6. Spectrum Analysis of Instruments and Voice

PURPOSE AND BACKGROUND

We continue with our discussion of harmonics. All musical instruments produce tones that are unique and have a characteristic *timbre* or quality of sound. The frequency spectra tell the harmonic content of a tone and how it can be synthesized. Electronic keyboards make use of this to reproduce sounds. We analyze the sound from a variety of string instruments, wind instruments, and the human voice.

I String Instruments

All musical instruments use a driving force to set an oscillator into motion. Stringed instruments use a bow or plucking for exciting the vibrations. The strings of a violin are tuned to the notes G3, D4, A4, and E5; for the guitar, they are E2, A2, D3, G3, B3 and E4. You see that the note G3 is common to both instruments. Figure 1 shows an example of a frequency spectrum from the open G3 strings of a guitar (top) and violin (bottom).

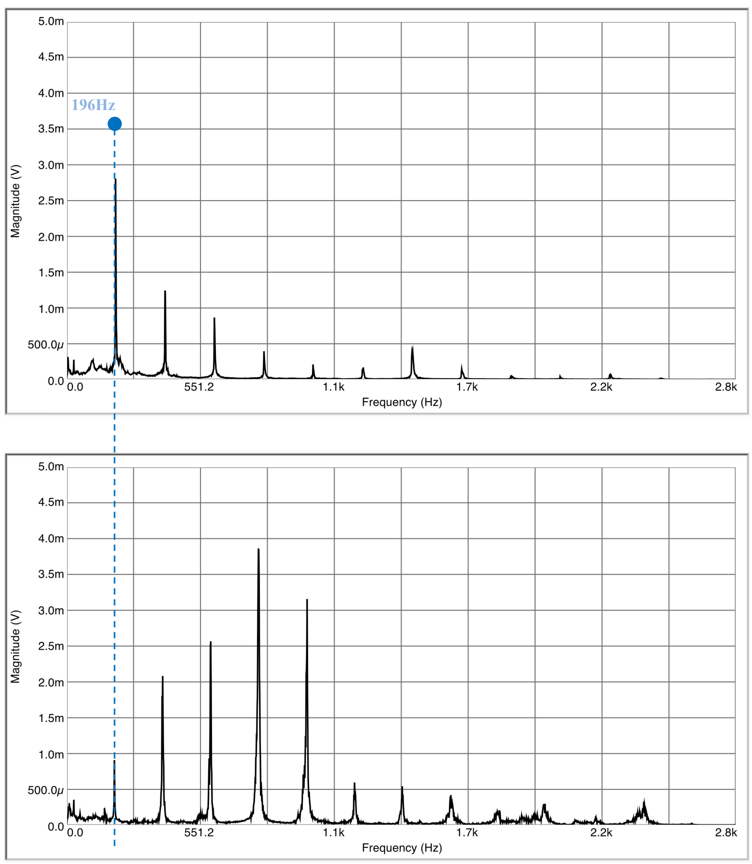

Figure 1: Frequency spectra of the plucked open G3 strings of a guitar (top) and violin (bottom). The fundamental frequency (pitch) and frequencies of the harmonics are the same. But the timbre (quality of sound) is very different because of the different relative amplitudes of the harmonics.

1. What differences do you see in the frequency spectra for the guitar and the violin?
2. Placing a finger down on the fingerboard reduces the effective length of the string and increases the pitch. How do you think the two spectra would change if you increase the pitch of the G3 strings on the guitar and violin? What will be similar?
3. How do you think the spectrum for the violin would change if the violin string were *bowed* instead of plucked?
4. The lowest and highest notes on a violin have fundamental frequencies of 196 Hz (open G3 string) and 2093 Hz (C7 played on the E3 string). Approximately how many octaves apart are these two notes?

II Wind Instruments

Wind instruments use air as the vibrating medium. Brass instruments have closed pipes, with the closed end near the mouth. Woodwinds such as the clarinet, oboe and bassoon also are closed pipes, with a reed at the closed end. The lowest harmonics of these instruments are primarily the odd harmonics, as is expected for closed pipes. This applies especially to the clarinet due to its straight cylindrical bore. For other wind instruments, all harmonics are present without a special dominance of odd or even harmonics. Flutes, piccolos, recorders and, more exotically, an ocarina, are open pipes with even and odd harmonics.

Figure 2 shows the simple, almost purely sinusoidal, frequency spectrum from a slide whistle.

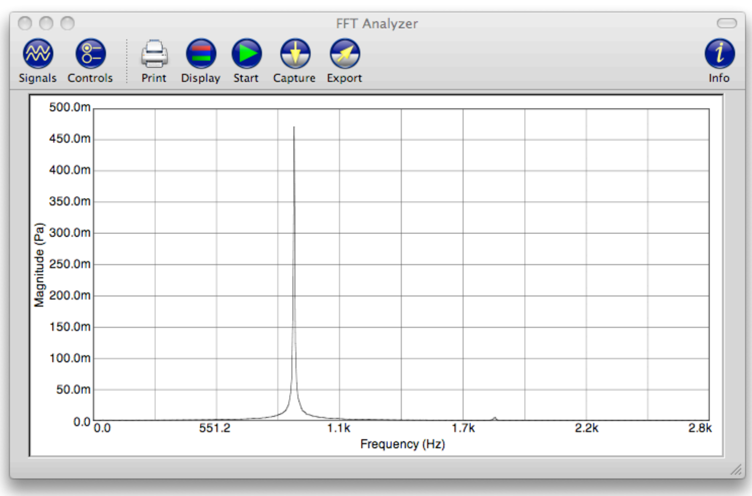

Figure 2: Frequency spectrum of a slide whistle with $f = 880$ Hz.

