

# Technical Information

# THIEL

## SmartSub<sup>®</sup> Subwoofers



## THE GOAL

Our goal in developing a subwoofer system was to produce a product that achieved very high sonic quality and that did not exhibit the sonic problems typical of subwoofers. In particular, subwoofer systems usually do not integrate well sonically with the other speakers in the system and this product was originally inspired by the conception of an electronic means of generating subwoofer low-pass crossover characteristics that could be made to perfectly

match any main speaker. Further impetus was added to the project by the realization that the placement problems of altered and unbalanced response caused by nearby walls could also be solved.

We believe that the major problems of subwoofers have been effectively eliminated in the SmartSub subwoofers and the following details the highlights of their performance features.

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## THE PROBLEMS

Subwoofer performance problems can be categorized into 3 types:

- 1) Output/distortion/uniformity problems.
- 2) Problems of sonic integration with the main speakers.
- 3) Room interaction problems.

Examples of the first type are thumpy, dirty and strained low frequencies; of the second disjointed sound character, misbalanced levels and seemingly disconnected low frequencies; of the third are subjectively overly dominant or “missing” tones and sonic balance and character that change with different subwoofer placement.

### Low Frequency performance

It is difficult and expensive to reproduce deep bass at high loudness levels with the low distortion that can be achieved by high quality speakers at higher frequencies and/or lower loudness levels. Therefore, many subwoofers do not attempt to reproduce truly deep bass but rather are designed to accept very high input levels of bass energy without obvious distress. Often this characteristic is achieved by restricting reproduction of deep bass and by incorporating severe compression of the signal so that demanding inputs do not overtax woofers and amplifiers of modest ability.

These limitations of most subwoofers can be overcome with normal engineering. However, such performance requires very high output drivers and a large amount of power, neither of which can be obtained at low cost. And even when a product *is* engineered to provide a truly high level of low frequency performance, this does not solve the two other categories of problems subwoofers exhibit.

### Integration

The second category of problem is the result of the fact that the crossovers typically employed are generic types and that they do not take into account the low frequency characteristics of the main speakers. This is true whether the crossover used is the bass management capability of the processor or the built-in crossover included with most subwoofers. Usually these crossovers will provide the desired blending only for the theoretical case of the main speakers and the subwoofer both having low frequency response flat down to DC. Since this is never true, the results obtained are off a little or a lot, depending on other variables.

Most subwoofer crossovers attempt (or merely profess) to deal with the unknown variables of the main speaker’s response by providing additional controls, including phase, polarity, and separately adjustable low- and high-pass frequency. While it is *possible* that in some cases good results can be obtained by use of these controls, in most cases it is still not possible to achieve the desired blending and integration of the subwoofer and the main speakers. And even in cases where good results can be obtained, there is no way to know how the controls should be set to achieve optimum performance since the required settings are not usually those that would seem logical.

We needed a completely different approach to subwoofer crossovers that was able to take into account the response of the main speakers in order to provide crossover performance that achieves desired results with simple and logical control settings. The conception of the technical means to achieve such performance was the original impetus for the THIEL SmartSub development.

### Room effects

The effects of the third category of problem are well known. Almost every subwoofer installation is plagued by response irregularities that are habitually attributed to “room resonances”. A study of the situation reveals that the majority of serious problems are not, in fact, and strictly speaking, room resonance problems, but rather, *boundary* problems of cancellation and reinforcement. Even though the effects on performance are similar, the distinction is important because it indicates a quite different type of solution. Room resonance problems cannot really be solved by any method other than physically changing the proportions and size of the room. Further, even mitigating the effects with equalizers can only be accomplished for one listener location, with the usual result of worsening the problems for other locations.

In contrast, boundary problems are fundamentally and importantly different. Boundary effects are substantially consistent throughout the room and therefore corrections are improvements for all locations. Also, the effects of nearby boundaries are predictable and therefore can be corrected without measurements. Such a built-in system of boundary compensation is an important aspect of the THIEL SmartSub system.

## SMARTSUB

The most noteworthy features and benefits of the THIEL SmartSubs can be listed in four categories. These topics are the subject of this paper.

