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Analysis of Bowed-String Multiphonics

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ABSTRACT

By carefully positioning the bow and a lightly touching finger on the string, the string spectrum can be conditioned to provide narrow bands of pronounced energy. This leaves the impression of multiple complex tones with the normal (Helmholtz) fundamental as the lowest pitch. The phenomenon is seen to be caused by two additional signal loops, one on each side of the finger, which through the repeating slip pattern get phase locked to the full loop of the fundamental. Within the nominal period, however, the slip pulses will not be uniform like they are during the production of a normal "harmonic", but may vary considerably in shape, size, and timing. For each string there is a certain number of bow/finger combinations that bear the potential of producing such tones. There are also two classes, depending on whether the bow or the finger is situated closest to the bridge. Touching the string with the finger closest to the bridge will somewhat emphasize the (Helmholtz) fundamental. The technique is applicable to double bass and cello, while less practical on shorter-stringed instruments.

INTRODUCTION

Multiphonics in wind instruments has been around for a while. Nowadays you often hear saxophone players utilizing the technique in jazz and contemporary music. In brass instruments the effect probably dates back even longer, and can be found in music even from the classical period: here the musician sings along with the lip-controlled pitch, and thus creates a quite audible series of difference tones. Woodwind players mostly use special quite fingering in combination with very precise embouchure. In string instruments multiphonics is mainly a filtering technique, where certain partials of a low fundamental are restrained by a lightly touching left-hand finger pad on the string, which brings out the remaining partials in narrow clusters.

Although probably performed by Italian double bassist Fernando Grillo [1] already during the 1970ties, the first comprehensive description of multiphonics is dated to 1995, when French bassist Jean-Pierre Robert published his bilingual book "*Les modes de jeu de la contrabasse – un dictionnaire de son/Modes of playing the double bass – a dictionary of sound"* in collaboration with IRCAM [2]. This research, which started in 1985, also made a noticeable impact on composers working in Paris and IRCAM at the same time. A similar description on the production of multiphonic sounds was later found in the article *A personal pedagogy* by Mark Dresser (2000) [3]. Dresser has been further exploring multiphonics, without being much influenced by the European achievements, and his discoveries were presented in several articles published in The Strad, autumn of 2009 [4].

A comprehensive and detailed study on multiphonics on the double bass was later presented by Michael Liebman in his article *Multiphonics: new sounds for double bass*, which unfortunately has remained unpublished. His study on new sonic opportunities of string instruments began in 1997 and manifested itself quickly in the composition *Movement of Repose* (1998) for cello, and the article *Multiphonics Neue Moglichkeiten im Cellospiel* (Das Orchester 4/2001) [5]. In the material from Robert, Liebman and Dresser we find extensive information about the technical production and timbre variations of multiphonics sounds, together with chord schemes (spectral analysis) that illustrate the most known multiphonics. However, the acoustical implications in terms of string waveforms, etc. were never touched upon by these authors.

MEASURING METHOD

In order to understand how the string moves, a hybrid technique was utilized in our experiments: After a traditional recording of the string movement under the bow: with a strong magnet placed directly under the string and registration of the difference in voltage potential at the two string ends, the resulting (velocity) signal could be fed as the bow velocity input to a bowed-string simulation program. By combining this signal with a bow force that ensures static-friction grip at all times—and some sensible string-end and touching-finger reflections, the movements of the entire string could be visualized and analysed. (Conveniently, the string cannot "see" the difference between static and dynamic friction, only the resulting frictional force, which also can be derived from the simulation itself, provided the string impedances and the other parameters are correctly defined.) This proved to be a very convenient way of getting an overview over otherwise quite confusing phenomena, and enabled us to produce a slow-motion animation of every multiphonics.

