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).

Play G3 on the violin by plucking the lowest string and Observe the different frequency spectra in the FFT (Fast Fourier Transform) mode of the Electroacoustics Toolbox. Then play the same G3 on the guitar and observe its frequency spectrum.

Question 1 What are some simularties and differences between the tambre and the frequency spectrum from the violin and guitar?

We may also be interested in comparing different frequency spectrums created by the same instrument. Play G3, the lowest note on the violin, by bowing and by plucking.

Question 2 What are some simularties and differences between the frequency spectrum from the plucked and the bowed string?

Placing a finger down on the fingerboard reduces the effective length of the string and increases the pitch. Now repeat the above experiment plucking the violin string at a higher pitch.

Question 3 How did the frequency spectrums change between the lower and higher pitch.

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.

Use a slide whistle and obtain the frequency spectrum of its lowest note. Figure 2 shows an example of the simple, almost purely sinusoidal, frequency spectrum from a slide whistle. Try to

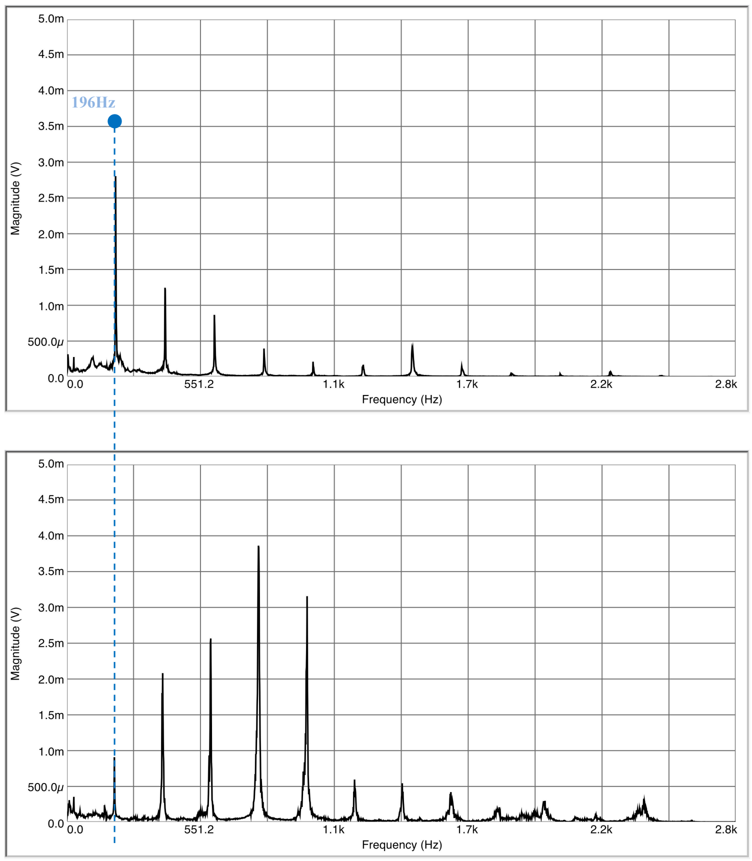

Figure 1: Frequency spectra of the plucked open G3 strings of a guitar (top) and violin (bottom). The fundamental frequency (pitch) and frequencies of the harmonics are the same. But the timbre (quality of sound) is very different because of the different relative amplitudes of the harmonics.

over-blow the lowest note and note the next harmonic f3 of the closed pipe. Blowing harder may produce f5 and even f7.

Question 4 what is the frequency range of the slide whistle by moving its piston? How does the frequency spectrum of the slide whistle compare to that of the violin?

Play and record the sound spectra from a flexible corrugated plastic tube ("whirly") by swirling it around in a circle.

Question 5 Determine the harmonic numbers N that are active in the spectrum of the corrugated plastic tube. Note that the fundamental most likely does not show. What are the musical intervals between the harmonics that are present (e.g. octave, fifth, fourth, third)?

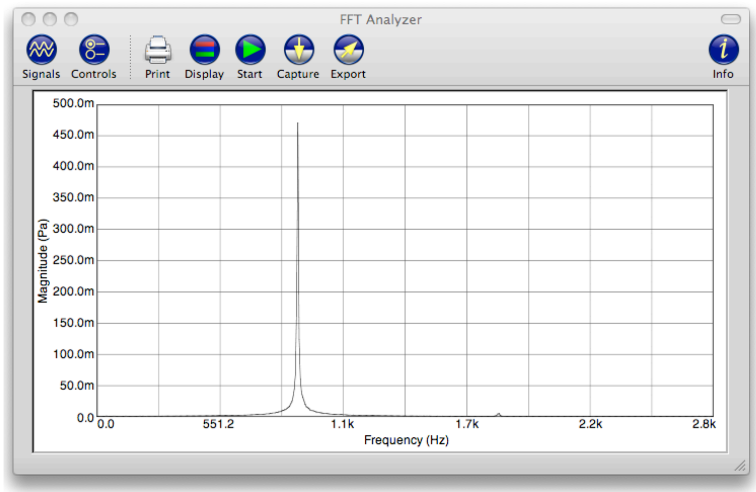

Figure 2: Frequency spectrum of a slide whistle with $f = 880$ Hz.

