On the Bridge-Hill of the Violin

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Introduction

Many excellent violins show a broad pick of response in the vicinity of 2.5 KHz, a feature which has been called the "bridge hill". This arises from a combination of resonance of the bridge and response of the violin body at the bridge foot positions [1]. Figure 1 shows a typical violin bridge and its rocking motion which is the main motion in a bridge resulting from its stiffness and its feet's motion.

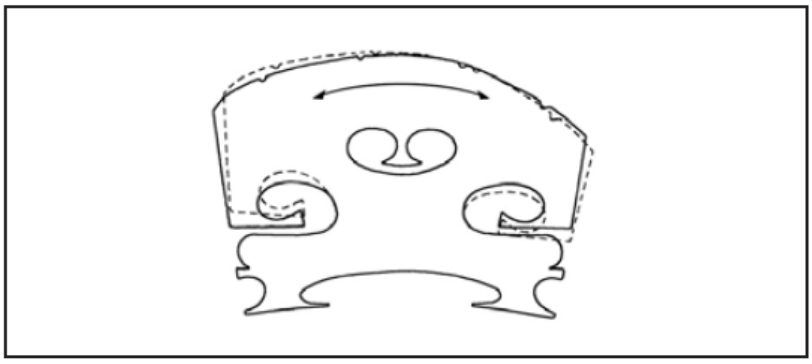

Figure 1 A typical violin bridge and its rocking motion [1]

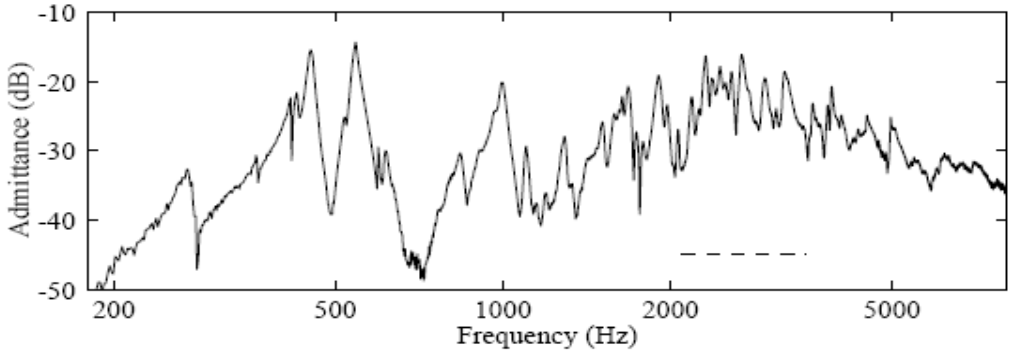

Figure 2 A typical violin response (or bridge admittance) [1]

Figure 2 shows a typical violin response or bridge mobility which is frequency response of measured velocity at top of the bridge resulting from an impulse force

applied to the same section of bridge(sometimes in opposite side and sometimes velocity is measured exactly at driving point). In this figure the bridge hill in frequency range of 2-3 KHz can be readily seen.

It's been claimed by many people that bridge-hill is one of the most important feature of a violin determining its sound quality. For this reason many people have tried to find the relation between violin parameters and the resulting bridge-hill most famous of whom Jansson, Woodhouse and Dunnwald.

Woodhouse Model for Violin Bridge and Bridge-Hill Estimation

Woodhouse proposed a violin bridge and body model using which he obtained and skeleton of violin response which could predict bridge-hill characteristics.

The simplified bridge model Woodhouse used is shown in Figure 3. It is a mass spring system in which m is bridge mass and a torsion spring is used to model rocking motion depending on bridge waist stiffness. Bridge base is the third part in the model receiving moment from the torsion spring. Parameters *d* and *a* in the model are distance between bridge feet and bridge height respectively [1].

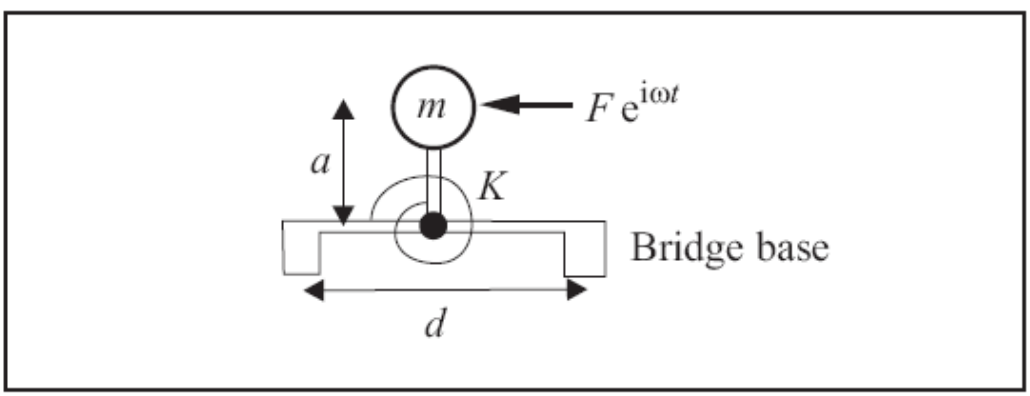

Figure 3 Mass spring model for violin bridge [1]

A rotational admittance is defined for the contact between torsion spring and bridge base (from that contact downward) which was shown can be obtained using following equation [1]:

$$R = \frac{Y_{11} + Y_{22} - 2Y_{12}}{d^2},$$

In which Y_{ij} is velocity response of the violin body at the position bridge foot *j* to a force of unit amplitude applied at bridge foot *i*. Using the obtained R and following relation violin response or bridge mobility can be obtained [1]:

$$Y_b(\omega) = \frac{(KR + \mathrm{i}\omega)a^2}{K - ma^2\omega^2 + \mathrm{i}\omega K m a^2 R}.$$

He finally concluded that if we consider two infinite plates for a violin and use the following relation to obtain Y_{ij} s for infinite plates:

$$Y_\infty(\omega, r) = \frac{1}{4h^2}\sqrt{\frac{3(1-\nu^2)}{E\rho}} \cdot \left[H_0^{(2)}(kr) - H_0^{(2)}(-\mathrm{i}kr)\right],$$

Skeleton of the responses can be obtained using which bridge-hill characteristics can be predicted. Indeed finally solving the following second-order equation gives complex conjugate roots the imaginary part of which gives bridge-hill frequency and ratio of imaginary part to real part gives the loss factor determining bridge-hill bandwidth [1].

$$\omega^2 - \mathrm{i}\omega R_\infty K - \Omega_b^2 = 0.$$

Figure 4 and 5 respectively show typical rotational and violin response with skeleton (dashed line) obtained from Woodhouse model.