With a fixed bow position on the string, a series of spectra can be obtained by moving the lightly touching finger along the string length. We recorded a selection from two such

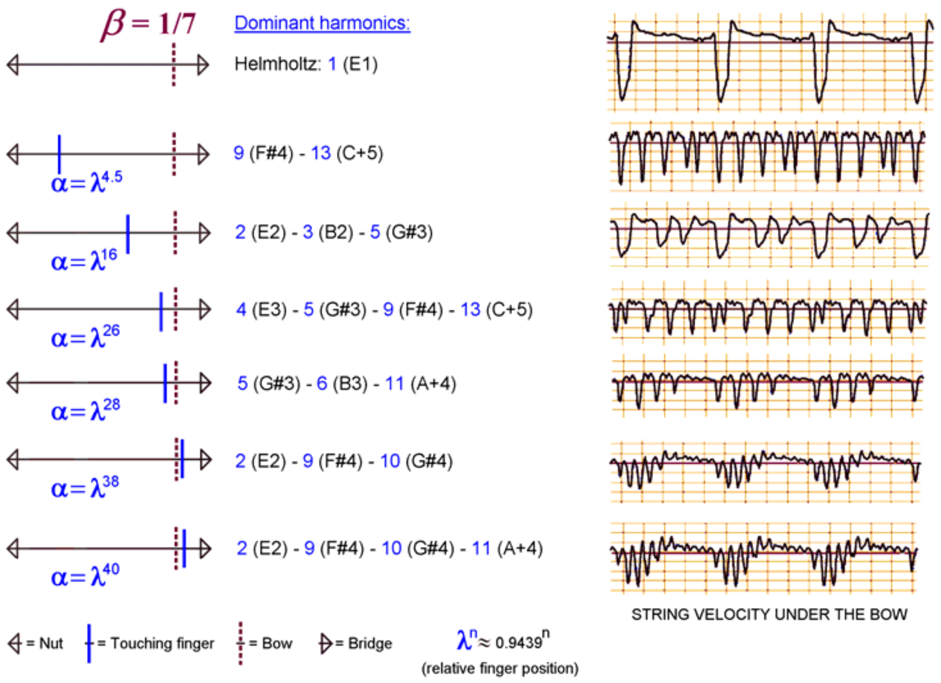

Figure 1. Examples of dominant harmonics (blue) and string wave forms under the bow, resulting from a fixed relative bow position β = 1/7 and a moving left-hand finger with positions (α). The exponent of λ indicates the position in terms of number of semitones above the open-string pitch, e.g., 4.5 refers to four and a half semitone above the fundamental E_1. That is a quartertone above $G\#_1$.

The right column of the figure shows string-velocity wave forms under the bow. The negative velocity values are strong indications of slips. It is seen than all multiphonics has more than one slip per nominal (Helmholtz) period.

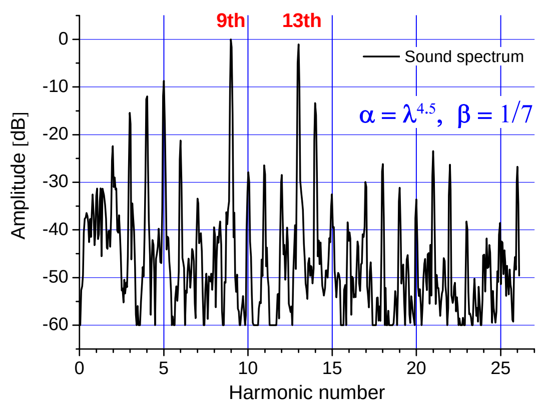

Figure 2. Spectral example of a finger-bow combination with positions α = $0.9439^{4.5}$ and β = 1/7. Notice that the 9^{th} and 13^{th} harmonics stand out, just as indicated in Figure 1, second row.

