"Computational Sound" (W16, CS489/689, Section #001)

Contact: Richard Mann (www.cs.uwaterloo.ca/~mannr, mannr@uwaterloo.ca)

Prerequisite: Scientific Computation/Matlab (CS370.1 or equivalent).

Evaluation: Assignments (60%), Project (40%). (* Grad students 60% project.)

Project Requirement: Students will complete an independent project. Implement a design or algorithm, perform experiments, and report on the results. Broad range of topics, including: acoustics measurements, speaker building, audio effects, music synthesis, signal processing, machine learning, ...

Math?

Linear systems and fourier analysis. Processing in Matlab/Octave.

All material will be derived in class, in particular, computation with Discrete Fourier Transform (DFT/FFT).

CS students saw a bit of this in CS370/371. Engineering students should already have some of this in 2nd year “systems” or “circuits” course.

References. All information given in class (Google docs). Main reference:

- Leo L Beranek & Tim J Mellow. “Acoustics: Sound Fields and Transducers”, Academic Press. 2012.

Other sources (to be added during the term):

- David M Howard and Jamie A S Angus. “Acoustics and Psychoacoustics”, Fourth Ed, 2013.
- Harry F Olson. “Music Physics and Engineering” Dover reprint of 1952 text.
-

Course Organization

Lectures: (focus on fundamentals of acoustics, measurement)

- Assignments/exercises in Matlab/Octave.
- Experiments/demos in lecture.
- Data will be collected, by instructor, using National Instruments "myDAQ".

Project:

- Any topic related to sound, acoustics, or computation!
- Undergrads may work in groups or alone. Grads must work alone.

Objective: Students will do a fun project, and they will measure performance using the techniques covered in class...

Lectures (week)	Assignments (60%)	Project (40%)
1. Introduction (today). Sound levels, units and measurement (Friday)		
2-3. Acoustic waves, spherical and planar. Room reverberation time, standing waves in tubes and rooms.	Asst #1 (15%)	
4-5 Computer waves. Fourier analysis, synthesis by DFT	Asst #2 (15%)	P0: Project proposal (5%)
6-7. Resonators and loudspeakers. Loudspeaker measurement	Asst #3 (15%)	
8-9. Digital Audio (ADC and sampling)	Asst #4 (15%)	P1: Progress report (10%)
10-11. Perception		
12. Guest lectures/student projects		EOT: Final report (25%)

Hardware	Software	Cost
USB 1.0 Audio (eg., Behringer UCA-222) - stereo input (16bit, 44.1/48 ksps, AC coupled) - stereo output (16bit, 44.1/48 ksps, AC coupled)	- Matlab/Octave (Win/Linux) - Python (Win/Linux) - C	$30 and up
Teensy 3.2 (PJRC.COM, SPARKFUN.COM) - 32 bit ARM Cortex-M4 72 MHz CPU (M4 = DSP extensions) - 2 analog inputs (16bit, 1M sps, DC coupled) - 1 analog output (12bit, DC coupled)	- Arduino/C	$20
National Instruments myDAQ - 2 analog inputs (16bit, 200 ksps, DC coupled) - 2 analog outputs (16bit, 200 ksps, DC coupled)	- **Matlab (Windows only)** - Labview (Windows only) - Python (Windows only)	$240 (Labview, student edition) *(www.Studica.ca, special disco* *negotiated for this course)*

