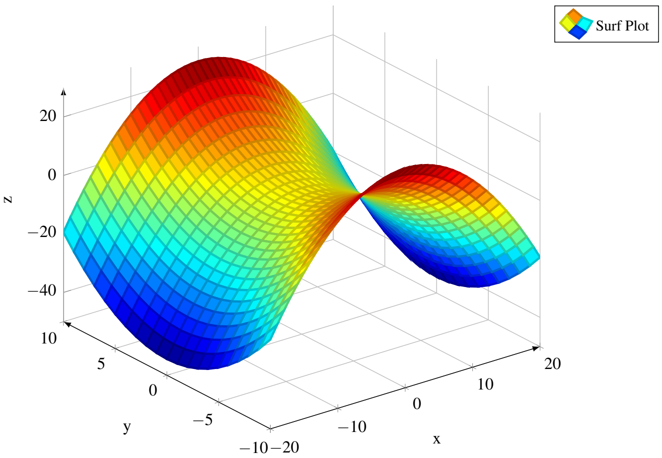
Worksheets for New Generation Guitar Tuner

September 2014

Group 714

Project worksheet



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STUDENT REPORT

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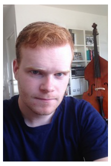

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Preface

Many electronic applications have signal processing as an important part of the system. The theme of this semester is .... The level is a 1st semester M.Sc project rated to 15 ECTS-points within AD:MT at Aalborg University. The target group of this report are supervisors and future developers of audio technologies such as students and other interested parties within the School of Information and Communication Technology at the The Faculty of Engineering and Science. The central aspects of this project are dealing with design considerations ... bla bla.

Reading Guide

The report is a worksheet for an article and therefore the structure is loose. There is one part called Worksheet.

The Analysis will be dealing with definition of the technology which will be developed and therefore it contains the necessary discussions for a Requirement Specification, which will result in guidelines and instructions for the Design and Implementation part. The Design and Implementation part contains development of the system which is implemented in the DSP and solutions to the issues discussed.

Appendices

Appendices are found after the main report **FiXme Fatal: insert reference** and on the attached CD. The appendices contains all source code, an extended analysis, measurement reports and work sheets. The CD also contains a digital version of the report and the web pages used. A complete list of the CD content can be found here **FiXme Fatal: insert ref**. When referred to the CD the following symbol is used

`path/to/stuff`

All figures, tables and equations are referred to by the number of the chapter they are used in, followed by a number indicating the number of figure, table or equation in the specific chapter. Hence each figure has a unique number, which is also printed at the bottom of the figure along with a caption. The same applies to tables and equations, the latter of which have no captions. Appendices are referred to by capital letters instead of chapter numbers.

Bibliography

At the very end of the main report, a Bibliography is listed which contains all sources of information used in the report. In the Bibliography books are indicated with author, title, publisher and year. Web pages are indicated with author and title. All information sources are referred to by the number which they feature in the list. This will look like this: [number]. If the sources reference is written just before a final dot, then it represents the source of information for the sentence in question. If the reference is placed after the dot it represents the source of information for the section in question.

Contents

Part I

Analysis

Chapter 1

Introduction

1.1 Motivation

Recently, new technologies for designing guitar tuners has been developed. These are called poly tuners. They have the ability to provide a the guitar player with a quick overview of the pitch of all strings, in order to speed up the process of tuning a guitar. Such technologies aims to estimate the pitch of several strings, simultaneously. Some limitations of such technologies are estimation of the extremely low fundamental frequencies and separation from background environmental noise**FiXme Fatal: Verify these assumptions** and it seems that the poly-tuner has difficulties if only one string is tabbed. Due to the limitations of the existing poly tuner, new methods for multi-pitch estimation is investigated. Therefore, this project aims to investigate the theory of multi-pitch estimation and consequently develop a software prototype application for improving some of these limitations **FiXme Fatal: Insert Table or a figure of overview of limitations**.

1.2 Initial Problem

Based on the motivation of this study an initial problem is formed in order to structure the further analysis.