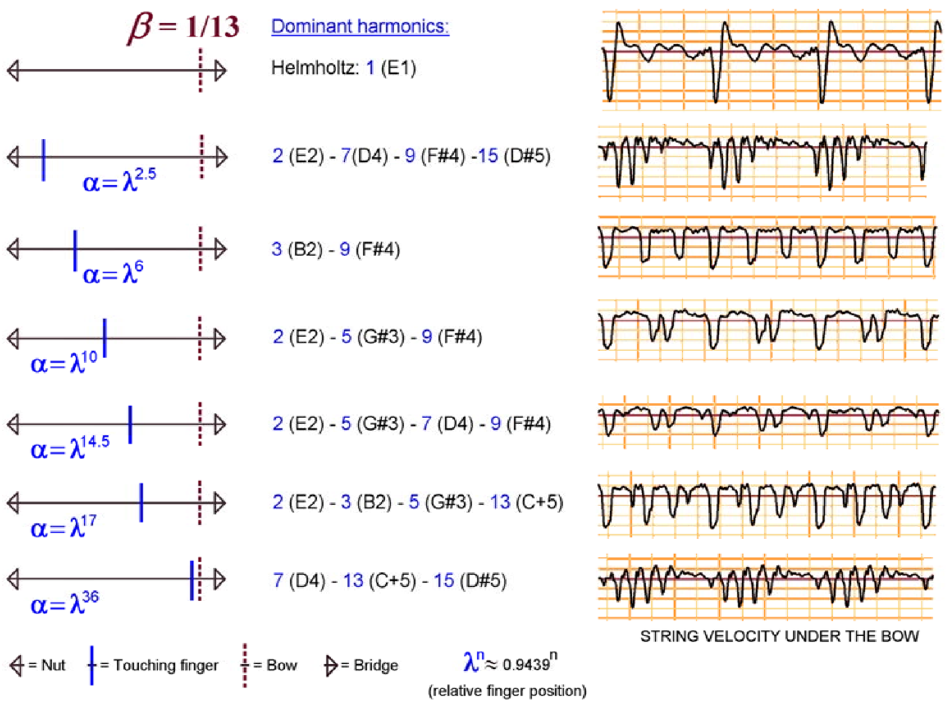

Figure 3. Examples of dominant harmonics and string wave forms under the bow, resulting from a fixed relative bow position β = 1/13 and a moving left-hand finger with positions (α). The exponent of λ indicates the position in terms of number of semitones above the open-string pitch.

In the wave form of the first row there is most likely only one slip per period in spite of some negative velocity values, the origin of which can be explained by great torsional string activity.

series on an open double-bass E-string: one with the bow placed at the point β = 1/7 of the string length from the bridge, and another one where β was 1/13. Spectral analyses were done both from the string signal itself, and from an audio signal picked up with a normal microphone in the near field of the instrument. In the plots above, α indicates the position of the lightly touching finger (measured from bridge), relative to the entire string length, while λ indicates the relative string-length decrement per semitone {i.e., Exp[–ln(2)/12] ≈ 0.9439}. Thus, the exponent of λ gives the number of semitones above the pitch of the open string, while the decimal 0.5 denotes a quartertone.

IMPULSE-RESPONSE ANALYSIS

In order to understand the filtering mechanism, it is useful to look at the impulse response with the lightly-touching finger on the string. In this connection the finger can be regarded as purely resistive with convenient reflection and transfer coefficients both equal to 0.5. Figure 4 shows the force on the bridge during the first 1.3 nominal periods after a unit impulse is given in the bowing point, β, at the time t = 0. With regular impulses at the start of each nominal period, it is clear that the picture will get considerably more complicated as the string accumulates the impulse history of previous periods. As is seen in Figure 4, there are two trains of fading impulses, one negative and one positive, both with intervals of T(1–α), but the positive series shifted Tβ with respect to the negative one. Another loop (between the finger and the bridge) has period Tα. (When played with a bow there might even be a loop of length T(1–β) if impulses are hitting the bow during stick.) When doing Fourier-transform analysis of a series of impulse responses, superimposed with a delay intervals of T, one gets a pretty good impression of which harmonics will dominate the spectrum, but a direct spectral determination based on a small selection of Dirac delta functions is not at all straightforward, since history plays such a crucial role, and each slip provides phase locking. This also implies that a certain transient time is required before the desirable, dominant harmonics pop up.