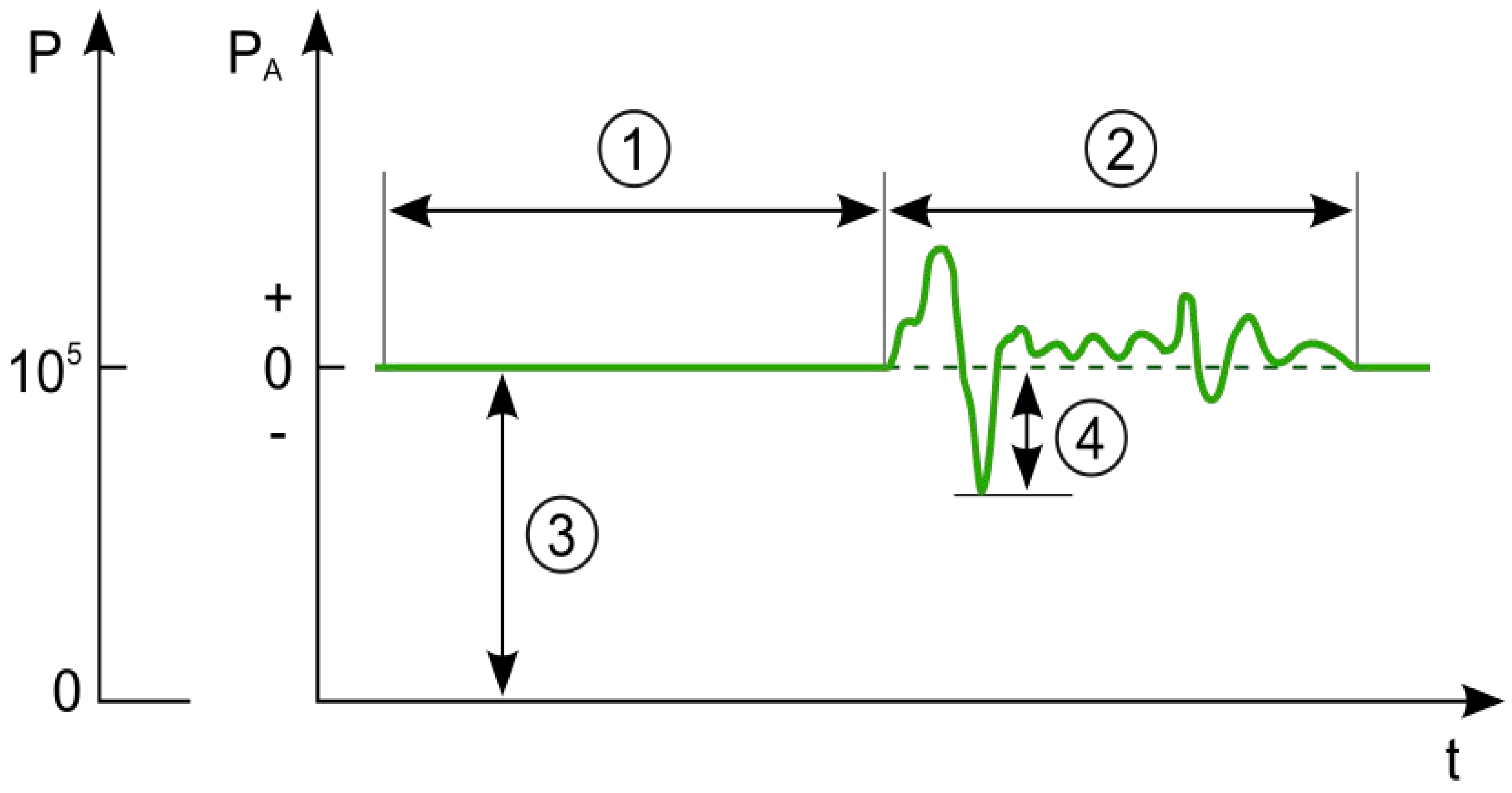
Project ideas?

- measure noise/ bit depth on the Teensy ADC/DAC.
- emulate analog guitar/synth effects
- measurement/calibration for surround sound system
- embedded programming for Teensy, eg., chromatic guitar tuner
- build your own subwoofer and measure it
- write open source software for realtime spectrum analysis
- …

Sound = changes in air pressure

1 atm = 14.7 psi = 103.1 kPa = 763 mm Hg = 406 in H20

Figure, https://en.wikipedia.org/wiki/Sound_pressure



P
P_A
1
2
+
10^5
0
-
3
4
0
t

Linear scale (Pascals)	Logarithmic scale (Decibels dB)
1000 Pa	154 dB
100 Pa	134 dB
10 Pa	114 dB
1 Pa	**94 dB**
0.1 Pa	74 dB
0.01 Pa	54 dB
…	
20e-5 Pa	0 dB (threshold of human hearing @ 1kHz)

Sou

Decibels are logartihmic scale,

20 decibels change == 10 x pressure change

Sound, wavelength

Speed of sound, c = 343 m/s = 1126 feet/s (20 C)

