Sound Analysis

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Last month's topic covered the basic low-frequency (or "Signature") modes of the violin. Now we'll look into how to use computer spectral analysis to find the modes, as well as the overall response of an instrument.

Sound is how we perceive air pressure variations. The output of a microphone or stereo system will be voltage which varies with time. If you take a time segment of this signal, mathematical magic can convert it into a plot of amplitude vs. frequency. The Fourier transform is the most well-known of these magical processes, but there are others.

Programs

These algorithms have been put into various computer programs; Spectra Plus is one of the most widely used in instrument sound analysis. I have been using one written by our own Ed Glass, but there is now a spectral analysis function available in AUDACITY, which can be downloaded from the internet for free. This is what was used for the displays shown in this article. It doesn't have a lot of display options, but it has all the basics you need.

Equipment

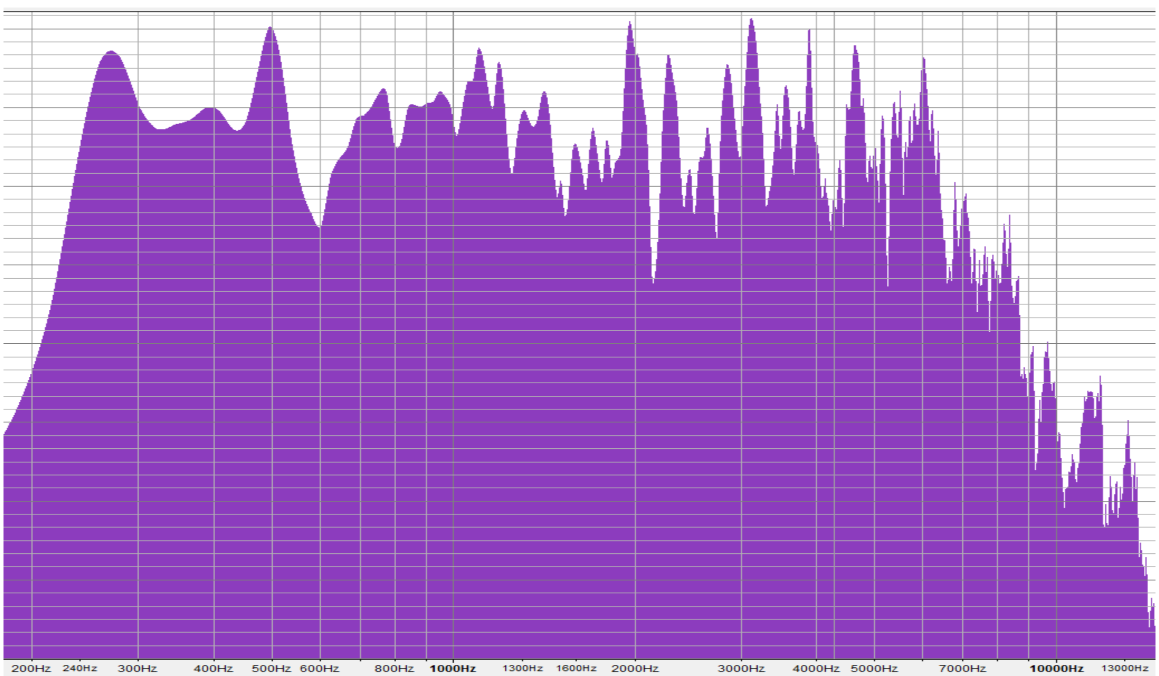
You will need a computer, microphone (you don't need a fancy or expensive one to cover the 200 – 6000 Hz range), and a "hammer" to tap on things. My hammer is cut out of spruce; it is 7" long and weighs 0.5 grams. There are reasons why I made my hammer this way:

1. The hammer needs to be light in order to get even energy input over the frequency range. Think about the bridge, which flexes at the waist at about 2500 Hz; if the hammer is too heavy, the bridge will bounce off the hammer and come back in less than a millisecond to hit the hammer again, screwing up the measurement. You need to get the hammer light so it bounces away from the bridge quickly.
2. Spruce was used to minimize denting damage worries when tapping on various parts of an instrument.

Measuring a Violin

One of the quickest and most useful measurements is to get an overall impact response spectrum, and this is the first measurement I always make. I hold the neck of the violin with my left hand, damp the strings with my fingers, press the endpin/chinrest into my body, and hold the hammer in my right hand. This is to get the response as it would be held during playing. I have the microphone 7" away from the bridge, directly above it.

After plotting the spectrum with Audacity (first setting the size to 2048 and using a log scale), we get:



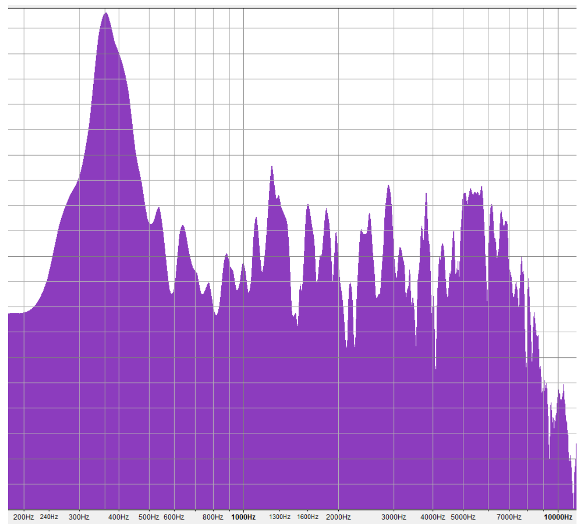
The A0, or Helmholtz mode, is always easy to find… it's the lowest prominent peak, in this case at 270 Hz.

