THE SCIENCE OF SOUND & MUSIC

STUDY GUIDE

THE SCIENCE OF SOUND

7S6X0

2

THE SCIENCE OF SOUND

FEBRUARY 2021

Table of Contents

1	Educational Structure of the Course	7
1.1	General Information	7
1.2	Learning Outcomes	8
1.3	Examination	8
1.4	Educational Forms & Teaching Models	8
1.5	Course Content & Programme	9
2	Organizational Structure of the Course	11
2.1	Instructor Information & Availability	11
2.2	Course Schedule & Assessment Dates	11
2.3	Landmark Events, Assessments & Due Dates	13
3	Programme by Week (In Detail)	14
4	Anti-plagiarism	23

Educational Structure of the Course

1.1 General Information

This set of lectures forms the middle part of the 'coherent keuzepakket' dedicated to acoustics, sound and music, abbreviated SOS2. With the first block (SOS1) focusing on creating awareness for the multitude of acoustic aspects surrounding each student, SOS2 provides the scientific background knowledge that helps the students to develop a real understanding of the observed phenomena and to enable them to perform analysis and synthesis regarding sound and music. The main format of this block are classical lectures, using a book as background source, in combination with concrete assignments and weekly tests.

Year	2020/2021
Lecture planning	Year 1 or 2, semester B, quartile 3
Target group	Bachelor (all departments), optional (coherent keuzepakket)
Credits	5 ECTS
Coordinating department	BE
Coordinating lecturer	prof.dr. Ir. M.C.J. Hornikx (BE)
Additional lecturers	prof.dr.ir. M.C.J. Hornikx (BE), prof.dr.ir. I. Lopez Arteaga (ME), T.U. Pathre M.Sc. (BE), dr.ir. R.H.C. Wenmaekers (Level Acoustics and Vibration)

Information on teaching and examination

Type of education	8 weeks, 2 blocks of 4 hours Block 1: 2 hours lectures (online lecture style is different per lecturer) Block 2: 2 hours self-study; 2 hours excercises
Examination	Interim tests (40%) Final exam (60%, written)
Prior knowledge	Acoustic Awareness (SoS1)
Study material	- Book: The Science of Sound (3rd edition). Thomas D. Rossing, F. Richard Moore, Paul A. Wheeler. Addison-Wesley, 2002. (Bol.com or studystore.nl) - Additional material at Canvas

1.2 Learning Outcomes

- Knowledge of mechanisms underlying sound sources, sound propagation and auditory perception;
- Being able to relate engineering acoustic applications to physical fundamentals and vice versa;
- Awareness of the current acoustic-related research carried out at TU/e.

1.3 Examination

The final grade for this course is based on two components: the grade of the final written exam, and grades of the tests. There are 4 tests, the 3 highest grades set the total intermin test grade. The interim tests grade counts for 40% of the total grade; the final written exam counts for 60% of the final grade. A minimum result for the final exam is required in order to pass the whole course, grade 5 (on a 10-scale).

1.4 Educational Forms & Teaching Methods

This course has a weekly schedule that is similar for each week and consists of lectures as well as weekly tests.

Lectures

The course content is conveyed partly by online lectures from the team of lecturers. The type of online lectures differs per lecturer, either a live online lecture or a recorded lecture posted online accompanied by a Q&A session.

The lecturers alternate, depending on the course subject. The main objective of the lectures is to clarify the course content by means of explanation and illustration. All course subjects will be related to the framework of source-transmission(path)-receiver, from which the connections between the various topics of the course become clear. The teaching level is based on the expectation that the students have prepared the content of the course prior to the lecture. The lectures (or Q&A session) take place at Monday in the third and/or fourth hour.

Tests

Four times during the course, a small test is taken in the ANS Delft environment. This can be a test with open questions or a multiple-choice test. The test takes place on Monday in the first hour, and the course content treated in the previous course block (covering 1 or 2 weeks) will be examined. Results of the intermediate tests will be available in the next week. The second hour on Monday will be used to explain and discuss the answers to the test.

Self-study

At Thursday in hour 5 and 6, self study is planned were student can study on the course material and start with the excercises, which will be handed out to the students at Canvas. The purpose of the exercises is to increase the understanding of the content of the course through applying the knowledge gained from the lectures and home-reading. Next to this, the exercises are meant as preparation for the test in the upcoming week. The type of exercises varies weekly and ranges from hand calculations from book questions, and analytical and numerical exercises using software tools as Matlab and Mathematica. In hour 7 and/or 8 on Thursday, a lecturer will online be available for Q&A on the exercises.

1.5 Course Content & Programme

The course content is mainly based on the book 'The Science of Sound' by Rossing et al. The book both treats the acoustic fundamentals as well as the principles of sound excitation and radiation, sound propagation and perception. Book chapters have an applied focus as room acoustics and electro acoustics.