Wavelength, lambda = c/f

Using c~=1000 feet/s

12,000 Hz = 1 inch

1000 Hz = 1 foot

100 Hz = 10 feet

10 Hz = 100 feet

1 Hz = 1000 feet

Sound pulse (Olson p.5)

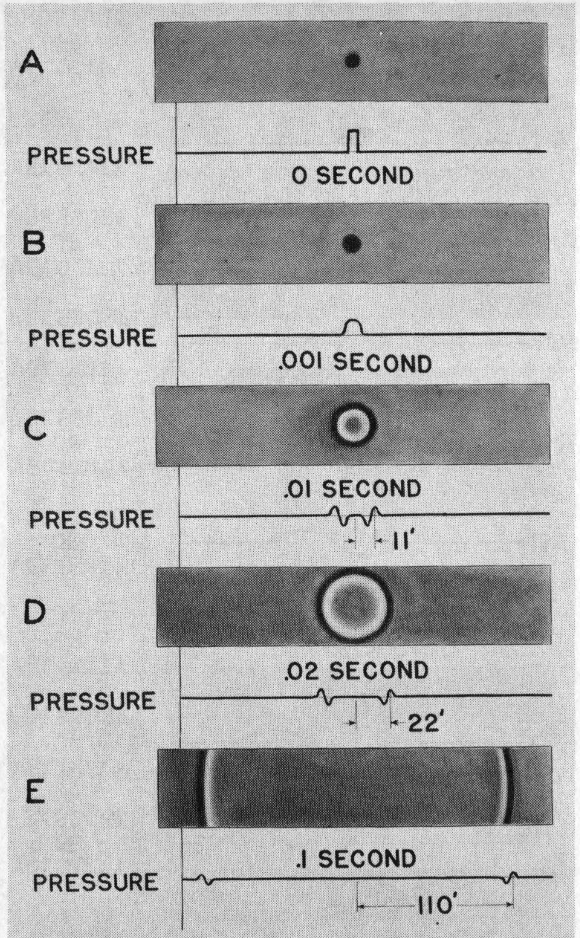


FIG. 1.1. The production of a sound wave by the bursting of a small balloon filled with compressed air. *A*. The balloon is filled with compressed air, and the air surrounding the balloon is in repose. The dark-gray area indicates the air in the balloon under pressure, and the gray area, the air in the undisturbed atmosphere. The graph depicts the pressure. *B*. The balloon has burst, and a pressure wave has started to move outward in all directions. *C*. This is a time 0.01 second after the bursting of the balloon, and the pressure wave has traveled 11 feet. Note that the condensation is followed by a rarefaction in which the pressure is below the normal undisturbed atmosphere. The pressure below the undisturbed atmosphere is indicated as a gray area which is of a lighter shade than the undisturbed atmosphere, while the pressure above the undisturbed atmosphere is indicated by a gray area which is darker than the undisturbed atmosphere. *D*. This is a time 0.02 second after the bursting of the balloon, and the sound wave has traveled 22 feet. Note that the amplitudes of the pressures above and below the undisturbed atmosphere have decreased as compared with *C*. This is due to the fact that the amplitude of the sound pressure is inversely proportional to the distance from the sound source in a spherical wave. *E*. This is a time 0.1 second after the bursting of the balloon, and the sound wave has traveled 110 feet. The amplitudes of the pressures have again decreased in accordance with

Continuous wave (Olson, p.8)

