COMBINATION TONES IN THE VIOLIN

... AND IN OTHER STRING INSTRUMENTS

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ABSTRACT

This study investigates the appearance of combination tones in violins.

Most modern textbooks emphasize that combination tones occur inside the ear (intra-aural) exclusively.
In this study this assumption will be subjected to scrutiny based on evidence found in an empirical study where combination tones were measured outside the ear (extra-aural).

An experiment was performed in which a violinist played two tones of a particular musical interval simultaneously. This was recorded and then subsequently analysed using a Fourier Transformation. In addition to the partial tones of the primary interval the resulting spectrum showed frequencies which correspond to combinations tones.
Such particular frequencies may influence the timbre of musical intervals played on the violin.

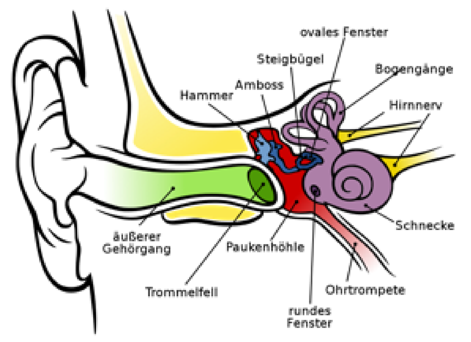
With a newly devised tone matrix one can compute all potential combination tones that can occur between any pair of partial tones. The detailed analysis of musical intervals by both the frequency spectrum and the tone matrix show characteristic mirror and point symmetries in their partial tone structure.

It is hoped that this research will lead to results relevant for interpreters, composers, violin makers and violin acousticians.

ORIGIN OF COMBINATION TONES

Combination tones are the product of nonlinear acoustic transmission systems. An example of such a system can be the human ear or a string instrument.

For the purpose of clarity, combination tones that are generated inside the ear will be called „intra-aural", those that occur outside and independently of the ear „extra-aural".



INTRA-AURAL

EXTRA-AURAL

METHODOLOGY

In an anechoic chamber, the string player played two notes simultaneously that corresponded to a particular musical interval. The sound was recorded using a microphone, positioned near the f holes. A section of approximately two seconds duration was taken from the recorded sound, and its spectrum was calculated using an FFT.

Figure 1: Violin 440/704Hz, 5/8, a'-f''

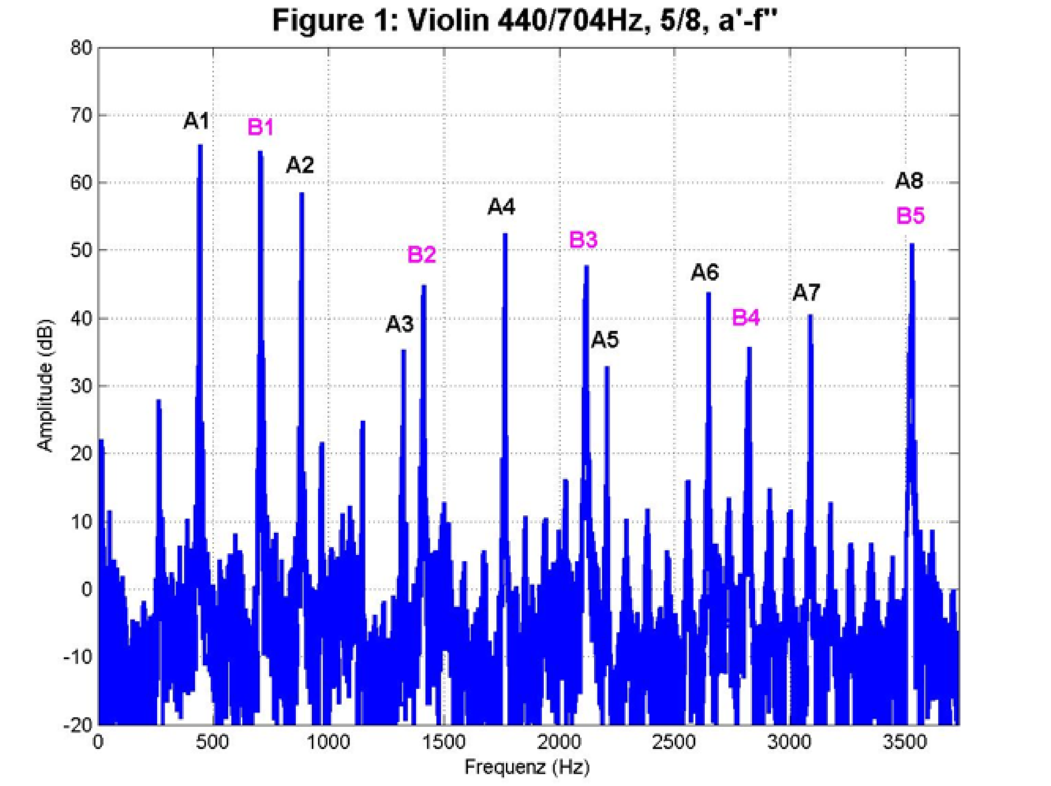


Figure 2: Viola, 293/469Hz, 5/8, d'-b'

