

Technical Information

THIEL CS.5

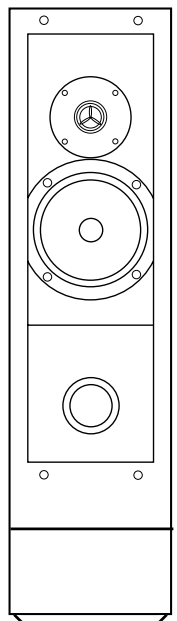
Coherent Source®

Loudspeaker

This paper describes some of the technical performance aspects, design considerations and features of the THIEL model CS.5 loudspeaker system. It is intended to supply information for those who are interested in such matters. It is not intended to imply that good measured technical performance is sufficient to guarantee good sonic performance.

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THIEL DESIGN PHILOSOPHY

All THIEL speakers are intended to be precision instruments that very accurately translate electronic information into musical sound. All our efforts have been directed toward achieving extremely faithful translation of all tonal, spatial, transient and dynamic information supplied by the amplifier. THIEL speakers are not intended to mask or mitigate shortcomings of the recording or other components in the music playback system. We believe this approach is the only way to provide the potential of experiencing all the subtle aspects that help make reproduced music a most enjoyable human experience.

Performance goals

Since quality of musical performance is a very complex issue it is helpful to objectively identify the aspects involved. We believe musical performance can be described, with not much oversimplification, as performance in four areas.

Tonal fidelity includes overall octave-to-octave balance, the fidelity of timbres, absence of vowel-like colorations, and bass extension.

Spatial fidelity includes how wide and deep the performing space seems, how convincingly instruments are placed from the center to beyond the speakers laterally, how realistic the depth perspective is, how little the speakers' positions seem to be the source of the sound, and how large the listening area is.

Transient fidelity includes how clearly and cleanly musically subtle low-level information is reproduced and how convincingly realistic is the reproduction of the initial or "attack" portions of sounds.

Dynamic fidelity includes how well the speaker maintains the contrasts between loud and soft and how unstrained and effortless is the reproduction of loud passages.

Fundamental design considerations

In our opinion, natural spatial reproduction requires creating a realistic sound field within the listening room by mimicking the properties of natural sound sources. These properties include wide area radiation and the absence of out-of-phase energy. To meet these requirements all THIEL speakers employ dynamic drivers. Dynamic drivers have the advantages of providing a point source radiation pattern with good dispersion of sound over a wide area, great dynamic capability, good bass capability and a lack of rearward out-of-phase energy. Another advantage of dynamic drivers is that their small size allows the multiple drivers to be arranged in one vertical line. This alignment avoids the problem of line source designs which must place their different drivers side-by-side, causing the distance from each driver to the listener to change with different listener positions.

The major potential disadvantages of dynamic speakers are diaphragm resonances ("cone breakup"), cabinet resonances and cabinet diffraction. Also, they share with other types of speakers the potential problems of time and phase errors introduced by multiple drivers and their crossovers. *None of these problems is a fundamental limit and all can be minimized or eliminated by thorough and innovative engineering, allowing the possibility of a speaker system without significant fundamental limitations.*

Technical requirements

The task of engineering a speaker system requires the translation of the musical performance goals into technical goals. Although there are also many minor design considerations, the following are what we believe to be the major technical requirements that contribute to each of the musical goals.

Tonal fidelity

- Accurate frequency response so as not to over or under emphasize any portion of the sound spectrum
- Absence of resonances in the drivers or cabinet so as not to introduce tonal colorations

Spatial fidelity

- Point-source, unipolar radiation
- Time response accuracy to preserve natural spatial cues
- Lack of cabinet diffraction
- Even dispersion of energy of all frequencies over a wide area

Transient fidelity

- Phase coherence to provide realistic reproduction of attack transients
- Very low energy storage to provide clarity of musical detail

Dynamic fidelity

- High output capability
- Low distortion

Design goals

The technical requirements result in the following major technical design goals:

