Nice Noise From Trucks

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Section of Acoustics
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Abstract

Dette afgangsprojekt analysere This Thesis documents the analysis and design of Nice Noise System (NNS) The purpose of the NNS is to find a solution to at problem at Sauer-Danfoss, where truck are driving around in an noise environment and not being heard. This is a safety hazard to the workers that is working along side the truck everyday. The thesis analyse the problem, in terms of the workers, the truck and the environment. The thesis also studies what sound would be appropiate for the truck, by defining principles based on the behaviour of the truck. The design of the NNS is based around a computersystem, digitally storing the sound for the truck. A pitch bending method is chosen to make the truck sound follow the speed of the truck, and to make the impression of a real truck, when in motion. A listening test has been carried out at Sauer-Danfoss, where workers from the production facility has participated. Sound and demos are included on a  in the back of the report.

Preface

This report is the final thesis made by group 1063 in the Section of Acoustics at the Institute of Electronic systems, Aalborg University.

The project concerns developing a sound for an electric truck, used in the production facility at Sauer-Danfoss. The reason is that Sauer-Danfoss have encountered a problem where these trucks are not easily heard and is therefore becoming a safety problem.

The target audience is students at the Section of Acoustics and people with interest psychoacoustics, hardware design and sound engineering.

Since this project is centered around sounds, there is included a CD-ROM in the back of the report, where all the sounds developed and used in this project are available. Throughout the report, some references would be to that CD-ROM, and it is recommended to listen to the referred sounds. The reference to the CD-ROM is marked with a symbol and a specific path on the CD-ROM. References to literatur is marked with a string (e.g [Cro98]), that corresponds to the source in the bibliography.

Figures an illustrations are refered to with a number. (e.g. figure 3.1, meaning the first figure in chapter 3)

Special thanks to my contact at Sauer-Danfoss, Gert Lumbye Hansen, and all the workers who have been in connection with the project.

Aalborg University, 7th of June 2007

Casper Michael Andersen

Contents

Chapter 1

Introduction

In times of the "green house"-effect and high gas prices, the petrol engine is slowly being replaced by other more environmental benign solutions as the replacing technology. The new technology is based on hybrid systems, where vehicles would be powered by for instance an electric-/hydrogen-engine.

Since the sound from a car engine (excited by the petrol engine) is well known and can be easily recognized, the matter of replacing the petrol engine might in some cases result in a rather silent vehicle. This issue could result in dangerous situations for soft road users, where the vehicle is not exciting recognizable sound in the environment.

The same problem exists at the company Sauer-Danfoss ApS where trucks based on an electrical driven engine as the motor, has resulted in a problem where vehicles are perceived as being rather quiet in the industrial environment at Sauer-Danfoss. This issue has become a hazard to the workers in the production facilities, where these trucks have their daily working routine, since the trucks are not heard in the environment. The vehicles are simply masked in background noise.

The problem has actually resulted in one accident and many critical contact situations between workers and trucks. The studies in this report are based on that very problem in the Sauer-Danfoss production facilities.

1.1 Scope

The scope of this master thesis comprise of two objectives. The first objective is to investigate the actual problem by analysing the background noise, and recognize what makes the truck inaudible, when it drives around the production facilities. Furthermore the human sound perception and psychology should be studied, to understand the basis for the truck sound, and what can be understood by making the truck sound nice.

The second objective is to design a system and sound in order to find a solution to the problem.

The Problem statement is as follow

How to develop a sound that can be played back through an electronic system, such that the truck in the Sauer-Danfoss production facilities can be heard by the workers, when the truck is driving around the production facilities

Chapter 2 is analysing the problem, with the focus on three elements and how they are related. Based on the analysis, chapter 2 will end up with a more specific problem formulation.

Chapter 3 is focusing on the design of a truck sound and design of a system that is ment to be installed on the truck and play back the designed truck sound.

Chapter 4 is about the listning test performed at Sauer-Danfoss, testing for the signal-to-noise ratio between the designed truck signal and different characteristic background noise for the production facilities at Sauer-Danfoss.

Chapter 5 is comprising the conclusion and future aspects

Chapter 2

Analysis

Chapter 2 involves the analysis of the problem. This is especially to get a better understanding about the actual elements constituting the problem. Chapter 2 will focus on a background noise analysis, the human psychology in relation to sounds and the sound for the truck.

2.1 General Overview

Sauer-Danfoss is located in Sønderborg, Denmark, and has approximately 2300 workers, spanning from 18 to 65 in age. Most of the workers are danish, but also people from germany and other nationalities are working in the production facilities.

Figure 2.1: The three elements of interest, located in the production facilities at Sauer-Danfoss

The production is running constantly 24 hours a day, where workers are doing day and night shifts of 8 hour span per shift.

The thesis will consider three main elements of interest in the production facilities at Sauer-Danfoss, and base the analysis on this and how they are related.

The three elements are the trucks, the machinery constituting the environment and then man (see figure 2.1)

The research is concentrated within two buildings, named L2 and L4, where the trucks of interest have their daily routine, moving cargo around the production facilities. The two buildings together comprise of $20000m^2$ space, where different kind of machinery is stationed, making parts for the Sauer-Danfoss product line.

Figure 2.2 and 2.3 shows the two buildings of interest. This in concern to the background noise, the route for the truck and where the workers are located and moving around.

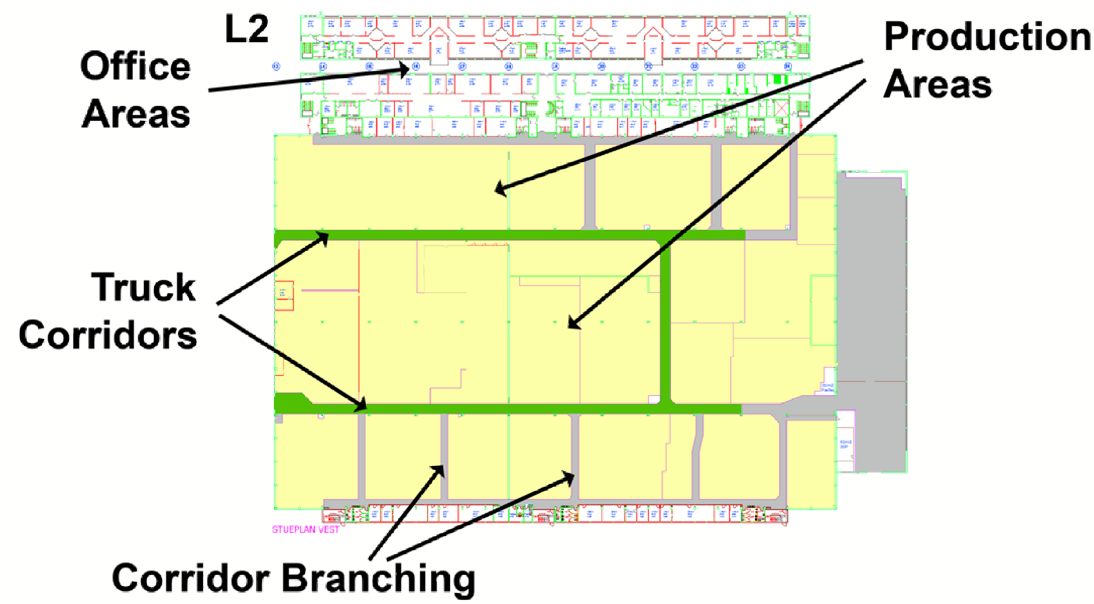


Figure 2.2: The green allocated passage ways are the areas where the truck are able to drive

The trucks have two main corridors in both buldings, where they can drive in both directions (Marked as Green on figure 2.2 and 2.3).

The trucks are not able to drive within the small corridor braches next to the main corridors, and nor able to drive around in the production areas (Marked as yellow). These areas are entirely occupied by machinery and only man is able to move around there.

The problem is mainly concerned along to the green areas. This is especially when workers are crossing these areas to move from one production area to another.

The problem is also related to the environment, which is mainly comprising of machinery.

The result is reduced field of view around the production facility, such that the contruction of the building (concrete pills) and the amount of goods stacked next to the green corridors reduce the visibility, and workers would have to lean forward or step out in the actual corridor to be able to orientate for a moving vehicle.

A likely situation found at Sauer-Danfoss is illustrated in figure 2.4, where workers are moving around the production facilities, comprising of different obstacles like machines and goods,

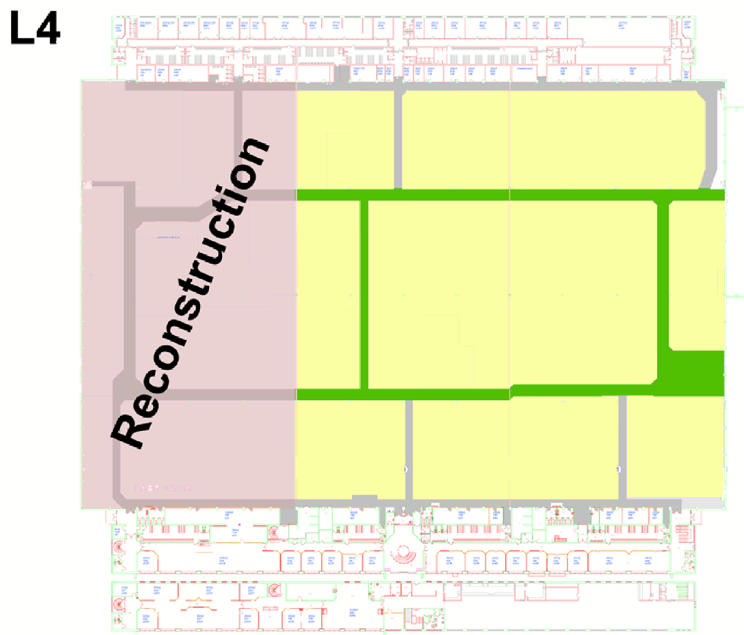


Figure 2.3: Building L4. Yellow areas are occupied by machinery and man only. A part of L4 is under reconstruction and the truck is not found to drive in this area in the future.

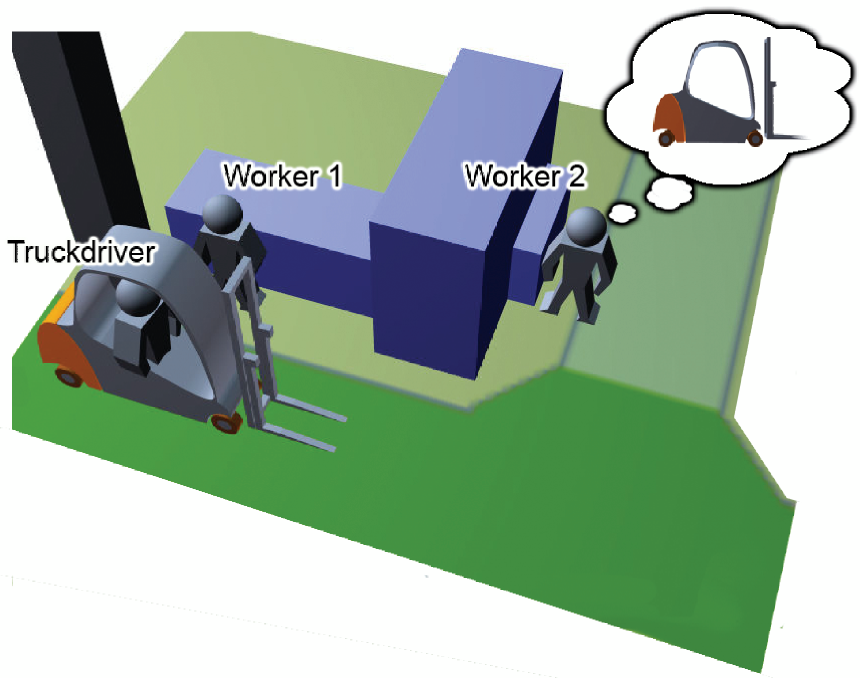


Figure 2.4: A likely situation found at Sauer-Danfoss, where a truck is driving along the main corridor and workers are positioned nearby the truck.

while trucks are driving back and forth in the main corridors.

Worker 1 can see the truck, but worker 2 is visually blocked by an obstacle and can therefore not see the truck. Futhermore er third worker is sitting inside the truck - the truckdriver.

The key issue is to spare the truckdriver and worker 1, in terms of artificial truck sound, but still make the truck noticeable for worker 2, such that he or she can take precaution, before entering the green area on figure2.4.

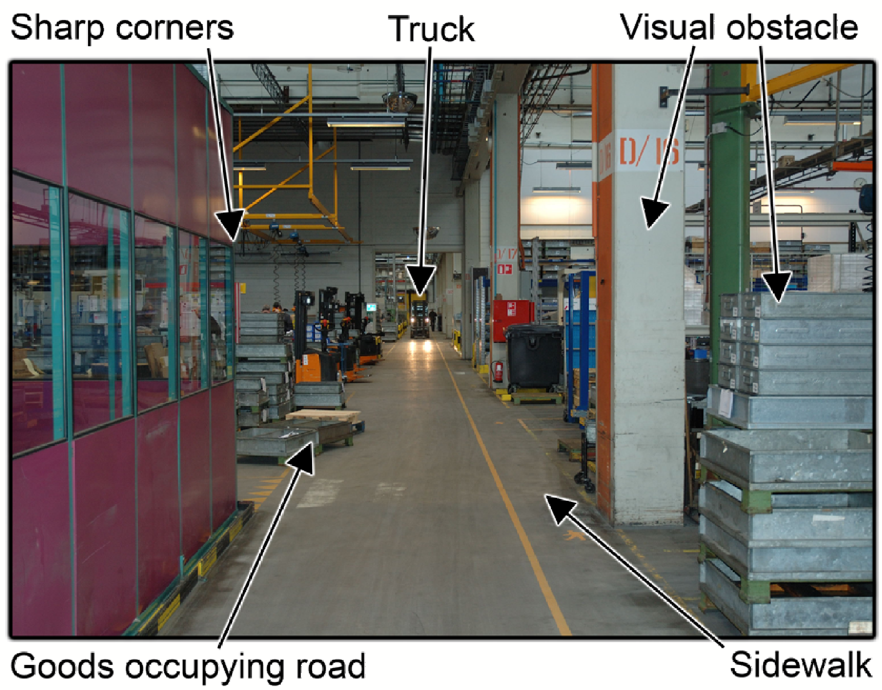


Figure 2.5: The picture is taken in the actually production facility at Sauer-Danfoss

The real environment at Sauer-Danfoss is shown in figure 2.5. The picture shows how different obstacles make up the environment. All obstacles will have an effect on the visibility and acoutics in the facilities.

2.2 Background noise

The main source of background noise is all the machines in the Sauer-Danfoss production facilities. The machines are performing various tasks, and located throughout the whole facility. Some machines run constantly, meaning that they are not shut off during the late evening or night. That also means that there will be background noise in the production facilities at all times. The amount of machines contributing to the background noise depends on the time of the day.

The day is divided in three shifts. The main activity in the production facilities is during the first shift, spanning morning and aftenoon. The second shift will take over at 15 pm and finish at late evening, where the third shift will take over and work during the night.

The buildings L2 and L4 are each divided into areas, with different purposes in the entire production. That also means that different machinery is encountered in different areas, resulting in different noise patterns, frequency content and sound pressure level for each area.

The background noise was recorded, monophonically, in the two buildings, L2 and L4. The measurement report can be found in appendix A on page 53, describing how the recordings were performed.

Figure 2.6 and 2.7 illustrates the different positions inside L2 and L4, where the the recording system was positioned for each recording.

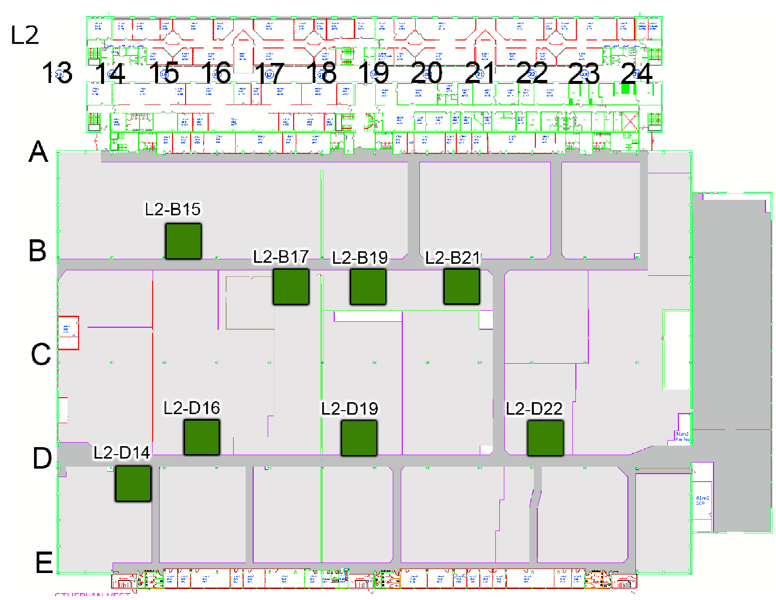


Figure 2.6: Recording positions inside the L2 Sauer-Danfoss building

The chosen recording locations are next to the truck corridors, since it is near these corridors that truck and man can collide and result in an accident.

Considering the background noise over time, for a given location, reveals that the sound pressure level and the frequency content varies - a time pattern. The way the background noise varies within a location depends entirely of what kind of machines that are located in the area, and

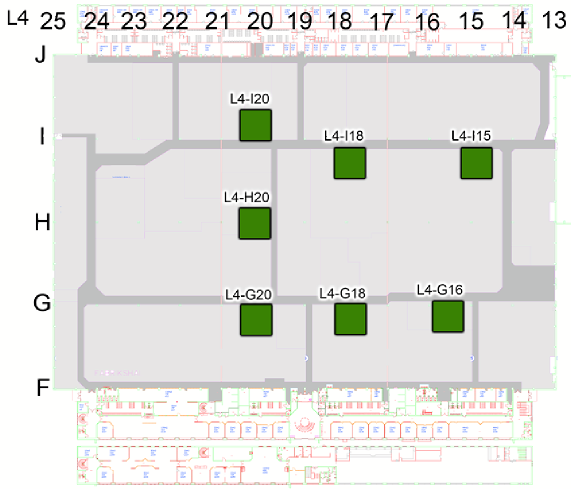


Figure 2.7: Recording positions inside the L4 Sauer-Danfoss building

what the machines are performing. The thesis is not focusing on what kind of noise a specific machine excites, rather consideres a location near the main corridors and what can be observed in terms of noise over time. That also means that the time pattern of the noise for a given location is a mixture of many different noise excited by many different machines, within that location.

Figure 2.8 shows a time-frequency analysis of 47 seconds of recorded background noise for the location L4-I18.

It can be observed that the time pattern comprise of different sound element appearing over time and that a constant low frequency mixture of noise is present at all times throughout the 47 seconds of recording.

The duration of the sound elements is rather short compared to the constant low frequency background noise. The importance of the duration of the these sound elements is considered later.

The entire collection of time-frequency plots for each recorded location can be found on the noise maps in appendix C and it is also these plots that the analysis of the background noise is based on.

Another matter is the sound pressure level of the noise for different locations. Moving from one location to another will give a change in the time pattern of the noise, but can also give a change in the sound pressure level of the noise.

Since the production facilities are occupyied by machinery, also means that these machines will function as an acoustic barrier. The result is that noise propagating inside the production facilities is obstructed and reflected by the machinery. The effect of this is that some locations are still containing noise, but at a very different sound pressure level compared to other locations within the same building.

Table 2.1 lists the overall linear and A weighted sound pressure levels for the different recording locations.

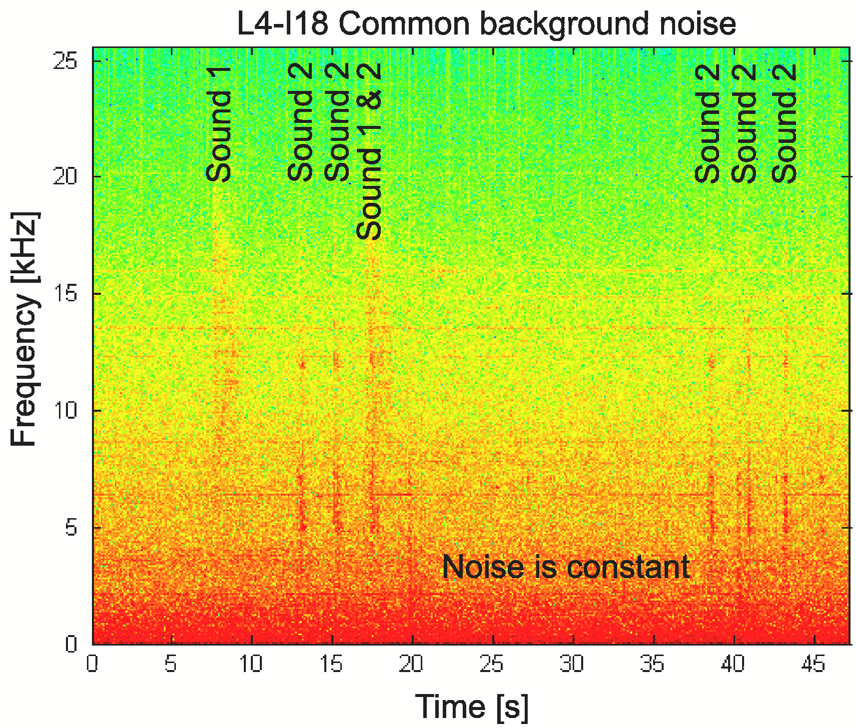


Figure 2.8: Spectogram of the background noise at location L4-I18 at Sauer Danfoss, where different sound artifacts appear over time.

Location	Linear scale	A-weighted scale
L2-B15	82.7 dB	73.5 dBA
L2-B17	79.9 dB	75.9 dBA
L2-B19	77.8 dB	69.9 dBA
L2-B21	82.4 dB	77.1 dBA
L2-D14	76.2 dB	67.7 dBA
L2-D16	76.7 dB	69.2 dBA
L2-D19	78.7 dB	74.2 dBA
L2-D22	78.9 dB	71.0 dBA
L4-G16	86.5 dB	84.2 dBA
L4-G18	78.8 dB	69.9 dBA
L4-G20	83.2 dB	74.6 dBA
L4-H20	81.8 dB	73.3 dBA
L4-I15	84.6 dB	84.2 dBA
L4-I18	79.1 dB	72.5 dBA
L4-I20	77.8 dB	71.6 dBA

Table 2.1: Table showing the maximum Sound pressure level for the measured locations at Sauer-Danfoss

Comparing location L2-D14 and L2-B21 shows that there is a differens in the sound pressure level between two locations. The overall differens is around 6 dB on linear weighted scale.

The overall sound pressure level is not revealing how the sound pressure level is spectrally spaced. The overall sound pressure levels (especially the a-weighted value) is instead used to determine the risk in case of noise exposure [Arb06].

So another way to analyse the backgroudn noise is in frequency bands.

Figure 2.9 and 2.10 shows the corresponding third octave band analysis of the background noise for location L2-D14 and L2-B21.

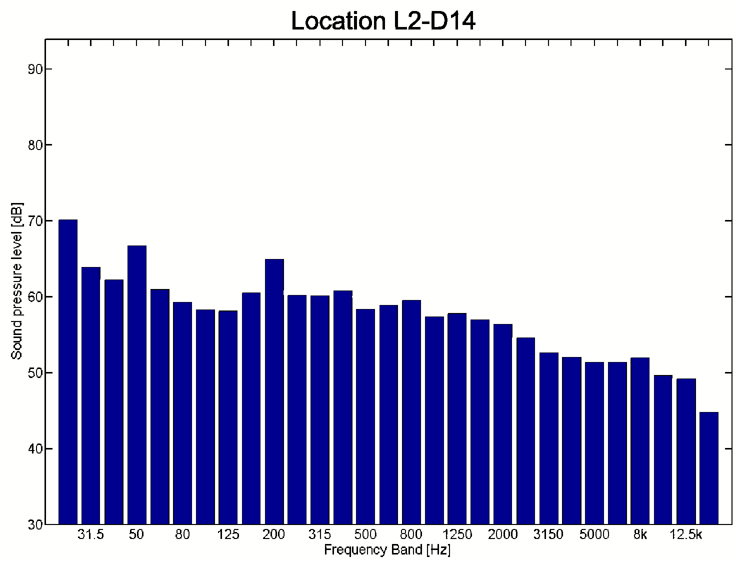


Figure 2.9: The Third octave band analysis of the background noise at location L2-D14

The full noise map of third octave band analyses of the noise for the different locations in L2 and L4 can be found in Appendix C The noise map in the appendix reveals that for any given recording location, low frequencies is to be more dominant than the high frequencies except for a few cased where a tonal (L4-I15) or broad band (L4-G16) noise situations is present.