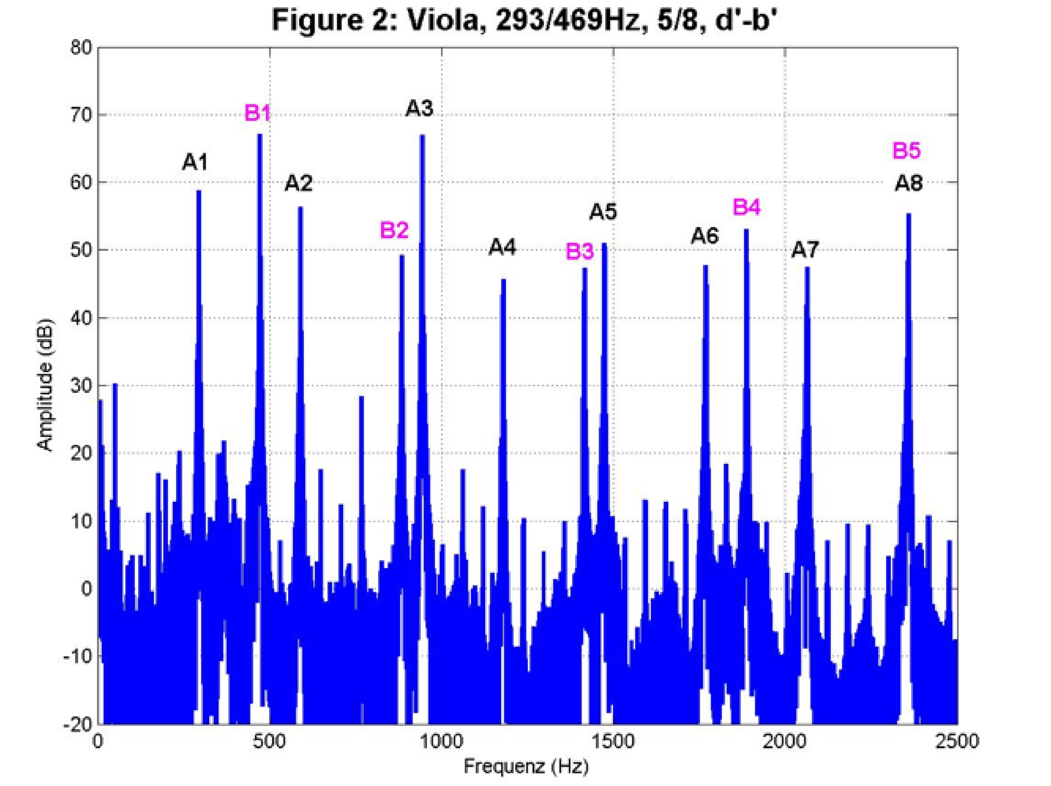
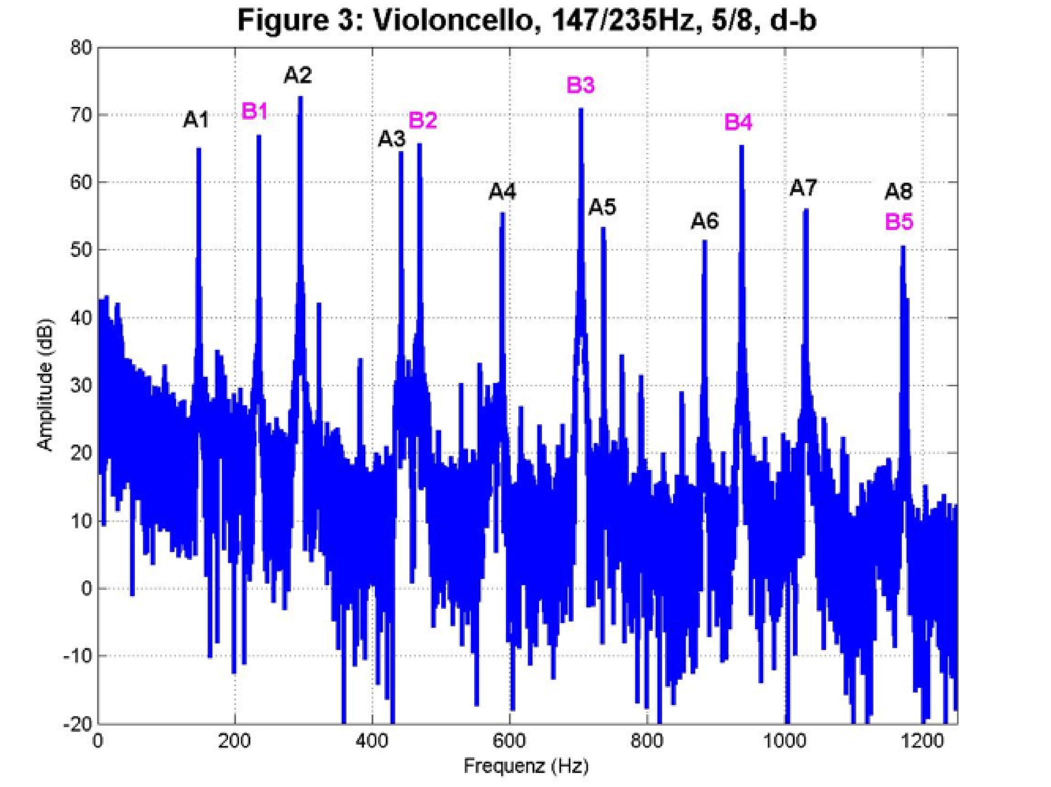


