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Music 5: The Math of Sound
Final Presentation Write-up
December 6, 2010

For my final project/presentation, I wanted to try and take some of the concepts we had learned in class, particularly dealing with resonance and timbre of different musical instruments, and apply them to a medium I'm familiar with and interested in. Specifically, I decided to look into the impact of different design features in saxophone mouthpieces on the tonal elements and projection of sound. From a musician's standpoint, these design differences have a great impact on the tone quality, projection, and ease of play, and it is very common for musicians to change mouthpieces when performing multiple genres, or searching for a different sound.

The sound production of the saxophone begins with the mouthpiece and reed. Through combined lip pressure underneath the reed and air pressure into the mouthpiece, the reed vibrates rapidly over an opening into the mouthpiece, closing entirely over the mouthpiece about 50% of the time, being completely about open 25% of the time, and being in motion about 25% of the time. This process displaces air inside the mouthpiece and thus causes a vibration of the air column throughout the instrument, with the frequency determined by the length of the tube.

However, while this describes the general mechanism for producing a sound, even the most casual of listeners can discern the difference between a beginner and experienced saxophonists, and more applicably, between a classical and jazz tone. While much of the difference is in the ability and stylistic preferences of the musician, subtle, nuanced design differences have a profound impact on tonal quality as well. These design differences are particularly relevant in the mouthpiece, as the initial source of sound that carries through the rest of the instrument. While, admittedly, the mathematical and acoustical grounding for these

observed phenomena is extremely complex and under-researched, it's worth noting a few of the general concepts that underlie design choices. As discussed on the UNSW page on saxophone acoustics, the vibrations of the reed itself emit a high natural frequency (the source of "squeaks" in beginner players). Though the lower lip of the player absorbs some of this vibration, the natural frequency produces higher harmonics that resonate in the mouthpiece cavity, and the prominence of the different harmonics are thus impacted by the size of the cavity and the amount of the chamber that the reed is in contact with (window length). Dalmont's article also discusses another important factor, which has to do with the compliance of the reed, which is interrelated with the volume of the mouthpiece cavity. As observed, these differences impact the amount of air displaced and the velocity of the airflow in the mouthpiece, with implications for tuning, particularly in the higher register, and projection.

Another important concept to mention, which is discussed at length on the UNSW website and in Fletcher's book, is acoustical impedance, which is the relationship between the acoustic pressure (related to the oscillating reed and pressure differences in the mouthpiece) and acoustic volume flow (related to the natural frequency series of the tube). This is particularly relevant in the mouthpiece, as the source of the sound, and the different shape and sizes of the resonating cavity, as a result of acoustical impedance, have an impact on the strength of the resonance of different partials. This is also particularly relevant to the mouthpiece because, though most mathematical modeling operates under the assumption that a saxophone is a perfect conical resonator, it is in fact a truncated cone with a resonating cavity (mouthpiece) attached. As a result, as Nederven discusses in his book, slight changes in the shape of the mouthpiece and size of the bore can impact the relative strength of resonance at different partials, thus impacting the tone quality produced. Finally, as discussed in Fletcher's book, different levels of lip pressure

have the impact of diminishing the tip opening and acoustical pressure, as a result impacting acoustical impedance and timbre. These same principles are applicable when discussing design differences in the size of the tip opening and shape of the mouthpiece interior at the opening (baffle), rather than variation in human manipulation of the reed itself.

Given all of these acoustical principles impacting mouthpiece design and the timbre, it's worth quickly outlining the primary elements of tonal quality and their relationship to quantifiable data. Within the overarching concept of *timbre*, or the relationships between different overtones that allow us to distinguish between different instruments, *intensity* can be approximated as the overall acoustical energy produced. *Resonance*, as it relates to timbre, can be approximated as the efficiency with which the initial source of power (the human body) is translated into sound by the generating mechanism, or instrument. *Core* is related to resonance, and is also linked to the overall consistency and stability of tone and intonation. *Color* has to do with the overall proportions of partials within the overall signal, with a *dark* tone signifying a higher proportion of lower harmonics, while a *bright* tone signifies a signal with a comparatively larger proportion of higher partials. Finally, *edge*, a closely related concept, refers to the presence of a few much higher partials, rather than the overall proportion of the partials, particularly at the point of initial attack. It is because of these two qualifiers that it is possible to achieve a dark tone that still has lots of edge to it. An example of this distinction can be seen with a comparison of the full, growling sound of Coleman Hawkins (dark and edgy), versus the more directed, forceful sound of Michael Brecker (bright and edgy).

In considering the design of a saxophone mouthpiece, there are a few particularly relevant factors that impact the tonal quality, projection, and control of the sound (See the mouthpiece diagrams in the appendix for specific design features). The first is the facing

length/tip opening, which impacts the ease of response of the instrument, as well as projection and intensity. Smaller tip openings allow for more controlled vibration of the reed, while also allowing less air into the mouthpiece, and thus, less projection and intensity, while a larger tip opening is more difficult to control and play softly, but allows for more projection. The baffle, the first point of contact for the airstream (just inside the mouthpiece), impacts the edge, color, and projection of the sound, due to the directionality and force of the air stream and impacts on acoustical impedance. As a result, higher baffles (such as step or rollover baffles), create a brighter, more edgy sound, while lower baffles (straight, concave) create a dark, mellow sound (see diagrams). Side walls have a related impact on color, as well as the focus of the tonal center, by impacting the directionality of the airstream and the efficiency of sound production. Curved side walls allow for a less-focused sound, while straight side walls create a consistent, focused tone (for this reason, they are most common in classical performance). Window length is closely linked to tip opening, as it impacts how much of the air column is exposed to the vibrating reed. Thus, a longer window opening will allow for slightly less control, but more projection. Finally, the size of the chamber, in relation to the bore of the rest of the mouthpiece, has the biggest impact on color and resonance/core. Larger chambers result in a darker, fuller sound, particularly in the lower register, while smaller chambers create a brighter, thinner, more directed sound.

