MUSICAL TIMBRE
COMBFILTER-COLORATION FROM REFLECTIONS

Tor Halmrast

Composer/M.Sc. in Acoustics
Statsbygg , P.O.Box 8106, Dep. N-0032, Oslo, Norway
tor.halmrast@statsbygg.no

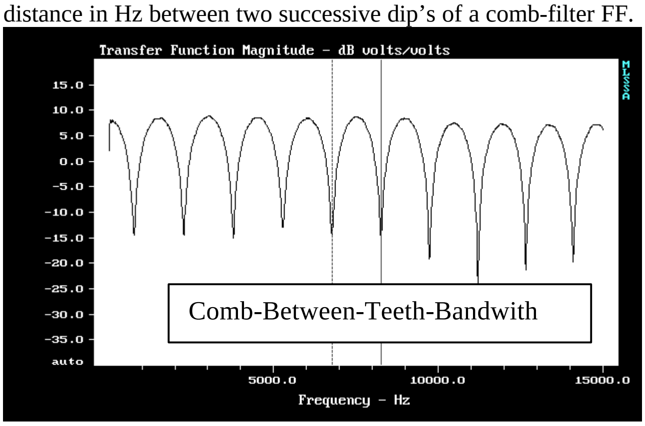
ABSTRACT

Coloration is defined as changes in Timbre/ ”Klangfarbe”. Adding a reflection will automatically change the frequency response of a signal, giving some kind of coloration. This might be looked upon as distortion. However, reflections has been a natural part of sound distribution since the Greek amphi-theatres, indicating that some coloration must be acceptable, or even “wanted” , depending of the type of signal/musical material. The question is: “Which reflections give disturbing/unwanted coloration”?

Part 1 gives a general overview of combfilter-effect for different time-delays. Part 2+3 gives the main results of a large practical investigation of coloration on orchestra platforms in concert halls. In Part 4+5, these results are compared with psycho-acoustical studies on coloration.

1. COMB FILTERS, GENERAL OVERVIEW

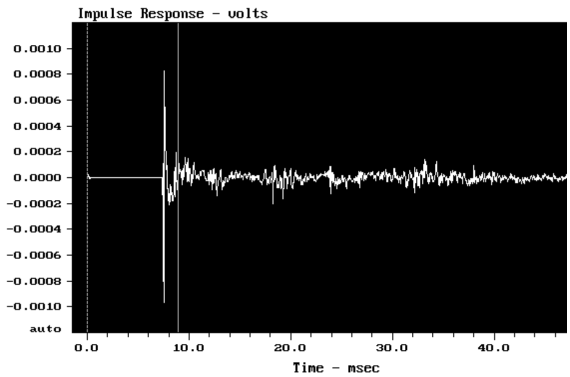
A distinct reflection arriving after the direct sound will always give a Comb-filter. For the further investigation of Comb-filters we need to define the **Comb-Between-Teeth-Bandwidth** as the distance in Hz between two successive dip’s of a comb-filter FF.



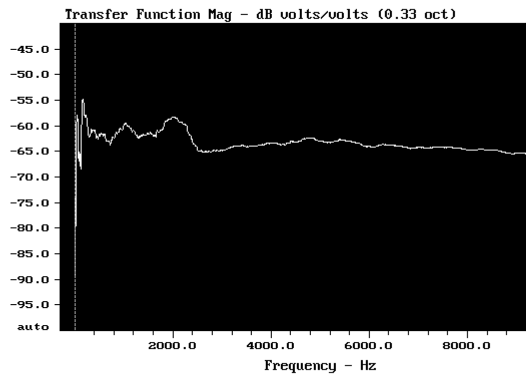
For a single reflection with a time delay of Δt msec, this “Comb-Between -Teeth-Bandwidth is 1/Δt.
A “short reflection” will give a very broad combfilter, and reflection arriving “late” will give only small “ripples” in the FFT, (and probably echoes in the time domain).

