Carlsson Ortho- Acoustic Loudspeakers: Design and Performance Principles

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Foreword

The main purpose of this booklet is to present the scientific basis of Carlsson Ortho-Acoustic Loudspeakers. An additional purpose is to help the interested listener to understand how conventional loudspeaker technology has influenced the quality of recordings.

This is a condensed version of the message:

The sound reflected off the boundary surfaces of the domestic listening room severely degrades the stated frequency response as well as the transient response of all conventional loudspeakers.

The discrepancy between the stated and the real performance of conventional loudspeakers is the main cause of tonal imbalances in reproduction, and the prime reason why music is often recorded with a faulty tonal or instrumental balance, and why recordings usually lack the timbral qualities of live music.

Carlsson Ortho-Acoustic Loudspeakers are designed to make the sound that is reflected off the boundary surfaces of the listening room enhances the quality of reproduction instead of degrading it.

The frequency response performance of Carlsson Ortho-Acoustic Loudspeakers in a normal listening room is more well-defined than that of any other loudspeaker, and this allows Carlsson Ortho- Acoustic Loudspeakers to be designed to have a virtually flat frequency response curve under normal listening conditions.

Carlsson Ortho-Acoustic Loudspeakers keep the sound that is reflected off the wall behind the loudspeakers from interfering with the direct sound. The wall virtually disappears to reveal the acoustic space of the performance and to create the impression of an extended listening space. Moreover, Carlsson Ortho-Acoustic Loudspeakers allow the listener to enjoy a musically and spatially informative stereophonic reproduction throughout a surprisingly large part of the listening room, affording a wide choice of listening acoustics.

The performance of Conventional Loudspeakers in Normal Domestic Listening Rooms

Even the very best conventional loudspeakers are designed for optimal performance in an anechoic environment. Their frequency response and transient response are measured and perfected under free-field conditions. As a result, their performance in normal listening rooms only conforms to the specification during the first 1/1000 or 1/500 of a second of each sound, before the sound reflected off the boundary surfaces of the listening room begins to interfere with the direct sound from the loudspeakers.
To reduce the influence of the listening room, conventional technology recommends that loudspeakers and listeners be positioned far away from walls, floor, and ceiling. However, when the frequency response is specified, no listening room effects are included, and yet their influence on sound quality is considerable.

In music as well as speech, any sound consists of a number of transient sounds: sounds that start and change and come to an end, all of which can be described as changes of sound.
Any change of sound in a room is actually a rapid succession of changes. The change in the direct sound from source to listener arrives first and is followed by the corresponding changes in the sound reflected off the boundary surfaces of the room. The direct sound of a good loudspeaker may approach a flat frequency response curve, but each of the reflected soundwaves is coloured according to the frequency response of the loudspeaker in the direction in which it was radiated. In the case of conventional loudspeakers, even an initially almost flat frequency response curve will

rapidly switch to an irregular curve having the bass boosted and the treble attenuated. The resulting tonal imbalance amounts to some 5 or 10 dB with details varying according to the design of the loudspeaker and the relative positions of loudspeakers and listener in the room.

This great discrepancy between stated and real performance is not found anywhere else in the audio chain. The reasons for stating the performance of loudspeakers without including the effects of the listening room are mainly historical. Basic acoustic measurements have always been performed under free-field conditions, often in an anechoic chamber, and such measurements are still required to investigate the initial or direct sound from a loudspeaker. Furthermore, many engineers regard any reflected sound from the listening environment as a distortion which should only be minimised. Yet a living room with acoustic properties that serve live sounds to good advantage is unlikely to minimise this 'distortion'.

How Conventional Loudspeakers Have Influenced Recordings

When starting stereophonic recording around 1955, many of the major recording companies were enthusiastic for the opportunity to reproduce the acoustics of a musical performance. Listeners having stereophonic recordings more than 25 years old have noticed that some of these records, when reproduced by present day equipment of high quality reveal an unusually rich, spacious, and airy quality. This acoustic richness of ten surprises a listener accustomed to the lack of this quality in more recent recordings made after the recording industry had adapted itself to the limitations of stereophonic record production, consumer playback equipment, and conventional loudspeakers.

The shortcomings of conventional loudspeakers, due to the discrepancy between their stated and their real performance, share responsibility for the slow progress, or even regression, in same aspects of stereophonic recording. Many recordings are made to suit a particular type of conventional loudspeaker which the recording company believes to be representative of listener systems. Instead of having a natural instrumental and acoustic balance and a flat frequency response, these recordings are balanced to compensate for the deficiencies of that particular type of loudspeaker.

The dull tonal balance of conventional loudspeakers in a normal listening environment discredits recording procedures capable of capturing the richness, colour, and flavour of live music.
It produces a general need to engineer a compensatory, penetrating brightness in recordings in order to emphasise treble sounds and/or suppress bass sounds. Some of the means employed can be compensated for in playback, and are therefore less harmful, but others cannot. A simple treble boost and/or bass attenuation may be harmless, because a correctly designed tone-control circuit can restore the original balance. However, other means are irreversible. They include microphone placement close to the individual sound sources, and other acoustic re-arrangements to make the various parts sharply distinct and separate from one another, even when the original sound was intended to be richly rounded and blended.

Recordings having a more natural timbral and instrumental balance have mostly come from small, specialist companies. The last ten years have seen several recordings aiming at a flat frequency response, and demonstrating an intent to include a natural acoustic ambience. The recordings by Mark Levinson and many of the records from Reference Recordings, as well as direct-to-disc productions by Crystal Clear and Miller & Kreisel RealTime, are valuable as reference recordings with respect to tonal balance.
In Mark Levinsons recordings, two Bruel & Kjaer type 4133 free-field measuring microphones were used, capturing the direct sound and part of the reflected sound with a flat frequency response. But most of the reflected sound is likely to arrive off-axis at the microphones to such an extent that its highest treble will be somewhat attenuated, causing a loss of airiness.
Many small record companies primarily serving music connoisseurs rather than audio specialists

also appear to be recording with a virtually flat frequency response and with an intent to present a natural acoustic ambience. Some of these companies produce excellent recordings which may be used as secondary references for tonal balance.

Can Recordings Capture the Timbral Qualities of Live Music?

Improvements in the general quality of recording equipment during the last 30 years have primarily been of advantage to acoustically uncomplicated popular music recorded with the microphones close to each instrument. In these recordings, the sound reflected by the acoustic environment is often reduced to a minimum, and sometimes it is replaced by a synthetic background.