Figure 3: Violoncello, 147/235Hz, 5/8, d-b



EXTRA-AURAL COMBINATION TONES IN VIOLINS, VIOLAS AND VIOLONCELLI

Extending the experiment, viola and violoncello players were invited. To establish a basis for comparison the same interval (cf. figures 1, 2, and 3: a sixth 5/8) was played on all three instruments on the two uppermost strings. The measurements show that combination tones appear in all three instruments. In the examples on the left, partial tones are marked with letters A or B. All lower peaks (untagged) represent combination tones. Obviously, the violoncello tends to generate less extra-aural combination tones than the violin. The peaks of combination tones are not chaotically distributed. On the contrary, they can appear only in a regular pattern of equal distance, which is determined by the greatest common divisor (GCD) of the two primary tones. In our example with the frequency ratio 5/8, the GCD is 1, which corresponds to 88Hz (Violin), 58,6Hz (Viola) and 29,4Hz (Violoncello).

MATHEMATICAL MODEL OF COMBINATION TONES

Both extra-aural and intra-aural combination tones can be described with the same quadratic equations:

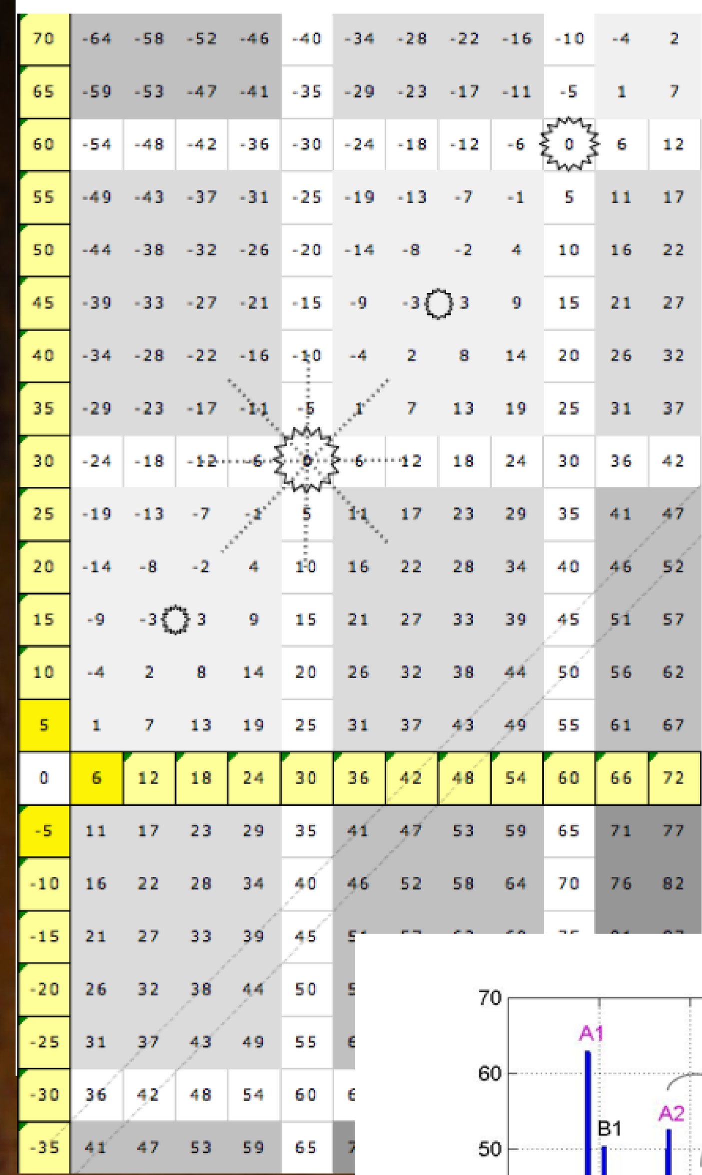
$$y = (\cos f_1 + \cos f_2)^2$$

$$\Updownarrow$$

