# Sound control in windy weather

Master Thesis

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**Abstract:**

Will come later

# Preface

This report is composed by Jonas Buchholdt during the 10th semester of Electronic Engineering and IT at Aalborg University. The general purpose of the report is *Signal Processing and Acoustics* .

For citations, the report employs the Harvard method. If citations are not present by figures or tables, these have been made by the authors of the report. Units are indicated according to the SI standard.

Aalborg University, February 17, 2019

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# Contents

# Glossary

**AC** Air Conduction. 3, 4, 23
**ACE** Air Conduction Earphones. 23

**BC** Bone Conduction. 3, 4, 23
**BCT** Bone Conduction Transducer. 3, 4, 23

**FOH** Front Of House. 10

**HINT** Hearing in Noise Test. 23

# Chapter 1

# Introduction

Human sound perception has typically been based on airborne sound for a majority of situations. However, bone conducted sound has been extensively used for diagnostic purposes [ISO 389-3:2016]. The main application of Bone Conduction (BC) is to perform pure-tone audiometries in subjects with hearing loss. In conjunction, with Air Conduction (AC) audiometry, it can be assessed, where the damage is situated. It has been established that BC circumvents the outer and the middle ear, which allows for conclusions based on a difference between AC and BC audiometry.

This medical use leads to the question of whether the use of BC could be extended further to day-to-day applications. This expansion of usage could range from leisure activities, such as music playback, to specialised usage, such as communications systems, that do not block the user's ears or conversely, that are used in noisy enviroments, where hearing protection is an imperative. With this objective in mind, the project at hand is proposed by RTX A/S, as foundational research for the usage of BC in communication systems.

The focus of the project is testing the feasibility of incorporating Bone Conduction Transducer (BCT) in communications equipment by comparing its performance with classic AC-based systems. However, there are different applications within this research area, such as utilising a BCT in order to not block the ear canals and maintain environmental awareness in high-risk situations (e.g. firefighters and law enforcement). Another possible application is to substitute AC transducers in equipment used in high noise level environments, adding the possibility to isolate the user's ears with both earplugs and protective headphones and thus reducing the risk of hearing damage (e.g. helicopter pilots and F1 mechanics). For any of these situations, the main concern is the assessment of intelligibility of the transmitted signal.

## 1.1 Problem Statement

It has been decided to constrain the scope of the project and focus on BCT use in noisy environments. Comparing its performance to the one of an AC-based system in terms of a subject-based speech intelligibility test. In the course of doing so, the following aspects will be investigated:

- How does BC differ from AC in terms of speech intelligibility?
  - Which intelligibility test method is suitable for the task at hand?
  - Can it be ensured that the perceived level is the same for AC and BC?
- What types of BCT are available at the moment?
- Where should the BCT be placed?

# Part I

# Problem Analysis and Requirements

# Chapter 2

# Analysis of sound propogation in outdoor venue

## 2.1 Live venue sound challenges

This section is to explore the challenges of producing live concert in a outdoor venue. The challenge of producing a good sound experience for the audience will be analysed from the calibration of the system to the end of the concert. What is affection the sound doing the concert and does the calibration change over time.

## 2.2 Static atmospheric conditions impact on sound propagation

The aim of this section is to analyses the sound wave propagation in static atmospheric conditions. It is well known that the propagation is highly depending on the atmospheric conditions and the affect is not linear in frequency. The attenuation difference in frequency can be above 80 dB [Corteel et al., 2017], and is highly depending on temperature, humanity, atmospheric pressure and wind. The resulting attenuation is expressed as an frequency depending absorption coefficient in dB pre meter. The following sections will make a short introduction to the effect of the stated impact on sound propagation. All section will be based on far field of the speaker, which mean that the spreading loss is 6 dB per doubling of distance, where the atmospheric conditions is excluded [Bauman et al., 2001] .

