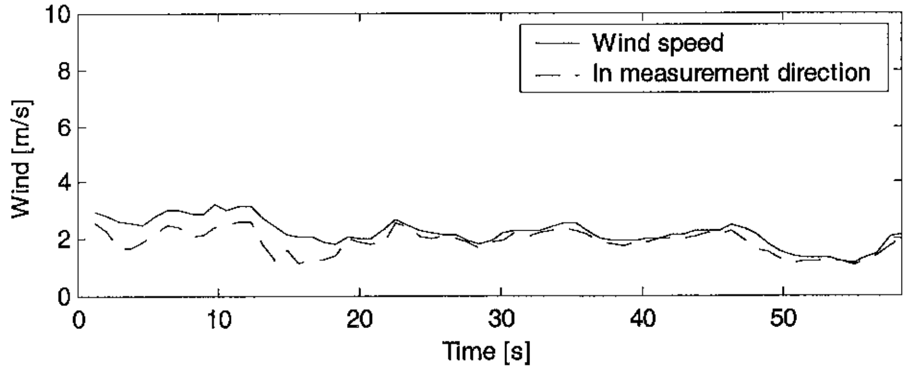


Figure 27
Wind during the measurement shown at I15 supply depot.

6.7 Rångedala Twin Peaks

6.7.1 Background

At Rångedala the sound source and three microphones were fixed and a number of recordings were made.

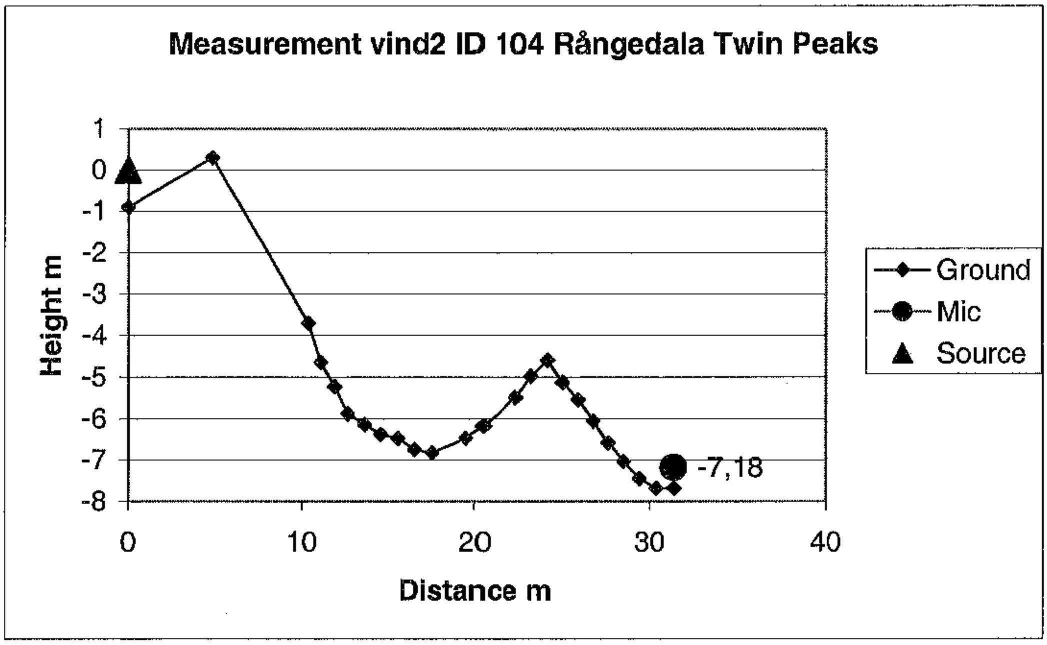


Figure 28
Dimensions in measurement at Rångedala Twin Peaks.

The wind gauge was placed near the microphones about 4 m above ground. The driver broke down during the measurement, so not all of them could be used.

6.7.2 Result

The presented measurement and calculation from Rångedala Twin Peak have the following data:

Surface	Gravel (moss from source to first edge)
Source position	x = 0; y = 0 [m]
Microphone position	x = 31,39; y = -7,18 [m]
Channel	2
Tape	Vind2
Measurement ID	104
Background ID	103
Calibration ID	101
Ground impedance class at calculation	63 kPas/m^2 (under source: 25 kPas/m^2)

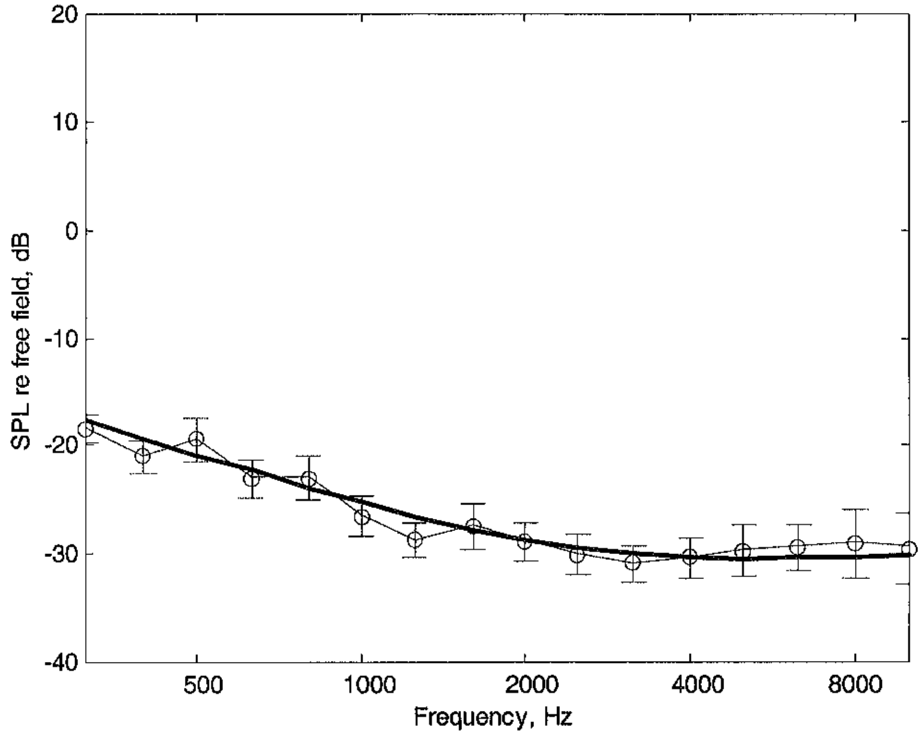


Figure 29
Sound propagation at Rångedala Twin Peaks. For legend see description of figure 23.

