Loudspeaker Placement for Optimised Phantom Source Reproduction

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LOUDSPEAKER PLACEMENT FOR OPTIMISED PHANTOM SOURCE REPRODUCTION

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Abstract:

The influence of loudspeaker placement on virtual image recreation is an often underestimated factor. A comparison of different popular loudspeaker setups based on common knowledge on psychoacoustics is made, and the superiority of one special approach will be shown. Two methods are described to enhance the sharpness of phantom sources via measurements or listening by finetuning of the loudspeaker placement.

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0 INTRODUCTION

Although room acoustics are well understood [1] recommendations for loudspeaker placement for stereo systems are seldom found in the engineering literature and deal mostly with positions for best low frequency extension and linearity [2 - 4]. Another important factor, at least since the introduction of stereo in the 1950's, is the creation of phantom images in normal rooms with reflecting walls. During years of informal experimenting with loudspeaker set-ups in many different rooms a method has evolved which consistently gives a very spatially transparent reproduction even in acoustical difficult rooms, although it is somewhat dependent on the loudspeakers being suited to the task. Despite the fact this method is based on empirical knowledge, we believe there is sufficient psycho-acoustical data to explain the benefits of our set-up. It is also proposed that the true performance of a loudspeaker system including the phenomena of diffraction and baffle size, can only be judged when a loudspeaker is optimally installed in a room to maximise stereophonic performance. All too often manufactures design a loudspeaker for an optimal location that is determined more by bass alignment than stereophonic performance, we conjecture that this method of design specification is misplaced and is not guided by the requirements for three-dimensional stereophonic sound reproduction.

1 PSYCHOACOUSTICS AND LOUDSPEAKER PLACEMENT

It is well known that the brain can not distinguish between direct sound and reflections, provided that they are not spaced more than approximately 30 ms (depending on level difference). This effect has been named the "Law of the First Wavefront" or precedence-effect, and has lead some observers to believe [5], that early reflections do no influence the perceived image and that only later reflections are harmful. However, examining the literature (e.g. [6] p. 180, [7] p. 82) one discovers that a number of different perceptions exist that depend upon level, delay and direction of the reflection. For example, reflections in the sub 1 ms range can spatially pull the perceived image in their direction. Also, it should be noted that most reflections are frequency dependent so these spatial shifts are also frequency dependent, which implies sub 1 ms reflections can distort the outline of an image for all but the smallest bandwidth sounds.

For delays in the 1 ms to 5 ms range a broadening of the perceived image results sometimes also in conjunction with a shift of the image from the source towards the reflection. It should be noted that the absolute perceptual limit for reflections is about -30 dB referenced to the source level. Reflections with longer delays than 5 ms but shorter than about 30 ms to 80 ms do not detract from our ability to localize sounds but are perceived as an increase in spaciousness [7], especially if laterally distributed. An increase in spaciousness is often accepted as worthwhile in stereo reproduction [8] because of the restricted angular coverage of stereo, this is especially true for purist recording techniques which produce convincing phantom images [9]. Reflections with delays longer than 80 ms are perceived as echoes so they should be avoided by appropriate design of the room and its interior. It should be clear therefore, that any loudspeaker layout optimised for best phantom image reproduction should minimize the number of early reflections below 5 ms and should maximise the level difference between the loudspeaker signal and these reflections.

2 PROPOSED LOUDSPEAKER LAYOUT

Figure 1. shows the starting point of the recommended layout. In a normally shaped listening room the loudspeakers are placed

near the foci of an ellipse that just fits within the room boundaries (this is an oversimplified model, as it will fail in quadratic rooms). The listening position is located close to one of the longer walls of the room midway between the loudspeakers, the distance being typically 0.4 m to 1 m depending on room size. To reduce those room modes which are maximally exited for loudspeakers placed at the midpoint between two walls, the loudspeakers are either moved a little in a direction towards the listener if the subtended angle between them and the listener is below 60° or alternatively, a little in the opposite direction. The resulting subtended angle should be in the 70° to 90° range. In a companion paper [10] it is shown that the centre image (considered to be the weakest part of a two loudspeaker stereo sound stage) in a 74°/low reflection-layout can be more stable than the two thirds off centre image of a 60°/high-reflection layout.