> *How can multi-pitch estimation improve poly-tuner technology?*

- Verify limitations of existing technologies.
- Investigate the physics of the guitar and how to model the guitar strings.
- Investigate methods for multi-pitch estimation.
- Set up a solution approach for improving the verified limitations.
- Investigate implementation methods for a software prototype.

FiXme Fatal: Elaborate on the items

Chapter 2

Preliminary Analysis

2.1 Guitar String Harmonics in Practice and Theory

In the following section the physics of the guitar strings will be analyzed, briefly. Firstly, this is done by analyzing the harmonics of 6 individual open strings of an electric guitar. Note that it is only done for one recording on six open strings on an electric guitar. All audio material and source code for figures in this section is available in the following directory. The software is very easy to alter to in order to analyse other recordings.

`analysis/code/string_analysis/`

In order to initialize the modeling of guitar strings, 6 recordings of guitar strings are analyzed. The spectrograms of their string response is used for evaluation of the relations between the harmonic frequencies and the pitch of a guitar string. These results will be compared to the inharmonicity model of [RW02], which relates the harmonic interval to the stiffness of a guitar string as in eq. (2.1).

$$f_n = nf_1[1 + (n^2 - 1)A], \tag{2.1}$$

for a solid wire without wrapping $A = \frac{\pi^3 r^4 E}{8TL^2}$,

- r is the radius of the string.
- E is Young's Modulus.
- T is the tension.
- L is the length.

The inharmonicity is smallest for long, thin wires under great tension. The preceding experiment is compared to the simpler form of a stiffness model of inharmonicity of strings from [GJ09]. This will be called the Ξ model in the following. The Ξ model is shown in 2.2.

$$\Xi_{k,l} = \omega_k l \sqrt{1 + B_k l^2} \tag{2.2}$$

where

- k is the index of the fundamental frequency.
- ω is the fundamental frequency.
- l is the index of the harmonic frequency.
- $B << 1$ is an unknown stiffness parameter of the specific string.

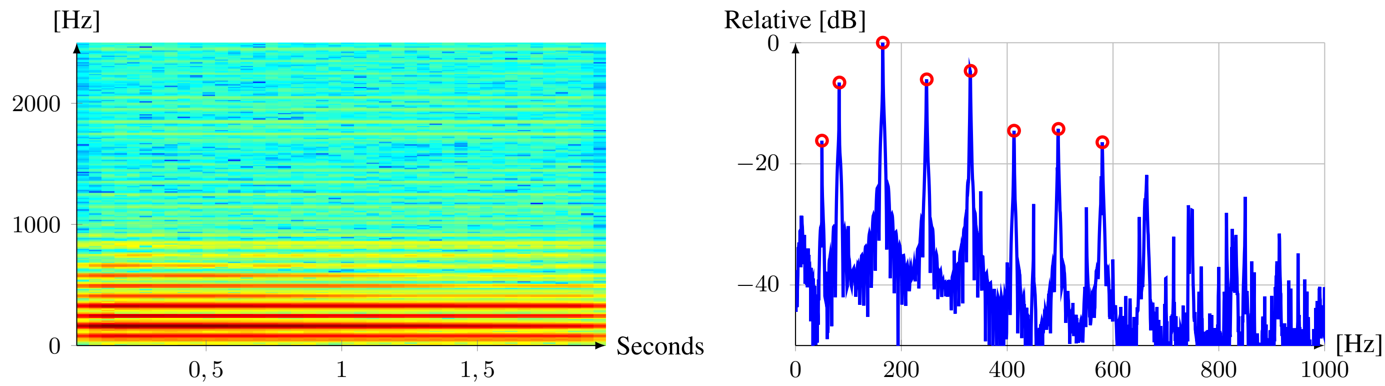

Figure 2.1: Frequency content of the lowest E-string with indicated peaks.

