

The myth of "harmful" early reflections

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If you read online discussion forums, audio magazines and manufacturers' websites, the constant message that early reflections of the first order are fundamental are bad and must be eliminated or reduced in level, either by strategic Positioning of speakers and listening position (Theiss 1996b), through acoustic treatment (Völker 1998, Völker 1999), or by using loudspeakers with high directivity or by Dipolen (Linkwitz 2007). Often there are listening conditions in studio control rooms (Keyword: reflection-free zone) or standards or recommendations such as SSF-01 2002 referred to where reflections should be 10 dB quieter than that within the first 15 ms Direct sound.

1. In closed rooms, the direct sound emitted by a sound source is always from Accompanying reflections on the space boundary surfaces.

What are early first order reflections?

Early first order reflections are those reflections that are 1st from only one Space boundary surface are reflected before they reach the listener and the 2nd inside arrive in the time window in which the precedent effect is effective. The relevant literature (e.g. Blauert et al. 2005, Damaske 1967/68, Kuhl 1978, Litovsky 1999) exist for various Signals (click sounds, noise, speech, slow or fast music) different upper limit this time window, the maximum value is 80 ms (see also Michelsen et al. 1997). In acoustically small rooms, however, ie in rooms in which the room dimensions are smaller than the wavelengths in question (17.15 m at 20 Hz), there are no early reflections such delays compared to direct sound. With regard to Devantier (2002) and Bech (1995) in particular seems 20 ms an appropriate value.

The duration of the early reflections determines the impression of the size of the room. this applies for natural hearing and also for two-channel sound transmission (Kuhl 1978).

In performance halls, early reflections (<80 ms) are responsible for the spatial impression, Broadening of the figure, apparent expansion of the sound source (Blauert 1986, Tohyama 1989), while late reflections (> 80 ms) are responsible for enveloping the listener.

2. First two questions have to be asked (Rubak 2004):

1. Where are the absolute perceptibility thresholds AWS
2. When are reflections considered disruptive

With this question, it is interesting to note that “AWS by no means the sensation of the describe audible reflections, namely what multidimensional changes in perception occur as soon as reflections are above the AWS ”and“ reflections can be clearly heard be, but not perceived as disturbing ”(Brüggen 2001).

Ideally, the experiments to find answers to the above questions are listed at Realistic home listening conditions performed, ie in acoustically small rooms and with Music played on 2-channel stereo speakers. "Take room acoustic changes however it always takes a certain amount of time. This makes the room acoustic memory of the Test subjects often overwhelmed. It is also usually impossible, only one To change sound field parameters separately and independently of the others ”(Reichardt et al.

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1967). The best solution is therefore to use synthetic sound fields (Bech 1995, Reichardt et al. 1967), or approaches such as the "active listening room" by Naqvi (2005). Currently only a small number of researchers have actually shown interest in this particular topic. Farther music is the least suitable signal to the perceptibility of individual reflections to be investigated because music is continuous, has a complex structure over time and mostly Contains reverberation that has a masking effect (Jensen et al. 2003).

However, parameters such as AWS or the limits of the time window are precedent effects are different for artificial signals, speech and music, subjective impressions of spaces different for language and music (Völker 1983a, Völker 1983b), the influence of e.g. Reflections (contralateral and from behind) on the image size is less with music than for example for pulses or speech (Wrightson et al. 1986), the threshold values for echo interference are in Language lower than that of music (see Fig. 7, Dietsch et al. 1986). Therefore, results from Experiments using artificial signals or speech are not readily available Music are transmitted.

In order to put the determined AWS into perspective, measured averages are taken over time Delay and attenuation of early reflections compared to direct sound in real ones Listening rooms specified (Devantier 2002); Numbers in brackets calculated by Bech (1995):

Floor: 1.8 ms, 1.5 dB (3.6 dB)
 Blanket: 4.9 ms, 3.6 dB (5 dB)
 Sidewalls: 9.3 ms, 3.6 dB (smallest angle: 0-20 °) (9.7 dB)

12.6 ms, 5.7 dB (2nd angle: 30-70 °)
9.1 ms, 6.6 dB (3rd angle: 80-110 °)
4.4 ms, 3.3 dB (widest angle: 110-180 °)

2.1 Fig. 1 shows the AWS of a side reflection for different signals (click sounds, noise, Language, music):



Fig. 1 (Olive et al. 1989, Fig. 6)

If you look at the AWS for (typical of the living space) 10 ms delay, you will find that Click sounds are the easiest to hear, followed by noise, music and speech. As Fig. 2 and 3 shows, the AWS hang for music with values between -18 and -10 dB (Fig.2: directional) and between -25 and -18 dB (Fig.3: 60° lateral) strongly from the music motif.

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With noise there was a difference of up to 8 dB between the individual listeners (Olive et al. 1989).



