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Some aspects of the acoustics of the Hardanger fiddle

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The Hardanger fiddle (HF) is a highly decorated, baroque-like Norwegian folk music instrument with four or five sympathetic strings. Compared to a violin, it has shorter and lighter gut, G, D and A, and E steel strings, a flatter bridge and fingerboard, longer f-holes and the top has a flatter cross arch, mainly between and above the f-holes. Acoustically it is closely related to the violin. Its "ringing qualities" relate it to other bowed string instruments with free vibrating string designs, like the Swedish folk *drone fiddle* and the *nyckelharpa*, and also to the more "distant relative" the *Viola d'amore*. Acoustic properties and the construction of the HF are compared to the violin, showing close similarities in the lower frequency range. The bridge design and the tonal ideals are different, especially for the higher frequencies. A Hardanger fiddle will in general be a little quieter than a violin, but it may sound more "intense". Scordatura is often in use and the HF is traditionally played solo. The tuning of the A-string can be any frequency between A_4-D_5 (440 Hz - 587 Hz), with B_4 (494 Hz) being the most typical pitch.

1 Introduction

The investigations discussed in this paper were undertaken in the hope of gaining some information on the acoustics of the Hardanger fiddle (HF). The design of the HF, with its sympathetic strings, differs from the violin.
The rise- and decay time effects from these on the bowed notes were investigated by Michaelsen [1]. Trueman later investigated the radiation properties as part of a sound synthetization project [2].

1.1 Literature on the HF

The last 20 years a registration project on HF's made prior to 1900 has taken place. A database over registered old instruments was built up containing pictures and some vital data. A webpage and a book have been published on that material, Blom et al [3], Aksdal [4]. We do have some research articles, informal books and biographies on the HF and some of its makers [5]-[10]. However, most of it is written in Norwegian. The Hardanger Fiddle Association of America publishes *The Sound Post* quarterly [11]. Recently a growing interest in the older instruments has taken place e.g. by concerts performed on historical fiddles as well as recordings, Hauk and Knut Buen [12], Hamre and Maurseth [13].

1.2 Own work

I have earlier published several analyses based on Long Time Average Spectra (LTAS) extracted from recordings of fine violins [16]. LTAS from played scales on a larger set of instruments have now, for some time, been collected systematically using calibrated sound level meters under identical measurement conditions. Impulse responses and modal analysis have also been conducted on a set of violins and HF's parallel with detailed registration of material properties and geometrical data from these instruments.

2 Construction and tuning

The violin is usually tuned G_3 (196 Hz), D_4 (294 Hz), A_4 (440 Hz) and E_5 (659 Hz). On HF's, the A-string can be tuned to any frequency between A_4 and D_5 (587 Hz). The most typical tuning is with the A-string tuned to B_4. The strings are then tuned: B_3 (247 Hz), E_4 (330 Hz), B_4 (494 Hz), and $F\#_5$ (740 Hz), and the five sympathetic strings: $C\#_3$ (277 Hz), E_4 (330 Hz), $F\#_4$ (370 Hz), G_4 (392 Hz) and B_4 (494 Hz). The HF is usually played only with the hand in the "ground position" and more than twenty different tuning schemes exist, offering a variety of timbres and tonalities. Of these tuning schemes "a handful" is more often used.

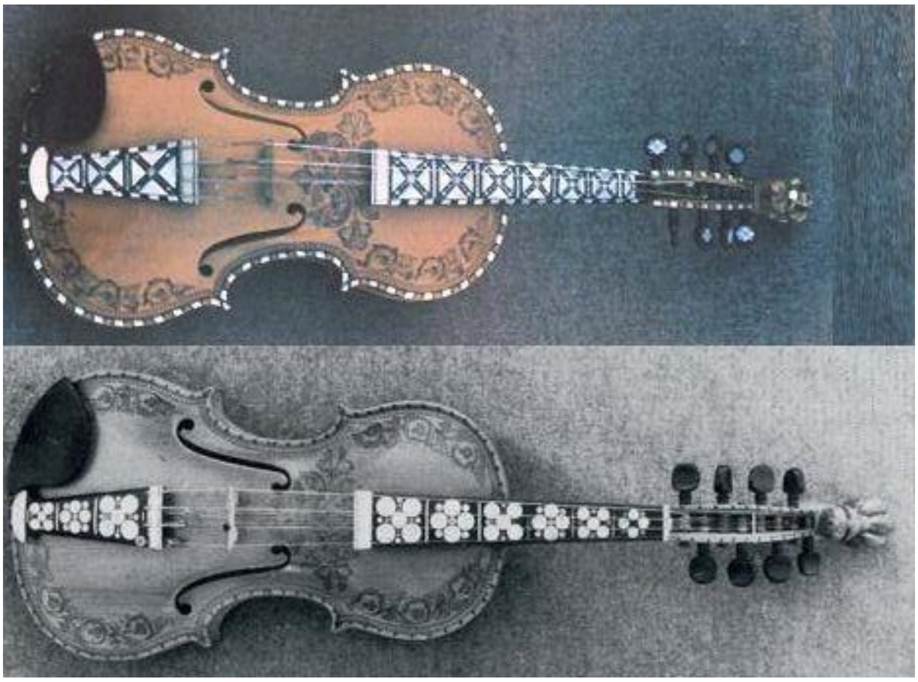

Figure 1: Hardanger fiddles made by Olav K. Venaas from Gransherad in Telemark in the early 1930ties. The upper is an exhibition instrument. The lower is one of the main instruments in the Buen folk music family. Photos: Asmund Buen.

Figure 2: A violin bridge (not trimmed) and a Viken type HF- bridge.

The sympathetic strings run under the fingerboard and rest on a "bridge" below the playing strings, typically some 18-20 mm above the top plate, see Figure 2.