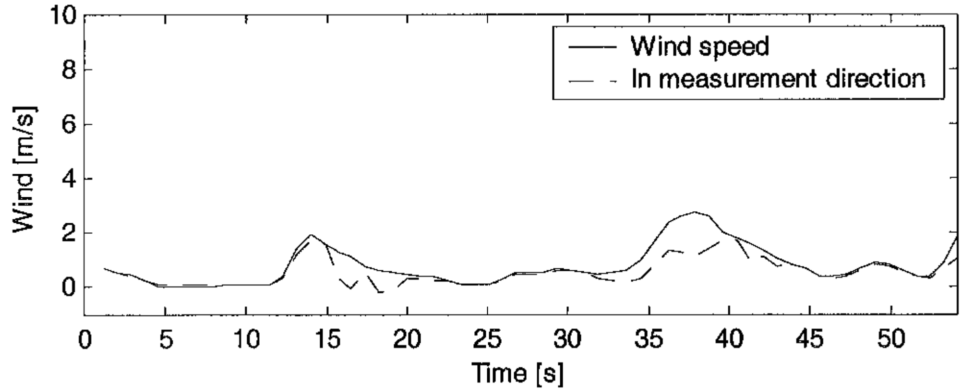


Figure 30.
Wind during the measurement at Rångedala Twin Peaks.

6.8 I15 shooting-gallery

6.8.1 Background

At the I15 shooting gallery the sound source was fixed and two microphones were placed at 4 locations.

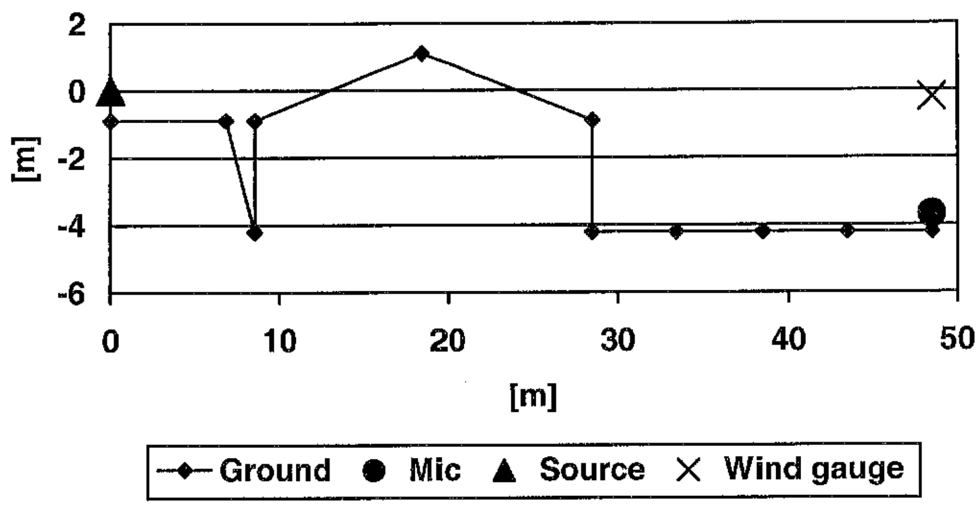


Figure 31
Dimensions at I15 shooting gallery.

The wind gauge was placed near the microphones about 4 m above ground.

6.8.2 Result

The presented measurement have the following data:

Surface	Gravel / sheet metal
Source position	x = 0; y = 0 [m]
Microphone position	x = 48,5 , y = -3,7 [m]
Channel	2
Tape	Vind3
Measurement ID	214
Background ID	212
Calibration ID	203
Ground impedance class at calculation	Gravel: 400 kPas/m^2 House: 2000 kPas/m^2

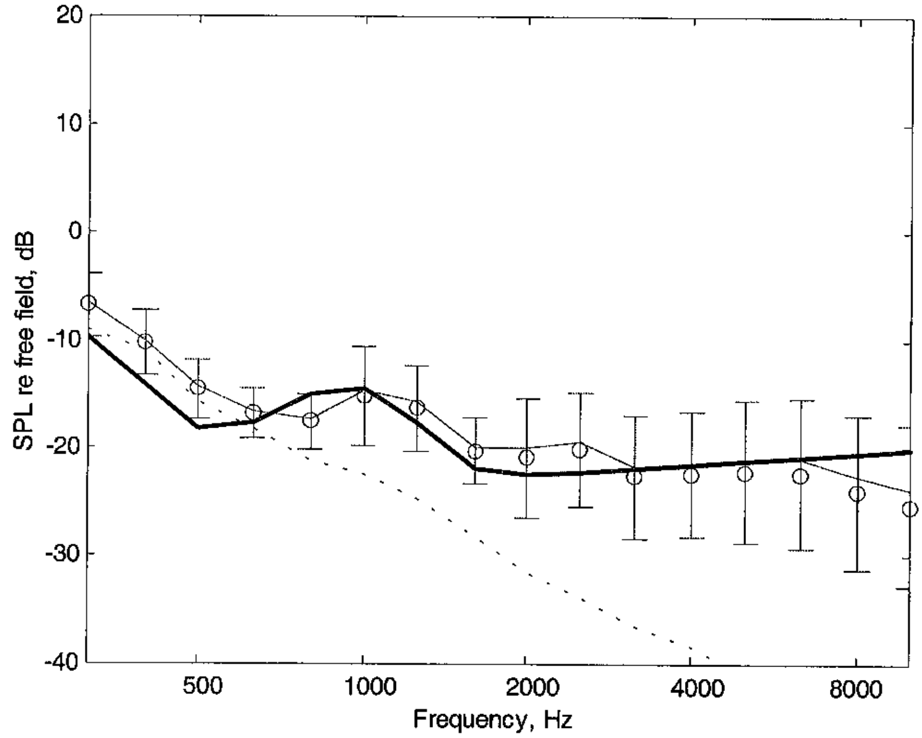


Figure 32
Sound propagation at I15 shooting gallery. For legend see description of figure 23.

