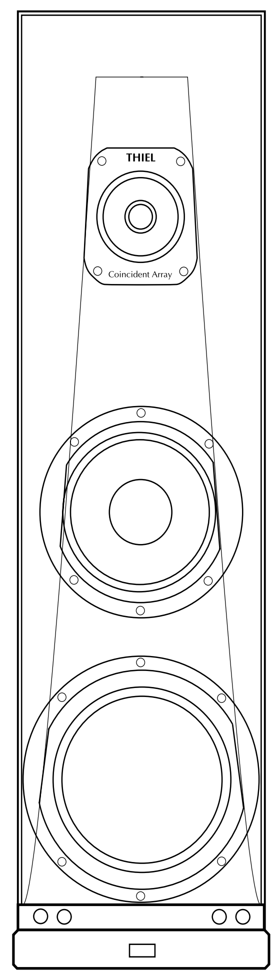
Technical Information

THIEL CS6

Coherent Source®
Loudspeaker



This paper describes some of the technical performance aspects, design considerations and features of the THIEL model CS6 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.

THIEL • 1026 Nandino Boulevard • Lexington, Kentucky 40511 • USA
Telephone: 859-254-9427 • Fax: 859-254-0075 • E-mail: mail@thielaudio.com
Web: www.thielaudio.com
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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 employs 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 side-by-side driver placement which causes the distances 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 to not 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 CS6 SPECIFICATIONS

Bandwidth (-3 dB)	**27 Hz - 34 KHz**
Amplitude response	**29 Hz - 18 KHz ±2 dB**
Phase response	**minimum ±10°**
Sensitivity	**86 dB @ 2.8 v-1m**
Impedance	**4Ω, 2.4Ω minimum**
Recommended Power	**100-500 watts**
Size (W x D x H)	**13 x 18.5 x 50 inches**
Weight	**175 lb**

Driver Complement:

Woofer

10" (8.2" radiating area) with anodized aluminum cone, cast frame, 2" dia voice coil. Underhung coil (short coil/ long gap) motor system. Linear travel 5/8" pk-pk, 36 in^3 linear displacement. 10 lb magnet, 20 lb total magnet structure. Copper pole sleeve, copper magnet ring. Made by THIEL.

Midrange

5" (4.1" radiating area) with 3 layer anodized aluminum/ polystyrene/aluminum diaphragm, cast frame, 1 1/2" dia voice coil. Underhung coil (short coil/long gap) motor system. Linear travel 1/8" pk-pk. Two magnets with total weight of 5 lb power midrange and tweeter. Copper pole sleeve. Made by THIEL.

Tweeter

1" (1.2" radiating area) with anodized aluminum dome. Underhung coil (short coil/long gap) motor system. Linear travel 3/16" pk-pk. Copper pole sleeve. Ferrofluid. Made by THIEL.

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. Our design goal for the CS6 was to achieve accuracy in the design prototype of ±1 dB and a production tolerance of ±1 dB. The result is a tolerance in every production speaker of ±2 dB and a tolerance from speaker to speaker of ±2 dB at all frequencies.

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 0.2 dB 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 was to achieve octave-averaged response within ±0.5 dB from 50 Hz to 15 KHz. Any deviation more than .5 dB is confined to only a narrow frequency range and therefore will have less effect on the perceived balance.

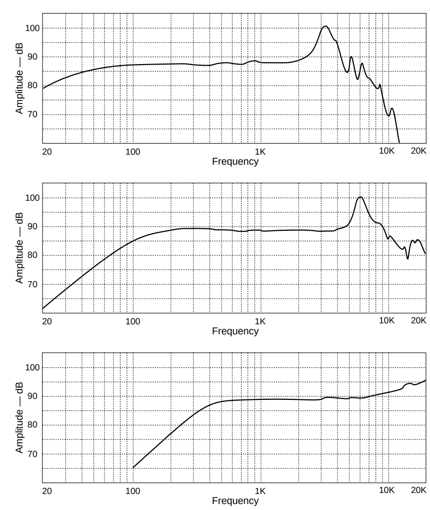
Achieving these goals requires the use of drivers with very uniform responses, reduction of usual cabinet diffraction which causes response errors, and compensation of driver response anomalies in the electrical network.

Driver response

The major cause of nonuniform driver response is diaphragm resonances. These resonances are also the major energy storage mechanism. In the CS6 all three driver diaphragms are constructed of anodized 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 higher compressive strength results in more of the energy of a transient attack being transferred to sonic output rather than being absorbed in compression of the diaphragm material. In the case of the CS6's tweeter the lowest diaphragm resonance occurs above the range of hearing at 22 KHz. The lowest diaphragm resonances for the other drivers are 3 KHz, and 6 KHz, putting them 2.5 and 1 octave above their respective crossover points of 500 Hz and 3 KHz. So, in every case, each driver has no internal resonances in its operating range to cause response irregularities and colorations of the speaker's tonal response.