In music using unamplified instruments - whether orchestral, chamber, instrumental, or vocal music - the sound reflected off the boundary surfaces of the performance hall is likely to be essential for the tonal qualities created by the musicians. Failing this reflected sound or a suitable timing of it, much of the richness and the inherent timbral qualities of the individual instruments, as known and appreciated from live performances, will be lost. The shortcomings of conventional loudspeakers, and a lack of understanding of musical acoustics and psychoacoustics, may share responsibility for the fact that these kinds of music usually fare less well in recordings.

Listening to live music in a good hall, the audience first receives direct sound from the various instruments, followed by a large number of different arrivals of reflected sound from various directions of the hall. The early arrivals of reflected sound enrich the timbral quality of the individual instruments, give lustre and body to the tone, and increase the perceivability of the sound, while the late arrivals form the reverberation of the hall. The early arrivals of reflected sound consist of sound that has travelled from about one to ten or fifteen meters longer distance than the direct sound. Unlike reverberation, they are not heard as a separate entity.

Each of the various arrivals of sound from an instrument conveys its own spectral representation of the sound of the instrument. Together the various arrivals may be said to scan the directional characteristics of the instrument. The timbral enrichment produced by this plurality of arrivals is influenced by the relative strengths and arrival times and spectral contents of the individual arrivals, and also by their directions of arrival at the listener. If a recording of various instruments did not include the early arrivals of reflected sound essential to the timbral qualities of the individual instruments, the original timbral qualities will be lost forever. No other delayed sound, such as that of a reverberation system, can recover them.

Most recordings lack the timbral enrichment produced by the early arrivals of reflected sound because too little reflected sound is captured by the microphones within the short time span in which timbral enrichment can occur. The positions of instruments and microphones in the recording venue, and the directional characteristics of the microphones, are seldom chosen to allow this part of the reflected sound to be captured strongly enough and in time. On the contrary, the early reflected sound is often avoided by recording technicians.

Differences in recording techniques will be more obvious the higher the quality of the playback equipment. Good loudspeakers will demonstrate the timbral superiority of recordings that include the early reflected sound of the recording hall. The enrichment produced by this part of the reflected sound needs to be more widely known, but the technical means to methodically include it in recordings are already available.

As soon as the shortcomings of conventional loudspeakers are no longer allowed to delay progress in recording, there are no technical reasons why recordings should not capture the timbral qualities of live music.

An Introduction to Carlsson Ortho-Acoustic Loudspeakers

Consider a quite normal living room - four walls, a floor, a ceiling and soft as well as hard furnishings - which has the usual combination of reflecting and absorbing surfaces that gives a pleasant sound to live voices and instruments.

Imagine a loudspeaker which is wall-mounted or floor standing near a wall. Any loudspeaker has its transient and frequency responses modified by the sound reflected off the wall and the floor. This usually boosts the low bass but causes interferences in the upper bass and in the midrange, resulting in a loss of bass and midrange definition. Imagine the loudspeaker being designed to avoid interferences due to reflected sound from the wall. And imagine this loudspeaker being carefully designed to make the direct sound from the combination of loudspeaker and wall have virtually accurate transient response and virtually flat frequency response.

After the arrival of the direct sound, the listener receives a great number of reflected sound waves from the room boundaries. With a loudspeaker of normal type, the spectral balance of the reflected sound differs from that of the direct sound because most of the reflected sound originates from directions in which the loudspeaker has an inferior frequency response, with a darker tonal balance. Imagine the directivity patterns of the drive units being arranged in such away that the reflected sound from the room boundaries will have substantially the same spectral balance as the direct sound from the loudspeaker/wall combination. The loudspeaker can now reproduce the body, openness, and airiness of live sounds.

With conventional loudspeakers musical as well as stereophonic information is often focused to a very restricted listening area equidistant from the two loudspeakers. Imagine the directivity patterns and orientations of the drive units being arranged to allow the listener to enjoy a musically informative stereophonic reproduction throughout a large part of the listening room.

Frequency Response and Subjective Loudspeaker Evaluation

Carlsson Ortho-Acoustic Loudspeakers are likely to have a more accurately flat frequency response performance in actual use than any other loudspeaker. There are three reasons to prefer their virtually flat frequency response performance to the largely unknown frequency response performances of other loudspeakers:

1. When both the direct and the reflected sound in the listening environment have a virtually flat frequency response, the resulting response is more likely to be smooth than if one has a flat response, and the other an irregular response.
2. A good tone control unit is easier to design and use if its sole function is to compensate for the tonal imbalances of the individual recordings without also having to compensate for the tonal imbalance of a particular type of loudspeaker.
3. Loudspeakers having a flat frequency response can reproduce any recording having a flat frequency response and a natural timbral and instrumental balance with all of its richness and colours intact without the use of tone controls.

Unfortunately, to find out which loudspeaker has a flat and smooth frequency response performance and an accurate tonal balance in actual use is more difficult than to verify a flat frequency response in any other audio component. A technically accurate loudspeaker evaluation is practically impossible for all but a few professionals. No single response measurement covers the complex frequency response performance of a loudspeaker in a real listening environment.

Subjective loudspeaker evaluations can easily be compromised by unsuitable listening rooms and recordings. Music listeners are likely to find most audio demonstration rooms acoustically unsatisfactory in comparison with normal living rooms. And superior loudspeakers will of ten reveal a lack of richness in recordings used to demonstrate inferior playback equipment.

A valid listening test requires recordings of voices and instruments that are well-known to the listener, and the microphones used in the recordings should have a flat frequency response in all directions of relevant sound reception and should be positioned to capture a sound with which the listener is familiar. Even professionals and reviewers testing loudspeakers usually lack such a reference for examining frequency response and tonal balance. Sometimes their opinions are based on anechoic response measurements, but most often the reports refer to recordings which are subjectively accepted as a reference.
A recording usually attains reference status because it sounds right and informative when reproduced through loudspeakers similarly accepted as a kind of reference. This cycle of identifying reference loudspeakers and reference recordings invites old shortcomings and misconceptions to perpetuate themselves.
Although a flat frequency response is a flat frequency response everywhere, reference loudspeakers and reference recordings differ markedly from one country to another. Most of these local differences in the tonal balance of the references are explained by the use of different reference loudspeakers in combination with different equalisations in the recordings to compensate for the inherent shortcomings of the reference loudspeakers.

A reviewer who has not read this presentation is likely to report that Carlsson Ortho-Acoustic Loudspeakers have a boosted treble and/or insufficient bass. He will perhaps refer to the fact that little is known about how the tonal balance of the first arrival of sound and the tonal balance of the later arrivals of sound actually combine, and state that investigations show the first arrival of sound to be of greatest importance. However, in this case any uncertainty as to the relative influence of the first and the later arrivals of sound on the perceived tonal balance is largely eliminated. The frequency response of the direct sound from the combination of a Carlsson Ortho-Acoustic Loudspeaker and a room wall and the frequency response of the sound as reflected off the remaining boundary surfaces of a normal listening room are rendered practically equal.