Fig.2 Dependency of the AWS from the music motif, directional reflection (Schubert 1966, Fig. 2)

- 1 violin pizzicato
- 2 chorale f. Violin, cello, clarinet, oboe
- 3 Mozart: Symphony KV 385
- 4 Mozart: Symphony KV 543
- 5 Handel: Concerto grosso
- 6 Ravel: bolero



Fig.3 Directional dependency the AWS for different Musical motifs (Schubert 1966, Fig.4)

In Fig. 1-3, the studies by Barron (1971), Olive (1989), Schubert (1966) and Seraphim (1961) used a single speaker as a source for direct sound became a single reflection in the reflection-free room.

Absolute thresholds of perception of a single reflection in a complete sound field were von Bech (1995) and Olive et al. (1989). Bech (Fig. 4) used a synthetic one Sound field with 17 reflections + reverberation and a single speaker as a source for the Direct sound. Olive et al. (Fig. 5) conducted the tests in a room according to IEC 268-13 through, with (RRF) and without additional acoustic treatment (IEC).



Fig. 4 AWS of a single reflection in a complete Sound field (Bech 1995, Fig.3)

Noise

* Language

° natural Level (calculated)

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Table 1 Delay and level the reflections of the synthetic sound field (Bech 1995, Table 1)

In general, the natural levels are below the respective AWS, exceptions are Reflections 1, (floor), 3 (ceiling), 8, 12 (wall), whose level is above or approximately equal to that respective AWS is. In accordance with Fig.1, Bech also has the AWS for language generally higher than for noise. From further experiments Bech (1996a) concludes that for Rush only the floor reflection and for speech none of the reflections on an individual basis Tone color contributes.



Fig. 5 AWS for side reflection (65°) and language (Olive et al. 1989, Fig.11)

△ IEC room untreated

▲ IEC room treated (RRF)

□ reflection-free space

If reverberation is added, the AWS increases by up to 11 dB (Bech 1995, Begault et al. 2004, Olive et al. 1989, Seraphim 1961, Völker 1997). The AWS are a single language Side reflection (65°) in a complete sound field (reflections + reverberation) by 5 dB (Olive 1989, see also Fig. 5) or 11 dB (Bech 1995) higher than the AWS in the reflection-free room. This effect is known as back masking (Yamada et al 2006).



Fig. 6 Influence of reverberation on the AWS for noise (Bech 1995, Fig.4)

It was also found that the presence of other reflections with the same Delay has a masking effect for individual reflections, the AWS then higher are (Bech 1995).

It follows that individual reflections can be heard in rooms with low reverberation times can and thus make an individual contribution to the timbre of the sound field. In such Therefore, the level of the individual reflections must be given greater attention become (Bech 1995).

Furthermore, reflections are easier to perceive at higher levels than at low levels (Buchholz 2001). AWS are lower as the distance from the source decreases (Jensen et al. 2003).

If the reflection comes from a direction different from the direction of the direct sound comes, the AWS are lower than the AWS for directional reflections (see Fig. 2, 3). The reason for this is that with the same direction of incidence, the direct sound masks the reflection (Buchholz et al. 2001). If two speakers are used (phantom source) are for If the AWS noise is a little higher (3 dB), the phantom sound source thus masks laterally Reflections better (Burgtorf 1963, Burgtorf 1964).

Another investigation of the AWS early reflections in a sound field was conducted by Holzkämper et al. (1988), using Claves (wooden bars) and Language (tracks 26 and 49 of the EBU SQAM CD) were used. In a measuring room artificial head recordings made for different configurations and with one to the artificial head adapted headphones played. The walls and ceiling of the room were 25 cm thick Absorbent material clad, the floor with carpet, the back wall with absorbent Screens are covered. The front wall was untreated because of reflections from there the directional characteristics of the control room speakers (Klein + Hummel 092) are not taken into account needed what was proven by TDS measurements. The reflection to be examined were generated by simulation over loudspeakers (Klein + Hummel 098), whereby those of both Control room speakers produced reflections on the side and rear wall by one each Speakers were simulated.

The following configurations were examined:



Fig. 7 (Holzkämper et al. 1988, picture 1)

a 1 reflection from the right

a 2 reflection from behind

Reference: no reflection



Fig. 8 (Holzkämper et al. 1988, picture 2)

b 1 reflection from the right

Reference: reflections from left and rear



Fig. 9 (Holzkämper et al. 1988, Fig. 2)

b 2 reflection from behind

Reference: reflections from right and left

In another configuration c 1 , c 2 , the reflection from the mixer was also simulated.

In the listening tests, test situation B was compared to reference A: ABAB. The level the reflection to be examined was changed in steps of 4 dB.

The perception thresholds determined show that additional reflections (configuration b 1 , b 2) increase the AWS of the reflection to be examined. The AWS of the side reflection is correct roughly corresponds to that determined by Schubert (1966). It also shows that side reflections (Configuration a 1, b 1) are perceived rather than reflections from behind (a 2 , b 2), which is associated with the results of Schubert (1966) and Bech (1995).



Fig. 10 (Holzkämper et al. 1988, Fig. 6)

Absolute thresholds of perception

The mixer reflection is considered critical because of the high level and the short delay time (- 4 dB, 1 ms) leads to sound discoloration caused by the comb filter. This The result coincides with the statements by Toole (2008) and the results from Clark (1983).

