

Mahalia Lotz

Dr. Grant Gustafson

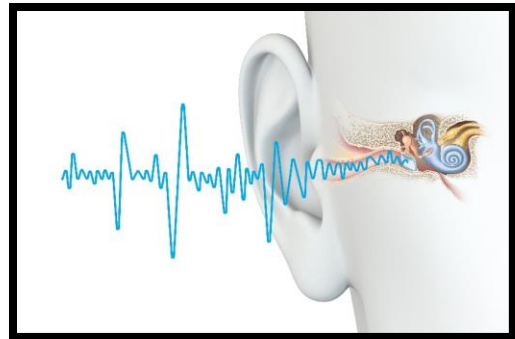
MATH 2270

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Variations in Waveforms and Energy Spectra between Musical Instruments

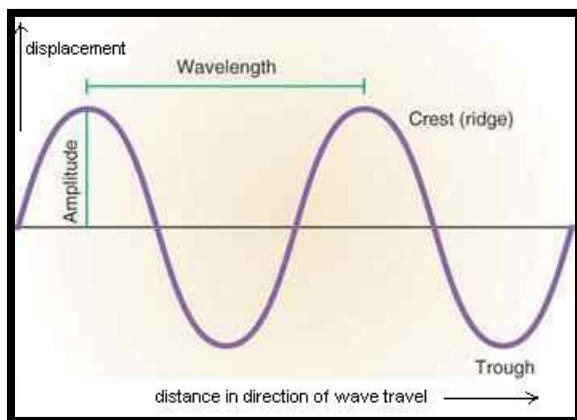
Sound occurs when particles are displaced by some initial motion to create a wave-like motion, or vibration. People are able to aurally observe some of these vibrations as sound when the waves travel through mediums such as air and pass into the ear. This does not hold true for every vibration because the human body is not capable

of distinguishing every vibration as sound; the human range of hearing contains approximately 1,400 separate pitches. Within the inner ear a biological process converts the vibrations into neural signals



which are finally translated into the particular sound they correspond to in the brain.

In the field of physics, sounds can be characterized by five attributes: frequency/wavelength, speed, amplitude, intensity/pressure, and direction. Frequency refers to the

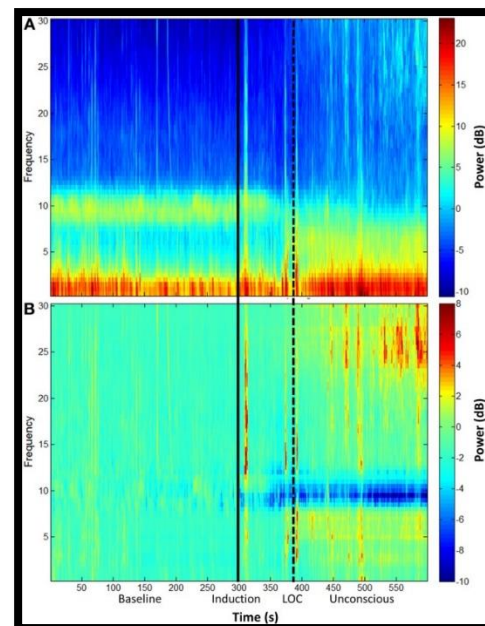


time it takes a wavelength to repeat from one peak to the next, or the speed of the wave, and is measured in hertz. Amplitude is a measurement of the vertical length between peak and trough. Intensity is closely related to amplitude and can be simply defined as loudness. Intensity is

measured in decibels. Direction is sufficiently self-explanatory for the purposes of this paper.