How Carlsson Ortho-Acoustic Loudspeakers Control the Influence of the Listening Room

The specified performance of a conventional loudspeaker is based on response measurements under free-field conditions only, and it refers only to the direct sound in frontal directions. The sound radiated off-axis, which has a much inferior tonal balance, is reflected off the walls, floor, and ceiling of the listening room, and degrades the quality of the transfer. Is this degradation a fault of the loudspeaker, or is it a fault of the listening room?

Human hearing actually benefits from the acoustic properties of the domestic environment. The size of a normal living room and the usual combination of soft and hard furnishings are advantageous because they allow the listener to extract a maximum of details from the sound. The reason is that the reflected sound reiterates the information conveyed by the direct sound, and aural perception benefits from a suitable amount of repetition. In a well-furnished living room the reverberant energy is dissipated rapidly enough not to mask any subsequent information. Most of the reflected sound will then arrive early enough to enhance the quality of the direct sound and increase the perceivability of the sound.

Consequently, normal domestic living rooms often provide excellent acoustic environments for listening to music, whether live or reproduced. Human hearing prefers this type of environment to the anechoic type. The main limitations of the domestic listening environment are found in the bass range, in which the wavelength of sound is of the same order as the dimensions of the listening room. The domestic listening environment may also seem lacking in acoustic space when compared with a concert hall. These limitations are caused by the small size of domestic rooms compared with concert halls. But this small size also results in superior midrange and treble perceivability.

All musical instruments have their own characteristic directivity patterns which contribute to their individual timbral qualities in a room or hall. Loudspeakers are intended to reproduce all kinds of instruments and should therefore have no such qualities of their own. Conventional loudspeakers are designed to be used with their drive units facing the listener. The best of them having virtually flat frequency response on-axis. In all other directions they produce a darker and more irregular spectral balance because, inherently, they are largely omnidirectional at low frequencies and more directional at higher frequencies. By means of its reflected sound the listening room changes the spectral balance of the loudspeaker in a few milliseconds from that of the on-axis response to that of a kind of mean spherical response. This rapid change in spectral balance is a coloration characteristic of the loudspeaker not seen in the anechoic response measurements.

The listening room also changes the bass quality of any sound source in the room and boosts the lowest bass. This coloration is a characteristic of the room and of both source and listener positioning in the room. How the performance of a loudspeaker will be affected cannot be seen from anechoic measurements.

There are two ways, conceptually opposite to try to avoid these colourations. One is to accept that conventional loudspeakers are designed with little attention to the influence of the listening room, and modify the listening room to make parts of it approximate an anechoic environment. This requires extensive arrangements of sound absorbing materials. The other is to accept the domestic listening environment that serves most live sounds to such good advantage and create loudspeakers capable of preventing the sound reflected off the boundary surfaces of the listening room from degrading the quality of the reproduction.

These two ways give very dissimilar perceptual results because human hearing is quite sensitive to its acoustic environment. Despite its small size, the domestic living room comes closer to the acoustic character of a music room or a concert hall than does an anechoic environment.

Carlsson Ortho-Acoustic Loudspeakers are engineered to allow the listener to take full advantage of the intrinsic acoustic merits of the domestic listening room. Within their pioneering shape they have the means to govern, in different ways, the quality of the sound reflected off a nearby wall behind each loudspeaker as well as the quality of the sound that will be reflected off the remaining walls and the ceiling. The Achievement is best described in two parts:

1. Carlsson Ortho Acoustic Loudspeakers are designed to operate with their backs close to a wall. In this position they neutralise the acoustic effects of the wall. The wall virtually disappears and opens the listening room into the recording venue, creating the impression of an extended acoustic space. (The acoustic technique for neutralising the effects of the wall is given a separate presentation.)
2. Characteristic differences between direct and reflected sound are avoided. The direct sound from the combination of loudspeaker and wall has a virtually flat frequency response, and so has the sound reflected by the listening room. This is achieved by means of a unique sloping panel on which carefully selected drive units are mounted to face a point well above the central listening area, and above the listener's ears.

The result is clear, solid reproduction of each individual instrument within the spatial topology of the recording. The sound is liberated from 'room' colourations and other clues that remind you of loudspeakers and listening room rather than of the true sound of a live performance in a suitable environment.

Carlsson Ortho-Acoustic Loudspeakers can in some respects actually outperform the sound of live instruments in a domestic environment because they are less affected by the acoustic limitations of a small room than are the musical instruments themselves. They avoid interferences from nearby room boundaries in a way live sound sources cannot.

How Carlsson Ortho-Acoustic Loudspeakers Neutralise the Acoustic Effects of a Room Wall

Any sound source positioned adjacent to a room wall will have its tonal balance and its transients altered by the sound reflected off the wall. However, loudspeakers have a unique advantage over other sound sources because they can be designed to neutralise the acoustic effects of the wall behind them.
To understand the acoustic effects of an adjacent wall, imagine a box-type loudspeaker placed in front of a wall. A listener will receive a reflected soundwave from the wall a few milliseconds after the direct sound. At very low frequencies, the wavelength of sound is long enough to make the reflected soundwave arrive almost in phase with the direct sound, and the reflected sound causes an increase in sound level by about 5 dB. The higher the frequency, however, the shorter the wavelength. The difference in path lengths between the reflected and the direct soundwaves gradually introduces a phase lag into the reflected sound. The greater the phase lag, the smaller is the increase in sound level caused by the reflected sound. At a frequency which corresponds to a wavelength 6 times the difference in path lengths, this increase in sound level still amounts to about 4 dB. Less than one octave higher, when the wavelength slightly exceeds 3 times the difference in path lengths, the reflected sound ceases to add to the sound level. This happens at some frequency between 100 and 300 Hz, depending on the size of the loudspeaker.

This frequency is a kind of transition frequency. The increased efficiency of the loudspeaker below the transition frequency may be used to good advantage. Above the transition frequency, the reflected sound interferes with the direct sound. Throughout the frequency interval of a full octave in which the wavelength varies from 3 to 1.5 times the difference in path lengths, the reflected sound cancels part of the direct sound. The frequency response curve will show a dip at the frequency which corresponds to a wavelength twice the difference in path lengths, and a peak will follow at twice that frequency. The difference in sound level between the peak and the dip of ten reaches the order of 10 or 20 dB! Dips may recur at 3, 5, 7, etc. times the frequency of the first dip, and peaks may recur at 4, 6t 8t etc. times the same frequency.

