Influence of Early Recording and Playing Devices on Musical Sound: FRF Measurements of Horn, Soundbox and Tonearm

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Introduction

The acoustical era of music recording corresponds to a time period starting from the invention of the phonograph and gramophone in the second half of the 19th century until the advent of electrical recording in the 1920s. When listening to modern recordings and to recordings from that period there are clear differences, the most obvious being the limited frequency spectrum. But there are many other aspects to be investigated in the chain between the actual sound produced by musicians in the recording studio, sometimes more than one century ago, and the sound that reaches the ears of a contemporary listener. The fact alone that records are not replayed at the intended rotational speed can completely distort the impression about the musical performance.

All researchers that intend to draw conclusions about musical practice while listening to historical recordings should be aware of the technological aspects that influence the sound and can bias their opinions, as was already being discussed in the 1980s[1].

The consequences of the development of sound recording techniques have often been discussed from the media revolution perspective (see [2, 3], among others). As early as 1890, an article in the Scientific American journal (as cited in [4, p. 62-63]) mentions the influence of soundbox diaphragm's modes on sound as a quite obvious and well known factor. The influence of elements in the recording and playing chains on sound has been discussed in sparse works over the last decades [5, 6, 7, 8, 9, 10], but without reaching or even aiming for quantitatively describing the entire vibro-acoustical path. And in only very few works [11] has the possible retroaction of these technological aspects on the musical practice come to light.

There are reports of Thomas Edison being very picky about the vibrato when selecting artists to be recorded for his brand [12]. This raises questions such as: did the devices add a type of modulation sideband? Did the artists adapt to it? In order to test such hypotheses by objective means, it is necessary to understand and replicate these effects.

The measurements presented here are a step forward on this way of quantifying and modelling the whole path between musician and listener for mechano-acoustical recording and playing devices. Divided into sections for playing and recording, the Frequency Response Functions (FRFs) of the main parts in the signal chains, obtained by means of transfer function measurements, are presented and discussed.

Understanding the playing chain

The class of playing devices that is the focus of this work is the gramophone. The main elements of a gramophone that are acoustically relevant are the needle, the soundbox, the tonearm and the horn. The spring motor of a gramophone was an important factor, dividing low and high performance devices. In the ideal case, however, it would provide a constant rotation during an entire playing period, thus having no influence on sound.

There were needles of different materials with different tip shapes; they were commonly classified in soft, medium, and loud tone needles. The influence of the needle type on the sound is perceptible and relevant, but introduces an enormous variance factor that was not part of this study where only a medium tone steel needle was used.

Transfer function measurements were performed on a set of devices consisting of four soundboxes (Apollo, Academy, HMV 4 and HMV 5B), one tonearm, and one external horn (both of the latter elements being part of an original Academy gramophone).The measurement setup is shown in figure 1.

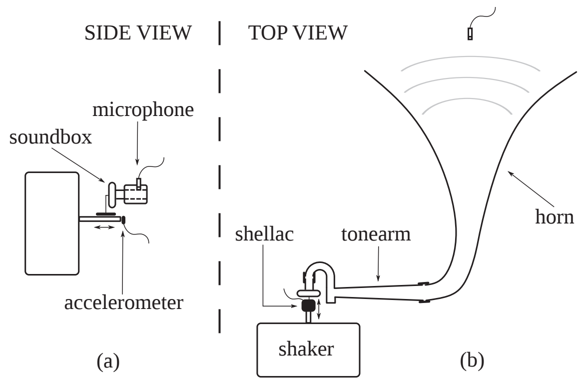

Figure 1: Measurement setup used for obtaining the FRFs of the playing chain

A logarithmic sweep sent to a shaker was used as an excitation signal. A rod was attached to the shaker with a piece of shellac adhered to it in order to emulate the lateral displacement of the needle tip. The energy input to the system was tracked by means of an accelerometer adhered to the rod. Beginning with the soundbox, the output of each element in terms of sound pressure was assessed with a measurement microphone. The calculation of the

$$\text{transfer function} = \frac{\text{sound pressure}}{\text{velocity}} = \frac{\mathrm{p}(j\omega)}{\int \mathrm{a}(j\omega)} \qquad (1)$$

between the signals coming from the microphone and accelerometer led to the FRFs.