The string length is typically 25-30 mm shorter than on a violin (328 mm). The strings are usually thinner and lighter, so the higher pitch is, to some extent, compensated for regarding the string tension. A HF tuned in B_4 (using gauge 10.5) will have a somewhat higher total string tension than a violin with normal Dominant, G, D and A strings and a 0.26 mm steel E. The string tension in HF's should, of course, be measured.

3 Experiments

Instrument response spectra are collected with the fiddles mounted vibration-insulated, on textile covered rubber bands, in a “Curtin rig”, [27]. The excitation is impulses from a miniature PCB 086E80 impact hammer, mounted as a pendulum. The head weighs 1.38 g. A PCB model 480E09 signal conditioner, an Earthworks M30 ¼” omnidirectional microphone, or a PCB 352A73 accelerometer, connected to a t.c. electronic konnekt 8 external soundcard and a laptop running SpectraPlus SC or George Stoppani’s analysis software is used for the analyses. A B&K mini accelerometer type 4374, a type 2647A preconditioner as well as a DeltaTron Power Supply type WB 1372 is also used in some of the analyses.

Long Time Average Spectra (LTAS) of played scales are collected using a calibrated Norsonic N140 sound pressure level (SPL) meter mounted about 1 m from the player seated in a corner of a “hard room”. The room dimensions are: L x W x H = 2.7 m x 1.6 m x 2.2 m, and the average reverberation time over the 1/3rd octave bands from 200 Hz to 20 kHz is: T_{30} = 0.35 s. The reverberation radius is 0.3 m so the mic @ 1 m is well inside the reverberant field.

The Schroeder frequency, indicating the start of the statistical region of the room modes, is a bit high at 374 Hz, but the reverberation time curve is almost flat, with no ringing modes.

3.1 Signature modes and “mode clusters”

The resonances of fiddles appear in separate identifiable *signature modes* up to about 1 kHz, where the resonances start to overlap and form *clusters*. Figure 3 show a spectrum of the volume change of a fiddle body calculated from modal analysis of the top and back plates up to 1 kHz using G. Stoppani’s software. The accompanying vibration shapes are shown with their names.

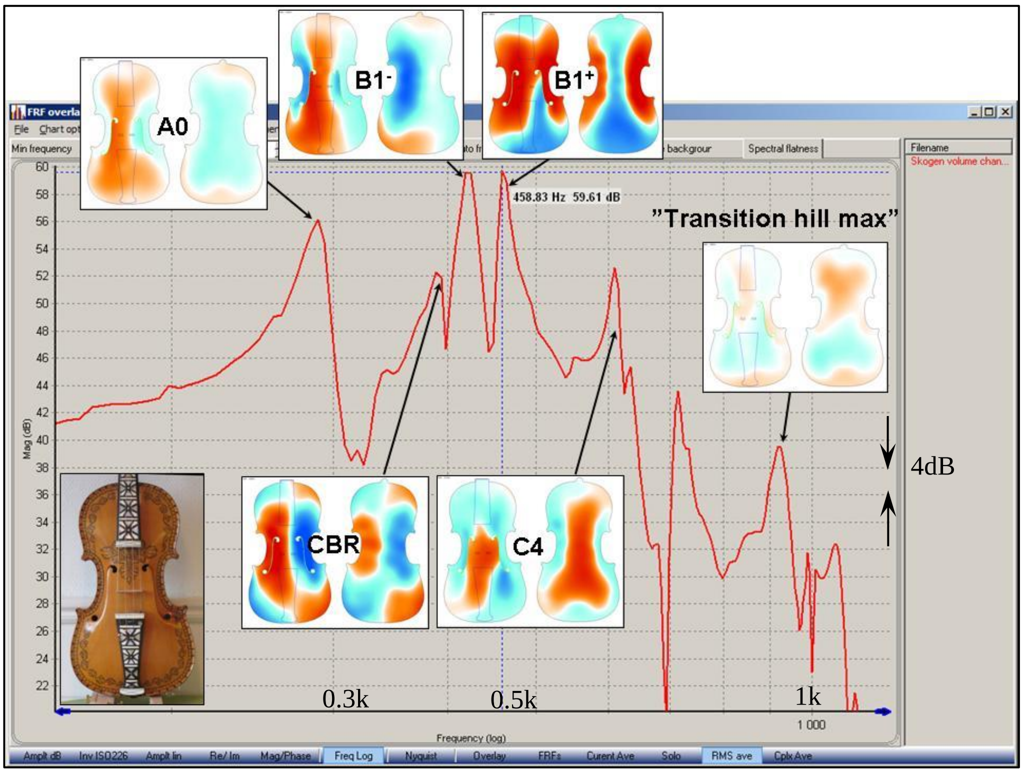

Figure 3: Volume change per Newton input force (mm^3/N) of a HF with names and vibration shapes for the signature modes. The top and back plates are both seen from the outside. Red and blue regions move in opposite directions. Same colour in large areas of the top and back plates indicates a significant *breathing* motion of the body giving a larger net volume change.

The *signature modes* have been given names related to their shape and function:

A0: is the *main air resonance* formed by the f-holes, the volume inside and the flexibility of the plates, like the Helmholz air resonance of a bottle. A *breathing mode* (Most of the top and back plate move like a “breathing body”)

CBR: The *C Bout Rhomboid* with a plate-like bending motion of the body. The name is related to the vibration shape of a section through the C-bout region. The symmetric form makes it a weak sound radiator, but it can radiate significantly if it has a *breathing component* as can be seen in the example in Figure 3.

B1- and **B1+** *Baseball modes*, from how the modal lines look somewhat like the stitching lines of a baseball. The nodal lines cross the back plate upper and lower bouts and along the top on each side in B1- and reversed for the B1+. Both are "breathing modes", usually with strong sound radiation.