The reflected soundwave has a characteristic influence on the transient response of the loudspeaker. Each sound will be started by the direct sound only and will then be changed by the arrival of the reflected soundwave from almost the same direction. No frequency-domain equalisers can compensate for these effects; thus, many loudspeaker manufacturers recommend their loudspeakers to be placed well away from the wall. (Not only box-type loudspeakers, but all types of loudspeakers have their performance degraded by the interference from a wall behind the loudspeaker. Open-panel, large-diaphragm loudspeakers, such as electrostatic loudspeakers, are actually still more sensitive to these interferences, because the rear radiation of these loudspeakers is 180 degrees out-of-phase with respect to the frontal radiation. The previous description applies, but reinforcement turns into cancellation, and cancellation turns into reinforcement; instead of being increased by 5 dB, the level of the low bass will be drastically reduced, of ten by more than 10 dB.)

When a Carlsson Ortho-Acoustic Loudspeaker operates with its back close to a room wall, the acoustic effects of the wall are neutralised in the following way:

1. The drive units are located at a comparatively short distance from the wall. The increase in efficiency caused by the wall will then cover most of the bass range, and the transition

frequency rises to at least 300 Hz.
2. The loudspeaker has an absorbent panel that covers a small part of the wall. The absorbent panel successfully reduces the amount of sound that is reflected off the wall at frequencies above the transition frequency. It thus keeps this reflected sound from interfering with the direct sound of the loudspeaker.
3. The frequency response curve of the loudspeaker is tailored to counterbalance the increase in efficiency caused by the wall at frequencies lower than the transition frequency. The combination of loudspeaker and wall thus achieves a virtually flat frequency response curve.

Floor-Standing Models of Carlsson Ortho-Acoustic Loudspeakers

Thus far, attention was focused on the combination of a loudspeaker and a single room wall. This combination was stated to have a virtually flat frequency response. Such a statement is accurate with respect to OA-51, the wall-mounted model of Carlsson Ortho-Acoustic Loudspeakers, but the still more advanced design of the floor-standing models requires a more complicated description. The original statement was made to contrast clearly the acoustic design principles of Carlsson Ortho-Acoustic Loudspeakers with conventional design principles aiming at a flat frequency response in an anechoic environment.

In domestic listening rooms, reflected soundwaves from most of the room boundaries are likely to arrive early enough to be almost in phase with the direct soundwave at very low frequencies. Each reflected soundwave adds to the level of the direct sound from the loudspeaker at frequencies which are low enough to make the wavelength of sound greater than 4 times the difference between the path length of the reflected soundwave and that of the direct soundwave. These early arrivals of reflected sound thus increase the efficiency of the loudspeaker at the very lowest frequencies. This increased efficiency has to be counterbalanced in the design of the loudspeaker, if the transfer from loudspeaker to listener is to maintain a flat response.

The first arrival of reflected sound from the floor usually has a similar effect to that of the first arrival of reflected sound from the wall behind the loudspeaker. Floor-standing models of Carlsson Ortho Acoustic Loudspeakers are designed to neutralise the acoustic effects of both floor and wall, but they do not include the sound absorbing means required to reduce or eliminate the interferences from the floor in the mid and upper midrange and in the treble. These sound absorbing means have to cover part of the floor and extend at a distance from each loudspeaker. It seems most suitable to use deep pile carpets or rugs for this purpose. Strategically positioned cushions can also be used.

The acoustic design of the floor-standing models can now be described as follows:
Floor-standing models of Carlsson Ortho-Acoustic Loudspeakers are designed to operate standing on the floor with their backs close to a wall. They will neutralise the acoustic effects of both floor and wall, provided the sound absorbing means as specified in the next paragraph are sufficient to avoid interferences from both. The frequency response of each loudspeaker is tailored to counterbalance the increase in bass and lower midrange efficiency caused by both floor and wall. When the above sound absorption requirement is met, the direct sound from the combination of loudspeaker, floor, and wall will have a virtually flat frequency response above 70 Hz. Below 70 Hz, the frequency response is also tailored to counterbalance the increase in efficiency caused by the remaining boundaries of a normal domestic listening room. Those parts of the sound reflected by the listening room which have a substantial phase lag with respect to the direct sound also have a virtually flat frequency response.

The absorbent panel featured on all Carlsson Ortho-Acoustic Loudspeakers reduces or eliminates interferences due to reflected midrange and treble sounds from the wall behind the loudspeaker. (The performance characteristics of the wall reflex absorbers are found in the technical specification.) To reduce interferences due to reflected midrange and treble sounds from the floor, it is recommended that the floor between the loudspeakers and the listener be covered with carpets, rugs, or cushions.

How Positioning Affects Clarity

Loudspeaker positioning influences the sound quality in more than one respect. We have already seen how nearby boundary surfaces affect the bass and midrange response of a loudspeaker. However, even in the finest domestic listening environments, and with careful design and positioning of the loudspeakers to reduce the position-dependent frequency response aberrations, an important quality of the reproduction still varies according to the positioning of both loudspeaker and listener: clarity. The clarity of the acoustic transmission from loudspeaker to listener is determined mainly by the ratio of direct to reflected sound at the listener's position. The clarity of the reproduction of the directional and ambient information conveyed by stereophonic recordings is also influenced by the time intervals between the arrival of the direct sound and the arrivals of the first reflected soundwaves from the various room boundaries.

The clarity related to the ratio of direct to reflected sound can be improved by increasing the level of the direct sound, or by reducing the level of the reflected sound. In this context, the term reflected sound will cover only those parts of the reflected sound which have a substantial phase lag with respect to the direct sound, while the term direct sound is extended to include any reflected sound that arrives closely enough in phase with the direct sound to add to the level of the direct sound.

Clarity can be improved by reducing the listener's distance to the loudspeakers. This increases the level of the direct sound, while the level of the reflected sound is largely independent of the listener's position in the room. Clarity can also be improved by increasing the amount of sound absorbing objects in the room, such as deep pile carpets and soft upholstered furniture. A familiar way to increase clarity is to select loudspeakers that are more directional, but the directivity of such loudspeakers varies with respect to frequency to such an extent that the direct sound and the reflected sound will have very dissimilar frequency response curves.