Figure 1 shows the frequency response (in an infinite baffle) of the CS6's drivers. You will notice that in each case the response is virtually perfect below the primary diaphragm resonance.

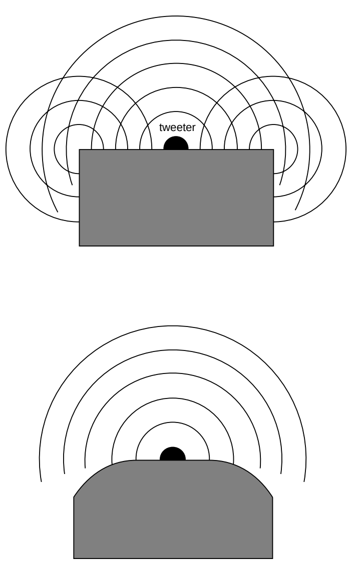
Figure 1 Woofer, midrange and tweeter driver responses



Diffraction

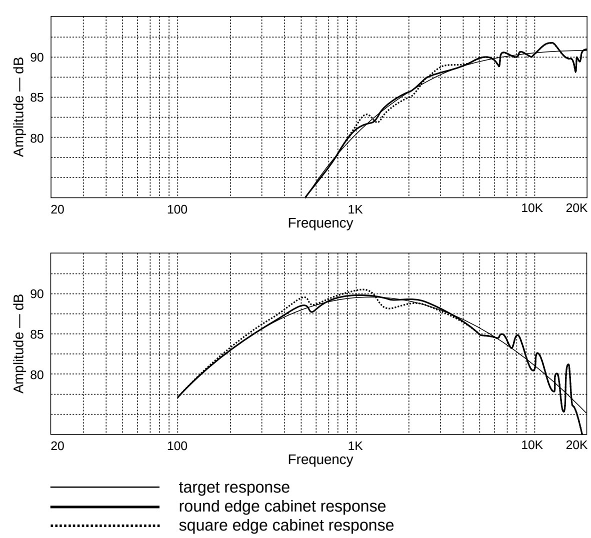
Diffraction causes frequency response and time response errors and therefore a reduction in tonal, spatial, and transient fidelity. Diffraction occurs when some of the energy radiated by the drivers is reradiated at a later time from cabinet edges or other sudden change of environment. For musical signals 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.

Cabinet-edge diffraction



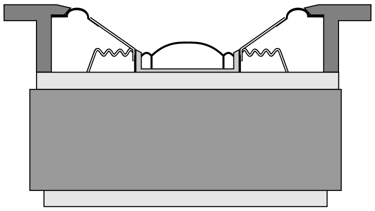
To greatly reduce diffraction the CS6 employs a baffle that is curved at the edges so energy radiated along the baffle can continue into the room without encountering abrupt edges. Figure 2 compares the response of the tweeter and mid drivers in a conventional square-edged cabinet and in the CS6's cabinet with the target response. It can be seen that response imperfections are reduced by approximately 75% in the mid driver's bandpass and in the response of the tweeter below 6 KHz.

Figure 2 Target response, response with rounded-edge cabinet and response with square edge cabinet for tweeter (top) and mid drivers.

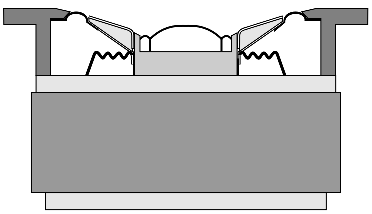


Coaxially mounting the tweeter and mid driver would normally be another source of diffraction of the tweeter's energy. The upper diagram on page 4 shows a tweeter mounted in a normally shaped mid diaphragm. The conical shape of the tweeter's environment causes response irregularities shown in the upper graph of Fig. 3. To solve this response problem the CS6 uses a

Coaxially mounting of tweeter in normal midrange diaphragm

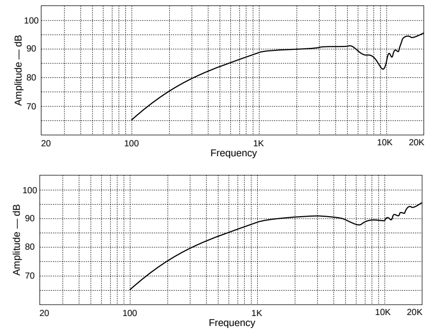


Coaxially mounting of tweeter in CS6 midrange diaphragm



mid diaphragm shaped with a very shallow flare which provides much improved tweeter response as illustrated in the lower graph of Fig. 3. However, this shallow diaphragm shape would cause poor response of the mid driver and so the CS6 utilizes a 3-layer diaphragm that provides the shape required for the tweeter while providing a very strong structure for the mid diaphragm. The 3-layer sandwich is constructed of a cast polystyrene central core laminated with anodized aluminum on both surfaces.