The course material is completed by additional material as excerpts from other books and journal papers, that will be posted on Canvas. The document containing this additional material will be available prior to the start of the course weeks. The weekly programme is summarized in the table below. The chapter x of the book is denoted by Bx.

Week	Contents	Book Chapters/ Additional Reading (AR)
1	*Module 1: Physics of sound* Introduction to the main concepts in acoustics: definition of acoustic waves, frequency, wavelengths, speed of sound, impedance, resonance frequency, etc.	B1,B2,B3,B4
2	*Module 1: Vibroacoustics and musical instruments* This week is fully based on the concept source-transmitter-receiver applied to vibro-acoustics and duct acoustics. We will pay attention to sources of vibration of sources of sound, structural and acoustic transmission paths, sound radiation and radiation efficiency and the idea of transfer function.	B10 and B13
3	*Module 2: Sound perception* Introduction of basic aspects of human auditory perception: frequency range, amplitude range. Perceptual descriptors like loudness, pitch, timbre. Spatial perception (direction, distance, compactness of sources, listener envelopment). Resolution, just noticeable differences, masking. Some basic anatomy and physiology and behavioural testing.	B5,B6,B7

Week	Contents	Book Chapters/ Additional Reading (AR)
4	*Module 2: Acoustic communication* Speech production and relation to speech perception: anatomy, acoustics, source-filter model of speech production, formants, prosodic features. Influence of room transfer on speech intelligibility. Animal acoustic communication: Types of sound generation, interrelation with sound signal propagation and reception	B15,B16 AR: Ch. 2 + 3 (ca. 90 pages) from: Principles of animal communication, Bradbury and Vehrencamp.
5+6	*Module 3: Room and electro-acoustics* This part of the course covers the principles of free field and diffuse field sound transmission in rooms (calculation- and measurement methods, room acoustic parameters, speech intelligibility, Just Noticeable Differences) with and without the use of electronic reinforcement systems.	B23, B24, B25 (25.1)
7	*Module 4: Environmental acoustics* Physical aspects of sound propagation in outdoor environments: influence of ground, meteorology, screening and urban environments. Noise control for environmental acoustics by mitigation measures in the transfer path.	B30, B32 AR: Excerpts from 'Computational Atmopsheric Acoustics' (Salomons) and 'Predicting Outdoor Sound' (Attenborough et al.)

Organizational structure of the Course

2.1 Instructor Information & Availability

Lecturers		Department/Company	Module
prof.dr.ir. M.C.J.	Hornikx	Built Environment	4
prof.dr.ir. I.	Lopez Arteaga	Mechanical Engineering	1
M.Sc. T.U.	Pathre	Built Environment	1,2
dr.ir. R.H.C.	Wenmaekers	Level Acoustics and Vibration	3

All lecturers are available via e-mail. General questions may be directed to the course assistant, Tanmayee Pathre (t.u.pathre@tue.nl)

2.2 Course Schedule & Assessment Dates

The courses are scheduled in two blocks of 4 hours and the timeslots can be found below. All contact moments are online.

Timeslot	Monday	Thursday	Location
1	Test (weeks 3, 5, 7, 8)		Canvas Conference or Teams
2	Test discussion (weeks 3, 5, 7, 8)		Canvas Conference or Teams
3	Lecture		Canvas Conference or Teams
4	Lecture		Canvas Conference or Teams
5		Self study	Canvas Conference or Teams
6		Self study	Canvas Conference or Teams
7		Excercises	Canvas Conference or Teams
8		Excercises	Canvas Conference or Teams

Weekly schedule

Week	Monday Hours | Type of education	Thursday Hours | Type of education	Date
1	3+4 Lectures Module 1		1 February
		5+6 Self-study Module 1	4 February
		7+8 Excercises Module 1	4 February
2	1+2+3 Lectures Module 1		8 February
		5+6 Self-study Module 1	11 February
		7+8 Excercises Module 1	11 February
3	1 Test Module 1 2 Test dicussion		22 February
	3+4 Lectures Module 2		22 February
		5+6 Self-study Module 2	25 February
		7+8 Excercises Module 2	25 February
4	3+4 Lectures Module 2		1 March
		5+6 Self-study Module 2	4 March
		7+8 Excercises Module 2	4 March
5	1 Test Module 2 2 Test dicussion		8 March
	3+4 Lectures Module 3		8 March
		5+6 Self-study Module 3	11 March
		7+8 Excercises Module 3	11 March
6	3+4 Lectures Module 3		15 March
		5+6 Self-study Module 3	18 March
		7+8 Excercises Module 3	18 March
7	1 Test Module 3 2 Test dicussion		22 March
	3 Q&A Module 4		22 March
		5+6 Self-study Module 4	25 March
		8 Q&A Module 4	25 March
8	1 Test Module 4 4 Test dicussion		29 March