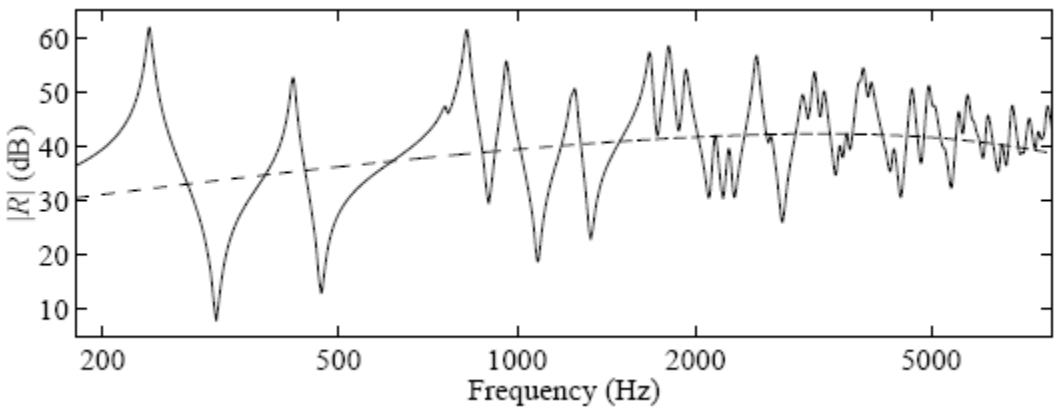

Figure 4 Rotational admittance and its corresponding Skelton obtained from woodlouse's model [1]

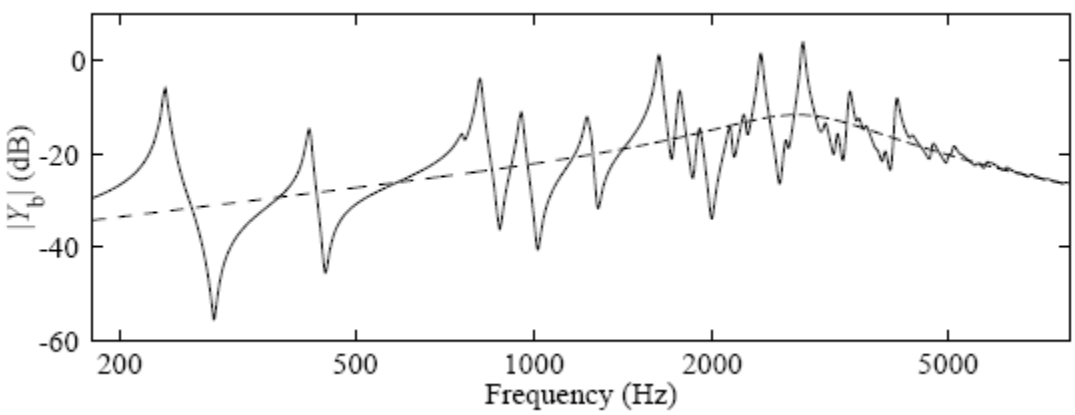

Figure 5 Typical bridge admittance and its corresponding Skelton obtained from Woodlouse's model [1]

Table 1 shows different violin bridge and body parameters and considered in Woodhouse model and their typical values:

Table 1 Standard parameter values for the "violin" and "bridge" models [1]

Plate property	Symbol	Unit	Spruce	Maple
Density	ρ	kg/m^3	420	650
Elastic	D_1	MPa	1100	860
constants	D_2	MPa	67	140
	D_3	MPa	84	170
	D_4	MPa	230	230
Length	L_1	mm	321	321
Width	L_2	mm	204	204
Thickness	h	mm	2.9	4.0
Modal damping	Q		50	50
Property	**Symbol**	**Unit**	**Value**	
Bridge foot	(x_1, x_1)	mm	(120,87)	
positions	(x_2, x_2)	mm	(120,117)	
Soundpost pos.	(x_3, x_3)	mm	(110,117)	
Clamped freq.	$\Omega_b/2\pi$	Hz	3000	
Bridge mass	m	g	0.5	
Bridge height	a	mm	20	
Foot spacing	d	mm	30	

Dependency of Bridge-Hill on Bridge and Violin Body

There are some important issues and questions regarding bridge-hill phenomena, some of which are consistent with what Woodlouse's model can predict and some not. One important question consistent with Woodlouse's model is: does bridge hill depend only on bridge characteristics? Since initially it was assumed that bridge-hill results directly from bridge resonances. Jansson did some experiments to answer this question. In the first experiment he used two different bridges with completely different resonances: A normal bridge and a solid plate bridge that are shown in Figure 6. But after setting them up on the same violin the final mobility responses were very close (see figure 7).