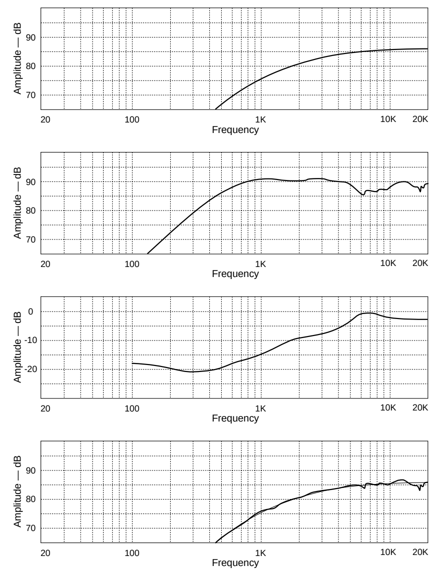
Figure 3 Response of tweeter in conical mid diaphragm and in CS6 mid diaphragm



Network correction

The last method for achieving accurate frequency response is to include electrical correction of response irregularities. The CS6 makes extensive use of network compensation. 12 of the 32 network elements are used to achieve correction of what would otherwise be minor response irregularities in the complete speaker system.

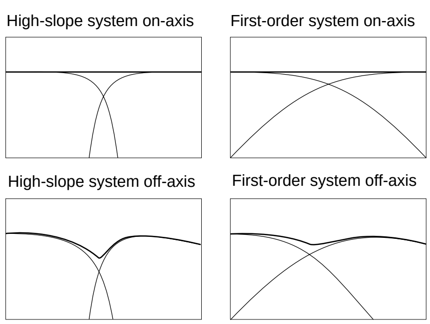
Figure 4 Tweeter's target, driver (in cabinet), network, and resulting response.



As an example, figure 4 illustrates, for the tweeter, the target response, driver (in cabinet) response, the network response and the final acoustic response (which is the sum of the driver and network responses). As can be seen, the actual response matches the target response very closely. Without the inclusion of 7 additional network elements the response would be much less ideal. Notice in the network response the non-simple shape of the curve; for example, the depression around 4000 Hz and the strong response near 7 KHz.

Off-axis response

In addition to on-axis response accuracy, it is also important that the off-axis response be properly balanced, 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 a measure of how uniform the total energy response of the speaker is. 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.

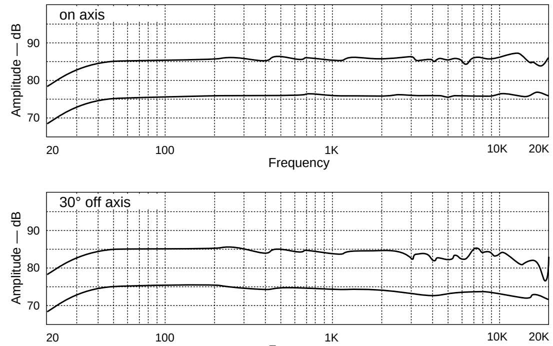


Most speakers with high-slope crossover systems cannot maintain uniform off-axis response because the dispersion of a driver narrows as frequency increases toward the crossover frequency. Above the crossover frequency the radiation of the next driver is again wide since it is operating at the low end 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, like the CS6, therefore, usually have a more uniform off-axis response and much more uniform total power 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. The upper graph of figure 5 shows the on-axis frequency response of the CS6. It is uniform within ±1.5 dB from 29 Hz to 18 KHz. Subjectively even more important is the octave-averaged frequency response, shown offset 10 dB. The graph shows this response to be within ±0.5 dB from 45 Hz to 15 KHz which indicates extremely 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. The lower graph shows the 30° off-axis response to be within ±2.0 dB from 30 Hz to 13 KHz, showing very uniform dispersion of energy at all frequencies.

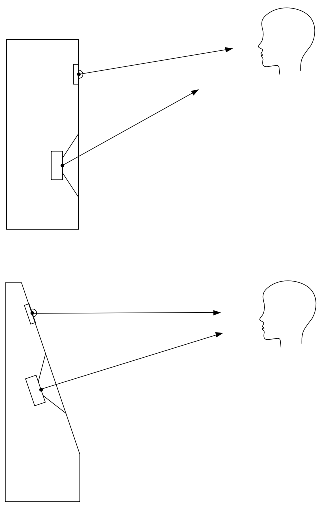
Figure 5 Normal and octave-averaged frequency response on-axis and 30° off-axis.