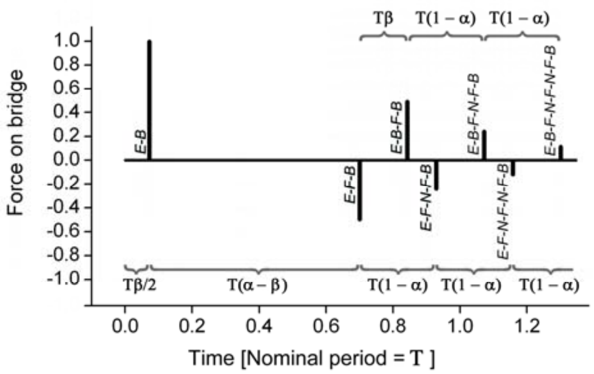

Figure 4. Impulse response at the bridge when the string is excited at the bowing position β, and a finger is touching the string at point α. The letters *E-B-F-N* symbolises: *Excitation point* (i.e., bow position), *Bridge, Finger,* and *Nut,* respectively, and indicate the paths the impulses have been travelling on the string.

It would, of course, have been quite attractive to use an inverse Fourier transform on a given selection of harmonics to calculate the bowing and finger positions in terms of Dirac delta-function loops, but we have not been able to resolve that yet.

NOTATION SYSTEMS

Although multiphonics is a recent development, several notation systems have already been employed in order to instruct the player to produce the correct sound. The position of the left hand causes no problem, as a normal note with a diamond or rectangular head will do nicely, and is readily understood by the musician. The position of the bow is somewhat harder to indicate in a concise manner, as the sign should be small and placed either below or above the fingered note. Liebman suggests two ways of indicating the bow's position: (1) a series of Italian expressions ranging from "*molto tasto*" to "*molto ponticello*". These ranges are predefined with approximate distances from the bridge. (2) Indication of bow position in cm from the bridge (see Figure 5 and 7 below). However, in this area of the string, the (accomplished) player will be more familiar with the positions of the highest harmonics (flageolet tones), and should without too much of a problem be able to place the bow there, regardless of non-standardized string lengths and other trivialities.

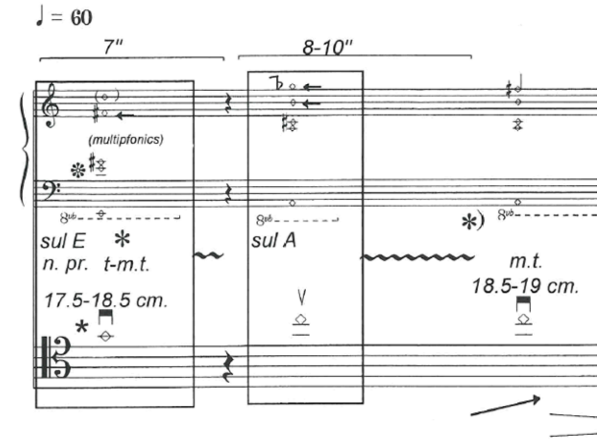

Figure 5. Example of notation by Liebman (from "Legato Sonore"). By playing the lower stave with the bow placed in proper distance from the bridge, the harmonics (multiphonics) shown in the upper two staves will be dominant.

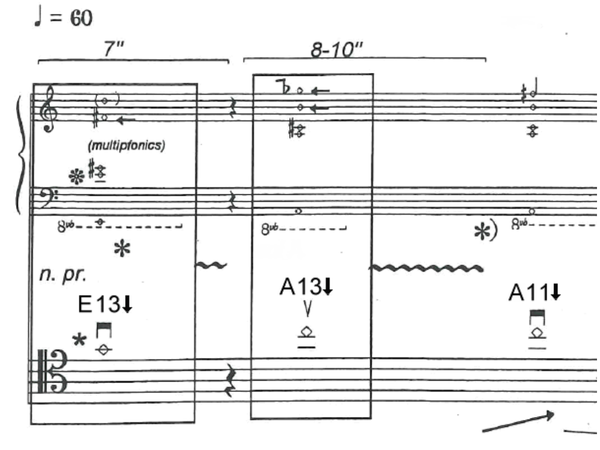

Figure 6. Alternative notation of bow position and string choice based on natural harmonics: E13↓ and A11↓ mean bow positions of the 13^{th} and 11^{th} harmonics, second node, on the E and A string, respectively. See Figure 7 for explanation.