C4: A *ring mode* in the back plate. Both bridge feet move in phase, so it is easier driven by up and down movement of the bridge than a sideways drive. The C4 also can show significant *breathing* of the body.

The next modes are a *cluster* named the ***Transition Hill*** (TH) which is the frequency region where the sound-post (right) bridge foot starts to move more than the bass bar (left) bridge foot. (Name courtesy: Evan C. Davis, Boeing). The inner f-hole wings usually start to move a lot in *free edge motions* in this region. The high level peak of the TH is called the Transition Hill max, $\mathrm{TH}_{\mathrm{max}}$

Figure 4 show a wider normalised SPL frequency spectrum of the fiddle in Fig 3 tapped on the G string side of the bridge with an impulse hammer.

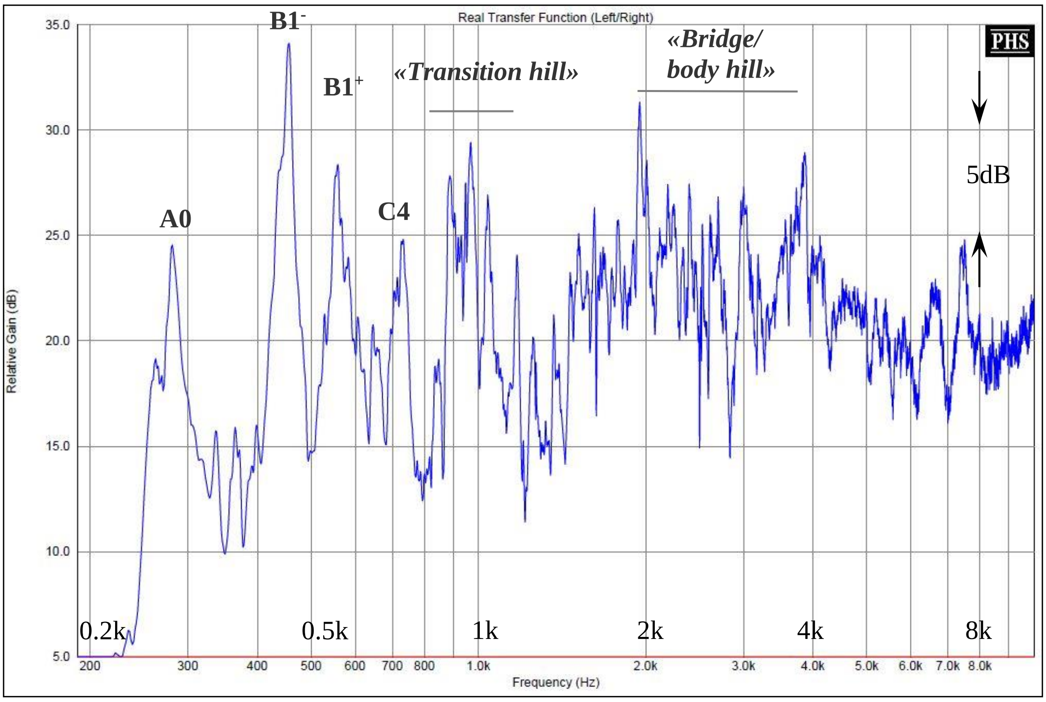

Figure 4: An impulse response spectrum (SPL/Force) averaged over 360 degrees around the fiddle with descriptors for the signature modes and names for the *clusters*.

The bridge/body hill is a cluster with details not yet disclosed in detail. It is believed to be related to the first bridge in plane resonance and properties of the top plate in the central region, including the f-hole wings.

Figure 5 shows average signature mode frequencies and levels for a set of 42 violins (orange) and 50 HF's (blue). The data overlap, with a tendency for the C4 mode to lie lower in frequency for the HF's. Figure 5 also shows data from twelve Old Italian violins, six contemporary master-built violins as well as a Vuillaume in green, data courtesy of Joseph Curtin. The level for the green data points in Fig 5 is adjusted to fit the other data, so absolute level comparisons are not possible between these.

The transition hill maximum ($\mathrm{TH}_{\mathrm{max}}$) is relatively a little weaker in the green data in comparison to the other two instrument groups. The signature mode frequencies are otherwise quite similar, but with less spread in the data.

Figure 6 shows LTAS of played scales on the violins and HF's. (Whole and half notes, as well as open strings, are played). In general, the SPL is in average 3dB lower for the HF's. The levels tend to overlap for all frequency regions, except for the 3.15-4 kHz bands where the violins have a significantly stronger response. The reason for this is likely to be the bridge design and the higher first in plane resonance of the violin bridges: 3270 ± 303 Hz versus 2720 ± 408 Hz for the HF-bridges, all measured with the bridge feet fixed in a vise.

The average overall SPL are: $L_{eq} = 87.9 \pm 2.2$ dB for the HF's and $L_{eq} = 91.1 \pm 1.7$ dB for the violins (± one σ) both linear values (no weighting of the spectrum is used). The source effect is: $L_w = L_{eq} + 0,3$ dB.