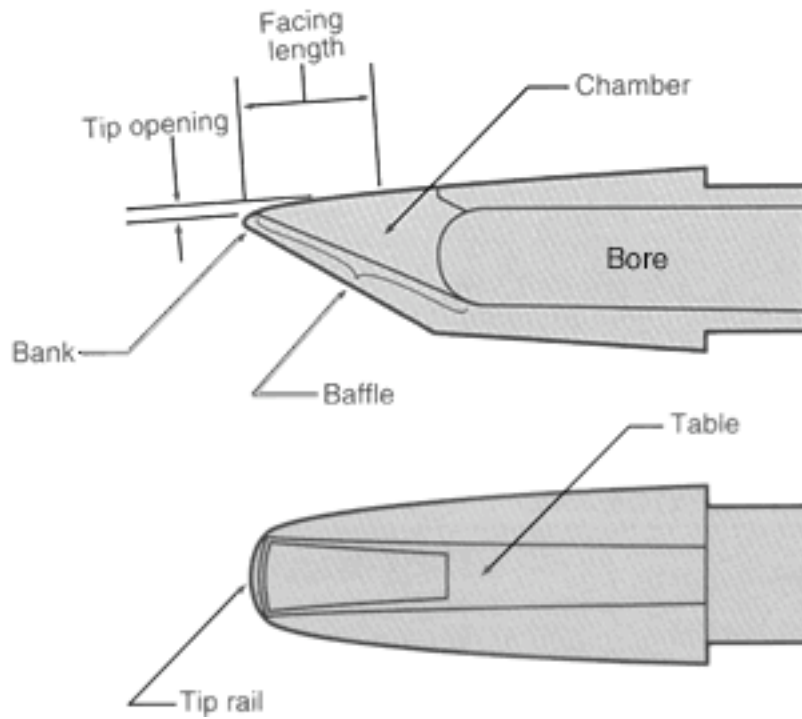
I tested the impact of these design features by recording myself playing five different types of mouthpieces and comparing the spectrographs and spectrums produced to the specifications of their design features. While the specific design features of mouthpieces are interrelated and nuanced, and do not necessarily have standardized, easily quantifiable proportions, the general principles in their design were found to have the expected impacts on the sound produced (see Appendix for the spectrum graphs). For example, in Case 1, a comparison

of baffle heights shows that, a mouthpiece with a higher baffle (Jody Jazz) has the strongest isolated higher partials, a mouthpiece with a medium baffle (Otto Link) has slightly fewer isolated higher partials, and a mouthpiece with a low baffle (Selmer S80) has the very few higher partials (all on the pitch G5). In Case 2, a comparison of different chamber profiles shows that a mouthpiece with a large chamber (Meyer) shows a higher proportion of lower and mid-range partials, while a slightly smaller chamber (Jody Jazz) has a slightly higher proportion of mid range and higher partials, while the smallest chamber of those sampled (Selmer Super Session D) has an even lower proportion of mid range partials and a stronger presence of higher partials (all on the pitch G3). Finally, in Case 3, a comparison of side wall design and tip openings shows that a mouthpiece with a small tip opening and straight side walls (Selmer S80) has far fewer non-harmonic partials in the mid-range, resulting in a more focused, centered sound, as opposed to a mouthpiece with a larger tip-opening and curved side walls (Jody Jazz), which have more non-harmonic tones in the mid-range, resulting in a less directed, more open sound. This can be observed by looking at the presence of “extra” frequencies on the spectrum that don’t fall into the harmonic series, mostly clustered at low amplitudes in the low and mid range.

While there is undoubtedly much more research to be done in this field on the specific acoustic principles at work, it seems clear from the data collected that there is a link to mouthpiece design features and the varying features of the produced timbre. These principles are considered regularly both by craftsman in designing and building mouthpieces and by musicians in choosing their mouthpiece to achieve a certain desired sound, and as a result, the saxophone is one of the most versatile wind instruments in existence, able to introduce variation in timbre that can be suited to a brooding classical concerto, an easy-swinging big band chart, or a soaring, electrifying funk tune.