In a further step, the influence of the room width (widening in 5 steps from 3.9 at 7.3 m) was examined for the AWS of the right side reflection (b 1). For this purpose the simulated reflection of the desired width emitted with a time delay. It was an increase in the AWS of about 4 dB was found.



Fig. 11 (Holzkämper et al. 1988, Fig. 5)

Influence of the room width on the AWS of the right Side reflection

It will briefly go into further details that reflect the qualitative aspects of earlier reflections Investigations pointed out, from which it emerges that strong damping in particular the Side reflections do not appear to be the optimum, since the reflections are consistently positive Effect is attributed.

2.2 After a certain delay, the reflection becomes an independent, disturbing sound event perceived; the delay values depend on whether they are slow or fast music. For slow music, values of 150 ms (Dietsch et al. 1986, Wagener 1971), for fast music approx. 50 ms (Dietsch et al. 1986) or 70 ms (Wagener 1971) determined. The thresholds increase with decreasing delay. With the same delay fast motifs have the lowest threshold values (ie level difference relative to direct sound) (Dietsch et al. 1986). At a delay of 50 ms, the threshold values for a directionally identical are Reflection and reflection from the side (90 °) by 0 dB, that means that in small rooms typical delays of less than 15 ms reflections are not perceived as disturbing, because they are too low.



Fig. 12 Echo thresholds for Music and speech (Dietsch et al 1986, Fig.6)

3. There are usually two reasons for the need to treat early reflections

called:

1. Superimposing the acoustics of the recording and playback room
2. Sound discoloration

3.1 Superimposing the acoustics of the recording and playback room

Olive et al. (1989) and Bech (1998) have the spatial aspects of a single reflection (Mapping threshold) examined.

Olive et al. (1989) found that in speech "at reflection levels well above the AWS at Delays below 10 ms broaden the image from the sound source to Reflection was perceived, with delays between 10 and 30 ms a broadening of the Mapping as well as increasing spatiality, and further with even greater delays increasing space and a clear echo. When the level of the Reflection came to a point where broadening of the figure was no longer evident and the reflection was no longer identifiable as such. This was the one for determining the figure Threshold necessary condition. There were always others at this threshold Artifacts, however, did not change the location and apparent extent of the sound source influenced ".

This threshold was in the reflection-free room, in the IEC room (IEC) and in the acoustic treated IEC room (RRF).



Fig. 13 Mapping threshold at Page reflection language (65°) (Olive et al. 1989, Fig.12)

△ IEC room untreated

▲ IEC room treated (RRF)

□ reflection-free space

In the reflection-free room, the values were on average 12.3 dB higher than the AWS, in the RRF by 8 dB, in the IEC around 7 dB.

For pulses and noise it was found that a recorded reflection by the directional ceiling reflection were not covered. This is logical since the one recorded Reflection is a component of both direct sound and room reflection.

The influence of a single reflection on the extent and location of the sound source are, according to Olive et al. (1989) important in connection with live performances and stereo playback in the event that signals only come from one speaker.

As soon as the playback takes place via stereo speakers, a phantom sound source or Phantom image generated between the speakers.

If you compare a phantom source with a single speaker, you will find that small tonal and larger image differences (image sharpness, expansion, Distance) exist; both differences vary with signal type and recording technique (Lee 2004).

The extension of the phantom source was about 2 times that of the mono reference, the Mono reference which was somewhat darker in sound than the phantom source (Theiss et al. 1996a). The interaural cross-correlation in 2-channel stereo speakers is lower than in a single one Loudspeakers (Furlong et al. 1992). Therefore, the question seems appropriate, what value Investigations of the type single speaker / single reflection for the arrangement of the type 2-channel Have stereo / multiple reflections.

In further experiments, the effects of a single side reflection on the Phantom sound source investigated, which is perceived in the middle between the two speakers and compared to a single speaker in the same place as that Phantom sound source was placed.

“When AWS and mapping thresholds were determined, first with a real one, then with one Phantom sound sources, in the presence of an asymmetrical, single side reflection, were the Differences are negligible ”(Toole 2008).



Fig. 14 Differences between perception thresholds for real and phantom sound source, in untreated IEC space, for speech (Toole 2008, Fig.6.12)

— AWS

- - - Mapping threshold

Bech (1998) determined the AWS, in which a second sound source was clearly perceived. In speech, all values, with the exception of ground reflection, were above the respective natural level (natural level: see Fig.4).



Fig. 15 Thresholds for the Appearance of a second, separate Sound source (Bech 1998, Fig. 6)

■ noise

□ language

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The part of the experiments where the absorption of the space boundary surfaces was simulated (Fig. 10) corresponds most closely to the natural conditions in real rooms, so Bech concludes that under these conditions only the ground reflection is strong enough to individually to contribute spatial impression.

The size of the mapping thresholds depend on how the stimulus, based on one Change of space or image is perceived, defined and how the threshold itself is defined (Bech 1998). With language they move Threshold values for a 10 ms delay between -6 and +10 dB (Fig. 15).