### 2.2.1 Humanity and temperature impact

The humanity and temperature have two different effect on sound propagation. One effect when the temperature and humanity is similar in the hole audience area and in the wave field. The second effect occore when the temperature and humanity is dependent on the hight in the wave field. The first effect will be adressed first. The effect of humanity and temperature as an absorber. is a lowpass filter. It mostly do not affect the low frequency where the high frequency is depending on the humanity and temperature. This means that the attenuation in the high frequency range per doubling of distance in far field will depends not only depend on the spreading loss but also temperature and humanity. Therefore, for long distance the atmospheric conditions will have a high effect on the frequency spectrum delivered to the audience. The humanity and temperature attenuation is already well studied and standard [ISO 9613-1:1993] gives an overview of calculating the frequency attenuation with respect to the distance, temperature and humanity. The following article [Corteel et al., 2017] gives some examples of attenuation at a distance of 100 m. As it can be seen in [Corteel et al., 2017], if the humanity increases proportional to the temperature the lowpass effect is small, but if the change in temperature and humanity is opposite of each other, for example the high temperature but dry, the lowpass effect is high. The second humanity and temperature effect is the speed of sound. At temperature range from 0 °C to 40 °C the speed of sound with humanity change is spars, where in temperature change the speed of sound is raises approximate by 0.6 m/s for every degree Celsius. The speed start at 331 m/s at 0 °C and 0 % humanity. At a non chansing temperature and humanity in the hole wave field, this effect does not affect the delivered frequency spectrum to the audience other that the phase alignment might be come off for subwoofer and line source array ellement.

The following TABEL show the speed of sound with with respect to humanity and temperature.

### 2.2.2 Wave propagation in wind

The speed of sound depends on the atmospheric wind. When the wind is blowing in the same direction as the sound wave is propagation, the sound speed is raised. When the sound is propagating in the opposite direction the speed of sound is lowered. The relation between the speed of sound and the speed of wind is a linear system and the speed of wind shall just be added to the speed of sound of a sertaine temparature and humanity, to get the resulting speed of sound.

### 2.2.3 Wave propagation in atmospheric pressure impact

The effect of atmospheric pressure change is low compare to humanity and temperature impact. The average attenuation from 4.0 kHz to 16.0 kHz with fixed temperature was 2 dB while going from 54.02 kPa to 101.33 kPa. The atmospheric pressure then only have a negligibility impact is on sound and is not frequency dependent.

## 2.3 model wave equation

The following Equation 2.1 calculate the speed of sound based on temperature and wind speed.

$$c = u + 331\sqrt{1 + t/273} \tag{2.1}$$

Where:

| | | |
|---|---|---|
| c | is the speed of sound | [m/s] |
| u | is the speed of wind | [m/s] |
| t | is the temperature | [°C] |

When the wind is coming from the side the sound wave

## 2.4 Dynamic atmospheric conditions impact on sound propagation

The aim of this section is to analyses the sound wave propagation in dynamic atmospheric conditions.

### 2.4.1 Atmospheric refraction

When the speed of wind, the temperature and humanity is assumed to be equal in the sound field and the sound wave is plan, the sound is travelling in a strage path, but often the wind speed is slower near the ground at a live venue. Furthermore the temperature and humanity is nether the same in the wave field, it changes with respect to the hight and with the time at the day. Along the day the sun have heated the ground, so when the sun set and the concert area is full of audience, the eath and audience radiate varm air which make the air at a low hight warm but the temparature at a higher hight cooler. This temperature difference in the wave field makes the speed of sound to depend of the hight. The speed of sound will therefore decay with respect to hight and result in a upwards refraction. With respect to wind speed, a concert area is often a protected area with for example barrier, stage and building and so thourgth. This blogage slows down the wind speed close to the ground, and from the nature it self the wind speed is often raise with respect to the hight. When the stage is playing in along with the wind the atmospheric refraction is down wards, where agenst the wind the atmospheric refraction will be downwards. The following Figure 2.1 shows the phenomena both against and with the wind.

