UIUC Physics 406: Acoustical Physics of Music
Course Syllabus

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Introduction to Course, Course Structure, Organization:

- This course meets 3×/week, 4 credit hours.
  * Lecture/demos Tues & Thurs 12:30-1:50 pm in 6105 ESB, and:
  * 3 hr Lab Friday, either: Lab1: 11am-2pm, or Lab2: 2:00-5:00 pm in 6105 ESB
- Lecture/demo/lab/hands-on interactive/investigative-type format
- 1 HW assignment/week, lecture related.
- Take-Home Midterm & Final Exams.
- Lecturer: Steve Errede 435 Loomis, email: serrede@illinois.edu
  Phone(s): 333-0074 (office); 333-4225 (lab), 333-4452 (HEP sec'y)
- 2 TAs: Matt Ziemann mrziema2@illinois.edu, Andrew Ferrante aferran2@illinois.edu
- UG Lab Teaching Specialist: Jack Boparai 6101 ESB, email: jboparai@illinois.edu
- Course Project - of own choice (must be relevant to course), can be wide-ranging
  * Brief oral presentation on project @ midterm
  * Final oral presentation & final written report @ end of semester, substantive effort.
  * Final written report will be posted on P406POM Student Reports web page.
- Web page for course, URL: http://courses.physics.illinois.edu/phys406/
- Final grade: mix of HW, midterm, final exams, active participation in class & labs, project midterm & final oral presentation(s) and final report(s) on project(s).

Course Content:

- Essentially acoustical physics, with emphasis on music and musical instruments.
- What is music? For humans? For other animals?
- Why does music exist? Why is it important? For humans? For other animals?
- Why/how did music evolve? History of music/musical instruments.
- Human music, music associated with other living creatures…
- Importance of music today in our societies. In future? Evolution of music?
- Music in Nature/Music of the Cosmos… earth, sun, other plants, universe…
- Scientific study of music/musical instruments (history):
  * Ancient Greeks - Pythagoras (~ 500 BC) at least. Earlier endeavors?
  * Since then: Aristotle, Ptolemy. Huygens, Euler, Ohm, Young, Helmholtz
- How is music made?
  * (Collective) vibrations of atoms of matter
  * Matter vibrations coupling to air - collective vibrations of air molecules
  * Propagation of sound waves in air, other media, fluids & solids.
- How/why is music heard/perceived? Human & animal hearing/sound perception
  * Evolution - why is it beneficial to perceive sound?
  * Psychoacoustics - study of human hearing
  * How human ear(s) + brain work
  * Hearing in other animals
- Simple Vibrating Systems
  * Simple harmonic motion - e.g. mass on a spring, tuning fork
    + Frequency, period, wavelength, amplitude, phase, energy, energy loss/damping/dissipation, power

* Travelling waves and wave propagation in a medium
  + One-dimensional medium - bead-spring system
  + One-dimensional transverse and longitudinal waves
  + Wave propagation in two and three dimensions
* One-dimensional standing waves
  + Sum/superposition of two counter-propagating travelling waves
  + Boundary conditions for standing waves
    - Reflection, refraction, diffraction of travelling waves
    - Interference effects
    - Resonance effects
  + Transverse standing waves, e.g. on a guitar/violin/piano string
  + Longitudinal standing waves, e.g. in air - organ pipes/flutes
* Standing waves in two and three dimensions
  + Vibrating membranes/plates - drums, cymbals, musical saw, Chladni's law
* Doppler effect - source/observer motional effects on sound waves in air.
* Beats - interference between two frequencies
* Distortion - non-linear response & generation of harmonics of fundamental
* Intermodulation distortion - non-linear response with 2 or more frequencies.
* The Human Ear/Human Hearing
  + Structure of the outer & inner human ear, and its response to sound
  + Why two ears? Phase sensitivity, source location determination.
    Human hearing localization optimized for sound propagation in air…
  + Sound Intensity, I (Watts/m^2)
  + Sound Intensity Level, L (decibels)
    - Threshold of hearing, threshold of pain, noise levels/occupational exposure
  + Sound Pressure Level, L_p (decibels)
  + Loudness Level (phons)
  + Loudness (sones)
* Musical Tone Quality/Timbre
  + Pure tones/simple tones - sine/cosine waves
    - have well-defined frequencies/wavelengths, amplitudes & phases
  + Partial tones (= partials) - assembly of pure tones
    - = a mix of different frequencies & amplitudes
  + Complex tone - superposition of simple tones - complex waveform
  + Periodic complex waveform - has fundamental + harmonics/overtones
    - harmonics/overtones = integer multiples of fundamental frequency
    - phase sensitivity of human ear to complex tone/tone quality/timbre
    - harmonic (Fourier) analysis of musical instrument tones
  + Formants - resonances
  + Sound Envelope - attack time/decay time
* Sound Effects
  + Vibrato, tremelo, chorus, phase shift/flanging, reverberation/echo, etc.
  + Noise
  + Subjective tones - (non-linear response/distortion in the ear)
  + Auditory sensation "tricks"
* Musical intervals, musical scales, tuning and temperament
  + Consonance/dissonance
  + Discrete frequencies = scale