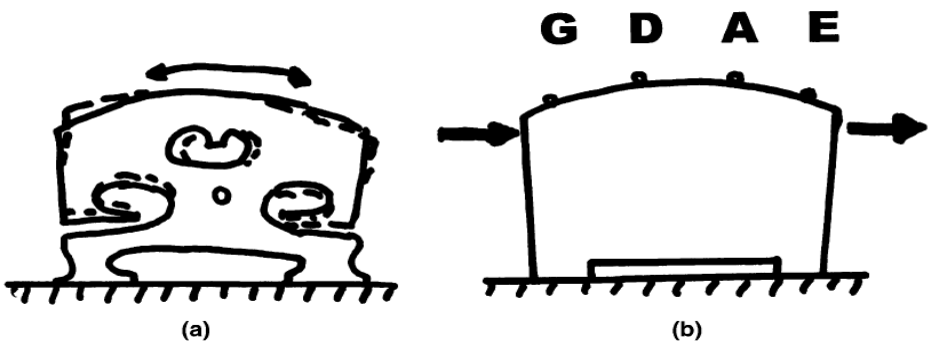

Figure 6 A normal and a solid plate bridge [2]

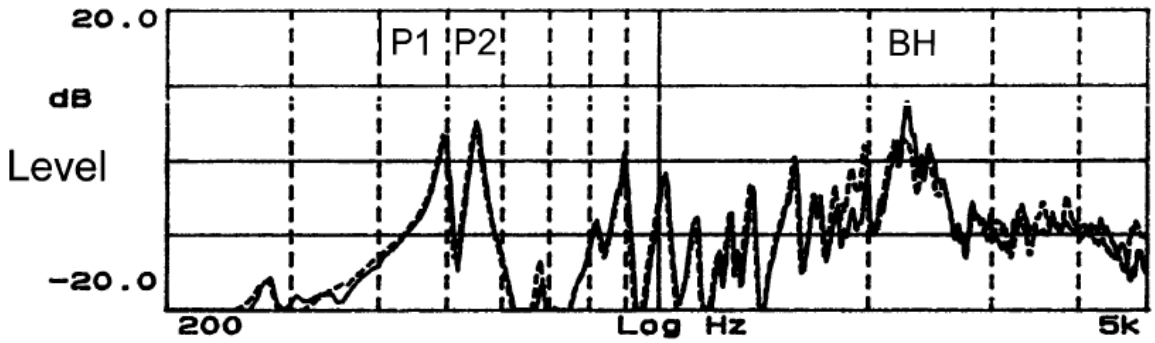

Figure 7 Bridge mobility (violin response) for the normal and plate bridges used [2]

In the second experiment they used a single normal bridge for two different violins: a very good old Italian violin (Stradivarius 1709) and a new violin (Stefan Niewczyk). The bridge mobility for both of them is shown in figure 8. It can be seen that even though the same bridge was used they show very different bridge-hills. These two experiments showed that bridge-hill cannot be due to bridge alone [2].

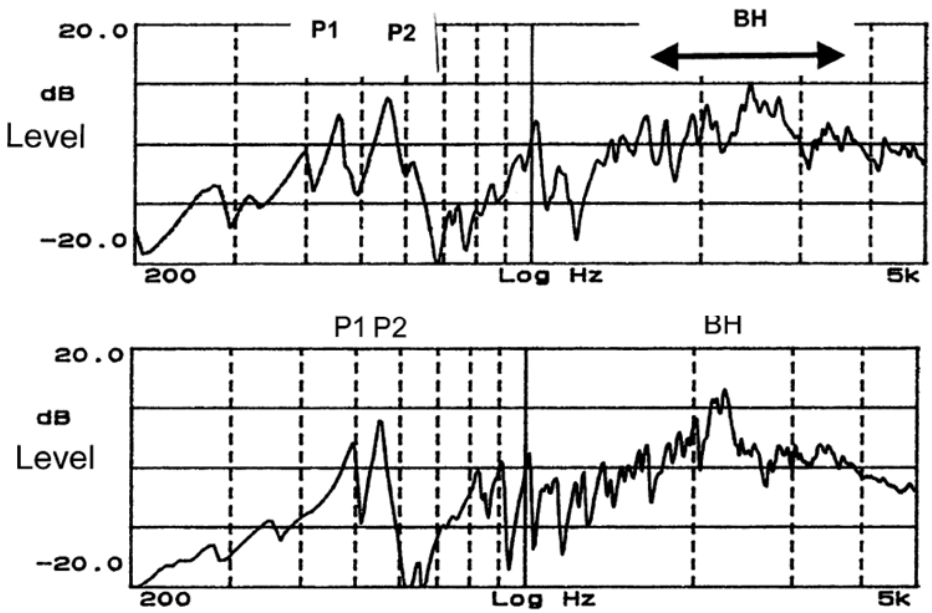

Figure 8 Bridge mobility of a very good old (Stradivarius 1709) and a new (Stefan Niewczyk) using the same bridge for them [2]

In contrast, another question is: Does bridge-hill depend only on violin body characteristics? Another experiment was done by Jansson the result of which gives a negative answer to this question and is consistent with what Woodhouse model predicts. In this experiment Jansson considered four plate bridges with different shapes. The first one was a bridge with just one foot and the other ones had two feet but different widths (see figure 8).

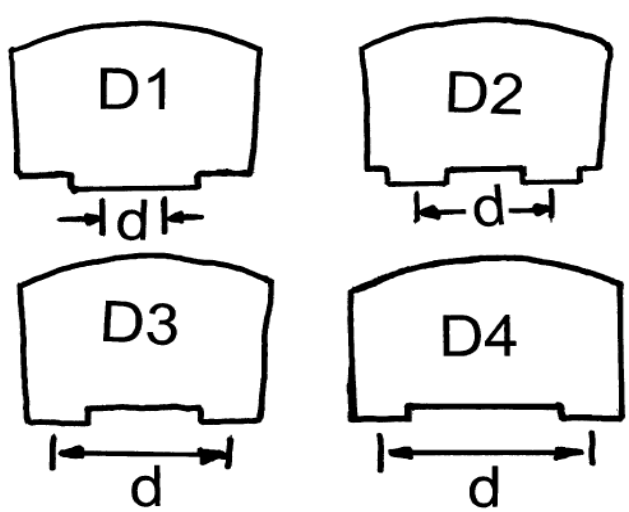

Figure 9 Different bridges with different shapes [2]

Figure 9 shows mobility of a normal bridge (a) and the different plate bridges used (b-e for bridges D1-D4). It can be seen that for bridge D1 there is no bridge-hill and for the other ones by increasing the width bridge-hill center frequency is increased but its level is decreased.

