

Technical Information

THIEL

Coherent Source®

Loudspeakers

This paper describes some of the technical performance aspects, design considerations and features of THIEL *Coherent Source*® loudspeaker systems. 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 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 ENGINEERING

All THIEL speakers share several very unusual (and costly) engineering features that are fundamental to our engineering approach and enable them to achieve very high performance. The most noteworthy of these are:

- Complete phase coherence (the elimination of phase distortion) achieved by the use of first-order crossovers.
- Accurate time coherence (absence of inter-driver time delays) achieved by coincident/coaxial driver placement and/or sloping baffles.
- Short coil/ long magnetic gap motor systems that drastically reduce distortion.
- Very rigid, heavy cabinet construction.
- Reduced cabinet edge diffraction achieved with rounded baffle edges.
- Aluminum driver diaphragms whose stiffness eliminates resonances in the operating range.

The following material briefly explains the engineering techniques used to achieve our design goals. Under frequency response is discussed driver diaphragms, diffraction, network correction and off-axis response. The section on time response covers correction by driver alignment. Phase response explains phase correct first order crossover systems. Energy storage covers cabinet construction and distortion covers various aspects of motor system design.

Some generic examples and measurements are given and the reader is referred to model-specific information and measurements that are contained in the model-specific technical information pamphlet.

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. Even though incorrectly balanced speakers may sound pleasant, and even be preferred by some people, our goal is to produce very accurately balanced speakers. 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 is to achieve octave-averaged response within ± 0.5 dB from 50 Hz to 10 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 this goal 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 THIEL products all driver diaphragms (with the exception of the CS.5 woofer and the CS3.6 midrange) 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 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. High enough diaphragm resonances can be obtained so that, in every case, each driver has no internal resonances in its operating range to cause response irregularities and colorations of the speaker's response.

Figure 1 CS6 woofer response

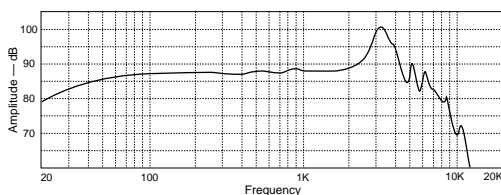
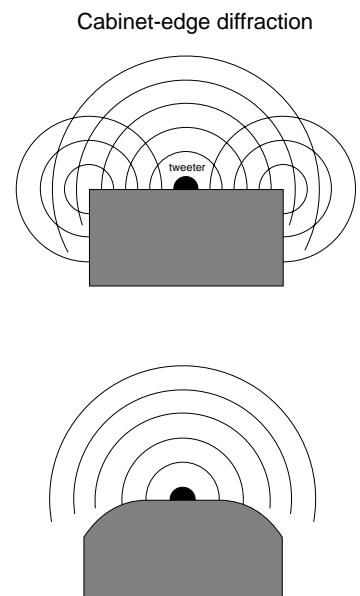


Figure 1 shows the frequency response (in an infinite baffle) of the CS6's woofer. You will notice that the response is virtually perfect below the primary diaphragm resonance and that the resonance is above 3 kHz, a very high frequency for a 10" woofer.

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. 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 greatly reduce diffraction THIEL speakers employ baffles that are curved at the edges so energy radiated along the baffle can continue into the room without encountering abrupt edges. Figure 2 on the next page compares the response of the CS6 mid driver 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 particular, 2 dB plus and minus errors in the 1 kHz to 2 kHz range are practically eliminated.



Network correction

The last method for achieving accurate frequency response is to include electrical correction of response irregularities. THIEL speakers make extensive use of network compensation. Typically, about 40% of the network elements are used to achieve correction of what would otherwise be minor response irregularities in the complete speaker system.

As an example, figure 3 illustrates, for the CS6 tweeter, the target response, driver (in cabinet) response, the network response

Figure 3 CS6 tweeter's target, driver (in cabinet), network, and resulting response.