Fig. 16 Mapping thresholds for different perceptual criteria for language (Bech 1998, Fig. 7)

The following perception criteria were used:

SB: occurrence of a second sound source

O&T: moving, broadening of the image, spatiality

M&S: occurrence of a second sound source

L&B: occurrence of a second sound source

The clear differences are due to the different definitions of the threshold values as well due to the different spatial conditions: M&S defined the threshold values with hardly, L&B and SB with clearly perceivable second sound source, M&S and L&B worked in reflection-free space, SB and O&T in complete sound fields with reflections and Reverberation.

Yanagawa et al. (2001) found that for noise pulses (4 seconds) (single speaker / Single reflection) the image became wider with increasing delay of the reflection (without Delay, the image was located in the middle between the two speakers). At Delays above 10 ms became the broadening of the figure subjective Diffusivity about.

Direction and image sharpness of phantom sound sources generated by stereo speakers was developed by v. Ripka et al. (1987). For correlated noise ($k = 1$) it was found that a reduction in the listening distance was accompanied by an increase in image sharpness. At the same time was a clear difference bzgl. the sharpness of the image between the speakers used observed.

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Loudspeakers with different bundling dimensions BM produce different proportions horizontal or vertical reflections (Linkwitz 2007, Ringlstetter et al. 1996). There is indications that these different sized parts differ in the sharpness of the image lead (Kuhl et al. 1978), to differences in phantom source width (Ringlstetter et al. 1996) and differences in phantom source localization (Linkwitz 2007). For noise were the differences in the sound source width are small. In terms of preference, none clear tendencies were found when assessing various bundling measures (Flindell 1991, Kuhl et al. 1978).

Early reflections still seem to have very little impact on image quality and To have space (Flindell et al 1991).

In tests with sound engineers who should add a solo voice to an orchestral recording (3rd different passages of the same CD), the level of the mixed voice being measured it was found that with different treatments the side walls of 2 control rooms with diffuser, porous absorber, reflective plasterboard no or only a slight difference between the mixes to be created, the absorber testing the test subjects on prevented most from producing consistent results (King et al. 2011). It was found furthermore that the music material had a significant influence on the mixing.

In a continuation of the tests in the first of the two control rooms with the same Music materials were the same acoustic treatment elements on a motorized rotatable carrier mounted, which the switching times between the various acoustic Conditions reduced to a few seconds, causing the variable to adjust the handset the changed acoustic conditions could be eliminated (King et al. 2013a). In turn it was found that the level of the mixed voice was approximately the same for all treatments, in this experiment the greatest variance is not with the absorber but with the reflector was found while the absorber showed the smallest variance, suggesting a beneficial one The effect of the absorption treatment seems to indicate. Again it turned out that that Music material had a statistically significant effect on the level of the mixed voice,

as well as a very large influence on the variance of the respective passage.

The authors point out that the absorbers are unnaturally close to the Listening place were placed, so that in comparison to the first test series (King et al. 2011) others acoustic conditions existed, whereby the results are not directly comparable.

Further tests with the same protocol and the same acoustic treatment elements as in (King et al. 2013a) were carried out in a half-space (reflecting only the floor). At A global analysis of the results showed only minimal differences between the various acoustic treatments (absorber, diffuser, reflector). At Looking at the individual results of the 20 test subjects, there seemed to be a trend towards this to indicate that the diffuser had a positive effect.

In a pair comparison test of artificial head images of 9 different room treatments (Listening distance 1.5m) and playback via headphones, where the sound and the spatial Playback descriptive attributes were assessed on a scale from -3 to +3 found that early reflections have a statistically significant influence on spatial aspects (Sound source width, envelope) as well as clarity, but not on sound aspects (Brightness and naturalness of the timbre) and preference for almost all compared pairs (Imamura et al 2013).

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The distance of the phantom source does not appear to be affected by early reflections (Michelsen et al. 1997).

For speech, all known mapping thresholds are above or approximately the same natural reflection level so that the conclusion can be drawn that natural Reflections are too weak to have the effects indicated above (occurrence of a second Sound source, shifting or widening the image).



Fig. 17 Perception thresholds of one Single reflection in the reflection-free Space for language (Toole 2006, Fig. 7)

- Second sound source (L&B, M&S)
- Moving, broadening the figure (Olive et al. 1989)
- AWS of a 65 ° side reflection (Olive et al. 1989)
- First 6 reflections (Devantier 2002)

Looking at the context of playing music, all of the above are measured Reflections (Devantier 2002) above the AWS of a single reflection. Toole (1990): "In many normal listening situations are some reflections above the AWS. The fact that the Thresholds are high, which means that the resulting interference is generally not very are significant. This undoubtedly helps explain why stereo imaging in these situations and the sound quality is as good as it is. "

In any case, levels and delays of early reflections in typical listening rooms are wide below the levels and delays both in speech (Ando et al. 1977, Toole 2006) and can also be perceived as disturbing in music (Dietsch et al. 1986, Wagener 1971).

Furthermore, there is evidence that early reflections in typical listening rooms are not strong and are late enough to have optimal effects (Ando et al. 1977, Muncy et al. 1953, Toole 2006).