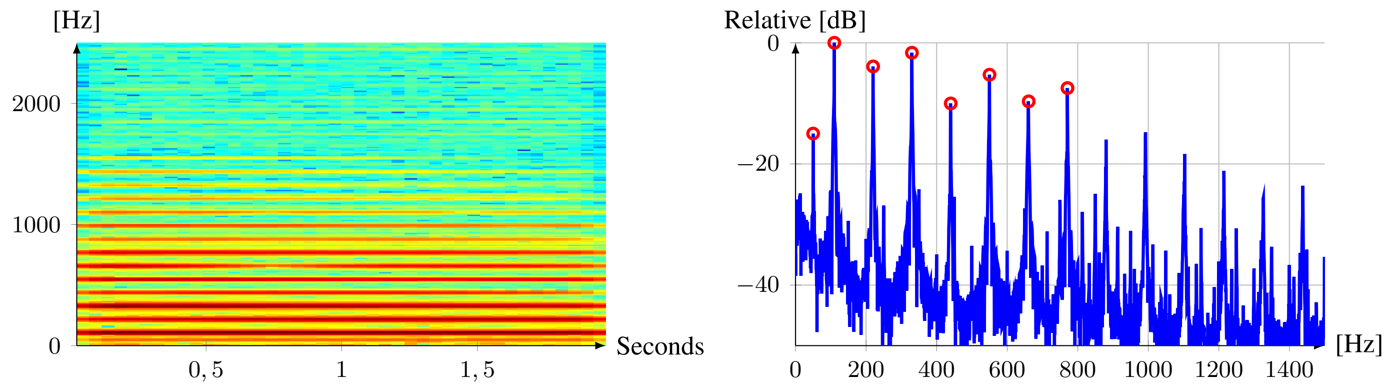

Figure 2.2: Frequency content of the A-string with indicated peaks.

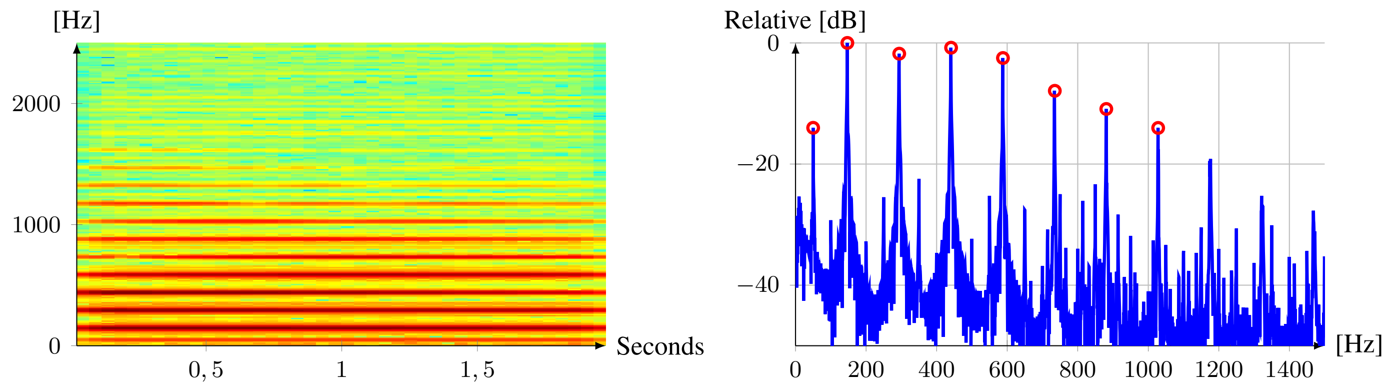

Figure 2.3: Frequency content of the D-string with indicated peaks.

2.1.1 Experiment

Six open strings is being recorded individually. They are all tuned referenced to $\mathtt{A} = 440\,\mathrm{Hz}$. The harmonics is identified by locating the first eight peaks in the magnitude response of the frequency domain. Every figure that shows the frequency resopone in this section is produced from a two seconds file, sampled at $fs = 44.1\,\mathrm{kHz}$. The spectrogram of fig. 2.1 depicts the frequencies of the lowest E-string. The harmonics below 800 Hz is extracted and the peak-indices can be located from a full windowed FFT, which is plotted as the magnitude response, normalized to the highest peak. At first glance, it seems that the harmonics are close to the integer multiple of the fundamentals. Therefore, all peaks are extracted and put in a table of harmonics table 2.1a. Be aware, that from the plots it is seen that they all suffer from 50 Hz hum noise, which is not shown in the table.