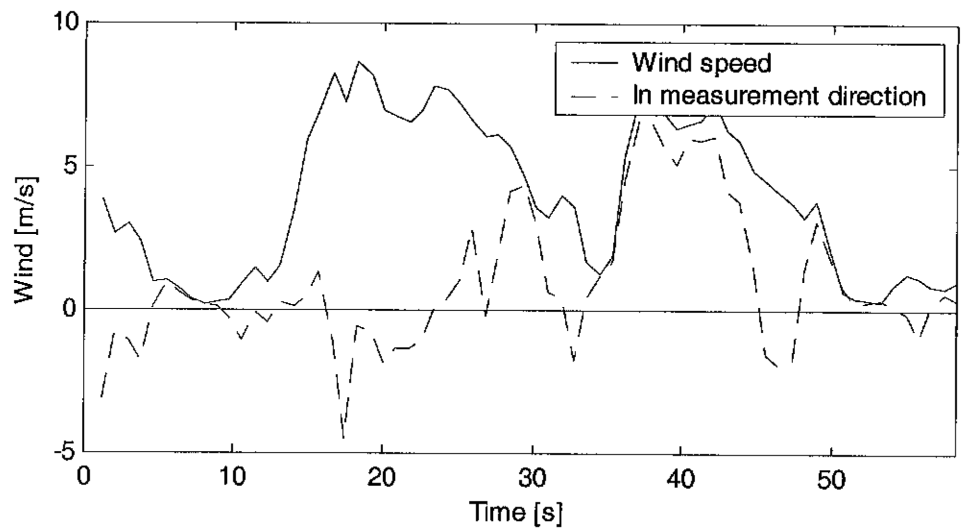


Figure 33
Wind during measurement at I15 shooting gallery.

6.9 I15 loading ramp

6.9.1 Background

At the I15 loading ramp the sound source was fixed and two microphones were placed at 3 locations.

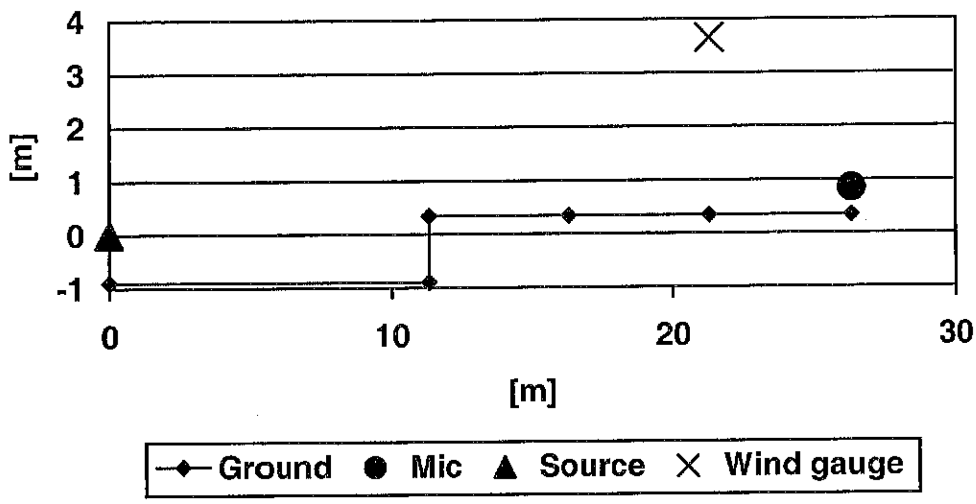


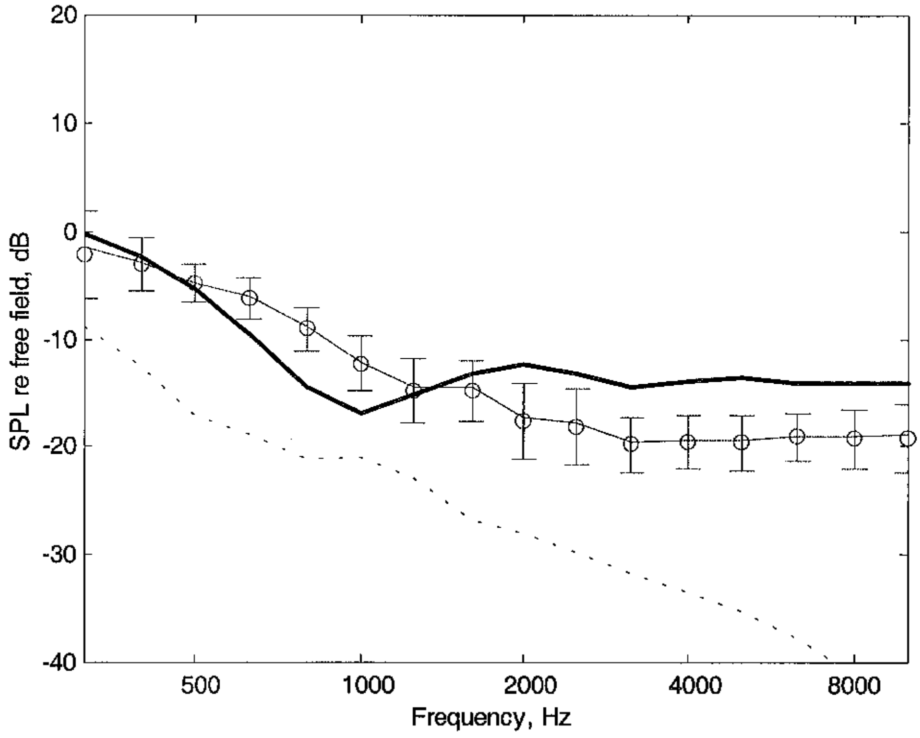
Figure 34
Dimensions at I15 loading ramp.

The wind gauge was placed near the middle microphone position about 4 m above ground.