The B1- mode is the next significant peak, usually in the 400 – 480 Hz range. The small peak on this plot is at just under 400 Hz, which is unusually low and might be skewed by some other weakly radiating modes nearby (we'll look at this shortly).

The B1+ mode is usually one of the stronger modes, and this particular violin is very strong, at 495 Hz. That is also quite low in frequency compared to most violins.

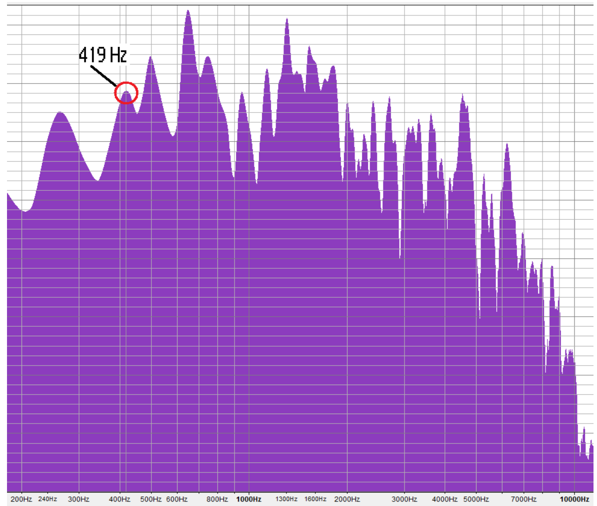
Now let’s look in more detail at what might be going on around the B1- mode, where the weakly radiating CBR and A1 modes might be lurking.

The CBR mode (see the Martin Schleske website for an animation, which he calls the “torsion mode”) is a twisting of the center bouts, normally in the 350 – 420 Hz range. It does not cause a volume change of the body, and therefore can not create much sound at this low frequency. However, it does cause significant bridge motion, and can create wolf notes. To get a good measurement of this mode, I place the microphone very close to one edge of the center bout, and tap the other.



There’s no mistaking the peak of the spectrum at 360 Hz.

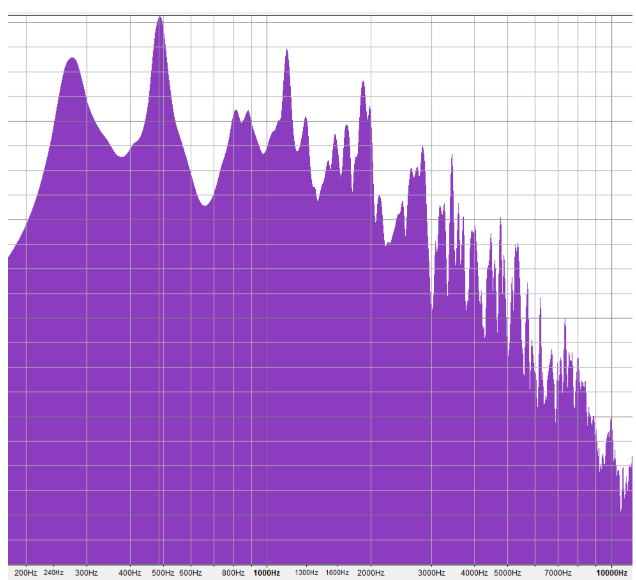
Now let’s measure the B1- mode more accurately. Again, referring to the Schleske animations (and again, he has a different name for this mode), the largest movement in the body is in the center bout area of the back, on the bassbar side. To get the strongest signal, one would like to tap and mike this area, but I prefer to tap directly in the middle of the back, in order to not excite the CBR mode which is nearby in location and frequency.



Now we find a modest peak at 419 Hz, which is most likely the actual B1- mode. It is likely that the weakness of this mode and the strong nearby CBR mode combined to show the small peak at 400 Hz in our initial measurement.

Finally we'll look for the A1 mode. This is the second air mode, with the air sloshing back and forth between the upper and lower bouts. It is weak for two reasons: it does not get much excitation, as body displacement is primarily at the center of the instrument at this frequency range, and the central location of the F-holes is at a nodal line… i.e. there is no pressure variation here, therefore no sound comes out.

It is possible to get a measurement, though. I place the microphone at the lower eye of the F-hole (farthest from the center bouts, where there should be some pressure variation), and tap on the upper bout to excite the mode.



