KTH Tal, musik och hörsel

DT2410

# Audio Technology

Autumn 2020

KTH EECS TMH

School of Electrical Engineering and Computer Science
Division of Speech, Music and Hearing, TMH

**Canvas web page: https://canvas.kth.se/courses/21129**

Course director: Prof. Sten Ternström, stern@kth.se
Lindstedtsvägen 24, level 4.

# Welcome to the course in Audio Technology!

In this paper you will find all the information that is available when the course starts. Course news are posted on the course web page.

Please fill in the following for your own reference:

I belong to group number _____

together with _____

and _____

and the topic we have chosen for our assignment is

_____

My lab session times are:

Lab A: Studio _____

Lab B: Audio coding _____

Lab C: Illusory reproduction _____

Lab D: Virtual acoustics with Ambisonics _____

# DT2410 Audio Technology

This course teaches the principles and current technology for the production and distribution of sound, including music and speech. The purpose is to give an integrated view of how various complex audio systems are constructed and used when analog and digital techniques are used together with general storage and communication technology. The course is not about *using* audio technology.

**Goals**
The participants shall upon completion of this course

- be able to specify at a block diagram level the functions/components that must or may be included in audio systems for various applications; with regard for technical constraints such as channel count, converter types, data reduction methods, power requirements and storage.
- be able to assess audio systems with regard to sound quality and suitability in given applications
- be acquainted with how real-time audio data are usually managed in audio software and in operating systems
- understand the theoretical principles underlying audio bit-rate reduction techniques, and their typical impact upon the sound
- have obtained basic experience with using a mixing desk and its major peripherals such as dynamics processor, reverb unit and equaliser
- be able understand the first few pages of data sheets for audio integrated circuits
- be able to participate in the planning, deployment and maintenance of new and existing audio systems
- have a broad perspective on how transforms, signal theory, discrete mathematics, information theory, electronics and physics come together in audio applications

## To be examined

Written exam 4.5 hp, laboratories 1.5 hp, group assignment 1.5 hp.

You are also required to submit a suggestion for an exam problem. See "Examination" on pages 12-13.

**Please make sure that you are registered for the course!**

## Literature

1. **Course book**. The updated sixth edition of Ken C Pohlmann's *Principles of Digital Audio* is available on www.bokus.com for 529 kr in paperback. Allow 8 weekdays for delivery. (https://www.bokus.com/bok/9780071663465/principles-of-digital-audio-6th-edition/), 800 pages). This book is the preferred book for the course. It contains a huge amount of material, so below you will find a reading guide for the parts that are the most important.

**Reading guide to Pohlmann, *Principles of Digital Audio,* sixth edition**

| Chapter | Topic | Notes |
|---|---|---|
| 1 | Sound and Numbers | Repetition - read through |
| 2 | Fundamentals | Important |
| 3 | Recording | Important |
| 4 | Reproduction | p 77 -108 important, the rest is optional |
| 5 | Error correction | Only the general principles are important, not the details |
| 6 | Optical disc media | Read through |
| 7 | Compact disc | 187-208 important, the rest is optional |
| 8 | DVD | Optional - not in exam |
| 9 | Blu-ray | Optional - not in exam |
| 10 | Low bit-rate coding theory | p 335-363 important, the rest is optional |
| 11 | Codec design | Be able to describe in general terms the various codecs, but without going into detail |
| 12 | Speech Coding | not in this course - skip |
| 13 | Audio Interconnection | Recognise the different types of connections and what they are for, but not the details of the protocols |
| 14 | PC Audio | Read through so that you recognise the various acronyms and what they are for |
| 15 | Telecomm & Internet | Optional - only very simple exam questions |
| 16 | Digital Broadcasting | Only the parts that are relevant to audio |
| 17 | DSP | Read through - no mathematical exam problems on this |
| 18 | Sigma-delta conversion & noise shaping | The principles are important to understand |

The book contains little on spatial sound (lectures F2-F4 and tutorial 1), nor on software for audio, nor streaming. Those topics will be covered by substantial handouts and web links. For the first ten days of the course, we will be using Prof. Damian Murphy's handout material on spatial audio, so there should be ample time for you to order Pohlmann's book.

## Additional reading

The course begins with a substantial block on multichannel sound and surround sound, which, curiously, is not covered by Pohlmann or Watkinson. Prof. Damian Murphy's handout is the main source for this block, complemented by the article series on Surround Sound at http://www.sospubs.co.uk/ (of Sound on Sound magazine).

Other relevant books for those who are interested:

Everest, F. Alton. *The Master Handbook of Acoustics*. ISBN 0-8306-4437-7. (mostly on the design of studios)

Davis, Don & Davis, Carolyn. *Sound System Engineering*. ISBN 0-240-80305-1. (construction and planning of large installations.)