1.1) EXAMPLE, SOUND CONTROL ROOM

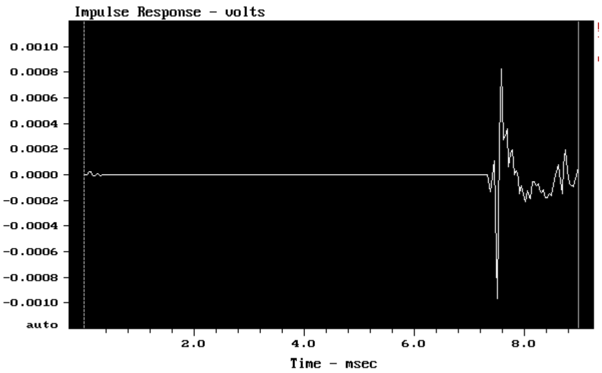
The Impulse response measured from one of the loudspeakers in a well treated , but not perfect sound-control-room to the mixing position might look something like this:

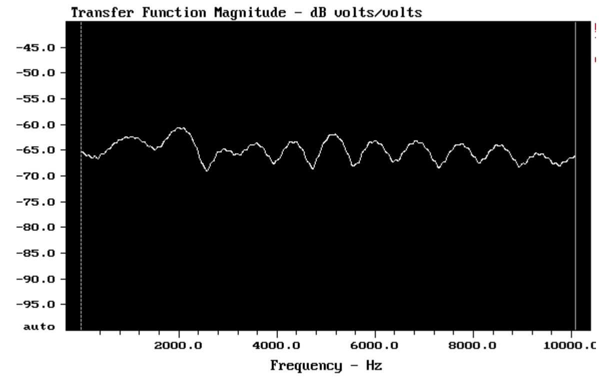


This Impulse Response does not show any strong/dangerous reflections. The FFT of the whole measurement-time (2 sec) does not show any visual signs of coloration:



Psycho -acoustic studies (see part 4 +5) indicate that coloration is formed in the first part of the sound. For this sound control-room, it is therefore interesting to investigate the FFT of the direct sound + the first reflection (localised to arrive from the mixing console). Therefore, we will “zoom in” on the part of the Imp. Resp. Before the cursor in the figure above, and perform a FFT for this time window:





The Comb-Between-Teeth-Bandwidth from this "mixing console-reflection" is some 800 Hz. Examples of other comb-filters are given in the Appendix. (Multiple Reflections etc.)

Are these combfilter "dangerous" concerning coloration?

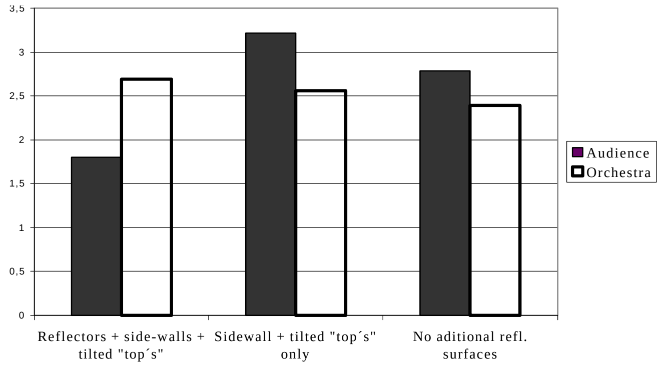
That of course depends on the type of source, its frequency content etc. First we will investigate the situation on an orchestra platform, then compare our results with psycho-acoustic studies with broadband-noise, and at last consider Loudspeakers.

2. INVESTIGATIONS IN CONCERT HALLS

Our work on orchestra-podium acoustics started with an investigations for the Oslo Philh./Mariss Jansons in Oslo Concert Hall. Investigations for improving the musicians ability to hear each other were carried out in a full-scale test with the orchestra playing short musical examples, and in sequence introducing reflecting surfaces closer to the orchestra. The subjective impressions of these changes were reported in questionnaires by both orchestra and public seats[1]. The following figure shows that the questionnaire parameter "Klangfarbe" (Timbre) was reduced for the audience when adding the reflectors over the orchestra.

