Spectral Analysis of an Alto Saxophone

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I. Introduction

While there are a wide variety of wind instruments commonly played, they generally fall into two categories: brass and woodwinds. All saxophones are part of the woodwind family. While brass instruments depend on the player's lips to act as a pressure-controlled valve to maintain oscillations in the air column of the instrument, saxophones and woodwinds function quite differently. As an avid musician and saxophonist for over ten years, I was interested in learning more intimately the inner workings of a saxophone and how this can be objectively measured from a scientific viewpoint.

The saxophone functions by means of a pipe-reed system, where the "pipe" is the instrument itself. The player supplies a source of air, which in turn vibrates the instrument's reed. This creates a pulse of positive pressure traveling through the instrument until an open end is reached, at which point excess pressure drops to zero and a negative pressure pulse travels back to the original source, where there is now a closed reed. The same process occurs now in reverse, as the closed reed sends a negative pulse traveling to the open end and a subsequent positive pulse coming back start, pushing the reed open and letting in more air. This cycle of *positive feedback* is what produces continual sound as long as an air stream is supplied.

In contrast to a brass instrument, which produces a frequency largely depending on the player's vibrating lips and pressure, the reed has little control of the specific frequency produced. This is taken care of by keys along the entire length of the horn controlled by the player's fingers. The more keys that are closed, the longer the "pipe" becomes, until all keys are closed and the sound travels all the way to the saxophone's bell. As a conical bore, the saxophone's harmonic spectrum includes both even and odd-numbered harmonics.

II. Background

In measuring physical properties of the saxophone, the most important, and subsequently informative, measurement is acoustic impedance, notated by Z. A complex number, it is the ratio of complex sound pressure P at the measurement point over complex particle velocity U. Similar to electrical impedance, the acoustic input impedance measures how much resistance there is to various pressures being put through the tube of the instrument. Higher impedance corresponds to higher pressure variation and a larger reflection of pressure waves at the source. This essentially controls the reed's vibrating frequency and makes the instrument play close to specific resonant frequencies. On a graph of frequency vs. impedance, the peaks correspond to resonant frequencies. Magnitude and sharpness of these peaks indicate how prominent a frequency is for a particular fingering and how stable it is, respectively. An interesting consequence for the saxophone, with its curved frame, is the lowest note with all keys closed has a stronger resonance on the second harmonic than the fundamental. This is shown in Figure 1 and

Figure 2. The result is that the lower note on a saxophone is more difficult to play than further higher notes.