It should be noted that the sound pressure level and third octave band analysis, for each recording location, is based on a longer part of each recording that corresponds to the actual background noise. Moreover, activities close to the microphone, that is considered not as being a part of the actual background noise has been avoided before performing the third octave band analysis.

The following is a summary of the characteristics found in the background noise for the two buildings L2 and L4 by observing the phenomenons in time-frequency and third octave bands.

The background noise comprise of:

- Constant low frequency content, that dominates the spectra of the background noise.
- Long term low-band tonal phenomenons
- Long term mid-band tonal phenomenons

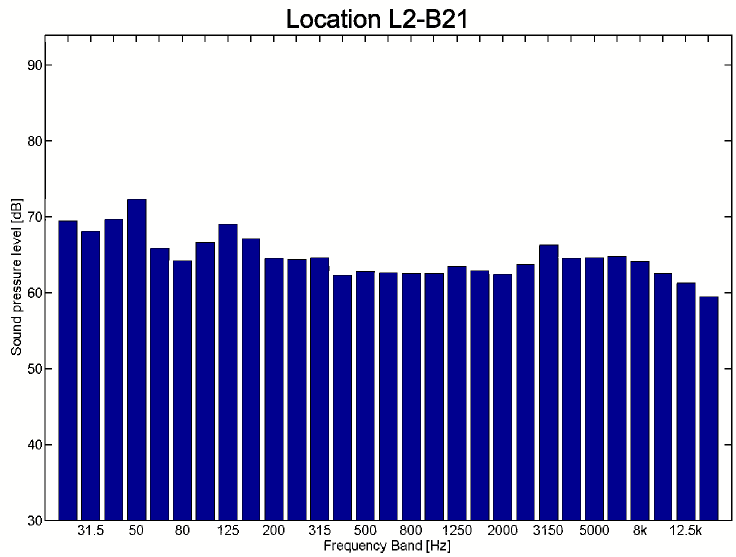


Figure 2.10: The third octave band analysis of the background noise at location L2-B21

- Long term broad band background noise.
- Short-duration broad band noise bursts.

Eventhough the background noise has been analysed in terms of frequency content and sound pressure level, and different time-frequency patterns have been recognized, a final aspect has to be considered. The aspect is about the physical environment.

Sauer-Danfoss will from time to time move the various machines to new location in the production facility. That can be in connection with optimization of the production, or simply to remove or replace a machine. The result will be that new time-frequency patterns will emerge for a specific location and changes in sound pressure level, for the specific location, will happen.

2.2.1 Masking

The reason why the truck is not being heard manifests in the fact that the background noise level is too loud compared to the real noise from the truck. In hearing, masking generally is defined as the interference with the perception of one sound (the truck sound) by another sound (the background noise). The interference may decrease the loudness of the signal, may make a given change in the signal less discriminable, or may make the signal inaudible [Cro98, p. 1147]

The absolute threshold for a truck sound would be depending on following factors

- The frequency of the truck sound
- The bandwidth of the masker (background noise)
- The duration of the masker

The background noise can, for some areas, be considered as a long duration broad band masker. But for most locations within the production facility the masker could easily be a short burst of broad band noise, that temporally mask the truck sound.

Most of the background noise in the production facilities is in the low frequency region. It is also constant over time, meaning that the sound pressure level and frequency content is not changing over time, in that spectral region. Focusing on the constant background noise and masking, could lead to the concept on-frequency masking, if the background noise and truck sound is simultaniously present over time.

On-frequency masking occurs when the masker (background noise) contains significant power in the frequency region of the signal (truck sound)[Cro98, p. 1150]

Moving the signal away from the frequency region of the masker would at first overcome the on-frequency masking, but since intense low-frequency tones may mask high-frequency tones[Cro98, p. 1152], the low-frequency background noise can still mask the truck sound even if it is spectrally positioned away from the spectral energy of the background noise.

The duration of the masker is also of importance. The short burst of broad band like background noise (Observe the short-duration broad band noise spikes in the the time-frequency analysis on the noise maps in appendix **??**) can temporally mask the truck sound, but it depends on the duration of these noise bursts. If it is considered that these short bursts are of white noise characteristics, a duration of a bursts between 0.1 milisecond and 1 second, is well described by a power function with an exponent of about -0.75. This indicates that thresholds decrease about 7.5dB for each 10-fold increase in duration[Cro98, p. 1148]

2.3 The Truck

The truck of interest is a Still RX 20-20 truck, shown in figure 2.11. It is a common truck in the sense of storing or moving goods. The maximum speed of the truck is, by the manufacture Still, specified to 16 km/h, but Sauer-Danfoss have reduced the maximum speed to 10 km/h, simply to raise the safety in the production facilities.

The interesting about the truck is that it is not powered by gas like other types of trucks. The truck is entirely electric, and it runs on a battery. The Still RX 20-20 truck has replaced the previously used Still RX70-40 truck, that is running on gas.

The reason why Sauer-Danfoss have chosen the electrical driven truck is due to the fact that it is cheaper than a gas driven truck, but also due to environmental problems caused by the gas truck. The gas truck whirled dust and dirt up in the air during operation, resulting in a widespread contamination in the Sauer-Danfoss production facility.

The drawback of an electric truck is that the electrical driven motor has showed to be very far from noisy compared to the gas driven trucks (This relative to the level of the background noise). This results in that very problem of concern that the electrically driven truck is not being heard when it drives around in the noisy production facility.

Figure 2.11: The Still RX 20/20 truck

2.4 People and sound patterns

Before even considering to make a sound for the trucks, it is important to understand how people are reacting to sounds in general and how people classify a sound.

Humans are very visual oriented and rely mostly on the visual impression when moving around in the surrounding world. But the visual part is not entirely the only key player in the total impression of an environment. The hearing sense is also playing a role since sounds can appear all around us, even at places where the visual system is not able to see the object originating the sound. That means, that in case of situations where sounds are coming from the behind, we still allocate the object making the sound. That is a good feature in case of danger where we are alerted about what is happening behind us.

Another matter is how people relate the sound and the visual object making the sound. In the case of a warning, a sound can only be a warning if we have heard it before and have associated it with a warning, or can relate the sound as being of a pattern similar to the sound, that has been classified as a warning.

So when people are perceiving a sound, the mind is extracting information in the sound, like timbre, loudness, pitch, duration, rythm and tempo[Moo06]. This extraction of information from the auditory signal is then made suitable for storage in the memory with an adequate label of identification, and compared with previously stored and identified information. So a perceived sound by a listener is analyzed and will result in an auditory image corresponding to the listeners understanding of that sound[GB89].

The following two subsection is about sound quality and annoyance. The reason for considering sound quality and annoyance is to give an explanation of the term "nice" in relation to a truck sound and in what way this thesis will use the term "nice".

2.4.1 Sound Quality

Sound quality is one of the more broad terms often used, but never really given a precise meaning, when used [Let89, p. 1].

[Let89, p. 6] defines sound quality as that assessment of an auditory image in terms of which the listener can express satisfaction or dissatisfaction with that image. Sound quality can be judged by comparing images produced by several external stimuli or by referencing a perceived image to the concept residing in the listeners memory.

So the sound quality of the truck sound is actually based on the individual auditory image residing in the workers mind, in terms of how a truck should sound like. Since the Still RX20-20 truck is not producing a significant level of sound, that is perceivable when it drives around the production facilities, also means that there is no clear sound from the truck to constitute a distinct auditory reference. Moreover, the auditory sensation of the Still RX20-20 truck is somewhat not existing, in the Sauer-Danfoss production environment.

The previous truck (replaced by the Still RX20-20 truck) was gas driven, and was making perceivable sounds in the background noise. The workers recall this truck as being noticeable in the noisy environment, since the truck (along with the engine noise) also excited some high frequency bursts when relieving hydraulic pressure. Considering this also means that a possible auditory image residing in the workers mind could be the sounds excited by the previously used truck (Still RX70-40 truck).

Annoyance

Introducing a sound on the truck should also be considered in respect to annoyance. It would be inappropiate to have a sound on the truck that in the long term would be annoying to the workers. Unfortunately it is difficult to state exactly what is going to be annoying and what is not.

Annoyance is highly subjective and may emanate from the individual mood, a psychological overexposure of the same sound or simply because the sound relates to a bad feeling. Sounds are experienced affectively and the affects they produce are called pleasure and displeasure[RGS98, p. 2].

The thesis will not go deeply into the field "annoyance" in general, rather reflect on the matter in a "truck sound and background noise" concept.

The workers, at this moment, are used to a truck that is not being heard in the production facilities. The day a sound is perceived from the truck, might lead to a truck sound that attracts attention to itself. It is especially in this introductory period that workers would either accept the truck sound or repel it.

It is in the company interest to give every worker the optimum workplace. An unpleasant sound would make the company question whether or not this is the solution to the problem, if workers are starting to complain about this new truck sound.

Based on the considered aspects above, the thesis will interpret the term "nice" as being a truck sound that sounds natural. In that way the sound quality of the truck, resembles the way the workers might understand it. Futhermore, it is considered that the workers will notice the truck sound in the introductory fase of the lifecycle of the sound, meaning that it is important that the workers experience the sound solution as working, the day the sound is on the truck.

2.5 A Sound-concept

The thesis defines a term called "sound-concept". A sound-concept for a given object means that specific collection of different characteristic sounds, that is reflecting the behaviour of the object.

A simple example of a sound-concept could be for a bus. The bus comprise of an engine sound, and sounds reflecting various behaviours like for instance opening of the bus doors. This bus example considers the sound from the engine (also when the bus is in motion) and the sound from the doors opening, as those two sounds in this bus sound-concept example. That means, that the sound-concept for this bus example, comprise of two different characteristic sound.

The sound-concept for the truck can also comprise of different sounds based on the behaviour of the truck. The behaviour can be directly observed when the truck is in function.

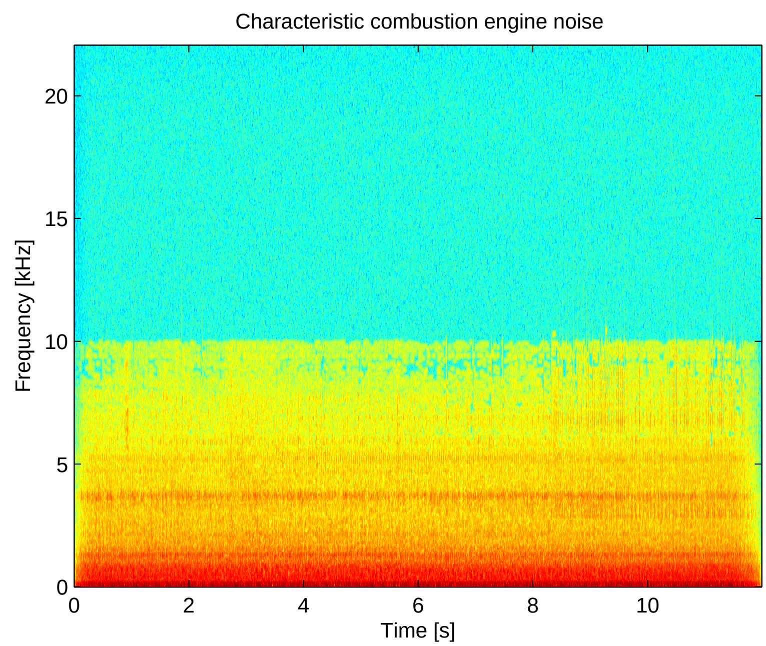


Figure 2.12: The time-frequency plot of a combustion engine sound

Since the purpose of the truck is to move goods around the production facility, the behaviour is reflecting that purpose, resulting in a truck that is in motion at different speeds, stopping and lifting goods.

It is especially the motion of the truck that has to be represented by a sound. That also means that the fundamental sound in the truck sound-concept is based on the behaviour "motion".

Focusing on the possibilities for a motion sound, that would be suitable on the Still RX20-20 truck, is bounded by the visual impression of the truck. That means, that basing the motion sound on the actual visual impression of the truck, would probably also lead the mind towards some kind of engine sound. That could be basing the motion sound on an electric engine or imagine the truck equipped with a combustion engine and base the sound on that instead.

The combustion engine must be familiar to people, since it has been around for decades, especially used in petrol cars. The electrical engine though, has not gained ground in becomming the engine for cars. Considering the two engines, in terms of sound, reveals that their characteristics are quite different.

The combustion engine [,Trucksounds/truck3idling.wav>] has a kind of pumping nature, originating from the combustion cycle, where pistons moves back and forth inside cylinders, igniting a fuel mixture in each cylinder. The result is a controlled explosion inside the cylinder, exciting a sound that propagates through the entire structure of the engine and vehicle.

The time-frequency plot can be seen in figure 2.12.

The electrical engine [,Trucksounds/motorlift.wav], in contrast, has a more constant tonal non-pumping character. Figure 2.13 shows the time-frequency plot of an electrical engine that have sound characteristics that could be used in the sound for the truck.

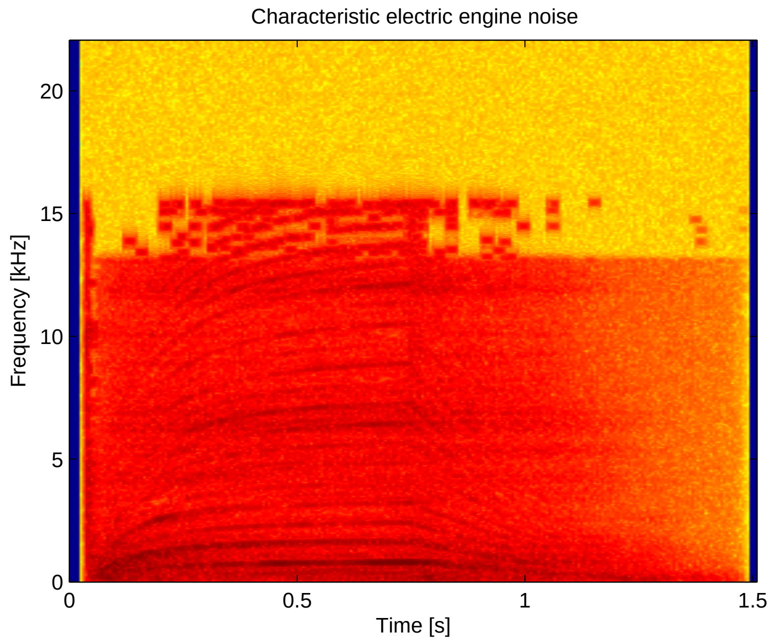


Figure 2.13: The time-frequency plot of a characteristic electric engine noise

Eventhough there is a differens in the characteristics of the sound from the two types of engines, there is yet another distinct differens. The electrical engine, in reality, is only making sound when it is in motion where the combustion engine makes sound at all times, since it excites sound when it runs in idle speed. Since the sound-concept is no limited to only comprising of one sound, having more than one sound on the truck could also make it more likely to hear the truck, if one of the sounds are masked by the background noise. Whether or not this is really true also manifests in the fact that sounds in the truck sound-concept is not going to be constantly present at all times. Reflecting on the bus example once again. The sound of the opening door is not present between two bus stops, since the behaviour of the bus is not to open the doors while driving. The same can be said about sounds for the truck. Some sounds are present more often than other, since the presentation of the sounds is bounded by the behaviour of the truck.

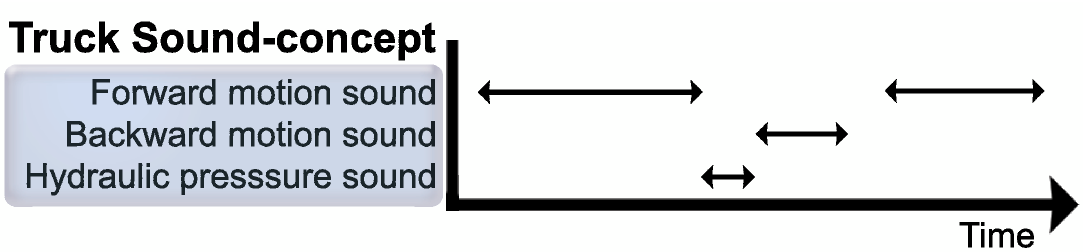


Figure 2.14: An illustration of a timeline, where different sounds in a truck sound-concept is present at different points in time. The presence of the sounds are according to the behaviour of the truck.

Figure 2.14 illustrates a timeline, where different sounds in the truck sound-concept is appearing at different points in time.

The number of sounds for a given object is at some point unlimited, as long as a certain behaviour of the object can be identified and represented by a sound. Its is also important that there is space in time for a given sound, such that two sound wont mix into an incomprehensible concept.

It should be noted that the different sounds in the sound-concept is bounded by each other. That means, that the different sounds as a group is representing one object and should lead the mind to an understanding of one object. New sounds added to the group should stil make the sound-concept reflect one object

2.6 The sound source

A sound source has to be associated with the truck, such that the truck sound follows the truck, when it is driving around in the Sauer-Danfoss production facilities.

The sound source has to propagate the truck sound a distance ahead of the truck, such that workers can hear it from a distance and are not noticing the truck, the moment it is too late.

The sound source would be a loudspeaker. The four main criteria for the loudspeaker is the outputtet sound pressure level, frequency response, size and radiation pattern.

The sound pressure level from the sound source is depeding on the spectral position of the truck sound and what can be said about the background noise within that spectrally span. That means that it is difficult at this point to state, what the outputtet sound pressure level from the sound source actually has to be. This matter will be covered in the chapter 3.

The size of the loudspeaker should not change the overall dimension of the truck, such that a speaker mounted on the roof would make the truck higher, nor should it make the truck wider if mounted on the sides of the truck. That is especially in mind that the truck should be able to drive in the same environments as usual, with the loudspeaker mounted, without introducing new problems in narrow space or low ceiled environments.

The radiation of the loudspeaker is also of major concern. Th truckdriver is the one worker who is positioned closest to the sound source at all times.

The driver cabin is open on each side of the truck and a window is positioned in the front and the back of the truck. This means, that truck sound and background noise can enter the driver cabin directly from the sides of the truck.

Another matter is workers positioned nearby the truck. There is no need to expose workers that have already seen the truck or are not positioned near the main corridor. It is of course difficult to make absolutely sure that whena worker has seen the truck, he is not exposed to truck sound, but at least the level of the sound should be loudest where it matters.

The radiation of the loudspeaker would therefore have to focus the beam of sound in the direction of drive. That would limit radiated truck sound to the back of the sound source and therefore spare the truck driver and workers facing the side of the truck is not directly exposed to the truck sound.

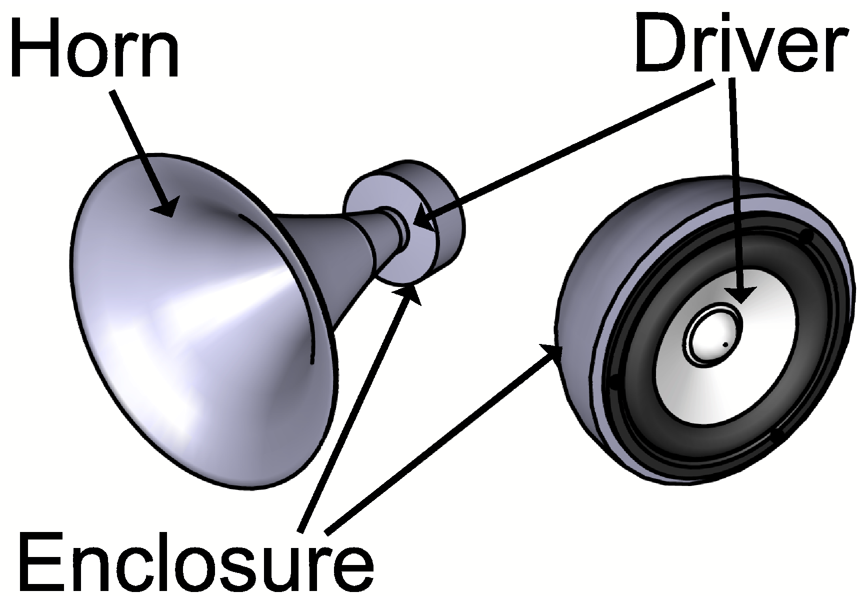


Figure 2.15: The two loudspeaker types: the horn loudspeaker and the conventional piston-type loudspeaker

Two types of loudspeaker are considered - a traditional piston-type loudspeaker and a horn loudspeaker. Figure 2.15 illustrates the two loudspeaker types mentioned.

Horn Loudspeakers have two major usefull properties. They can act as an acoustic transformer, amplifying sources of sound and they create boundaries for controlling the direction of propagation of sound [Hol]. This is two good features, especially on the truck, where the radiation of the sound and the sound pressure level is of interest. Using a horn also implies that the frequency response becomes irregular, resulting in the so called "horn sound". Futhermore, depending on the frequency content of the desired truck sound, the size of the horn will have to vary in size according to have far down in frequency the horn has to be able to represent the truck sound. So in order to playback low frequency truck sound content, the horn opening would become large in size [EBB87].

Furthermore the sound should be amplified proper to the background noise to be heard, and the frequency response of the sound should be represented as intended.

The piston-type loudspeaker distiguish from the horn loudspeaker in terms of the horn, but the actual difference between the two loudspeaker types is the directivity. Conventional, piston type loudspeakers diaphraphms have a directivity pattern that depends upon the wavelength of the sound being radiated.[Hol]. When the diaphragm is attached to a horn, the presence of horn walls in front of the diaphragm prevents the sound from propagating to any anglewider than the horn walls[Hol, p. 2] Moreover, the radiation of truck sound would be more narrow and focused in front of the direction of drive.

The truck is an already finished product never intended to have an loudspeaker mounted in the first place, but the truck has som existing fittings for lights, that is not in used. The position of these fitting are on the roof of the truck and would be preferable when considering the truck sound having the possibility of reaching areas beyond stacked cargo. Figure 2.16 shows the available fittings.

Figure 2.16: The fittings available for mounting the speaker

2.7 Problem formulation

In the view of the analysis a problem formulation is arranged.

There has to be developed a sound, or a concept of sounds, such that this concept represents a real truck, the way the workers at Sauer-Danfoss might understand it. The sounds should also, in some extent, be able to be heard without tuning up the volume too much, and without being masked by the changing characteristic background noise.

There has to be design a system that can play back the sounds. There has to be designed a method to make the designed sound follow the speed of the truck and give the sensation of a real truck, driving at different speeds. The system would have to be able to turn the volume up and down according to the background noise level for a given location.

Chapter 3

Design

This chapter will go through the design steps in order to develop a system and sound for the truck. The chapter will at first concentrate on the methods used to developing the sound and then the hardware system comprising of a microphone, a computersystem and a loudspeaker. The chapter will also thoroughly go through the software developed to control the outputted sound pressure level and how the algortithm is operating on a given input from background noise measured and simulating different speeds of the truck.

3.1 The truck Sound

The consideration in the design of a sound is first of all based on the visual object "truck". The Still RX20-20 truck at Sauer-Danfoss is not exciting a sound audible in the environment. The truck has therefore to be defined in terms of sound, and the truck is thought to sound like a real truck since such a sound-concept would relate to the conceptual understanding resising in the mind of the worker.

The consideration in the designing of a sound is also based on the knowledge of the background noise, in terms of the frequency content for different locations, the duration of different sound elements.

3.1.1 Sound Engineering

The sound-concept for the truck is thought to comprise of 3 sounds. The first sound is a fundamental engine sound, that is following the motion of the truck in forward drive. The second sound is resembling backwards drive, and would be a variant or the same as the first sound. The third sound is representing hydraulic pressure releases from the sound.

The sound engineering process is based on experimental trails, and experience in working with sounds.

Fundamental Engine Sound and Motion

The fundamental sound [, Trucksounds/funengine.wav], is the sound that is played back when the truck is holding still and is in motion. This sound would have to change its characteristics according to the speed of the truck, such that the sensation of a moving vehicle emerge.