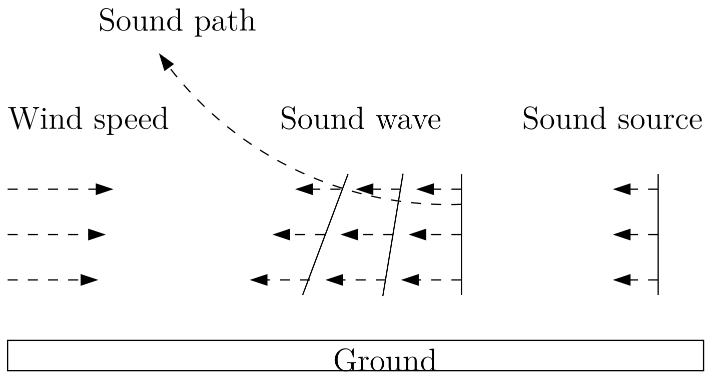


**Figure 2.1:** Wind against sound propagation direction

## 2.5 Atmospheric condition at a concert

A concert sound system is often calibrated in the midtle of the day when the stage is finished. The concert often starts in the evening and goes along to the late evening. at night the refraction goes the downwards direction

The concert area is dense packed with audience. The concert area might therefore be warmer nears the ground and cooles down with respect to the hight. This atmospheric condition refract the sound up in the air and not to the audience.

## 2.6 Calibration of sound system

This section analysis the calibration method, which is used by a selection of some Danish sound company. By expirence of the athor of this master projet, the hypothisis is that the sound system is calibrated in one point and the microphone is placed just in front of the Front Of House (FOH). The FOH is often a little tent, where the sound engineer control the sound system. The tent is only open in the direction of the stage and reflection might occore from the tent celling to the calibration microphone.

## 2.7 Sound pressure level measurement doing the concert

# Chapter 3

# Summary of Problem Analysis

Three effect of atmospheric conditions have been observed on the analysis, pure attenuation, lowpass effect and refraction effect

# Chapter 4

# Problem statement

Based on the knowledge founded in chapter 2 and the concluction drawn from **??** a problem statement can be made. For the rest of the project the following will be the focus.

**Is it possible by signal possessing and with an array of wind and temperature sensors to limit the sound shadow created be atmospheric atmospheric**

## 4.1 Deimitation

The following delemitation is made for the search for a solution of atmospheric atmospheric.

# Part II

# Test Design

# Chapter 5

# Design

# Part III

# Results

# Chapter 6

# Results

# Chapter 7

# Discussion and conclusion

## 7.1 Conclusion

As stated in section 1.1, the main objective of this study is to assess the performance of a Bone Conduction (BC)-based communications channel, as compared with an Air Conduction (AC)-based one, in terms of intelligibility. In order to do so, it has been decided to design and perform a subject-based perceptual intelligibility test to obtain relevant data. However, extensive literature research about the matter of BC sound and the state of the art in transducers was needed beforehand. During the course of the project, the questions presented in section 1.1 have mostly been answered, and all relevant data for the final intelligibility evaluation has been extracted. Based on relevant literature, the RadioEar B81 Bone Conduction Transducer (BCT) was chosen for all subsequent applications placed on the condyle. A key point of the project has been finding a way of linking the perceived levels from both the BCT and the Air Conduction Earphones (ACE) for the intelligibility test. In order to do so, a level matching routine has been developed, and although it does not provide exact data about excitation of the basilar membrane caused by the BCT, it provides a framework in which the inter-subject assessment of intelligibility can be performed by looking at the relative performance difference for each individual subject. The final decision has been made on the type of test to perform. Based on the potential application and the background of the project proposal, the Hearing in Noise Test (HINT) was deemed to be most suitable both in terms of obtainable results as well as practical feasibility. This test is based on short sentences, that are unknown to the test subjects.

After analyzing the results from the HINT, it can be concluded that there is a tendency, that the performance of BCT regarding intelligibility might be worse than the performance of ACE-based systems. With the obtained data, this tendency could not be shown to be statistically significant. A higher variance of the performance of subjects could be observed for the BCT. However, the difference in performance appears not to be so drastic, so that the difference does not render BCT as an invalid option for communication applications. The performance could likely be further increased by flattening the frequency response of the BCT with signal processing. Also a possibility of combining AC and BC in hybrid systems in order to increase the overall performance seems feasible as a subject of future research.

# Part IV

# Appendix

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