Rumsey, Francis. *Spatial Audio*. Focal Press Music Technology Series, ISBN 0-240-51623-0 (Surround Sound, 2D- and 3D-reproduction)

The course web page has a files section, where you can find uploaded selected articles written by participants in earlier course rounds. Most but not all of these are in English. These provide interesting insights into special areas and real-life installations.

## Laboratories

**Signing up**: The laboratory sessions will take place in the weeks number 47-49. The lab times are given in the lab schedule in Canvas, where you also sign up for the four labs. **You must make sure** that you are signed up for each of the four labs A-D. Lab instructions will be provided for download from the course web page and as hardcopy on request. If you cannot attend a laboratory session, then try first to swap with someone else in the course. If this is not possible, please let me know straight away so that we can make other arrangements!
**Rooms**: Labs A and C are given in the "Mätlab" at TMH on the basement floor (level one) in the TMH building, Lindstedtsvägen 24. This year, lab B is a home assignment (so as to reduce contagion); however, a lab assistant will be available in Zoom at the times given in the schedule, for getting help and for handing in your work. Lab D will be given in the Performance and Multimodal Interaction Lab (PMI-Lab), Teknikringen 14, ground floor.

**Lab A** is about **signal manipulation** with the most usual tools: level faders, equaliser, dynamics processor, and reverb unit. You will make measurements and listen to what the machines do to the sound. 3 participants per session, in the "Mätlab". A handout from the book *WSound* will be provided.

**Lab B** is about listening to the effects of bit-rate reduction. You will have access to various encoders for bit-rate reduction and your task is to evaluate subjectively the performance of the encoders. Place: home assignment with scheduled lab assistance over Zoom.

**Lab C** is about **illusory reproduction** of monophonic speech in a room. Given a selection of microphones, loudspeakers and equalisers, try to create the illlusion that a recorded voice is actually someone talking in the room. This is an exercise in listening and applying technical knowledge. 3 participants per session, in the "Mätlab".

**Lab D** is about **spatial sound reproduction** with Ambisonics. This session will be held at the PMI-Lab, Teknikringen 14, ground floor. You will test various loudspeaker configurations, and assess the localisation of sounds in different directions. You are expected to bring some B-format encoded WAV files that you have prepared in advance, as described in the lab instructions. 3 participants per session.

## Lab crew

Lab A: Karl Johannes Jondell, KTH/KMH
Lab B: Samuel Westman Granlund, KTH
Lab C: Mattias Hållsten, KMH
Lab D: Mattias Hållsten, KMH

## Tutorials with Q/A sessions and weekly reports

Audio technology is a *smörgåsbord* of engineering. The ingredients include mathematical methods from Fourier analysis, the Laplace transform, source coding, signal theory, combinatorics, and more. The potential for mathematical detail is immense, and from your time at KTH you will know where to look. However, a more important objective of this course is to build an overall perspective at a qualified level, and to show how different technical systems work together. The textbook is fairly extensive, but it does not contain exercises, and not much mathematics. Also, the organisation of the textbook is a bit unclear in some respects.

**Questions**: In our tutorial sessions we therefore make extra room for questions and answers. This is structured as follows: first agree within your group on things that need to be clarified (often someone else in the group will be able to explain). Unsolved issues can be submitted to me, collected in one weekly e-mail per group. Please put "Audio? Group xx" in the subject line, it will help me a lot. This will give me some time to prepare a proper answer for the next time we meet.

**Signs of life**: Even if you do not have any questions, please send me exactly one e-mail per week from each group to let me know how your assignment is going. Put "Audio! Group xx" in the subject line, please.

We will have tutorial sessions on spatial audio, sampling rate conversion and system design considerations. Two tutorial sessions will be allocated to field trips. Please feel free to make suggestions for other field trips.

## Lectures and tutorials in DT2410 Audio Technology, autumn 2020

The lecturers will assume that you have read the Pohlmann chapters listed below in advance. If you think of questions before or after the lecture, do not hesitate to ask by e-mail. We will discuss them in the tutorials. The schedule below **does not include the laboratory sessions**. The room Fantum is at the TMH department, Lindstedtsvägen 24, 5th floor. It seats all 12 students with physical distancing. The lectures will be accessible live through Zoom, and will also be recorded to a archive in Canvas, but they will not be edited. We will attempt to render sound examples in stereo and surround even over Zoom (special Zoom instructions will apply).