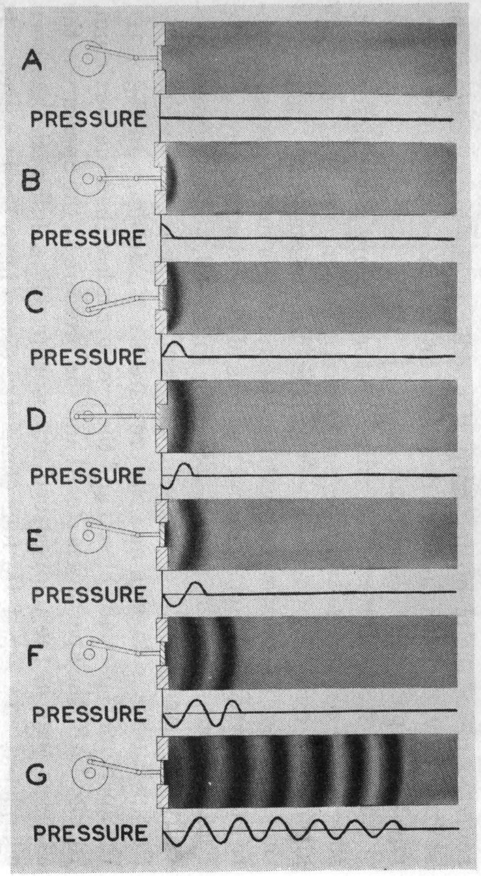


FIG. 1.3. The production of a sound wave by a vibrating or oscillating piston. The piston is moved back and forth by a crank and connecting-rod arrangement. The graph depicts the pressure. For reasons of simplicity, the conditions on the back of the piston are now shown. As in the preceding examples, the gray areas depict the normal undisturbed atmosphere, the dark-gray areas depict condensations or pressures above the normal undisturbed atmosphere, and the light-gray areas depict rarefactions or pressures below the normal undisturbed atmosphere. *A*. The piston is at rest. *B*. The crank has made a one-quarter turn. The motion of the piston produces a pressure above that of the normal undisturbed atmosphere. *C*. The crank has made a half turn, and the pressure at the piston is the same as that in the normal undisturbed atmosphere. *D*. The crank has made a three-quarter turn, and the pressure at the piston is below that of the normal undisturbed atmosphere. *E*. The crank has made a complete turn, and a complete cycle has been produced. The sound wave consists of one-half cycle with the pressure above the normal undisturbed atmosphere and one-half cycle with the pressure below the normal undisturbed atmosphere. *F*. The crank has made two turns, and a sound wave of 2 cycles has been produced. *G*. The crank has made six turns and a sound wave of 6 cycles has been produced. It will be seen that the amplitude of the sound pressure falls off with the distance from the sound source.

Diffraction (Olson p.15)

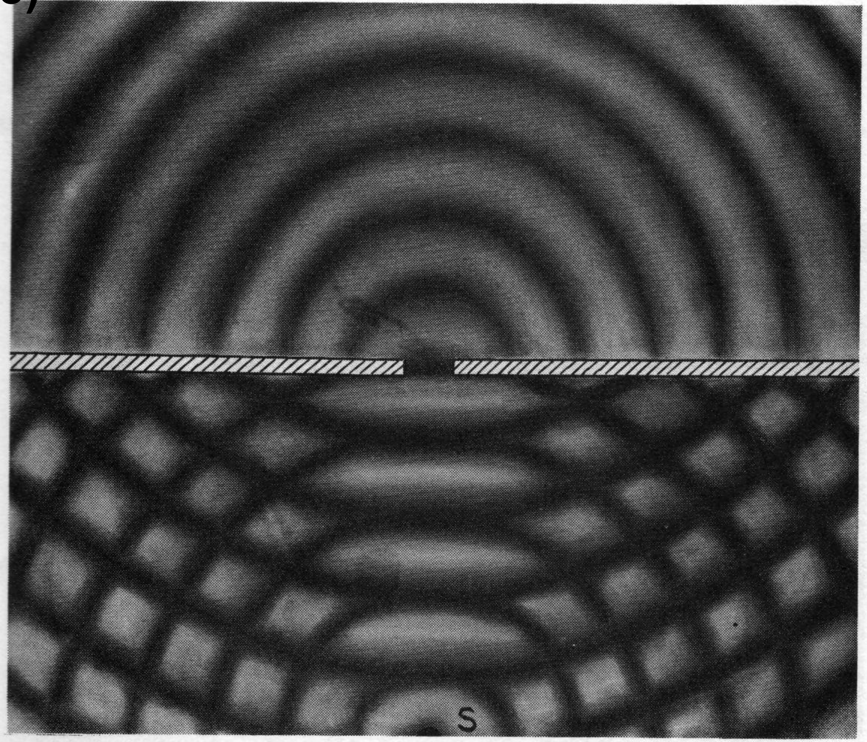


FIG. 1.6. The diffraction of sound. Sound waves emitted by the source S impinge upon the reflecting wall and the small aperture in the wall. The dimensions of the aperture are small compared to the wavelength of the sound. A major portion of the sound wave which impinges upon the wall is reflected. A small portion of the incident sound wave is transmitted through the small aperture. The sound waves which pass through the aperture radiate in all directions in the same way as though the aperture were a source of sound waves. The spreading of sound waves due to the passage through an aperture is termed diffraction.