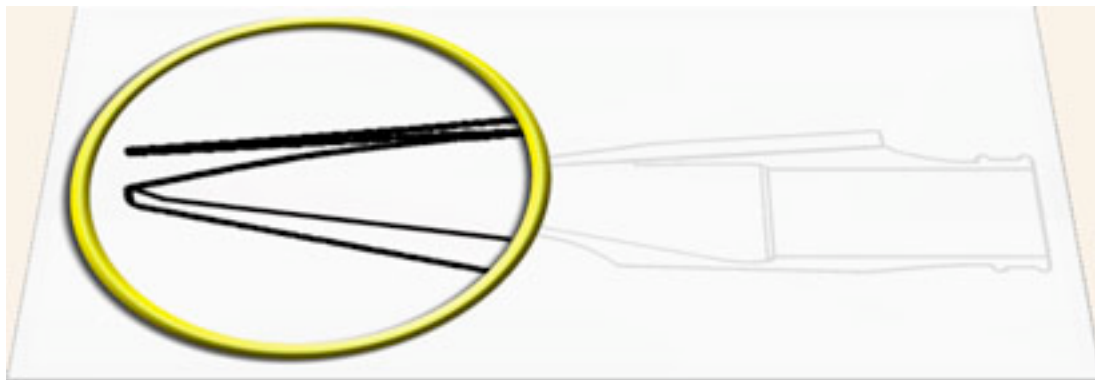
Appendix

Mouthpiece Diagram:

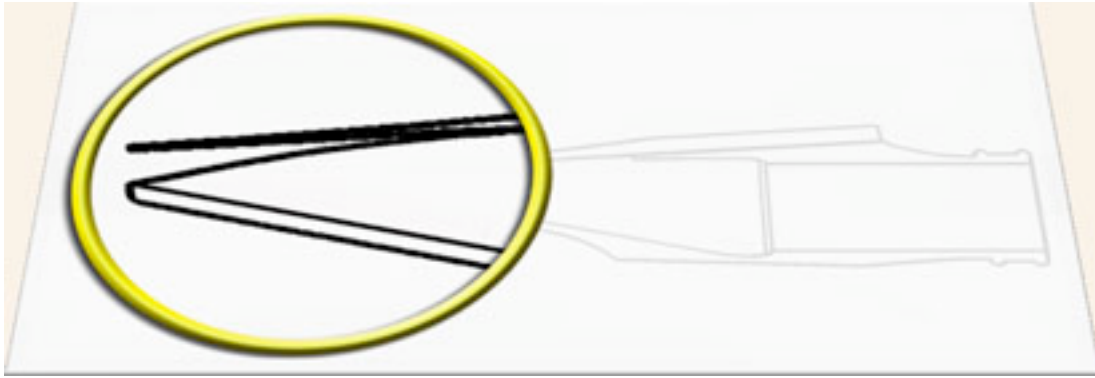


Baffle Types:

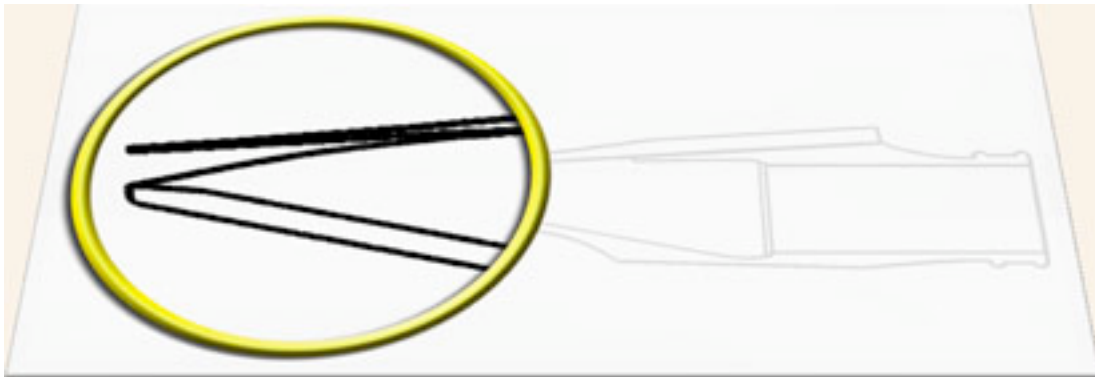
Concave Baffle



Straight Baffle



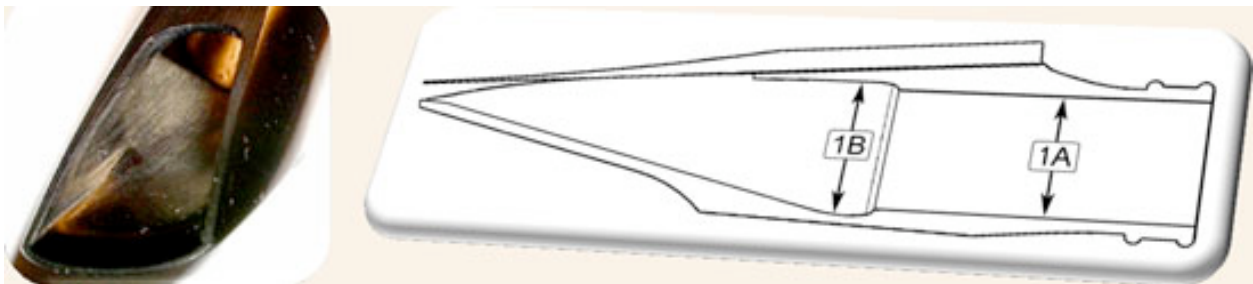
Rollover Baffle



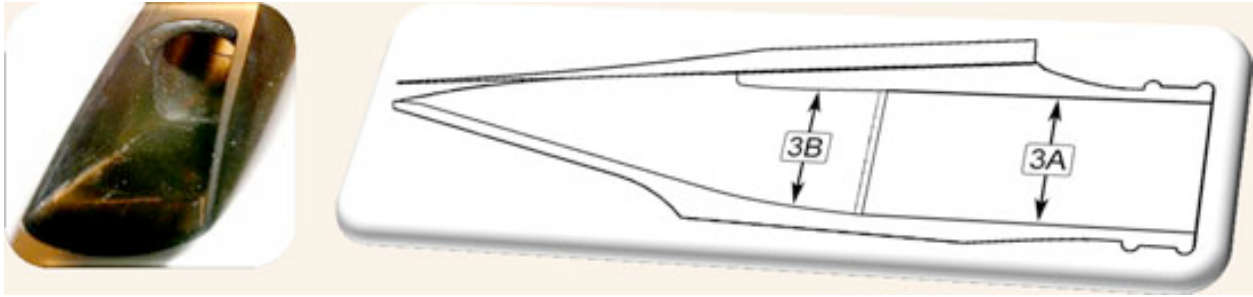
Chamber Profiles:

Large

Chamber



Small Chamber

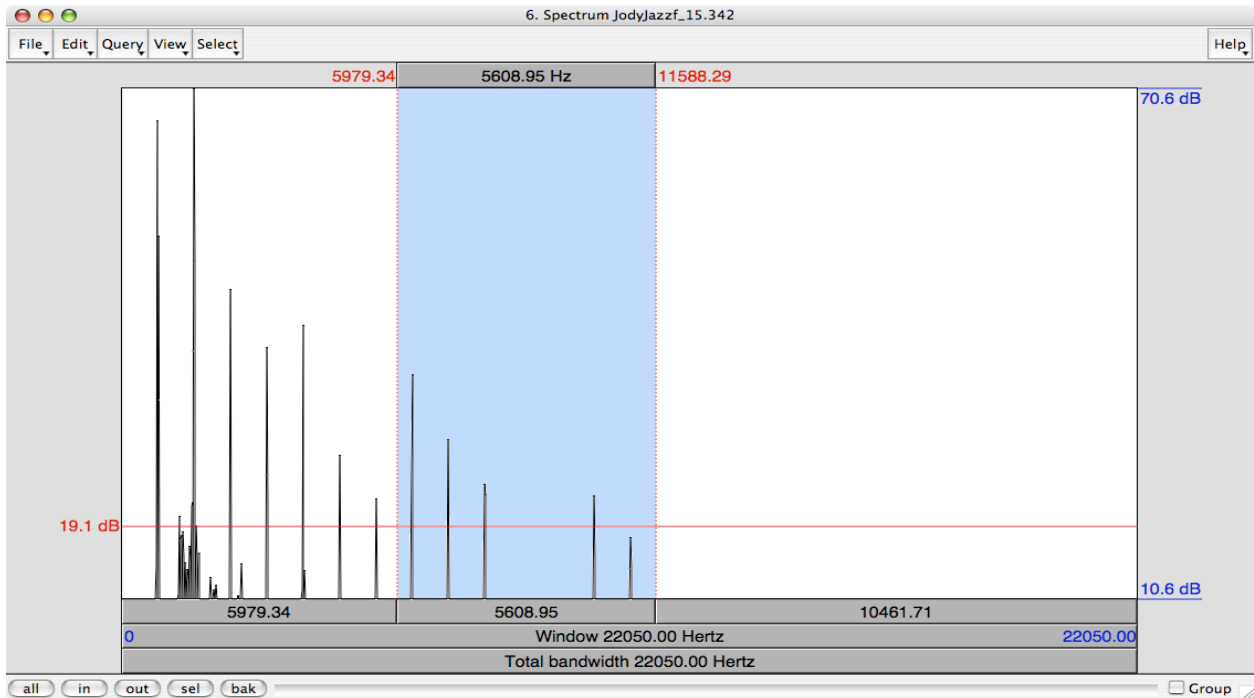


Mouthpiece Specifications

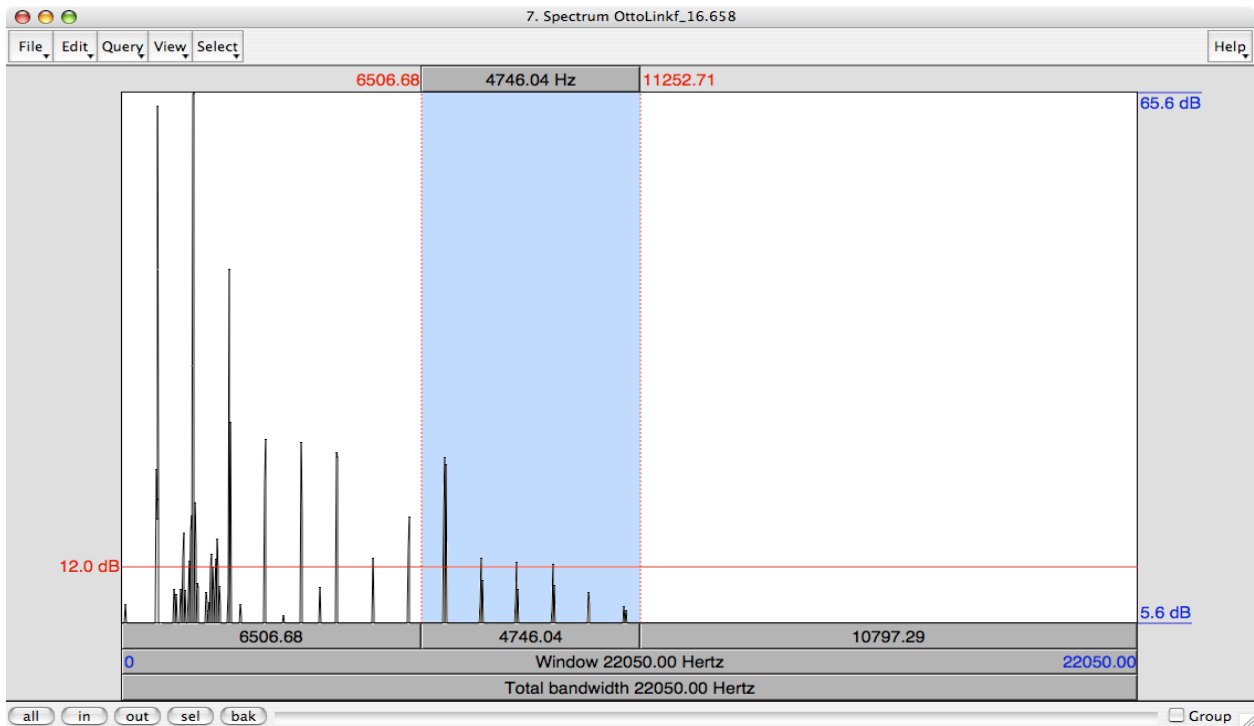
Brand	Selmer S80 (Classical)	Selmer Super Session (Jazz)	Jody Jazz HR* (Jazz)	Meyer (Jazz)	Otto Link (Jazz)
Facing	C*	D	6M	6M	6
Tip Opening	1.65 mm	2.01 mm	1.98 mm	1.93 mm	1.90 mm
Material	Hard Rubber	Hard Rubber	Hard Rubber	Hard Rubber	Gold- Plated Metal
Chamber Profile	Medium (square)	Medium- Small (arched)	Medium (arched)	Medium- Large (arched)	Medium (arched)
Baffle	Small Scooped (concave)	Small Rollover (convex)	Medium Rollover (convex)	Medium Rollover (convex)	Small Rollover (convex)
Side Walls	Straight	Curved	Curved	Curved	Curved
Window Length	37.0 mm	39.0 mm	36.0 mm	38.0 mm	36.0 mm

Case 1:

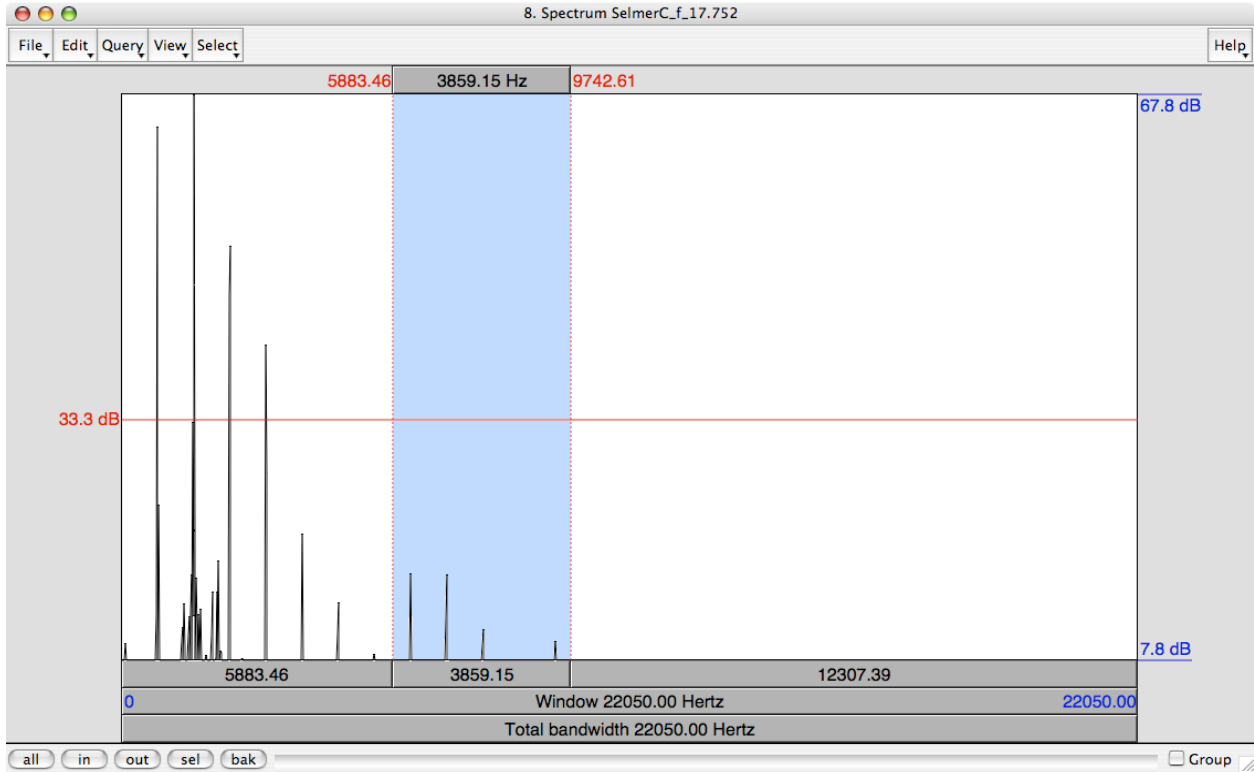
Medium Rollover Baffle (Jody Jazz)