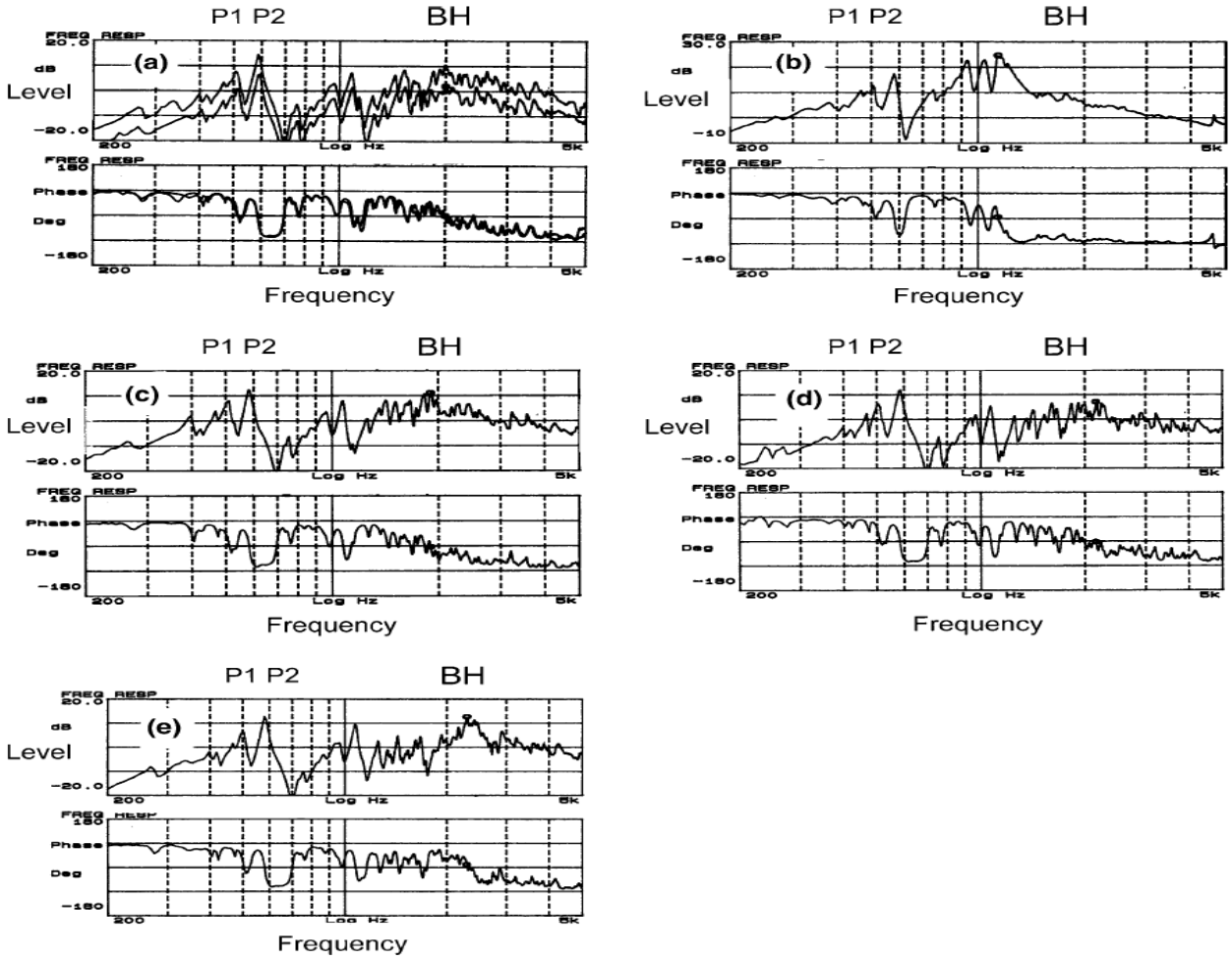

Figure 10 Frequency responses (bridge mobility) of the LB violin. In each pair, the upper frame shows the level response the lower frame shows the phase response of the LB violin with: (a) original bridge, (b) plate bridge D1 (c) plate bridge D2, (d) plate bridge D3, and (e) plate bridge D4. The P1 peak, the P2 peak and the BH-hill are marked. Small circles, mark selected frequencies, levels and phases of the BH-hill [2].

The individual results for different violins and the averaged data was shown again in Tables 2 (bridge-hill center frequency) and Table 3 (bridge-hill level). This experiment shows that bridge-hill as its name comes from bridge can't be due to violin body alone and is very sensitive to bridge shape.

Table 2 Frequencies for the BH-hill peak (kHz) for original bridges and different plate bridges D1–D4 [2]

Violin	Original	D1	D2	D3	D4
N92	2.28	1.21	2.25	2.45	2.6–3.6
LB	2.0	1.14	1.91	2.16	2.3
PW	2.2	0.83	1.37	2.15	2.36
EJN52	2.16	0.87	1.13	1.13	2.46
HS71	2.24	1.01	2.10	2.19	2.84
GL	1.8	1.00	1.82	1.93	2.41
Average	2.11		1.76	2.00	2.50

Table 3 Levels for the BH-hill peak for original bridges and different plate bridges D1–D4 [2]

Violin	Original	D1	D2	D3	D4
N92	3	11	1	0	0
LB	2	11	4	0	5
PW	4	13	7	0	−2
EJN52	6	17	8	12	−3
HS71	0	16	4	7	1
GL	5	16	7	2	5
Average	3.3		5.2	3.5	1.0

Effect of Violin f-Holes on Bridge-Hill

A very important issue that was not considered in Woodhouse model is effect of violin f-holes on bridge hill. In some work by Jansson and his co-worker [3] this issue was evaluated. Using a simplified model of f-hole (see figure 11) that had three sections: upper section, straight section and lower section they tried to figure out what effect of each section is on bridge-hill characteristics.