Diffraction (Olson p.16)

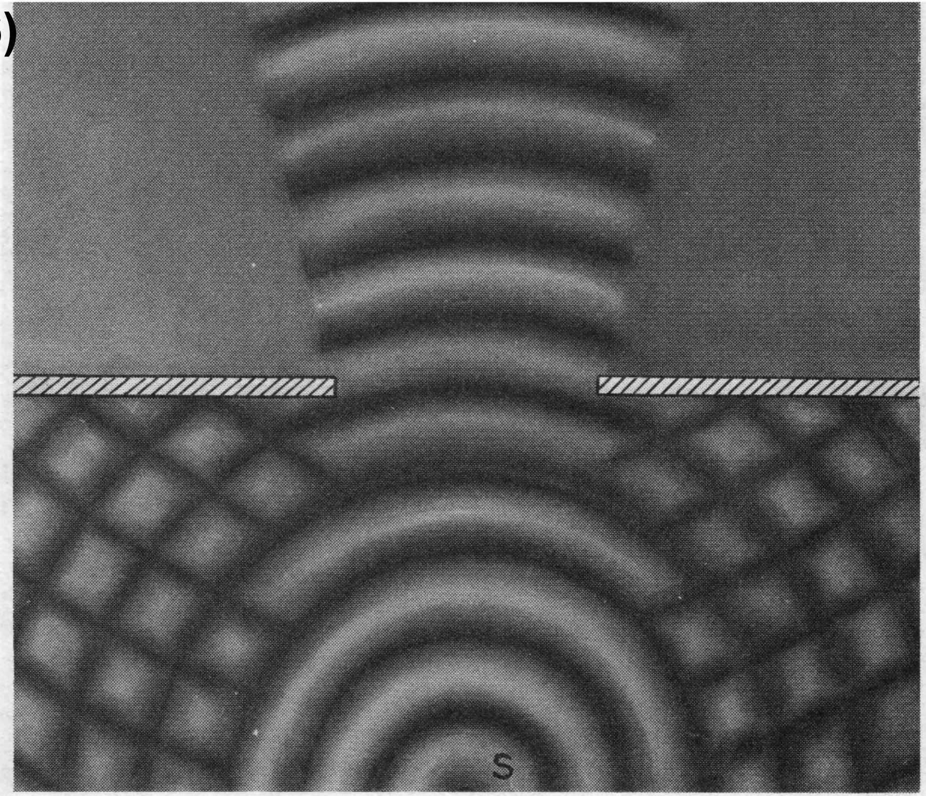


Fig. 1.7. The transmission of sound through a large aperture in a reflecting w
Sound waves emitted by the source *S* impinge upon the reflecting wall and the la
aperture in the wall. The dimensions of the aperture in the wall are large compa
to the wavelength of the sound. Under these conditions, sound is transmitted throu
the area defined by the aperture with no loss in intensity. Furthermore, the tra
mitted-sound beam is geometrically defined by the aperture. The sound waves whi
impinge upon the wall are reflected.

Occlusion (Olson p.17)