A means to increase clarity employed in Carlsson Ortho-Acoustic Loudspeakers is to make each loudspeaker combine with one or two room boundaries to render the reflected soundwaves from these room boundaries virtually in phase with the direct soundwave.
This method has the advantage of being fully effective even in the bass range in which domestic listening environments are less sound absorbent and loudspeakers are less directional than they are at higher frequencies. In the bass range, such a combination of a box-type loudspeaker and one, two, or three room boundaries increases the ratio of direct to reflected sound by 3, 6, or 9 dB, respectively, relative to that of a free-standing, box-type loudspeaker. These figures stand comparison with the 5 dB increase in the ratio of direct to reflected sound which is gained by substituting a free-standing, open-panel, large- diaphragm loudspeaker for a free-standing, box-type loudspeaker. All figures refer to the bass range and are based on the assumption that the listener's distance to the loudspeaker is fixed. When this distance is reduced by one half, the ratio of direct to reflected sound is augmented by 6 dB.

Loudspeaker positioning also affects the timing of the first arrivals of reflected sound from the various room boundaries. Normal domestic positioning of stereophonic loudspeakers causes reflected soundwaves from the room boundaries to arrive too early after the arrival of the direct soundwave. Within a short time span, beginning approximately 1.5 milliseconds and ending approximately 3.5 milliseconds after the arrival of the direct soundwave, reflected soundwaves from several of the following room boundaries are likely to arrive at the listener: from the floor, from the wall behind the loudspeaker, from the ceiling, from a side wall, and from the wall behind the listener. Besides causing an excessive bass boost below 100 Hz, such an early cluster of reflected soundwaves is likely to affect the listener's perception of the directional and ambient information conveyed by the recording.

In a normal domestic listening room, the reproduction of the directional and ambient information of a stereophonic recording is likely to have maximum clarity, if the first reflected soundwaves from as many as possible of the six room boundaries are suppressed in such away that they do not include components that interfere with the direct soundwave, and if the first arrivals of reflected sound from the remaining room boundaries are delayed as long as possible. This means that each loudspeaker should be positioned adjacent to as many room Boundaries as possible, provided the first reflected soundwaves from these room boundaries are suppressed by absorbent panels or by other means. It also means that the loudspeaker should be positioned at maximum distances from the remaining room boundaries.

The above suggests floor-standing loudspeakers in two corners of the listening room to be optimum for a seated listener, but this positioning usually makes the soundstage abnormally large. In most cases floor-standing loudspeakers positioned close to one of the longest walls of the room and at maximum distances from sidewalls is the best choice. Whenever floor-standing loudspeakers are unsuitable, the best alternative is wall-mounting the loudspeakers at or below ear height on one of the longest walls of the room, and at maximum distances from sidewalls. In each case the loudspeakers have to be combined with sound absorbing material to prevent adjacent boundary reflections from interfering with the direct sound from the loudspeakers.

A comparison of the positioning requirements for a maximum ratio of direct to reflected sound and for an optimum timing of the first arrivals of reflected sound will indicate that the two requirements coincide. However, to take advantage of positioning for maximum clarity, the loudspeakers have to be designed to neutralise the acoustic effects of the adjacent room boundaries. Carlsson Ortho-Acoustic Loudspeakers are designed to take full advantage of the acoustic merits of positioning the loudspeakers close to a long wall and far from side walls, the floor-standing models OA-50 and OA-52 allowing a maximum of acoustic clarity, and the wall-mounted model OA-51 being intended for the best alternative positioning. Floor-standing Carlsson Ortho-Acoustic Loudspeakers allow seated listeners in a domestic listening room of normal size to be practically free from interfering reflected sound until 5 milliseconds after the arrival of the direct soundwave. The first reflected soundwave from the floor arrives approximately 0.5 millisecond after the direct soundwave. It is intended to be suppressed by carpets or rugs. The first reflected soundwave from the wall behind the loudspeaker arrives slightly more than 1 millisecond after the direct soundwave. It is suppressed by the absorbent panel included. Reflected soundwaves from the remaining room boundaries will usually begin to arrive 5 milliseconds after the direct soundwave.

How Carlsson Ortho-Acoustic Loudspeakers Afford the Listener a Wide Choice of Listening Acoustics

Loudspeaker directivity varies with respect to frequency. This causes the frequency response and transient response of the direct sound from a pair of conventional stereo loudspeakers to vary from one listening position to another. The difference in tonal balance between direct and reflected sound also varies from one listening position to another. As a result, musical as well as stereophonic information is often focused to a very restricted listening area, limiting the choice of listening acoustics.

Carlsson Ortho-Acoustic Loudspeakers have very wide directivity patterns and a unique orientation of the drive units to make the frequency response and transient response of the direct sound from the combination of a loudspeaker and a room wall unusually uniform throughout a surprisingly large part of the listening room. The result is twofold: Any listening position in the room receives direct sound of high quality. And the sound reflected off the room boundaries has a tonal balance very similar to that of the direct sound.

Carlsson Ortho-Acoustic Loudspeakers afford the listener a new acoustic freedom in stereophonic listening. When liberated from unnatural directional effects and position-dependent variations in spectral balance, the listener is free to identify that distance from the loudspeakers which produces the preferred ratio of direct to reflected sound. Listeners are free to choose listening positions and listening acoustics to their own liking. The preferred listening acoustics may be different for different kinds of music. Carlsson Ortho-Acoustic Loudspeakers afford the listener a choice of listening acoustics which ranges from positions having a high ratio of direct to reflected sound at short distances from the loudspeakers to the more concert-like listening perspectives experienced at greater distances from the loudspeakers.

With less response aberrations and other acoustic anomalies from the loudspeakers, any unwanted system-characteristics inherent in stereo recording and reproduction will be more easily observed. One such system characteristic reduces the fidelity of the reproduction at listening positions equidistant from the two loudspeakers. These listening positions are of ten recommended because they allow the images to be precisely located, but they actually introduce a bass and midrange boost into the sound of all sound sources located in the central field of the soundstage. This boost skews not only timbres and levels within the soundstage, but also diminishes ambience, because any ambience of the central sound sources that appears in the side fields of the soundstage will not be boosted. (The boost amounts to 3 dB, and the loss of ambience may approach the same figure.) The superior timbral and spatial homogeneity to be experienced at off-centre listening positions is easily noted when auditioning a pair of Carlsson Ortho-Acoustic Loudspeakers.

The Vertical Imaging of Carlsson Ortho-Acoustic Loudspeakers

In recordings, any information capable of producing impressions of height, depth, or airiness is conveyed by delayed replicas of the sound to which the information refers. Usually this delayed sound consists of the first soundwaves reflected off the various boundary surfaces of the recording environment. To avoid masking spatial information in recordings, loudspeakers should produce no impressions of height, depth, or airiness of their own.