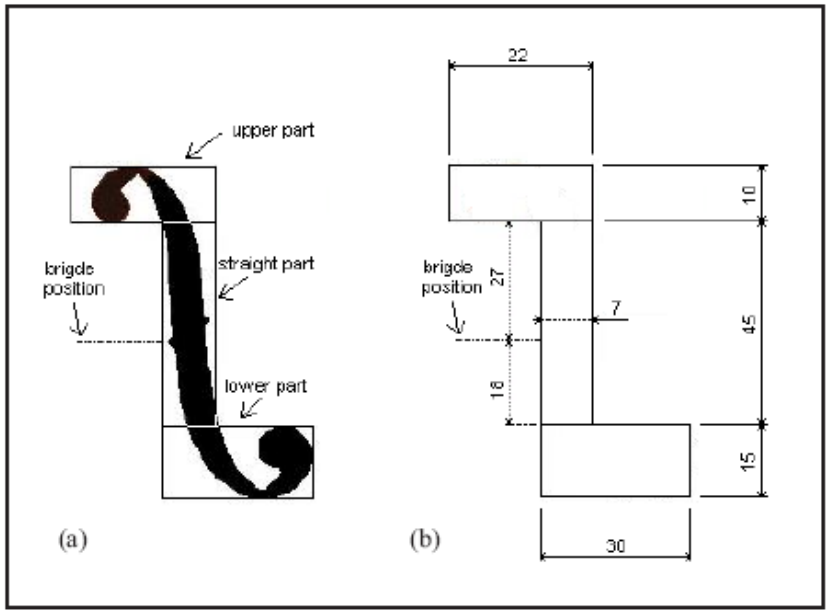

Figure 11 (a): F-hole models, typical f-hole in black and experimental "f-hole" with straight lines (b): dimensions of the model in mm [3]

In the first experiment they considered two steps: In first step f-hole had just its lower and upper sections and in the second step straight section was added (see figure 12).

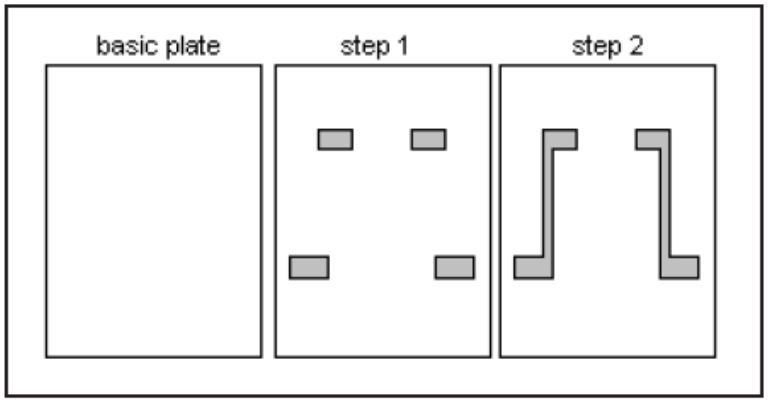

Figure 12 Rectangular plate and "f- hole" cutting steps [3]

The results for this experiment were shown in figure 13. It is seen that there is no considerable bridge-hill for the case there is no f-hole and there is no straight

section. But when the straight section is added bridge-hill appears in mobility response.

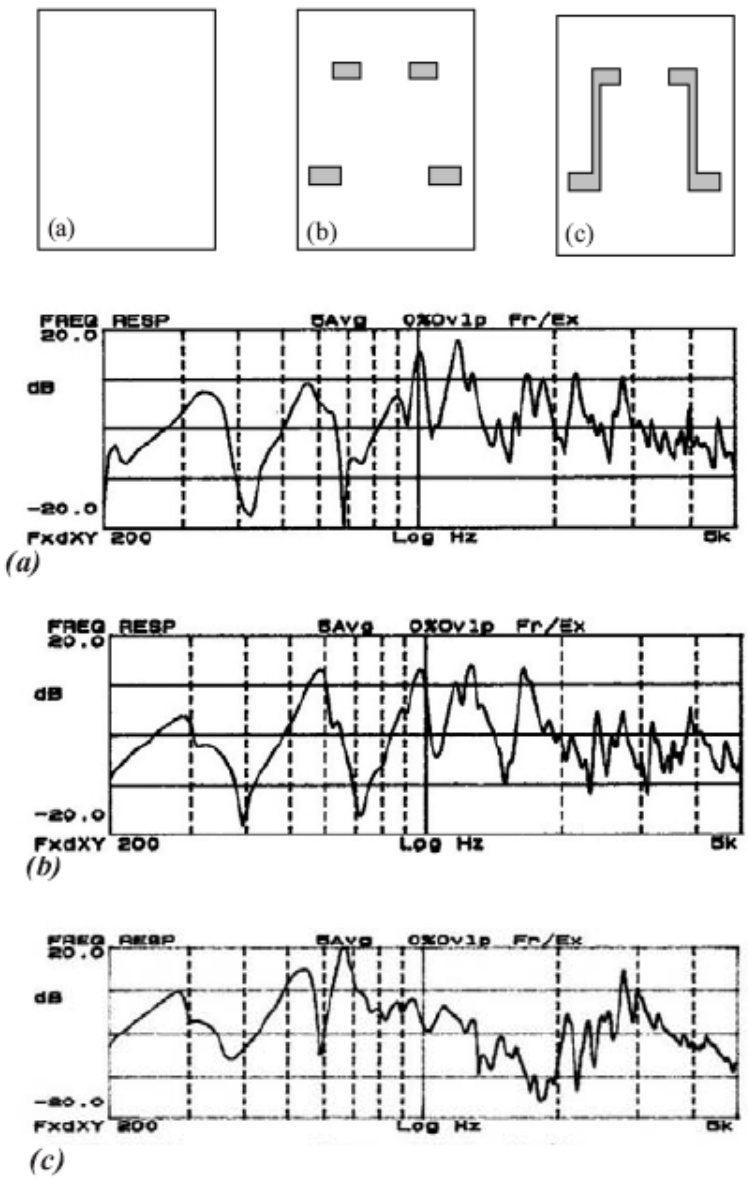

Figure 13 Bridge mobility, level and phase, of cutting steps in Figure 12 and marked above [3]

In the next experiment, they first created just the straight section and in the next step added the two other sections. As can be seen in figure 14 when there is just straight section bridge-hill is much weaker than when the two other sections are added.