Small Rollover Baffle (Otto Link)

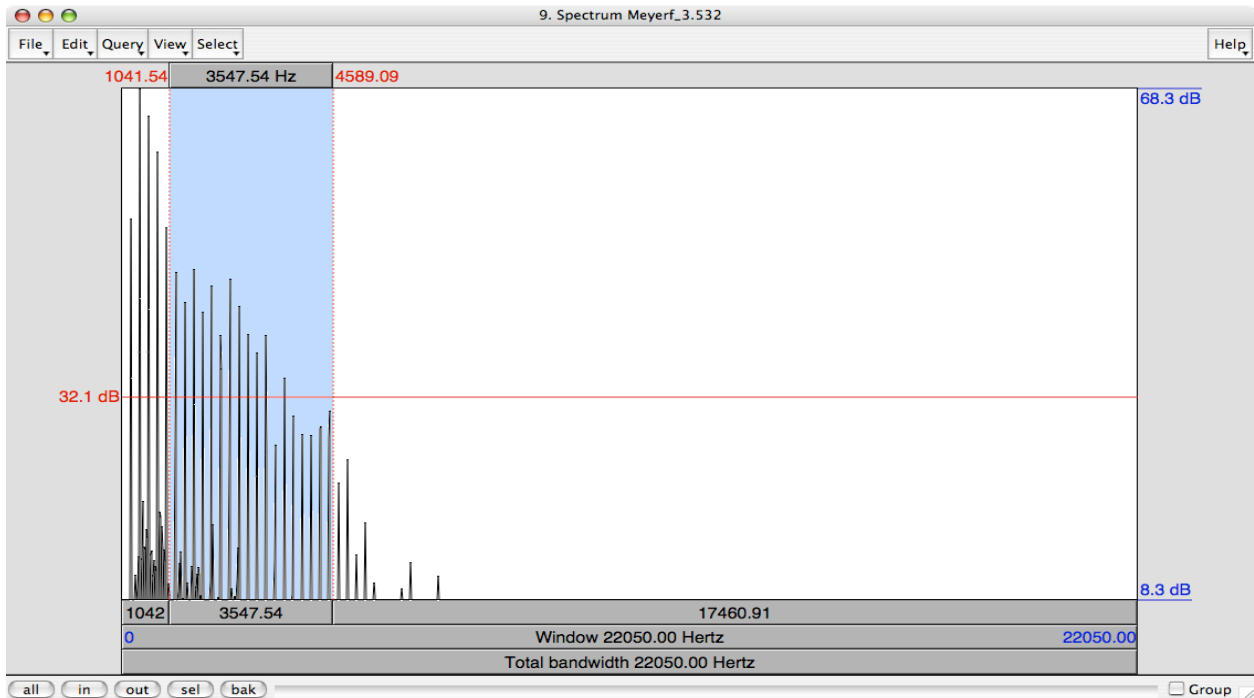


Straight/Concave Baffle (Selmer S80)