6.9.2 Result

The presented measurement from have the following data:

Surface	Gravel
Source position	x = 0, y = 0. [m]
Microphone position	x = 26,3, y = 0,85. [m]
Channel	2
Tape	Vind 3
Measurement ID	219
Background ID	218
Calibration ID	203
Ground impedance class at calculation	Gravel: 630 kPas/m^2 Vertical part: 20000 kPas/m^2



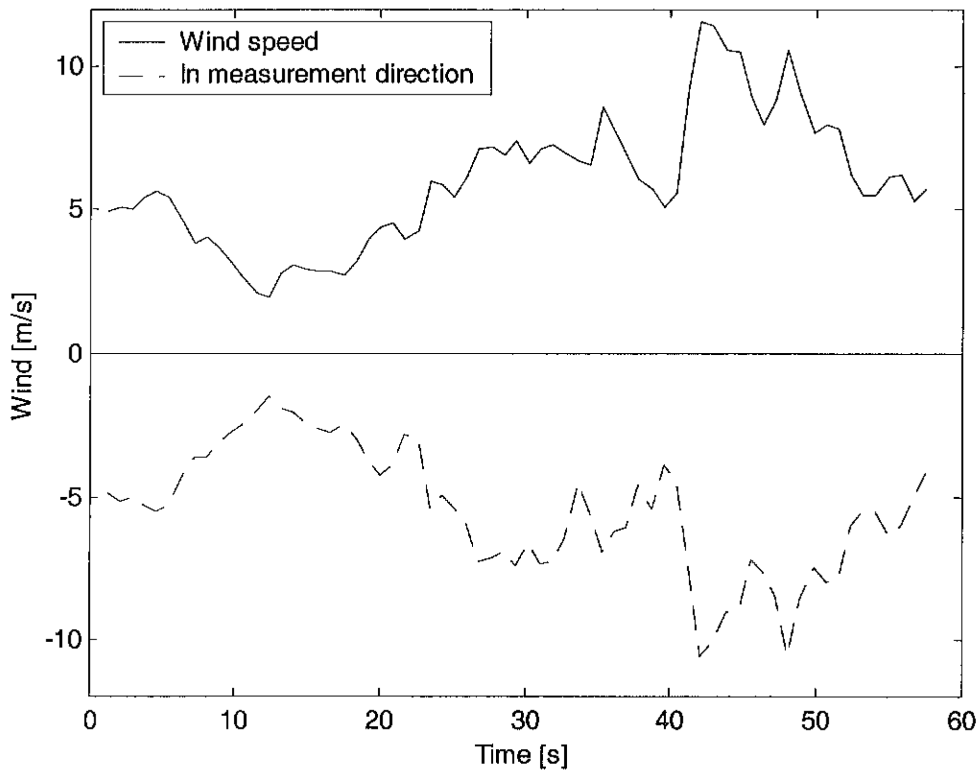


Figure 35

Upper: Sound propagation at 115 ramp. Model calculation: Thick line. Background noise: Broken line. Measurement result: thin, with rings. The error bars indicate 95% confidence in propagation variations during the measurement. Lower: Wind during this measurement at 115 ramp.

6.10 Rångedala Flat

6.10.1 Background

At Rångedala Flat the sound source was fixed and the microphone was placed at two different heights on four locations.

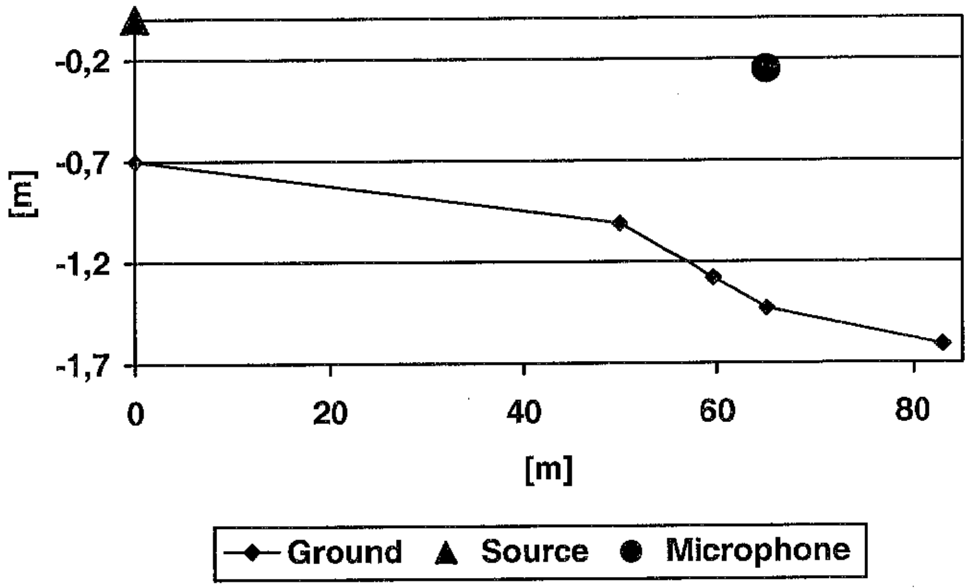


Figure 36
Dimensions at Rångedala Flat.

The wind gauge was placed near the 83 m microphone position about 4 m above ground. No wind was detected during the measurement. Figure 37 shows an example of how irregular and rough the surface was.

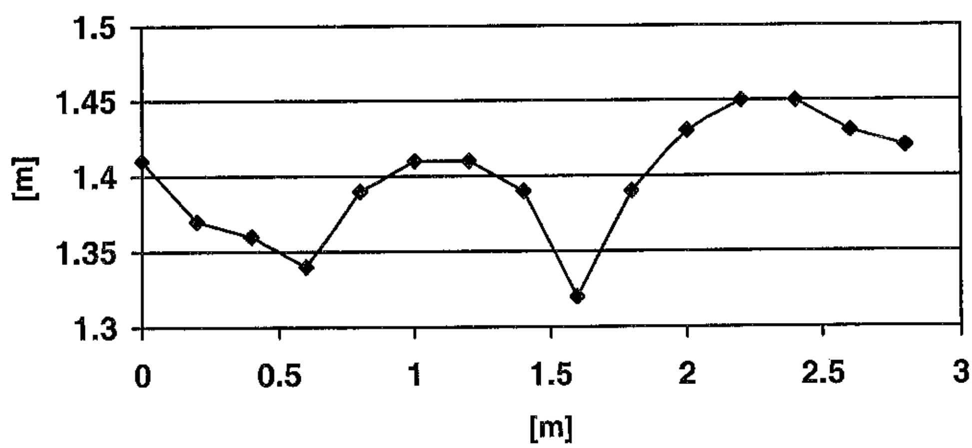


Figure 37
An example of ground irregularity at Rångedala Flat.