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An interesting experiment was carried out by Naqvi (2005): in a room according to ITU-R. BS.1116 a reflection-free zone was formed by the early spatial reflections Panels were directed past the listening zone (see Walker 1995). Due to the Dimensions of the panels could only be deflected frequencies up to about 500 Hz.



Fig. 18 Non-reflective zone 2-channel arrangement (Naqvi 2005, Fig. 13)

This "geometric, absorption-free" approach avoided that at the same time as the Attenuation of the reflections and the reverberation time was reduced (according to Niaounakis et al. (2002) the perception threshold for the change in the reverberation time at approx. 0.05 s). Indeed omnidirectional NXT flexible wave loudspeakers were used as panels, which in addition to the Guiding away the early reflections shown by the main speakers also artificial ones themselves Could generate reflections. The change in reverberation time by adding the artificial Reflections were less than 0.012 s, i.e. below the threshold.

Recordings in the anechoic room of horn, trumpet, acoustic guitar were used as signals used. In the experiments, these recordings were made as direct sound over a single, central LS (i.e. mono sound source) reproduced. About a Lexicon processor early reflections (15-40 ms) and reverberation (> 40 ms) generated and in equal parts on 2

additional front speakers were given (see Neher 2002). Via the generated in the processor
 Relative levels of the reflections were observed at different distances
 Sound event generated (very close, close, very far).

It was now examined (ABX method) whether added artificial reflections unified
 would have a noticeable effect. There were 12 reflections with a delay from 1.5 to 12.5
 ms and a relative level of -7 to -12 dB. In all cases, adding the
 artificial reflections are perceived (> 75% correct answers), with the
 Hit rate was different depending on the signal.



Fig. 19 Results of the ABX test (with / without reflections) (Naqvi 2005, Fig. 25)

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In most cases, the presence of the artificial reflections widened the
 Sound source and a reduction in image sharpness result. However, it should be noted that
 even this experimental setup is not the usual 2-channel stereo setup with a central one
 Corresponds to phantom sound source.

The influence of the listening room (early reflections, reverberation) on the quality of the perceived
 The sound event of the 2-channel stereo playback was described by Schneider and Spikofski (1992)
 examined. A 7-channel system (Klein +
 Hummel O92, O98) synthesized sound fields, recorded via artificial head and via one to the
 Fake headphones reproduced. The space to be simulated was divided into 7 sectors
 divided.



Fig. 20 (Schneider et al. 1992, Fig.2)

Sector concept: Solid lines represent the
 Sector boundaries. Are drawn with dashed lines
 1st order reflections of the left speaker L.

Sound field situations were created for 3 different room sizes: R1 = 90 m
 3rd
 ; R2 = 120
 m
 3rd

; R3 = 150 m
3rd

. Three different reflection situations (only horizontal reflections, floor and Ceiling were neglected) were simulated: 1. all 1st and 2nd order reflections; 2: the two earliest reflections occurring in a sector; 3: one reflection per sector. The label Space x / y characterizes the situation in space x, reflection situation y. Reverberation (mean Reverberation time 0.36 s) was radiated incoherently over all 7 loudspeakers.

Language and piano were used as program material. Selected ones
Sound field situations compared with a reference situation and the degree of perceptibility on a five-point scale from “imperceptible” to “clearly perceptible”.

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For the tests, the sound field situations room 2/2 and room 2/3 were used as reference situations as well as speaker and piano selected as test signals. For comparison with the reference were the directions of incidence changed as follows:

- A) Swap the reflections from the left front (L) and right rear (RS1, RS2)
- B) Swap the reflections from the front (L, C, R) and back (LS2, RS2)
- C) Reflections from the front (LC, R) are also emitted from the rear (LS2, RS2)



Fig. 21 (Schneider et al. 1992, Fig.5)

Influence of the direction of sound incidence on the Degree of perceptibility

The degrees of perceptibility determined are between 1 and 2, ie between “not perceptible ”and“ just perceptible ”. The degrees are for the different directions of incidence the reflections are not significantly distinguishable, from which the authors conclude that the Direction of incidence is of little importance.

For the sake of completeness, the studies by (Imamura et al. 2014) should be mentioned. In a quasi-reflection-free room, the influence of the reflections from the front, back and the Side on clarity (timbres) and spatial clarity, as well as apparent Extending the sound source ASW and enveloping the receiver LEV examined. For this, the Reflections of one loudspeaker simulated, with and without considering the Radiation behavior of the direct sound source. Two time delays were used, 10 and 30 ms, ie 3.4 or 10.3 m path length difference. In the case of reflections from the front and

A delay of 30 ms seems unrealistic because the sound source or the listener must be placed 5 m in front of the respective wall. The individual reflections were in pairs compared with each other. It was tested with a 30s long music passage, played by a mono sound source.

The following results were achieved:

1. The time delay of the reflection has a strong influence on clarity, ASW, LEV
2. The side reflection has a strong influence on spatial clarity, ASW, LEV
3. The consideration of the radiation behavior of the sound source has a significant influence on the results.