2.1 Influence of listener-loudspeaker distance

The loudspeaker listener distance has a major influence on phantom image recreation. First of all it defines the delay of the first reflection from the ground (see Figure 2). With the listener's ears at a height h1 listening to the sound source at a distance d and a height h2, the delay Δt of the reflection caused by the ground is,

$$\Delta t = \frac{1}{c} * \left(\sqrt{d^2+(h_1+h_2)^2} - \sqrt{d^2+(h_1-h_2)^2} \right) \qquad (1),$$

where c m/s is the speed of sound. The function is a monotonic function of d and has a maximum at d = 0. Consequently, the shorter the distance between loudspeakers and listener the longer is the delay of the ground reflection, similar reasoning applies to the ceiling reflection. Another advantage of a short distance is the increase in direct sound pressure level.

2.2 Comparative survey of different layouts

The impulse responses of some popular loudspeaker layouts have been measured in an empty room of 5.78 m by 3.96 m by 2.4 m, where Figure 3 shows the different positions of the loudspeakers and the measuring microphone used. In Figures 4 to 6 the resulting impulse responses of the first 5 ms are shown where it can be observed that there are many time-smeared reflections for layouts A and B. This is attributed to the obtuse angle under which they are reflected before reaching the microphone. A smearing in the time domain will also cause a smearing in the frequency domain, leading to frequency dependent phantom images. In our proposed set-up only three reflections are observable and these closely resemble the initial transient. Also, it should be noted that the first of these reflections comes from the wall directly behind the listening position, where it is believed from experience that this reflection is not so objectionable for phantom image perception. The advantages obtained by damping or by moving loudspeakers and listening position by the same margin into the room are rather subtle, and do not outweigh the gain in bass reproduction by close-boundary listening. Figure 7 demonstrates the extent the remaining reflections can be attenuated by using 1 m by 0.5 m sheets of 10 cm thick knob formation foam mounted flat on the reflecting surfaces.

2.3 Micro placement of loudspeakers

The nature of this arrangement is that it is critical upon equi-distant listening position and equi-angled loudspeakers. For a subtended loudspeaker angle of 80° for instance a central image will shift 1° per 25 μs of time delay in one channel ([6], page 179, Figure 133). This means that with the resolution of human hearing at about 1.4° a misplacement of one loudspeaker by 12mm will be noticeable. Two methods have proved useful in achieving what we call "micro placement".

2.3.1 Micro placement by ear

When the correct approximate position for the loudspeakers has been found, one listens to monophonic music of wide bandwidth from the intended listening position. When the phantom image of the music is to one side at all frequencies, the loudspeaker on this side has to be moved further away by small increments until the main part of the music is perceived from the centre. When the high frequency part of the music is more to one side, either the loudspeaker on this side should be "toed out" or the loudspeaker of the other side should be "toed in", again by small increments. Both steps should be repeated until a firm centre image is reached at all frequencies.

2.3.2 Micro placement by measurement

For this method a microphone is placed at the centre location normally occupied by the listener's head. Measuring the impulse response of both loudspeakers in parallel a difference in distance can be observed as a double pulse (see Figure 8). Next, the position of one speaker is changed until only one pulse is observable. Now one speaker is wired "out of phase" and the angle of this speaker is changed until the suppression of the pulse is maximised. Figure 9 shows for comparison, two example sum and difference signals of two optimally positioned loudspeakers.

3 LOUDSPEAKER REQUIREMENTS

Not every loudspeaker works equally well in a this set-up. A level difference of 0.5 dB between the two loudspeakers of a stereo pair can shift an image 1° (interpolated from [6] p. 164, figure 123), so level matching within a range of ± 0.5 dB should be mandatory. The loudspeaker should also be designed for low cabinet edge diffraction, as diffraction also causes secondary wave radiation (see for instance [11]) which compromises stereo focus. Further, the design axis of the loudspeaker where frequency and impulse response are optimum should point in a direction towards the listener, a minimum requirement for any competent loudspeaker design, although not always met. Finally, the distance where the soundfields of all drivers merge should not be too far away from the loudspeaker.

4 CONCLUSION

A loudspeaker set-up has been shown which consistently gives excellent results in phantom image reproduction. Although this layout has evolved over several years of subjective experience, its advantages can be related to well proven psychoacoustic knowledge and also backed up by measurements. It is the aim of this paper to encourage people concerned with three-dimensional audio reproduction to experiment in the direction described in this paper. It is only then that the true potential of two-channel, two loudspeaker stereo can be correctly assessed.

