Music 175: Pitch

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Pitch

- Pitch is the characteristic of sound that makes it sound high or low, or that determines its position on a musical scale.
- Though pitch is our perceptual response to frequency, and in particular to the *fundamental* frequency, other contributors include:
  - intensity
  - spectrum
  - duration
  - amplitude envelope
  - presense of other sounds

Review Pitch and Frequency

- A periodic waveform is one that repeats itself after a time interval T (the period).
- The frequency is the inverse of the period.
- For complex tones having an inverse period of f_0, the spectrum consists of *harmonics* of f_0.

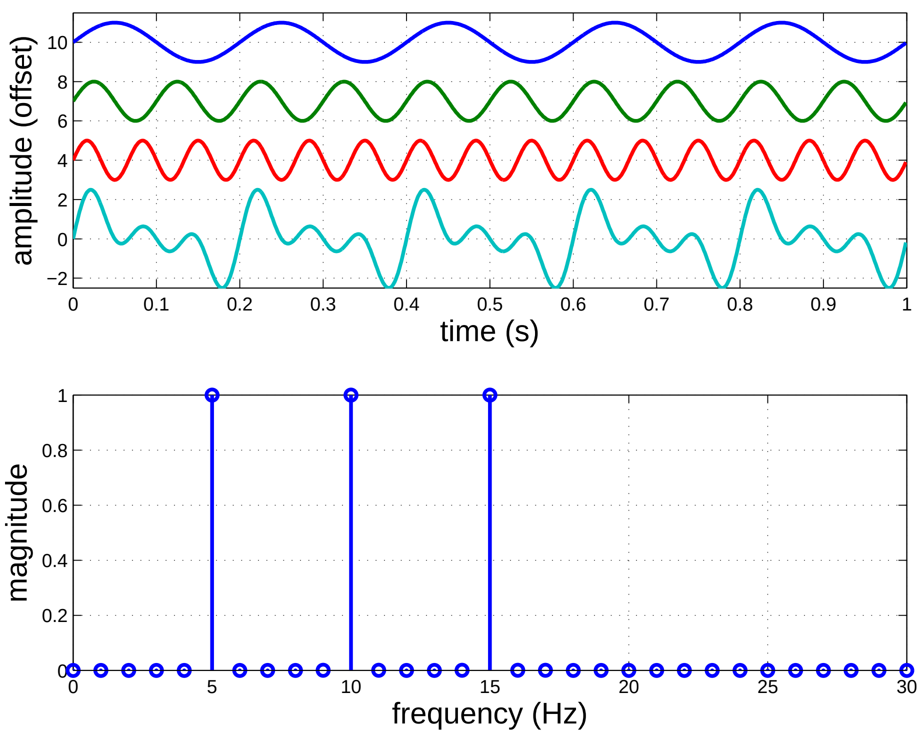

Figure 1: Adding sinusoids at 5, 10, 15 Hz in both time and frequency domain.

Frequency and Pitch

- Frequency dependence is seen in the patterns of firing of various fibers of the auditory nerve.
- In determining the pitch, the ear apparently performs both a *time* and *frequency* analysis of the sound.
- Two majar theories of pitch perception:
  1. place (or frequency) theory;
  2. periodicity (or time) theory.

Place Theory

- *Place theory of hearing*: different frequencies excite resonant areas on the basilar membrane (BM).
- The cochlea converts a vibration in *time* into a vibration pattern in *space* (along the BM);
  maximum vibration along BM depends on frequency
- This, in turn, excites a *spatial* pattern of neural activity:
  - different nerves go to different parts of the BM to pick up the pulses caused by vibrations
  - nerves that transmit information from different regions of the BM encode frequency tonotopically (tono = frequency and topos = place);
  - neural firing rate is a function of place (highs near the oval window and lows toward the other end);
- Experiments on cochleas removed from human cadavers allowed for observation of wavelike motions of the BM in response to sound.
- Place theory explains MANY—but not ALL—aspects of auditory perception.

Periodicity Theory

- One difficulty, in particular, is in explaining why *we hear complex tones as one entity with a single pitch*.
- According to *Periodicity Theory*, the ear performs a *time analysis* of the sound wave:
  - time distribution of elecrical impulses in the auditory nerve holds information about the time distribution of the sound wave;
  - yet nerve pulses aren't fast enough to encode exact waveforms.
- *Place theory* is necessary to account for our reception of the finer details in a waveform.