(Arbitrary Score scale.)

Remarks were given that when introducing the suspended reflectors, "it sounds like if the orchestra is placed inside a



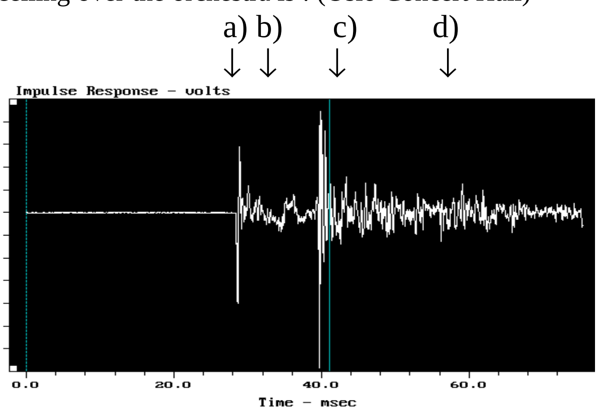
bucket or a small box". The term "Box-Klangfarbe" will be used for this type of coloration.

3. TOR –MEASUREMENTS

(Through Orchestra impulse Response) TOR-measurements are MLS Impulse Response Measurements used to investigate the acoustic conditions between different members of the orchestra, taken diagonally across the with the orchestra on the platform.[1]

3.1) TYPICAL TOR-IMPULSE-RESPONSE

A typical Impulse Response from TOR-measurements on an occupied stage with suspended reflectors or a low ceiling over the orchestra is : (Oslo Concert Hall)



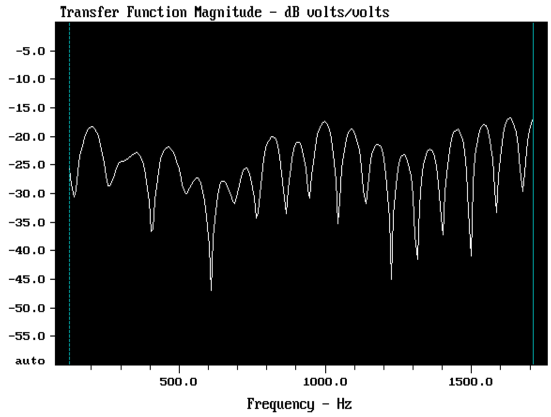
- **a) Direct Sound**
- **b) Very Early Reflections**
- c) **Reflection from Ceiling/Suspended Reflectors** Note that with the orchestra on the platform, this reflection is stronger than the direct sound.
- d) **Late Early-Reflections** (> 25 msec after the direct sound)

Taking the FFT of the whole measuring time (app.2 sec.), gives no visual indication of the coloration-effect reported, see [1]. We must use shorter time-windows for the FFT to see the "colorating" comb-filters.

We will now investigate coloration using shorter time-windows for the FFT of the TOR-Impulse-Response, successively increasing the time window. We will compare these Short-Time FFT´s with the detailed information about klangfarbe given from the questionnaires and the distances/time-delays from each reflecting surface introduced in the test.

Region ***b***: Introducing surfaces that give Very-Early-Reflections in fig.2 (sidewalls close to musicians etc.) were reported not to give any Box-Klangfarbe for the overall orchestra-klangfarbe. A strong/discrete reflection within time region ***b*** would, theoretically, create a broad combfilter with more than some 300 Hz between the dip´s. Combfilter-coloration from Very-Early-Reflections is discussed further in Part 5.