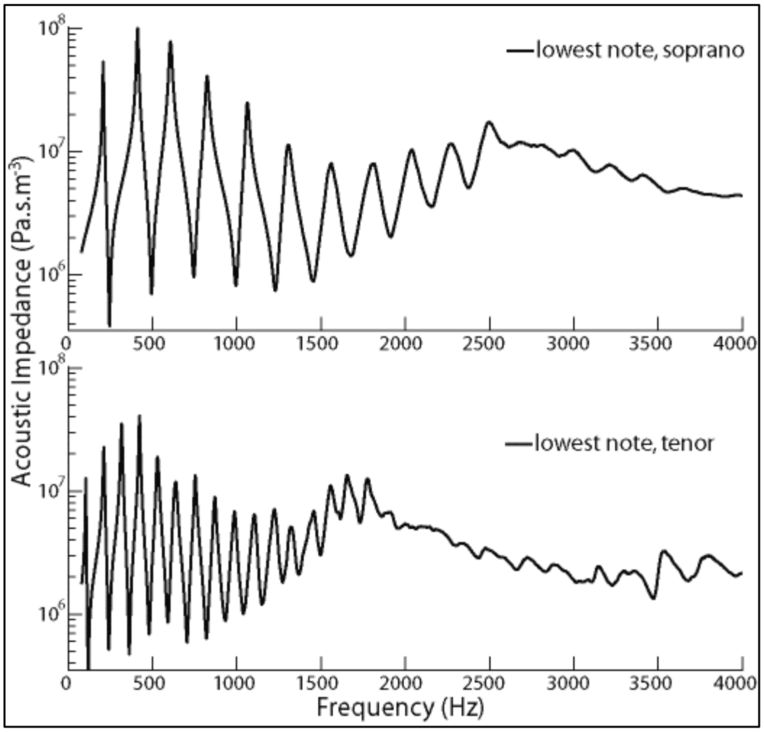


Figure 1. Impedance curves for all keys closed on a soprano and tenor saxophone

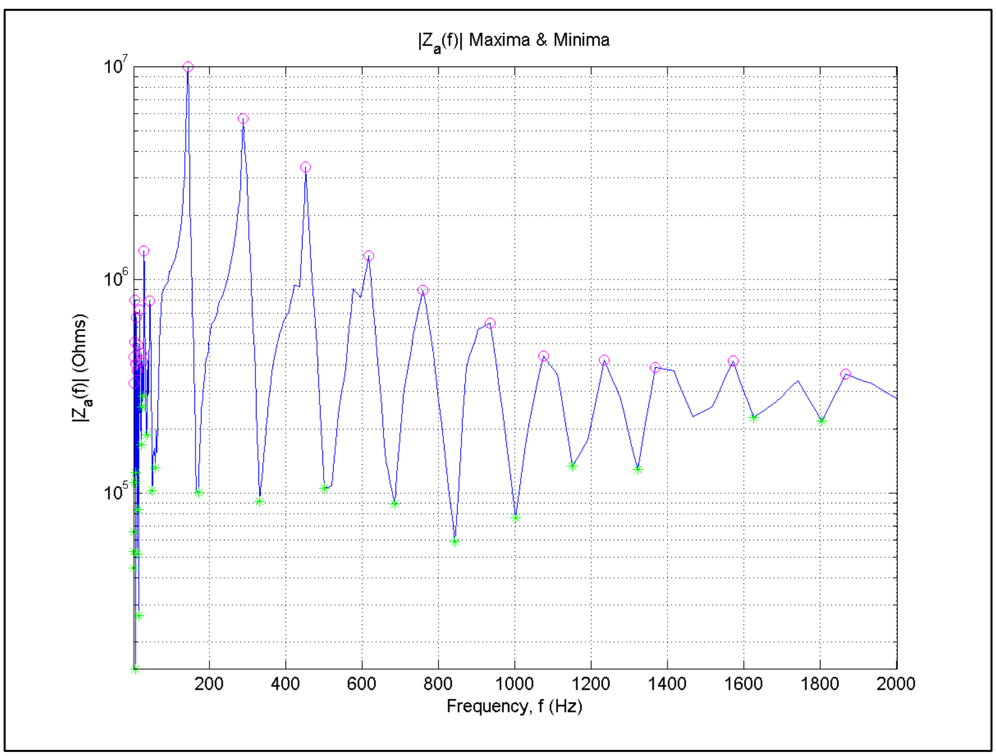


Figure 2. Impedance curves on the lowest note of my alto saxophone

The added complication of measuring these curves for a saxophone is the vast amount of possible fingerings. Whereas a trumpet has three valves for a total of 7 fingerings, the saxophone has 30-32 notes in its standard range, all with different fingerings. As a result, I only measured some of the stronger notes that I knew were present and would still represent the full range of the horn.

Additionally, I chose to measure the spectrum of a few multiphonics. Conventionally, wind instruments are only capable of playing a single note at a time. However, there exists an extensive list of altered fingerings that produce an effect on the saxophone known as multiphonics, which plays multiple notes simultaneously. I was interested to see how this would affect the resonances and various impedance magnitudes.

III. Experimental Setup & Procedure

The measurements for the spectral analysis were conducted with an HP-3562A Dynamic Analyzer. The actual physical excitation of the horn was achieved using a piezoelectric transducer sealed into where a reed is normally on a saxophone mouthpiece. The mouthpiece's main chamber was drilled into from both sides to have two condenser microphones inserted to measure sound pressure and particle velocity, shown in Figure 3 and Figure 4.