The sound is designed around a sampled string instrument from a keyboard. The resulted sound emerging is an engine like sound. Since the sampled string instrument is of a reapiting nature, only a few periods of the sampled instrument is used and then played back in a loop

Figure 3.1 shows the piece of the sampled string instrument that is used as the fundamental engine sound

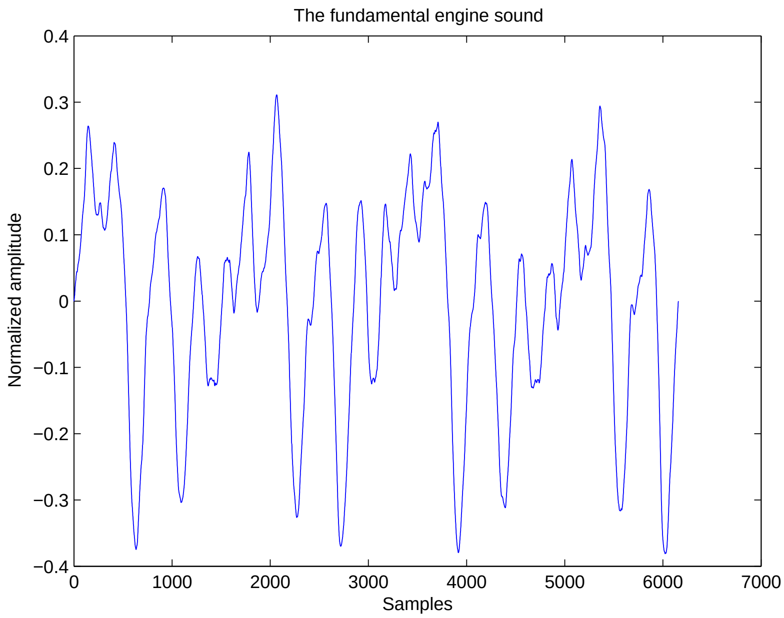


Figure 3.1: A piece of the fundamental engine sound for the truck in time.

The main spectral energy in the signal is centered around the low frequency band, which would be a be critical compared the background noise, that for most locations in the production facilities also would be of low frequency content. The possibilty is to shift the sound, by pitching the sound up in frequency. This method is explaned later.

Backwards Drive

The backward drive will comprise of the same sound as forward drive. But in reality should the sound for the backward drive be a variant of the forward drive, such that it is possible to hear whether or not the truck is driving forward or backwards. Another reason is also that different sound with different characteristics might stand out from the constant background noise and make the truck noticeable.

Hydraulic Pressure sound

The third sound in the truck sound-concept is a hydraulic pressure sound [, Trucksounds/idlewindhigher.wav]. The sound is thought to resemble the release of a hydraulic pressure on a real gas truck. The sound i designed around an enveloped white noise signals. The signal is illustrated signal is shown on figure 3.2

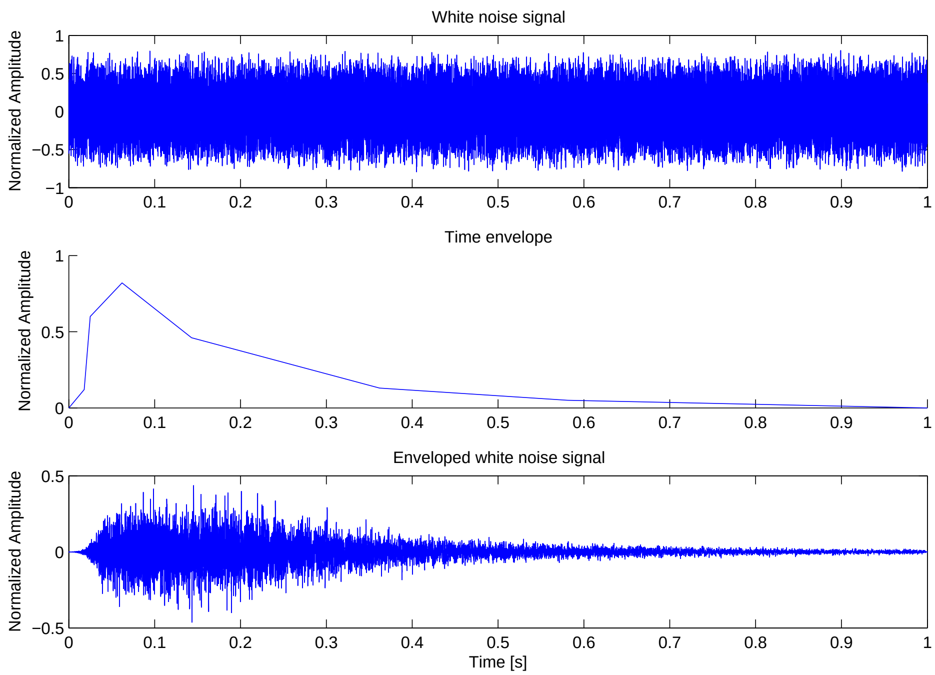


Figure 3.2: The hydraulic sound

The hydraulic pressure sound is also characteristically different than the fundamental engine sound

The truck sound-concept

As defined in the analysis, the truck sound-concept should reflect the behaviour of the truck. This means, that the three designed sounds would appear according to the activity of the truck.

When the truck is in function it will present the fundamental engine sound. Depending on the forward speed of the truck the fundamental engine sound i manipulated, such that the sensation of motion is presented. The technique used to attain this sensation is explaned later. The hydraulic pressure sound is thought to function as a stop sound. So when the truck i coming to a hold, the hydraulic pressure sound is played back. Furthermore, a variant of the same sound is used during drive. The variant is a short-duration variant of the original hydraulic pressure sound. The same technique for the

It is important to state that the stop sound should resemble the hydraulic pressure build-up in the imagined truck system, an would also mean that this sound is only presented when the imagined pressure has been build up. So for at truck that is at a hold and starts moving and with the intention to stop again within a short period of time, will not neccesarilly play back the hydraulic pressure sound.

3.2 Nice noise system - hardware

Figure 3.3 shows the design of the entire nice noise system.

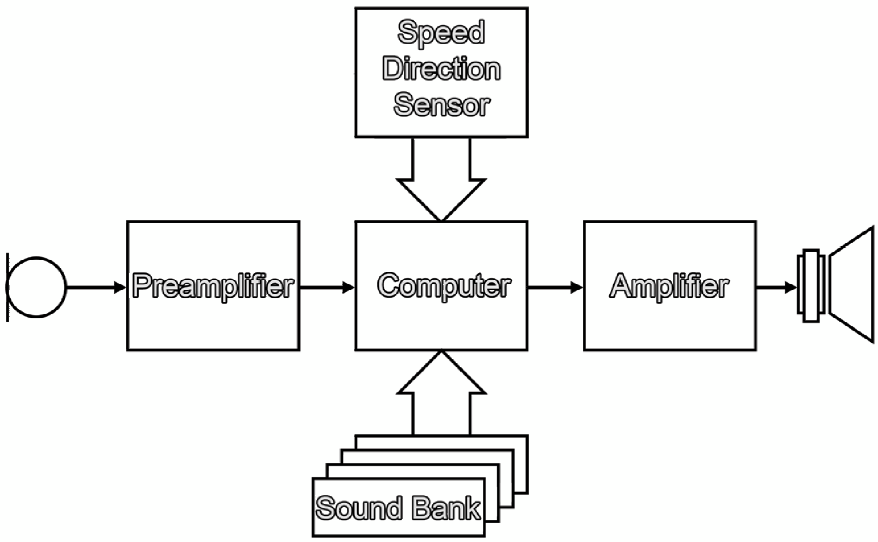


Figure 3.3: The general nice noise system

The system comprise of a microphone and preamplifier used as an input to the computer system, such that the background noise can be sampled for a sound pressure level or other data to be extracted from the background noise. An accelerometer is interfaced to the computer, basing the speed of the truck purely on the acceleration forced excited on the truck when its in motion. An external memory bank is used as the sound bank, allowing the nice noise system to have enough space for the audio files that is played back a loudspeaker driven by an amplifier. The main idea in the design of a system for the truck is that it should power up, and be instantaniously ready when the truck is powering up. The reason for this is simply to avoid a system where the worker would have to wait for the Nice Noise System to be ready before he or she can start the actual work.

3.2.1 Microphone and microphone preamplifier

In order for the system to be able to have a measure of the level of the background noise inside the facilities at Sauer-Danfoss, a microphone with an associated preamplifier would have to be interfaced to the computer system. As recognized from the background noise measurements at Sauer-Danfoss, the microphone should be able to handle a sound pressure at 100 dB. Futhermore should the output from the preamplifier work within the voltage limit set by analog-to-digital converter in the the computer system.

The frequency response of the microphone should either be flat or measured, such that in cased of a non-flat frequency response, a filter can compensate for this.

3.2.2 The computer system

The main purpose of the computer system is to playback the developed sounds.

The Nice Noise System is designed around a microcontroller. The reason for this i simply that microcontroller is basically a small computer and comes in various sizes in terms of input-output connection and memory capacities. The chosen contoller for the design is a PIC16C765 (See figure 3.4) from microchip, having a instruction cycle of approximately 200ns, build-in analog-digital converters, build-in Pulse Width Modulator (PWM) and Digital input outputs.

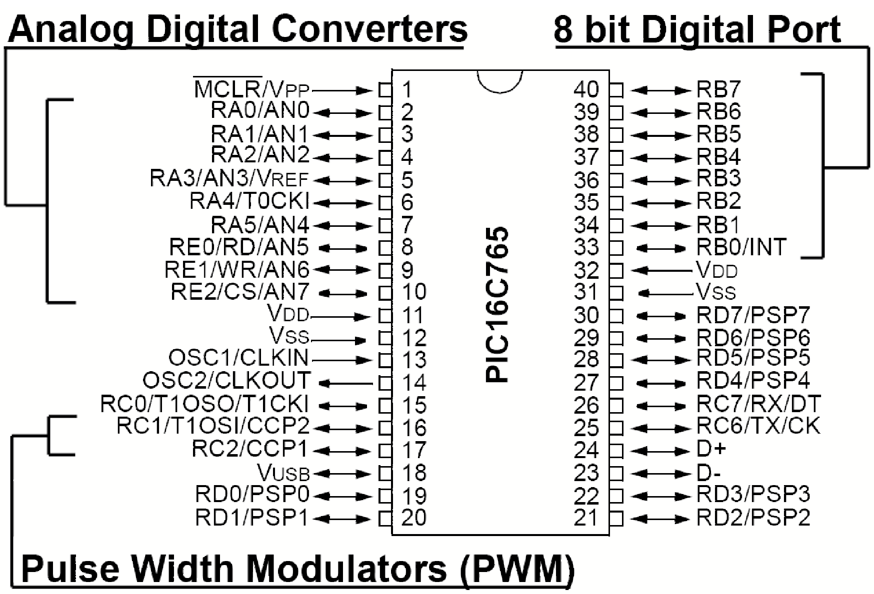


Figure 3.4: Top view of the PIC16C765 microcontroller from microchip.

Analog-to-digital converter

For analog-to-digital conversion, the build-in converter on the microcontroller is used. There are 7 possible connection to the build-in analog digital converter, meaning that its possible to sample from ANx pin seen in figure 3.4

The converter can either operation on supply voltage or a reference voltage.

Digital-to-analog converter

The microcontroller has not directly a build-in digital to analog converter, meaning there is not a single pin on the microcontroller able to supply an analog signal based on digital data. The design of the the digital-to-analog converter is considering two possibilities. The purpose of the digital-to-analog converter is to transform the digital stored truck signal into an analog signal. One way of converting the digital signal is through a resistor network, comprising of two different resistors configured as seen in figure 3.5

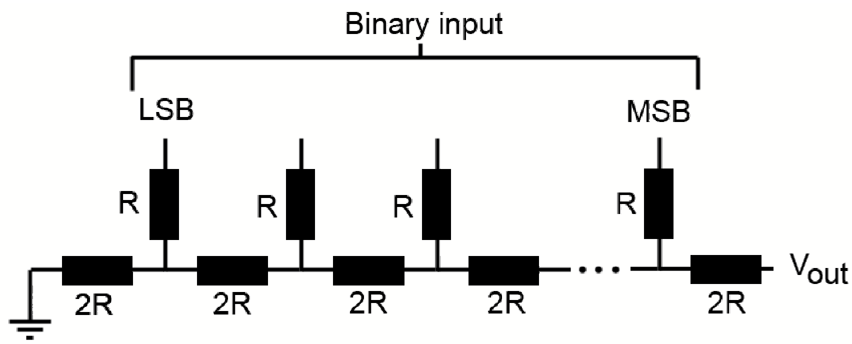


Figure 3.5: A R-2R resistor network usesfull in digital to analog conversion

The 8 bit digital port can be connected through this resistor network and the result will be an analog voltage representing the digital bit combination. Further information on the ladder network can be found in appendix B

Another way to convert the digital data to an analog signal is using the PWM (Pulse width modulator) as a part of the microcontoller. A PWM signal is a digital signal with fixed frequency but varying in duty cycle. An example of such a signal is shown in figure 3.6. If the duty cycle of the PWM signal is varied with time, and the PWM signal is filtered, the output of the filter will be an analog signal.

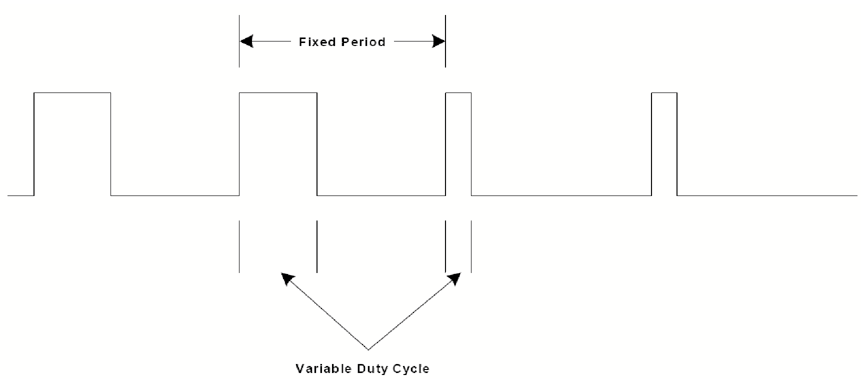


Figure 3.6: A PWM signal with fixed period and variable duty cycle

Figure 3.7 shows the digital-to-analog PWM principle, where the PWM signal is connected to a analog filter, lowpass filter, converting the PWM signal to an analog signal.

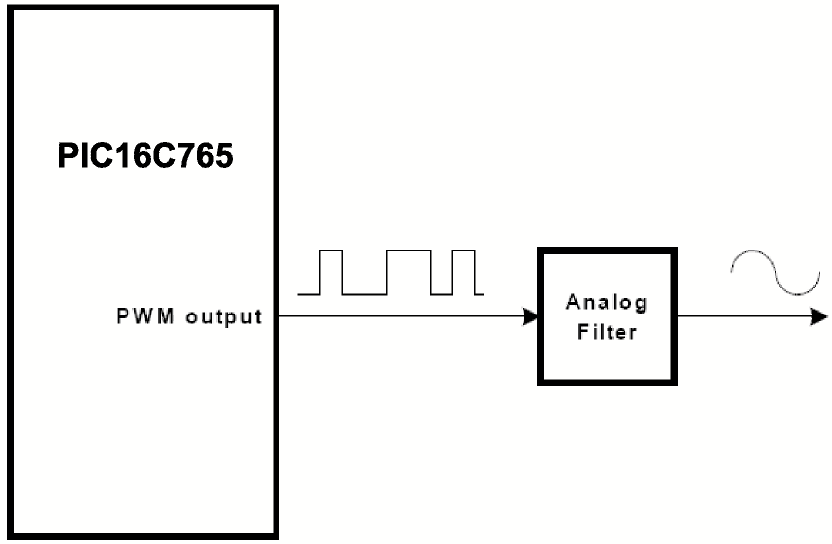


Figure 3.7: Det er iorden mester

Working with digital-to-converter, also includes the matter resolution of the converter. The PWM on the microcontroller PIC16C765 has a 10-bit resolution. That also means that the duty-cyle can vary in 2^{10} steps within the fixed frequency.

It is known that chips providing the digital-to-analog conversion exists, but would also require timing issues between the microcomputer and the Digital-to-analog converter. The chosens designs offer a straight forward approach in the digital-to-analog conversion.

3.2.3 Sound bank

Since the microcontroller is not capable of supplying enough memory storage, in general, an external memory block is interfaced to the microcontroller. In this way enough memory can be attached to the system, giving the possibility of storing larger amounts of data, like truck sound files. The sound bank is therefore comprising of all the different sounds that is to be played back during operation of the truck. This is typical the fundamental engine sound, but also other types of sounds when the truck stops or moves backwards.

The memory block could simply be a smartmedia card with a command, address and data cycles.

3.2.4 The loudspeaker and amplifier

The important part of the nice noise system chain is the loudspeaker. The loudspeaker is converting the electrical truck signal in the computer system to an acoustic wave front, propagating away from the truck.

The main concern in the design of a the loudspeaker is the size, sound pressure level and frequency response.

The loudspeaker chosen in this design is a coaxial loudspeaker, see figure 3.8

Figure 3.8:

The enclosure of the loudspeaker is formed as a ball with the diameter of 16 cm. It should be noted that the on axis diameter is 14 cm. That also means that the size of the chosen loudspeaker is not changing the overall dimensions the truck and can be well mounted on the existing fitting on the roof of the truck. The same loudspeaker can be mounted in the front and back of the truck.

Sound level

The sound pressure level of a loudspeaker is typically measured one meter in front of the loudspeaker. The radiated sound has to reach a certain distance in front of the truck and the sound pressure level has to be above the background noise level at this distance.

There is a relation between the distance and sound pressure level. The sound pressure level decrease 6 dB by doubling the distance. Moreover, the sound pressure level next to the truck will be louder than for instance further away from the truck. It can be discussed what distance would be the absolute distance, where the sound presure level of the truck sound would be above the background noise level.

The analysis of the background noise reveals that most of the spectral energy is located at low frequencies(below 100 Hz). For some areas the low-frequency energy is 10 dB higher than compared to the rest of the frequency spectra.

The sensitivity of the speaker is specified to 88 dB SPL at 1 meter for 2.83 Vrms. Comparing that to the background noise found in the noisemaps in appendix C, reveals that this loudspeaker should be able to deliver a sound pressure level above the background noise, if it is considered that the truck sound is positionen above 100 Hz in frequency and that the background noise above 100 Hz is found to have maximum of 70 dB. A rough estimate would be that the sound is able to be heard from a couple of meters distance ahead of the truck.

The frequency range of the loudspeaker is +- 2dB 60 Hz - 17 kHz up to 30 degrees off-axis in any direction.

3.2.5 Locomotion sensor

The crucial thing in terms of making a system that can playback sound corresponding to the movements of the truck, is the sensor that is going to track the movements of the very truck. The movements will be in terms of speed and direction. The rotation of the truck wheels comprise of all the information that is needed in terms of the truck movements, but would also require a sensor extracting that information about the wheel. That can be in terms of direct contact with the wheel or other means that can do the sensoring of the rotation without physical contact or a wireless solution.

Another way could be to consider acceleration and base the speed on behalf of the acceleration measured. When the truck is on a hold and starts off moving down the corridor in the factory, it begins to accelerate. Moreover the speed is increased. In other words is the acceleration is a measure of how fast the speed is changing over time. At some point the truck has reached its maximum speed, or merely a speed suitable for a certain drive and the acceleration of the truck is zero, but the speed is not zero. In this case a system would have to track the acceleration, so when the truck is accelerating the system is increasing a speed parameter, and when the truck is deccelerating (breaking or coming to a hold), the system would decrease the speed parameter in the system.

Acceleration forces apply to any moving object changing its speed over time, meaning that it exists for the truck as well. This is a part of the physics in nature.

The sensor measurering acceleration is called an accelerometer. It can be found with various sensitivity, meaning that how sensitive is the accelerometer in measurering the acceleration force. Moreover, a very sensitive accelerometer, would be able to measure even weak acceleration forces on the truck. The accelerometer is found in one chip, that can either output digital or analog signals based on the acceleration excited on the chip, meaning that in the end would the chip have to be physically mounted on the truck to measure the acceleration on the truck. Furthermore the chip has to be mounted correctly, such that the axis of acceleration of the truck corresponds to the acceleration axis on the chip. Due to lack of time, this concept has not been proven. The possibility in using an accelerometer as the speed and direction sensor, would mean that it is possible to use the same designed system on other vehicles, regarless of any interface to the vehicle.

3.3 Noise noise system - Software

3.3.1 Pitch bending

To give the sensation that the truck is travelling at a certain speed or change from one speed to another, the truck sound is pitch bended. This means that all the frequency components in the sound are moved along the frequency axes by the same factor.

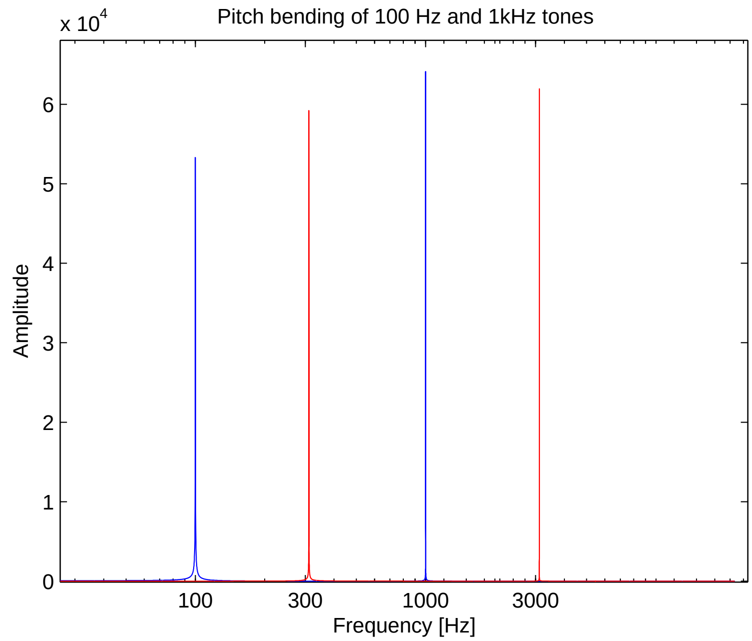


Figure 3.9: The result of pitchbending. The original frequency components (100 Hz and 1000 Hz) are shifted by the same factor (3), resulting in frequency components at 300 Hz and 3000 Hz

Figure 3.9 illustrates the concept of two pures sinus tones where the blue curve correspond to the original sound (100 Hz and 300 Hz), and the red curve is the pitch bended sound (300 Hz and 3000 Hz).

Moving frequencies in the frequency domain, would require a tranformation of the signal into the frequency domain, using fast fourier transformation, and then shift the entire axes corresponding to the speed. The cost in computational power, and in time used to implement an FFT algorithm on the microprocessor, can be enoughmous.

Another way of doing this is simply to change the sample frequency at which the samples are outputtet from the system. The effect would the same. [,Trucksounds/funenginepitched.wav] is an audio example of the pitchbended truck sound.

The pitch bending method is used to make the sensation that the truck is changing speed. So according to the speed of the truck, from the speed sensor, the fundamental truck engine sound is pitch bended.

Figure 3.10 showes how the truck is positioned spectrally, when pitched. The components in the truck sound is moving up en frequency by the same factor.

The pitch bending method is also used in case of a truck on a hold. Since the truck sound is played back even when the truck is not driving (such that i represent idle speed of the truck), the pitch bending method is used to make the sound change just a bit, corresponding to a combustion engine that is keeping the engine running. The sensation is a truck sound that is not constantly, but is changing it characteristics, but not in such a way that i seems that the truck is increasing in speed

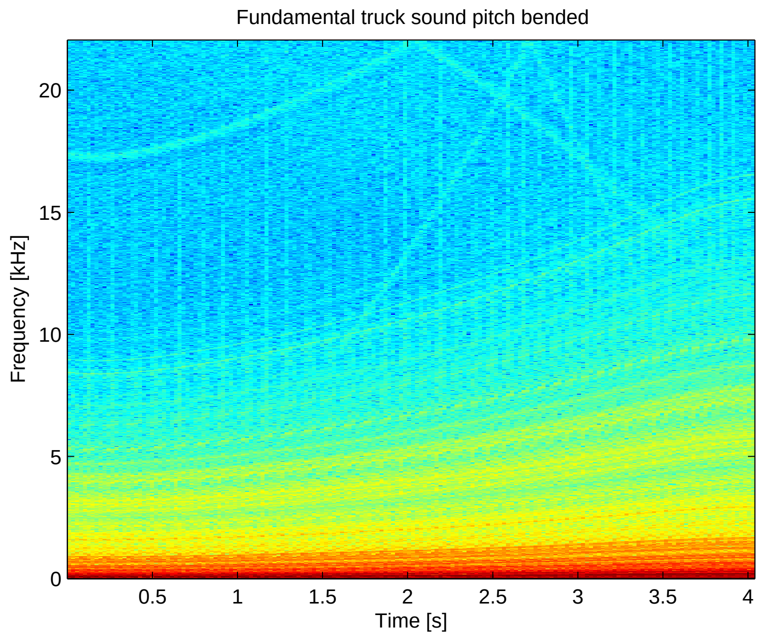


Figure 3.10: The fundamental truck sound, pitch bended, resemble an increase in speed of the truck

Figure 3.11 shows how the pitch bending method is changing the truck sound when the imagined combustion engine is at idle speed [, Trucksounds/funenginepidle.wav].