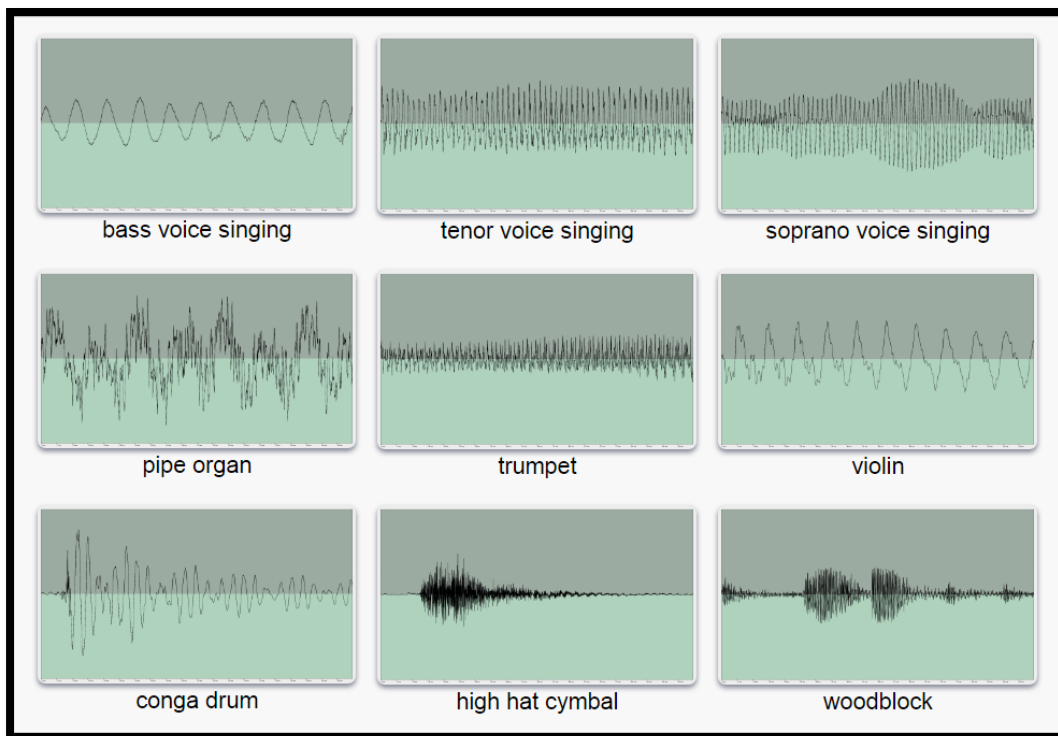
The field of music incorporates further criteria for analyzing sound that also qualifies as music, defined as ordered sound. It is important to note that the system for musical rules and structures fluctuates over time and between cultures and genres, but this paper refers to current, Western conventions. The most important characteristic of musical sound to comment on is pitch. Pitch is the relative highness or lowness of a note and is determined by the frequency of the sound wave, or speed of the vibration. The higher the frequency, the higher the pitch. The note A4, the A above middle C, is conventionally set to 440 hertz. An octave above A4 is A5, which is set to 880 hertz, twice the value of A4. This concept of exponentially, that each successive octave covers twice the frequency values as the previous, holds true for the entire range of notes. Another important instrumental fact to mention here include that some instruments are designed to produce sustained sound while others cannot sustain sound.

Waveforms and energy spectra assist in the analysis of sound. A waveform is simply a graph that shows a soundwave's amplitude on the y-axis and time on the x-axis. The sine wave is an example of a basic waveform. This makes important characteristics such as amplitude, frequency, duration, speed, pitch, etc. easily discernable. Oscilloscopes are the instruments used to project the waveform of a sound onto a screen. Energy spectra constitute a more complex method for analyzing sound, and this is where linear algebra becomes applicable. A process called spectral analysis, or Fourier analysis, is used to take apart a waveform and transforms it into an infinite series of discrete sine and/or cosine functions. The graph that results, or the spectrogram, show spectral density with respect to time.



Spectral density is defined as the energy of a sound at some time with some frequency. The Fourier analysis is necessary to calculate spectral density. This graph of spectral density is useful because it displays frequencies produced at unusual intensities.

The figure above shows the waveforms for nine different musical instruments. They



obviously display different frequencies and wavelengths, indicating different pitches; these musical instruments played a variety of notes. For example, the waveform of the bass voice has a lower frequency than that of the tenor voice, which in turn has a lower frequency than the waveform of the soprano voice. This makes sense, as basses generally sing at lower pitches than tenors, who sing at lower pitches than sopranos. Also, a difference in intensity can be observed between instruments which rely on breath (or some other renewable motion) to sustain sound and those which do not. For example, the waveform of the high hat symbol shows a concentration of waves with large amplitude that die away, while the waveform of the trumpet displays relatively consistent waves throughout. This makes sense, as the cymbal is hit once, producing an explosion

of sound that gradually dampens, and the trumpet's sound can be sustained with continuous breath. As a final observation, even if frequency/pitch/note is held constant across instruments, volume can vary, which will produce different amplitudes in the waveforms.

The analysis of sound is a popular topic in many academic fields, particularly physics and music, as well as in practical enterprises that relate to producing, recording, or projecting sound and music. Waveforms and spectral analysis assist a great deal with answering the diverse questions that arise in there, especially since the discovery of Fast Fourier Transformations (FFT), which has increased access and accuracy for spectral analysis in recent decades.

Citations

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