The listener's impression of the height of a sound source is primarily produced by the two soundwaves that are first to arrive: the direct soundwave from source to listener, and the first arrival of sound reflected off the floor. When the sound source is a loudspeaker, the height positions of the drive units produce their own impressions of height below which no impressions of height can be transferred to the listener. Recordings which include no delayed sound replicas will be reproduced with the height of the sound determined by the loudspeakers only.

When a recording includes sound that is reflected off the floor of the recording environment with a delay typical of floor reflections in real life, this reflected sound may produce an impression of height which rises higher than the impression of height produced by the loudspeaker. The lower the impression of height produced by the loudspeaker, the more the vertical images of recordings can be reproduced. If recordings lacking in spatial information are to be given a soundstage at ear height, the wall-mounted OA-51 may be the - preferred model of Carlsson Ortho-Acoustic Loudspeakers. However, with recordings that are rich in spatial information, the floor-standing models OA-50 and OA-52 are likely to be preferred. The impression of the wall behind a pair of Carlsson Ortho-Acoustic Loudspeakers disappearing comes only from the loudspeakers and up, and the floor-standing models will make most of the wall disappear to reveal the acoustic space of the performance.

Stig Carlsson – Designer of Carlsson Ortho-Acoustic Loudspeakers

Stig Carlsson has designed loudspeakers for more than three decades. None of them has been conventional; instead, Carlsson's designs were acoustically novel enough to justify international patent protection. The first Carlsson designs to reach audio markets outside Sweden we re the

Sonab loudspeakers of the early Seventies. Their marketing publicity provoked controversy among reviewers. But according to the April 1984, issue of a leading British audio publication, the Sonab loudspeakers "were uniquely different with their own special qualities".

Carlsson has never been part of the staff of a recording, manufacturing, or marketing company. For most of the period from 1948 to 1965, he served as head of the Electro-Acoustic Laboratory at the Royal Institute of Technology in Stockholm.
It’s measuring equipment and anechoic chamber facilities allowed him to investigate the technical performance of recording and reproducing equipment. He created new measuring methods, designed experimental loudspeakers, and arranged experimental recording sessions. In 1974, thanks to the royalties from Sonab, he moved into his own laboratory which he equipped with special measuring facilities for the creation of his new series of Ortho-Acoustic Loudspeakers.

Carlsson has always favoured a scientific approach to the art of sound recording and reproduction, although his primary goal is to recreate the sensuous beauty afforded by live music in a suitable acoustics. The scientific approach requires that the transfer have a flat frequency response - from the sound arriving at the recording microphone to the sound produced by the loudspeakers in the listening environment. Carlsson found that this requirement called for scientific knowledge in the selection of microphones for recordings as well as in the design, testing, and selection of loudspeakers. He discovered that the usual anechoic response measurements gave very little information about the tonal balance of a loudspeaker in actual use. Also he recognised that the early arrivals of reflected sound help to create much of the sensuous beauty experienced in music. Early arrivals of reflected sound in the performance hall are essential to the display of the inherent timbral and spatial qualities of musical instruments. Furthermore, reflected sound reaching the listener from various directions appears to be essential to the listener's experience of acoustic richness.

Carlsson used a single, omnidirectional microphone, whether recording a single instrument or a full symphony orchestra with choir and soloists, and his recordings preserved the original dynamics of the performance. The microphone of his choice was Swedish, had "a very smooth frequency response in all directions", and "was located at a point where direct sound, reflected sound, and reverberant sound combined to make timbre, balance, and reverberation satisfactory as judged by musicians and recording team jointly" (quotations from technical notes accompanying Carlsson's recordings on various Swedish labels during the years
1965 - 67). In their stereophonic recordings for Proprius, Håkan Sjögren and, later on, Bertil Alving employed a spaced pair of this type of microphone during the years 1969- 76. Thus, the microphone of Carlsson's choice was used in Alving's famous Cantate Domino and Kör. To achieve wide dynamic range and a tonal balance suitable for ordinary playback equipment, Carlsson's recordings had a 3 dB treble boost which was specified in the technical notes. Sjögren and Alving also employed this amount of treble boost or more even though it is not always specified.

Early Loudspeakers Designed to Co-operate with the Listening Room

Stig Carlsson began to investigate loudspeakers and the influence of the listening room upon their performance before stereo became a commercial reality. The second edition (1947) of Olson's Elements of Acoustical Engineering had just arrived, but Waterhouse's pioneering paper on the output of a sound source in reflecting environments (The Journal of the Acoustical Society of America, January, 1958) and Thiele's major work on bass reflex enclosures (first published in Australia, 1961) had yet to appear.

Carlsson filed his first two patent applications in 1953. One described a new range of design parameter values in bass reflex enclosures, resulting in smaller enclosures and an improved transient response. The other described a loudspeaker designed to co-operate with the adjacent

boundaries of the listening room. The loudspeaker had a cabinet in the shape of a truncated cone standing with its wide end near the floor and with the axis of the body tilted. The woofer was mounted in the bottom wall which was intended to be located at short distances from the floor and one or two walls. The midrange unit was mounted in the top wall to be distanced from all of these adjacent room boundaries. It was surrounded by four tweeters arranged to approximate the omnidirectional radiation of the German 'Kugelstrahler', a free-standing, professional loudspeaker. When Waterhouse's paper appeared, it offered a useful evidence of the value of the new positioning of the bass and midrange units in Carlsson's patent. Efficient arguments in favour of this loudspeaker were a freedom from point-source effects when the top of the loudspeaker was distanced from the wall behind it as intended, and an accurate bass reproduction when the bottom was located close to the wall.
Carlsson demonstrated a prototype of this loudspeaker in Sweden and England in 1954. Then he built a special acoustic chamber for the measurement of the frequency response of the total radiation of the loudspeaker as positioned in a corner of a room. The two opposite walls and the ceiling of this chamber were covered by absorbent material so as to be fully anechoic. The frequency response was measured by adding the radiation from 36 directions at 81 frequencies. The loudspeaker was designed to have this response flat within - 3 dB from 28 to 12,000 Hz as measured with sine tones. The commercial version, which was marketed in Sweden in 1959, had two transformers tube amplifiers built into the stand. The bass amplifier had negative internaloutput impedance and a special equalisation circuit with a three-position attenuator. This served to select a flat frequency response from the loudspeaker when the woofer was close to one, two, or three room boundaries.

Carlsson filed another patent application of historical interest in 1962. It described a loudspeaker line which Sonab was founded to market in 1966. These Loudspeakers had a rectangular cabinet, rather high and deep, but narrow. Its bass and midrange drivers were positioned close to the rear wall to be located close to the room wall behind the loudspeaker. The four tweeters were mounted crosswise to face each other, at a distance from each other, on the frontal part of the top wall, simulating omnidirectional radiation. The new position of the midrange unit reduced the interferences from the room wall, an effect that was demonstrated successfully to the Examiner of the U.S. Patent Office.