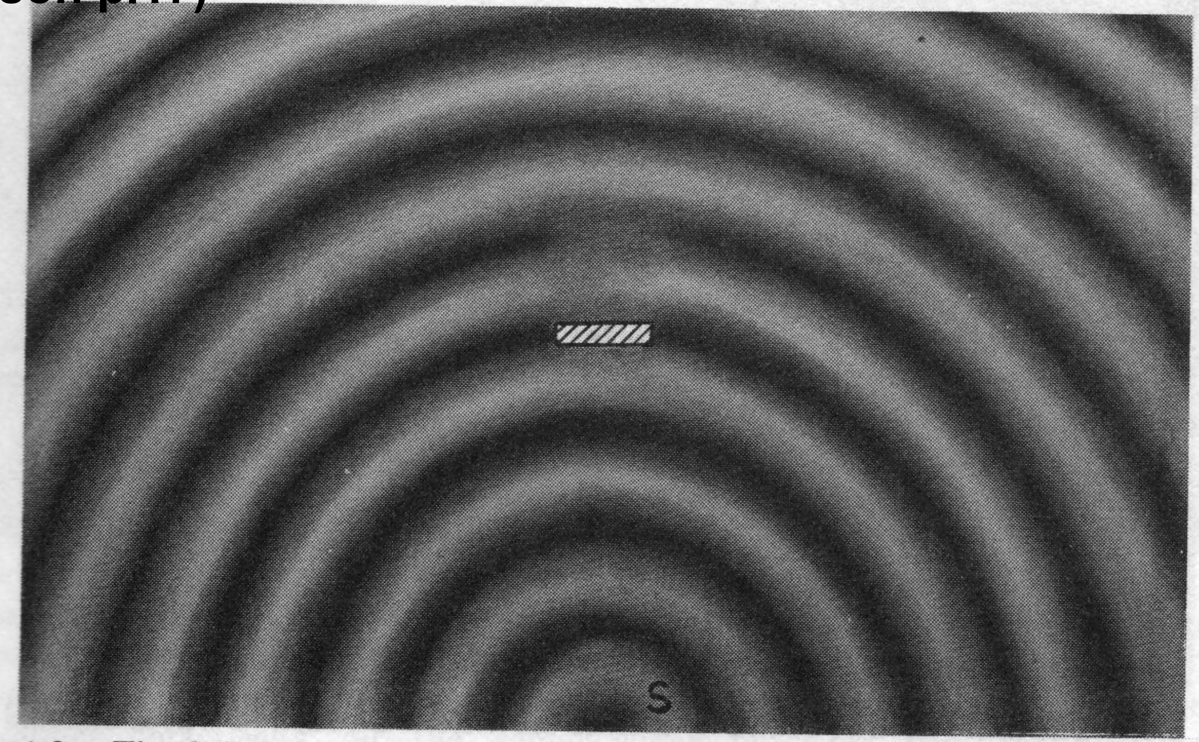


FIG. 1.8. The diffraction of sound by a small obstacle. Sound waves emitted by the sound source S impinge upon the small obstacle. The dimensions of the obstacle are small compared to the wavelength of the sound. Under these conditions, the sound waves bend around the obstacle and the sound shadow cast by the obstacle is negligible. The passage of sound around an obstacle is termed diffraction. Since the dimensions of the obstacle are small compared to the wavelength of the sound, the amount of reflected sound is negligible.

Course system: National Instruments “myDAQ”

- USB powered device, Digital I/O
- Two analog inputs (16bit, 200ksps), two analog outputs. DC Coupled.
- +/-15V analog supply + Optional Prototyping board.

Software “Virtual instruments”