| | | |
|---|---|---|
| F1 | Mon 26/10<br>13-15 Fantum | **Mandatory attendance.** Course overview. Division into groups. Allocation of laboratory schedule. Introduction to the group assignments. *ST* |
| F2 | Wed 28/10<br>10-12 Fantum | "You are surrounded!" Background & theory for spatial sound. (**handout material**.) Guest: Prof *Damian Murphy, dept of Electronics, Univ of York*. (via Zoom, presented in Fantum) |
| F3 | Fri 30/10<br>08-10 Fantum | Recording for stereo and spatial sound. *Damian Murphy*. (Recapitulate on microphones from earlier courses) (via Zoom, presented in Fantum) |
| Ö1 | Mon 2/11<br>10-12 Fantum | Numerical methods for room acoustics simulations. DM, ST (handouts). (via Zoom, presented in Fantum) |
| F5 | Wed 4/11<br>**14-16** Fantum | A/D-D/A-conversion part 1. Sampling and quantisation for audio. (*Pohlmann* chapters 2-4) *ST* |
| F4 | Thur 5/11<br>**14.00-16.30**<br>**KMH Lilla Salen** | Alternative 3D sound systems: Ambisonics, wavefield synthesis and binaural/transaural presentation. (handouts) *Damian Murphy*. Demo of the Klangkupol. NOTE: At the Royal College of Music, Valhallavägen 105. |
| F6 | Fri 6/11<br>13-15 Fantum | A/D-D/A-conversion part 2. Dither, convertors. (*Pohlmann* chaps 3, 4, 18) Oversampling, noise-shaping, single-bit-converters. *ST* |
| Ö2 | Mon 9/11<br>13-15 Fantum | Exercise on A/D-D/A. Methods for sampling-rate conversion. *ST* |
| F7 | Wed 11/11<br>08-10 Fantum | Hardware for audio part 1: IC's and buses for digital audio, construction examples (handout materials). Physical attendance is recommended. *ST* |
| F8 | Thu 12/11<br>10-12 Fantum | Coding and compression of audio signals (*Pohlmann* chaps 10+11) |
| F9 | Mon 16/11<br>13-15 Fantum | Software architectures for audio, part 1. How audio is handled in different operating systems, in many layers of protocol. *ST* |
| Ö3 | Thu 19/11<br>10-12 Fantum | Group assignments workshop: status reports, problem solving. *ST* |
| F10 | Mon 23/11<br>10-12 Fantum | Software architectures for audio, part 2. Common high-level tools and applications. Pohlmann chap 17. ST |
| F11 | Tue 24/11<br>13-15 Fantum | Hardware for audio part 2, transmission: types of cables and networks. The AES75 standard (*Pohlmann* chap 13, 14, 15) *ST* |
| Ö4 | TBA | Field trip to a recording or mastering studio |
| F12 | Tue 1/12<br>15-17, **Zoom** | Audio in broadcasting: current distribution technologies and strategies. *Paul Nygren*, *Marja Doerr* and *Jim Eld* from Sveriges Radio. (*Pohlmann* chap 16). On Zoom, *and* screened in Fantum. |
| Deadline | Wed 2/12 | **Electronic submission of your exam problem, by 17:00.** |
| Deadline | Mon 7/12 | **Electronic submission of group assignments by 10:00** |
| F13 | Mon 7/12<br>13-15, Fantum | Audio streaming. Guest lecturer: Andreas Rossholm, Spotify. |
| F14 +<br>F15 | Tue 8/12<br>**13-16,** Fantum | Course Finale, assignment presentations! Open to all audiophiles at KTH. Course conclusion. Fantum is accessible from 12.30. **The home exam is handed out**. *Sten Ternström* |
| Deadline | Fri 8/1 2021<br>10-11 | Deadline for turning in **the written exam: 10.15-11.00**. Sten's office, LV24 level 4. |

## Assignment: Write a technical article

At the start of the course, you will form groups of two or three students. For the group assignment, your group may choose to write a technical article on some specialised topic of your own choice within audio technology. Sound examples to go with it are of course encouraged. Examples of such topics are given below, or can be found in the collections from earlier years. The assignment should be started on as soon as possible, and the idea is that you do your own research in the field, on the web and in libraries. The TMH library contains some material of interest.

The primary readership for these articles is future participants of this course. The text must contain a list of references similar to that at the end of each chapter in the textbook. There must also be an account of how the different subtasks were allocated to the group's members. The assignment text may be written in Swedish if you so prefer, but the **presentation on 8 December** must be given in English, including the slides. There is a Microsoft Word document template with a suggested format for the articles available on the course web page. Please see the **Assignment** page for details.

Your group assignment report must be handed in electronically, no later than **7 December at 10:00**. We will arrange for the collected articles to be printed, so that you can receive them all on 8 December at the course finale.