6.10.2 Result

The presented measurement from Rångedala flat has the following data:

Surface	Rough soil
Source position	x = 0; y = 0 [m]
Microphone position	x = 65, y = -0,25 [m]
Channel	1
Tape	Vind4
Measurement ID	5
Background ID	1
Calibration ID	0
Ground impedance class at calculation	400 kPas/m^2

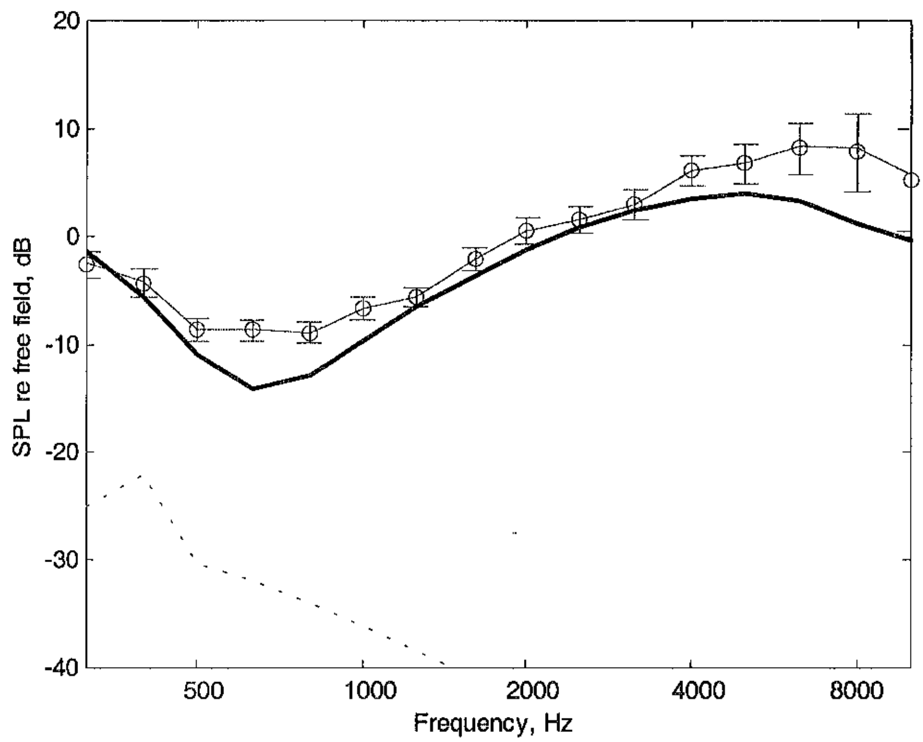


Figure 38
Sound propagation at Rångedala flat. For legend see description of figure 23.

6.11 Delivery of evaluated data

The evaluated data consist of .mat files from "utv.m". The .mat-files can be found on CD-R. A description of the measurements is delivered as an Excel workbook with one sheet for each location. Each sheet contains a figure over the ground profile, source and microphone positions, filename of the .mat-files, tape name and ID on tape for the measurements on one location. The ground profile and microphone positions, are delivered as a series of X,Y coordinates with 0,0 in the sound source. The workbook is called "geometries.xls" and can be found on CD-R (Annex 5).

Delivery of the data was done by saving the .mat-files and the Excel-file on a shared disc in the local LAN-server. In Annex 1, wind and mean sound propagation data are plotted in diagrams, one per measurement.

6.12 Sound Measurement accuracy

The main factor limiting the accuracy is the FFT discussed in section 5.3.2. The maximal errors are a systematic error, b_f, from the conversion from narrow bands to 1/3 octave bands and an estimation error, C_f, from the narrow bands. These errors are frequency dependant. In IEC 1260 [41], the limit of b_f is +1,0 dB, -2,0 dB.

To this we have to add the inaccuracy of the equipment used. All equipment is properly calibrated as a part of the SP normal calibration program. The equipment excluding software fulfills specifications as sound level meter type I according to IEC 651 [42]. This means maximum ± 0,7 dB on the sound level. This error is assumed not to be frequency dependent. The addition of these faults for different 1/3 octave bands are shown in Figure 39.