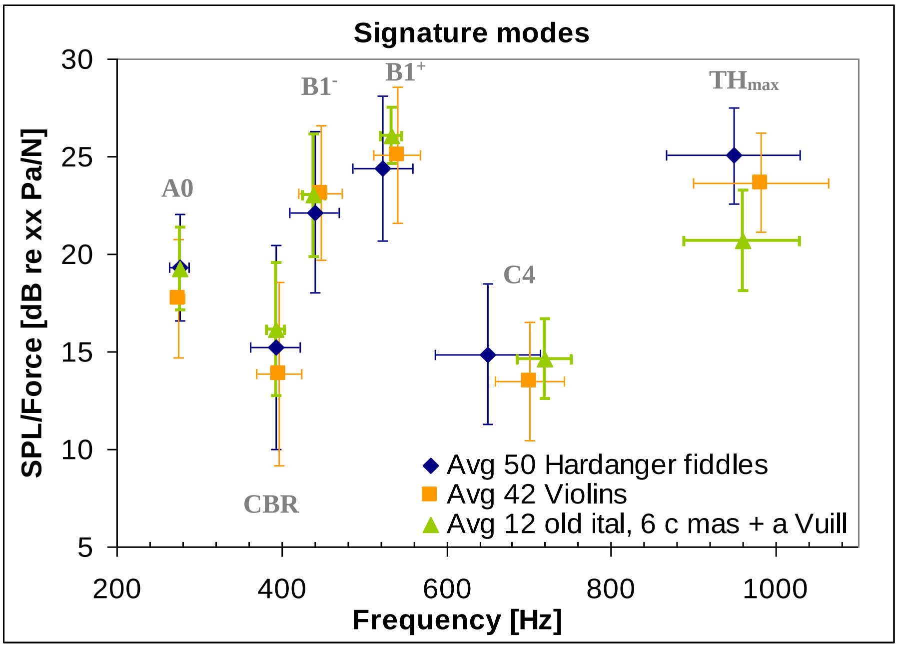

Figure 5: Average signature mode frequencies and levels of 12 Old Italian, 6 contemporary masters + a Vuillaume (green triangles) compared to the data from 50 HF's (blue diamonds) and 43 violins (orange squares). Error bars show one standard deviation to each side of the data point.

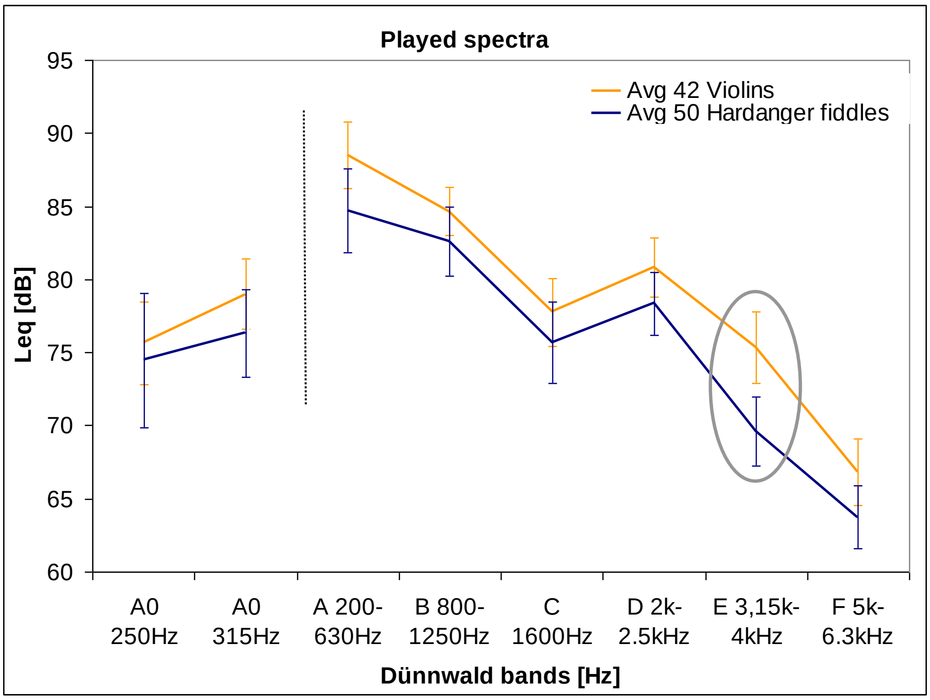

Figure 6: Long Time Average Spectra of played scales on 42 violins (orange) and 50 HF's (blue). The frequency regions are calculated from 1/3rd octave band values. The 250 Hz and the 315 Hz bands are shown because of the A0. The other bands are adaptations to those used by Dünnwald. The error bars show one standard deviation variation to each side of the line.

3.2 Test of bridge designs

Most makers have their own bridge designs. E.g. the Valdres makers Knut Ø. Rudi (1878-1972) and Olav Viken (1921-2005) have very different bridge designs: Figure 7 shows Rudis model and Fig 2 show a copy of Olav Vikens model. Among makers and players with some experience, the design difference between these is known to have an influence on the instrument timbre.

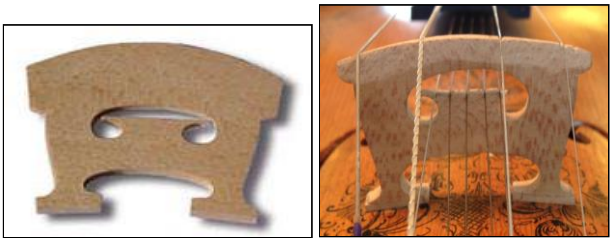

Figure 7: A Rudi HF bridge type (not trimmed) left and a fitted one right. [Left: From Wulffnstejns Hardanger fiddle and Mandolin works http://www.hardingfele.com/]

I tested this hypothesis on a fiddle using LTAS of played scales with a Rudi and a Viken type bridge on the same instrument. The first in plane resonance of the bridges was tested with the feet fixed in a vise: Rudi bridge: 4.1 kHz/1.71 g and the Viken bridge: 2.9 kHz/2.01 g. (The Viken bridge was 0,4 mm higher than the Rudi bridge, an insignificant difference). Fig 8 shows the resulting spectra with error bars showing one σ variation to each side of the curve, calculated from three separately measured spectra.