3.3.2 Volume control

The sound pressure level in the Sauer-Danfoss facilities can change from one location to another. The purpose of the nice noise system is not to annoy the workers near the corridors, hence designing the system having a volume control managing the outputtet sound pressure level, allows the system to adjust the nice noise sound to be above the background noise floor. Moreover, in case of the truck driving in a low level background noise area, the volume is turned down, such that the nice noise from the truck still stands out from the background noise.

The volume control is based around an rms value index calculated on behalf of the root mean square formular .

$$x_{rms} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2} \tag{3.1}$$

The system will collect samples of the background noise during operation of the truck and apply the calculation, ending up with a RMS value. The RMS value is compared up against the output level, using a prepared table performing the arethmetric operation in the conversion of the root mean square value and decibel level.

It is important that the system is not turning the volume up and down rapidly, according to short-duration changes in the background noise level.

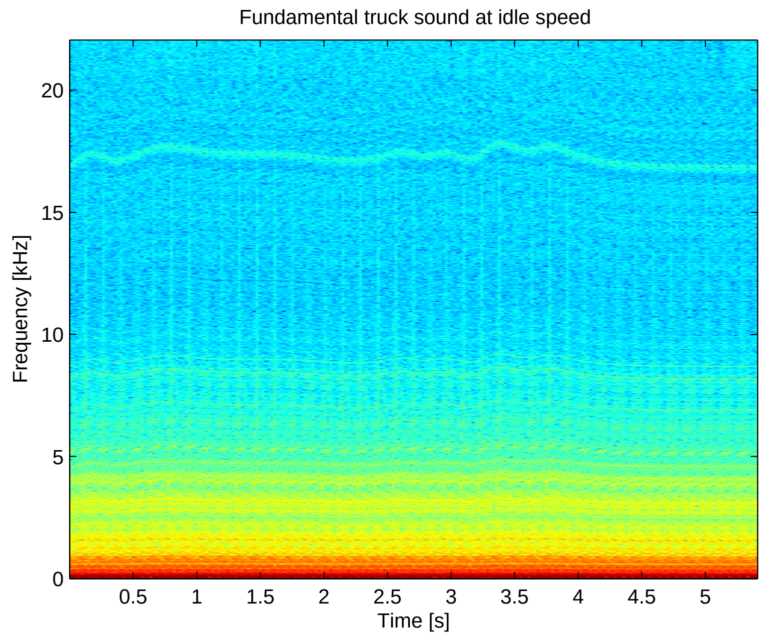


Figure 3.11:

Figure 3.12 shows a time-frequency plot, where L2-D16 has rapid spectral changes over time, and L2-B19 longer duration of the same spectral energy. Meaning, not changing rapidly in a spectral sense.

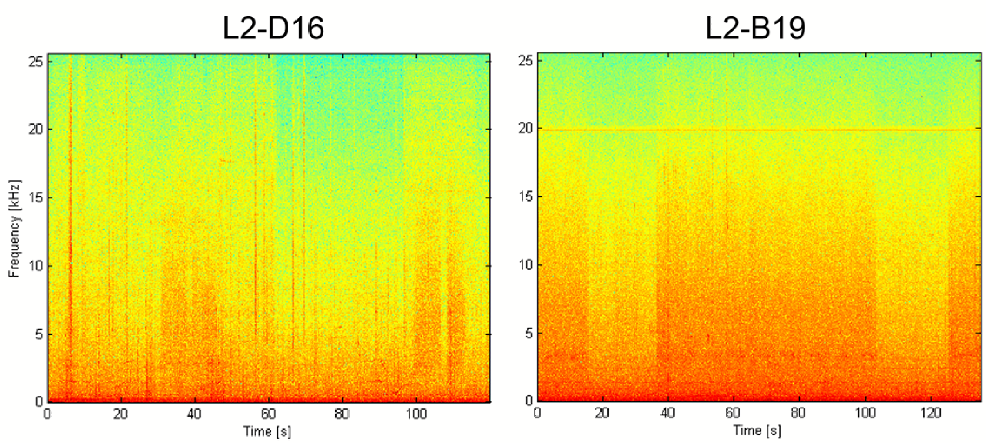


Figure 3.12: Comparison between two location in building L2, in terms of spectrally changes over time and the duration of each spectral change.

3.3.3 Estimation of speed

The sensor measuring the speed of the truck will set the parameter for the simulated speed for the sound. Since it is only a matter of changing the sample frequency, a relation between speed and sample frequency will be determined.

Chapter 4

Listening Test

To avoid an unneccesary sound pressure level of the outputtet truck sound and to investigate how well the truck sound is perceived in a monoural mixture of background noise and truck sound, a listening test is developed to enable workers at Sauer-Danfoss to give an answer to these to matters.

The Listening test has the following purpose.

To investigate the absolute sound pressure level limit at which the truck sound simulated at different speeds, is still perceived in the background noise for different locations in the Sauer-Danfoss facilities

The listening test comprise of a playback of audio signal. The signal is a mixture of background noise and truck sound. The subject is asked to answer the question "Is the truck there?", where the subject can choose "yes" or "no" as the answer.

Background noise

The background noise chosen for the test is based on the frequency content and special characteristics in the noise recorded for a given location at Sauer-Danfoss

Since there is ongoing work in the facility during the recordings, the different background noise for the test are based on avoiding temporal masking effect by short noise artifacts from people interacting with the environment or making noises close to the microphone at the moment of the specific recording

The considered noise files can be found the [, Backgroundnoise]

Truck sound

The truck sound is pitch bended, such that two versions of the truck sound is obtained[, Trucksounds/funengine.wav, Trucksounds/funenginemaxspeed.wav]. It is then these two versions that are used in the listening test.

The subject

The subjects for the listening test is primarily workers at the Sauer-Danfoss company. The listening test is considering people that are situated in the same facilities as the truck, having their daily working routine in the same background noise as the truck. As recent exposure of noise may cause temporary elevation of the hearing threshold, the resulting threshold from the listening test, may be different if subjects from the offices areas are chosen. Since the test is considering the real life situation, where workers are daily exposed to the background noise (temporary threshold shift) and would have to hear the truck, a temporary threshold shift for the worker may give the actually absolute threshold for the truck sound to be perceived under normal working conditions.

Audiometry is not performed as a part of the listening test. The

Flow of test

The test has 4 stages.

- Subject identification (Name, age and sex)
- Instruction (what is going to happen)
- Familiarization (the truck sounds and background noise)
- Absolute SPL Threshold for a given truck sound and background noise

The identification stage is to let the subject identify him/her self to the system. Figure 4.1

The instruction stage gives a brief decription of what is going to expected further on.

The familiarization stage is presenting the truck sound and the different background noise examples, such that the subject can get familiar with the sound that he/she would expect to hear throughout the test. Figure 4.2 and Figure 4.3 shows the two screens presented to the subject.

The Threshold stage presents a mixture of background noise and a truck sound as the stimuli and the subject would have to answer the question "Is the truck there?", by choosing "yes" or "no". Figure 4.4 shows the screen for the threshold stage in the test.

Performing Psychophysical experiments and testing for a threshold will involve that a certain absolute has been reach in the test, which can result in answers from the subject, based on a sensation (a stimulus that only exists in the mind)[Møl], previous stimulus, the personality of the subject, mood and judgement.

The method chosen for the listening test is the Ascending method, where ascending an descending trials will evaluate the absolute threshold perceived by the subject for a given mixture of background noise and truck sounds.

It is considered that the listening test from beginning to end, is only lasting 20 minutes. The subject should at least have a break if it last for more than 20 minutes [DS75]. The reason for

Figure 4.1: The identification screen

Figure 4.2: The Familiarization screens - a picture is associated to the screen

Figure 4.3: The Familiarization screens - a picture is associated to the screen

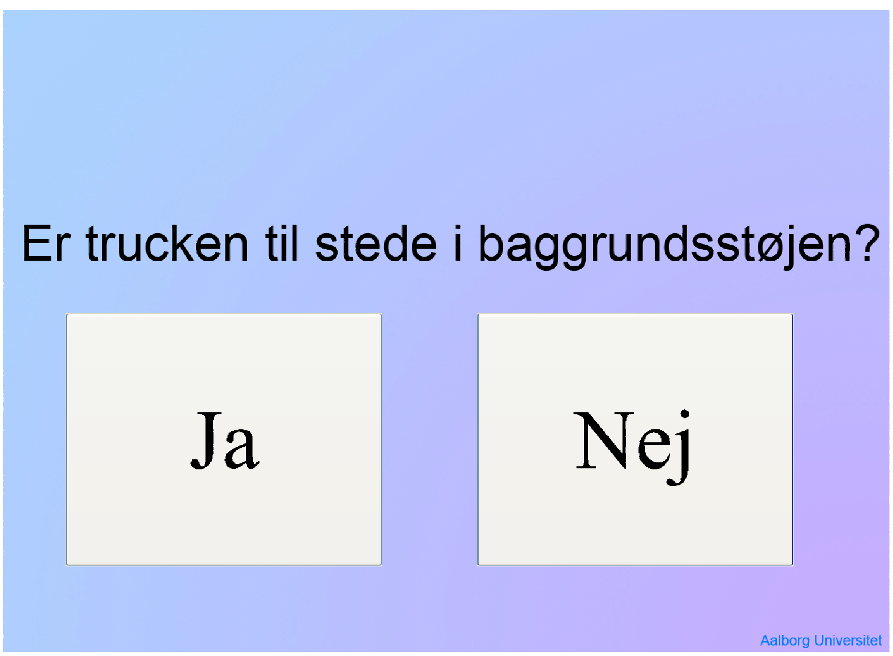


Figure 4.4: The main test screen

the 20 minutes is simply that the test is comprising of a lot of parts, where a given background noise and truck sound is compared. The subject is therefore faced with the same screen, see 4.4, and exposed to similar characteristic stimuli, throughout the test. From a psychological point of view, and previous experiences in listening tests, such a situation is monotonic of nature and would result in psychological fatigue.

Futhermore the subjects are chosen from the actual production facility, volunteering on the day. The workers from the production facility are not all used to concentrate in a static situation. That also means that it can probably be too long a test, if it is spanning an hour.

Test setup

The test setup is illustrated in figure 4.5.

Figure 4.5: The listening test setup: Laptop, headphones and the subject

The setup comprise of a laptop associated with a set of heaphones.

The system is calibrated on a head and torso simulator, such that the level presented for the subject is know. Furthermore are the headphones equalized according to [dS06]. The volume on the laptop is digital, meaning that is it possible to achieve the same outputtet sound pressure level at each boot-up of the machine, compared to an analog volume control where the possibility is that the button setup could be change during transportation of the laptop. The presented level of the stimuli is 76 dB. It has been decided to present the same sound pressure level for all background noise stimuli, such that the differens from one background noise stimuli to the next is not fatiguing the subject during the test. At least should this aspect not be a parameter in the test, that would bias the result for at given truck sound background noise combination, only because the previous truck sound and background noise combination was louder in level.

Results

Figure 4.5 shows the listening test setup at Sauer-Danfoss. The laptop was placed in a quiet place, such that the subject would not be disturbed, by background noise, during the test.

The total of 13 people from Sauer-Danfoss have taken the listening test. They were instructed in the same way, and made sure that they had understood the task in the test.

The data has been analyzed in terms of the mean of the signal-to-noise ratio and the standard deviation around the arithmetic mean.

Figure 4.6 shows the 10 different combinations of truck sound and background noise, and the mean and standard deviation for each combination.

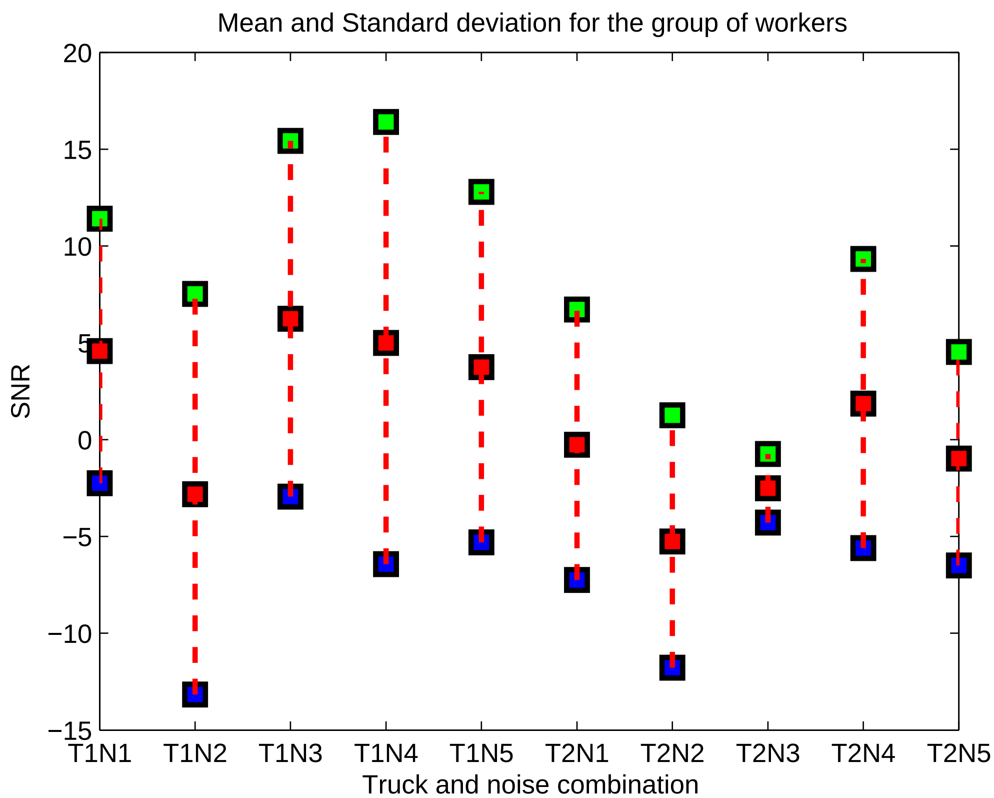


Figure 4.6: The results from the listening test, showing the mean and standard deviation for each combination of truck sound and background noise

The results are not ambiguous.

It has been difficult for most of the subjects to clearly differentiate the truck sound from the background noise. That has also resultet in answers where is has been difficult to estimate the actual signal-to-noise ratio for a given truck sound and background noise mixture . The listening test constituted monoaural stimuli, that was played back to each ear. That means that the auditory experience is happening in the center of the head[Bla97], and background noise and truck sound is not to be differentiated by localization. Furthermore the truck sounds was kept in a constant manner, meaning that the truck sound was not representing simulated motion of the truck (sweeping pitch) . The difficulty finds expression in the data from the listening test, Some subjects tend to hear the truck sound at all times, untill they find it strange that they havent answered "NO" a single time, resulting in a following consecutive number og "NO" answers (see figure **??**

There is a tendency that subjects are tuning in on the truck sound, such that a conscecutive number of "YES" answers exist at a certain SNR level, eventhough previous trials show that the same subject has answered "NO" to the very same SNR of truck sound and background noise.

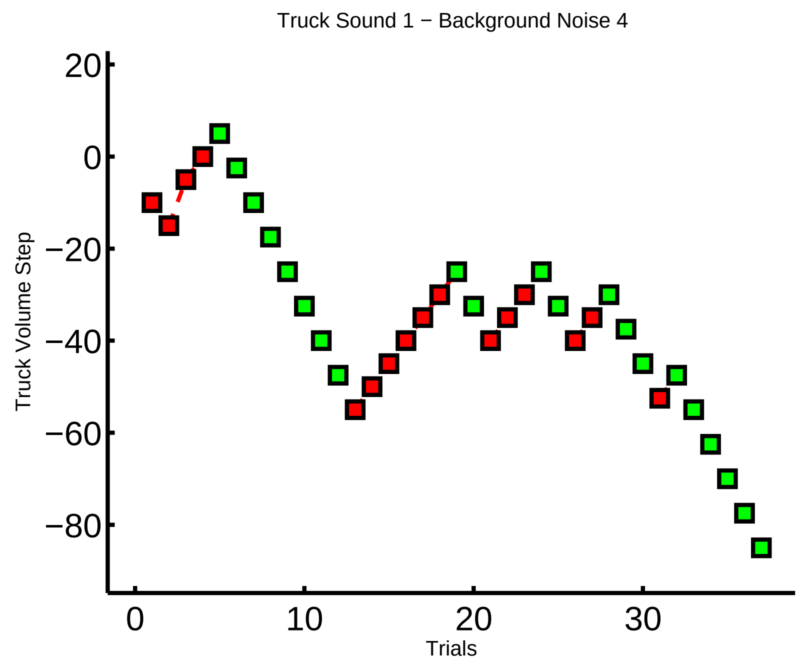


Figure 4.7: An example of answers from the listening test

Figure 4.8 shows a good response from one background noise an truck sound comparison. It is clear to see the estimation of the threshold.

Furthermore, the subject is only taken through 22 trials out of 36, for one comparison session, meaning that the algorithm used in the test has estimated consistency in the data, and moved on to the next comparison. This was one of the features implemented in the test, such that the test would be faster, if consistency in the reponses was present.

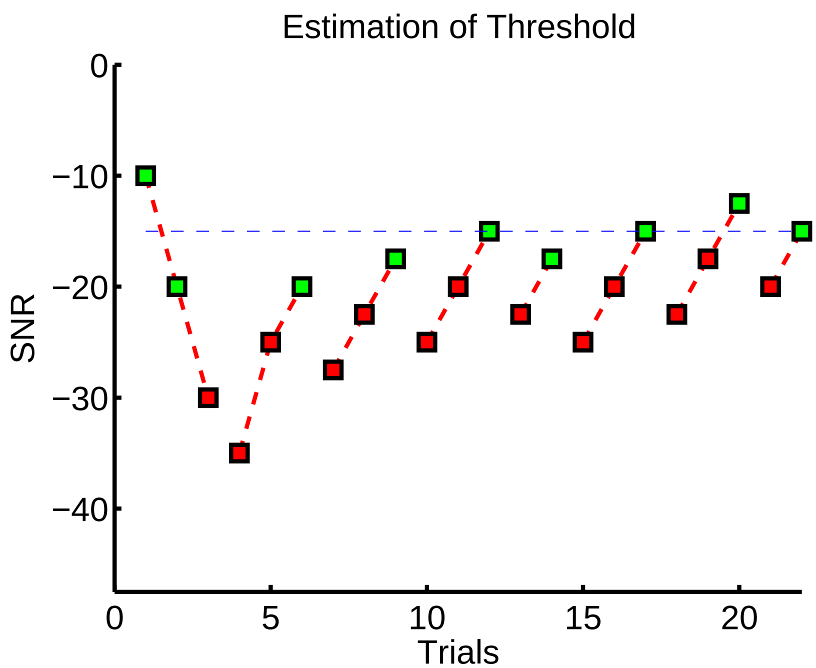


Figure 4.8: A typical good response from the test.

Chapter 5

Conclusion

The problem formulation was as follows *There has to be developed a sound, or a concept of sounds, such that this concept represents a real truck, the way the workers at Sauer-Danfoss might understand it. The sounds should also, in some extent, be able to be heard without tuning up the volume too much, and without being masked by the changing characteristic background noise.*
There has to be design a system that can play back the sounds. There has to be designed a method to make the designed sound follow the speed of the truck and give the sensation of a real truck, driving at different speeds.
The system would have to be able to turn the volume up and down ccording to the background noise level for a given location.

5.1 Conclusion

A sound-concept for the truck at Sauer-Danfoss has been designed. The sound-concept is based on the philosophy behind the Human sound perception and psychology, meaning how the workers might expect the artificial truck sound to sound like. The sound concept is based on sounds from a real truck. Futhermore principles are outlined, describing in what way different sounds for the truck is to follow the behaviour of the truck.

The sound-concept comprise of an artificial combustion engine sound, and sounds representing hydraulic pressure releases. The designed engine sound is based on a sampled instrument, at a very low pitch, from a keyboard. The sound is around 6000 samples long an repeated in a loop, resulting in a constant engine sound. To make the constant engine sound vary over time, a pitch bending method has been used, such that the sensation of increasing or decreasing speed of the vehicle is reflecting the sensation of a changing speed for a real vehicle.

The pitch bending is also used in idle speed situations, where the truck sound is only a constant looping sound. That gives the impression that the truck is at idle speed, but that the sound is representing sound from a real truck, by small pitch changes over time.

A hardware system has also been design. The focus is mainly having as sound source that is able to play back sound, such that i can be heard in the production facilities, and be heard a distance ahead from the truck.

It can be discussed if workers would accept an artificial truck sound on the truck. The one thing the workers understand is the problem and the danger in crossing the truck corridors without orientating for moving vehicle. The important thing is that the workers experience that an artificial truck sound is working as the solution.

5.2 Future aspects

The thesis has been focusing on a system that is using a loudspeaker to give the whereabouts of the truck. Since some workers are using hearing protectors often used in noisy environments, it could be possible to make a system that comprise of a wireless solution, and in that way transmit the truck sound to the individual worker, when the truck is near. Some workers are also using hearing aids, and since the technology in the hearing aid business is moving towards wireless solutions. It might be possible to actually interface to these hearing aids and through a wireless connection broadcast the artificial truck sound.

Bibliography

[Arb06] Arbejstilsynet. *Arbejstilsynets bekendtgørelse nr. 63(6) feb 2006 - http://www.at.dk/sw19871.asp*. 2006.

[Bla97] Jens Blaurt. *Spatial Hearing, the psychophysics of Humand Sound Localization*. MIT press, 1997. ISBN 0-262-02413-6.

[Cro98] Malcolm J. Crocker. *Handbook of Acoustics*. Wiley-Interscience Publication, 1998. ISBN 0-471-25293-X.

[DS75] DS. *International standard ISO 532*. DS, 1st edition edition, 1975.

[dS06] Yesenia L. Parodi Casper Michael Andersen Lars Enggaard Carlos Orellana Eric de Santis. *Assesment of using an artificial human sound source in nera field binaural synthesis*. Aalborg University, 2006.

[EBB87] Jan Voetmann Eddy Bøgh Brixen. *Praktisk elektro akustik*. 1987. ISBN 87-571-0985-0.

[GB89] M. Sankiewicz G.K.E Budzynski. *The definition of sound-image quality and its influence on sound engineering concepts*. AES - Audio Engineering society, 1989.

[Hol] Keith Holland. *Horn loudspeakers for live sound*. Institute of Sound and Vibration Research, University of Southhampton, UK.

[Inc] International Resistive Company Inc. *http://www.irctt.com/pdf_files/LADDERNETWORKS.pdf*. Internation Resistive Company.

[Let89] Tomasz Letowski. *Sound Quality assesment: Concepts and Criteria*. AES - Audio Engineering society, 1989.

[Moo06] Brian C. J. Moore. *Psychologi of Hearing*. Elsevier Academic Press, 2006. ISBN 0-12-505628.

[Møl] Morten Lydolf Peder Chr. Frandsen Michael Friis Sørensen Henrik Møller. *Comparison of eight psychophysical methods for measurement of threshold of hearing*.

[RGS98] U. Felscher-Suhr R. Guski and R Schuemer. *The concept of annoyance: How international experts see it*. 1998.

[sta91] Dansk standard. *International standard ISO 8253-1*. DS, 1991.

Appendix A

Sauer-Danfoss Background Noise Recordings

Purpose

- To record the background noise from different machinery stationed in two production facilities at Sauer-Danfoss
- To analyze the sound pressure level on behalf of the recordings and analyze the recordings in terms of frequency and time patterns.

Description

The measurement is carried out in two production buildings at Sauer-Danfoss. Each building comprise of different machinery making a various of different sounds in time and frequency. Figure A.1 and figure A.2 shows the overview the two buildings where the research is carried out.

The recording locations (Green squares in figure A.1 and figure A.2) are allocated next to the corridors where the trucks of interest are driving. They drive along these corridors and people offen cross these to get from one part of the production to another.

The points are scattered out covering most of the area along the corridors of the two buildings (L2 og L4).