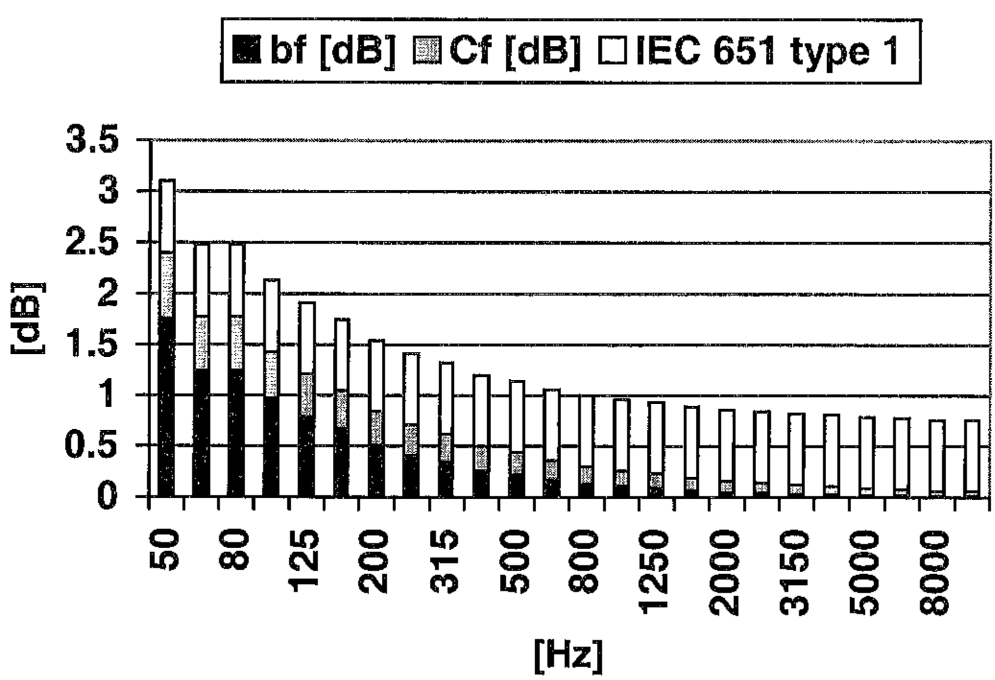


Figure 39
Total maximum error for different 1/3 octave bands.

The variations in sound source (6.3.3) is ±1,09 dB. This gives a confidence interval of ± 2,14 dB at 95% confidence.
The DAT recorder has a drift of ± 0,1% and a DC linearity of ±0,1% according to [13]. The drift affects the wind values and the energy distribution between frequency bands. The DC linearity can affect sound pressure levels.

Variations in sound propagation during one measurement are from ±5 dB up to at least ±20 dB. In this perspective the errors from above are small enough not to seriously reduce the usefulness of the measured results.

6.13 Discussion

Wind direction data from Gässlösa is unusable. To make any calculations of cases with wind influence on propagation over such a topography that measurement has to be repeated. However, the wind speed (2 – 6 m/s) is similar to the speed at the I15 supply depot measurement and some of the microphone locations at I15 supply depot can be used for valley type calculations, so the need is not overwhelming.

Variations in sound propagation during one measurement are probably mainly caused by atmospheric variations in temperature, wind and turbulence. These variations can not depend on the wind only. Rångedala flat, where no wind could be measured, shows the same magnitude of propagation variation as the other measurements.

All samplings of all measurements on all channels are preserved. This allows for evaluation in other ways later. For example by filtering the 1/3 octave bands instead of using FFT.

The relationships wind / sound propagation and wind / turbulence can be studied. These measurements cover rough ground, hill, wedge and dual hill in full scale with propagation measured in 1/3 octave bands. Much of this has not been measured before. Measurements do not cover distances over 80 m.

The evaluation of measurements in software is not validated against any standard. The desired frequency range was the one of IEC 1260[41], which in 1/3 octave bands is 25 – 20 000 Hz. This has not been achieved. The reasons for this is:

- The noise file fed to the amplifier was high pass filtered from 150 Hz.
- The FFT was at an early stage limited to 50 – 10000 Hz due to fewer than 3 narrow bands in each 1/3 octave band. Later in the project evaluation was enhanced by overlapping of the FFT windows. This gave a larger number of narrow bands for each octave band, but not so large that it was possible to increase the frequency range.
- The calculations have been limited to 315 – 10000 Hz, mainly due to background noise problems.

What can be done to reach the full 25 – 10000 Hz range?

- Another sound source has to be used, which can produce enough sound pressure down to 25 Hz.
- The conversion error b_f can be calculated exactly for pure tones. Using these as corrections for the conversion will decrease the error considerably even for non-sinusoidal signals.
- Tape speed can be doubled to admit a doubling of the sampling frequency. This will increase the number of narrow bands in each 1/3 octave band and reduce the conversion error b_f and/or the estimation error C_f. It will limit the DAT-recorders capacity to 4 channels, though.
- MLS can be used to reduce the problems with background noise.
- It is possible that filtering 1/3 octave bands instead of calculating them with FFT can give better performance at low frequencies.

The correspondence between calculated and measured values is good.

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Annex 1. Graphs over all measurements

Contents:

Name	Tape	ID	Site	# channels	Rem	Rem II
vind2id1	Vind 2	1	Gässlösa	1		
vind2id2	Vind 2	2	Gässlösa	1	Ljudkälla 1m	
vind2id3	Vind 2	3	Gässlösa	1	5 m	
vind2id4	Vind 2	4	Gässlösa	1	10 m	
vind2id5	Vind 2	5	Gässlösa	1	15 m	
vind2id7	Vind 2	7	Gässlösa	1	20 m	
vind2id9	Vind 2	9	Gässlösa	1	25 m	
vind2id10	Vind 2	10	Gässlösa	1	30 m	
vind2id11	Vind 2	11	Gässlösa	1	35 m	
vind2id12	Vind 2	12	Gässlösa	1	40 m	
vind2id13	Vind 2	13	Gässlösa	1	45 m	
vind2id14	Vind 2	14	Gässlösa	1	Bakgrund	
vind2id103	Vind 2	103	Rangedala Twin Peaks	3	Bakgrund	
vind2id104	Vind 2	104	Rangedala Twin Peaks	3	Mätning 1	
vind2id106	Vind 2	106	Rangedala Twin Peaks	3	Mätning 2	
vind2id107	Vind 2	107	Rangedala Twin Peaks	3	Bakgrund	
vind2id108	Vind 2	108	Rangedala Twin Peaks	3	Mätning 3	
vind3id2	Vind 3	2	I15 supply depot	2	Ljudkälla ch 1	
vind3id3	Vind 3	3	I15 supply depot	2	Bakgrund	
vind3id4	Vind 3	4	I15 supply depot	2	15 m	
vind3id5	Vind 3	5	I15 supply depot	2	12m	
vind3id7	Vind 3	7	I15 supply depot	2	10 m	
vind3id8	Vind 3	8	I15 supply depot	2	8 m dålig vind	
vind3id9	Vind 3	9	I15 supply depot	2	8 m dålig vind	
vind3id10	Vind 3	10	I15 supply depot	2	6 m tåg på slutet	
vind3id11	Vind 3	11	I15 supply depot	2	6 m	
vind3id12	Vind 3	12	I15 supply depot	2	6 m bakgrund	
vind3id13	Vind 3	13	I15 supply depot	2	6 m micar 1,25/1,6 m	
vind3id14	Vind 3	14	I15 supply depot	2	6 m bakgrund	
vind3id204	Vind 3	204	I15 shooting gallery	2	Pos 5m	33.7
vind3id212	Vind 3	212	I15 shooting gallery	2	Pos 15m	bakgrund
vind3id213	Vind 3	213	I15 shooting gallery	2	Pos 15m	43.5
vind3id214	Vind 3	214	I15 shooting gallery	2	Pos 20m	48.5
vind3id215	Vind 3	215	I15 shooting gallery	2	Pos 20m	48.5
vind3id218	Vind 3	218	I15 loading ramp	2	Bakgrund	
vind3id219	Vind 3	219	I15 loading ramp	2	15 m	26.3
vind3id220	Vind 3	220	I15 loading ramp	2	10 m	21.3
vind3id221	Vind 3	221	I15 loading ramp	2	5 m	16.3
vind3id222	Vind 3	222	I15 loading ramp	2	5 m	16.3
vind4id1	Vind 4	1	Rangedala Flat	1	1	Bakgrund
vind4id2	Vind 4	2	Rangedala Flat	1	83	h = 1,75
vind4id3	Vind 4	3	Rangedala Flat	1	83	h = 1,18
vind4id4	Vind 4	4	Rangedala Flat	1	65	h = 1,75
vind4id5	Vind 4	5	Rangedala Flat	1	65	h = 1,18
vind4id6	Vind 4	6	Rangedala Flat	1	59.7	h = 1,75
vind4id7	Vind 4	7	Rangedala Flat	1	59.7	h = 1,18
vind4id8	Vind 4	8	Rangedala Flat	1	50	h = 1,75
vind4id9	Vind 4	9	Rangedala Flat	1	50	h = 1,18