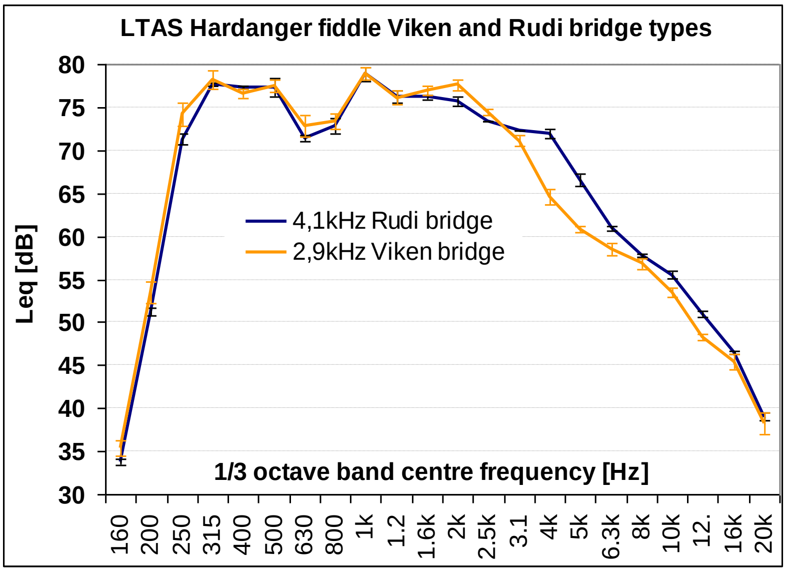

Figure 8: Long Time Average Spectra of played scales on a HF with a Rudi (blue) and Viken (orange) type bridges measured @ 1m. The first in plane resonances of the Rudi-bridge: 4.1 kHz and the Viken-bridge: 2.9 kHz. The error bars show one standard deviation. The fiddles do have understrings in both cases.

We see that the response in the 2 kHz band has increased and the 4-12 kHz bands have decreased using the lower tuned and heavier Viken type bridge. The difference in the 4 and 5 kHz bands are 7 and 6 dB respectively. The author prefers the instrument with the Viken style bridge.

3.3 Influence on the signature modes from the HF neck design

The HF has four or five extra pegs and thus a longer and heavier pegbox and neck. The string length is shorter, and the grip region will be shorter too. As the HF usually is played in the ground position, the length of the fingerboard (FB) is shorter by about 40-50 mm (~220-230 mm versus 270 mm for the violin). A violin FB weighs 60-70 g while the shorter and hollowed out HF fingerboard can weigh less than half of that, a bit dependant on design and material.

A solid built Guarneri model violin was picked for a "makeover" from violin to HF. LTAS of played scales, SPL/Force and Acceleration/Force spectra was recorded before and after the experiment. The sound post was not moved in the process.

The violin weighed 428 g without chinrest and 456 g as HF, also without the chinrest, so the HF version weighed 28 g more.

Figure 9: A HF pegbox and neck. Right: The Guarneri model violin fitted with a HF neck. The violin fingerboard (FB) was carved flatter and hollowed out for the sympathetic strings on the HF. Response curves were measured for each step in the working process.

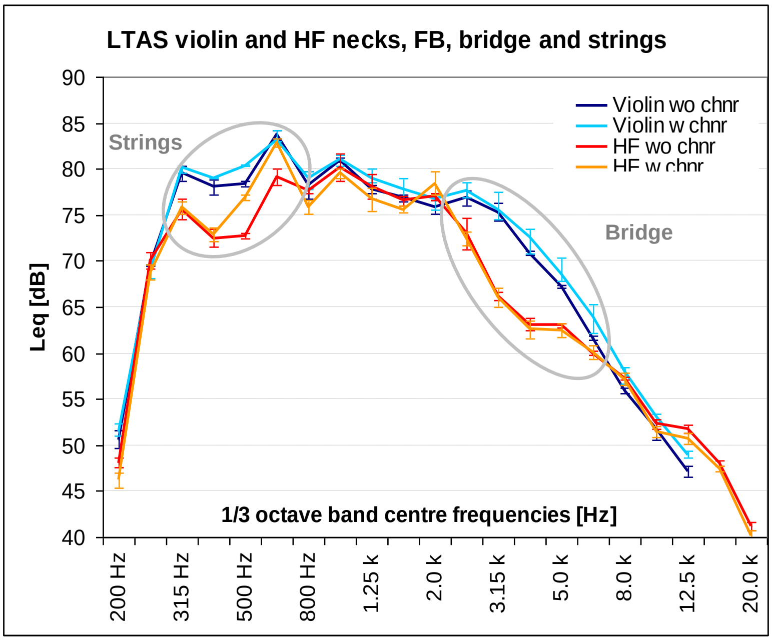

Figure 10: LTAS of scales played on the same fiddle body with a violin and a HF neck, FB, bridge and strings, see Figure 9. Separate runs with and without mounted chinrests are shown.

From Figure 10 we see that the frequency response from 2.5 kHz up to 5 kHz is much stronger in the violin setup. This is likely to be due to the different bridges. The in- plane resonance frequencies and weights of the violin and HF bridges are: 3.4 kHz/2.35 g and 2.7 kHz/1.96 g, respectively.

Also, the 250 Hz and 315 Hz octave bands are weaker, probably due to the thinner, shorter and lighter HF strings. The HF strings are 10.5 gauge and the violin strings are higher tension of Chinese origin with a vibration sensitivity about 4-6dB higher than the HF strings for the G, D and A. The E is only about 2 dB higher. The difference seen in the low frequencies are likely to be related to the heavier and higher tension violin strings. We also see the chinrest allows for extra sound output, especially in the 500 Hz and 630 Hz bands for the HF.

The strings were put on for the experiment and to experience how the fiddle played and sounded. The fiddle was surprisingly interesting. The E-string is even sounding. It sounds a bit shallow compared to many HF's. It may have some similarities to some thick plated HF designs. As a HF, the instrument is "ringy", suggesting that a stiff body (see the signature data in Table 1) might make the sympathetic string decay a bit longer than normal. We will return to that issue in sec 3.4.2.

From Figure 11 and Table 1 we see that the modes have moved somewhat lower with the heavier HF neck and 9 pegs. The "P resonance" is influenced by both the pegs and the FB.