1. Very uniform frequency response
2. Time response accuracy
3. Phase response accuracy
4. Low energy storage
5. Low distortion

THIEL CS.5 SPECIFICATIONS

Bandwidth (-3dB)	55Hz - 20KHz
Amplitude response	55Hz - 20KHz ± 3dB
Phase response	minimum $\pm 10^\circ$
Sensitivity	87dB @ 2.8v-1m
Impedance	4Ω, 3.2Ω minimum
Recommended Power	30-150 watts
Size (W x D x H)	8 x 11 x 31 inches
Weight	35 pounds

Driver Complement:

Woofers

6 $\frac{1}{2}$ " (5" radiating area) with treated paper cone, cast frame, 1" diameter voice coil. Underhung coil (short coil/long gap) motor system. Linear travel $\frac{1}{4}$ " pk-pk. Two magnets with total weight of 1.4 lb. Copper pole sleeve.

Tweeter

1" aluminum dome with short coil, ferrofluid, vented pole to rear chamber, reinforced chamber cup.

DESIGN AND ENGINEERING FEATURES

FREQUENCY RESPONSE

Since frequency response errors are a measure of tonal imbalances which alter music's tonal characteristics, we believe that accurate frequency response is an absolute requirement for a truly good speaker. In our opinion the human ear is sensitive enough to the balance between component harmonics of musical sounds to detect frequency balance errors of as little as 0.2dB if they are over a range of an octave or more. Therefore, even more important than the maximum amount of response error at any frequency is the octave averaged, octave-to-octave balance which has a very high correlation with perceived tonal balance. Our design goal for the CS.5 was to achieve octave-averaged response within $\pm 1\text{dB}$ from 100Hz up to 10KHz with even tighter tolerance within the midrange from 200Hz to 3KHz. Therefore, any deviation more than these limits is confined to only a narrow frequency range and therefore will have less effect on the perceived balance.

Achieving these goals requires the use of drivers with very uniform responses, drivers with high consistency (so that few units need be rejected), reduction of usual cabinet diffraction which causes response errors, and an unusual degree of compensation of driver response anomalies in the electrical network.

Driver response

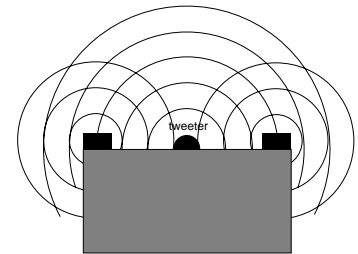
The major cause of nonuniform driver response is diaphragm resonances. These resonances are also the major energy storage mechanism. All THIEL tweeter diaphragms are constructed of aluminum which provides much higher stiffness and compressive strength than conventional diaphragm materials. The primary benefit is that the lowest internal resonance is much higher than with other materials. Below this lowest resonance there are no resonances to store energy and cause ringing. An additional benefit is that the aluminum's much higher compressive strength results in almost all the energy of a transient attack being transferred to sonic output rather than being absorbed in compression of the diaphragm material. In the tweeters the lowest diaphragm resonance occurs above the range of hearing at 26KHz. Therefore, there are no resonances in the audible range to cause energy storage or response irregularities.

Diffraction

Diffraction causes frequency response and time response errors and therefore a reduction in tonal, spatial, and transient fidelity. Diffraction occurs when some of the energy radiated by the drivers is reradiated at a later time from cabinet edges or other sudden change of environment. For musical signals that remain constant for a few milliseconds, diffraction causes, by constructive and destructive interference, an excess of energy to the listener at some frequencies and a deficient amount of energy to the listener at other frequencies. Diffraction also causes all transient signals to be radiated to the listener a second (and possibly a third) time, smearing transient impact and distorting spatial cues.