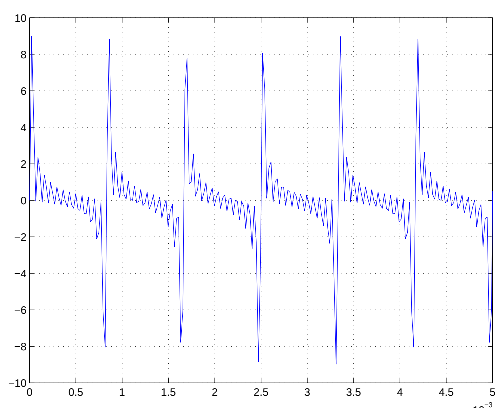

Figure 2: Peaks and wiggles.

Pitch and Brightness

- How is **pitch** different from **brightness**?
  - **pitch** depends on *periodicity*.
  - **brightness** depends on *distribution of total power between high and low frequencies*.
- High-frequency partials make a sound *bright*.
  - since musical tones ordinarily have no partials *below* their pitch frequency[1], *a high pitch tends to be brighter than a low pitch*.
- Example: at the same pitch:
  - vowel /i/ ("beet") is brighter than /u/ "boot";
  - trombone sounds brighter than a French horn:
    * Trombone
    * French Horn

Figure 3: French horn played facing away from the listener with hand in the bell.

[1]There are exceptions to this, as some tones (e.g. overtones) may have *subharmonics* appearing below the fundamental

Experiments with Clicks

- Periodic waveforms *must have sufficient duration (number of cycles)* to contribute to the sensation of pitch.
- A sinewave with only 4 cycles sounds like a click (no pitch), bright or dull depending on the frequency.
  - try `clicks.m`: Ncycles $=$ 4 and f0 $=$ 110, 3520.
  - short click, low frequency $\longrightarrow$ *dull*
  - short click, high frequency $\longrightarrow$ *bright*
- As the number of cycles is increased from 4, we begin to hear more of a pitch and less of a click:
  - try `clicks.m`: f0 $=$ 440, Ncycles $=$ 4, 10, 25.
- Number of cycles necessary to hear a pitch rather than a click
  - *increases somewhat with frequency* but
  - lies in the range of tens of cycles.

Pitch and Partials/Harmonics

- Musical tones have partials that are integer multiples of a fundamental frequency—the *pitch frequency*.
- The fundamental frequency need not be present.
  - (illustrate with `pitchpartials.m`).
- In experiments by Fletcher, filtering out low frequencies would not
  - impede recognition of instruments
  - change sensation of pitch.
- This is conistent with our everday experience listening through earbuds in which a full bandwidth is not present.
- Fletcher initially (incorrectly) proposed that the missing fundamental was recreated by nonlinearities in the ear.
- Later concluded that a tone must include 3 successive harmonics in order to hear the pitch frequency.

Terhardt

- Terhardt defined
  - *virtual pitch*: charaterized by the presence of harmonics or near harmonics.
  - *spectral pitch*: corresponding to individual audible pure-tone components.
- Terhardt defines the crossover from virtual to spectral pitch to be at 800 Hz.
  - for frequencies well above 1000 Hz the pitch frequency is heard only when the fundamental is actually present.
- Most pitches we hear in normal sounds are virtual, whether fundamental is present or not.

High and Low Pitches

- The mechanism of human pitch perception is different at low and high pitches:
  - Fletcher's observations on pitch do not apply at very low frequencies and above 1000 Hz;
  - Terhardt defines the crossover from virtual to spectral pitch to be at 800 Hz.
- At very low frequencies, we may hear successive features of a waveform, so that it is not heard as having just one pitch.
  - try pitchpartials.m at low 27.5
- For frequencies above 1000 Hz, the pitch frequency is heard only when the fundamental is present.
  - try pitchpartials.m
- Fletcher proposed **place theory for high pitches** and **a time mechanism for low frequencies**.
- There is no apparent discontinuity in the sensation as we play notes from lowest to highest pitches—two mechanisms overlap in frequency range.

Experiment with Pitch and Partials

- Using `pitchpartials.m`:
  - add successive equal-amplitude harmonics to f0 = 55 and f0 = 440.
  - listen for gradual reinforcement of the pitch frequency.
  - listen for a sense of a higher frequency (especially f0 = 55).