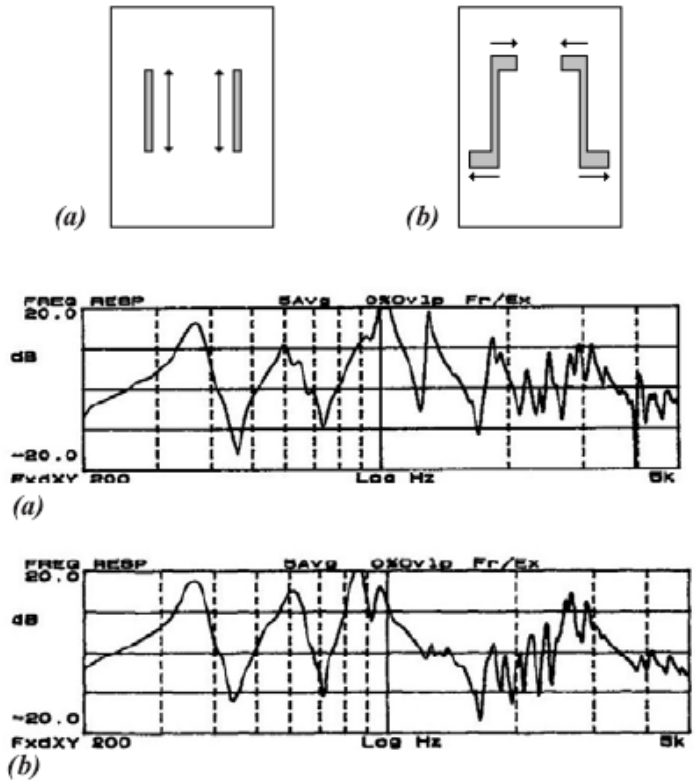

Figure 14 Bridge mobility, level and phase, of steps 1 and 2 marked above [3]

In fact what they finally concluded was the bridge-hill depends on f-hole wings area. The wings are shown in figure 15 and f-holes with different wing area are shown in figure-16.

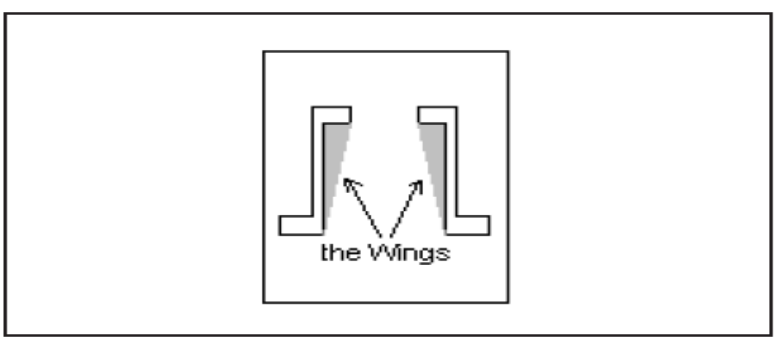

Figure 15 the Wings at the f-holes [3]

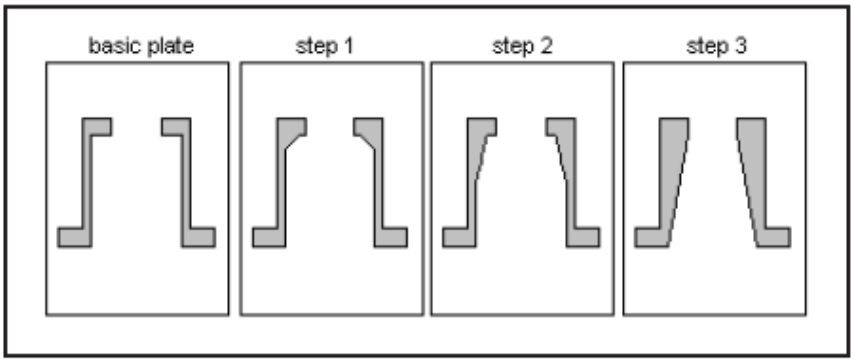

Figure 16 Basic plate and "f-hole" cutting steps [3]

The result for the case that the wing area is zero is compared with that of the case with typical area in figure 17 and as it can be seen when the wing area is zero there is actually no bridge-hill.

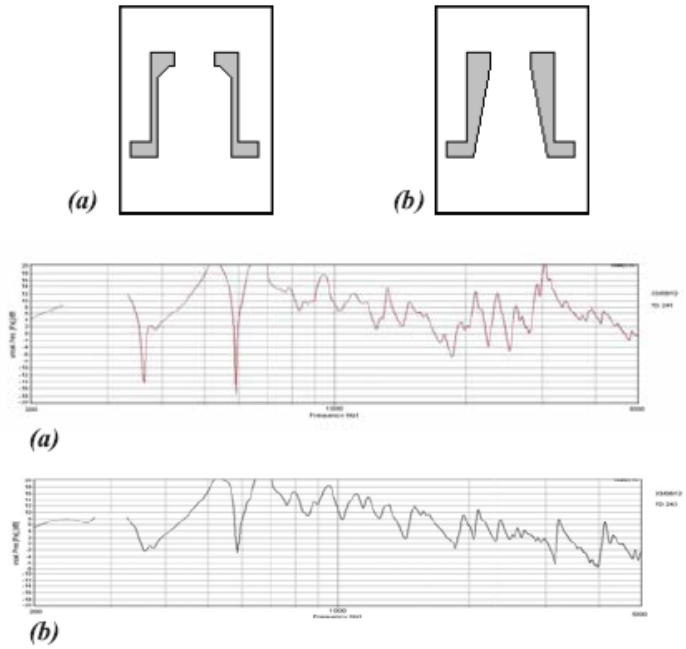

Figure 17 Bridge mobility, level and phase, of basic plate and step 1 and 3 in Figure 16 and marked above [3]

To see effect of changing area on bridge-hill characteristics they also performed another experiment in which they decreased wing area in two steps. The results are shown in figure 18 and say that decreasing wing area increases bridge-hill center frequency but decreases its level.