Other designers who have explored the loudspeaker/room interface are Amar Bose and Roy Allison. Bose's 'direct-reflecting' loudspeaker was described in his patent application filed in 1967. He stated that an 89 10 content of reflected sound in the listening room required that eight out of nine drive units radiate only by means of reflections off the room boundaries, thus leaving only one out of nine drive units to provide direct sound, but the scientific foundation of this statement appears not to have been published. Allison's first loudspeaker designed to optimise boundary augmentation so that the radiation angle is controlled and the acoustic power input to the room is constant with frequency' was presented in 1974.

A Comparison of Three Types of Frequency Response Performance

In previous loudspeakers designed to co-operate with the listening room, such as those from Sonab and Allison Acoustics, the specified frequency response curve referred to the total sound radiation of the loudspeaker into the listening room. This energy response is relevant to sounds of long duration, but it gives no information about the reproduction of the beginning of each sound. The transient response and frequency response during the first milliseconds of each sound from these loudspeakers were unsatisfactory because interferences throughout the midrange and the treble made the combination of loudspeaker and room wall have a very irregular response as measured in any single direction. This held true even when the sum of the responses in all directions was quite smooth. In fact, a measurement of the unsatisfactory early response gives little indication of the fine sound heard from some of these loudspeakers. These early loudspeakers designed to co-operate with the listening room thus have an inaccurate reproduction of the beginning of each sound, but the best of them tend to have an accurate frequency response during the main part of each sound, when the listener is receiving sound from a great number of directions. This accurate response is likely to be reached between 5 and 20 milliseconds after the arrival of the direct sound from the loudspeaker. In a normal-sized living room, the listener receives sound from approximately 60 different directions within 20 milliseconds from the arrival of the direct sound.

Conventional, forward-facing loudspeakers display the opposite order of good and bad. The best ones reproduce the first 1 or 2 milliseconds of each sound accurately, but when the reflected sound from the listening environment begins to arrive, the response starts changing into a darker, more irregular tonal balance. This change in tonal balance during the first 10 milliseconds of each sound is usually on the order of 10 dB.

Carlsson Ortho-Acoustic Loudspeakers make the choice between these unsatisfactory alternatives obsolete. They combine the accurate initial response of the best front-facing loudspeakers with the accurate main response of the best loudspeakers designed to co-operate with the listening room.

No single response measurement is capable of presenting the complex response performance of a loudspeaker in a real listening environment. Carlsson Ortho-Acoustic Loudspeakers are designed with close attention to three stages of frequency response:

1. The anechoic response in a free sound field, or the response of the direct sound from the loudspeaker only.
2. The anechoic response with the free sound field limited by the adjacent one or two room boundaries or the response of the direct sound from the combination of loudspeaker and adjacent room boundaries.
3. The semi-reverberant response in various listening rooms, or the response of the total sound when all paths from the loudspeaker to the listener are operating.

Technical Specifications

<table>
<tr><th>Technical Specification</th><th>OA-50</th><th>OA-52</th><th>OA-51</th></tr>
<tr><td>The drive units for the bass and midrange

Performance characteristics</td><td>Made exclusively for Carlsson. 165 mm steel chassis. Paper diaphragm.
Good midrange reproduction thanks to a small and well-made diaphragm.
Good bass reproduction is possible because the drive unit is designed for large cone excursions, and the17.5 mm long voice coil has a maximum movement of 9.5 mm with full magnetic flux.</td><td colspan="2">Made exclusively for Carlsson 177-mm chassis casts in magnesium alloy Voice coil of aluminium wire Paper diaphragm.

Good midrange reproduction thanks to a small and rigid diaphragm with good damping.
Good bass reproduction is possible because the drive unit is designed for very large cone excursions, and the18.5 mm long voice coil has a maximum movement of 12.5 mm with full magnetic flux. The reproduction is clean and has low intermodulation distortion and good resolution of stereophonic details thanks to a copper cylinder around the centre pole of the magnet (as per Ragnar Lian's patent).</td></tr>
<tr><td>The drive units for the treble

Performance characteristics</td><td colspan="3">A standard dome tweeter with a 25 mm dome made of specially processed textile.

Maintains a wide directional response even at the highest audio frequencies. Designed to provide a flat power response to 17000 Hz.</td></tr>
<tr><td rowspan="4">The Crossover network

Crossover characteristics</td><td>The woofer is connected direct.</td><td colspan="2">The woofer is connected in series with an air core inductor.</td></tr>
<tr><td colspan="3">The tweeter is shunted by an air core inductor and connected in series with a polypropylene capacitor</td></tr>
<tr><td>And a resistor and an automatic circuit breaker</td><td>-----</td><td>And a resistor</td></tr>
<tr><td colspan="3">The acoustic crossover from the bass and midrange unit to the treble unit is in the frequency range between 2500 and 3000 Hz. Filter components of high performance and close tolerances are used. The drive units are connected in-phase.</td></tr>
<tr><td>The Acoustic Co-ordination of the drive units</td><td colspan="3">The tweeter is mounted immediately above the woofer. The drive units have a common vertical symmetry plane and are displaced horizontally to provide a good impulse response.</td></tr>
<tr><td>The Orientation of the drive units.
Performance characteristics</td><td colspan="3">The speaker panel is sloping backwards and inwards to make the drive units face a point above and slightly in front of the regular stereo seat.
A musically informative stereophonic reproduction is available throughout a large part of the listening room. Above 500 Hz the frequency response of the direct sound approaches that of the total sound.</td></tr>
<tr><td rowspan="4">The Position of the drive units

Performance characteristics</td><td colspan="3">The speaker panel is located very close to the rear of the loudspeaker in order to allow the woofer to be positioned close to a room wall</td></tr>
<tr><td colspan="2">The front centre of the woofer will be 0.3 metre above a floor.</td><td>-------</td></tr>
<tr><td colspan="3">The bass range will have improved definition and impact because the interferences of the reflected sound from a room wall directly behind the loudspeaker are reduced.</td></tr>
<tr><td colspan="2">This close to a floor the upper bass and lower midrange will have improved definition and impact because the interferences of the reflected sound from the floor are reduced.
At the same time the reproduction of the early ambience from the recording hall is improved because the interval of time between the first arrival of reflected sound from the floor and the first arrivals of reflected sound from the ceiling is increased to a practical maximum.</td><td>-------</td></tr>
</table>