2.3 Landmark events, assessments & Due Dates

Intermediate Exams
The intermediate exams consist of the average grade of the tests with the three highest scores. The grade counts as 40% of the whole grade,

Tests in Canvas Quizzes
Monday 08:45-09:30 (week 3,5,7,8)

Final Exam on campus
The final exams are scheduled at:

1st attempt: 12 April 2021, 13:30-16:30
2nd attempt: 21 June 2021, 18:00-21:00

Programme by Module (In Detail)

Module 1: Physics of sound

Preparation	Course material related to the weekly test	B1 (except 1.5 and 1.8), B2 and B4
		B3 + additional material at Canvas
Contents	What is sound?	Definition of basic concepts such as sound, sound sources, speed, velocity, force, energy and power
	Vibrating systems & resonance	Harmonic motion of a mass-spring system, resonance frequency, resonators, strings, beams and plates
	Waves	Definition of sound waves, relationship wavelength, frequency and speed of sound, acoustic impedance
		Wave types, reflection, refraction, diffraction, interference, Doppler effect
Self-study	Exercise time	B1: Review questions 8, 17, Exercises: 12 B2: Review questions 2, 7, Q2, Exercises: 1, 2, 4 B3: Review questions 2, 6, 11, 12, Exercises: 4, 6, 9 B4: Review questions 6, 8, Exercises: 1, 5
Learning Goals	Understand the concept of wave and the relationship between wave speed, wavelength and frequency	
	Understand the concept of harmonic motion and resonance frequency of a spring-mass-damper system	
	Understand the principles of sound reflection, diffraction, refraction and interference	
	Be able to perform basic calculations regarding quantities such as resonance frequencies, acoustic impedance or acoustic energy	
	Be able to perform basic calculations regarding the design of acoustic resonators	

Module 1: Vibroacoustics and musical instruments

Preparation	Course material related to weekly test	B10, B13
		Additional material at Canvas
Contents	Source-transmitter-receiver model	The implementation of this model for vibro-acoustics will be explained paying attention to airborne and structureborne sources, to airborne and structural paths and to the principle of superposition at the receiver. The concept of transfer function will be explained.
	Sound radiation	Sound radiation from plates and radiation efficiency
	Duct acoustics	Resonances in ducts, lambda/4 resonators, 4-pole models, radiation from open ends
		Sound generation due to flow and temperature
Self-study	Exercise time	Exercises will be provided

Learning Goals

Understand the concept of source-transmitter-receiver

Understand the concepts of airborne and structureborne sources and paths

Understand the concept of transfer function

Be able to determine the sound level due to a number of sound and vibration sources and paths

Understand resonances in ducts and the boundary conditions at open ends

Understand the sound generation due to flow and temperature

Be able to build a simple duct model and determine the end impedance, for example.

Module 2: Sound perception

Preparation	Course material related to weekly test	B5: Sections 5.1, 5.2, 5.5, 5.7 B6: Sections 6.1, 6.2, 6.3, 6.5
Contents	Basic anatomy of hearing system	Outer, middle, inner ear. Dimensions, functions. Effects on sound transfer. Relation to perception Compressive characteristic w.r.t. intensity. Logarithmic characteristic w.r.t. frequency
	Relation physical-perceptual parameters	Definition of loudness, pitch, timbre and relation to physical descriptors of sound. Critical bands. Parameters of spatial perception Sensitivity to changes, just noticeable difference, masking
	Relevance for speech and music	Temporal resolution and integration, role of pitch. Room acoustics and perception
Self-study	Exercise time	B5: Review questions 1, 2, 13, 14 Exercises: 1, 2, 4, 5 B6: Review questions 4, 5, 9, 17 Exercises 1, 2, 4
Learning Goals	Understand the relation between sound frequency and amplitude/level for the hearing range Understand the limited resolution (in terms of amplitude, frequency) of the hearing system Get to know perceptual parameters, and their relation with physical descriptors Get to know major anatomical structures of the hearing system, and their influence on sound perception Experience and understand the concept of masking	

Learning Goals

Understand the various sound aspects that are reflected in the percept of pitch (harmonic signal, periodic signals, amplitude modulated signals)

Understand the role of dimensional parameters of the human body, head, and outer ears for spatial hearing