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The following must be noted about these investigations

- a) there is no reverberation
- b) Mono sound source
- c) no complete sound field (reflections from floor and ceiling are missing, there was one each single reflection compared to another single reflection)

3.2 Sound discoloration

When direct and reflected tones are mixed, phase disturbances occur (interference) and comb-like structures with minima and maxima appear on the envelope of the Spectrum (Seki 2003). The frequencies of the maxima of this comb structure are given by n / T ($n = 0, 1, 2, 3 \dots$) that of the minima by $(n + 0.5) / T$, where T is the time delay of the reflection in Reference to direct sound. A reflection delayed by 1 ms results in a comb structure Maxima at 1000, 2000, 3000 etc. Hz and minima at 500, 1500, 2500 etc. Hz. One by 10 ms delayed reflection results in a comb structure with maxima at 100, 200, 300 etc. Hz and minima at 50, 150, 250 etc. Hz.



Fig. 22 Comb filter for white noise, $T = 5$ ms (Solomon Islands 1995, Fig.2.1)

If a microphone is used for recording under such circumstances, the reproduced sound is often perceived as tonally discolored. It is well known that a such discoloration is less noticeable when listening directly to the sound source (Koenig 1950). The central question is, do these comb filters lead to audible discoloration?

The amplitude (or depth of modulation) of the comb filter depends on the level of reflection. Each the lower this, the lower the resulting amplitude and the sound discoloration decreases (Solomon Islands 1995). The discoloration also depends on whether a single or multiple Reflections are present and in the case of multiple reflections, whether these are regular or be distributed irregularly on the timeline. Irregularly distributed room reflections lead to a lower amplitude of the comb filter and the perceived sound discoloration smaller if the number of such reflections increases (Case 2001, Halmrast 2000, Salomons 1995). In the case of small delays (of the order of 1 ms), a large one is required with white noise Number of irregularly distributed reflections to avoid discoloration: 16 Reflections hardly suppress the discoloration (Bilsen 1995, Salomons 1995). With larger delays (of the order of 30 ms), 3 irregular reflections are sufficient, to achieve a suppressive effect.

For regularly distributed room reflections, the discoloration increases with the number of Reflections stronger.

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The interaction of a tone with its repetition has been extensively investigated (e.g. Atal et al. 1962, Bilsen 1967, Salomons 1995) and limit values of the perceptibility for individual and Multiple reflections, taking into account the frequency groups in the inner ear, have been determined (Solomon Islands 1995). For broadband noise, sound discoloration is most likely to occur in the Time window of 5-25 ms on (Atal et al. 1962, Salomons 1995). Discoloration effects when listening to Music is lower due to the continuous spectral changes (Solomons 1995).

For time delays of up to approx. 25 ms, the discoloration is perceived (for noise signals) mainly due to regular changes in frequency response (spectral Discoloration), with larger delays the perceived discoloration is mainly in the Time range, e.g. beatings (Rubak 2004). When there is white noise, human hearing is particularly sensitive to discolouration caused by delays of around 5 ms become (Johansen 2001).

Different delay times for reflections from left and right can be two-eared (Binaural) "sound discoloration suppression" (Solomon 1995).

Two-ear suppression of sound discoloration: if you hear two-ears, the direct sound comes and its reflections from different directions, an interaural level difference ILD is observed, the sound is perceived as less discolored than with one-eared (monaural) hearing (Salomons 1995, Zurek 1979). In an experiment on sound discoloration

and suppression of sound discoloration (Brüggen 2001), using binaural room simulation different rooms and different configurations of source and receiver in each Space (hereinafter referred to as "channels"), music was compared to speech, classified as too difficult to assess, in that the differences between the channels are not were as clear as in speech and beyond that certain sound describing attributes in were used exclusively for a specific piece.

Comb filter formation is a phenomenon of stationary sound fields (Everest 2001). Broadband signals like white noise is well suited to show spectral discoloration. However, music is one complex mixture of stationary and transient signals (Cox et al. 2004), so the Question to what extent studies using white noise or other artificial signals are relevant for listening to music in home listening rooms.

Hence, given the mechanism of binaural stain rejection, it is not useful to measure room frequency responses with a single measurement microphone at the listening position which phenomena like comb filter structures are naturally visible. It is also not it makes sense to use two microphones that are about 15 centimeters apart (corresponds approximately to the diameter of the human head) because such microphones in the Tat can show significant level differences, but the human ear can detect the signals of the integrated into both ears in the brain stem to create a “central spectrum”, something two microphones don't. In addition, such a measuring method does not take into account the interaural level and time differences (head related Transfer function), the spectral filters of the auricles are also taken into account (Rodgers 1981).

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Furthermore, the human ear reacts to sound signals from different directions different (outer ear, diffraction, absorption, resonance) what in different Eardrum frequency responses is expressed (Møller et al. 1995, Shaw 1965).



Fig. 23 Average values of the drum frequency responses out of 9 subjects, different directions of incidence (Shaw 1965, Fig. 4)

While artificial signals, combined with a few controlled reflections, are audible Comb filter effects produce, "the interaction of direct sound tends to interact with each of the numerous Reflections, in combination with the interaction of these numerous reflections with each other,

to form an average or one of the expected comb filter discoloration
To give it a random character”(Case 2001).