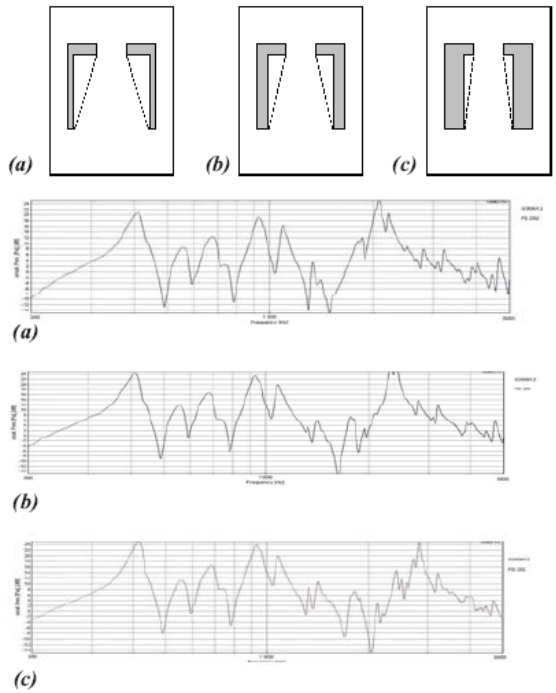

Figure 18 Bridge mobility, level and phase, of steps marked above [3]

They also performed another experiment to see effect of changing the relative position of bridge and f-holes on bridge-hill (see figure 19). Their results showed that bridge-hill is stronger when it is closer to wing mass center.

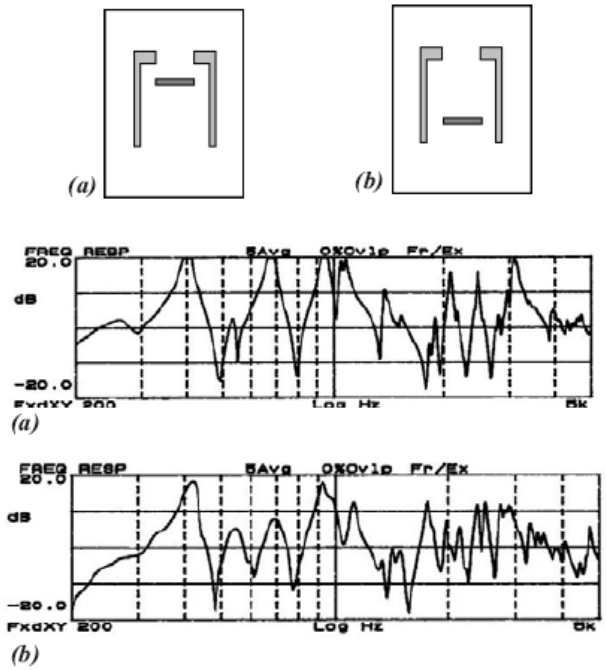

Figure 19 Bridge mobility, level and phase, of steps 1 and 3 marked above [3]

Relation between Bridge-Hill and Violin Quality

Finally there is some other work by Bissinger in which some interesting conclusion about relation between bridge-hill characteristics and violin quality is seen. The main parameter measured by him is radiation which is the ratio of sound pressure measured in space surrounding the violin to the force applied to the bridge. Left panel of figure 20 shows radiation curves for a good (thick line) and a bad violin (thin line) and the right panel shows radiativity ratio (good to bad) for these two violins in sound characterization scheme (originally proposed by Dunnwald [5]). Interestingly this ratio near bridge hill area is very close to unity and is one of the evidences used by him to say bridge-hill area is not as important as other frequency bands in determining violin quality [4].

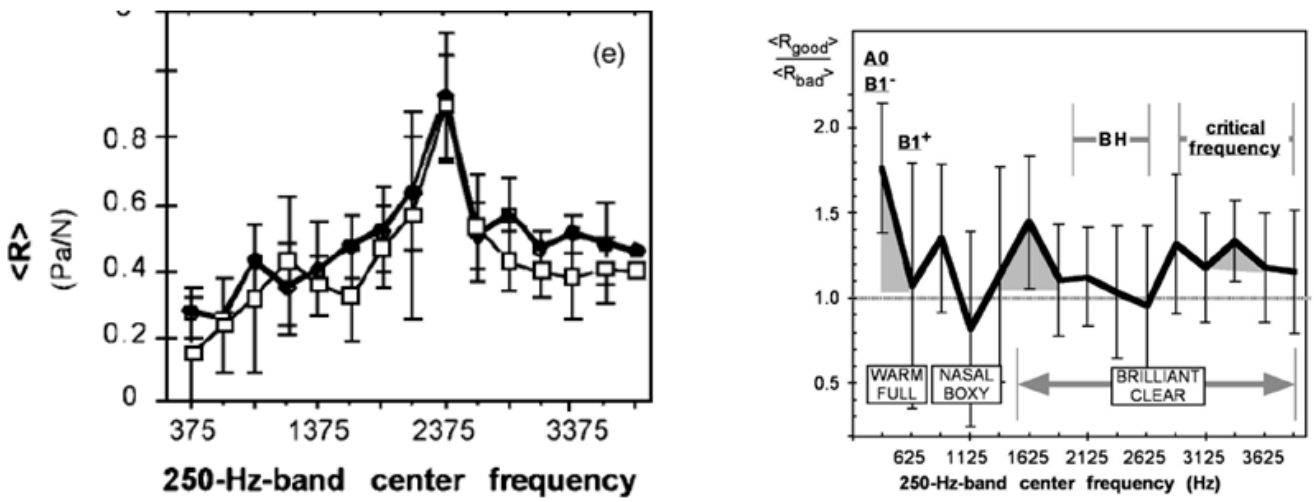

Figure 20 Left panel: Radiativity for a good (filled circle) and bad (open square) violin Right Panel: good-bad radiativity ratio for the two violins in violin sound characterization scheme originally proposed by Dunnwald [4]

Another cue for the above conclusion comes from another experiment in which effect of bridge waist trimming (to change its stiffness) on violin radiativity was evaluated. Left panel of figure 21 shows individual radiation change range resulted from trimming for Guarneri violin and a modern violin from Alf, 2003. Open symbols show results for least trimming and closed symbols for most trimming. Right panel in this figure shows three steps of trimming for Guarneri violin. As it can be seen in that figure radiation change for bridge-hill area is much less than the frequency range 3-5KHz and hearing tests showed that by going from least trimming (shaded curve) to most trimming (thick line) the very good violin Guarneri sounds like a very bad violin. This huge change in violin quality cannot

be predicted by considering just bridge-hill area but considering other frequency ranges.