Without FB, but with pegs, the “P top” is shown as two tops for both the violin and the HF. The same happens when there is no neck. Without FB and pegs the “P resonance” was divided into three tops.

Unfortunately, we do not have a modal analysis of the fiddle, so we do not know in detail how the mode vibrates, including the “P”. A modal analysis probably would have helped to explain why the pegs, the neck and the FB had such an influence.

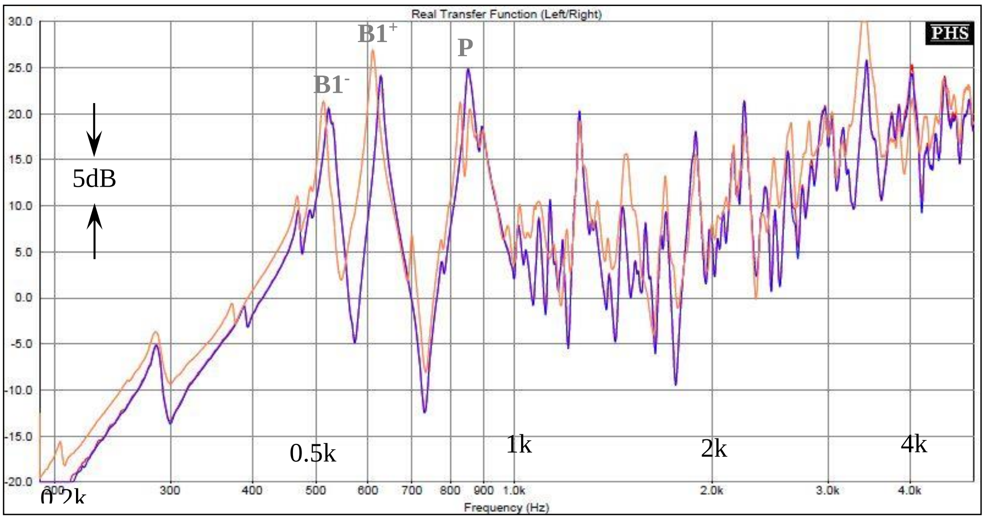

Figure 11: Accelerance a(ω)/F(ω) for the instrument shown in Figure 9 without strings fitted with a violin neck, pegs and a FB (blue curve) and a HF neck, pegs and FB (orange curve).

Table 1: Signature mode frequencies and changes measured for the violin and HF, both without a chinrest.

	Frequencies [Hz]			
	B1$^-$	**B1$^+$**	**C4**	**TH$_{max}$**
Violin	523	619	730	1083
HF	504	604	722	1089
Change [Hz]	19	15	8	6
Change [%]	4 %	2 %	1 %	0,6 %

3.4 How do sympathetic strings influence the sound?

Saunders found that playing the same note as one of the open strings on a violin, with the open string damped gave a 2 dB increase in the sound output [19]. A sympathetic string makes the played note sound “fatter”, and the note decays longer as the open string is not damped by the fingertips. The effect is clearly audible, especially for the HF where the understrings are always free to vibrate.

The effects are experienced while stringing up a HF playing the instrument with only the G, D, A, and E strings in place and later with the sympathetic strings in place. It is also easy to just dampen the strings below the fingerboard e.g. with a piece of rubber foam for playing tests.

The playing experience and the sound are quite different in the two cases. What happens to the sound and the playability?

3.4.1 Objective and subjective loudness

Figure 12 shows a comparison of LTAS of played scales taken from the same HF with the understrings damped and free to vibrate. The curves show no significant difference in the sound level using a t-test on the data sets of three separate scale runs. Spectra taken with and without the small foam rubber piece between the fingerboard and the understrings shows that the foam rubber piece does not dampen the instrument modes significantly.

Psychoacoustical, the ears and listening system integrate the nerve activity from a perceived sound over 100-200 ms duration, the so-called *Temporal integration [20]* A note with a string singing along and decaying parallel with it, and with a slower decay, could give the impression of a louder sounding note, even if we may get a lower reading from the SPL-meter. Repetitions increase the sensitivity to details in the sources of sound spectra **Feil! Fant ikke referansekilden.** . This should be investigated further.

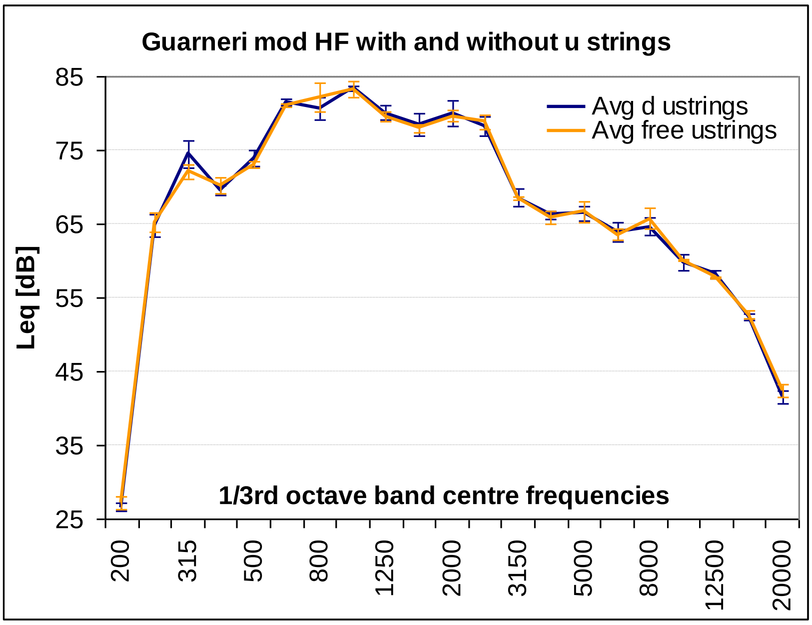

Figure 12: LTAS of scales played on the same fiddle with a HF neck, see Figure 9, with the understrings damped using a rubber foam piece under the fingerboard (blue) and no damping (orange). Errorbars show one σ variation to each side of the curve.

