8.2.4: Timbre (again!)

If you did the mini lab or played with one of the Fourier analysis apps you should have detected a different Fourier spectrum for instruments or voices that were different, even when they were playing the same note. According to Fourier, complex waveforms can be constructed from combinations of sine waves. It is these additional frequencies that are the main property that give a musical tone its *timbre*. As shown in the graphs below, we can tell a trumpet from a trombone, even when they play the same note because there are different frequencies present. These variations in frequency change the waveform (top two graphs which can be seen with an oscilloscope) and the Fourier spectrum (lower two graphs which can be determined from a Fourier analysis).

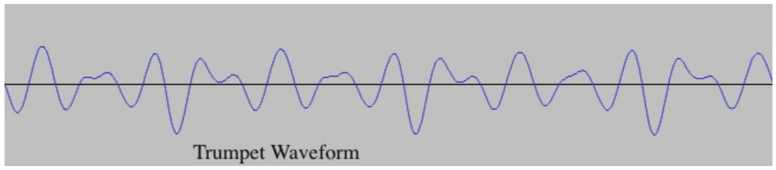

Figure 8.2.4.1

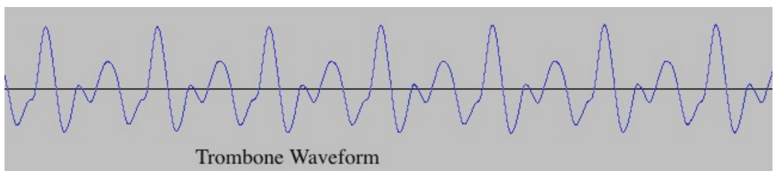

Figure 8.2.4.2

Below the Fourier analysis of each of the above waveforms using the program Audacity. Notice that the fundamental frequency (the lowest frequency) is the same for both instruments (around $230\ \mathrm{Hz}$) so they are playing the same note, even though they will sound different.

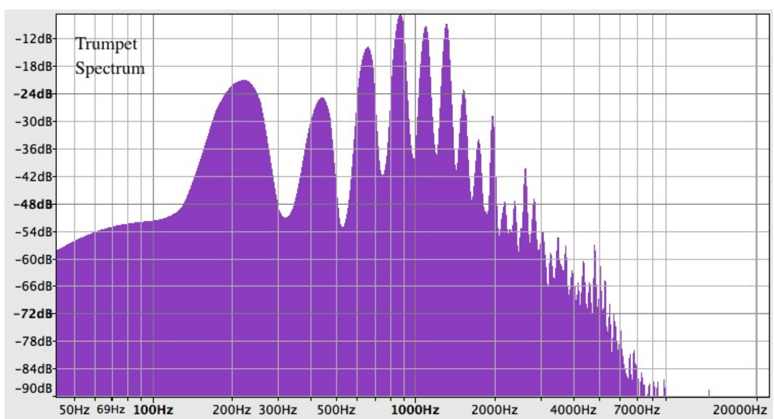

Figure 8.2.4.3

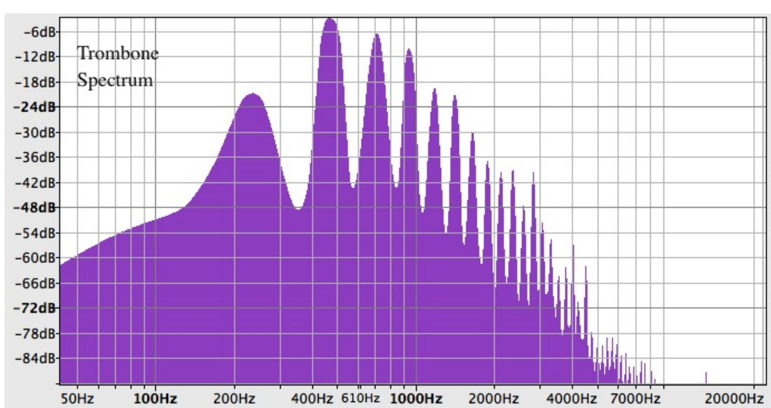

Figure 8.2.4.4

Most notes produced by musical instruments have higher frequencies that are multiples of the fundamental, or lowest frequency. When the higher frequencies are multiples of the fundamental they are called ***harmonics***. The more generic term for frequencies produced by an instrument or voice that are higher than the fundamental (whether multiples or not) is ***overtone***. We will discuss this in more detail in Chapter 11 on strings and stringed instruments.

Video/audio examples:

- Fourier spectrum of a clarinet and oboe and a trumpet.
- A 6 min. YouTube review of a few major points.
- Here is a Chrome Music lab demonstration of a few sound sources and their Spectrograms. A spectrogram shows the Fourier frequencies (plotted vertically) as they change over time (with time plotted on the horizontal axis). Audacity and some mobile apps (for example Spectral View) will show spectrograms.

Summary

The French mathematician Fourier discovered that you could build any repeating waveform by adding enough sine and/or cosine waves. This is called Fourier synthesis. It is also possible to analyze a repeating waveform to find out how much of each frequency is present. This is called Fourier analysis. For a repeating wave the extra frequencies present are all multiples of the fundamental and are called harmonic frequencies. The timbre of a musical instrument depends on the amount of each harmonic that is present.

Questions on Fourier:

1. What does the fundamental frequency of a musical instrument determine?
2. What is an oscilloscope? What does it do?
3. Explain Fourier synthesis.
4. Explain Fourier analysis.
5. What is a Fourier series?
6. In a nutshell, what is the difference between Fourier analysis and Fourier synthesis?
7. What are harmonics?
8. If the fundamental of a note is 220 Hz, what is the frequency of the second harmonic? Third harmonic?
9. What is a normal mode?
10. Use a graphing calculator (or paste these into the online graphing calculator www.metacalculator.com/online/) to graph the following series. What shape do you get for each?
    a. $1*\sin(x)+(1/3)*\sin(3*x)+(1/5)*\sin(5*x)+(1/7)*\sin(7*x)+(1/9)*\sin(9*x)+(1/11)*\sin(11*x)$
    b. $1*\sin(x)-(1/9)*\sin(3*)+(1/25)*\sin(5*x)-(1/49)*\sin(7*x)+(1/81)*\sin(9*x)$
    c. $1*\sin(x)-(1/2)*\sin(2*x)+(1/3)*\sin(3*x)-(1/4)*\sin(4*x)+(1/5)*\sin(5*x)-(1/6)*\sin(6*x)+(1/7)*\sin(7*x)$
11. For each of the above series, add a few more terms following the pattern and re-plot the series. What can you say about adding more terms to the series?
12. When a trumpet and a clarinet play the same note, they are making a sound wave with the same fundamental frequency. Explain why, even though they are playing the same frequency the two instruments sound different. (Answer with more than just “their timbre is different”.)
13. What is timbre and what causes it?
14. Why do different instruments or voices playing or singing the same note sound different?
15. Suppose you do a Fourier analysis of the sounds from a trumpet and a guitar, each playing the same note. What would be the same in the two analyses and what would be different?
16. Describe your experience with the program Audacity in the mini-lab. What did you do, what did you learn?
17. What is different about the Fourier spectrum of simple sound sources such as tuning forks and the spectrum of musical instruments?
18. What does a spectrogram show (this is one of the options in Audacity)?
19. In general terms, how do electronic synthesizers work?
20. How does an electric piano manage to sound like a piano?