## Extra literature

The Internet is all good and well, but some knowledge is found only in libraries. The TMH library is small but has a reasonable stock of sound books and journals. The library on level 4 contains journals and on level 5 you will find books. Please note that it is not permitted to remove any journal or book from the library – the material you need must be photocopied. For access to the library, please contact Sten.

## Suggested topics for an article

Some topics which we have not yet seen, but which would be interesting:

- Conference public-address: speaker mikes, participant mikes, feedback suppression
- Teleconferencing and telepresence
  (from conventional loud telephones to full virtual reality)
- Teaching singing or instrumental music in real time via the internet
  – problems and solutions
- Language training systems and systems for simultaneous interpreters
- Covert information technology (spy mikes etc)
- A selection of interesting recent audio patents (this is very instructive)

You are welcome to re-use earlier topics if you like, if you want to gain insight into this issues yourself. If so, refer to the existing article and improve on it significantly. Links to many earlier articles are provided in the wiki section of the course home page. Earlier articles have included:
*Existing sound installations*: Cosmonova, the Royal Opera, the Royal Dramatic Theatre, the Globe Arena, cinemas, sports arenas.
*Broadcasting*: surround sound at Sveriges Radio.
*Types of sound systems*: in churches, theatres, cinemas, cars, radio stations.
*Applications/technologies*: Sound in computer games, Speech in noisy environments, Audio on computer networks, Reverb simulation techniques, Data reduction techniques, Pro audio versus consumer audio, Binaural synthesis, HRTF's, Mastering, Archiving sound.

The article should always account for

- Conditions that are special for the application
- Specific requirements for the sound
- Other specific requirements, such as reliability, coordination, security aspects

If you are describing a type of installation, there should be a case study of a representative system, including approximate costs of acquisition, installation, operation and maintenance.

*Vocational information*

- Is there such a thing as an audio labour market? Who works with audio and how many?
- An overview of professional journals and magazines
- Book review

*Recording spatial sound*
We have a soundfield microphone for first-order Ambisonics (Soundfield SPS200) and an RME Fireface 800 audio interface to go with it. An assignment could be to make well-documented B-format recordings in live environments, for demo use in Lab D.

## Alternative assignment: Audio programming

If your group prefers, you may choose to do an audio programming task instead of the article.

*Goals*

A. Be able to include audio input and output (recording and playback) in your own programs, using call-back functions for sustained throughput.
B. Be able to modify an audio signal in real time using high-level tools.

*Task A: Soundfile I/O*

You need first to choose three things:

**1. Operating System**

Windows – Mac OS – Linux – other.
Choose what you like, so long as you can demonstrate it in class.
The TMH student lab facility has Windows workstations. You do not have to use these; in fact, it is probably easier to work on your own computer if you have one.

**2. Audio API's**

- Portaudio library (all OS). This is the preferred choice.
- Web Audio API
- Steinberg's ASIO (all OS)
- OpenAL (all OS)
- CoreAudio (Mac)
- WASAPI (Windows 7-10)
- PlayRec for MatLab (uses PortAudio)

**3. Programming language**

C, C++, C#, Python, Delphi, Matlab. Choose one that you like and that is available to you. The purpose is not to learn a programming language, but to learn how to program for audio, and especially how to use **callback functions**. Not all combinations of the above are practical or possible.

**Programming task**
Your programs should demonstrate as many as possible of the following actions (from easier to more difficult):

1. Play a given soundfile in its entirety, using a single high-level function call.
2. Play user-selected portions of a given soundfile, with user-selectable sampling rate. The program should display level meters in decibels that move appropriately during playback.
3. Play a long soundfile, with continuous event-driven double-buffering of the disk I/O.
4. Display real-time dB meters of two live inputs.
5. Record a short soundfile in its entirety.
6. Record a long soundfile, with continuous event-driven double-buffering of the disk I/O. The program must check for available disk space. The program must ask the user to confirm overwrite of any existing file.

*Task B: real-time modification of audio, with remote control over MIDI*

*Tools* – choose one of

- PureData (freeware, Windows – Mac – Linux)
- Max/MSP (similar to PureData but better and not freeware)
- SuperCollider (a Smalltalk-like language and server for sound synthesis)
- AudioMulch (Windows/Mac)
- PlogueBidule
- Reaktor (1 licence only at TMH)

The program or "patch" should demonstrate how incoming live audio is modified in some interesting way under remote control, and output again in real time. MIDI controllers can be borrowed from TMH.