3.4.2 Reverberation times of body, strings and room

The "ring" is a characteristic of the HF. Originally the HF was played in rather small and "dry" sounding rooms. Following the tradition after Torgeir Agundssons (Myllarguten's) concerts with Ole Bull, the HF did enter the concert hall stage around 1850. It is more often used in public meeting halls for dance, competitions and concerts. It is now fairly common with amplification, even in major larger competitions where sports halls often are used to fit an audience similar to the larger concert halls.

When the HF is amplified, the ringing understrings are well heard, also in seats in larger audiences, an experience a quiet and intimate auditorium otherwise would not ensure with no amplification of the HF.

Reverberation times of normal old and modern home environments may be 0.4-0.6 seconds, quite moderate values. The hypothesis is that the sympathetic strings give a more reverberant experience, somewhat resembling the reverb experienced in concert halls or churches. But without the envelopment one would experience from a full 3D decaying sound field.

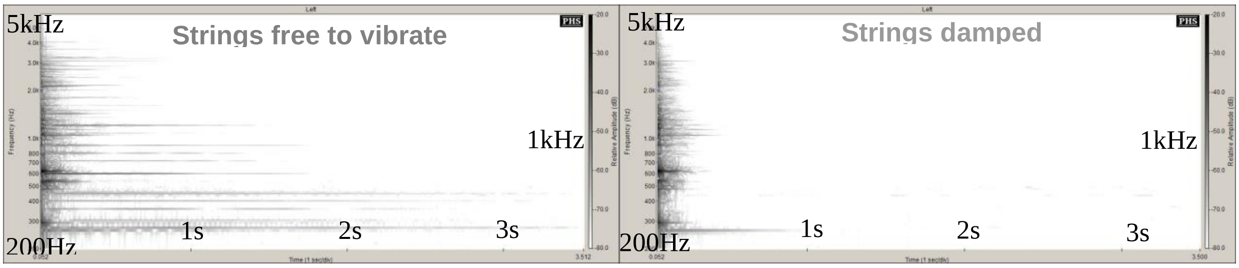

Figure 13: Spectrogram of a bridge tap on a HF with all strings free to decay and right damped. The plain sympathetic strings ring longer than the overwound playing strings. The grayscale is black: 0 dB white: -60 dB. "The ringing thing" below 300 Hz is a tailpiece resonance. Frequency resolution: 10.7 Hz time resolution: 0.09s.

In Figure 13 we show spectrograms of recorded bridge taps of the stiff experimental HF seen in Figure 9. The taps are done with a miniature impulse hammer with a soft tip. A soft tip gives a stronger low frequency response and a somewhat weaker high frequency response.

This mimics to a certain degree the 6 dB per octave decreased force input on the bridge from the bowed string. The spectra have not been normalized. Figure 13 b) we see that the body decays to -60 dB within 200-250 ms. (The decaying resonance ringing to about 1 s is from a resonance in the string-tailpiece system).

In Figure 13 a) the strings are free to vibrates and we see the same initial body decay overlapped by the ringing string fundamentals and harmonics. The lowest sympathetic string still rings after 3.5 s and the other four rings for at least 2.5 seconds while the harmonics around 1 kHz ring for about 1.4-1.7 s. The string resonances close to a strong body resonance will decay faster. E.g. the 1st sympathetic string, and the open A string, (here tuned to C_5=523Hz) close to the $B1^-$ mode decays faster than the other sympathetic strings with a weaker coupling to strong body resonances.

Now, can the spectrograms show any differences between instruments?

Figure 14 a) show a spectrogram of the ringing strings from an instrument with a stronger low frequency response. The sound looks, and indeed is, “fatter”. But the string fundamentals are ringing shorter than on the stiffer instrument in Figure 13 a)

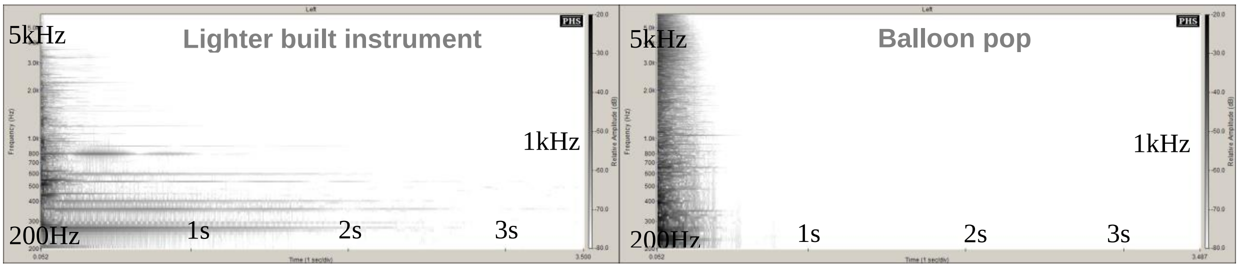

Figure 14: Spectrogram of a bridge tap on a lighter built HF with a stronger low frequency response. Right: Ballon pop in the room. The T_{30} is 0,43s. The grayscale is black: 0 dB white: -60 dB. Frequency resolution: 10.7 Hz time resolution: 0.09s

Figure 14 b) shows a spectrogram of a popped balloon in the measurement room used in Figure 13 and Figure 14. The impulse shows the decaying sound field in the room. The reverberation time is 0.43 s averaged over the 1/3rd octave bands 200 Hz – 20 kHz.

It is quite clear that the reverberation of the strings dominates the combined reverb of the living room and the decaying instrument, as it is much longer. The measurements in Figure 13 and Figure 14 are done with the microphone only 20 cm from the top of the fiddle, that is: in the near field. This simulates what a player will hear.