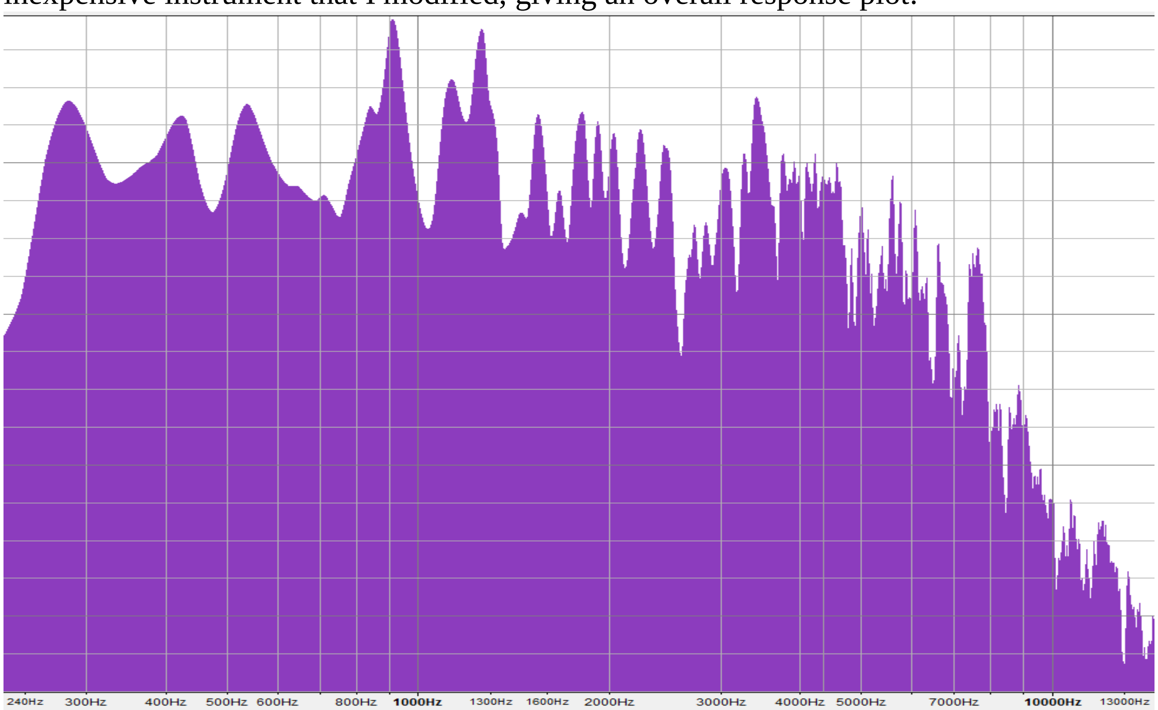
The highest peak shows up at 486 Hz. As a check to make sure this is A1 and not B1+, the same test was performed with the microphone at the upper area of the F-hole… and the peak all but disappeared. This is what should happen for A1, but not for B1+.

Discussion

This is all very interesting in an academic sense, but now what good is it? What is the "ideal" set of resonances, how do we perform in-process tests to get them?

\Joseph Curtin had an article in the July issue of "The Strad" showing the average of several Stradivarius violins was 272 Hz for A0, 437 Hz for B1-, and 531 for Hz B1+. Similarly, Guarneri instruments averaged 285, 447, and 531 Hz respectively. However, one must consider that instruments such as the "Ole Bull" Strad, which is not known to be horrible, has signature modes of 271, 405, and 499 Hz (very close to my violin modes of 270, 419, and 495 Hz). So we have evidence that good violins can have a wide range of signature modes.

Conversely, "normal" signature modes do not assure a good violin. I measured an inexpensive instrument that I modified, giving an overall response plot:



The signature modes measured a more "normal" 280, 424, and 535 Hz, with nice, even-looking amplitudes for each. However, this violin has a rather unpleasant sound. Looking at the response plot, there are two monster peaks at 911 and 1259 Hz, right in the range often described as the "nasal" frequencies. One would have to look at the higher body vibration modes to see what is causing this, and I believe it has to do with the arching and graduation in the cheeks of the bouts… too flat and too thin. Compare this to the first violin's response plot, where the "nasal" range is depressed below the lower and higher frequencies. I had intentionally kept the cheeks of the bouts thicker, with more curvature, to try to depress this range. While not conclusive proof, the results at least appear to support the theory.

At the moment, there are no good in-process tests I know of to obtain any specific result. Many attempts have been made to correlate free-plate mode shapes and frequencies with the assembled instrument modes and frequencies… all showing at best an extremely tenuous relationship, and even that is questionable.

I view this sound analysis as an assist to trial-and-error. Using my violin (the first one) as an example, the B1- and B1+ mode frequencies are too low; the B1- is too weak and the B1+ is too strong. The excessive strength of B1+ could also be due to being very close to the A1 mode. There are things I think I can do to the mass and stiffness that will lead to improvement of these modes on the next instrument. As demonstrated, these are not the most critical features of violin tone, but should help in evenness and playability on the lower strings. Each instrument built and analyzed will hopefully lead to a sequence of improvements.

So, at the end of all this, the critical middle and upper frequency ranges are still something of a mystery. That will be a topic of a future article, if I ever figure it out.