How Low Can the Violin Go?

Accomplished violinists can generate anomalous low frequencies on their instruments. These unusual tones can be understood in terms of multiple reflections of a single wave at the bow. In effect the reflections prolong the sound-producing cycle first analyzed by Helmholtz.

Almost all beginning violinists generate the sound of a small woodshop when practicing low notes. Almost no professional musicians cultivate that scratchy rumble to produce definite tones of lower frequency than the violin is normally capable of. Yet such tones can be generated, and several investigators are trying to make sense of them.

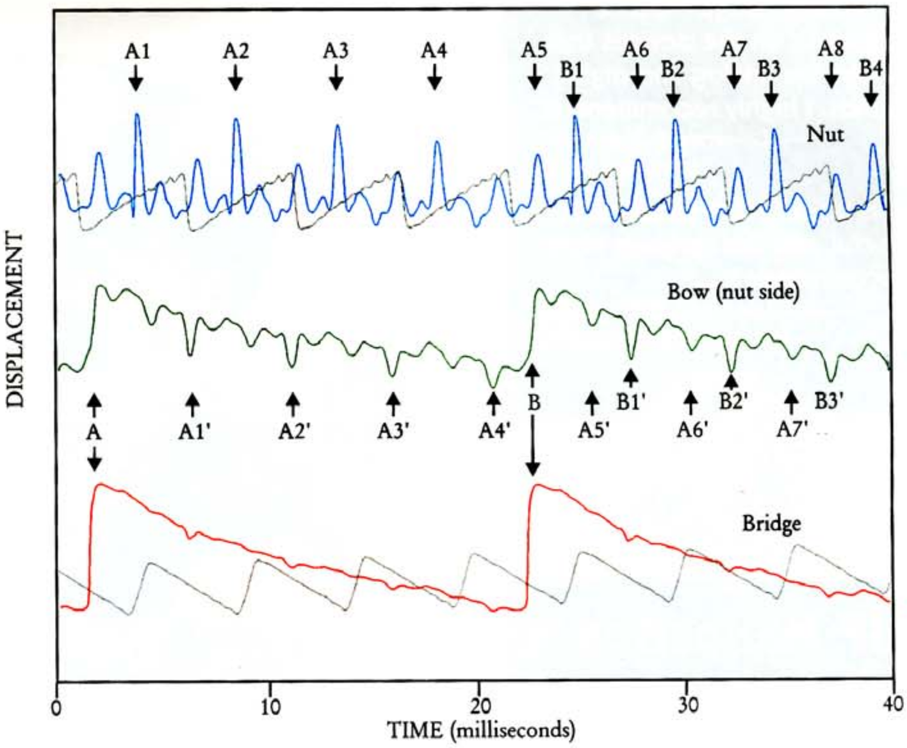
In 1989, at the University of Northern Iowa, in Cedar Falls, music professor Frederick Halgedahl discovered such tones and physicist Roger Hanson began to analyze them. By exerting larger-than-normal force with the bow on the lowest string (G at 196 Hz) and employing careful bow control, Halgedahl was able to isolate individual, stable tones ranging from 155 Hz (about a musical third lower than the open string) down to 47.4 Hz (slightly more than two octaves lower). These frequencies are not subharmonics; they have no simple relation to the fundamental frequency of the free string. From the sound spectra, Hanson discovered that the fundamentals for these anomalous low tones were either weak or missing, but because the subsequent harmonics in the sound were strong, the ear "heard" the true harmonic sequence, and the listener "perceived" the true low tone nevertheless. Hanson, with Andrew Schneider and Benjamin Ross, also observed the string with optoelectronic detectors and found very complicated waveforms, as shown in the figure on page 21.

The researchers anticipated that the low notes would have little musical importance. They were therefore surprised to read in the *New York Times* (21 April 1994) of a performance by concert violinist Mari Kimura in which she used these very tones, discovered independently, to musical advantage.

Knut Guettler, at the Norwegian State Academy of Music, in Oslo, had meanwhile become interested in this phenomenon. He performed numerical simulations of a heavily bowed string, based on D'Alembert's solution to the wave equation. The two physicists published companion papers with their analyses last year.[1] Hanson and Guettler met Kimura for the first time on 31 May of this year, at the Acoustical Society of America's meeting in Washington, DC, where she gave an electrifying performance to a standing-room-only crowd of acousticians.

WANT TO TRY IT?

Here are some tips from Frederick Halgedahl: "Beginning somewhere in the lower third (the *tasto* range) of the lowest string, where you can easily feel the flexibility of both the stick and the deformed string, and using about the same force as for a *fortissimo*, pull smartly but with a slow, sustained motion. Until you get the hang of it, you may have to put up with a ragged start until the relation between bow and string stabilizes. It may help to err on the heavy side as you begin and then 'lighten into it.' The most important factor in producing these low tones may just be knowing that they exist."



TRANSVERSE WAVEFORMS for a bowed string producing an anomalous low frequency of 47.4 Hz. Two cycles are clearly seen at the bridge (red) and at the bow itself (green). The string slips at the times marked A and B. The disturbance from slip A reaches the nut (blue) at the time marked A1 and is reflected back to the bow (A1′), back to the nut again (A2) and so on. The waveform at 196 Hz for the normally bowed string is superimposed (gray) over the waveforms at the nut and bridge. The vertical scales are all different and are arbitrary. (Adapted from ref. 1.)

As first observed by Hermann von Helmholtz[2] and elaborated by John Schelleng,[3] a bowed violin string follows a sawtooth pattern: The bow drags the string until a wave, reflected from the nut (near the tuning pegs), frees the string, which then slips along the bow until it is caught and pulled along again by the motion of the bow. The wave continues on to the bridge, where it contributes to the audible vibrations of the instrument. Meanwhile the string's release sends a new disturbance along the string, which triggers yet another release. This is the well-known stick–slip (or Helmholtz) cycle, which takes place at the same frequency as the oscillations of the freely vibrating plucked string.

Bearing down with the bow, as required for the anomalous low frequencies, has several consequences. The added frictional force prevents the normal release of the string from the bow hair and results in multiple bow–nut reflections before release occurs. In addition, the string tends to "roll" under the bow, introducing torsional waves that propagate faster than the normal transverse waves. These torsional waves may, in some cases, trigger the release. No experimental measurements of torsional waves on violin strings have yet been done.

With skillful bow control, a violinist can create a steady-state oscillation with a longer-than-normal period; to achieve this effect, the same portion of the waveform must trigger the delayed release in each cycle.

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References

1. R. J. Hanson, A. J. Schneider, F. W. Halgedahl, Catgut Acoust. Soc. J. **2**, 1 (1994). K. Guettler, Catgut Acoust. Soc. J. **2**, 8 (1994).
2. H. von Helmholtz, *On the Sensation of Tone*, Dover, New York (1954); the original German edition was published in 1877.
3. J. C. Schelleng, J. Acoust. Soc. Am. **53**, 26 (1973).