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 arrival times from each driver is that the only 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.

Time correction

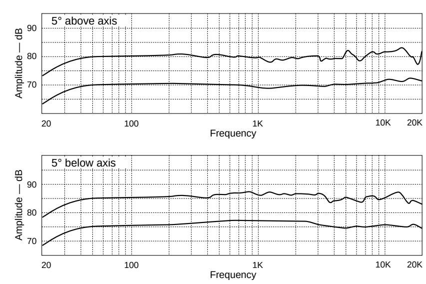


Another problem is that for realistic reproduction, it is important that the attack, or start, of every sound be clearly focused in time. Because more than one driver is involved in the reproduction of the several harmonics of any single sound, the drivers must be heard in unison to preserve the structure 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 millisecond or so 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 CS6 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, because the driver spacing is not more than the approximate wavelength of the crossover frequency, 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.

In the CS6, the arrival time error caused by non-ideal listener height is greatly reduced in the upper part of the frequency spectrum (where it is most problematic) by mounting the tweeter coaxially with the midrange driver. Coaxial mounting ensures perfect time alignment between these two drivers regardless of listener position. Figure 6 shows the frequency response 5° above and below the ideal listening axis. At normal listening distances ±5° represents a listening window height of about 2 feet. Even under these conditions the response remains very good, particularly in the high frequency range.

Figure 6 Normal and Octave-averaged frequency response



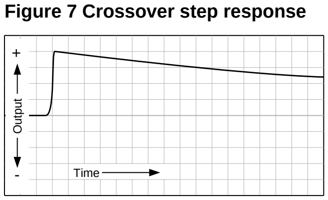
PHASE RESPONSE

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.

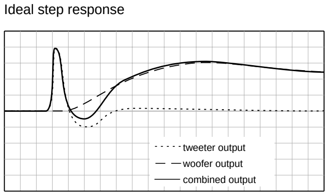
Usually, phase shifts are introduced by the crossover slopes, which change the musical waveform and result in the loss of spatial and transient information. The fourth order Linkwitz-Riley crossover is sometimes promoted as being phase coherent. What is actually meant is that the two drivers are in phase 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.

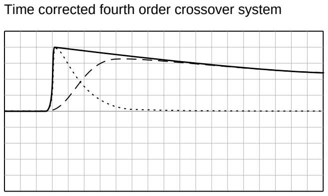
Figure 7 Crossover step response



Ideal step response



Time corrected fourth order crossover system



First order crossover system

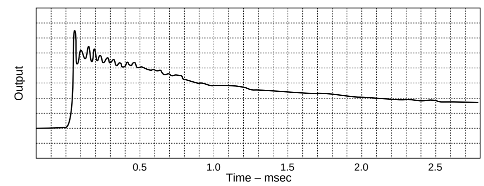
A first order system achieves its perfect (in principle) results by keeping the phase shift of each roll-off less than 90° so that it can be canceled by the roll-off of the other driver that has an identical phase shift in the opposite direction. (Phase shifts greater than 90° cannot be canceled.) The 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 7 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.

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 6 dB/octave and not simply for the networks themselves to roll off at 6 dB/octave. For example, if a typical tweeter with a low frequency roll-off of 12 dB/octave is combined with a 6 dB/octave network, the resulting acoustical output will roll off at 18 dB/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. Figure 8 shows the CS6's response to a step. That the step is reproduced so recognizably is the result of accurate phase, time and amplitude response

Figure 8 CS6 step response



ENERGY STORAGE

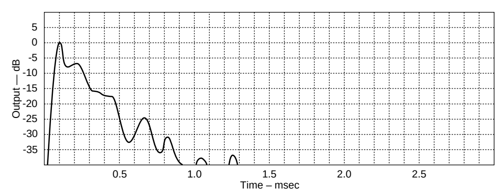
Any part of the speaker that absorbs energy will reradiate it later in time in a highly distorted manner. Although not loud enough to be consciously heard, stored energy causes significant detrimental effects by obscuring music's subtle details, causing both a reduction in clarity and loss of spatiality.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

One method of reducing stored energy is to apply viscous damping so the stored energy can be dissipated as heat instead of mechanical vibration which produces unwanted sound. This method has limited benefit because energy can only be dissipated as heat *after* there is unwanted mechanical vibration. Also, even though some of the absorbed energy is transformed into heat, it is still absorbed from the desired sonic output. A much better approach, in our opinion, is to reduce the energy absorbed.