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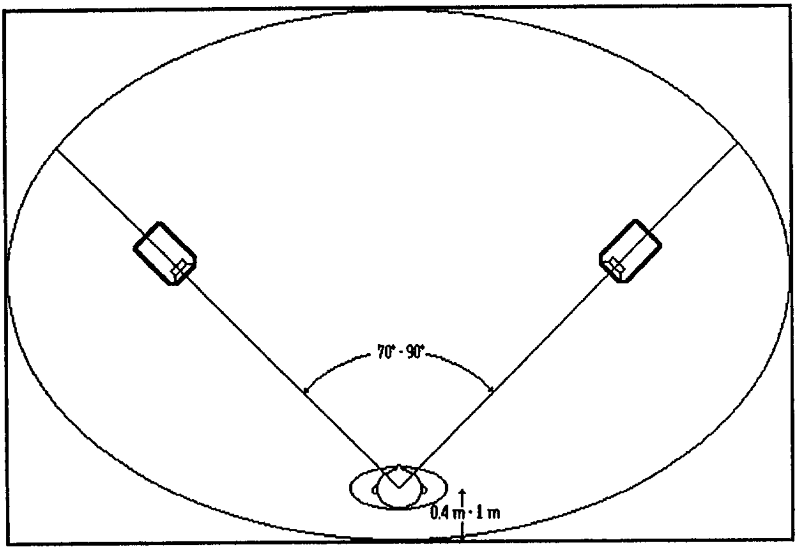

Figure 1. Sketch of the recommended layout.

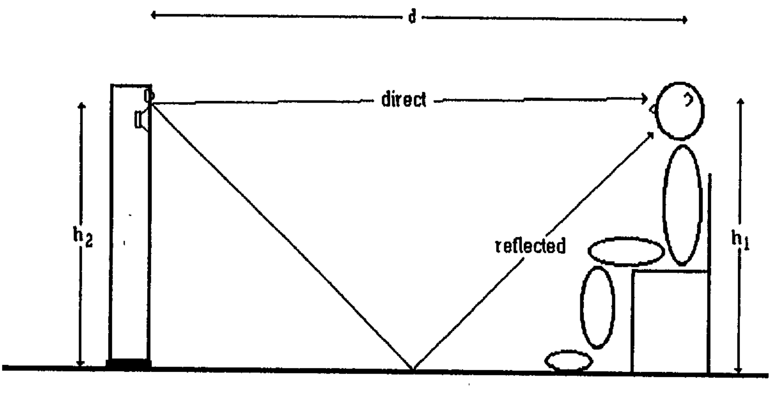

Figure 2. Ground reflection.

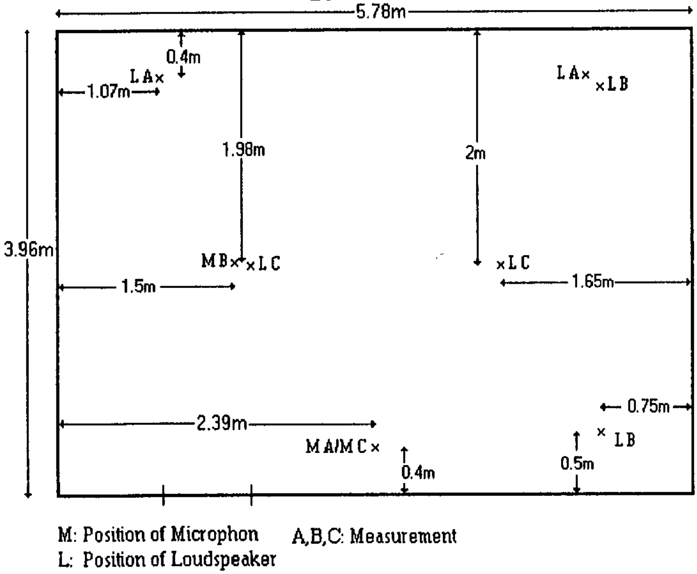

Figure 3. Positions of loudspeakers and microphone for measuring impulse responses.