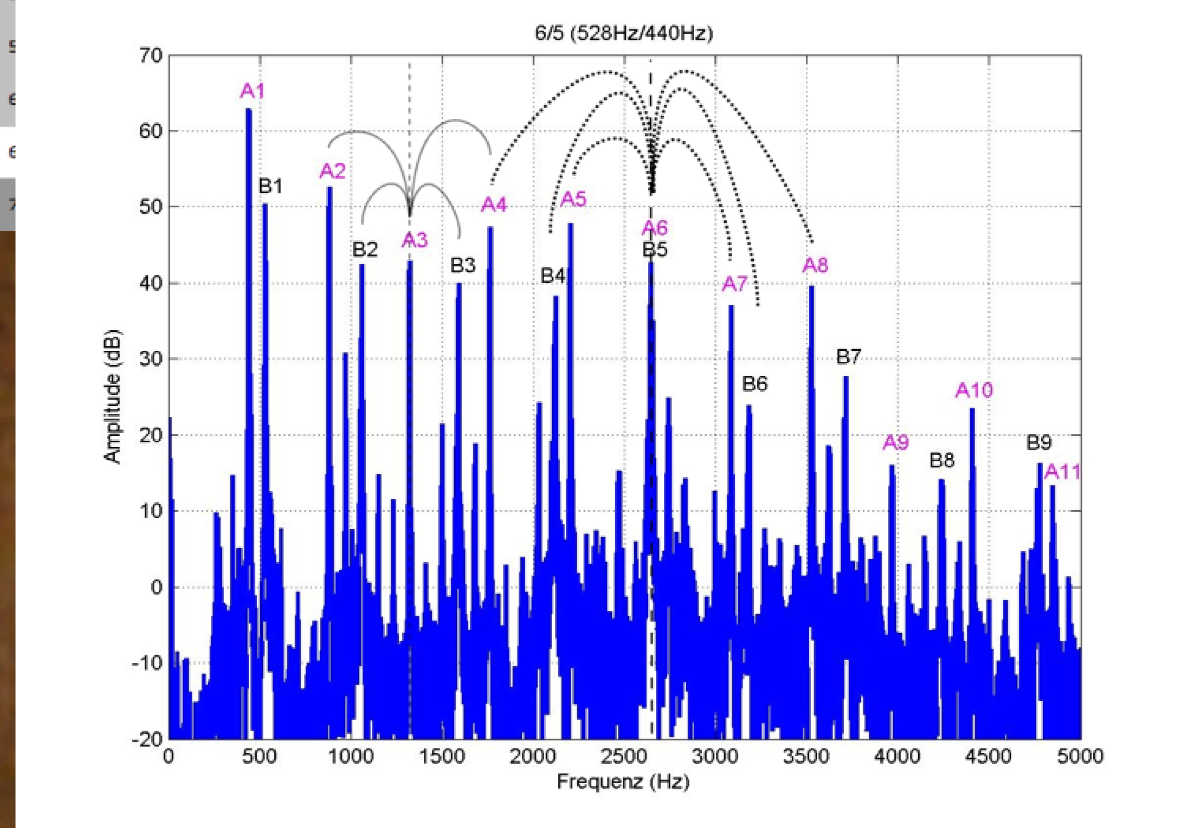
$$y = 1 + \frac{1}{2}\cos(2f_1) + \frac{1}{2}\cos(2f_2) + \cos(f_1 - f_2) + \cos(f_1 + f_2)$$

We get four new frequencies, including the difference tone and the summation tone.

COMBINATION TONES AND SYMMETRY



Combination tones can be represented systematically in a „tone matrix" (Figure at the left: partial tones in yellow, in the upper quadrant difference tones, in the lower summation tones). Depending on its ratio, each interval generates characteristic point symmetries. The same symmetries are visible in the corresponding spectrum too, but changed from point symmetry into mirror symmetries (see figure below).



VIRTUAL PITCH

When a musical interval is played on the violin, the sensitive ear can perceive not only combination tones but also a virtual pitch, which corresponds to the greatest common divisor of the two primary tones. We assume that the appearance of combination tones has a significant influence on this effect. Filling in the blanks between partial tones, combination tones complete the series of a grid of equidistant frequencies (see figure below) that suggest the harmonic series of a virtual pitch. This is similar to the „residual tone" phenomenon.

440/550Hz, 4/5, a'-cis''