Physics 199 Physics of Music

Lecture Notes Week VII

[Chapter VII — Frequency & Pitch, ***Acoustical Foundations of Music***]

Pitch = human ear's perception of frequency of a sound vibration

Low pitch ⇔ low frequency of vibration/oscillation
High pitch ⇔ high frequency of vibration/oscillation

Audible Frequency Range of Human Hearing:
$15-20\text{ Hz} < f < 20\text{ KHz} \quad (\simeq 3\text{ orders of magnitude})$

As we grow older, dynamic range of frequencies we can hear decreases (both high and low frequencies)

Frequency ranges of musical instruments typically ~ 100 Hz to $\sim$ few KHz
e.g. guitar Low E = 82 Hz
High E = 330 Hz

Piano highest note is ~ 4200 Hz
Very little above ~ 10 KHz (squeals & scrapes)

Human ear needs to be able to perceive a sound for a minimum length of time in order to determine pitch – this minimum time depends on frequency:

For $f \sim 100\text{ Hz}\ (\tau \sim 10\,m\text{sec})$: $t_{\text{min}} \simeq 40\,m\text{sec} \quad (\sim 4\text{ cycles})$
For $f \geq 1000\text{ Hz}\ (\tau \leq 1\,m\text{sec})$: $t_{\text{min}} \geq 13\,m\text{sec} \quad (\geq 13\text{ cycles})$

Perceived pitch also depends to some extent on the ***loudness*** of the sound.
— Effect arises due to non-linearities in the response of the ear.
— Pitch appears to ***decrease*** slightly as loudness increases.
— This effect exists only for pure/simple tones (!!!)
— Complex tones show ***no*** perceived pitch changes with intensity! (why??)

Two ears of the same person may ***NOT*** perceive sound of a given frequency as having the same pitch!!! = DIPLACUSIS – happens only for diseased and/or injured ears.

For ***normal*** musical purposes, frequency and pitch are synonymous (usually) — Applies only to ***periodic*** sound vibrations.

Sound ***pulses*** are made up of a ***continuum*** of frequencies, i.e. sound pulses are anharmonic and hence have ***no*** characteristic frequency and/or pitch.

Human ear can discriminate changes in sound intensity levels of ~1/2 dB. This corresponds to a ~ 12% change in sound intensity. Thus, the ear is not very sensitive to accurately discriminating changes in loudness of sounds.

Typical human ear can discern changes in pitch/frequency at the $\Delta f \sim 3$ Hz level in the frequency range $\sim 30 \leq f \leq 1000$ Hz.

Note that: $\frac{\Delta f}{f} = \frac{3}{30} = 10\% \quad (\simeq \text{ 2 semitones}),$

Whereas: $\frac{\Delta f}{f} = \frac{3}{1000} = 0.3\% \ (\simeq \text{ 0.1 semitones})$

A good musician can actually discern frequency/pitch changes that are ***much*** smaller than this. Above $f \geq 500$ Hz, ≈ 0.03 semitone!!!

∴ The human ear/brain *is* capable of detecting small changes in frequency!!!

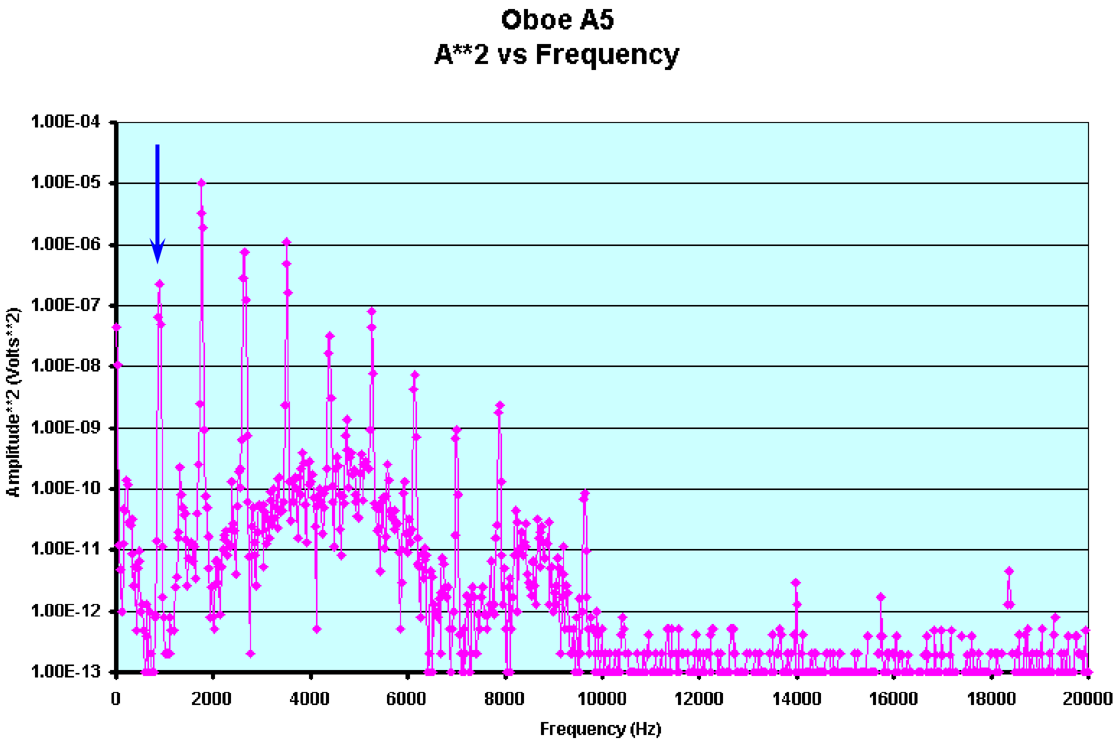
The human ear/brain is also capable of perceiving a fundamental even when ***no*** fundamental is actually present!!!