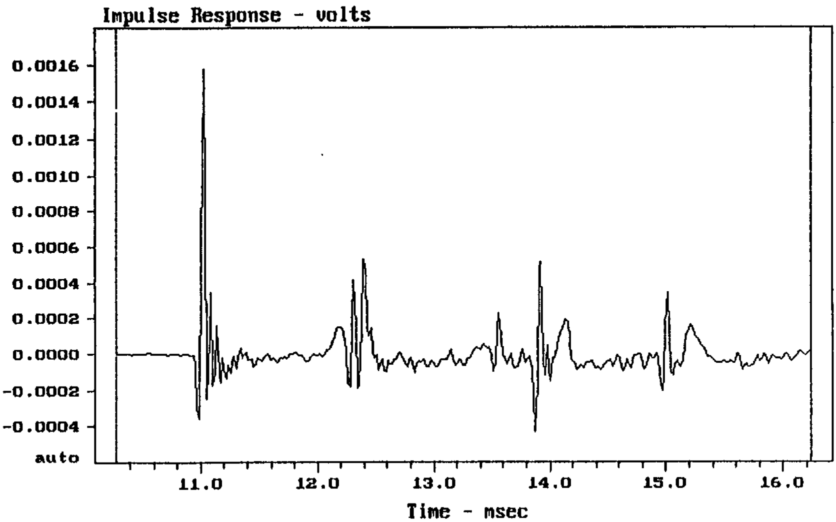

Figure 4. Impulse response for loudspeakers and microphone in position A.

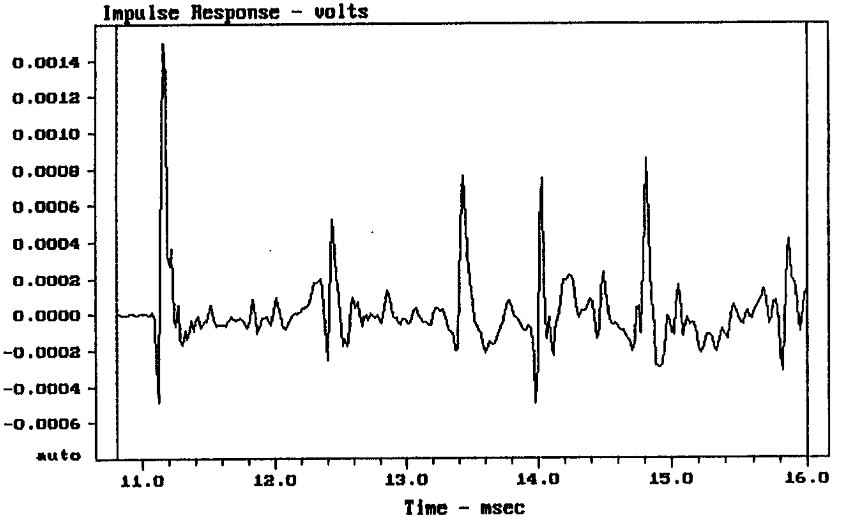

Figure 5. Impulse response for loudspeakers and microphone in position B.

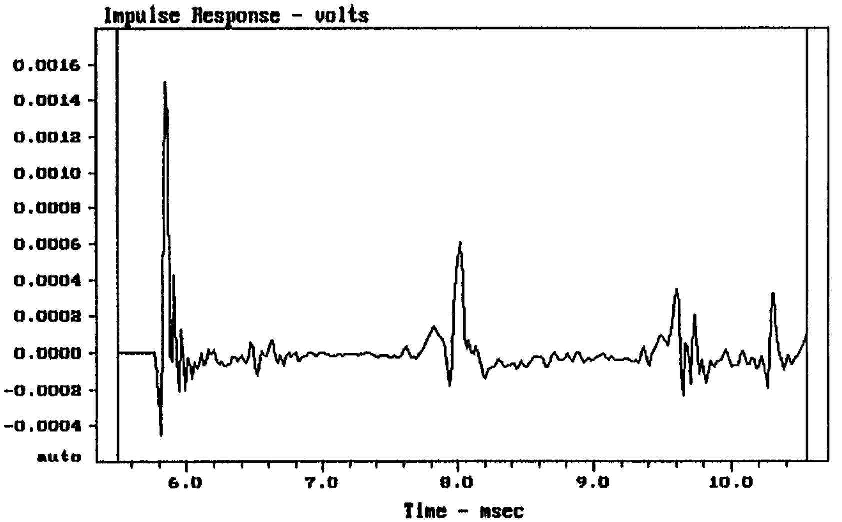

Figure 6. Impulse response for loudspeakers and microphone in position C, the recommended placement.