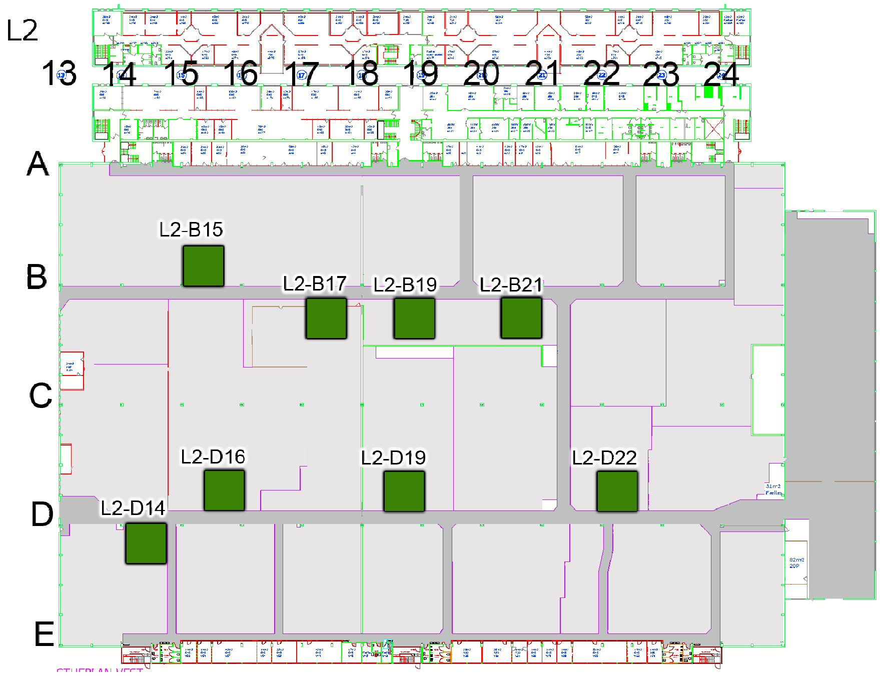


Figure A.1: The recording locations in building L2

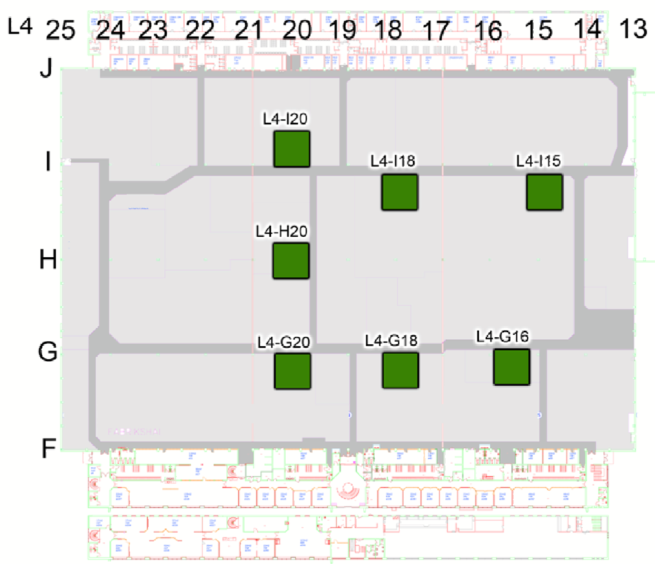


Figure A.2: The recording locations in building L4

Measurement setup

Figure A.3 shows the measurement setup.

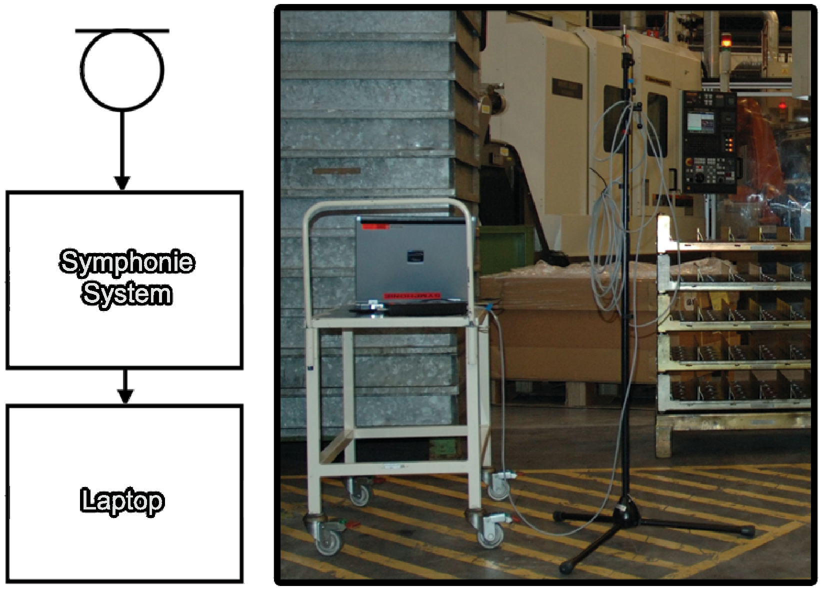


Figure A.3: The measurement setup for the performed recording at Sauer-Danfoss

Each recording is made by recording the sound using a B&K 4134 pressure field microphone pointing upwards. A Symphonie system is used to do the time recordings. The system is calibrated according to a 93.8dB SPL using a B&K calibrator providing 1 Pa sound pressure at a 1kHz sinus tone.

Equipment

Table A.1 lists the equipment used.

Type	Serial No.
Microphone B&K 4134	1253168
Symphonie system + laptop	—

Table A.1: The list of equipment used to record the background noise

Results

Table A.2below shows the overall linear-weighted and A-weighted sound pressure levels for the different recording locations within L2 and L4.

Location	Linear-weighted	A-weighted
L2-B15	82.7 dB	73.5 dBA
L2-B17	79.9 dB	75.9 dBA
L2-B19	77.8 dB	69.9 dBA
L2-B21	82.4 dB	77.1 dBA
L2-D14	76.2 dB	67.7 dBA
L2-D16	76.7 dB	69.2 dBA
L2-D19	78.7 dB	74.2 dBA
L2-D22	78.9 dB	71.0 dBA
L4-G16	86.5 dB	84.2 dBA
L4-G18	78.8 dB	69.9 dBA
L4-G20	83.2 dB	74.6 dBA
L4-H20	81.8 dB	73.3 dBA
L4-I15	84.6 dB	84.2 dBA
L4-I18	79.1 dB	72.5 dBA
L4-I20	77.8 dB	71.6 dBA

Table A.2: List of SPL for the recording at the Danfoss facilitis

The rest of this appendix shows all the time-frequency plots for all the recorded time signals at each location in figure A.1 and figure A.2. The essential matter to notice in all the plots is that the noise pattern, frequency content and sound pressure level varies a lot from location to location. Some locations reveals clear noticeable time patterns of different duration where other locations are more og less only comprising of a low frequency mixture of noise.

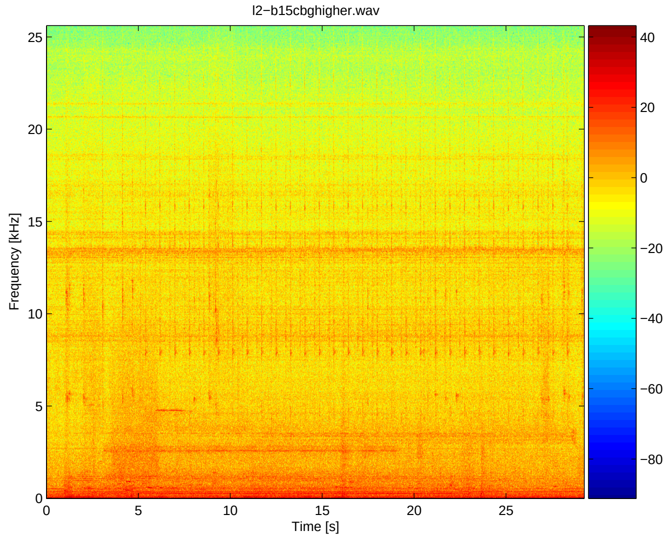


Figure A.4: Time-frequency analysis showing a constant low frequency mixture of noise and a high frequency noise artifact repeating every second

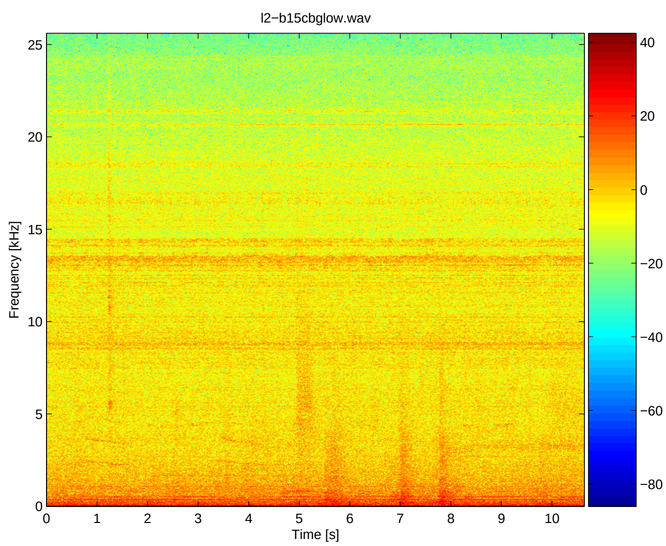


Figure A.5: Time-frequency analysis showing contant low frequency content and constant narrow band high frequency content

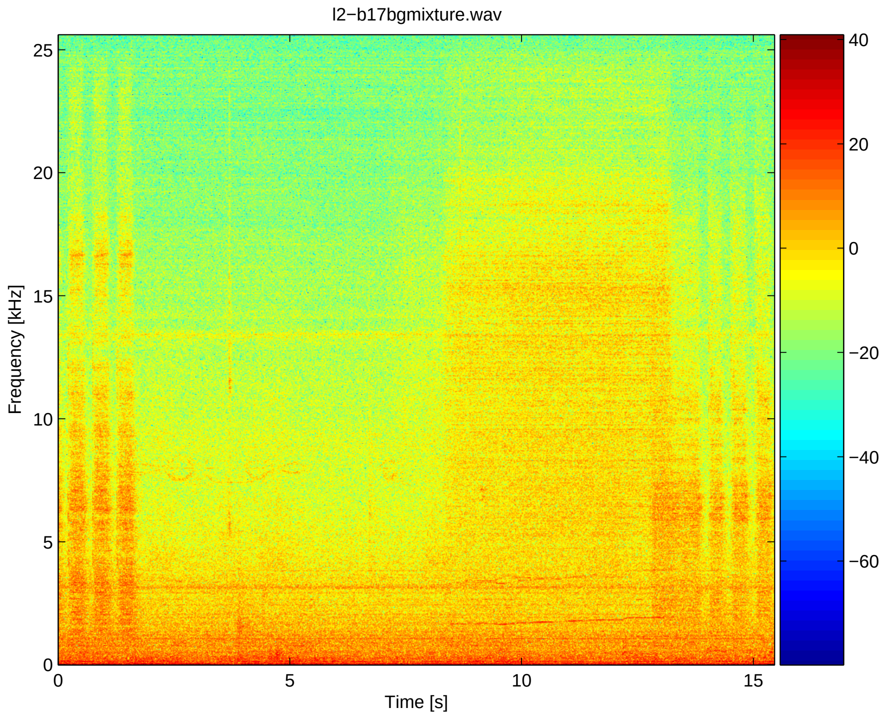


Figure A.6: Time-frequency analysis of location L2-B17, showing a mixture of different sound artifacts like short broad band bursts and long broad band noise duration

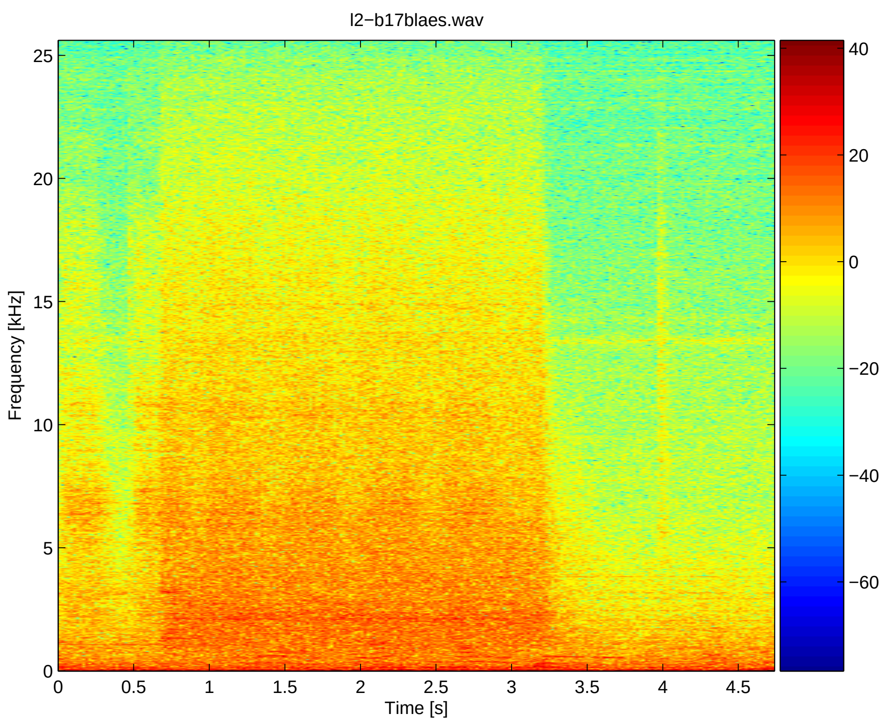


Figure A.7: Time-frequency analysis of location L2-B17, showing a broad band noise phenomenon but with concentrated low frequency content

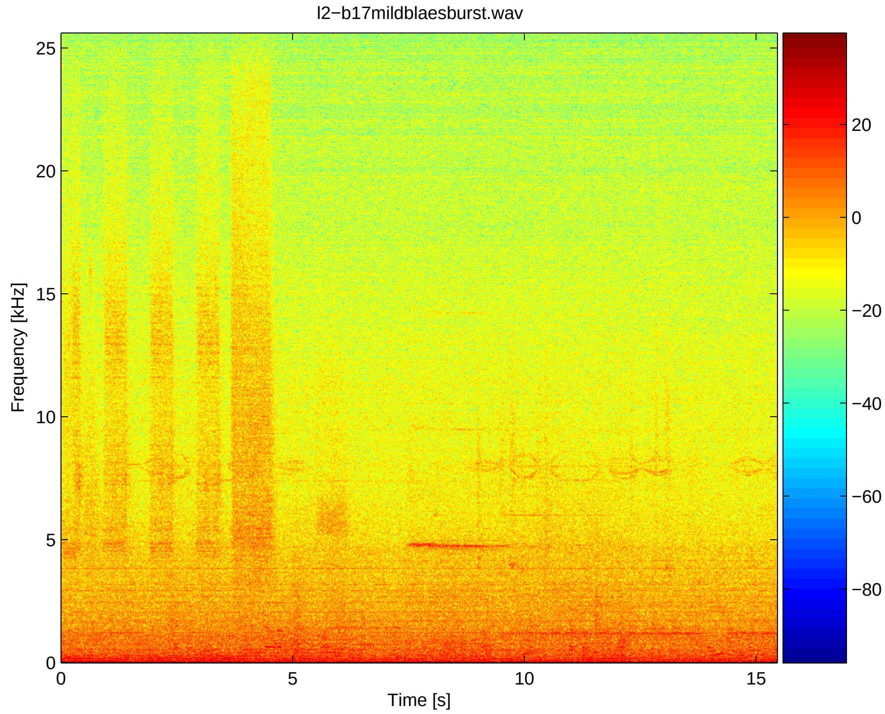


Figure A.8: Time-frequency analysis of location L2-B17, showing som repeating broad band noise artifacts followed by constant low frequency content of long duration

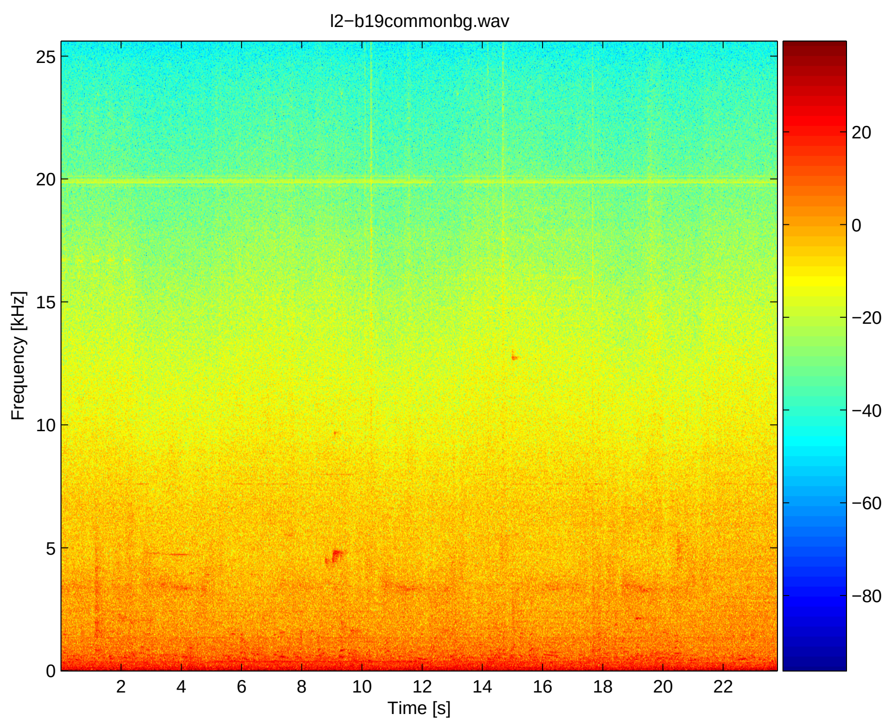


Figure A.9: Time-frequency analysis of location L2-B19, showing constant low frequency background noise

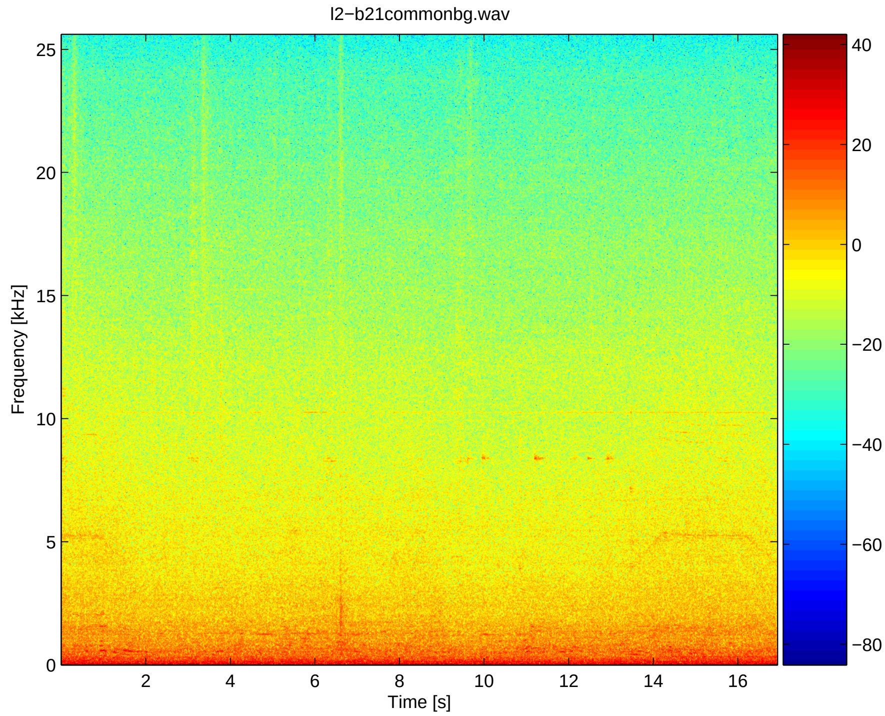


Figure A.10: Time-frequency analysis of location L2-B21, showing constant low frequency background noise

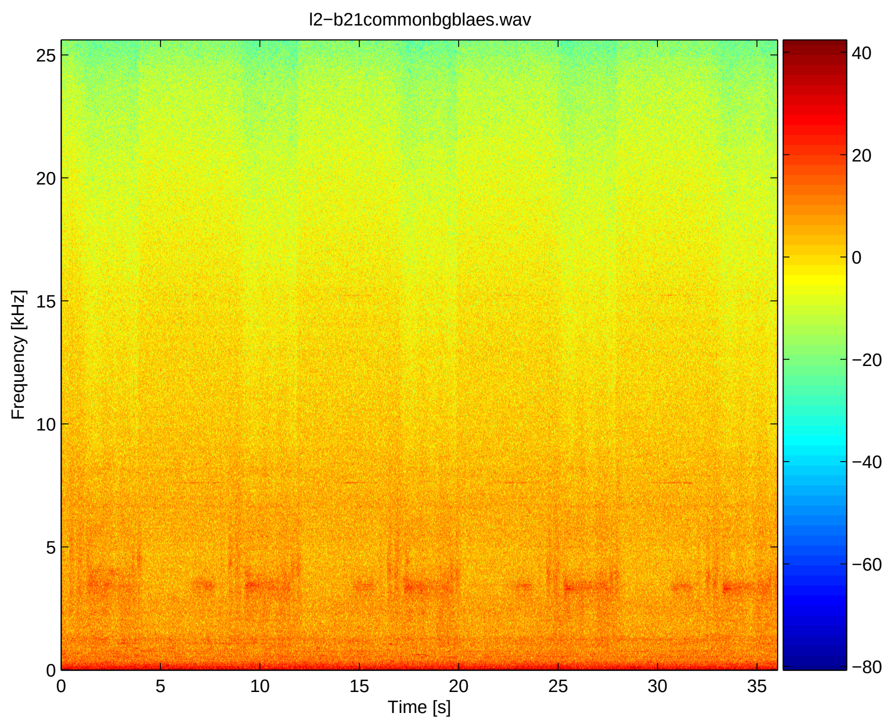


Figure A.11: Time-frequency analysis of location L2-B21, showing broad band noise of a repeating fashion

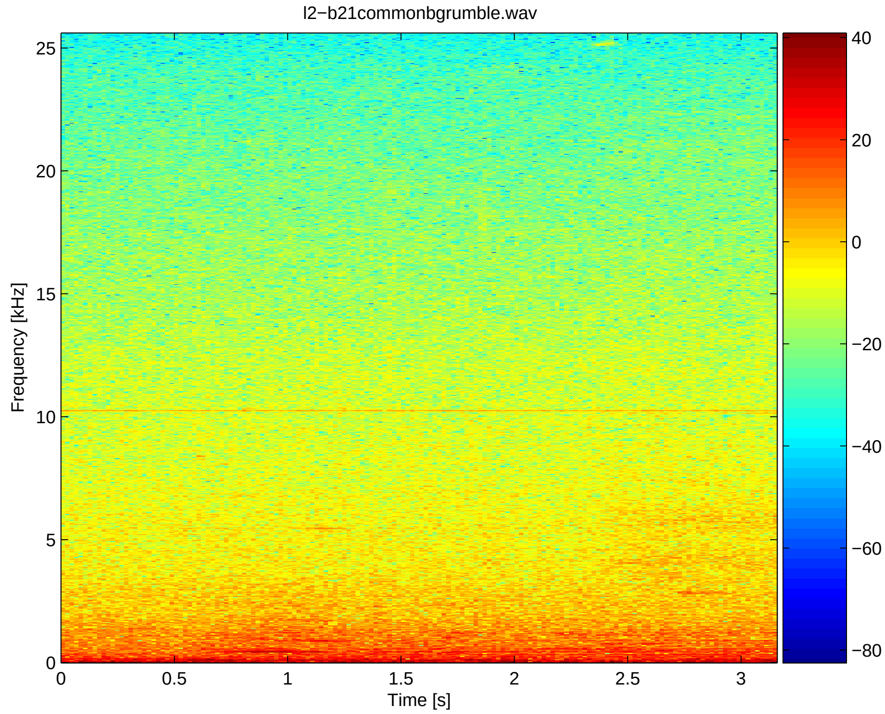


Figure A.12: Time-frequency analysis of location L2-B21, showing low frequency noise with tonal energy at 10 kHz