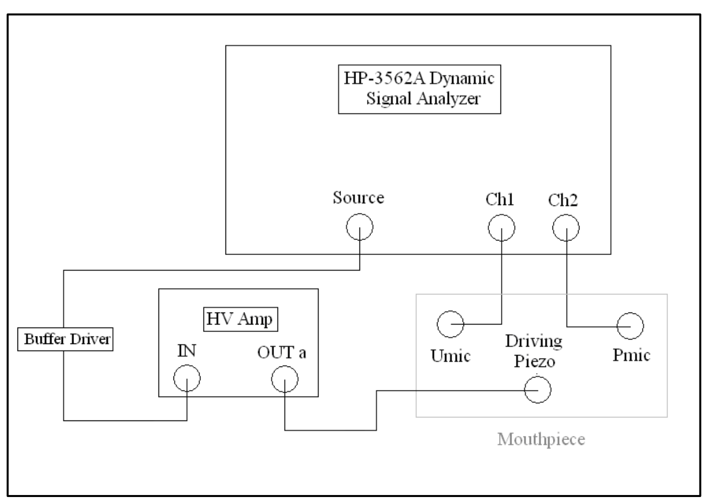
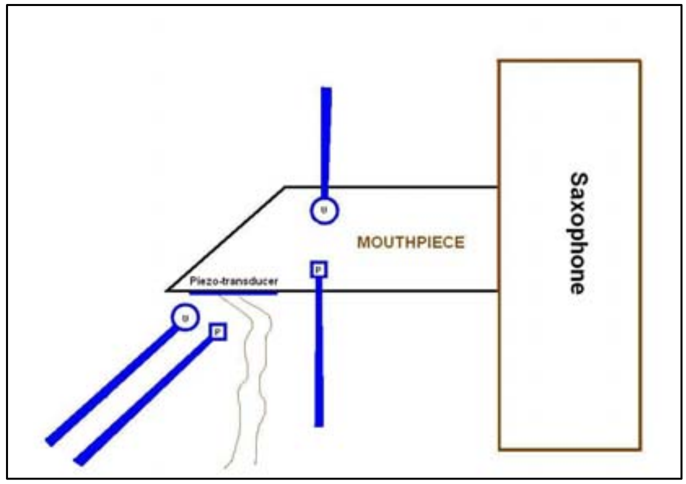


Figure 3. Complete setup with the signal analyzer and mouth-piece.

Figure 4. Mouthpiece with transducer, U and P microphones.



Of key importance to the mouthpiece setup was the complete sealant of all holes made by the transducer and microphone holes. Any air leak could significantly alter data. The actual measurements

The signal analyzer was capable of measuring and displaying five different quantities: frequency response (used to calculate the complex impedance), coherence, the velocity power spectrum, the pressure power spectrum, and the cross spectrum (used to calculate complex acoustical intensity). These results were then read into Labview computational software. Once stored as data in the computer, measurements were put through written scripts in MATLAB that calculated all of the various quantities mentioned above and plotted on a linear scale from 20-2000 Hz. Another useful calculation was the specific minima and maxima on each impedance graph. From these values, it was possible to compare the measured values of the fundamental to known values for each note.

In the actual collection process, I held the horn in place with the proper fingerings for the entire duration of the measurement. This was in contrast to previously similar experiments in which the fingerings were tied down and held down by themselves.

IV. Results

One of the most important comparisons to come out of the data was the comparison of maxima in the impedance graphs to the known frequencies of notes in the tempered scale. When observing the impedance graphs, the first resonance is the fundamental frequency of vibration in the instrument, where the second resonance and harmonic is the actual note sought.

Alto Note	Concert Pitch	Measured Impedance Max (Hz)	Known Tempered Frequency (Hz)	Impedance Magnitude (Ohms)
F6	Ab5	873.03	830.61	1,161,538
D6	F5	743.07	698.46	1,174,524
F#5	A4	491	440	4,357,881
G4	Bb4	246.05	233.08	11,482,160
Bb3	Db3	144.89	138.59	10,019,487

Table 1. Shows the measured impedance maximums for a specific alto note compared with the calculated frequency for the corresponding concert pitch on the tempered scale. Also shown is the measured magnitude of the impedance for each resonance.