## Equipment for the assignment

A station in the EECS MultiStudio (LV5, level 6) with Mac workstations, diverse audio software and MIDI-controlling hardware can be booked for half a day at a time.You may also borrow certain audio equipment from TMH for a few days.

## Presentation of group assignment works

The presentation session for both software and technical article assignments is on Tuesday, 8 December, from 13.15 until finished, at about 16.00. The room Fantum will be open for your preparations from 12.30. Computer projection and a surround sound system are available in this room. All group members should be active in the presentation, which should be no longer than 20 minutes, including time for demos and questions. The presentations must be of good quality, and should be of interest also to audio enthusiasts who have not followed the course.

## Examination

Compose a suggested exam problem, and do a written exam at home.

As part of the course examination, you must write a proposed problem for the home exam. Each problem is to be worth 10 points. A problem proposal must include

1. The problem text, with figures if necessary. The problem text shall clearly point out a minimum task that must be answered correctly and completely for grade E (such as fundamental facts or principles).
2. The grading criteria – what earns points, and what costs points?
3. A suggested solution

If the solution requires independent research (which is admissible) then sources should be suggested.

The exam problem is an individual task which you must do on your own. By submitting an exam problem you also attest (a) that the problem is your own work, and (b) that you intend to take the written exam (Sw. *tentamensanmälan*). Your proposed problem must be submitted to me by e-mail (stern@kth.se) no later than **Wednesday, 2 December at 17:00**. Please put your name and the page number on each page, even in electronic documents. Please also put your own name in the file name of the e-mail attachment, if used. It is also admissible to enter submissions on paper, in my mail slot at TMH.

I will select the best proposed problems, perhaps adjust them if necessary, and will compile a home exam with five problems for you to do at home. Hence the maximum total will be 50 points. As you can imagine, the bonus for having your proposed problem selected is that you can solve it very quickly. Look out, though, since I may have tweaked it a little! Preference will be given to compound problems that have a coherent theme and that require the solver to think independently. A problem whose answer is simply a quote from the book is not very interesting. The solutions may be narrative, or mathematical, or both. Multiple-choice problems are allowed if they are non-trivial and if the probability of guessing the right answer is low. Be creative!

The final exam text and the cover paper will be handed out at the end of the final project presentation on **Tuesday, 8 December, 2020**. The personal envelope you pick up there will contain also my comments to the problem you proposed; and a course evaluation sheet, which you are asked to complete.

**Submission of exam**. Your completed exam is due no later than **11.00 on Friday, 8th January, 2021**. I will be sitting in my TMH office between 10.15 and 11.00 to receive the exams. Exams may not be returned by e-mail or by fax - your signature on paper is needed. Exams that are returned too late will not be graded above C. The solutions may be written in English or in Swedish, but not both (excepting certain technical terms, which may not be available in Swedish, such as “dither.”)

**Language skills**. When you communicate as an engineer to other people, it is important to be able to explain things correctly in words. Because you will have ample time to think about your answers, I will be more particular than usual about the wording of your solutions. This means that I may subtract points if your wording is incorrect, unclear or incomplete, *even if* I can more or less understand what it is that you actually mean.

**Submit only your own work**. For both your submitted problem and the exam solution, the following applies. Do not cooperate with other students. Remember to cast the narrative into your own words, and do not copy the running text of web pages or other writers. The KTH-EECS Code of Honour applies. Please be aware of the rules, which are quite strict. I am obliged to report any instance of possible plagiarism. Such a report will in each case invoke a very time-consuming, costly and denigrating procedure involving about ten people, including the Rector of KTH, and which can lead to suspension of the student from studies at KTH.

**Grading**. The preliminary grading scale is A: 50-45, B:44-40, C:39-35, D:34-30, E: 29-25, Fx:24-23, F: 22-0. The indicated minimum tasks must all be correctly solved. Exams from earlier years will not be made available until after the deadline, on request.

Earlier students have found this form of examination quite challenging but inspiring, and also that it is a good incentive for really penetrating the subject.

To pass the **laboratories** you must have attended all four labs. If you are absent, for whatever very compelling reason, we will try to arrange an extra session, but this is not always possible. If not, you may be given an alternative individual assignment on a similar topic.

To pass the **group assignment**, all members of the group must be actively involved, and the course leader must approve the result. A good quality criterion for the article is that your material should be usable "as is" in the course materials for the following year.

The final grade on the course will be determined both (a) from the points you reach in the written exam, (b) from the quality of your assignment work and the presentation.

I will report the results incrementally in Canvas, but they will not be official until I have had them registered in LADOK.

## Course schedule DT2410 Audio Technology, period 2, autumn 2020

Please see the course Canvas pages for up-to-date info on all course events, including the lab sessions.