Files on CD-R.

Annex 2

Hjälptexter från Matlabfiler

utvhelp v1 000120 PER
skriver ut hjälptexter för inblandade filer

kalibrering version 1 000120 PER
function kalibreringsfaktor=kalibrering(filnamn,kanal,range)
Inparametrar
filnamn - med enkelfnuttar t ex 'D:\vind3\vind3id0.bin'
kanal - mellan 1 och 3
range - den lilla switcen (0, +20dB, +40dB)
0 - range = 0
+20dB range = 20
+40dB range = 40
Utparameter
kalibreringsfaktor[db]
plotar kurva i närheten av kalibreringsvärde på skärm

kjelleffektber v 1 000120 PER
function kjelleffektkurva = kjelleffektber(filnamn, avstand,
kalibrering1,range1,reflektion);
Förutsätter mätning på kanal 1
In
Inparametrar
filnamn - namn på .binfil med mätning. Med enkelfnuttar t ex 'D:\vind3\vind3id0.bin'
avstand - mellan källa och mikrofoner i meter
kalibrering1 - kalibreringsfaktor från "kalibrering.m"
range1 - den lilla switchen på "front end" (0, +20dB, +40dB)
reflektion - 6 för mic på golv, 0 för fritt fält [dB]
Ut
Utparameter
kjelleffektkurva - källeffekt relativt fritt fält. Uppdelad i tersband.

utv v1 000120 PER
function utv(infilnamn,utfilnamn,utfilhuvud, avstand, kjelleffekt,
kalibrering1,kalibrering2,kalibrering3,range1,range2,range3);
In
Inparametrar
infilnamn - namn på .binfil med mätning. Med enkelfnuttar t ex 'D:\vind3\vind3id0.bin'
utfilnamn - namn på utfil. Inget efternamn t ex 'c:\sonydata\vind3id6'. Får automatiskt
efternamn .mat
utfilhuvud - Bör innehålla: Band, id, datum, anmärkn
avstand - mellan källa och mikrofoner i meter
kjelleffektkurva - Ljudkurva vid källan
kalibrering 1, 2, 3 - kalibreringsfaktor från "kalibrering.m"
range1, 2, 3 - den lilla switchen på "front end" (0, +20dB, +40dB)
0 - range = 0
+20dB range = 20
+40dB range = 40
Inladdar filer
%vacker_f - Avrundade frekvenser för diagram
Ut

Utparameter
Utfil
utfilhuvud - utfilhuvud fr infil + "energimedelvärde decimerat med 1/10"
LjudTryckK_1 LjudTryckK_2 LjudTryckK_3 energimedelvärde över 10 fönster av ljudtryck kanal 1-3
LjudTryckRelFrittK_1 LjudTryckRelFrittK_2 LjudTryckRelFrittK_3 energimedelvärde över 10 fönster av ljudtryck relativt fritt fält
Vindhastighet - medelvärde av vindstyrka 10 fönster [positiv]
VindKomposant - medelvärde av komposant längs riktningen mic->källa över 10 fönster [-1...1]
Femtiden - Tid från början på mätningen för varje n (mittiden av de 10 fönster som medelvärdesbildas)
vacker_f - Avrundade frekvenser för diagram
bortkommenterad utfil - försiktighet, ej uppdaterad