- signal generator (sine, square waves), oscilloscope, spectrum analyzer

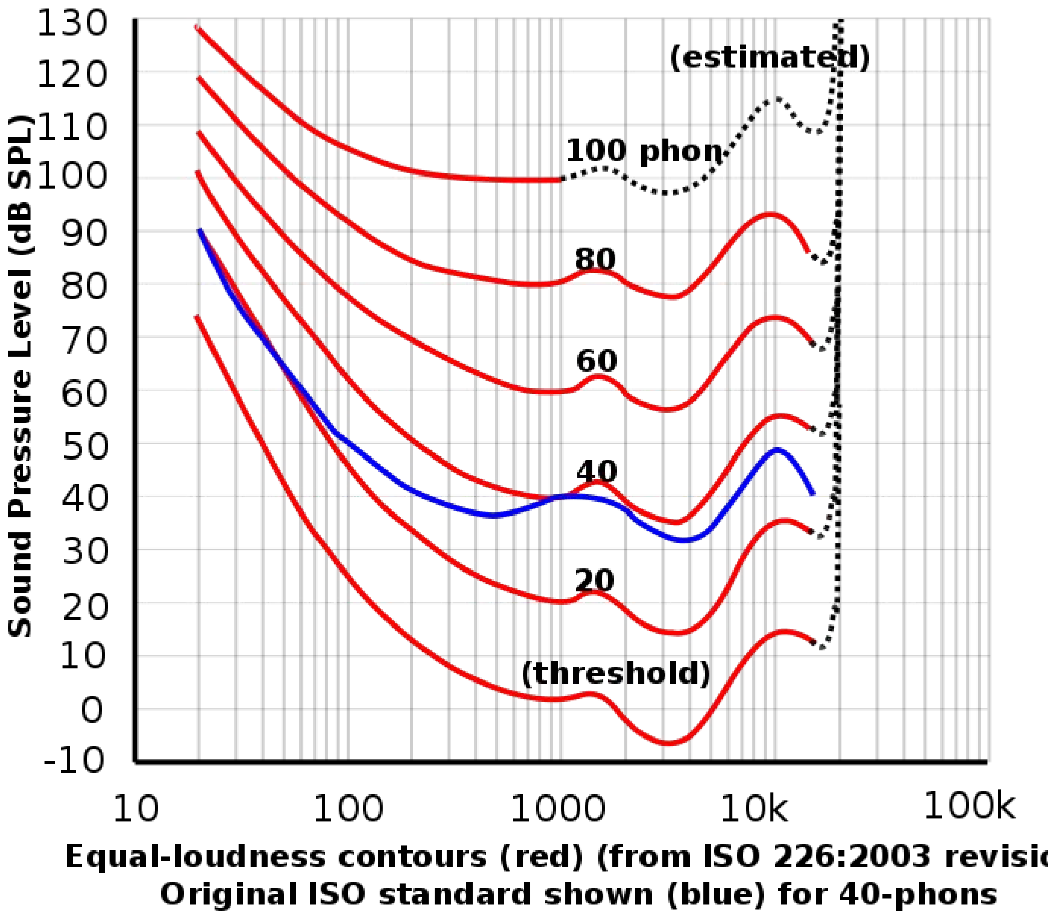
Programmable by Matlab/Windows. (Also works under Python/Windows)

(*) Not required, but students may purchase ($240CAD), includes Labview software.

(**) Qty 10 available for loan from School of Computer Science. Qty 4 PC machines with myDAQ will be available in AI lab (DC2306).

Demos. Signals

DEMO. Function generator into scope. Pure tones.



Fletcher-Munson curves, WikiPedia.

Loudspeaker

- Converts electrical energy (voltage/current) to mechanical energy (cone displacement).

DRAWING. (cf., Beranek p 243)

Loudspeaker

DEMO. Speaker moves air.

LINK. “Acoustic Levitation”. f ~= 25kHz, lambda ~= 1cm, level >140dB?

What sound pressures are possible in sealed cabinet?

DEMO: Cabinet pressure (hole closed). (Instrument: “MKS 223B Baratron”)

Loudspeaker

DEMO. Speaker in sealed cabinet.

How does sound wave (phase and pressure) vary with distance?

Loudspeaker measurement

Test setup: microphone level vs. signal generator input

Octave = doubling of frequency

Sequence of tones, from 16Hz to 512Hz, 5 octaves, 6 divisions/octave, total of 31 tones. For each frequency, 20 periods are played.

Bode Plot;

Loudspeaker

DEMO: Microphone inside cabinet (vs. signal generator)

Observation: inside pressure proportional to X (displacement) of cone

Note: resonance peak at approx 90Hz.

DEMO: Outside microphone vs inside microphone

Observation: outside pressure proportional to X'' (acceleration) of cone

Loudspeaker

DEMO Second speaker (“Optimus PRO-X44AV”)

Inside speaker vs signal generator

Note: no resonance peak. Shape of response depends on: box size, speaker mechanical properties (spring), and voice coil/magnet strength.

REF. Beranek p. 321

Loudspeaker

DEMO. Optimus Speaker mid frequency response.

+/-5dB variation is typical, and is certainly perceived by humans.

cf Beranek p.271. p.272.

Questions?

PC based sound measurement system.

Windows 7 laptop

Digigram UAX-220mic USB microphone interface

ASIO4ALL ASIO driver (free version)

Adobe Audition CS6 (IST site license)

NTI-2010 Measurement microphone x 2

DEMO: Calibrate rig.