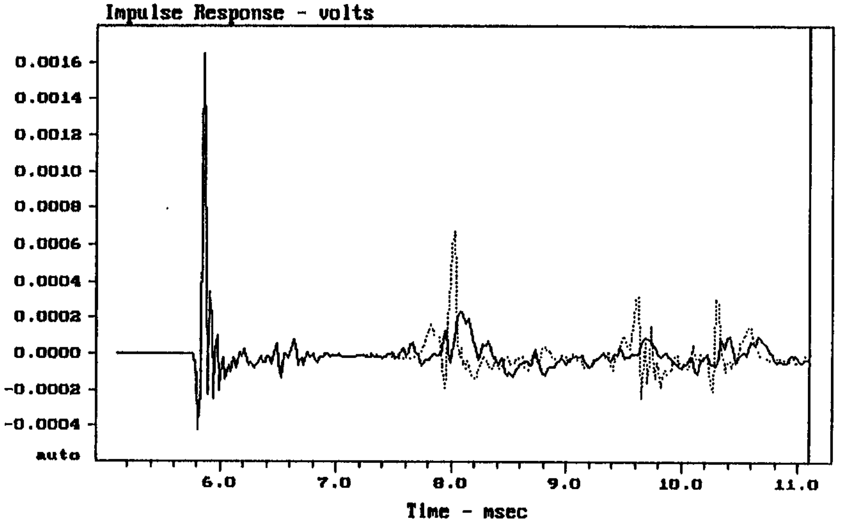

Figure 7. The influence of small amounts of damping on the remaining reflections.

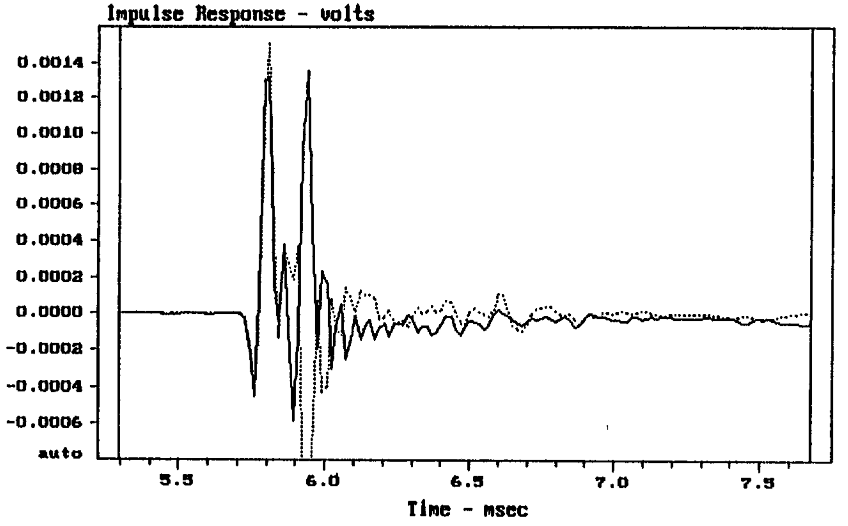

Figure 8. Sum- and difference impulse response with one loud-speaker 5cm off its optimal position.

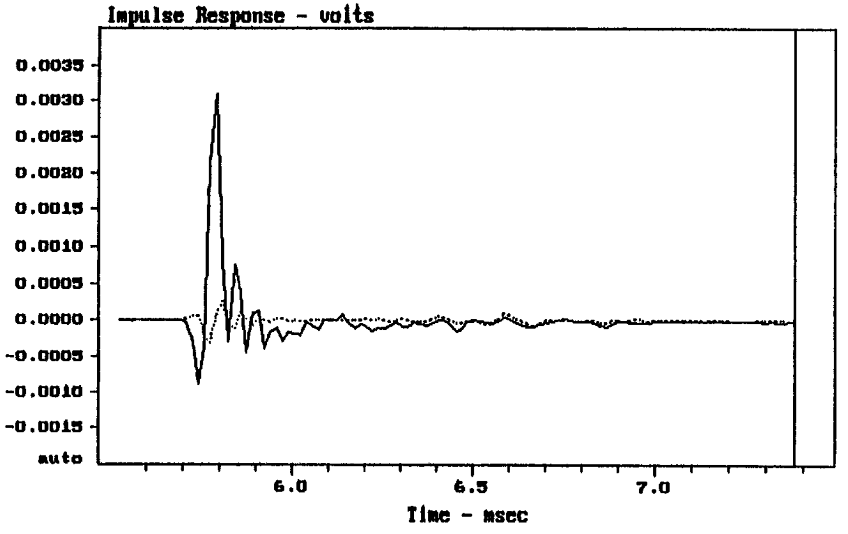

Figure 9. Sum- and difference impulse response after "micro placement".