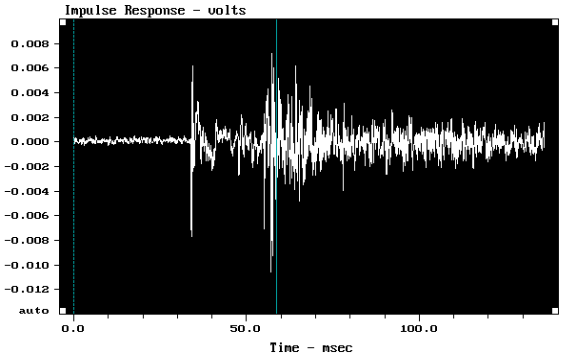
Region ***c***: Introducing plane suspended reflectors (h=6-7m) was reported to give Box-Klangfarbe. The following figure shows the Short-Time-FFT of the TOR-Impulse-Response taken for a time window up to 13 msec after the direct sound, indicated by the cursor in the Impulse Response just including the reflection from the suspended reflectors. We see a clear Comb-Filter-effect:

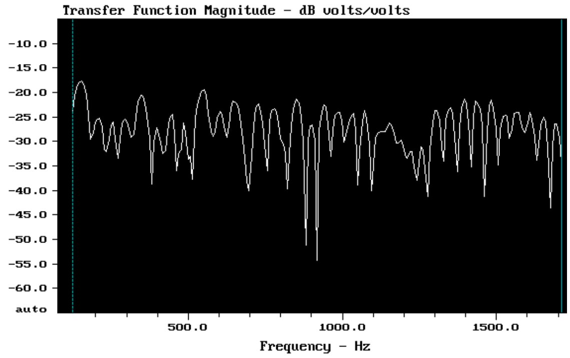


Region ***d***: "Late-Early-Reflections". No reports of Box-Klangfarbe was given due to introducing reflecting surfaces with a time-delay in this region. The TOR-FFT-analysis including this time region shows only additional small "ripples" to the main "envelope" created by the reflections in the earlier parts . When we increase the time delay of the reflection further, we enter the "time-domain"-region of sound-perception, and a "lonesome" reflection will be perceived as echo, not as coloration.

3. 3) HEIGHT OF SUSPENDED REFLECTORS

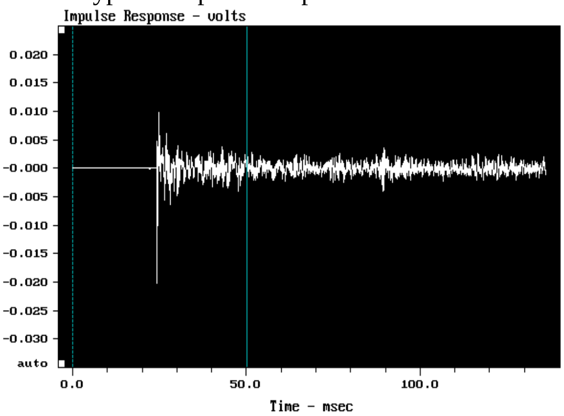
If we increase the height of the suspended reflectors from 6-7 m to 9m, the audience and orchestra reports less "box-klangfarbe", and smaller "Comb-Between-Teeth-Bandwidth" (Measurements with orchestra on the podium in Gasteig/ Munich, FFT up to 25 msec after direct sound).

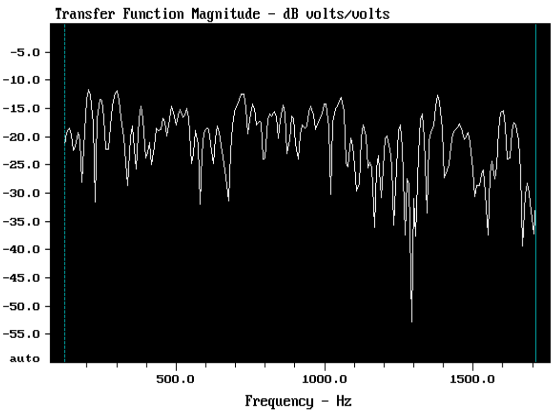




3.4) HALLS WITHOUT SUSPENDED REFLECTORS

The TOR-measurement in Vienna/Musikverein shows another type of Impulse Response/Short Time FFT:



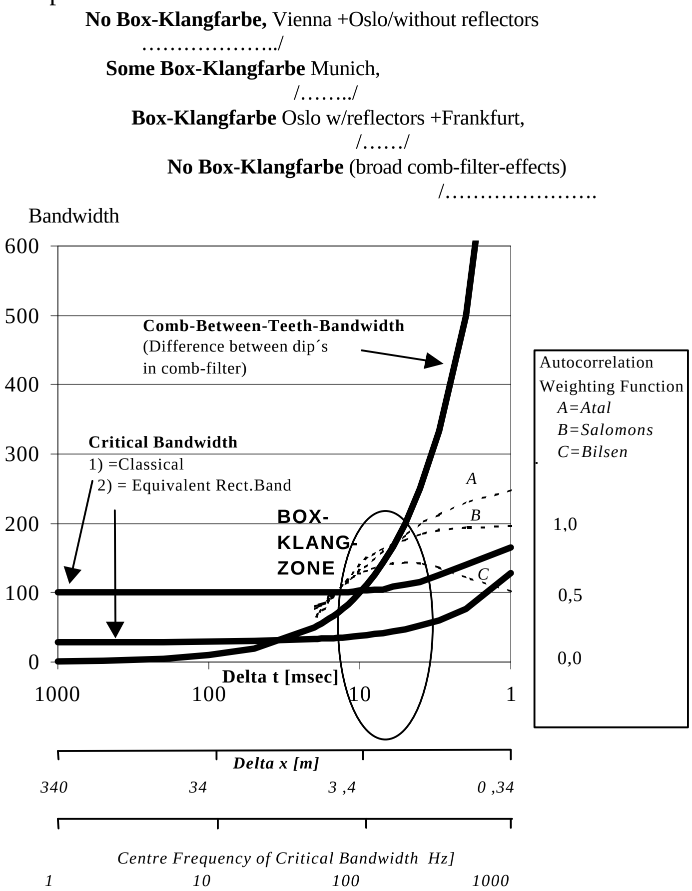


In Musikverein there is a very high ceiling, and no suspended reflectors, so we do not get any strong, discrete reflector- reflection as in the other halls. We notice the very smooth TOR-Impulse-Response due to the many reflections arriving just after the direct sound (the region called ***b*** in fig.2.) The stagewalls/ galleries/mezzanine give several reflections arriving in the time interval 0- 25 msec after the direct sound. In addition, Musikverein has very nice modulated surfaces and statues along the sidewalls giving
“diffuse”/scattered reflections.

After some 70 msec wee see the reflection from the roof of the hall, which would give a clear echo if the reflections arriving before that time were not so rich and well distributed in time. The FFT of the early part of the TOR-Impulse-Response in Vienna shows no “rhythmic behaviour”. No Box-Klangfarbe was reported.

4. EVALUATIONS

4.1) COLORATION AND CRITICAL BANDWIDTH
On top of the following figure is given the results from the practical/musical test in the 4 halls, showing the time-delay-regions of the most dominating reflections for the 4 orchestra platforms and remarks if Box-Klangfarbe was reported.



<u>For an orchestra on a platform, Box-Klangfarbe is perceived when a discrete reflection gives a clear comb-filter having a “Comb-Between-Teeth-Bandwidth” that is comparable in size to the Critical Bandwidth.</u>
This is indicated as a “**Box-Klang-Zone”.**

The exact borders of this Box-Klang-Zone must be further investigated, but our study shows that a strong, discrete reflection with a time-delay of some 5-20 msec (Comb-Between-Teeth-Bandwidth of some 200-50 Hz) will give Box-Klangfarbe. Adding more reflections in a random order into this Box-Klang-Zone, will smooth the TOR Impulse Response. The periodic behaviour of the Short-Time-FFT will then be more “unclear”, and the chances of Box-Klangfarbe will be reduced, as shown for Vienna. (Part 3.4)