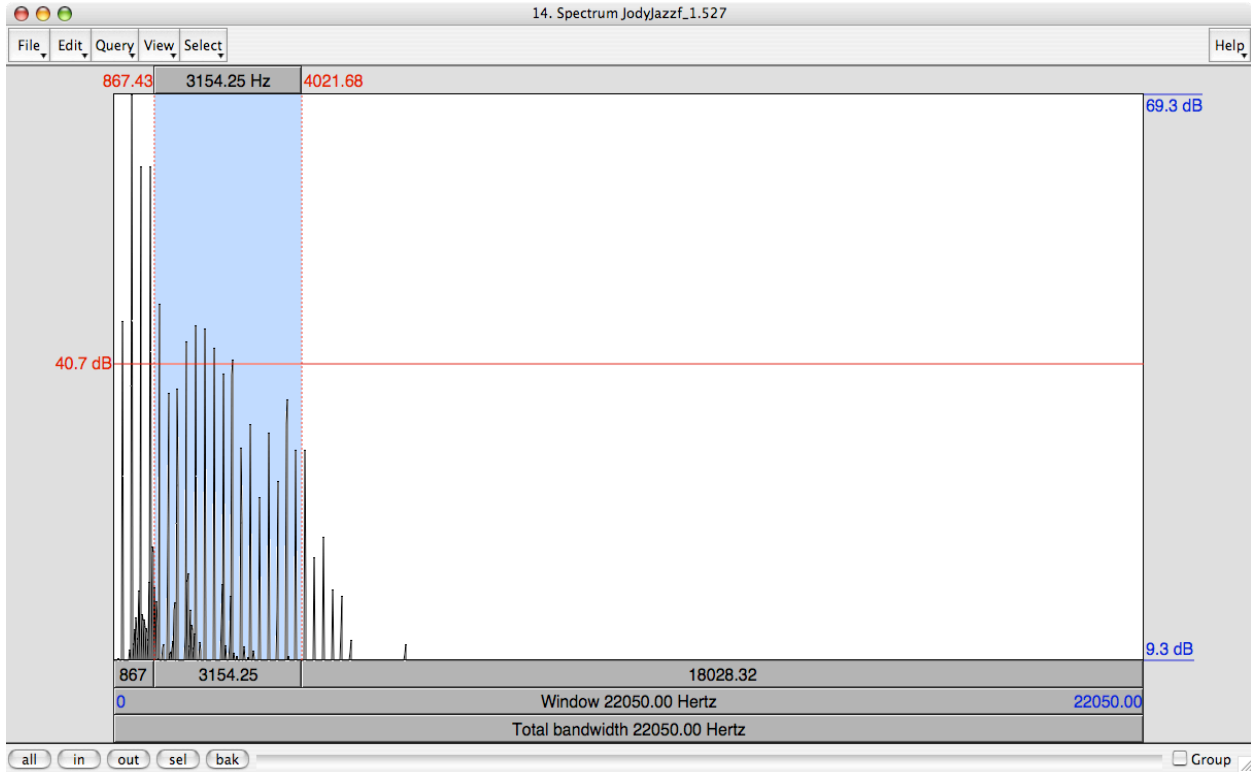


Case 2:

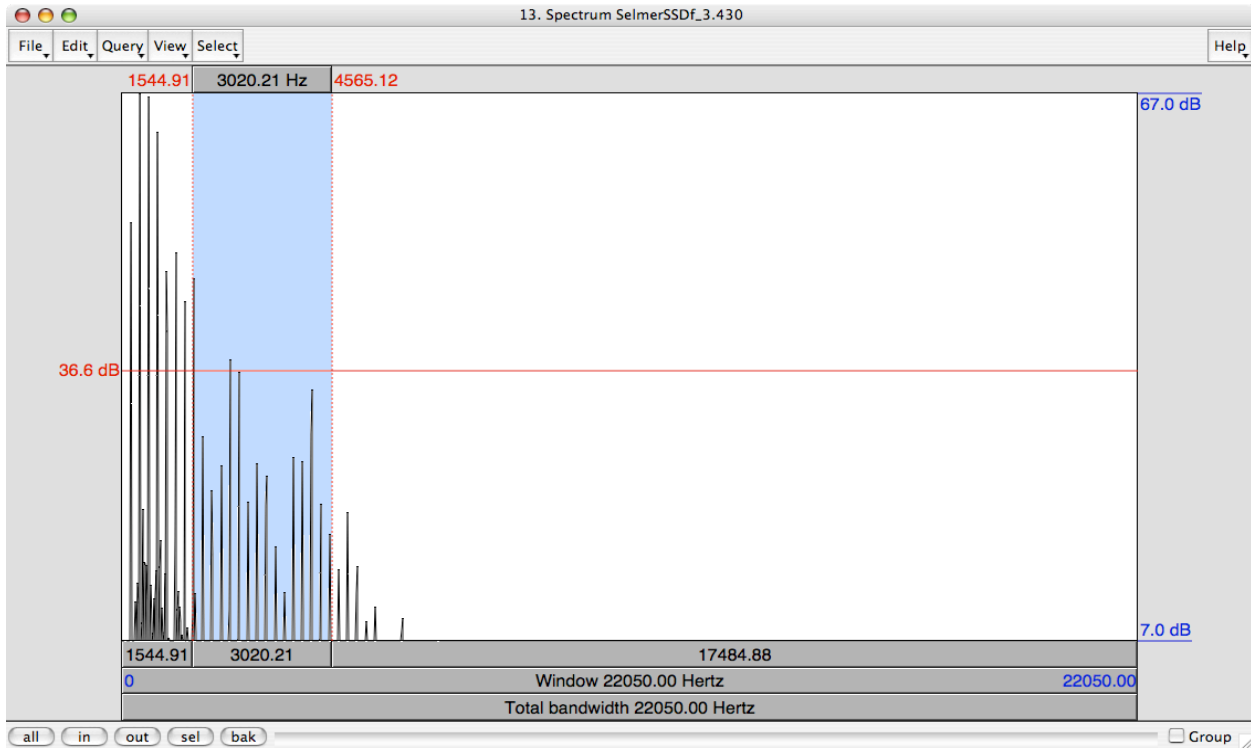
Large Chamber (Meyer)



Medium Chamber (Jody Jazz)