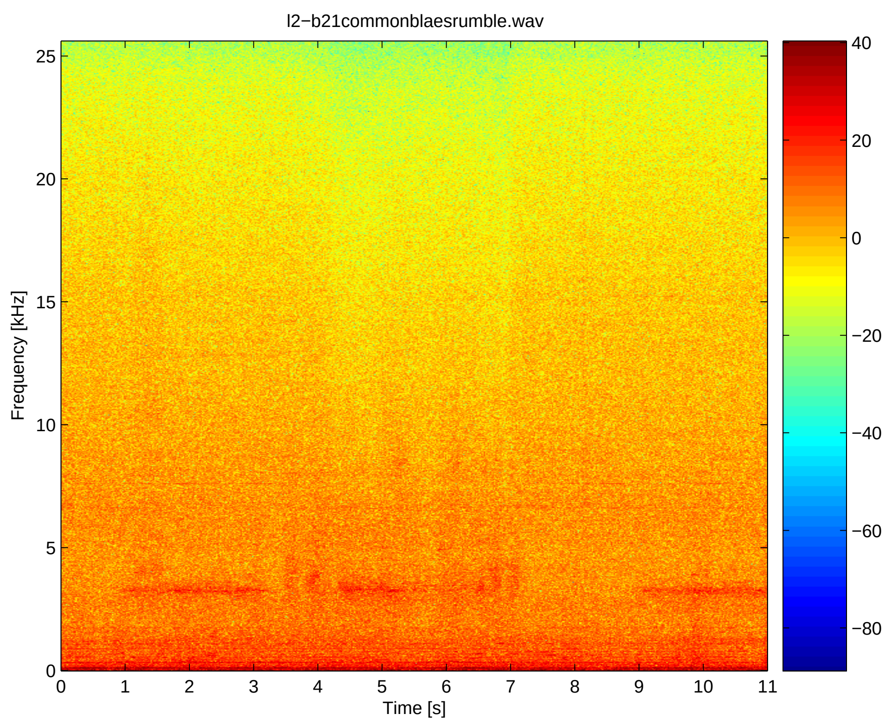


Figure A.13: Time-frequency analysis of location L2-B21, showing broad band noise, but with concentrated low frequency content

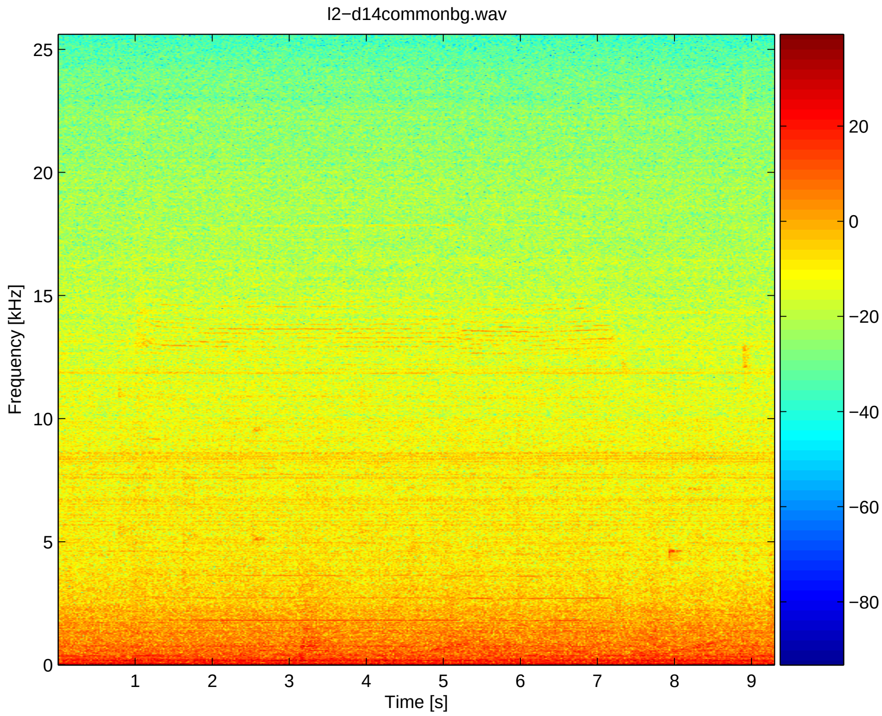


Figure A.14: Time-Frequency analysis of location L2-D14, showing low frequency noise content and narrow band noise at 8.5 kHz

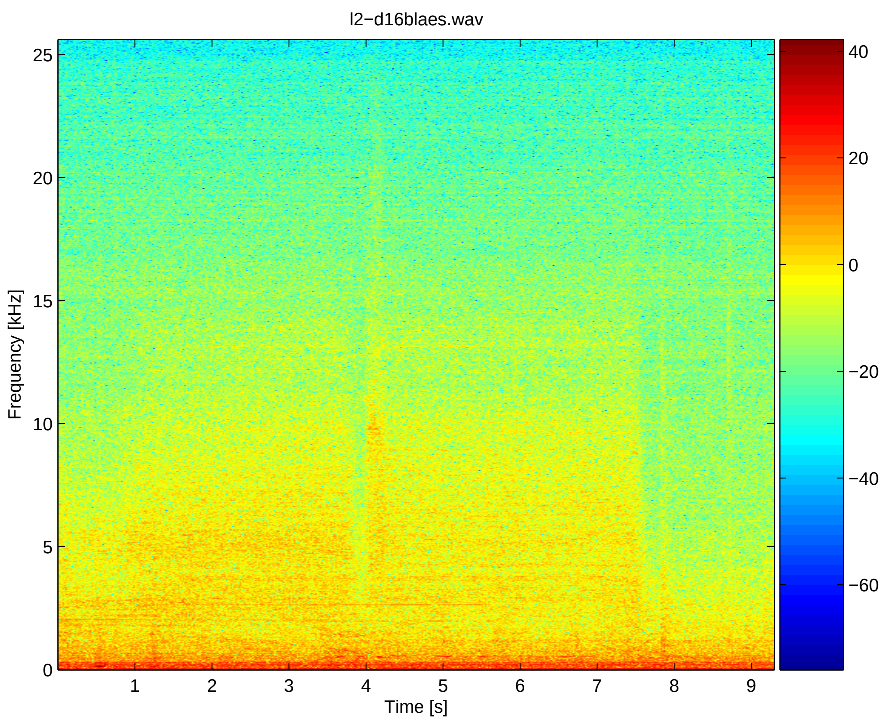


Figure A.15: Time-frequency analysis of location L2-D16, showing low frequency content and some more broad band noise bursts

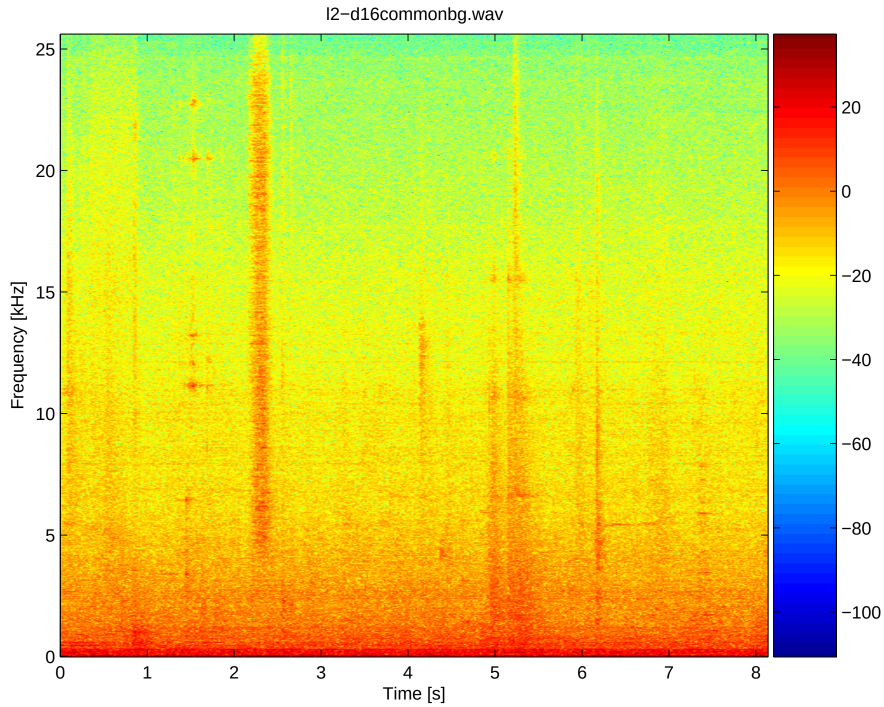


Figure A.16: Time-Frequency analysis of location L2-D16, showing low frequency noise mixture with many different more or less broad band noise phenomenons

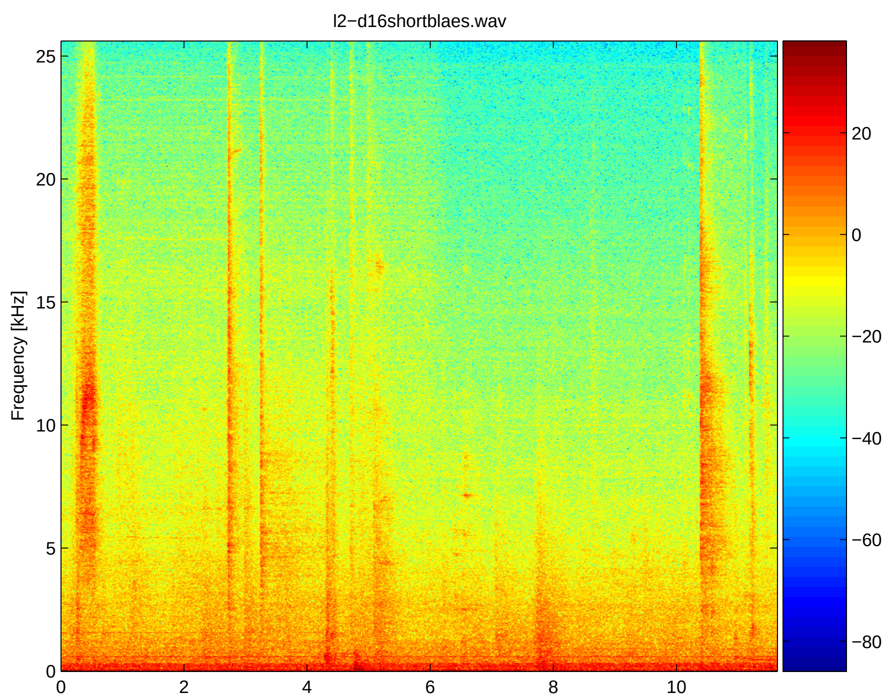


Figure A.17: Time-Frequency analysis of location L2-D16, showing low frequency content and many broad band, short duration, bursts

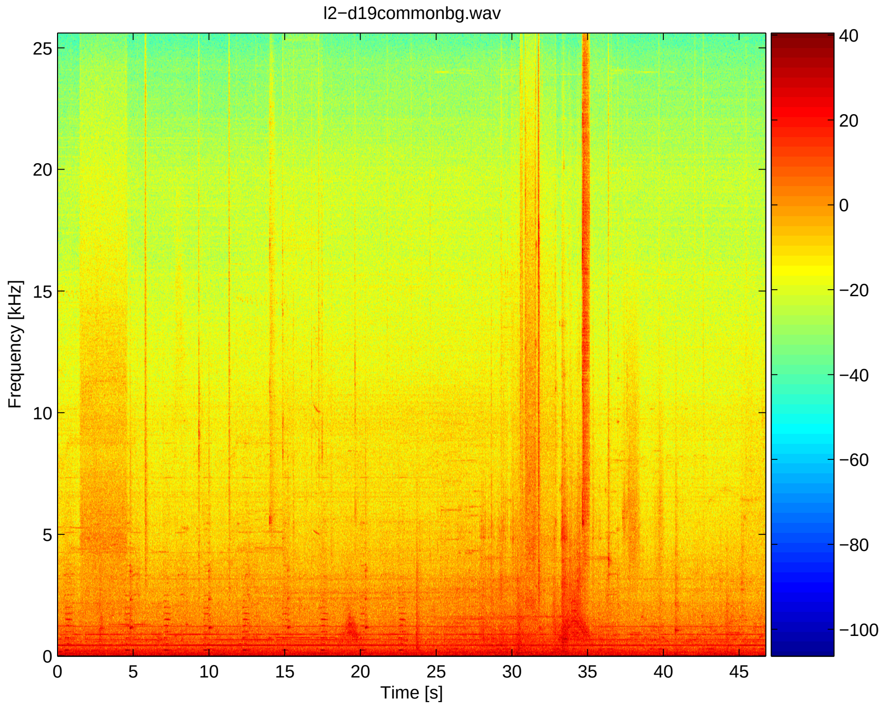


Figure A.18:

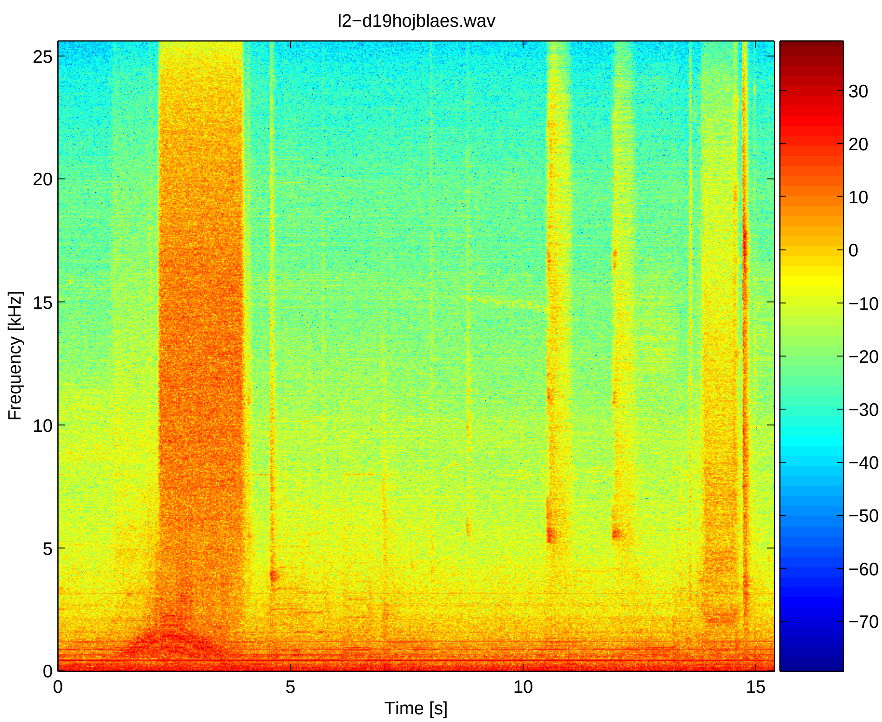


Figure A.19:

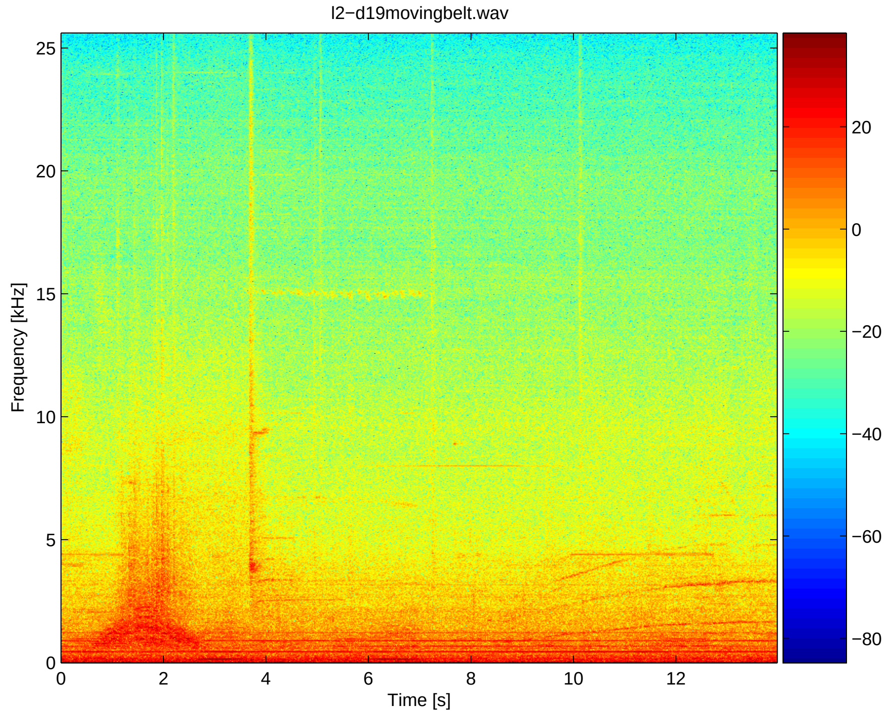


Figure A.20: Time-Frequency analysis of location L2-D19, showing low frequency content, broad band bursts of different magnitude and the noise from a moving belt

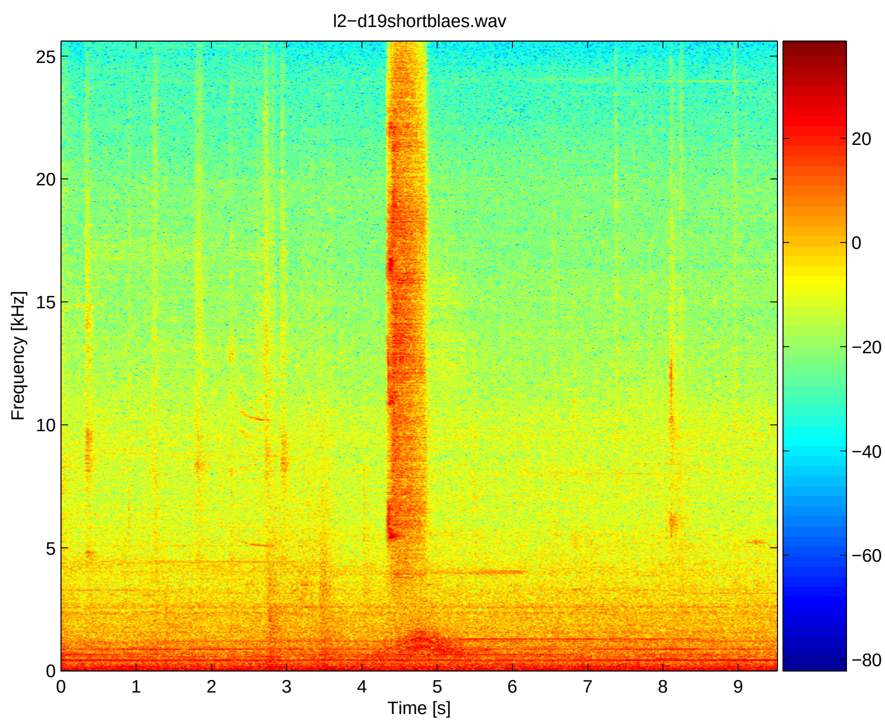


Figure A.21: Time-Frequency analysis of location L2-D19, shoiwng low frequency content and a short burst of broad band noise

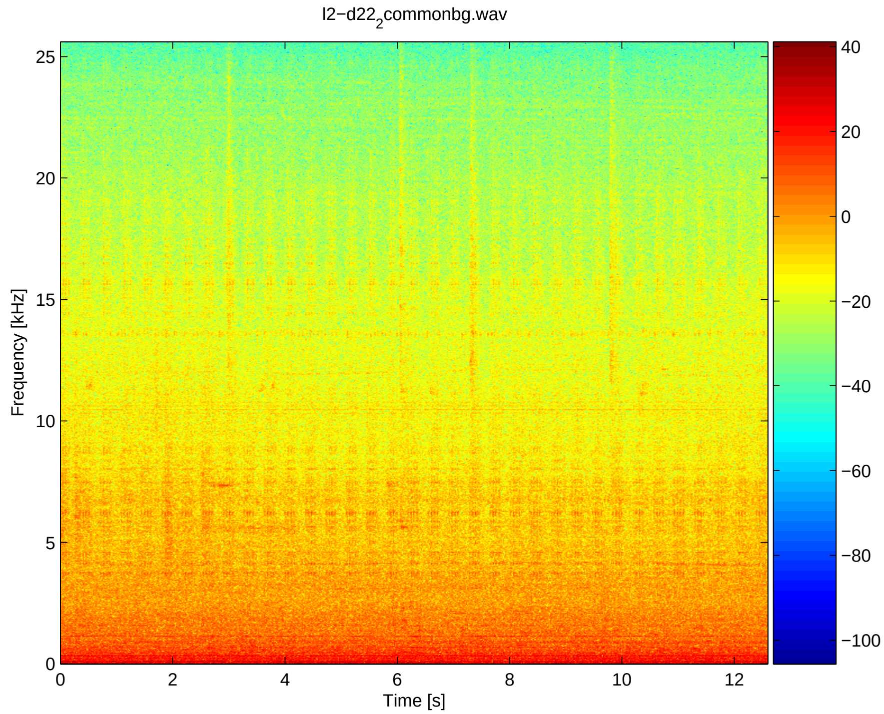


Figure A.22: Time-Frequency analysis of location L2-D22, showing low frequency content and a high repetition rate of a noise artifact

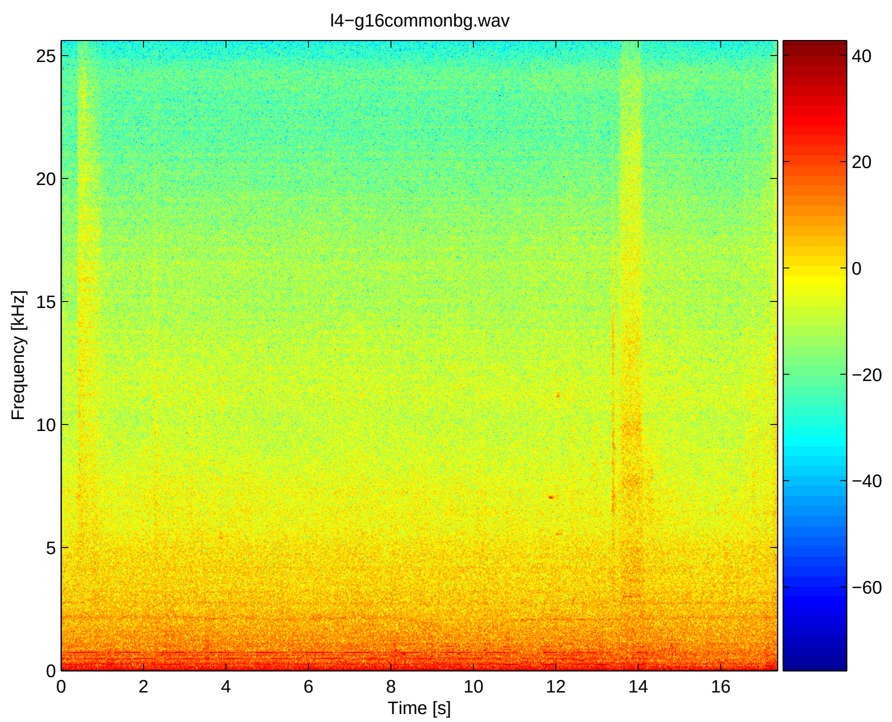


Figure A.23: Time-Frequency analysis of location L4-G16, showing low frequency content and short broad band noise bursts

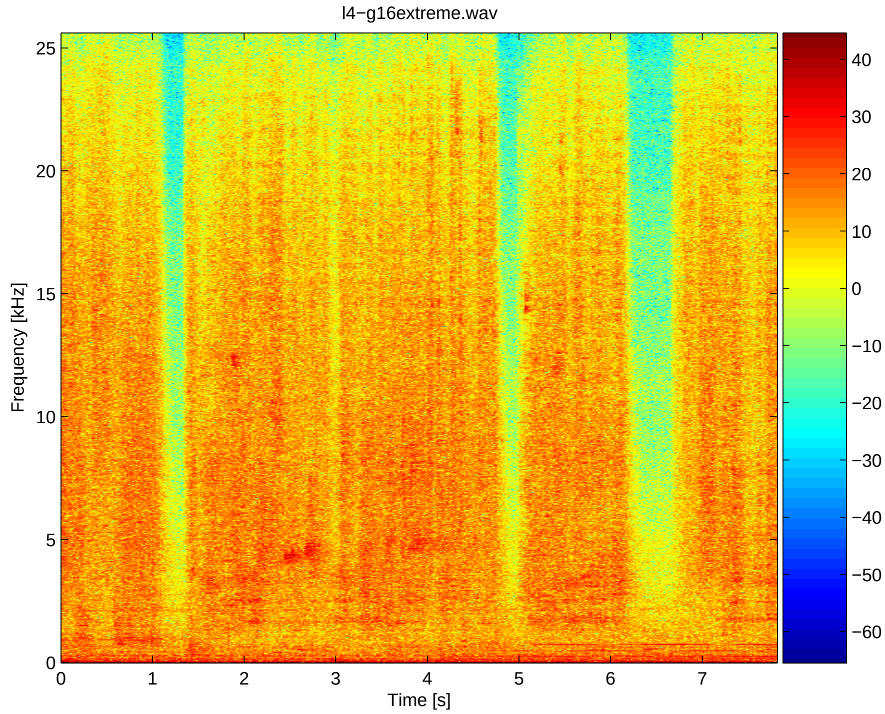


Figure A.24: Time-Frequency analysis of location L4-G16, showing and extreme broad band noise of long duration