4.2) COMPARISON WITH PSYCHO-ACOUSTIC STUDIES
Atal et al [4], Bilsen [6],[7] and Salomons [8] have investigated coloration in listening tests for broadband noises with delays. These investigations all conclude that coloration effects are generated in the early part of the received sound, defining ”Short Time Spectrum” which confirms our use of Comb-Filter investigations taking the FFT of the early part of the TOR Impulse Response. They also defined an Autocorrelation Weighting Function to describe the hearing organ.

A broader discussion about whether to use a frequency-domain or time-domain criteria for coloration, or if they are equivalent, is given in [4], [6],[7] and [8]. Here we will just point out for which region of time-delay(/quefrequencies) this Autocorralation Weighting Function has it heighest values, indicating that coloration is most likely to appear.

The Autocorrelation Weighting Functions in the figure above are after Salomons [8]. They show that there has been some uncertainty about this Weighting Function for short delay times. All three results are shown in the figure. We see that our results and the psycho-acoustic studies agree that coloration is most likely to appear for discrete reflections within some 5-25 msec after the direct sound. For shorter time delays the comparison is good for the results from Bilsen [6] (curve C), but not for the investigations of Atal[4] and Salomons[8] (Curve A and B), which shows coloration also for shorter time-delays than what is given for our musical study indicated as the Box-Klang-Zone.
For such short time-delays we should, however, take some practical/musical aspects into consideration. Reflections

on an orchestra platform with such short time delays might give some coloration but not necessarily an overall orchestra Box-Klangfarbe.

5. PRACTICAL/MUSICAL DISCUSSION CONCERT HALLS

The uncertainty reported for the very short time-delays in the psycho-acoustical studies can be somewhat eliminated for common orchestra platforms. Instruments placed as close to podium walls etc. to give reflections with such short time-delays (region ***b***) are often bass-instruments like double bass and timpani, see [1]+[10]. The frequency-spectrum radiated from these instruments are far from the broadband-noise signals used in the psycho-acoustic-experiments, see [1]. For such instruments, the reflections from nearby surfaces should be considered as a part of the instrument, and this "total instrument" might very well include some "good" coloration. The " Comb-Between-Teeth-Bandwidth" of such reflections are some 300-1000 Hz, indicated as *"No Box-Klangfarbe (broad comb-filter-effects)"* on the top of the figure above.

CONCLUSIONS CONCERT HALLS

On an orchestra platform a strong, discrete reflection arriving some 5-20 msec after the direct sound will give a Box-Klangfarbe. For such reflections, the "Comb-Between-Teeth-Bandwidth" is comparable to the Critical Bandwidth.

Adding more "diffuse"/scattered reflections with time delays of some 5-20 msec will reduce Box-Klangfarbe.

Our results on coloration for orchestra shows good agreement with psycho-acoustical studies on coloration, taking practical/musical situations into consideration.

Examples of "good" coloration is given in [1]+[9]: Closer positions of sidewalls and "tilted top´ s " will give an extra "punch" to double-basses and timpany**.** Examples of "Good Coloration " for chorused instruments are given in [2] .

Examples of improvements of the design of suspended reflectors, to reduce the coloration effect, are given in [1] + [12].

The extra travelling distance for an "arkeztra" reflection in a Greek Amphi-Theatre in excess of the direct sound is in the order of Δx up to some 1-10m, corresponding to a combfilter in/just below the "Box-Klang-Zone" in the figure in 4.1. Such reflections will improve the understanding of speech, but might effect the sound quality for "broad-band-music".

6. DISCUSSION, LOUDSPEAKERS

This investigation was for an orchestra on the platform.