The soundbox is the element responsible for converting the structure-borne sound, produced through the displacement of the needle tip according to the grooves of the disc, to airborne sound that will be fed to the tonearm, horn, room, and listener. The FRFs of four soundboxes are shown in figure 2. All were excited by the system shown in figure 1(a), attached to a cylindrical hard-PVC tube (6 cm long) with a hole for the microphone.

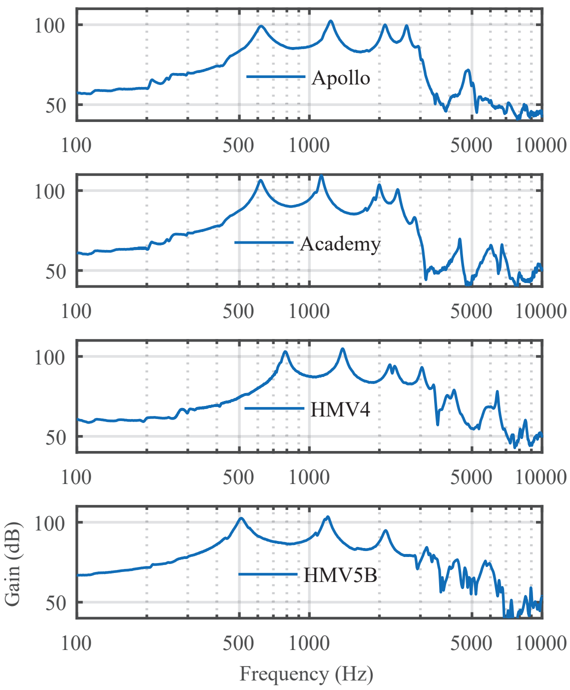

Figure 2: FRFs of 4 soundboxes

The soundbox part where the conversion actually occurs is the membrane or diaphragm. The vibrational modes of the membrane have an influence on sound [5, 7, 8, 10], enhancing the frequencies around the resonances. This "fingerprint" of the modes can be observed in figure 2 as well. The membranes are excited at their center, imposing there a displacement maximum, so that modes with nodal lines passing through the center cannot develop. The three most pronounced peaks in the FRFs in figure 2 correspond to the first three radial modes of the membrane, as evidenced by the close relation between the measured frequencies and the values for an ideal circular membrane (2,3 and 3,6, respectively [13, p. 75]).

Not only the resonances, but also the band-pass filtering that the soundbox applies can be observed in figure 2, especially the sharp slopes in the high-cut edge in the two upper graphs. This characteristic, common in less prominent and older soundboxes, becomes much softer in the models from the early 1920s onwards, as can be seen in the two lower graphs.

When attaching a tonearm to the soundbox, some resonances are shifted and tube resonances are added, as the comparison between the dashed and solid blue lines in figure 3 shows.

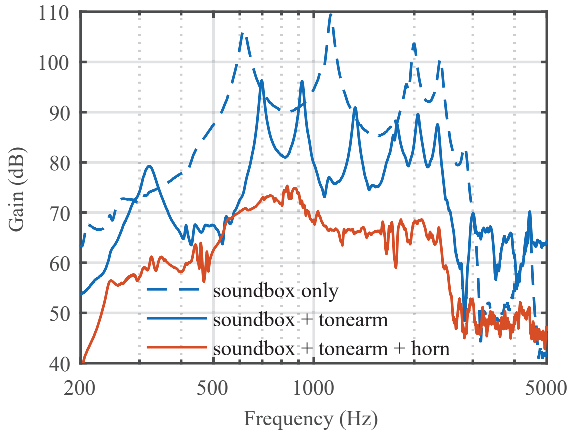

Figure 3: FRFs of the playing chain

One can observe from the red line in figure 3 that, when attaching the horn, the FRF becomes much flatter. This can be understood as a consequence of the horn as an impedance matching element between the duct and the surrounding air. Due especially to the exponential-like shape of the horn, the sound radiation is quite efficiently enhanced. The result is that there is less energy available for building up the sharper resonances that were observable in the previous setups.