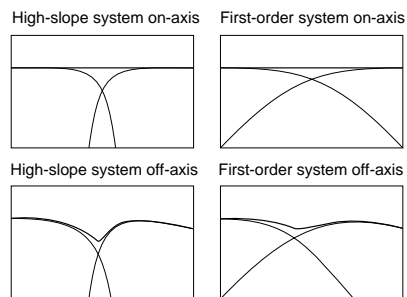
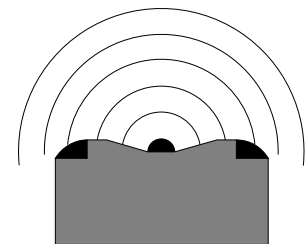
To reduce diffraction the CS.5 employs a grille board that fits around (rather than on) the baffle and one that is curved at the edges so energy radiated along the baffle can continue into the room without encountering abrupt cabinet edges.

Cabinet-edge diffraction



Off-axis response

In addition to on-axis response accuracy, it is also important that the off-axis response be even, without major dips, for two reasons. First, listeners may be located far from the optimum position and therefore will be hearing the speaker as it performs off-axis. Secondly, off-axis response is an indication of the uniformity of the speaker's total energy response. Since the total energy (in all directions) radiated from the loudspeaker determines the amount of reverberant energy in the room, it is important that the off-axis response be uniform to avoid changes in perceived character and spatiality at different frequencies.



Most speakers with high-slope crossover systems cannot maintain uniform off-axis response because the dispersion of a driver narrows as frequency increases toward the crossover frequency. Above the crossover frequency the radiation of the next driver is again wide since it is operating at the low end of its range. First-order crossover systems have an advantage in this regard. Since a significant part of the total energy below the crossover point is radiated by the upper driver, the narrowing of the dispersion of the lower driver has much less effect on the total output. Speakers with first-order crossover systems therefore can achieve a more uniform off-axis response.

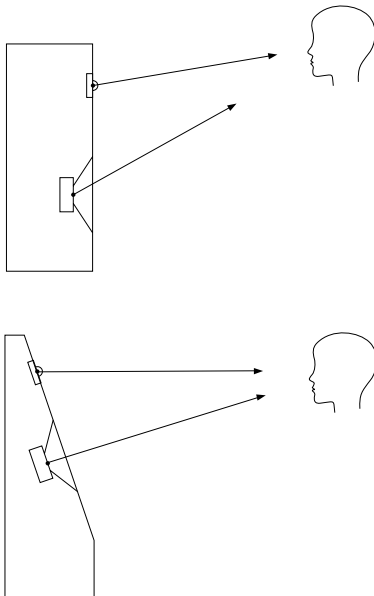
Results

The end result of reducing diffraction, reducing diaphragm resonances and correcting response anomalies in the network is a speaker with very accurate tonal characteristics. Figure 1 shows the on-axis frequency response of the CS.5. It is uniform within $\pm 2\text{dB}$ from 23Hz to 17KHz. Subjectively, even more important is the octave-averaged frequency response. Figure 2 shows this response to be within $\pm 1\text{dB}$ from 100Hz to 10KHz and within $\pm 0.5\text{dB}$ from 200Hz to 3KHz. These measurements indicate very accurate overall tonal balance. Furthermore, as a result of gradual crossover slopes, the off-axis frequency response of the speaker system is also smooth and well balanced. This unusual performance is important for producing a uniform amount of ambient energy at all frequencies, necessary for natural spatial reproduction. Figure 3 shows this octave-averaged, 30° off-axis response to be within $\pm 1.5\text{dB}$ from 70Hz to 10KHz, showing very uniform dispersion of energy at all frequencies.

TIME RESPONSE

In most loudspeakers the sound from each driver reaches the listener at different times causing the loss of much spatial information. One problem caused by different

Time correction



arrival times from each driver is that the only remaining dependable locational clue is the relative loudness of each speaker. Relying only on loudness information causes the sound stage to exist only between the speakers. In contrast to this loudness type of imaging information, the ear-brain interprets real life sounds by using *timing* information to locate the position of a sound. The ear perceives a natural sound as coming from the left mainly because the left ear hears it first. That it may also sound louder to the left ear is of secondary importance.

