9.1.6: Missing Fundamental Simulation

The simulation is actually the same as the Fourier simulation in the previous chapter but you will do something different with it. Up to eight harmonics (five on mobile devices) of a sine wave are shown and the fundamental is set at $f_1 = 200\ \mathrm{Hz}$. The second harmonic is $f_2 = 400\ \mathrm{Hz}$, the third harmonic is $f_3 = 600\ \mathrm{Hz}$, etc.

Note

The Fourier Series and Sound JavaScript Model uses the HTML 5 Web Audio API. This API is still under development and may not be supported on all platforms. Press the Reset button to reinitialize the simulation if the sound does not play when the simulations is first loaded.

Simulation Questions:

1. With a fundamental frequency of $200\ \mathrm{Hz}$, push all of the sliders to the right. Listen to the sound (you may need to use external speakers or good headphones since the built-in speakers in your computer are usually not very good). Describe the sound, the timbre.
2. Now slide the first slider, A_1, to zero. You will notice a change in the timbre of the sound but does the perceived pitch (the note being played) change?
3. Try sliding both the A_1 and A_2 amplitudes to zero, leaving the other amplitudes at 1.00. The timbre will again be different but does the perceived pitch change?
4. Try leaving only the highest two frequencies at maximum amplitude and the others at zero. Has the perceived pitch changed?

The missing fundamental is what makes it possible to hear music over small speakers that cannot reproduce the full range of frequencies. Small speakers often do not produce the lower base note frequencies but you still hear them because the higher harmonics are present and your ear-brain system fills in the missing fundamental. As we will see, for many musical instruments, percussion instruments in particular, the missing fundamental is the note we hear when the instrument is playing.

Experiments done with pure tones through headphones show that in fact you only need two frequencies, for example $200\ \mathrm{Hz}$ and $300\ \mathrm{Hz}$, to perceive a missing fundamental of $100\ \mathrm{Hz}$ if the notes are in phase. Even stranger is the fact that you will perceive the missing fundamental when the individual harmonics are played to different ears. Somehow the brain combines signals from both ears to hear one note at a frequency that isn't present. Any theory of how the ear works must be able explain this and other curious auditory phenomena.

The idea that certain regions of the basilar membrane respond to certain frequencies as an explanation for sound perception seems to be basically correct. The place theory, however, cannot explain the missing fundamental phenomena. If a fundamental frequency is missing it cannot cause that region of the basilar membrane to vibrate yet we perceive the frequency as being present. Somehow the harmonics add up to give us that experience. In fact, we would expect that if the harmonics were exciting different regions we might perceive separate harmonic tones instead of one single note but we don't; nearly all listeners hear a single missing fundamental.

In support of the temporal theory, the missing fundamental shifts in a peculiar way if the harmonics shift. For example a missing fundamental of $200\ \mathrm{Hz}$ is heard when harmonics of $1800\ \mathrm{Hz}$, $2000\ \mathrm{Hz}$ and $2200\ \mathrm{Hz}$ are played. It would be tempting to say that the difference of $200\ \mathrm{Hz}$ between the harmonics causes the perception of a $200\ \mathrm{Hz}$ signal. But if these frequencies are shifted to $1860\ \mathrm{Hz}$, $2060\ \mathrm{Hz}$ and $2260\ \mathrm{Hz}$, also a difference of $200\ \mathrm{Hz}$, the ear-brain system perceives a missing fundamental of about $207\ \mathrm{Hz}$. The temporal theory can explain this because the peak to peak period of the second combination of frequencies is around $4.83\ \mathrm{ms}$ which would be the same as a pure tone of $207\ \mathrm{Hz}$. On the other hand, the temporal theory predicts a greater sensitivity to the phase of a wave than we experience (under most circumstances we are unaware of the phase of a given frequency). The place theory does not have this problem.

It is possible (and there is some evidence to support the idea) that both place and temporal mechanisms work but operate in different frequency regimes. The place theory seems to be the more likely mechanism for frequencies above $5000\ \mathrm{Hz}$ while the temporal theory seems to be a better explanation for frequencies under $5000\ \mathrm{Hz}$. Someone with perfect hearing can hear frequencies up to $20,000\ \mathrm{Hz}$ but our sense of pitch and ability to distinguish differences in frequency gets much weaker for frequencies above $5000\ \mathrm{Hz}$ as noted in Section 8.1.3 on just noticeable differences in frequency. These features of our ear-brain system fit with a dual system of frequency detection. Most likely the mechanisms for both theories combine somehow to give us our perception of musical sound.