Understanding the recording chain

The main elements in a recording setup during the acoustic era were the recording horn(s), the recording soundbox, the tube (linking the first two elements), the recording lathe, and the wax disc as a media on which to be written.

The function of the recording lathe is basically to provide a constant rotation; thus, ideally having no effect on sound. The media on which the sound was to be written (a wax disc), on the other hand, certainly had an influence as a form of termination impedance, damping the movement of the cutting stylus. This influence could not be assessed so far, and for the present work it was neglected.

Figure 4: Replica of recording horn 11½

In the recording chain, the horn is the first element closest to the sound source. Each recording company had a set of horns with different sizes and forms that were selected for each session according to aspects like music style and instrumentation. The Gramophone Co., one of the leading companies in the acoustical era, had a set of at least 12 recording horns [6, p. 15]. A replica of one of them, the so called 11¹/2, was at the disposal of the authors for the investigations and is shown in figure 4.

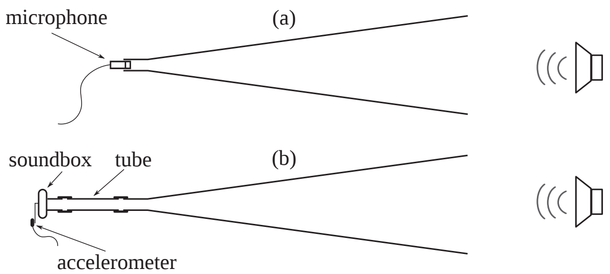

Figure 5: Measurement setups for obtaining the FRFs of the recording chain

The excitation signal was an exponential sweep sent to a loudspeaker positioned at 1 meter distance from the horn's mouth. A microphone was positioned at the horn's throat, sealing it as shown in figure 5(a). The FRF plotted with the dashed blue line in figure 6 (also in the top graph of figure 7) comes from the division of the sound pressure signal (from microphone) by the excitation signal in the frequency domain. The first and strongest resonance lies around 200 Hz.

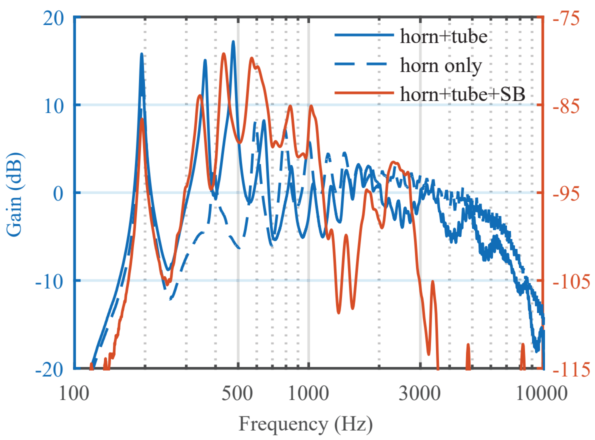

Figure 6: FRFs of the recording chain

The next element in the recording chain is the tube linking the horn's throat to the recording soundbox. Not much is known about this part, mainly that they were made out of rubber and were commonly about 10 cm long [7, p. 264]. Nevertheless, as already pointed out by Copeland [7, p. 265-266], their influence should not be underestimated. This can be confirmed by looking at the FRFs shown in figure 7, obtained by attaching soft PVC tubes of three different lengths to the throat of horn 11¹/2. For the two longer tubes, sharp resonances appear in the range between 300 and 500 Hz.