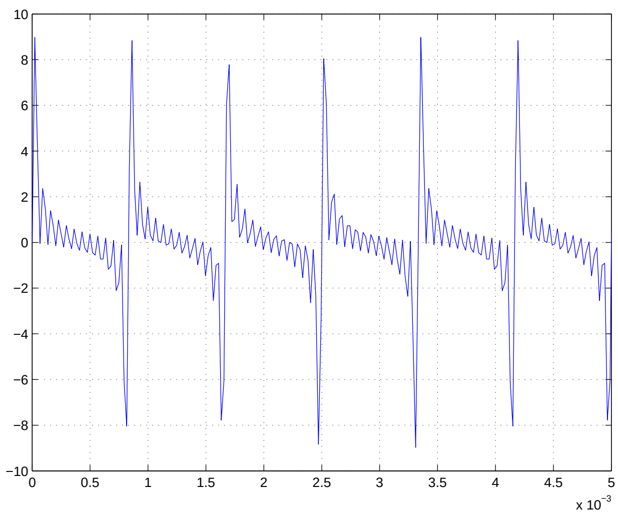

Figure 4: Peaks and wiggles.

- Regular peaks account for hearing f0, and wiggles creates sensation of a higher pitch.

- We can get rid of this sensation by choosing the relative amplitudes differently.
- At around 440 Hz, the ear can get the "right" pitch from the first 6-12 harmonics but NOT from harmonics 7 through 12.
  - at 440, the time resolution of the ear isn't good enough to follow the envelope;
  - instead, we get a sound based on the frequencies of all the wiggles, small or large.
- Duplex Theory of Pitch says we use two pitch mechanisms:
  - based on periodicty at lower frequencies,
  - based on frequency (place theory) at higher frequencies.

Experiments with Tone Bursts

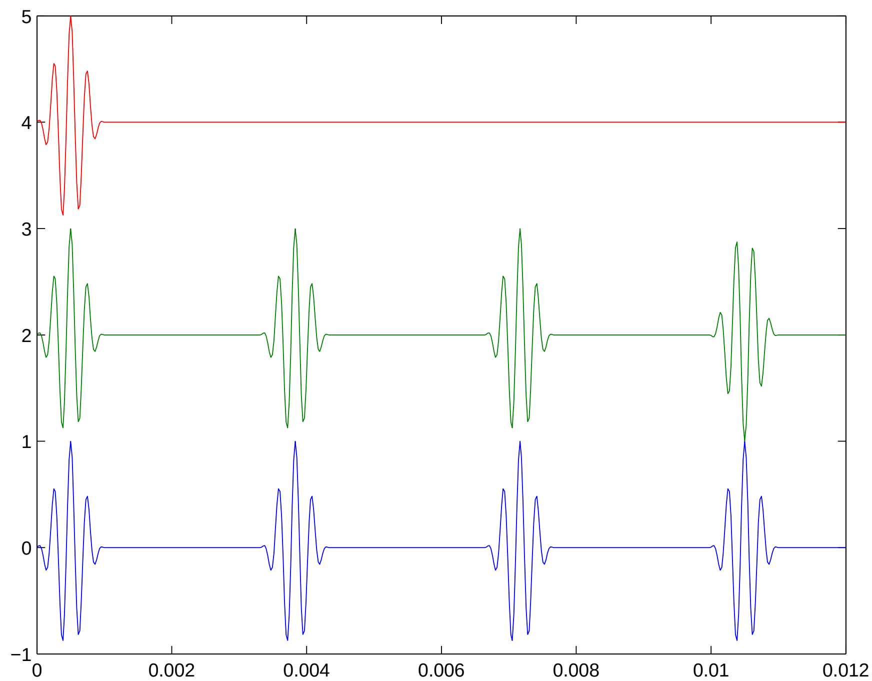

Figure 5: Sequences of tone bursts.

- See `tonebursts.m`
- Up to a rate of 300 tonebursts/s, (bottom) and (middle) have the same pitch and (top) is two octaves lower.
- At a rate above 1600, (middle) and (top) have the same pitch, which is two octaves below (bottom).

Two Mechanisms of Pitch Perception

- Experiments support this notion of two pitch perception mechanisms.
  - a sort of counting mechanism (lower frequencies)
  - another mechanism that takes over when the ear cannot “count” peaks in the signal’s time envelope.
- It is plausible that the high-frequency mechanisms relies on the amplitude of excitation along the basilar membrane.
- Mechanisms appear to be equally effective at about 640 Hz.

Odd Harmonics Only

- In a tone such as the clarinet, even harmonics are much weaker than odd.
- In a synthesized tone **with only odd harmonics**, we hear the fundamental (repetition) frequency ... except...
  - when the fundamental is absent;
  - sufficiently low frequencies;
  - see `oddharmonics.m`.
- When the pitch frequency is low, the *loudness* of the fundamental (and other low harmonics) is much less than that of the higher harmonics (recall *equal-loudness curves*).
- In the case of odd harmonics only, the frequency separation between successive odd harmonics is twice the pitch frequency.
  - the ear makes a pitch judgment based on the distance between the higher harmonics.