Another problem is that for realistic reproduction, it is important that the attack, or start, of every sound be clearly focused in time. Because more than one driver is involved in the reproduction of the several harmonics of any single sound, the drivers must be heard in unison to preserve the structure of the sound. Since, in most speakers, the tweeter is closer to the listener's ear, the initial attack of the upper harmonics arrives a substantial part of a millisecond before the body of the sound. This delay results in a noticeable reduction in the realism of the reproduced sound.

To eliminate both these problems the CS.5's drivers are mounted on a sloped baffle to position them so the sound from each reaches the listener at the same time. The sloping baffle arrangement can work perfectly for only one listening position. However, because the drivers are positioned in a vertical line the error introduced by a listener to the side of the speaker is very small. Also, the error introduced by changes in listener height are small within the range of normal seated listening heights provided the listener is 8 feet or more from the speakers.

PHASE RESPONSE

We use the trade mark *Coherent Source* to describe the unusual technical performance of time *and* phase coherence which gives THIEL products the unusual ability to accurately reproduce musical waveforms.

Usually, phase shifts are introduced by the crossover slopes, which change the musical waveform and result in the loss of spatial and transient information. The fourth-order Linkwitz-Riley crossover is commonly used in high performance speakers and is sometimes promoted as being phase coherent. What is actually meant is that the two drivers are in phase with *each other* through the crossover region. However, in the crossover region neither driver is in phase with the input signal nor with the drivers' output at other frequencies; there is a complete 360° phase rotation at each crossover point.

Since 1978 THIEL has employed first-order (6dB/octave) crossover systems in all our *Coherent Source* speaker systems. A first-order system is the only type that can achieve perfect phase coherence, no time smear, uniform frequency response, and uniform power response.

A first-order system achieves its perfect (in principle) results by keeping the phase shift of each roll-off less than 90° so that it can be canceled by the roll-off of the other driver that has an identical phase shift in the opposite direction. (Phase shifts greater than 90° cannot be canceled.) The phase shift is kept low by using very gradual (6dB/octave) roll-off slopes which produce a phase lag of 45° for the low frequency driver and a phase lead of 45° for the high frequency driver at the crossover point. Because the phase shift of each driver is much less than 90° and is equal and opposite, their outputs combine to produce a system output with no phase shift and perfect transient response.

Figure 4 graphically demonstrates how the outputs of each driver in a two-way speaker system combine to produce the system's output to a step input. The first graph shows the ideal output. The second shows the operation of a time-corrected, fourth-order crossover system. The two drivers produce their output in the same polarity and both drivers start responding at the same time. However, since the high-slope network produces a large amount of phase shift, the tweeter's output falls too quickly and the woofer's output increases too gradually. Therefore, the two outputs do not combine to produce the input step signal well but instead greatly alter the waveform. The third graph shows how, in a first-order crossover system, the outputs of the two drivers combine to reproduce the input waveform without alteration.

Figure 1 On-axis frequency response

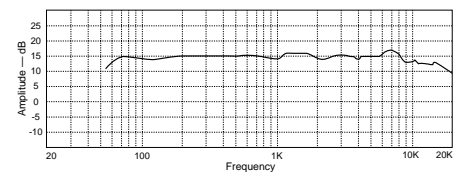


Figure 2 On-axis octave-averaged frequency response

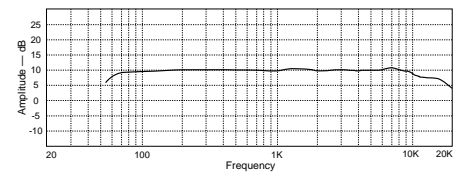
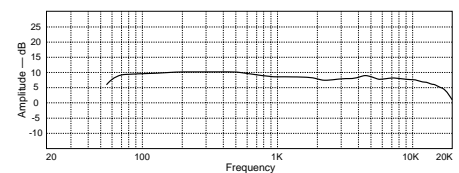


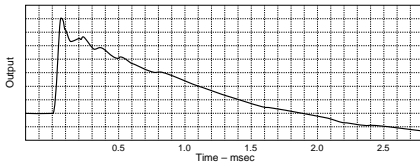
Figure 3 30° off axis octave-averaged frequency response