One aspect of the measurement that could be improved upon is the length of time over which the frequency sweep took place. Taking log sweeps with the signal analyzer with ten averages per frequency, a sweep of the horn from 20-2000 Hz took about ten minutes. Contrasted with the option of a ten hour sweep in which the horn could be isolated in a box, the method I used had considerably lower precision. Nonetheless, a good overall picture of behavior was still captured in the data.

Another potential flaw with some of the data can be explained by the differences in data collection and display. The signal analyzer collected measurements on a log sweep. As a result, measurements made at lower frequencies were closer together, i.e., at a higher resolution, than higher frequencies, since results were calculated and displayed on a linear scale. This lack of resolution could explain the lower accuracy at those higher frequencies. A higher resolution could also potentially show more accurate impedance maxima for resonances in Table 1.

Another interesting result was for a few of the multiphonics, in particular for multiphonic 1, which is the same as the low Bb with all keys closed except for one key still open.

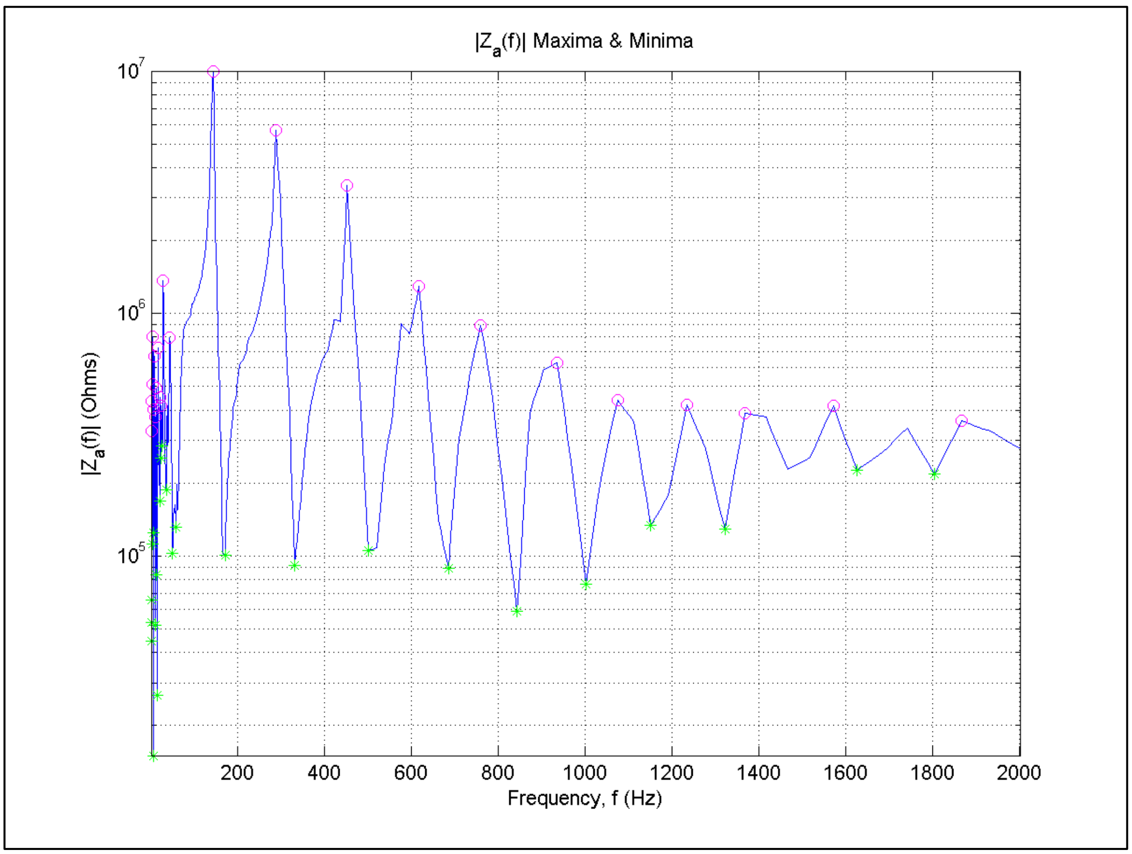


Figure 5. Same as Figure 2, the impedance resonances for Bb,
Lowest note with all keys closed