In Figure 6 we suggest a notation for bow position, where the upper-case letter determine the choice of string, the number gives the harmonic, and the arrow, indicate which harmonic node to use, starting with no arrow at the highest node. For example: the harmonic nodes 11↓↓, 11↓, and11 of Figure 7 denote β = 3/11, 2/11, and 1/11, respectively.

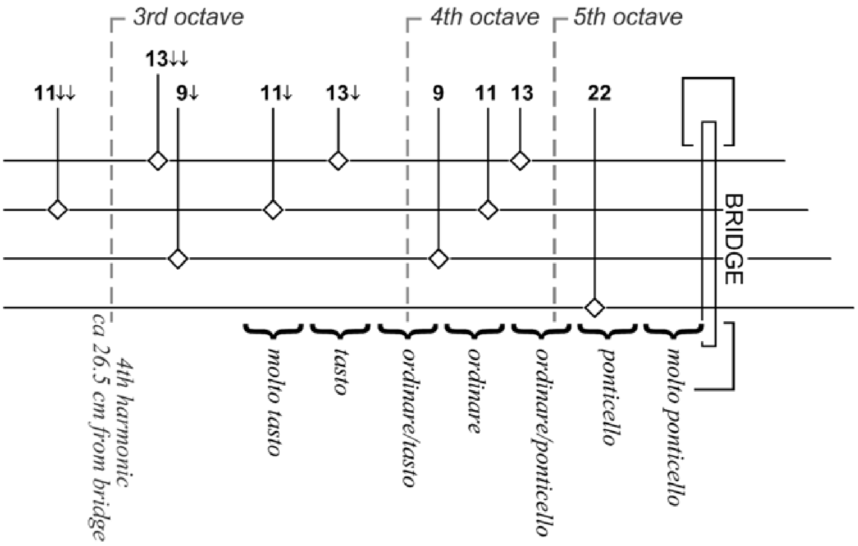

Figure 7. Chart of natural harmonics to be used for bow positions in multiphonics. Notice that all harmonics can be found several places along the string. Vertical arrows indicate which node to use, starting with no arrow at the uppermost node. At the bottom of the plot, Liebman's bow positions are included for comparison. Even though the harmonics' positions in this figure are marked on single strings only—for reasons of clarity—they can of course be used on every string.

PRACTICAL CONSIDERATIONS

The use of a lightly touching finger on the string defines the number of string slips during a nominal (open-string) period, and their pulse shapes. Their synchronization is often very fragile with small margins of stability. Since one aspect is the bow "pressure" (force), it is often feasible to indicate how much force to apply on the string with the bow in order to achieve the desired result. Also bow speed will influence the outcome. In general, bowing must be performed with great control and consistency.

As was mentioned in the abstract, the multiphonics comes in two classes, dependent on which side of the bow the lightly-touching finger is placed. If the finger is placed between the bow and the bridge, the stability increases noticeably, as the string waveform resembles Helmholtz motion with the exception that the (one) major slip is replaced by several minor ones appearing in quick succession within a short time interval. Between the finger and the nut, the string amplitude will move with a near parabolic envelope, as under true Helmholtz conditions. In Figure 1, the two last examples are of this class.

With the finger placed between the bow and the nut, as in normal playing, the stability is reduced, and the string-slip pulses are scattered all around the nominal period. The parabolic envelope vanishes, and the string appears restricted without clearly defined nodes or antinodes. In spite of being harder to execute, this class is the one most often employed, as it provides the most brilliant clusters and a greater variety of possibilities.

It should also be mentioned that multiphonics combined with natural harmonics on a different string provides a very attractive effect, as the stability and brilliance of the single-tone harmonic lend their features to all the tones in the cluster.

REFERENCES

1 Fernando Grillo, apparently in action with multiphonics of the first class. Picture from http://www.discogs.com/viewimages?artist=Fernando+Grillo

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