In practice, the proper execution of a first-order system requires very high quality, wide bandwidth drivers and that the impedance and response variations of the drivers and the cabinet be compensated across a wide range of frequencies. This task is complex since what is necessary is that the *acoustic* driver outputs roll off at 6dB/octave and not simply for the networks themselves to roll off at 6dB/octave. For example, if a typical tweeter with a low frequency roll-off of 12dB/octave is combined with a 6dB/octave network, the resulting acoustical output will roll off at 18dB/octave. Therefore, in practice, the required network circuits are much more complex than might be thought.

The result of phase coherence (in conjunction with time coherence) is that all waveforms will be reproduced without major alterations. The speaker's reproduction of a step waveform best demonstrates this fact since, like musical waveforms, a step is made up of many frequencies which have precise amplitude and phase relationships. For a step signal to be accurately reproduced, phase, time and amplitude response must all be accurate. Because this waveform is so valuable, it is commonly used to evaluate the performance of electronic components. It is not typically used for speaker evaluation because most speakers are not able to reproduce it recognizably. That THIEL speakers reproduce the step so recognizably is the result of accurate phase, time and amplitude response. Figure 5 shows the step response of the CS.5.

Figure 5 CS.5 step response



ENERGY STORAGE

Any part of the speaker that absorbs energy will reradiate it later in time in a highly distorted manner. Although not loud enough to be consciously heard, stored energy causes significant detrimental effects by obscuring the music's subtle detail, causing both a reduction in clarity and loss of spatiality. The main storage mechanisms are the driver diaphragms and cabinet walls, especially the baffle.

Figure 5 CS.5 time response

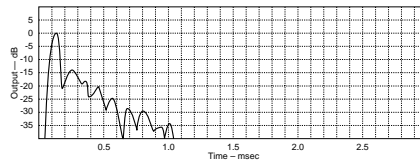
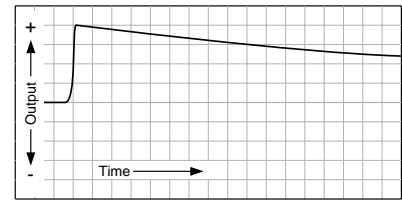
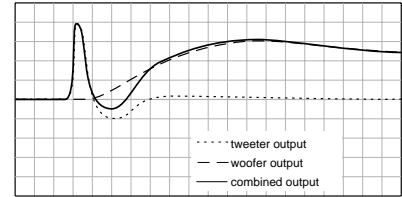


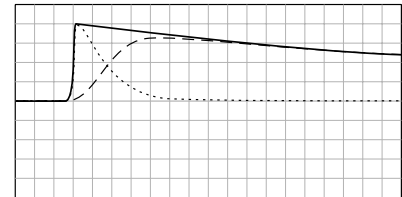
Figure 4



Ideal step response



Time corrected fourth-order crossover system



First-order crossover system

To reduce cabinet wall vibration the CS.5 speaker utilizes cabinet walls constructed with very thick, 1" MDF. Also, to increase the mechanical rigidity and therefore reduce unwanted vibration, all THIEL drivers incorporate chassis of cast magnesium or aluminum rather than stamped steel or plastic. The results are shown in Figure 6 where it can be seen that the output of the speaker falls to -40dB in 1 millisecond and to -20dB in only 400 microseconds. This performance provides very clean reproduction of music's subtle information.