Toole (2008): “The [comb filter] effect is audibly obvious ... if a single, strong one
vertical reflection (in the median plane) in an otherwise reflection-free environment
[such as the reflection from the mixer in the reflection-free zone in the studio control room].
However, for reflections that occur in a normal reflective environment with a variety of
Reflections that occur at large horizontal angles make this effect no longer a problem. ”

Blauert (1983) states: “Early reflections from rigid surfaces such as table tops or
Room walls can also lead to strong sound discoloration when listening with one ear. These
However, the phenomenon is less noticeable when listening to two ears, and sometimes not at all.
Hearing clearly has the ability to hear certain linear distortions when listening to two ears
of the ear signals when creating the timbres of the hearing event. ”

Clark (1983) used a single speaker and reflector arrangement,
which produces a side reflection, with accompanying comb filter:



Fig. 24 Frequency response and impulse response for single LS and side reflector (Clark 1983, Fig. 6)

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Clark: “The audible effect of the reflector was pretty difficult to perceive. As the reflector
placed on a table top, the effect was stronger. They were probably
Interference frequencies are now the same for both ears as the paths of direct sound and reflection
were the same for both ears. With the reflector on the side, the comb filter is for
each ear a different one, causing each frequency of at least one of the two ears
is perceived. ”

Differences in timbre with different proportions of horizontal or vertical
There were virtually no reflections in music (Linkwitz 2007, omnidirectional emitter vs dipolar),
low in speech and very low in singing (Ringlsetter et al. 1996, same (selected)
Speakers, in horizontal or vertical arrangement)

The main conclusion is that for natural (ie binaural) hearing in rooms
Sound discoloration is not a problem (Kuhl 1969, Toole 2006).

The ubiquitous claim that reflections when playing music through speakers
Comb filter discoloration is based on unsuitable evidence (clicks, noise,
Measurements with a single microphone) and is therefore not relevant for binaural hearing of
Music. Evidence that comb filters generated by reflections when listening to over
Speakers of music played in small rooms lead to discoloration of sound
not yet led. It appears that the above claim is a consequence of Richard's late 1960s
Heyser developed TDS (Time Delay Spectrometry) measuring method, which by early
Made comb filters visible for the first time in the measured frequency responses,
without any psychoacoustic examinations or hearing tests in this regard
(Voetmann 2007).

“The inevitable conclusion is that when listening naturally, there is no room reflection
Show problem.” (Toole 2006, see also Cremer et al. 1956).

4. In both speech and music, there are side reflections
preferred in the same direction (Ando 1977, Ando 1979), with language being the preferred
Angle of incidence is 30° (Ando et al. 1977), for music $55^\circ \pm 20^\circ$ (Ando 1976).

Reflections make a positive contribution to the listener's preference. The bigger the difference
of the signals arriving at both ears, the larger the space is perceived (Toole
2006). Reflections in the median plane (plane that runs vertically in the middle between the ears) can
The subjective preference may be detrimental because the signals coming from the left and right ear
arrive, are very similar to each other (Schroeder 1979). Coming from the front or back
Reflections are less preferred, while side reflections are more desirable
(Ando et al. 1977, Toole 2006). As a result, attenuation of reflections from central parts
the front or rear wall have advantageous effects. Reflections within 2-3 ms after
the direct sound, as generated by the speakers very close surfaces,
generate a high interaural cross-correlation and are therefore the least advantageous
(Ando 1977). Dampening such reflections can have a positive effect (Toole
2006, Walker 1994b). A high interaural cross correlation is with high binaural similarity
equated, which results in a low subjective preference (Schroeder 1979). On the other hand
the preference for unequal ear signals (high binaural diversity) high. Acoustic
Asymmetry lowers the interaural cross-correlation, leading to an increased feeling of
Spatiality leads and generally results in increased preference (Ando 1977, Toole 2006).

In order to achieve zero cross-correlation (maximum diversity) in two-channel stereo systems

the speakers should be at an angle of 23, 67, 126, 158° with respect to the listening axis be arranged (Damaske et al. 1972), according to Ando (1998) an angle of 26° is optimal for everyone. Signal types. The interaural cross correlation decreases with increasing reverberation time in the room (with improved spatial impression at the same time) (Kurozumi 1983).

"Individual reflections seem to flatter music and speech in general, and those that occur naturally in small rooms, if at all, too low in level, one to have optimal effect. Indeed, numerous early reflections have a positive one cumulative effect on intelligibility. Reduce from the perspective of sound quality multiple reflections the comb filter effects (good) and increase our perception of Resonances (good for the music and bad only if the resonances are in the speakers), " (Toole 2006).

Early reflections that arrive within speech integration time (approximately 30 ms) improve intelligibility (Bradley 2003, Toole 2006). The intelligibility improves in increasing if the time delay of a single reflection is reduced. For Performance spaces such as concert halls, there is abundant literature that shows the positive effects of Shows reflections (like Ando 1977, Barron 1971, Schroeder 1979). Moulton (1995) found that early Reflections in small rooms are generally considered to be beneficial.