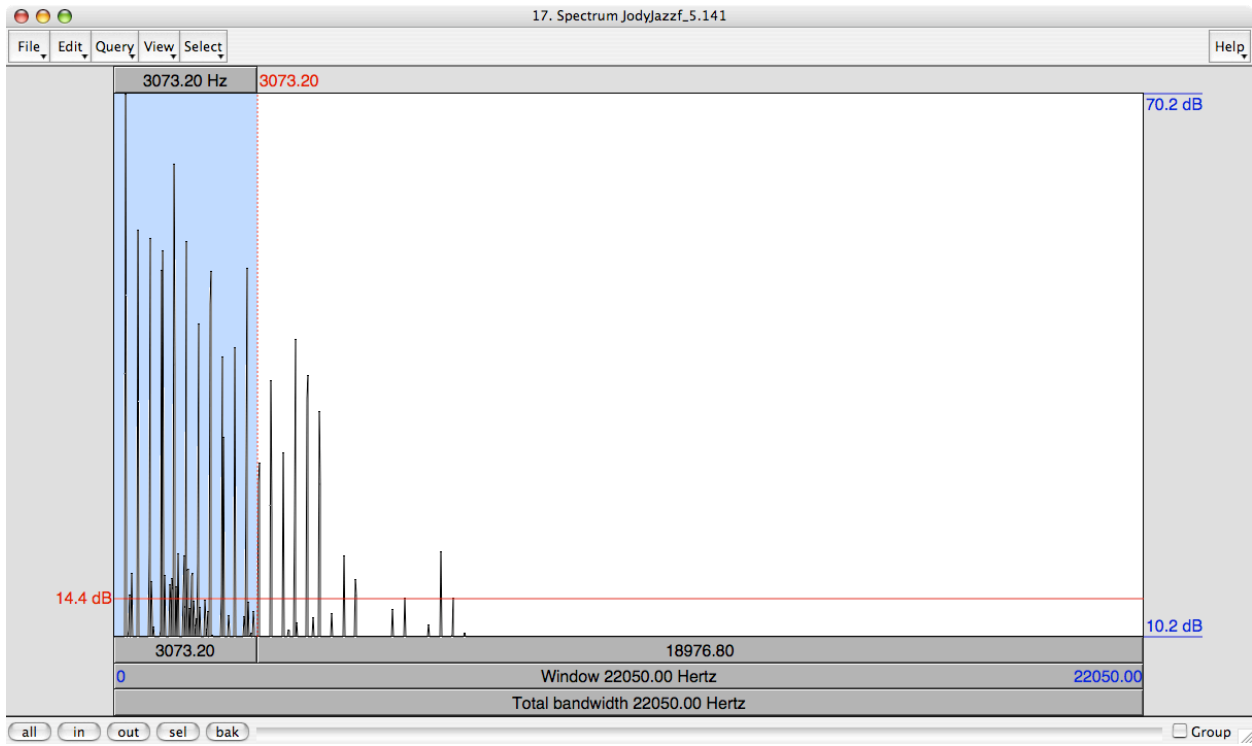


Small Chamber (Selmer Super Session D)

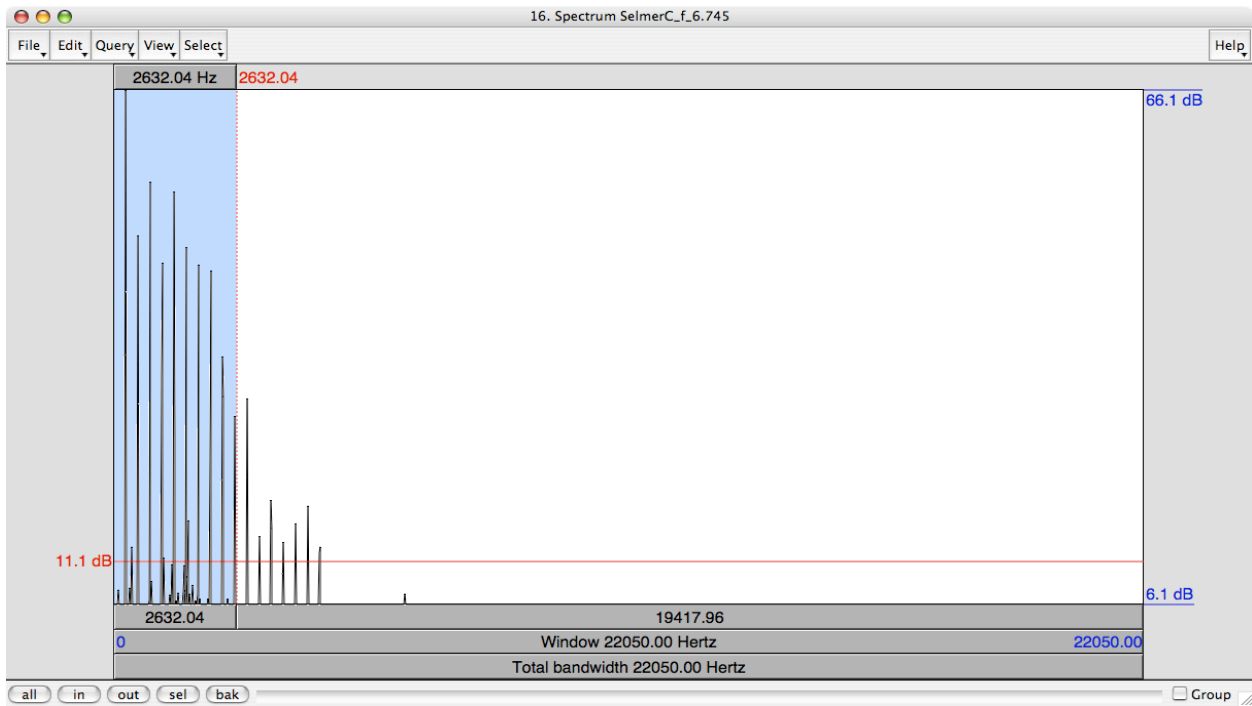


Case 3:

Large Tip Opening/Curved Side Walls (Jody Jazz)



Small Tip Opening/Straight Side Walls (Selmer S80)



References

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