For loudspeaker sources the comb-filter-problem is often more severe than for an orchestra, due to the fact that the number of loudspeakers is much lower than the number of individuals musicians in an orchestra*.*
A smaller number of sound sources will reduce the number of different comb-filter- reflection, and make the comb-filter/"Box-Klangfarbe" more severe.

For the Sound Control Room in Part 1, with reflection from the mixing console corresponding to a "Comb-Between-Teeth-Bandwidth" of some 800 Hz, we see that we are out of the "Box-Klang-Zone for reflections on an orchestra platform, but for loudspeakers, "putting all instruments at the same position" the psycho-acoustic experiments indicate that such a reflection will give a noticeable coloration effect. Such combfilters often also appears when a loudspeaker is positioned close to/under a reflecting surface, positions that would have been nice for bass-orchestra instruments, but not for loudspeakers.

7. REFERENCES

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[2] Halmrast,T: *"Orchestra Platform Acoustics.When will reflecting surfaces give "Box-Klangfarb*e" ICA/ASA Seattle 98 p. 347, JASA Vol. 103 p. 2786.

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[6] Bilsen. F.A: Ph.D.-thesis, Delft. 1968

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[11] Halmrast T., Pedersen, T.R: RadiOpera: ”Alfa and Romeo” Norwegian Broadcasting Corp. (Prix Italy 1998)
[12] Rindel, J.H: “Acoustic Design of Reflectors in Auditoria”. Proc. I.O.A Vol. 14 Part2 (1992), p. 119-128
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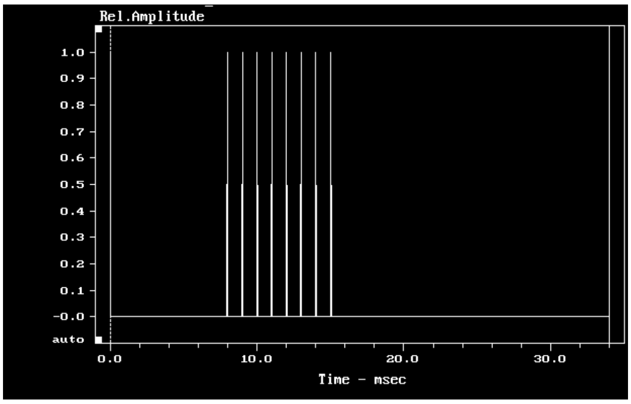
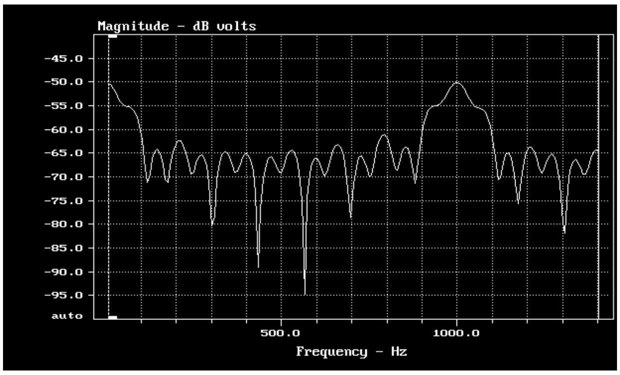
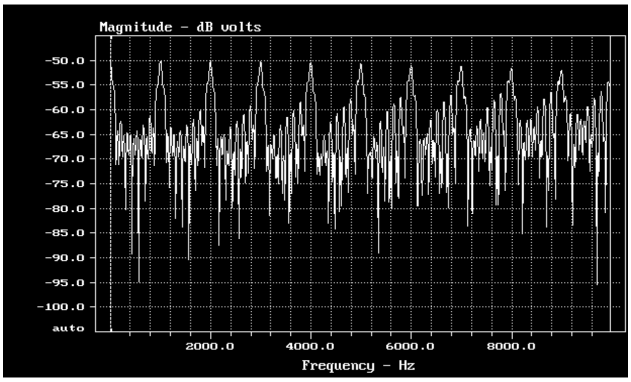
APPENDIX