1. How does the frequency spectrum of the slide whistle compare to that of the guitar or violin?
2. Since a slide whistle is closed at one end, what harmonics might you produce if you "overblow" the lowest note?

III Voice

The human vocal tract is an intricate system for producing sound. The voice of each person is unique. The sound is produced, and its quality determined, by the vocal tract consisting of throat, nasal cavity, and mouth. Each of these components acts as a resonator with characteristic resonant frequencies. The different vowel sounds come from different regions of the vocal tract. This allows for a large variety of sounds, but some general characteristics exist.

The frequency regions where several neighboring harmonics have high amplitudes are called *vocal formants*. Most people have similar formants because of the similar size and shape of their vocal tracts. The individual resonators of the tract produce the different formants. They can be adjusted by a change in size and shape of the throat, nasal cavity, and mouth. How this is done distinguishes a great singer from a bad one. Vocal formants are what we listen to in order to recognize persons. Adjusting the cavities of the vocal tract changes the formant regions. Adjusting the tension in the vocal cords changes the pitch and associated harmonics.

Figure 3 shows the frequency spectra of a male voice (top) and female voice (bottom) making the vowel sound "ee". Note the dominant formant regions.

1. The human throat has a typical overall length of 17 cm. Consider it as a simple pipe, with one end closed at the vocal folds and the other open at the mouth. What is the fundamental resonance frequency? What are the frequencies of the next three harmonics?

2. Identify any formant regions in the male and female voice in Figure 3, where the amplitudes are pronounced. Are they located around similar freqeuncies?

3. How can you effectively change the resonant frequencies of the vocal tract (formant regions)? How can you change the frequencies of the vocal folds?

4. Telephones transmit frequencies only in the approximate range 300-3000 Hz. Why do you think this frequency range is sufficient for most purposes?

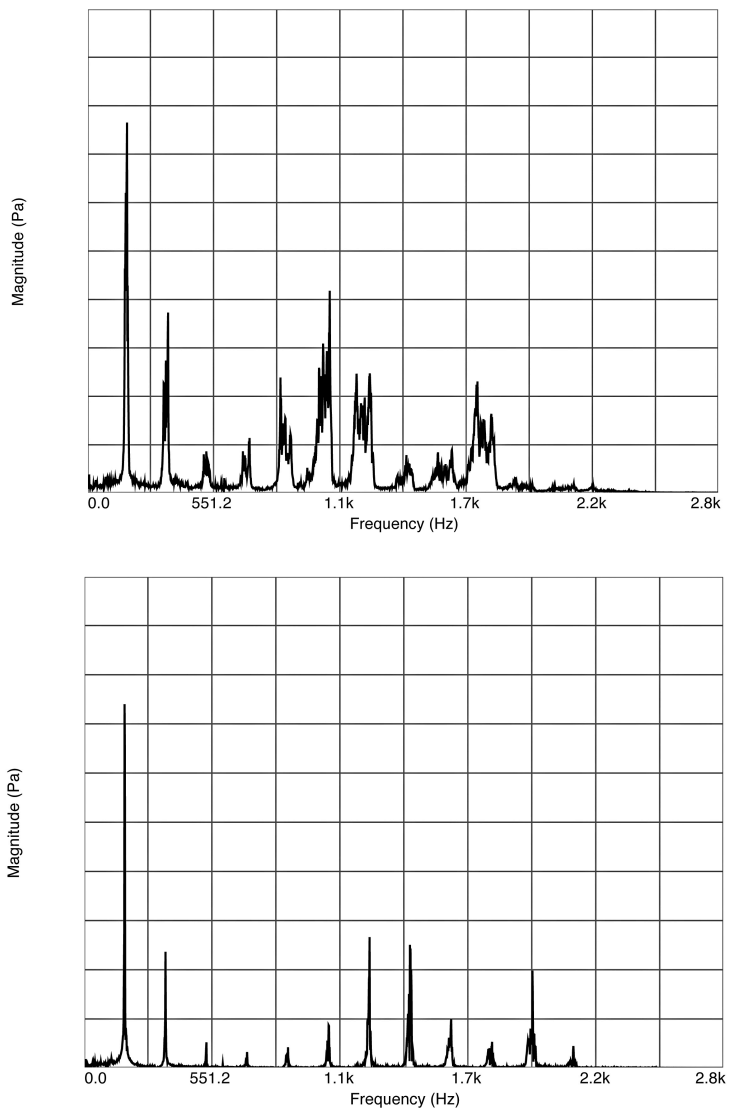

Figure 3: Vowel sound “ee” from a male voice (top) and female voice (bottom). The female voice has purer harmonics. Note the formant regions.