Table 2.1a shows that the harmonics are integer multiples of the fundamental w_k with a deviation $\mathbf{r} < 3.5\,\mathrm{Hz}$.

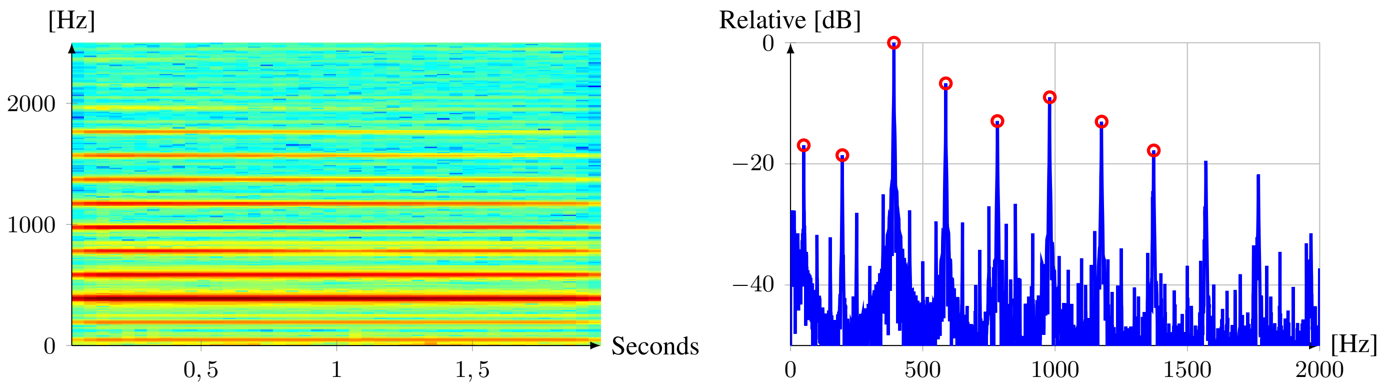

Figure 2.4: Frequency content of the G-string with indicated peaks.

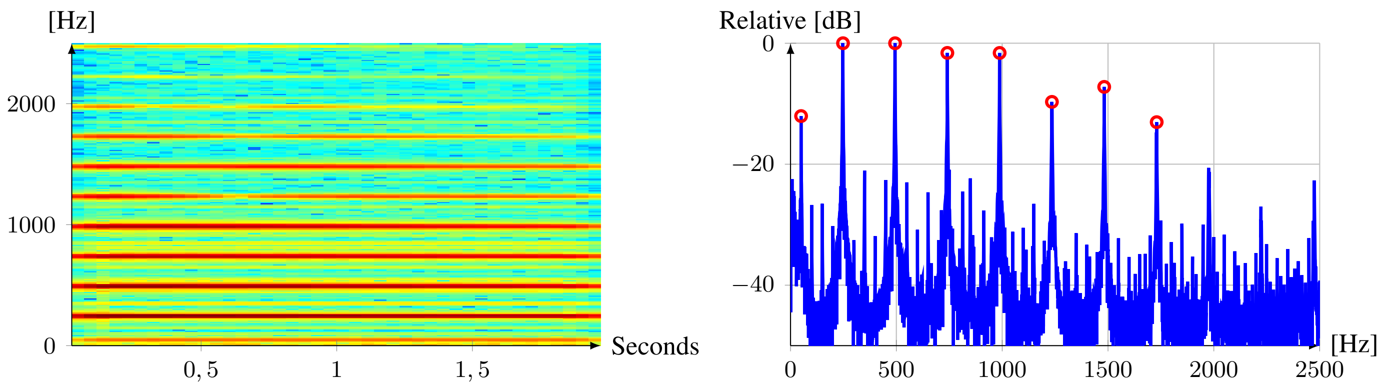

Figure 2.5: Frequency content of the H-string with indicated peaks.