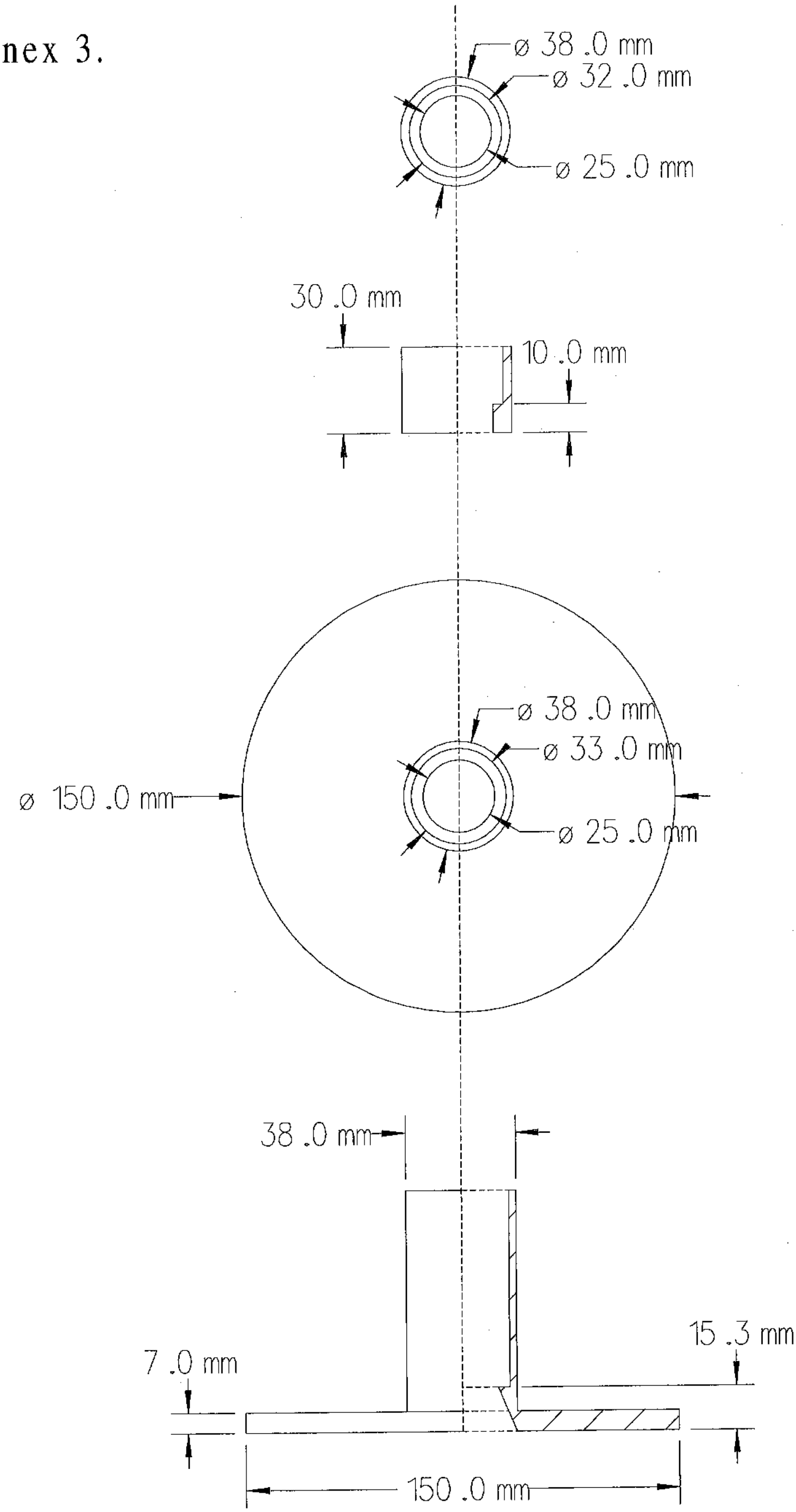
Tersband version 1 000120 PER
function L=tersband(Lin,fin);
Summerar SPL för tersband 100hz - 10khz
Inparametrar
Lin - Vektor med SPL för smalband
fin - Bandfrekvens för smalband
Utparameter
L - Vektor med SPL för tersband 50hz - 10khz
Lokalt
f - vektor med mittfrekvenser i tersband

EMEAN v0 MÖ
REV v1 000120 PER
Helptext tillagd
Energy mean value for "LEVEL" input (Leq for equal time steps).

vacker_f_ber 1 000120 PER
returnerar en vektor med nominella frekvenser för tersband enligt enligt IEC 1260 Annex A för skalning av axlar
50 Hz - 10 kHz
Utparameter - vektor med nominella frekvenser för tersband

utskr v1 000120 PER
function utskr(rubrikfilnamn,utfilnamn,bakgrund)
skriver ut ett blad med vindkurva och medelvärde på ljudutbredning
Inprametrar
rubrikfilnamn - namn på en mätfil. Skrivs i rubriken på utskriften. t.ex. 'vind2id103'
utfilnamn - namn på utfil från utv.m. Används för att läsa in variabler.
bakgrund - 0 om ej bakgrund >=1 om bakgrund. Default 0.

Annex 3.



ø 38 .0 mm
ø 32 .0 mm
ø 25 .0 mm
30 .0 mm
10 .0 mm
ø 38 .0 mm
ø 33 .0 mm
ø 150 .0 mm
ø 25 .0 mm
38 .0 mm
15 .3 mm
7 .0 mm
150 .0 mm

Annex 4

Kontaktlista

Mätplats	Namn	Telefon	Företag el dyl	Anm.
Båda Rångedala	Björn Samuelsson	033-279158	Rångedala grus	
Gässlösa, Bråt skjutfält	Krister Lundberg	0703-576716	Elfsborgsgruppen (Bråt skjutfält)	I första hand
Gässlösa, Bråt skjutfält	Elfsborgsgruppen	växel 475350	Elfsborgsgruppen	
Gässlösa, Bråt skjutfält	MKV	växel 031-692600	MKV	
Gässlösa, Bråt skjutfält	Rolf Andersson	031-692175	Fortifikationsenheten	
		0705-692175		
I15 supply, shoot,ramp	Lotta	33 127 050	Vasallen	

Annex 5. Contents on CD-Rom

Disc_1

Directorys

Doc	Thesis, textfiles
Programs	m files with programs described in the thesis
Examples	Examples of matlab program code used
Gasslosa	Evaluated.mat files from Gässlösa
I15ramp	Evaluated.mat files from I15 ramp
I15shoot	Evaluated.mat files from I15 shooting range
I15supply	Evaluated.mat files from I15 supply depot
Range_flat	Evaluated.mat files from Rångedala flat
Range_twin	Evaluated.mat files from Rångedala Twin Peaks

Comments on "Programs"

When in Matlab, help "program" prints a helptext for "program".
"utvhelp" prints helpfiles for all programs in \program directory

Disc_2

Raw_data	
Raw_data\Vind1	Raw data from tape "Vind 1"
Raw_data\Vind2	Raw data from tape "Vind 2"

Disc_3

Raw_data	
Raw_data\Vind3	Raw data from tape "Vind 3"
Raw_data\Vind4	Raw data from tape "Vind 4"