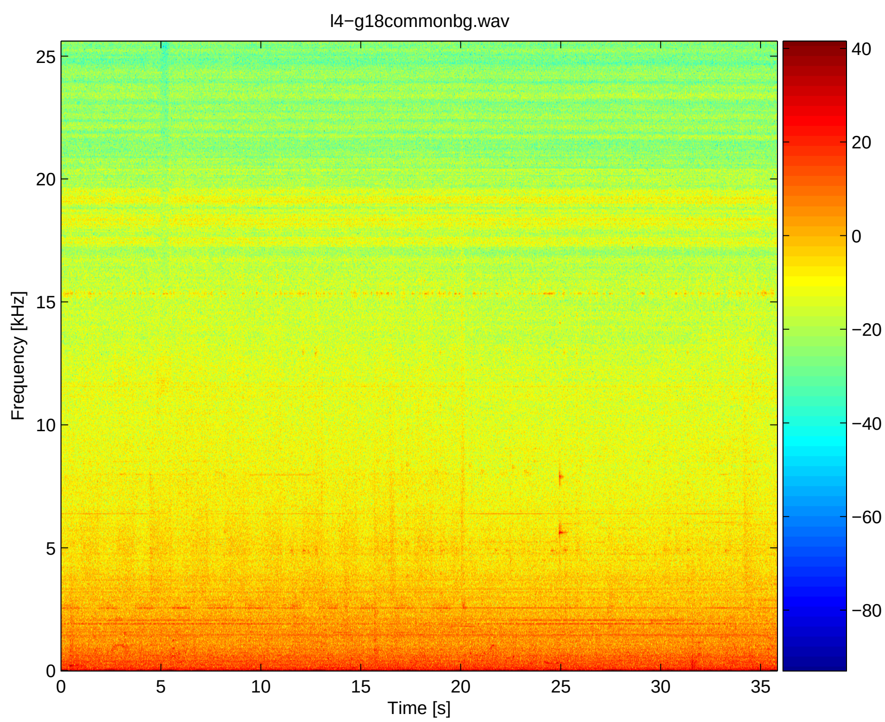


Figure A.25: Tiem-Frequency analysis of location L4-G18, showing a common low frequency noise mixture

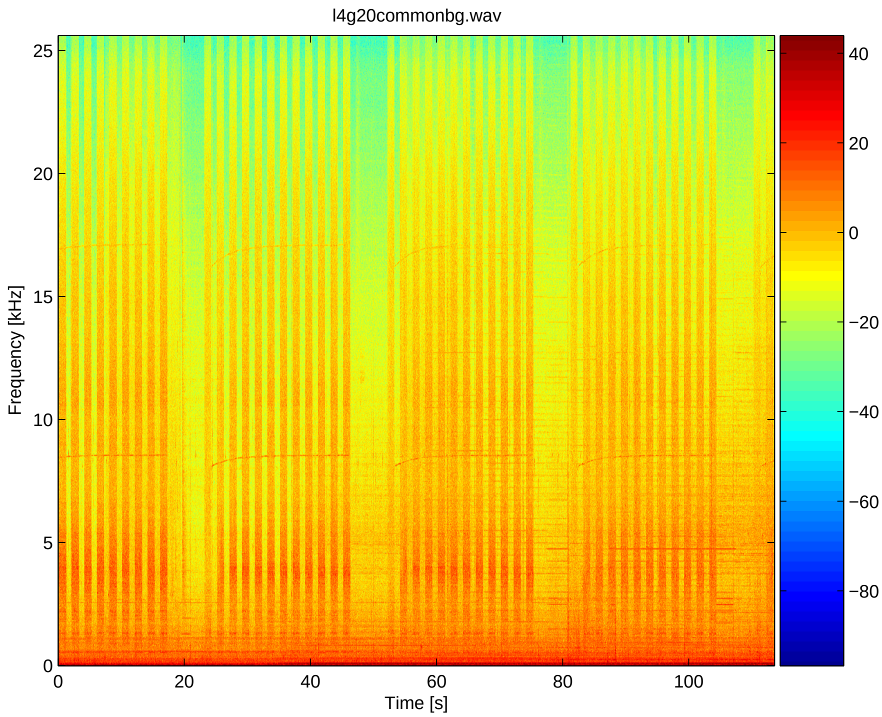


Figure A.26: Time-Frequency analysis of location L4-G20, showing a repeating fashion of broad band noise with short duration

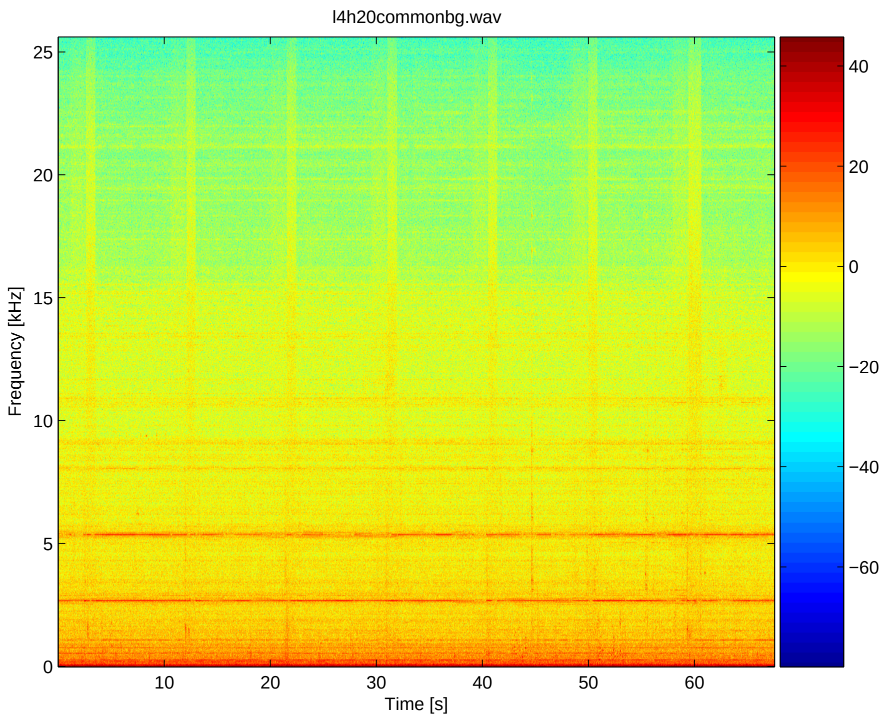


Figure A.27: Time-Frequency analysis of location L4-H20, showing low frequency content with tonal energy concentrated around 5.5 kHz with weak broad band noise bursts in a repeating fashion

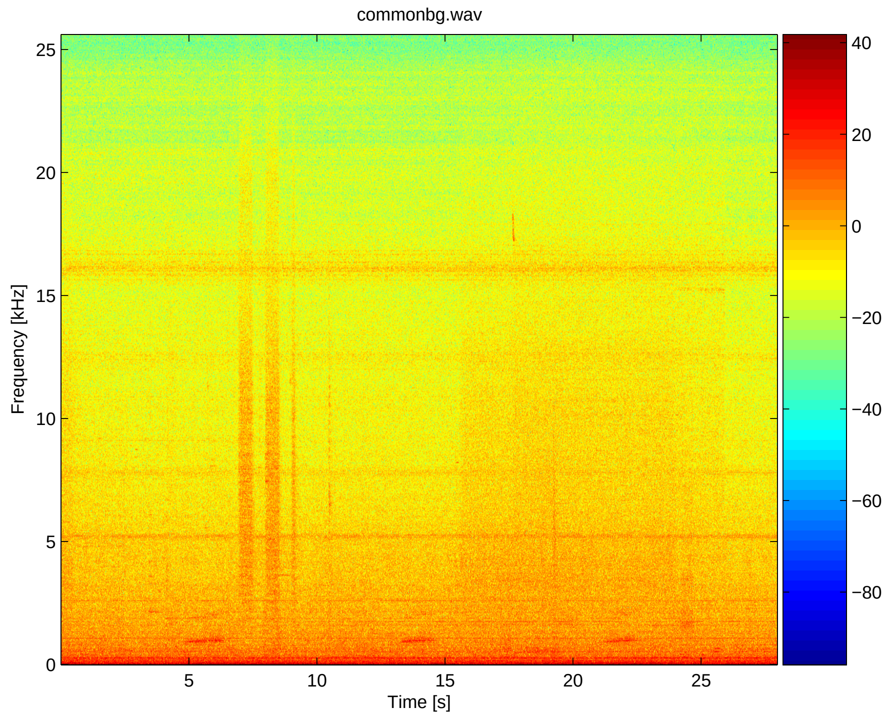


Figure A.28: Time-Frequency analysis of location LX-XXX, showing low frequency content, with broad band artifacts of various duration. Narrow band noise concentrated around 17 kHz

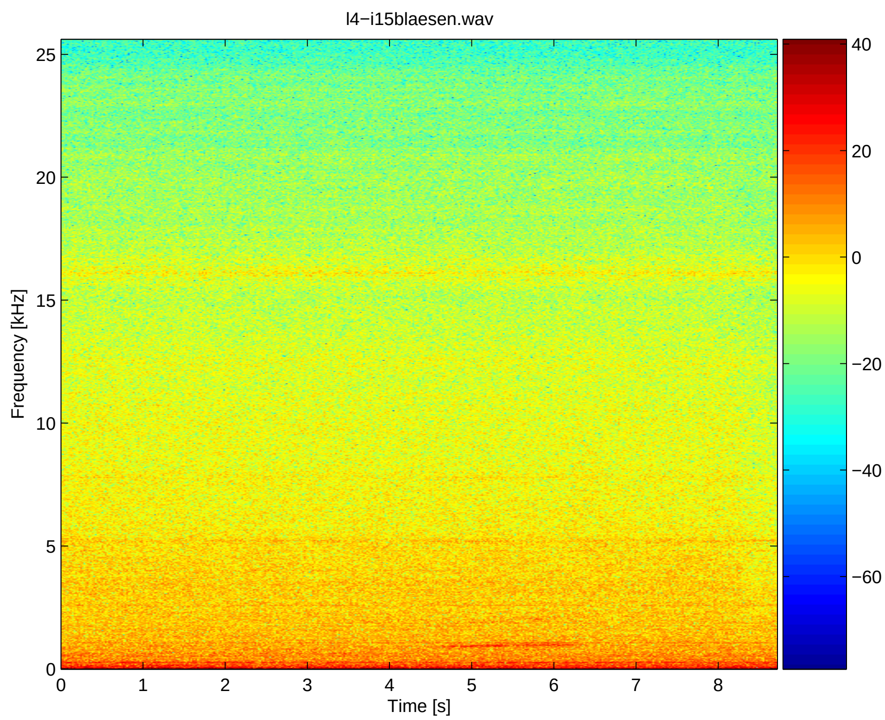


Figure A.29: Time-Frequency analysis of location L4-i15, showing low frequency content.

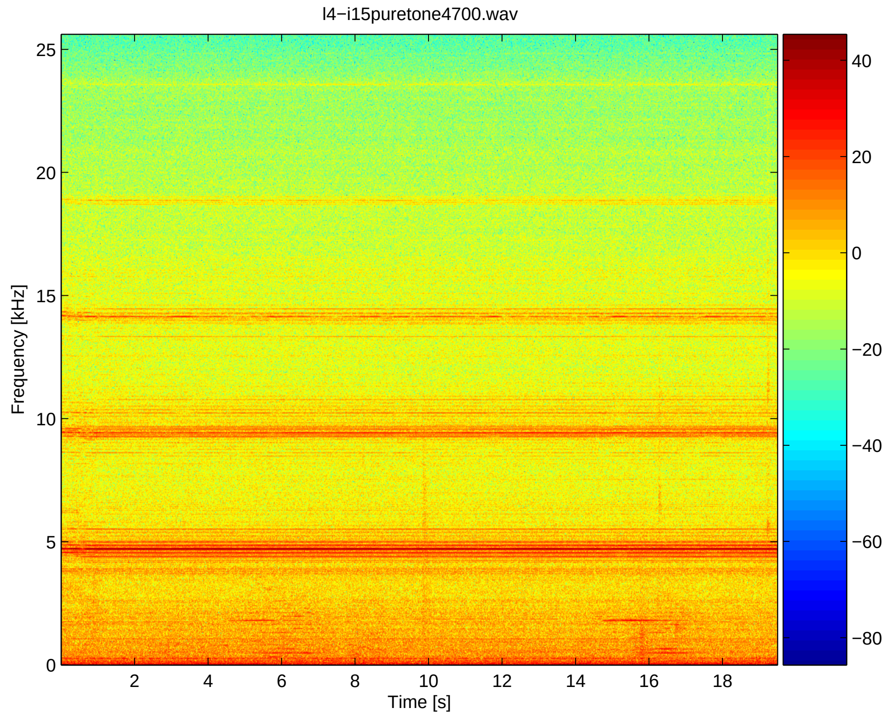


Figure A.30: Time-Frequency analysis of location L4-I15, showing pure tonal phenomenons and harmonics

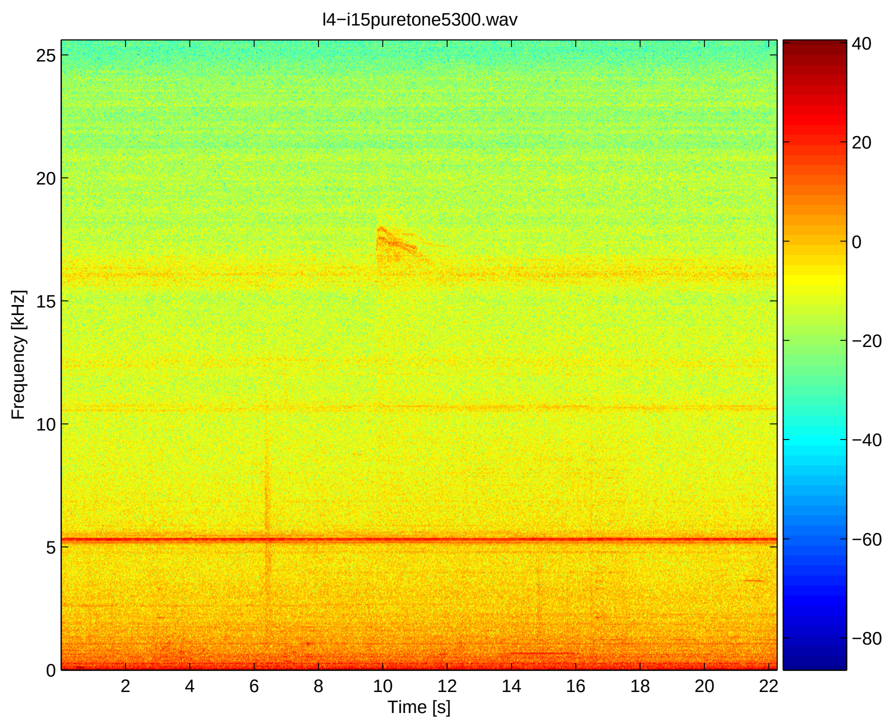


Figure A.31: Time-Frequency analysis of location L4-I15, showing pure tonal phenomenons and harmonics

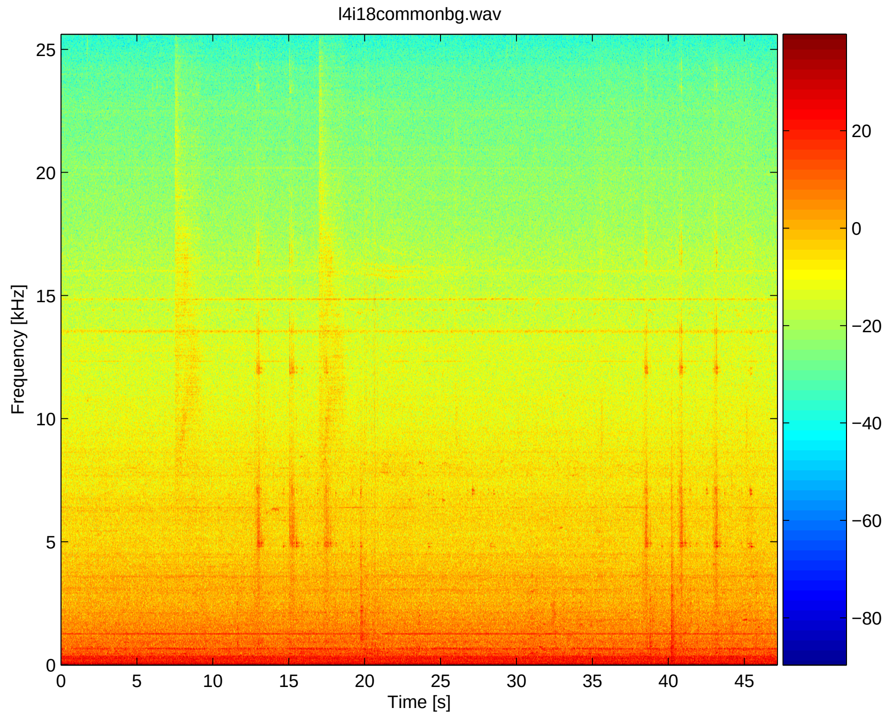


Figure A.32: Time-Frequency analysis of location L4-I18, showing low frequency content, with different noise artifacts appearing over time

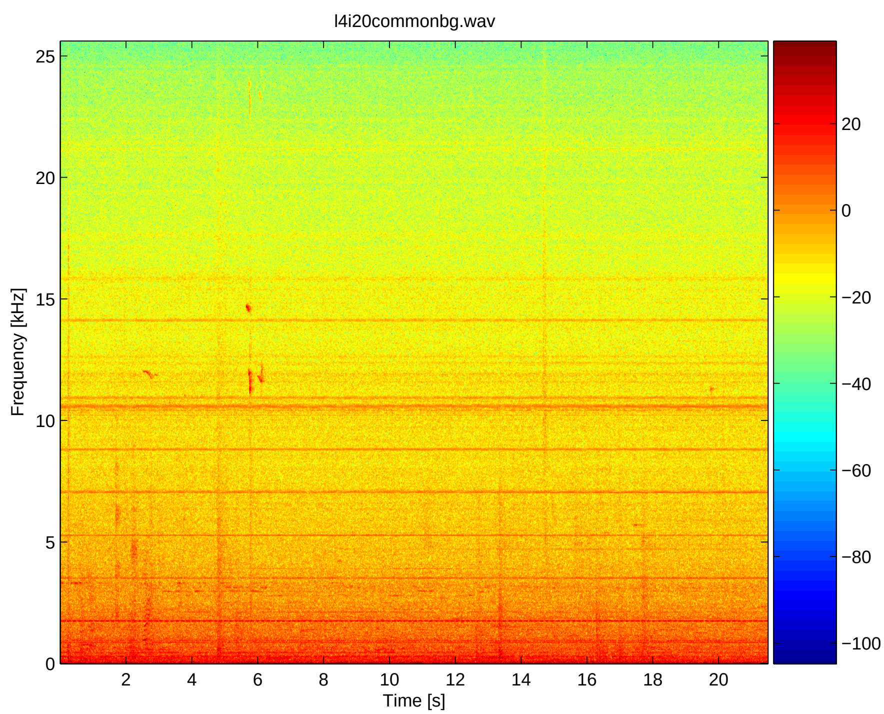


Figure A.33: Time-Frequency analysis of location L4-I20. showing low frequency content with tonal peaks

Appendix B

R/2R ladder networks

This appendix is concern about the R/2R laddernetwork used in digital-to-analog conversion The appendix is entirely based on an application note about this topic from International Resistive Company[Inc]. R/2R ladder networks provide a simple mean to convert digital information to an analog output.

There are different configurations that would convert the digital data to an analog representation. The configuration considered in this appendix is the R/2R-network, see figure **??**, but even simpler configurations can be found (Binary weighting ladder). The R/2R network provides the most accurate method of digital to analog conversion, compared to other types of ladder networks in digital to analog conversion.

Depending on the number and locations of the bits switched, V_{out} will vary between 0 volts and the digital high (5 volts) from the microcomputer. If all inputs are connected to ground, V_{out} is 0 volts. If all the bits are switched to high, V_{out} will be approaching 5V.

Since the an R/2R ladder is a linear circuit, it is possible to apply the principle of superposition to calculate V_{out}. The expected output voltage is calculated by summing the effect of all bits connected to V_r (5V). Table B.1 lists the voltag contribution from each each bit, when it is high in the circuit. So a bit string of 10100000 would correspond to $V_{out} = \frac{V_r}{2} + \frac{V_r}{8}$.

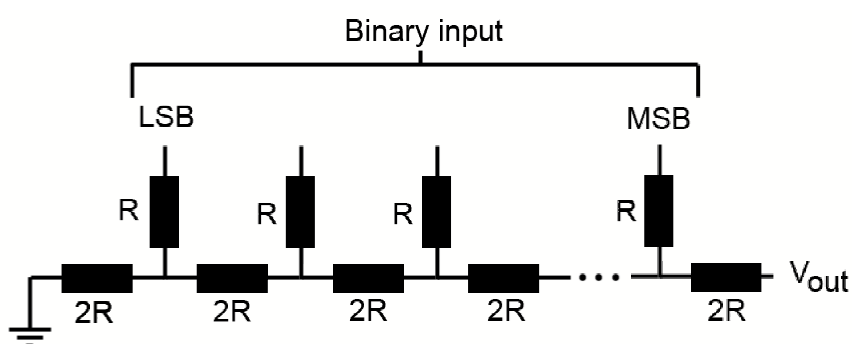


Figure B.1: The R/2R resistor network used as the configuration of digital data to an analog, respectively

Bit	V_{out}
1 MSB	$\frac{V_r}{2}$
2	$\frac{V_r}{4}$
3	$\frac{V_r}{8}$
4	$\frac{V_r}{16}$
5	$\frac{V_r}{32}$
6	$\frac{V_r}{64}$
7	$\frac{V_r}{128}$
8	$\frac{V_r}{256}$
N LSB	$\frac{V_r}{2^N}$

Table B.1: V_{out} is depending on the location of switched bits

The ladder operates as an array of voltage dividers whose output accurarcies are dependent on how well each resistor is matched to the others. Ideally, the resistors within the ladder are matched so that the voltage ratio for a given bit is exactly hafl of that for the preceding bit.

The DIP package with R/2R ladder networks in different bit sizes are available.

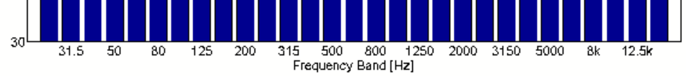
Appendix C

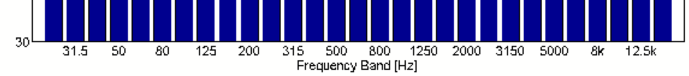
Noise maps

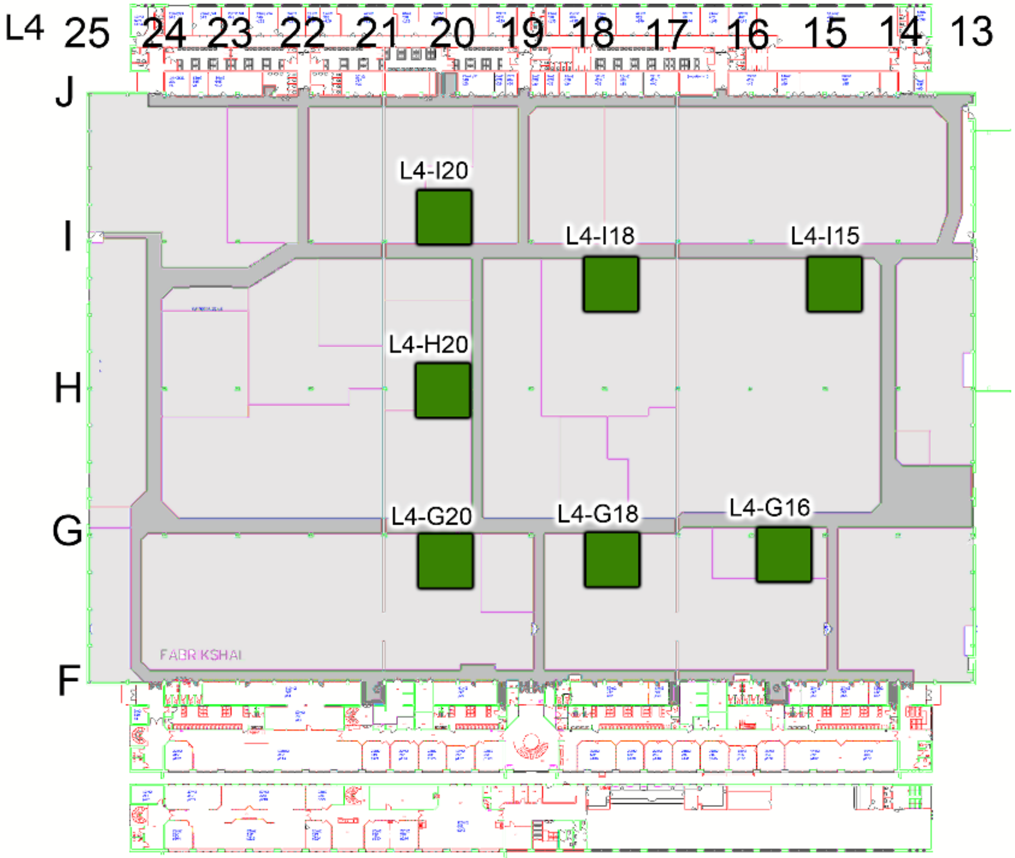
Appendix C includes four noise maps. The noise maps are showing the time-frequency analyses and third octave band analyses for the time recording at each recording location in the two buildings L2 and L4 at Sauer-Danfoss.