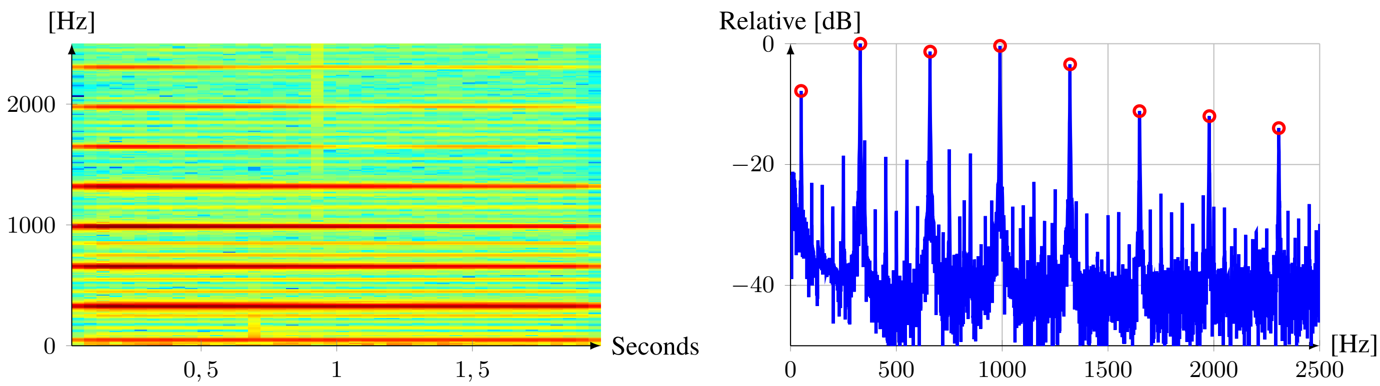

Figure 2.6: Frequency content of the highest E-string with indicated peaks.

The deviation $\mathbf{r}$ is shown in table 2.1b. Furthermore, some of the harmonics are shared between the individual strings e.g. 440 Hz, 588 Hz and 988 Hz. The deviation is found from the distance to the expected integer multiple $\omega_{1,k}$. It is found from

$$\mathbf{r} = r_{i,k} = \omega_{1,k} i - \omega_{i,k}, \quad \texttt{for} \quad i = \{1, \cdots, 7\}$$

, and k is the denoting the different sources. N.B. Due to the insufficient amount of tests, it is difficult to do a relevant conclusion from this standalone experiment. Still, it is implicated from the comparison in fig. 2.7 of the eq. (2.2) to recording, that an this open guitar string has linear integer harmonics. The graphs show the recordings in red and the model is shown for seven different values of B. These six recordings are similar to the case of $B = 0$. It is obvious that the next step is to compare the Ξ model to strings that are shorter i.e. all strings closed to the 12^{th} fret.

l	E	A	D	G	H	E
1	83	110	147	196	248	330
2	165	220	294	392	494	660
3	248	330	441	587	471	990
4	331	440	588	782	988	1301
5	434	550	735	980	1235	1649
6	497	661	881	1176	1483	1979
7	580	771	1028	1373	1730	2307

(a) Measured Harmonic Frequencies

E	A	D	G	H	E
0	0	0	0	0	0
0.4993	0.4993	0.4993	0	0.9986	-0.4993
0.4993	0.9986	0.9986	0	1.9973	-1.4980
0.9986	1.4980	1.4980	0.4993	2.4966	-2.4966
0.9986	1.4980	1.9973	-0.9986	3.4952	-1.4980
0.4993	1.4980	2.4966	-1.4980	3.4952	-1.4980
0.0000	1.4980	2.9959	-2.4966	3.4952	-0.4993

(b) The distance to the integer multiples

Table 2.1: Harmonics frequencies of experiment.