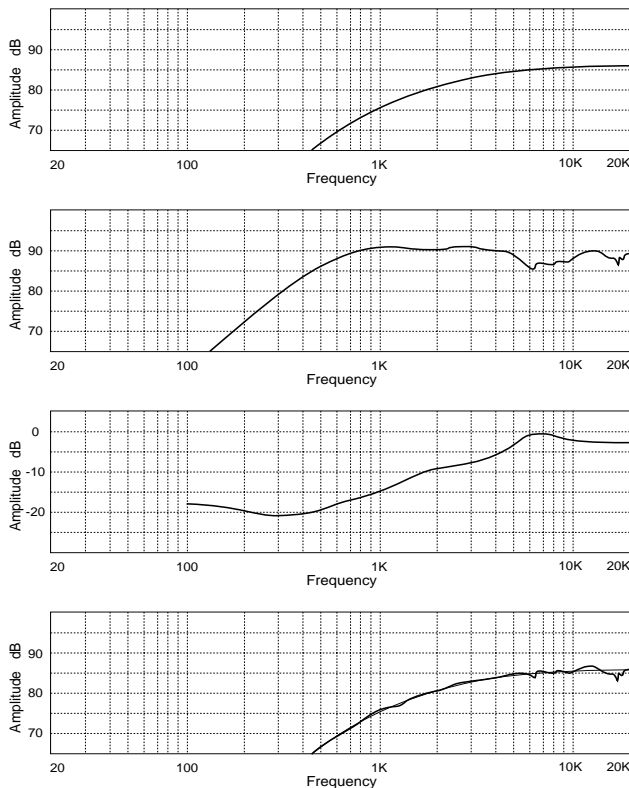
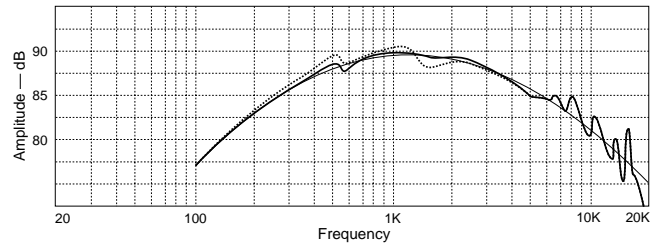
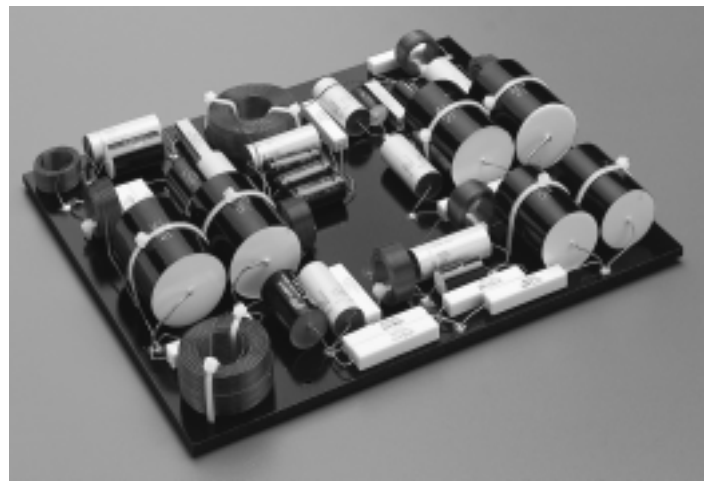


Figure 2 Target response, response with rounded-edge cabinet and response with square edge cabinet for CS6 mid driver.



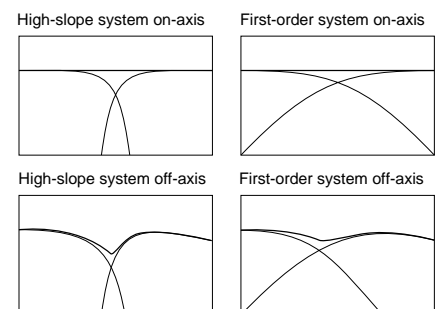
and the final acoustic response (which is the sum of the driver and network responses). As can be seen, the actual response matches the target response very closely. Without the inclusion of 7 additional network elements the response would be much less ideal. Notice in the network response the non-simple shape of the curve; for example, the depression around 4 kHz and the strong response near 7 kHz. The picture below of the CS6 crossover illustrates the complexity required to achieve very accurate frequency response.



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, 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. On-axis frequency response accuracy ensures a lack of colorations; octave-averaged accuracy ensures correct tonal balance and character; and off-axis uniformity ensures naturally balanced ambient energy. **Please see the model specific information pamphlet for each model's frequency response curves.**

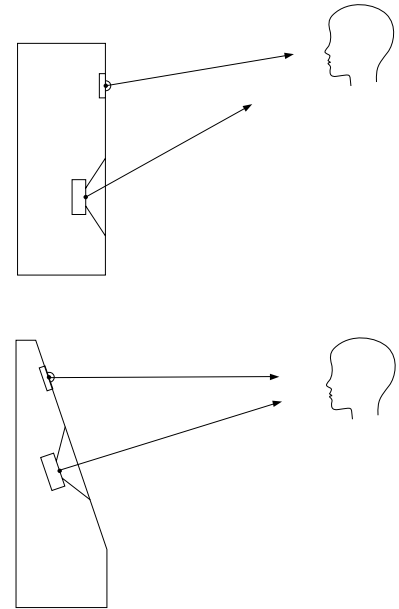
TIME RESPONSE

In most loudspeakers the sound from each driver reaches the listener at different times. This causes the loss of much spatial information. Different arrival times from each driver cause the only locational clues to be 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. Therefore, preserving accurate arrival times allows your ear-brain to interpret location of sounds in its normal, natural way and provides realistic imaging.

Another problem caused by separate arrival times from each driver is that the attack, or start, of every sound is no longer clearly focused in time as it should be. 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 can arrive up to 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 THIEL speakers use one of, or a combination of, two techniques. In some cases drivers are mounted coincidentally (not merely coaxially) and/or drivers are mounted on a sloped baffle. In either case, the positioning ensures that the sound from each driver 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. Coincident mounting ensures that the sound from the two drivers reaches the listener at exactly the same time, regardless of listener (or speaker) position.

Time correction



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 correct. 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.