— This is the so-called ***missing fundamental effect***.

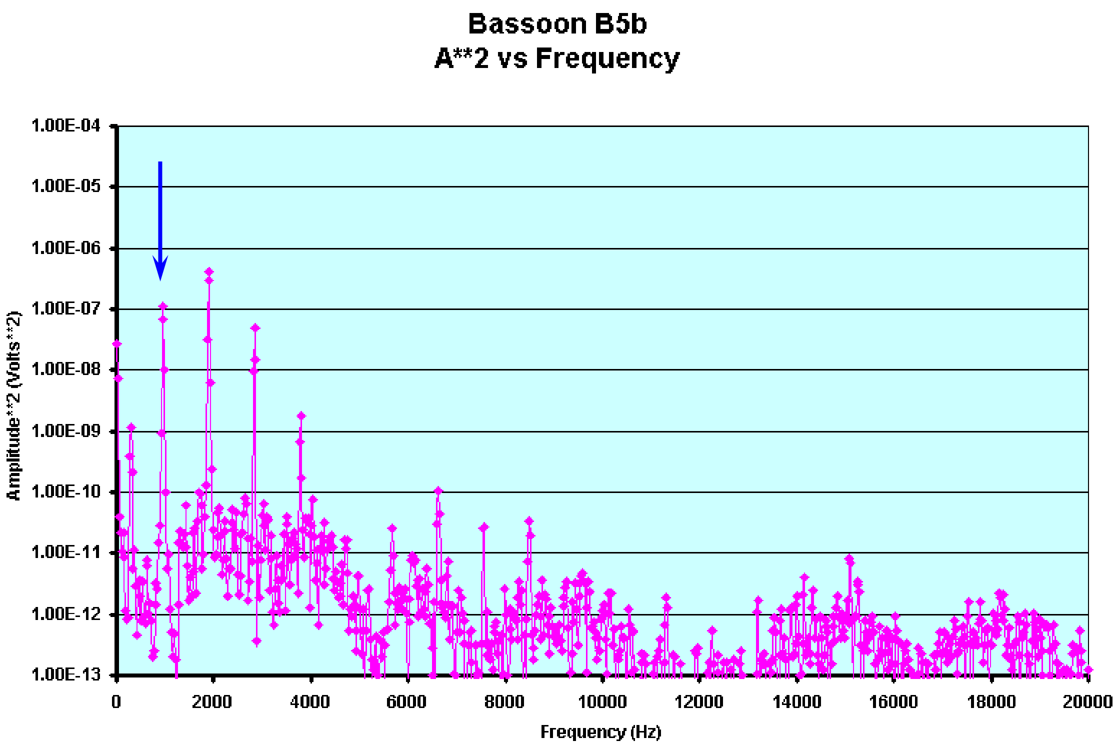
— This effect is likely due to the presence of a quadratic non-linear response in/inside the human ear itself and/or due to a quadratic non-linear response in the human brain's ***processing*** of frequency information.

Whenever a quadratic non-linear response exists (in any system), if two signals A and B with frequencies f_A and f_B are input to that system, sum and difference frequencies $(f_A + f_B)$ and $|f_A - f_B|$ are produced!
Thus, for a system with a quadratic non-linear response, a 2nd harmonic, $2f_1$ and a 3rd harmonic, $3f_1$ can produce a "missing" fundamental from the difference frequency, $|3f_1 - 2f_1| = f_1$!!! For further details on non-linear reponses and distortion, read e.g. Professor S. Errede's UIUC P498POM lecture notes on "Theory of Distortion I & II" – available on the web at:
http://online.physics.uiuc.edu/courses/phys498pom/498pom_lectures.html

— For some musical instruments – e.g. the trumpet, the oboe and/or the bassoon – the 2nd (even 3rd) harmonics have a ***larger*** amplitude than that of the fundamental, however we perceive the "note" that is played on the trumpet (and/or oboe, bassoon) as that of the fundamental!!!



$f_{A5} = 880.0$ Hz, $f_{Bb5} = 932.3$ Hz



Note that the vertical axes are displayed on a logarithmic scale.

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