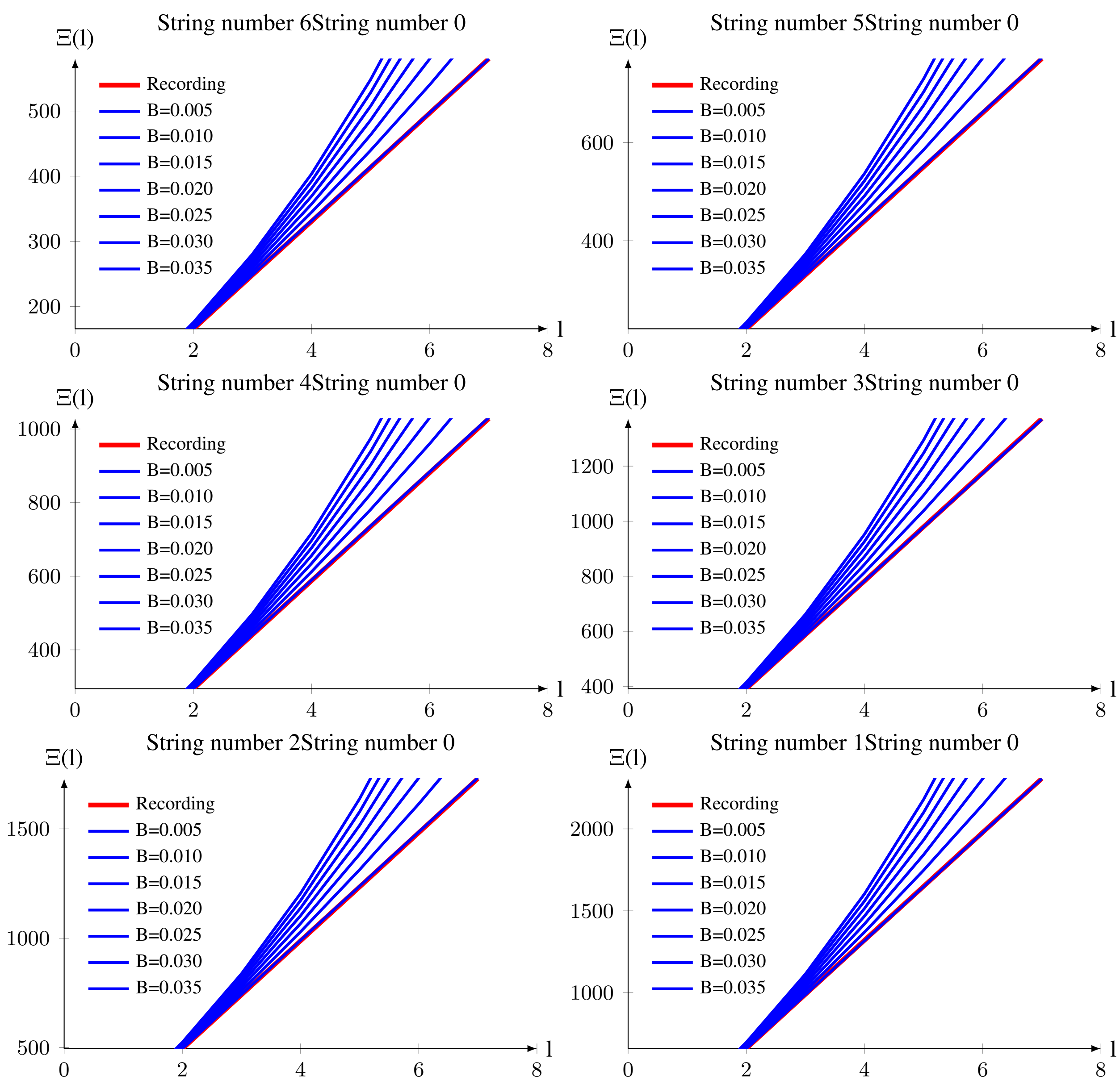

Figure 2.7: Ξ model compared to the recordings

. . . Input some more about the relation to the theoretical stiffness and give an example of the first model or leave it out by deleting it..

Chapter 3

Division of System into System Modules

Chapter 4

Interim Conclusion

Chapter 5

Requirements Specification

Chapter 6

Test Specification

Part II

Design

Part III

Implementation

Bibliography

[GJ09] Græsbøll and Jakobsen. *Multi-Pitch Estimation*. Morgan & Claypool, 2009.

[RW02] Moore Rossing and Wheeler. *The Science of Sound*. Pearson Education, 2002.

Appendix CD

List of Corrections