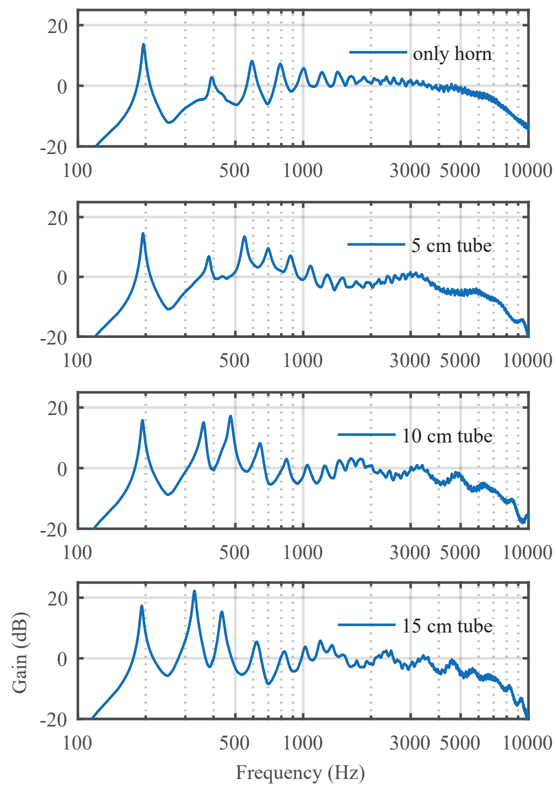

Figure 7: FRFs of tubes with different lengths attached to the recording horn's throat

The recording soundbox is the last element in the acoustical recording chain. The operating principle of a recording soundbox is very similar to a playing soundbox, except that the conversion is from airborne to structure-borne sound. As mentioned for recording horns, it was common that the recording engineers had a set of recording soundboxes at their disposal. The variation was essentially in terms of the membrane's diameter and thickness (typical ranges were 30-50 mm and 0,17-0,25 mm, respectively [7, p. 269]). Empirically, they selected the soundbox thought to be most adequate for each recording situation.

Only few recording soundboxes survived, and it was not possible for the authors to have access to either an original exemplar or a replica so far. In order to have a reasonably similar ending impedance at the recording chain and assuming that the functioning principal is similar, a playing soundbox was connected to the elements already described.

The measurement setup used for obtaining the transfer function of the three elements in the recording chain is shown in figure 5(b). The 10 cm tube was used in this measurement. The output signal is not sound pressure anymore, but the velocity obtained by integration of the signal coming from an accelerometer adhered to the needle's tip. The red line in figure 6 shows the corresponding FRF. It is possible to observe that some sharp resonances remain, even after adding the soundbox to the setup.

Combining the FRFs

The FRF representing the whole chain was obtained by multiplying the playing and recording FRFs (red lines in figures 3 and 6) and is shown in figure 8.

It can be observed that some sharp resonances of the recording FRF are softened when multiplying both spectra. Some sharp slopes are still present in the combined FRF, especially around 1 and 3 kHz in figure 8.

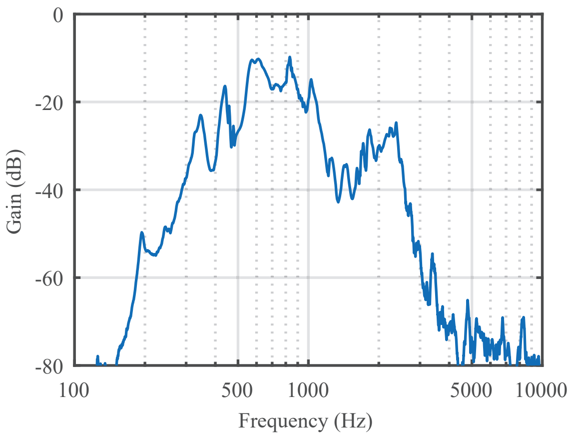

Figure 8: FRF resulting from the multiplication of playing and recording FRFs

Conclusions

The FRFs of the main parts in the playing and recording chains and their combinations, obtained by transfer function measurements with sweeps, made evident the influence of each part on sound.

Soundbox membrane and tonearm resonances dominate the FRFs in the playing chain. The impedance matching and radiation enhancing function of the exponential horn, however, flattens most resonances out, creating a desired close-to-linear frequency response.

Horn and tube resonances remain quite sharp in the recording chain, even after adding the soundbox as a termination impedance. The band-pass filtering, especially the sharp high-cut imposed by the soundbox, is clearly observable in both playing and recording FRFs and accordingly in the combined FRF.

When multiplying playing and recording spectra, some of the sharp resonances of the recording chain were softened, but some sharp slopes remained. The interaction of such slopes with formants and musical content can now be investigated by convolving dry voice recordings or synthesized voice with the impulse response corresponding to these FRFs.

Next steps include expanding the set of investigated devices in order to obtain a more representative sampling of historical playing and recording setups. In addition, investigating the influence of having a recording soundbox and wax impedance as termination should be included. The needle scratching noise should also be included in the models to be developed.

Acknowledgments

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