+ Frequency ratios: unison, octave, fifth, fourth, third, etc.
+ Interval = separation of two notes on a scale

* Musical Scales - Pentatonic, Pythagorean, Meantone Tuning, Just, Just Diatonic, Tempered Scales
  + whole tones, semi-tones, cents
  + pitch standard(s)
  + octave notation
  + frequencies of musical notes, e.g. in tempered scale
* Acoustics
  + Acoustics of auditoriums, recording studios, home listening rooms, etc.
    - Interference, sound absorption, Sabine eqn.
    - Reverberation & echo, spectral, octave & 1/3-octave band measurements of room/auditorium acoustics, T60, T30 measurements, etc.
    - Electronic Sound Reinforcement
    - Computer analysis/modeling electro-acoustics of auditoriums/studios/etc.
  + Acoustics of loudspeaker enclosures

- Production of musical sounds by musical instruments – mimic human voice, and/or natural human rhythms (percussion instruments).
  + Human Voice & Singing – 1st musical instrument – 1-D vibrational system.
    - vocal chords/larynx/hyoid bone/tongue/chest-mouth-nasal cavity & formants
    - Formants & use of formants/professional singers, Tuvan throat singing, etc.
  + Stringed Instruments
    - Physics of plucked & bowed vibrating strings
    - Plucked: acoustic/classical and electric guitar(s), mandolin, ukulele,etc.
    - Bowed: violin, viola, cello, bass
    - Hammered: piano, hammered dulcimer
  + Woodwind Instruments
    - Physics of whistles, reeds & organ pipes
    - Whistles: Whistle, recorder, flute
    - Reed: Clarinet, oboe, bassoon, saxophone
    - Pipe: Pipe organ, bagpipes
  + Brass Instruments
    - Physics of mouthpiece, bell
    - Trumpet, trombone, French horn
  + Percussion Instruments
    - Physics of vibrating bars, plates, membranes
    - Xylophone, glockenspiel, Fender-Rhodes piano
    - Drums (all kinds), cymbals (all kinds)
    - Musical saw
  + Electronic Musical Instruments
    - Electro-mechanical organs - e.g. Hammond B3
    - Electronic organs/keyboard instruments
    - Analog and Digital Sound Synthesizers,
    - MIDI & MIDI instrument
    - Computer-generated music
    - Electronic Stringed Instruments – guitars, bass guitar, cello, mandolin..
  + Analog & Digital Recording of Music & Sound
    - Edison phonograph - cylinder & disk records (analog)

    - Magnetic wire and tape recorders (analog & digital)
    - Digital recording (e.g. to CD, DVD, etc.)
    - Analog input transducers - condenser and dynamic microphones
    - Analog output transducers - loudspeakers
  + Music in the near-term and distant future
    - Human music - culture & society. New kinds?
    - Development of new kinds of musical instruments & technology.
    - Evolution of music in animals? Human - animal music interactions?
  + Sound Analysis Methodology & Analysis of Musical Sounds
    - Complex Harmonic Sound Fields – Euler's eqn., complex immittances, sound intensity, linear and angular momentum density, group and phase velocity, energy density.
    - Examples of Complex Sound Fields – near & far fields of acoustic monopole, dipole, quadrupole, … planar circular piston on oo-baffle…
    - Harmonic/Fourier Analysis/Fourier Synthesis – complex waveforms
    - Pressure and Particle Velocity Transducers
    - Phase Sensitive Measurements – Lock-In Amplifier Techniques
    - Near-Field Acoustic Holography – modal vibrations of drums, cymbals, acoustic guitars, etc.
    - Spectral Analysis Techniques – continuous & discrete Fourier transforms, FFTs, convolution, correlation, autocorrelation, cross-correlation, Wiener-Khinchine theorem, power spectral density, coherence function ….
    - Digital Signal Processing/Digital Filtering
    - Wavelet Analysis

- Physics of Electric Guitar Pickups, modeling EM properties of electric guitar pickups

- Physics of Loudspeakers, modeling of acoustic and EM properties of loudspeakers

- $1/f$ Noise in Human Music

- Diversity/Universality of Human Music

- Sustainability & Environmental Issues for Musical Instruments
    - Use of renewable natural resources for musical instruments – tonewoods….