DISTORTION

Driver motor systems

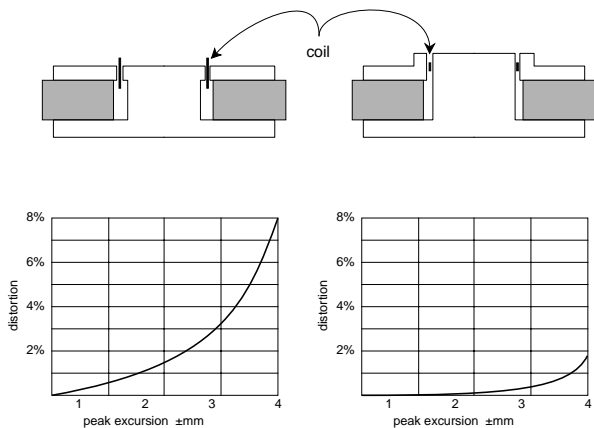
Unlike some sources of distortion, motor system distortion is very dependent on volume level, being low during quiet playback levels but increasing rapidly as volume levels increase. At moderate to loud playback levels it is the major source of distortion. The CS.5 incorporates several unusual features in its woofer to decrease distortion and increase dynamic range.

The purpose of the driver's motor system is to apply a force to the diaphragm that is directly proportional to the voltage supplied by the amplifier as modified by the electrical network. In order for the force to be directly proportional to the voltage applied, as desired, the magnetic field strength must be constant, the length of voice coil wire acted on by the magnetic field must be constant, and the current in the voice coil must be directly proportional to the applied voltage. In practice, none of these three conditions actually exist but the CS.5 woofer incorporates refinements of design that greatly improve the accuracy of each of these factors.

The first distortion mechanism is that the strength of the magnet's field is not actually constant in operation but is changed by the current from the amplifier through the coil. This change occurs because the amplifier current through the coil generates the force to move the diaphragm by creating its own magnetic field that "pushes" *against* the magnet's field. The magnet is somewhat demagnetized by the coil's magnetic field when current flows in one direction and is remagnetized when current flows in the opposite direction. Therefore, since the magnet's field strength is not constant, the force generated is not in the desired direct proportion to the current in the coil. To greatly reduce this effect the CS.5 woofer incorporates a copper sleeve around the center pole. With this sleeve any change in the magnet's strength induces an electrical current in the sleeve which generates a magnetic field that is opposed to and practically cancels the original change.

The second distortion mechanism results from the fact that almost all woofers use a long coil/short gap motor system where the long coil is acted upon not only by the field within the air gap but also by the "fringe" field in front of and behind the gap region. As the coil moves forward or backward to produce bass energy, the magnetic field acting on the coil becomes less intense because the coil is further from its rest position where the magnetic field is strongest. This weakening of field strength as the coil moves away from its rest position is the primary distortion producing mechanism in woofers.

To eliminate this problem the CS.5 woofer uses a very unusual short coil/long gap system where the coil is much shorter than the magnetic gap. Therefore, even when the coil moves a considerable distance from its rest position, it continues to be acted upon only by the uniform magnetic field in the air gap and does not experience the changes in magnetic field strength with position as in the conventional system. As shown below, the distortion produced by the CS.5 woofer's short coil motor system at normal excursion levels is only one-tenth that produced by the typical long coil system.



The third distortion mechanism is that the coil current is dependent not only on the driving voltage and the coil resistance but also on the coil inductance. The problem is that the coil inductance varies with the amount of iron inside the coil and therefore with conventional magnet system geometry, inductance changes during the excursions necessary to reproduce low frequencies. As the diaphragm and coil move back, more of the coil is around the pole, increasing the inductance and decreasing the mid-frequency output of the driver. As the coil moves forward, less of the coil is around the pole, the inductance decreases, and the mid-frequency response increases. By this mechanism the *frequency response* of the speaker is modulated by driver excursion. This problem has been virtually eliminated in the CS.5 woofer. The short coil design results in the entire coil surrounding the pole in all positions and therefore the coil's inductance does not change with the diaphragm position. In addition, the problem is further reduced by the copper sleeve which reduces the inductance of the coil to a fraction of its normal value by acting as a shorted turn of a transformer secondary winding.

An additional problem is that the voice coil is an iron-core inductor. Iron-core inductors are not linear and therefore introduce distortion. For this reason such inductors are avoided in high quality crossover systems. Nonetheless, one iron-core inductor remains in the signal path—the driver's voice coil. An additional benefit of the copper sleeve is that since it reduces the coil's inductance, it also reduces the associated distortion.