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.

Question 6 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?

Have a male and female student sing the vowels "oo" or "ah" into the microphone. Observe the resulting frequency spectrum with the FFT tool. Figure 3 shows such a spectrum for a male voice singing "ah" with a pitch of 220 Hz.

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.

Have two or more students with noticeably different voices sing the vowel sounds "oo", "ah", and "ee" into the microphone. Acquire the frequency spectra. Compare the formant regions of the students. In Table 1, record the first and second formant region for the two students. An example for the vowel sound "ee" from a male and female student is shown in Figure 4

Vowel sounds and corresponding vocal formant regions

	Student 1		Student 2	
Sound	1st Formant region	2nd Formant region	1st Formant region	2nd Formant region
oo				
ah				
ee				

Table 1: Table

Question 7 Telephones transmit frequencies only in the approximate range 300-3000 Hz. Why do you think this frequency range is sufficient for most purposes?

The human vocal tract produces various types of sound. Continuant sounds are consonant sounds such as "m" and "n" that have a soft continuous tone. Sibilant sounds are consonants such as "s" and "z" that can be continuous and sound rather harsh. Plosive sounds are short and explosive like "p" and "t". Observe some of these sounds and their frequency spectra.

Question 8 Which vocal sounds sound more "musical"? Hint: Which sounds have a discrete frequency spectrum as compared to a more continuous spectrum with many closely spaced frequencies characteristic of noise?

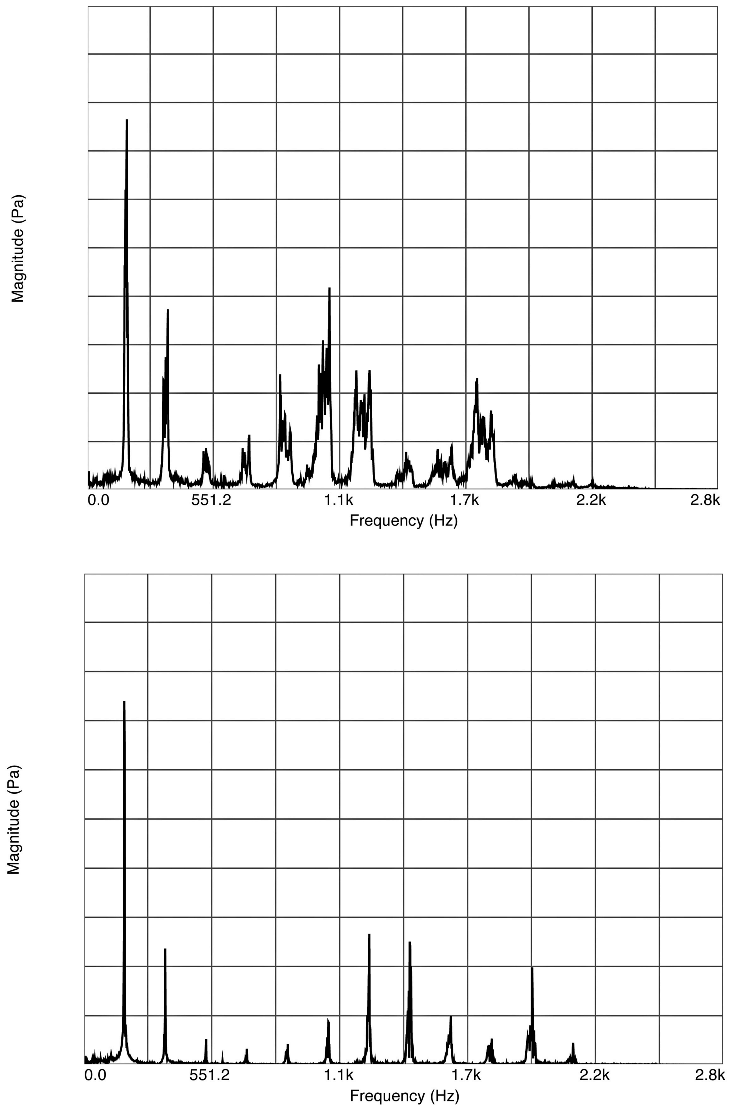

Figure 3: Vowel sound "ee" from a male voice (top) and female voice (bottom). The female voice has purer harmonics. Note the formant regions.