The primary cabinet problem is baffle vibration because driver movement can directly excite the baffle. The CS6 employs a thick cast concrete baffle to reduce unwanted vibration. The walls of the CS6 enclosure are constructed of 1" thick fiberboard, and extensive internal bracing further increases wall stiffness. To increase the mechanical rigidity and therefore reduce unwanted vibration, all CS6 drivers incorporate chassis of cast aluminum rather than stamped steel or plastic.

Figure 9 is the Energy-Time curve of the CS6. It shows how the output energy of the speaker is distributed in time. First, it shows that the energy is focused with a fast risetime and a smooth decay, a result of very good time coherence. It also shows that the speaker's output has already decayed to -20 dB after only 600 microseconds and has fallen to -40 dB after 1.4 milliseconds. This rapid decay provides very clean reproduction with very good inter-transient silence.

Figure 9 CS6 time response



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 usually the major source of distortion. The CS6 incorporates several unusual features in its drivers 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 CS6 woofer incorporates refinements of design that greatly improve the accuracy of each of these factors.

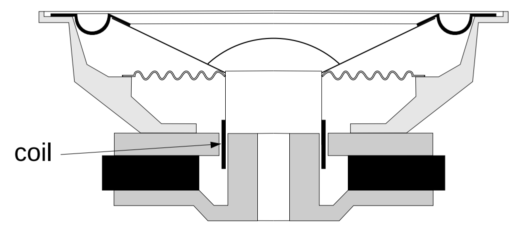
The first distortion mechanism is that the strength of the magnet's field is not actually constant in operation but is changed by the current from the amplifier through the coil. This change occurs because the amplifier current through the coil generates the force to move the diaphragm by creating its 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.

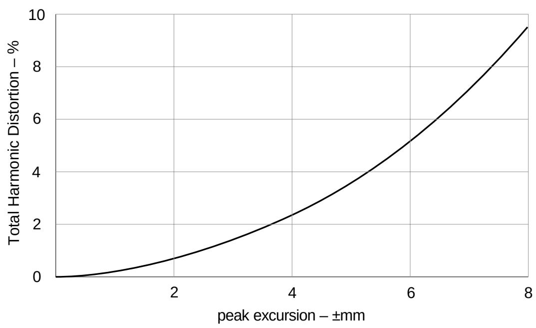
To greatly reduce this effect the CS6 drivers all incorporate a copper sleeve around the center pole. With this sleeve any changes in the magnet's strength induces an electrical current in the sleeve which generates a magnetic field that is opposed to and practically cancels the original change. In addition, the CS6 woofer also incorporates a heavy copper ring around the pole to maintain the stability of the magnetic field even under very high power conditions.

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.

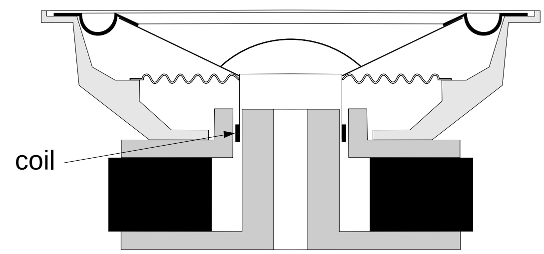
To eliminate this problem all three CS6 drivers use an unusual short coil/long gap system where the coil is much shorter than the magnetic gap. Therefore, even when the coil moves a considerable distance from its rest position, it continues to be acted upon only by the uniform magnetic field in the air gap and does not experience the changes in magnetic field strength with position as in the

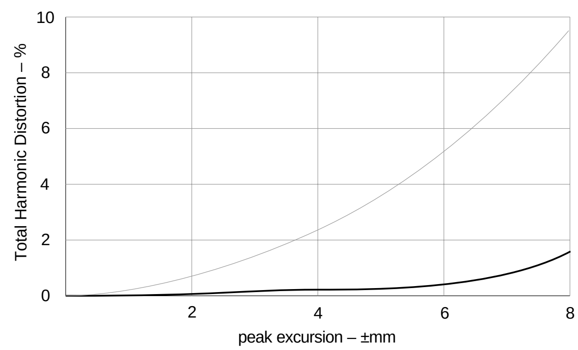
Conventional – long coil / short gap





THIEL CS6 – short coil / long gap





conventional system. As shown above, the distortion produced by the CS6 woofer's short coil motor system at normal excursion levels is only one-tenth that produced by the typical long coil system. Similar reductions are achieved in all the CS6's drivers.

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 all the CS6 drivers. 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.