MULTIPLE REFLECTIONS

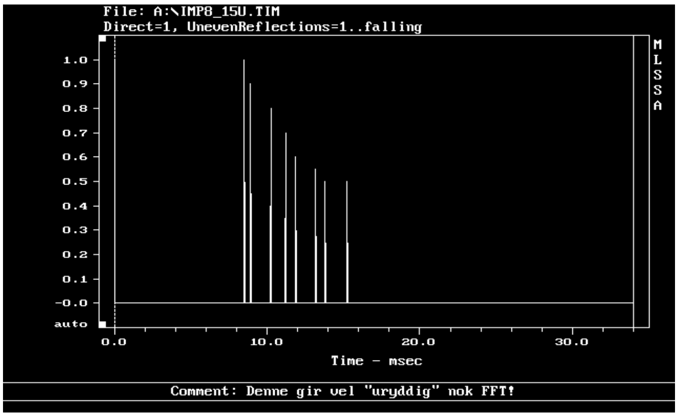
In order for additional reflections to reduce Box-Klangfarbe, they must not arrive too close to each other in time (as in more or less circular room, see[2] or too ”rhythmic”, but give ”randomness” in the TOR-Impulse-Response. As an example, a rhythmic reflection pattern of 8,9,10,11,12,13,14…… msec will, theoretically, give a clear colorating audible peak at 1000 Hz. Several simulations and listening verified this also for musical signals [1]. The “flutter-echo” is a typical example of “rhythmic-multiple-reflections”. Such rhythmic reflections might also be the result of evenly spaced “irregularities” of walls etc. in concert-halls and studios.

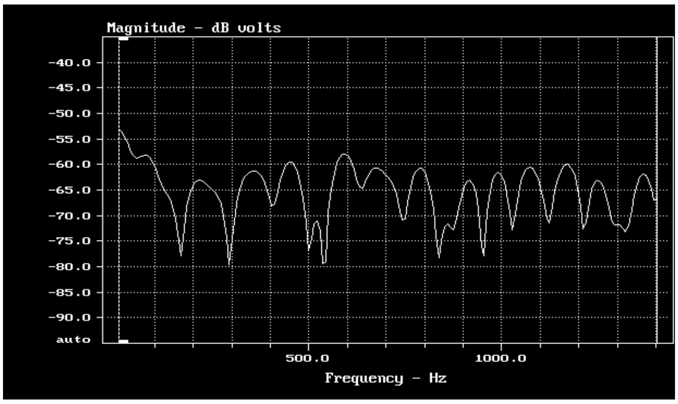


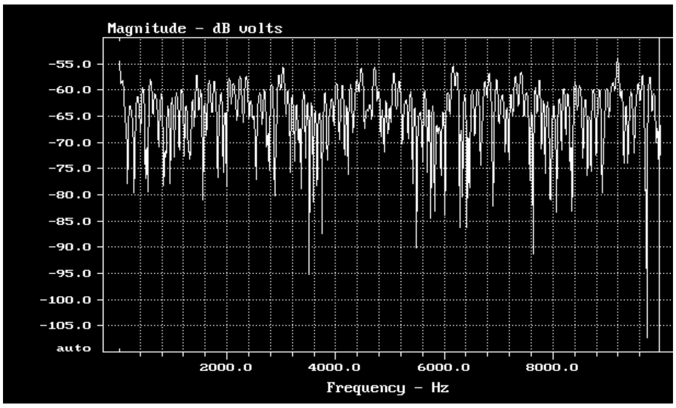




If the reflections are more “unevenly” distributed in time, we do not get such “rhythmic” repetitions in the frequency-domain:







Magnitude - dB volts
-55.0
-60.0
-65.0
-70.0
-75.0
-80.0
-85.0
-90.0
-95.0
-100.0
-105.0
auto
2000.0
4000.0
6000.0
8000.0
Frequency - Hz