Become aware of basic techniques of behavioral testing

Module 2: Acoustic communication

Preparation	Course material related to weekly test	B15. Sections 15.1-15.6, Additional material at Canvas
Contents	Basic anatomy and physiology of the human voice	Vocal organs: lungs, vocal folds, mouth and nasal cavity. Source-filter model of speech production. Speech articulation
	Basic aspects of speech perception	Spectro-temporal representation of speech, formants and vowel characterization; measurements and prediction of speech intelligibility; room acoustics and intelligibility, STI
	Animal communication: sound signal generation	Variety of mechanisms of vibration generation, efficiency of sound radiation, impedance matching, "speech" generation by animals, sounds as exploration signals (dolphins, bats)
	Animal communication: sound reception	Types of sound receptor organs, hearing range of various animals; relation to body size, and specific adaptations to environments
Self-study	Exercise time	B15: Review questions 2, 5, 12 Exercises 1, 4, 6 B16: Review questions 2, 7, Q1 Additional material related to animal communication
Learning Goals	Understand principles of human speech generation Understand the role of various articulators in the production process Role of pitch in speech prosody Understand interference with background noise and reverberation of speech intelligibility Learn the great variety of communication sounds used by animals	

Learning Goals

Become aware of different sound receptor organs

Understand the adaptability of acoustic communication to environmental and human-made factors

Module 3: Room and electro-acoustics

Preparation	Course material related to weekly test	B23, B24, B25 (25.1)
Contents	Room Acoustic Design	Free field and diffuse field sound transmission in rooms. Sound absorption (definition and types)
	Room Acoustic Measurement and Prediction	Prediction- and measurement methods, Music and Speech Intelligibility parameters, Just Noticeable Differences, Room Impulse Responses (RIR's)
	Loudspeakers, Microphones and Power Amplifiers	Types of loudspeakers (box, array, plane) Types of microphones (from omni to dipole) Sound power and Amplification
	Sound Reinforcement	Delay and feedback Speech Intelligibility improvement Room Impulse Responses and PA
Self-study	Exercise time 1	Exercises will be provided

Learning Goals

Understand the concept of source-transmitter-receiver in room acoustics

Understand the importance of impulse responses in room and electro acoustics

Be able to 'read' a room impulse response (sound receiver distance, direct sound, strong reflections, time delay gaps, flutter echo's etc)

Be able to determine the sound level at a certain position in a room or hall due to one or more sound sources (musical instruments, voices or loudspeakers)

Being able to distinguish different types of sound absorption in relation to materials & constructions

Module 4: Environmental acoustics

Preparation	Course material related to weekly test	B30: Section 30.2, 30.3, B32: Section 32.5, 32.6 Additional material at Canvas
Contents	Ground effect	Description of the interaction of sound waves with ground surface, characterization of ground surfaces; Physical effect of the ground surface on sound propagation; Possibilities for noise abatement of road/railway noise with ground treatments: Buried Helmholtz resonators, ground roughness, road surfaces, vegetation
	Meteorological effects	Mathematical and physical effects on sound propagation from: Refraction from wind speed profiles, refraction from temperature stratification, atmospheric absorption, atmospheric turbulence
	Screening, insulation	Prediction of the effect of noise barriers Performance of noise barriers, aspects considered: Barrier shape, barrier top, barrier surface material, meteorological effects Calculation of Sound insulation
	Urban effects	Prediction models for sound propagation in urban areas Applications: Street canyon effect, effect of façade reflections (absorption and diffusion), urban layout related to noise levels, noise mapping and quiet sides, sound insulation from various façades; Noise abatement measures: low vegetated screens, façade vegetation, green roofs

Self-study	Exercise time	B30: Review Questions 3, 4 Exercises 2 Extra exercises will be handed out B32: Review Questions 4, 5, 6 Exercises 2, 3, 6, 7 Extra exercises will be handed out

Learning Goals

Being able to identify and explain the main aspects that influence outdoor sound propagation

Being able to distinguish between the various physical phenomena interference, diffraction, diffusion, reflection, refraction and transmission

Summarize the current scientific challenges in environmental noise prediction

Given a certain environmental noise problem, being able to propose noise control measures related to the propagation path

Being able to relate outdoor sound propagation in the wider acoustic analogy of source-transmission-receiver

[1] CAA: Computational Atmospheric Acoustics (Salomons)
[2] POS: Predicting Outdoor Sound (Attenborough et al.)

Anti-plagiarism

When you submit your assignment under your own name you are asserting ownership or that work. When using ideas of another person, you must give that person credit through appropriate referencing. Referencing serves multiple purposes: (i) it allows readers to further explore sources you have consulted, (ii) it shows the depth of your own thinking and process of inquiry, (iii) it allows you and your readers to compare and contrast your position with other people's positions, agreeing with some, disagreeing with others, and (iv) it gives proper credit to the hard work that many people have done before you.

In this course an electronic tool Urkund will be used, that will perform a check on whether pieces of text have been copied from other texts (either from other students or from internet sources).

Evidently, the above does not apply to the answers to the open questions in the written exam.