It should now be clear that the only effect early reflections may have may have a change in spatial representation, such as a Displacement or broadening of the figure, however, in all cases only one Side reflection examined, in no case the reflections from both sides. Especially lateral reflections contribute to the spatiality (Blauert 1986, Damaske 1967/68, Schmidt 1973) the components below 3 kHz for imaging depth and components above 3 kHz for the Broadening of the figure are responsible (Blauert 1986). Whether this is good or bad is a pure matter of individual judgment.

It has been found that normal reflections in typical living spaces perceive the Do not hinder the spatiality of the recording room (Olive et al. 1989) and that for enjoyment walls reflecting recorded music have a better effect (Kishinaga 1979).

If reflection treatment is desired for any reason, then must (Frequency-independent) broadband absorbers can be used. The precedent effect is strongest, if the spectra of direct sound and reflections are similar. Masking effects are on strongest if the spectra of masker and masked signal are identical (Buchholz et al. 2001). If the spectrum of a reflection is different from that of the direct sound, the Greater likelihood that it will be perceived as a separate sound event (the Precedent effect is less effective). Therefore acoustic devices should be even

down to about 200 Hz (Olive et al. 1989, Toole 2006).

However, acoustic treatment causes a not insignificant, frequency-dependent change of the interaural cross-correlation coefficient IACC (Tohyama 1989) if absorbers or diffusers are attached, the coefficient decreases (King et al. 2011) with consequently reduced imaging range (Kishinaga 1979) and leads in extreme cases reflection-free space so that the perceived sound field is strongly different from the original field differentiates (Tohyama 1989).

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It should be clear that experiments such as that carried out by Salmi (1982) or proposed, in which a single floor reflection is examined in a reflection-free room with noise from a single speaker as a signal (with consequently the maximum possible Similarity of the signals on the left and right ear), without great value for the music playback through two loudspeakers (phantom sound source) in a reverberant environment like home Living room with multiple reflections.

It should also be clear that space pulse measurements, the drastic changes in the Produce the measurement result as soon as the position of the sound source or microphone is changed, whereas the listener does not notice such changes are of little use (Buchholz et al. 2001). It is also known that not everything in a room impulse response is visible, is also perceptible (Buchholz et al. 2001).

Obviously there may be situations in which treatment of reflections is necessary can be like for example

1. one speaker placed very close to the other very far from the wall
2. a speaker close to a wall, no wall on the other side
- 3rd frequency response on axis very good, frequency response off-axis catastrophic (Olive 1990, Olive et al. 2007, Toole 1990)
4. the room has a very low reverberation time (Bech 1995)

In such cases, appropriate treatment can improve the situation. Hence one must consider the subject of early reflections separately in each individual case.

Finally, a few passages from Floyd Toole's book (Toole 2008):

"... some deviations from acoustic rites and practices of an industry that is without Has developed support from science. "

"The topic of the side reflections of the front speakers (L, C, R) requires some discussion, due to the widespread belief that these reflections are eliminated by default have to. This ritual has its origins in recording studio control rooms, justified by Caution calls for comb filters, reduced speech intelligibility or Masking reflections contained in images. Taking a close look, it turns out none of these problems as such. The real factor seems spatial and this generating reflections, as well as the fact that sound engineers, as well as musicians, a have higher sensitivity than the average listener. Although many, if not all sound engineers feel that their work is hampered by side reflections, most people prefer the presence of these reflections when listening to music in their free time. "

"So what do you do with these reflections in your listening room? If the speakers are good Have radiation properties off-axis, and especially if the music lover with If I prefer listening to 2-channel stereo, my recommendation goes to the places on the side Reflections to leave the wall untreated. "

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"There seems to be no evidence in the now numerous literature that this lateral reflections of the first order in normal or slightly treated Are a problem. It is difficult to get the benefits without the apparent disadvantages Use of normal, wide-beam cone speakers with good radiation behavior ignore off-axis, with the corresponding locations of the side walls reflective stay."

"Use absorbers on the wall behind the speakers. Use absorbers or diffusers on the wall behind the listening position. "

Regarding the first of these two recommendations, however, it should be noted that Toole based on Kishinaga's research, which in this particular case Room was carried out in which the reflections from side walls, ceiling as well as the wall behind the listener were treated by absorption, what fact the perceptibility and increases the influence of the remaining reflections. As for the second of these two recommendations As for Toole, in the relevant section of the book, says that the reflection in question have little use in terms of spatial representation, it is presumably harmless, but one could consider treating them acoustically.

5. Conclusion

- There is no scientific evidence that early first order reflections at the Listening in 2-channel stereo is a fundamental problem.
- There are indications that early reflections have an audible influence on the spatial Presentation. Whether this influence is classified as positive or negative depends on the individual Consideration from.
- Reflections coming from the same direction as the direct sound are less preferred as side reflections so that treatment can have a positive effect.
- Have acoustic measures (absorbers, diffusers) to treat early reflections a decrease in the IACC interaural cross-correlation coefficient while high IACC values are preferred.
- As has been shown in a test (King et al. 2011), acoustic measures can also have a disruptive effect.

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