4 Discussion

Not much has been written about the acoustics of the HF, but the violin has been studied acoustically by enthusiasts for more than 200 years. That literature serves as a good reference for comparisons.

4.1 Signature modes

The average signature mode frequencies and levels of HF and violins in average lie quite close. The C4 (ring mode in the back plate) have lower frequencies, possibly due to somewhat thinner and, sometimes, softer backs (some instruments have black alder backs). The B1+ mode appears at a lower frequency, something we may relate to the heavier neck and more pegs.

The spread in the level and frequency data are larger for my sets than the Old Italian and modern violin set. I have included anything from mass produced to fine or regraduated instruments, often in “before and after” pairs. A larger variation in the data are thus to be expected.

4.2 HF bridge designs

HF’s sound different with a Rudi bridge with short legs as opposed to a long legged Viken style bridge. Spectra from played scales (LTAS) show that there is a cut in the higher frequencies by using a Viken type bridge.

It is assumed that the lower in plane resonance of the longer legged bridge is the cause for this effect. Even though the violin and HF bridges are very different looking this tie in with Woodhouses conclusion in his bridge hill article for violins, [22]. A working hypothesis is that the HF bridges have a "side to side" first in plane mode similar to the first in plane mode of the cello bridge, Rodgers [23]. Work is in progress to investigate this further.

4.3 The effect of the HF setup

The pilot study changing the violin neck to a HF neck and FB on a rather stiff violin body shows that the signature modes tend to move downwards 0,5-4%. The bridge design (and the first in plane resonance) influences the high frequency response, with the long legged Viken style HF-bridge cutting some of the higher frequencies. Both the thinner and somewhat lower tension HF strings drive the body with a weaker force, explaining the weaker SPL from a HF than a violin. On average the sound output from the HF in my set is 3 dB weaker. There are no studies known to the author comparing the acoustics of the violin and the HF, but the relation between the violin and the Baroque violin has been studied in a PhD work by McLennan, [24].

4.4 The effect of the sympathetic strings

A pilot study of played scales on an instrument with the sympathetic strings damped and not damped, using LTAS, indicates that there is no measurable difference in the sound output in the two cases. This is not supporting Saunders finding for the sympathetic effect of violin strings where he found a 2 dB increase of the sound output when the sympathetic (open playing) string was damped **Feil! Fant ikke referansekilden.**. The reason is likely to be the large level difference between the played and the sympathetic string.

Michaelsen found that while playing a single note on the HF, the sound level of the harmonics of the sympathetic string is 10-40 dB below its exciter [1]. Adding the sound level of two sounds with such a difference will give a very low or no effect on the net SPL, which fit well with the measured data in Figure 12.

The sympathetic strings decay more slowly than the playing strings. At a certain time, the sound level of the decaying sympathetic string will be louder than the playing string, if no energy is fed to the playing string. Psychoacoustically, a longer lasting sound should be perceived as being louder, due to the temporal integration effect.

4.5 Room acoustics and the decaying understrings

Traditionally the HF has been used in smaller rooms than the violin. Most HF's are probably played, mainly, in home environments, or in smaller practice rooms with similarities to "home acoustics". But the HF does not have the same history on concert hall stages, churches and "homes with high ceilings" as the violin. The extra reverb from the strings might be a compensation for not having "lively rooms" to play in. Or maybe it just turned out to be more fun to play the fiddle with sympathetic strings.

Preliminary tests indicate that the reverberation time (-60 dB decay) of the understrings may be in the order of 1.5 s to over 3.5 s. And it seems to be related to where their frequencies lie in relation to the HF body resonances, as indicated in Woodhouses work on the guitar **Feil! Fant ikke referansekilden.**. Sonograms seem to give a good qualitative indication of the decaying strings, and may be utilized in quantitative analyses, as suggested by Woodhouse [26].

Preliminary results and experiences indicate that stiffer built instruments might ring a bit longer than lighter built instruments. This gives a variation in the construction of the fiddles for their ringing qualities. Lighter built instruments, on the other hand, tend to sound more "bassy" and somewhat louder. The "ringy quality" of the HF is best heard in slower played music and by the player. But in intimate, quiet rooms, the ring is well heard, also by the audience. When the HF is amplified, the ring of the understrings, as it sounds for the player, is presented to a wider audience.

The decaying strings are, at least to a first approximation, following the simple physics of a decaying harmonic oscillator. The bowed strings, however, is a highly nonlinear physical phenomenon of "slip stick motion", Guettler **Feil! Fant ikke referansekilden.** and Woodhouse [28]. The effect the freely vibrating strings has on the playability, and the rise time of played notes, is something to investigate further. Michaelsens experimental study indicates that the rise time increases due to the sympathetic strings, but they have very narrow resonances to "hit", so the rate of hitting them is not guaranteed to be 100 % [1].

This is also a matter of how well the instrument is tuned, how "lossy" the string nuts and bridge are, as well as the intonation skills of the player. It may also depend on the detailed intonation style in the played tradition.

Even if the transients might become longer, sympathetic strings do not seem to prevent a fast playing style, as can be heard in some of e.g. Olov Johanssons *nyckelharpa* music (Väsen) or some of the HF "one string" music after Ola Mosafinn.

5 Conclusions

The HF show close similarities to the violin regarding its body resonances. The bridge design, strings and the tonal ideal is, however, different. The HF is somewhat weaker sounding, mainly due to the lighter and shorter strings. The first in plane resonance of the bridge should, ideally, lie lower in frequency than for a violin, at least in the author's opinion.

A more detailed study of HF should be done to reveal some of the acoustic effects of the more variable designs used in HF making historically. The effect of the sympathetic strings should also be investigated further regarding the playability and transients. The nature of the HF-bridge, and the different designs, should also be investigated in more detail

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