The noise maps are included in the following order

- Third Octave Band analyses of L2
- Time-Frequency Analyses of L2
- Third Octave Band analyses of L4
- Time-Frequency Analyses of L4







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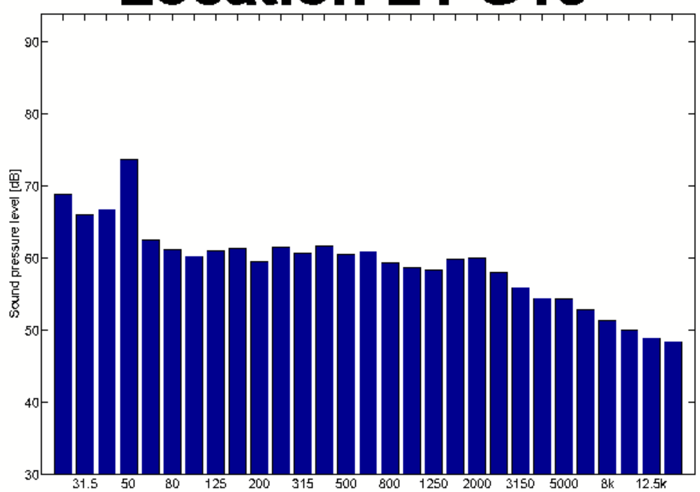

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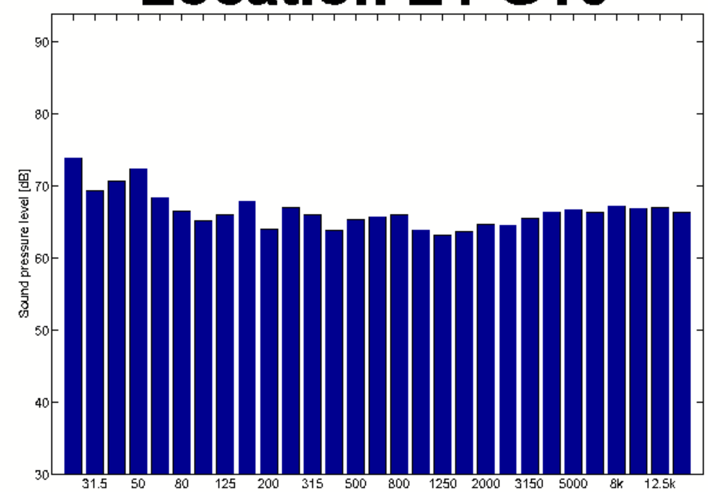

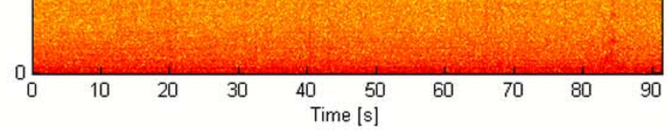

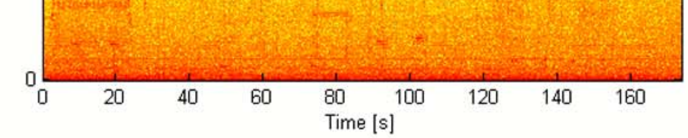

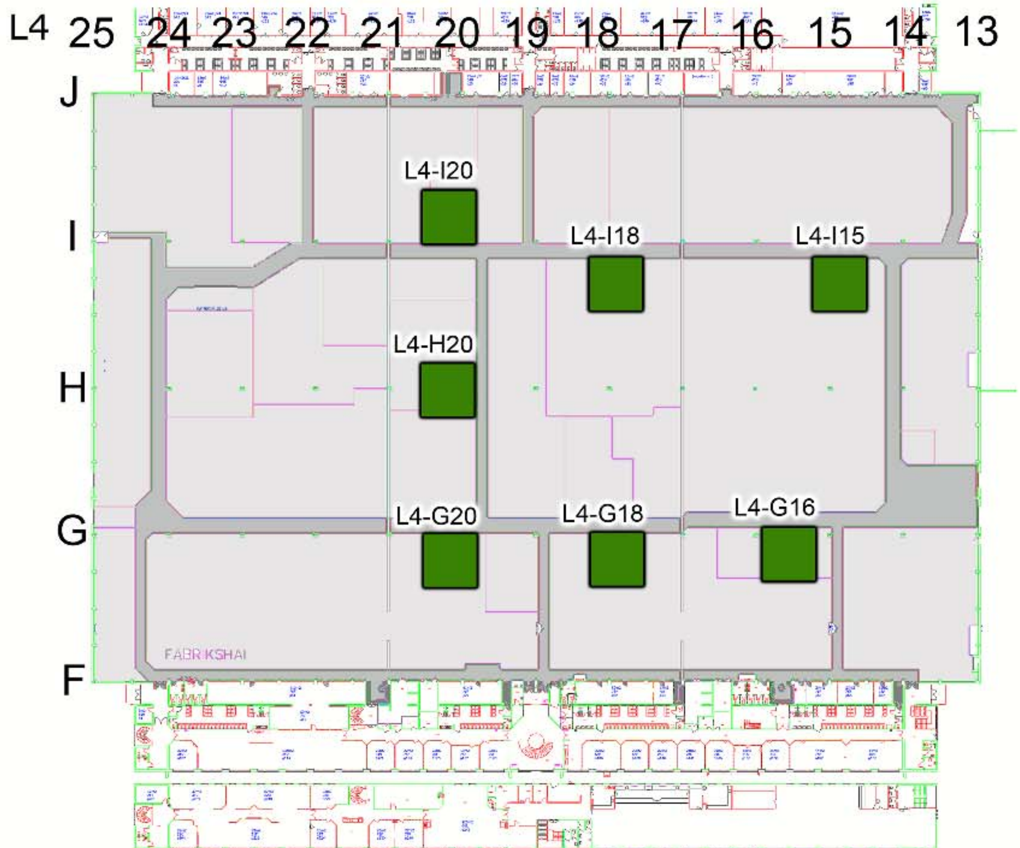

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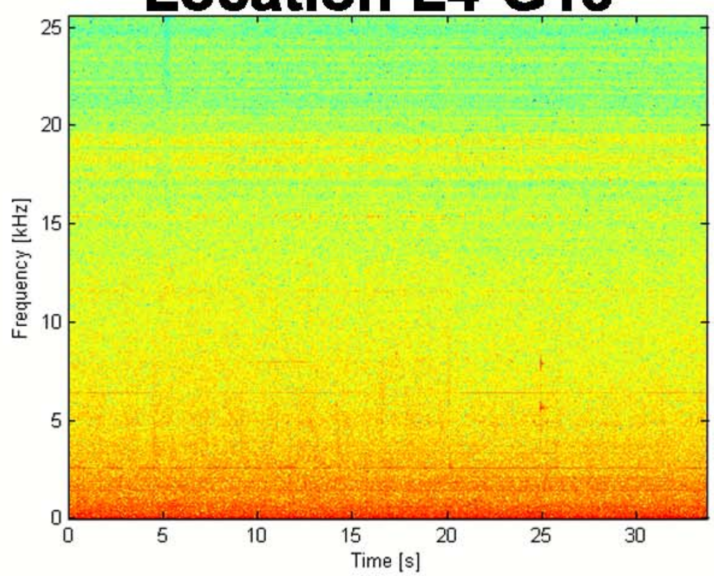

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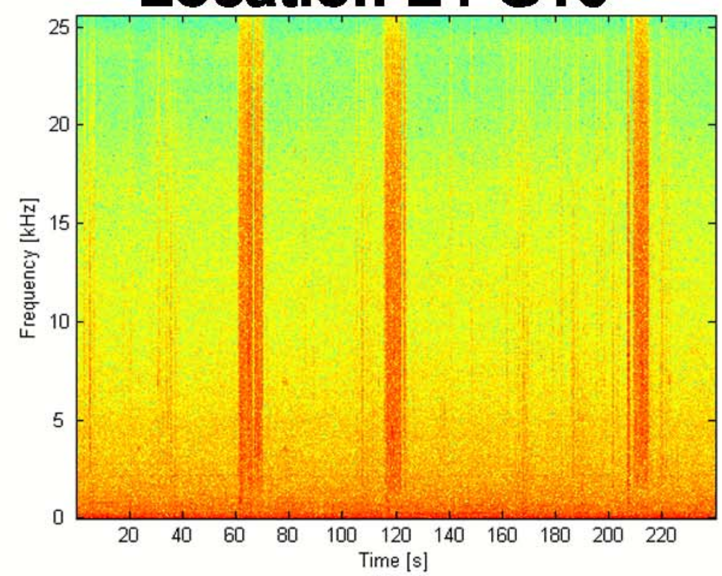

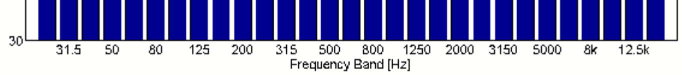

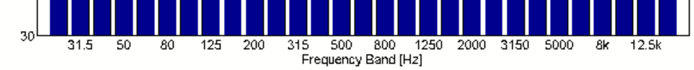

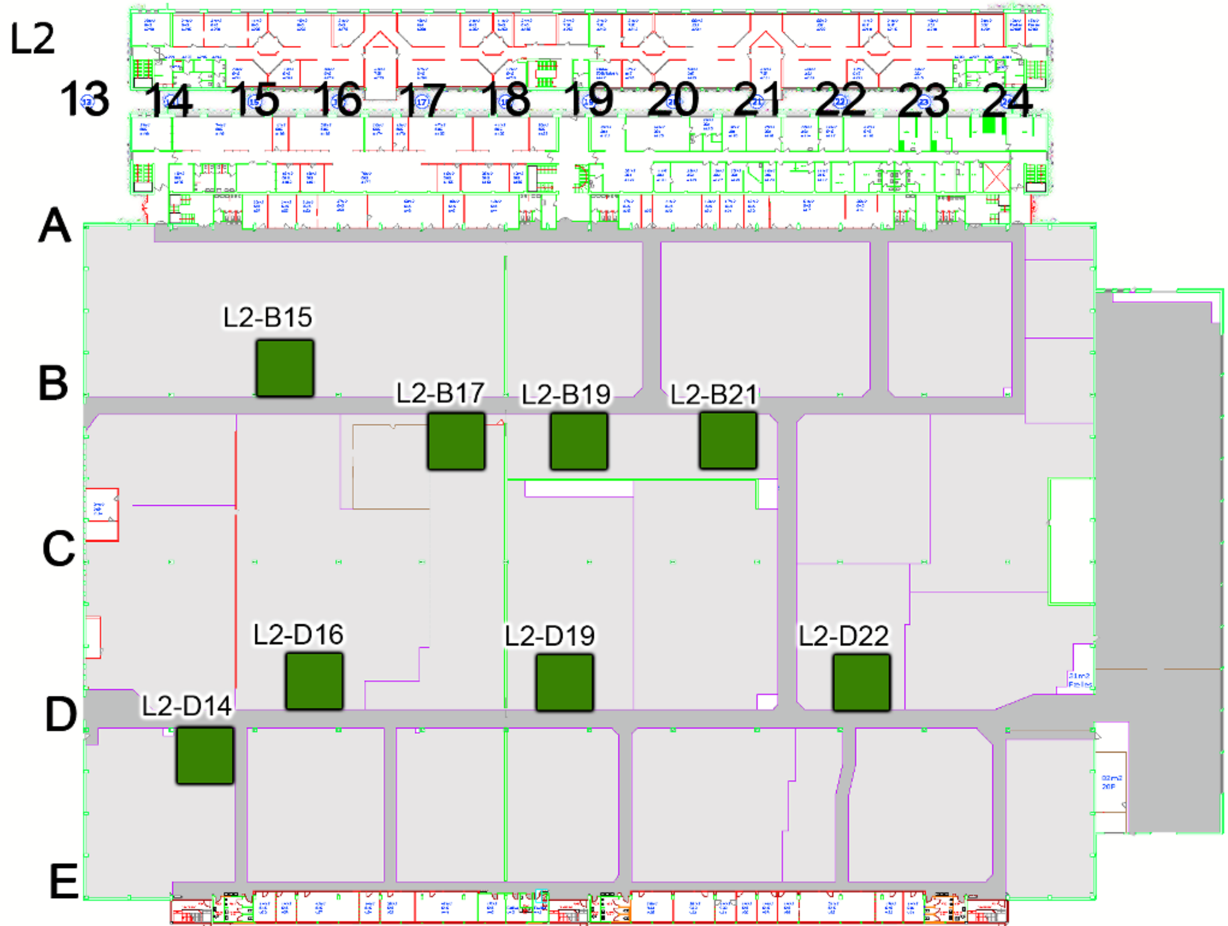

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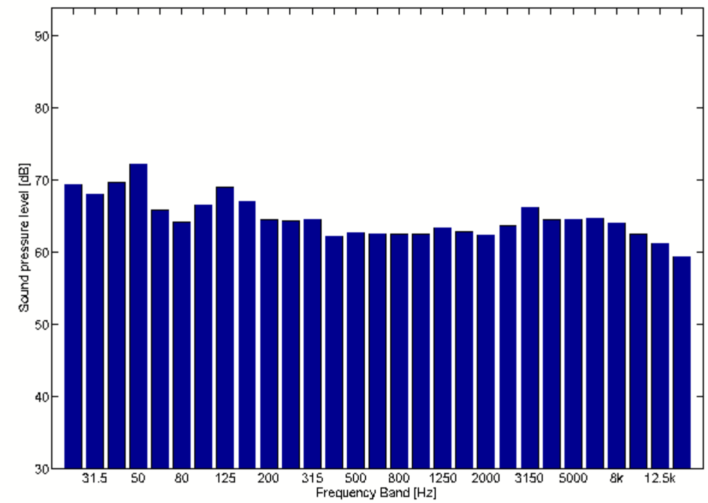

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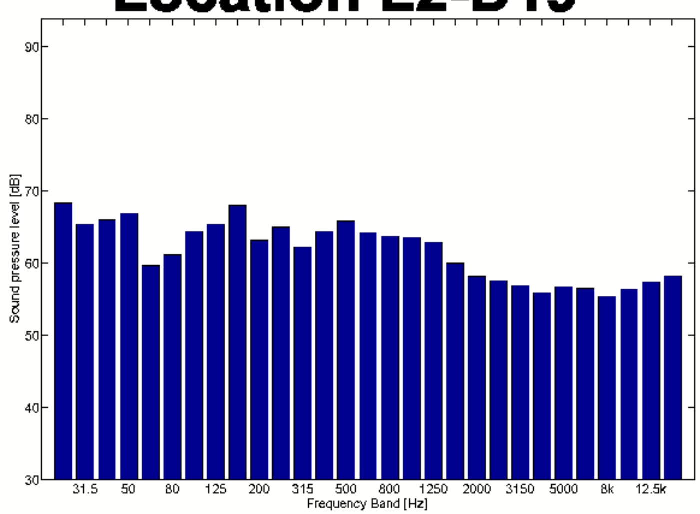

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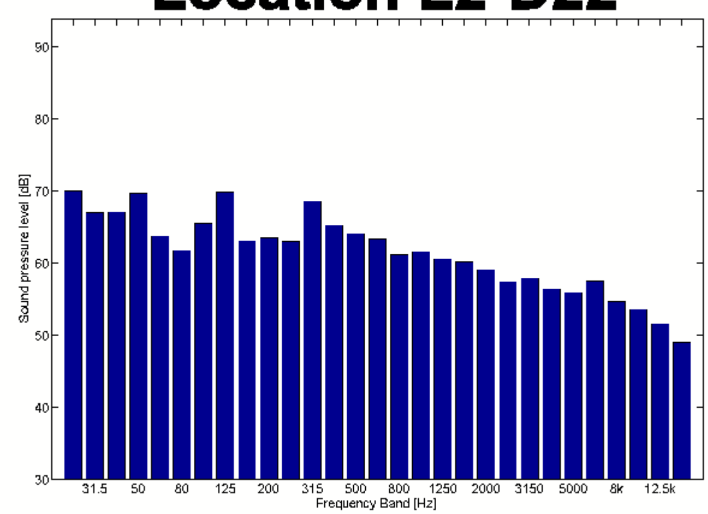

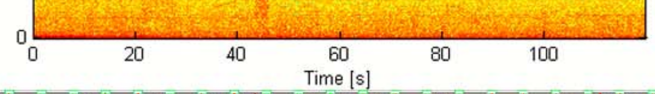

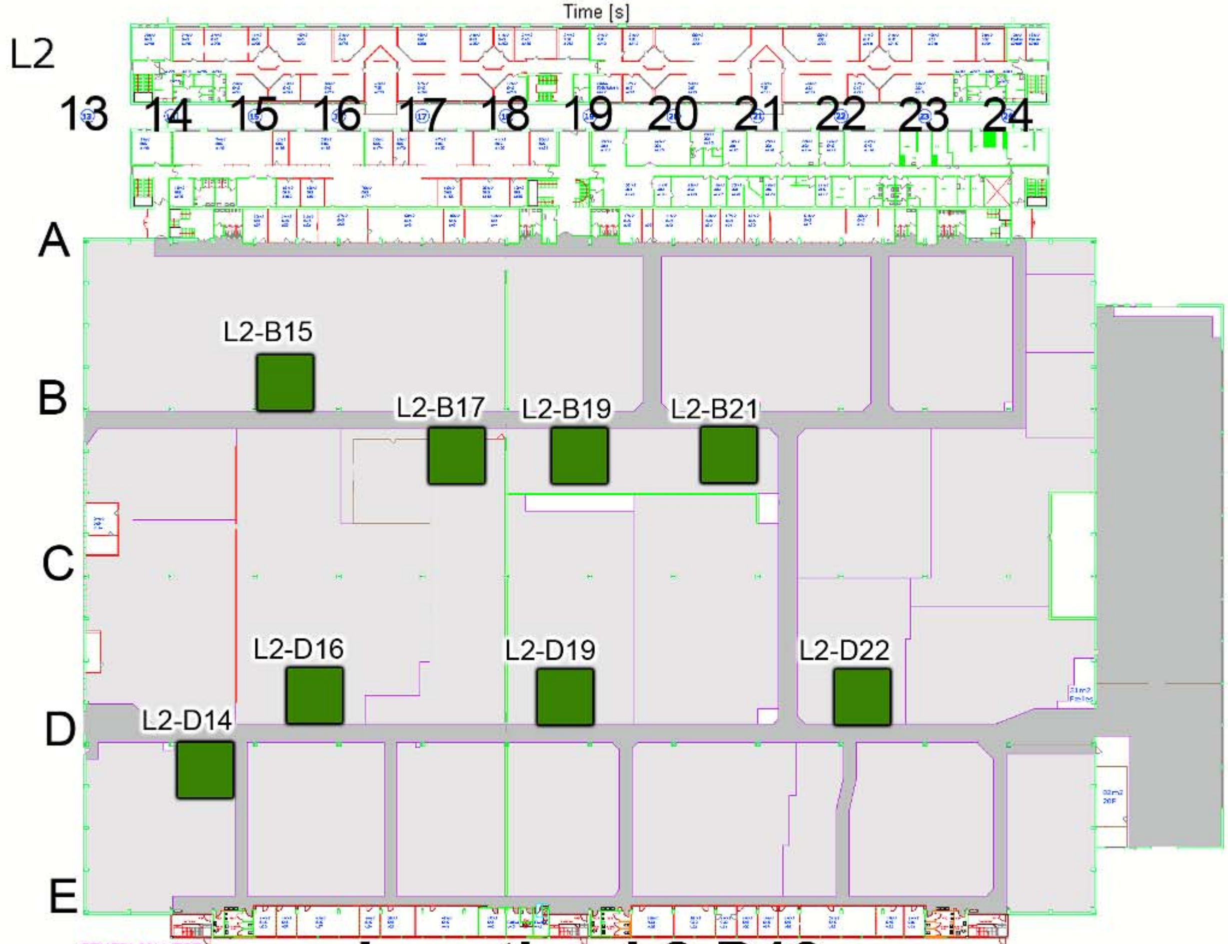

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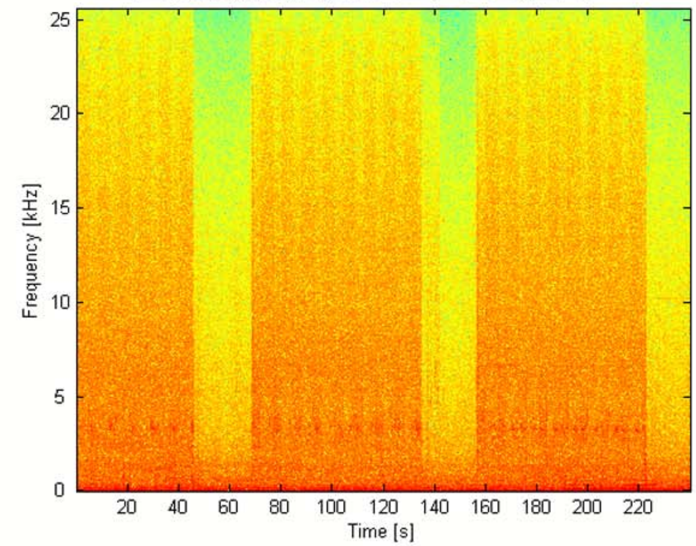

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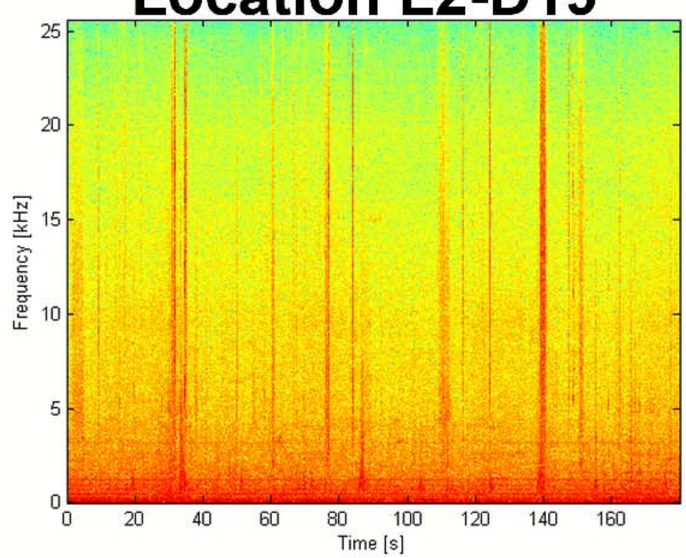

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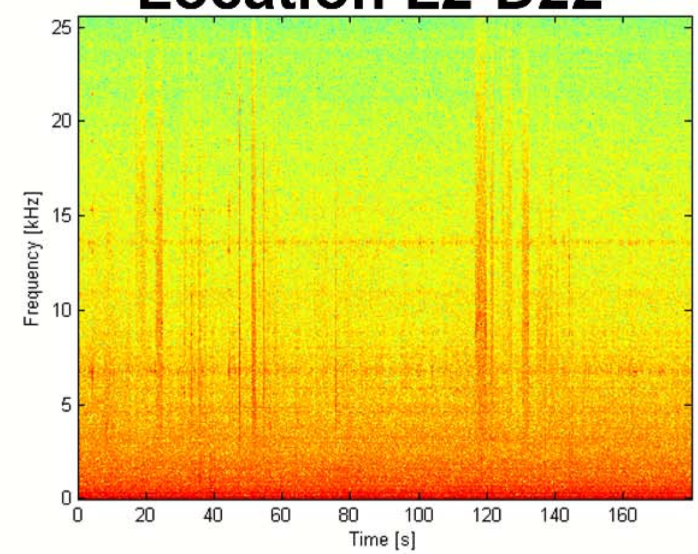

Appendix D

Included CD-ROM

The CD-ROM includes files that has been reffered to throughout the report [Cro98] [DS75] [Møl] [sta91] [EBB87] [Moo06]