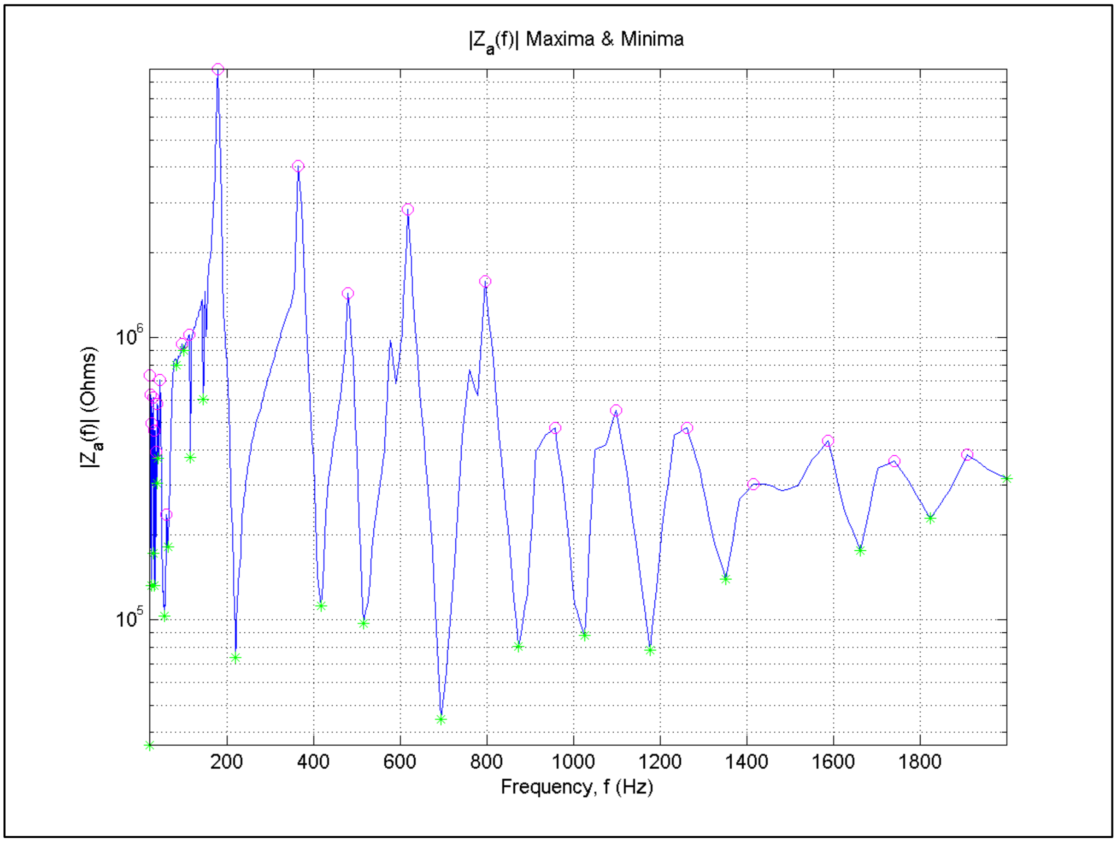


Figure 6. Multiphonic 1, same as Bb with one key open

The impedances are very similar, but a key difference is the location of the second harmonic, which is slightly lower than the Bb's. It would be interesting to further investigate how much this affects the resulting sounds that a multiphonic produces.

V. Conclusion

With a project of this nature, there is always more that could have be done. All notes and distinct fingerings in the written range of the saxophone could have been analyzed. Another interesting case could be inspecting various alternate fingerings for the same note to see which one is harmonically "superior."

At the end of the day, it's important to realize, too, that so much of these natural properties of the instrument fall to the responsibility of the musician to showcase. To excel, the harmonic qualities of each note require a good embouchure, air support, and mouthpiece, reed, and ligature setup by the musician.

As an extension of this project, I think an interesting follow-up case would be to examine the acoustic properties of various mouthpieces, which varying chamber shapes and sizes, as well as materials (metal, hard rubber, wood, or plastic). Combined with the information on the horn, a greater overall description of the instrument could be achieved.

VI. Acknowledgements

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