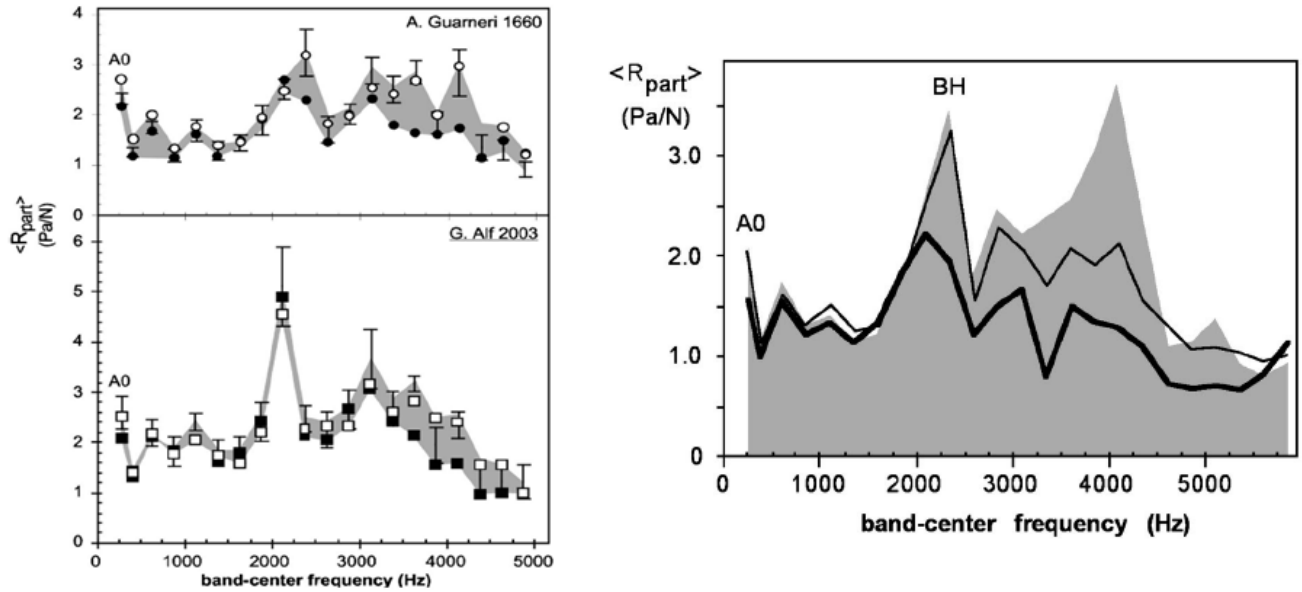

Figure 21 Effect of trimming on good and bad violin radiativity. Left panel: individual results Right panel: Effect of trimming in 3 steps on good (Guarneri 1660) violin [4]

Indeed Bissinger claims overall radiation curve is a much better criterion for judging about violin quality and in another experiment he compares radiation curve of the good violin (Guarneri 1660) having a standard bridge with 20 other Alf bridge trims (Alf violin bridge modification by trimming). His results showed that the trimming profile leading to highest violin quality is one with radiation curve (see figure 22) closest to Guarneri violin curve (thick line).

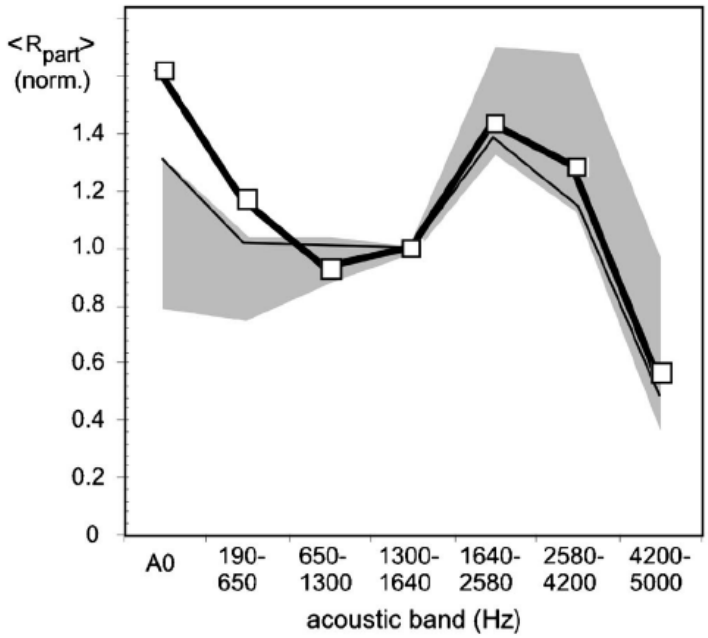

Figure 22 Acoustic profiles for 20 Alf violin bridge trims, compared to "target" A. Guarneri profile (thick line with open squares) [4]

Summary and conclusion

Woodhouse proposed a very good model to obtain a skeleton for violin response that could predict effect of bridge and violin body properties on bridge-hill. His model consideres most bridge and body parameters in a violin. But some important issue is that he didn't consider effect of f-holes on bridge-hill while Jansson showed f-holes had a great impact on bridge-hill. Also, Woodhouse concluded sound post position doesn't have considerable effect on bridge-hill while every violin maker is aware of the very important effect of sound position on violin sound quality. On the other hand Bissinger showed that in bridge-hill area radiation efficiency for good and bad violins is approximately the same. He also showed that bridge waist trimming had little effect on bridge-hill frequency and magnitude whereas much effect on violin quality. Considering all the obtained results raises a serious doubt if bridge-hill really is a determining parameter for violin quality or not. Future works are needed to give a clear answer to this question.

References

[1] J. Woodhouse, “On the Bridge Hill of the Violin”, *J. Acta Acustica United With Acustica*, Vol. 91, 2005.
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