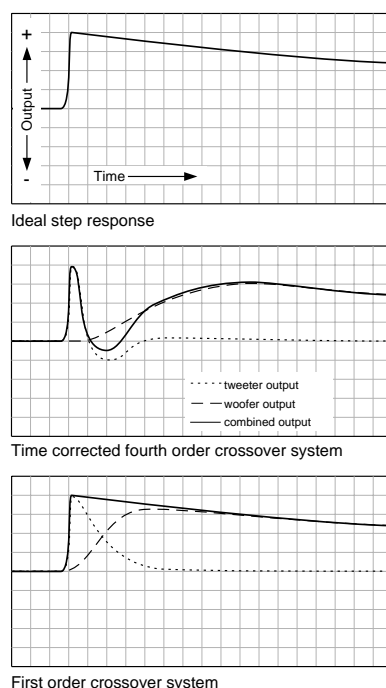
A first order system achieves its perfect (in principle) results by keeping the phase shift of each roll-off less than 90° so that it can be canceled by the roll-off of the other driver that has an identical phase shift in the opposite direction. (Phase shifts greater than 90° cannot be canceled.) The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

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 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

Figure 4 Crossover step response



will be reproduced without major alterations. The speaker's reproduction of a step waveform 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 5 gives the example of the CS6's step response. **Please see the model specific information pamphlet for each model's 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.

The primary cabinet problem is baffle vibration because driver movement can directly excite the baffle. THIEL speakers employ very strong baffles to reduce unwanted vibration. The smaller speakers use MDF from 1" to 3" thick; the larger speakers use cast mineral filled polymer or cast concrete. The walls of THIEL enclosures 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 THIEL drivers incorporate chassis of cast aluminum or magnesium rather than stamped steel or plastic.

Energy-Time curves show how the output energy of the speaker is distributed in time. For THIEL speakers they show that the energy is focused with a fast risetime and a smooth decay, a result of very good time coherence. They also show that the speaker's output decays rapidly, providing very clean reproduction with very good inter-transient silence. Figure 6 illustrates the CS6's accurate time response. **Please see the model specific information pamphlet for each model's energy-time curve.**

Figure 5 CS6 step response

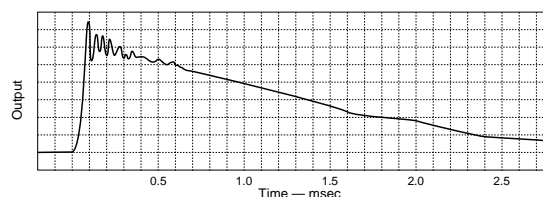
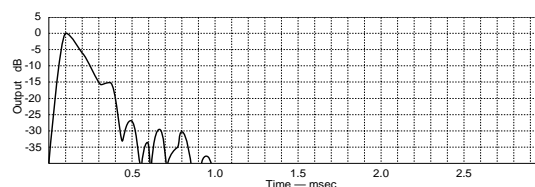


Figure 6 CS6 time response



DISTORTION

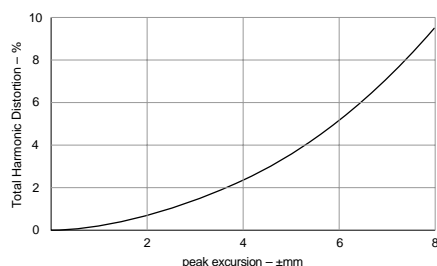
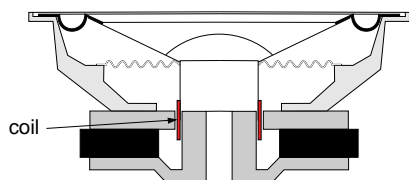
Driver motor systems

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. THIEL drivers incorporate several unusual features 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 all THIEL drivers incorporate 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

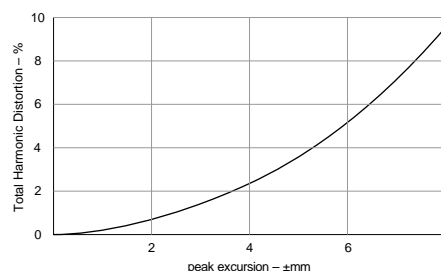
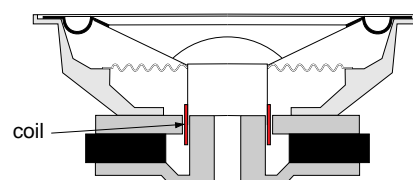
Conventional – long coil / short gap



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 all THIEL drivers 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

Conventional – long coil / short gap



cancels the original change. In addition, the larger woofers also incorporate 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 drivers use a long coil/short gap motor system where the long coil is acted upon not only by the field within the magnetic 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 farther 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 usually the primary distortion producing mechanism.

To eliminate this problem all THIEL drivers (except the CS3.6 woofer) 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 system. The distortion produced by short coil motor system woofers at normal excursion levels is typically only one-tenth that produced by normal long coil system. The penalty of this approach is that a much larger magnet is needed to power the much longer gap.

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, the 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 practically eliminated in all THIEL 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.