Technical Specification, continued	OA-50	OA-52	OA-51
Protective Cover	A removable wire mesh hood covers the upper half of the loudspeaker.	A removable wire mesh hood covers the upper half of the loudspeaker.	A removable foam grille covers the sloping speaker panel and can have a semi-permanent mounting by means of burr fasteners enclosed.
Type of Enclosure	20-dm3 bass reflex enclosure tuned to 30 Hz.	20-dm3 bass reflex enclosure tuned to 30 Hz.	16-dm3 bass reflex enclosure tuned to 38 Hz.
Performance Characteristics	This design renders even small drive units capable of having a good bass response with low distortion and good transient response.		
The Thickness and Material of the Enclosure Walls.	22 (and 16) mm particle board.	19 and 22 mm high-density hardboard (MDF).	16-mm high-density (birch) chipboard + veneer.
The Thickness and Material of the Speaker Panel.	30 mm high-density hardboard (MDF).	41 mm high-density hardboard (MDF).	As above.
Internal Bracing	One stay wall.	Six stay wall.	Battens and one stay wall.
Interior Sound Absorber	12 dm3 RockWool	12 dm3 RockWool	16 dm3 Glass-Wool
Exterior Sound Absorbers	A felt hood surrounding most of the treble unit. Panel of 0.7-dm3 glass-Wool with neoprene coating. Covers the horizontal wall in front in front of the drive units.	A felt collar surrounding most of the treble unit. Panel of 1.0 dm3 rockwool with textile coating. Covers the horizontal wall in front in front of the drive units.	---
Performance Characteristics	Eliminates interferences in the treble caused by diffraction at the edges of the speaker panel and by reflection at the horizontal wall respectively.		---
Wall Reflex Absorber	Panel of 1.3 dm3 glass wool with neoprene coating. Incorporated under the protective cover.	Panel of 2.8-dm3 rockwool with textile coating. Incorporated as an extension of the rear wall of the loudspeaker.	Panel of 3.1-dm3 rockwool in a plastic casing with a foam front. Screw mounted to the smaller side of the loudspeaker.
Performance Characteristics	Reduces the interferences of the reflected sound from a room wall directly behind the loudspeaker. Effective in the upper midrange and the treble.	Eliminates the interference of the reflected sound from a room wall directly behind the loudspeaker. Effective in the midrange and the treble.	Reduces the interferences of the reflected sound from a room wall directly behind the loudspeaker. Effective in the midrange.

Technical Data

<table>
<tr><th>Technical Data</th><th>OA-50</th><th>OA-52</th><th>OA-51</th></tr>
<tr><td rowspan="3">Frequency Range according to The Frequency Response Curve of the Direct Sound as measured in a frontal direction that forms a horizontal angle of 60° with respect to the back of the loudspeaker and an upward angle of 0° (OA-51) or 10° (OA-50 and OA-52). The measurement is made in a free sound field and using a sine tone.</td><td>28 - 20000 Hz.
Flat within ±3 dB
400 to 18000 Hz.</td><td>27 - 20000 Hz.
Flat within ±2 dB
400 to 17000 Hz.</td><td rowspan="3">32 - 20000 Hz.
Flat within ±2 dB 300 to 17000 Hz. The response below 300 Hz is attenuated to counterbalance the increase in efficiency caused by a reflecting wall directly behind the loudspeaker. Below 50 Hz the response is falling.
Relative to 100 Hz the response is 3 dB down at 42 Hz.</td></tr>
<tr><td colspan="2">The response below 400 Hz is attenuated to counterbalance the increase in efficiency caused by a reflecting wall and floor directly behind and under the loudspeaker. Below 70 Hz the response is falling smoothly to approximately counterbalance the increase caused by the other reflecting boundary surfaces of a normal living room.</td></tr>
<tr><td>Relative to 100 Hz the response is 8 dB down at 30 Hz.</td><td>Relative to 100 Hz the response is 7 dB down at 30 Hz.</td></tr>
<tr><td>The Frequency Response Curve of the Total Sound in a Normal Living Room
If deviations due to the standing Waves of the individual rooms are averaged out.</td><td>Flat within ± 3 dB from 30 to 18000 Hz when the loudspeaker is floor-standing close to one of the walls and far from other walls of the room.</td><td>Flat within ± 2 dB from 30 to 17000 Hz when the loudspeaker is floor-standing close to one of the walls and far from other walls of the room.</td><td>Flat within ± 2 dB from 40 to 17000 Hz when the loudspeaker is mounted on a wall far from the other room boundaries.</td></tr>
<tr><td>Total Harmonic Distortion at a nominal input of 5 W</td><td>Less than 0.9 % from 120 to 7000 Hz</td><td>Less than 0.4 % from 150 to 7000 Hz with the exception of occasional peaks at 1400 to 3000 Hz approaching 0.9 %.</td><td>Less than 0.4 % from 200 to 7000 Hz with the exception of occasional peaks at 1500 to 3000 Hz approaching 0.8 %.</td></tr>
<tr><td>Sensitivity (1W, 1m)</td><td>89 dB.</td><td>89 dB.</td><td>88 dB.</td></tr>
<tr><td>Impedance (5-100000 Hz)</td><td>8 Ohm Nominal and not less than 7 Ohm.</td><td>8 Ohm Nominal and not less than 7 Ohm.</td><td>8 Ohm Nominal and not less than 8 Ohm.</td></tr>
<tr><td rowspan="2">The Phase Angle of the Impedance (0-25000 Hz)</td><td>Less than 36°.</td><td>Less than 40°.</td><td>Less than 30°.</td></tr>
<tr><td>Less than 20° from 135 to 16000 Hz.</td><td>Less than 20° from 140 to Less than 13000 Hz.
Less than 12° from 180 to Less than 3200 Hz.</td><td></td></tr>
<tr><td>Power Handling Capacity</td><td>90 W</td><td>100 W undistorted music programme.</td><td>100 W undistorted music programme.</td></tr>
</table>

General Data

<table>
<tr><th>General Data</th><th colspan="3"></th></tr>
<tr><td rowspan="2">Placement</td><td colspan="2">Standing on the floor close to a wall.</td><td>Close to a wall.</td></tr>
<tr><td colspan="3">The wall should preferably be a long wall to allow the loudspeakers to be distant from the other walls. Adjacent objects may cause interferences.</td></tr>
<tr><td>Dimensions W*H*D mm</td><td>388 x 466 x 316</td><td>408 x 528 x 368</td><td>430 x 302 x 276 incl. foam front but excl. absorbent panel.</td></tr>
<tr><td>Weight</td><td>14.4 kg each.</td><td>17.5 kg each.</td><td>10.7 kg each.</td></tr>
</table>