- The ability to achieve a near-perfect, seamless transition with any main speakers when used to reproduce the bass range of channels other than LFE, in video or music systems. (Patents pending)
- The quality of bass reproduction; low distortion and very high output.
- The ability to accurately correct the problems of reinforcement and cancellations caused by nearby walls and corners. (Patent pending)
- The ability to correct lowered sensitivity and response changes that are otherwise caused by heating of the drivers' voice coils so that the response remains correct and uncompressed during high demand. (Patent pending)

The first of the above mentioned benefits is implemented with the separate companion crossover unit, the SmartSub Integrator, that can be used to process 2 channels of information and deliver a signal to multiple subwoofer units. The other three of these benefits of the SmartSub system are implemented in the subwoofer unit.

The Integrator is used if the subwoofer is required to reproduce the bass energy in channels other than the LFE channel, for example, in the left/right channels. Such a configuration is desirable if the main speakers either cannot reproduce the full range of bass or if they cannot play at sufficient sound levels without bass distortion.

The Integrator does not have traditional controls for directly controlling crossover characteristics such as slope or phase for either the subwoofer or the main speaker high pass filters. Instead, a different approach is taken. There are settings for telling the Integrator the characteristics of the main speakers being matched, if a main speaker high-pass is desired (crossover mode) or not (augment mode), and what crossover frequency is desired. With this information the Integrator calculates what filter characteristics will provide seamless integration of the sub with the main speakers.

The Integrator has speaker level inputs for use in augment mode and both balanced and unbalanced line level inputs and outputs for use in crossover mode. Signal is supplied to the subwoofer via balanced line level connections.

All signal processing is done with analog circuitry. Digital circuitry is used for user interface, calculation and circuit control functions.

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## OUTPUT ABILITY

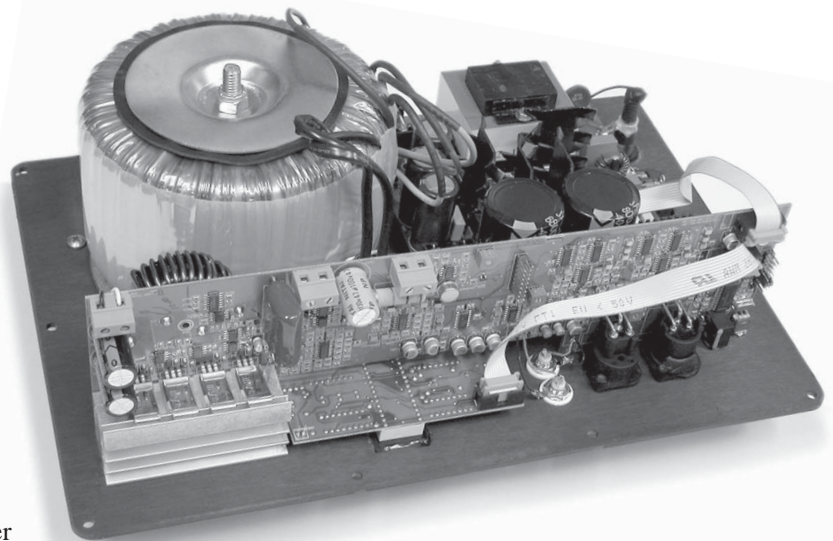
The ability to play deep bass loudly is a function of how much air the drivers can move without excessive distortion, which in turn is dependent on both the size of the diaphragms and their linear excursion. It is important to realize that simply possessing a large *mechanical* excursion is not beneficial if the magnetic excursion is not also large. If the cone can move 1" but the coil comes out of the magnetic gap, the distortion will be very high.

The SmartSubs include two very high excursion drivers with a linear excursion capability so large (1-1/4" pk-pk) that each driver can move considerably more air than most drivers their size.

The specially designed suspension allows a linear mechanical excursion of more than 2" pk-pk so that it does not contribute to non-linearity and distortion.

The SS2, SS3 and SS4 are internally powered with a 1000 watt rms switching mode amplifier to realize the full output ability of the drivers. This type of amplifier provides the benefit of high efficiency, about 92% in this case, which allows smaller heat sinks and power supplies. The sonic quality of this type of amplifier has improved greatly in recent years, to the point where they can provide high sound quality even in full range applications. They are very good for

powered subwoofer applications because they can develop a large amount of power with very little heat and because any residual "digital" distortions occur at high frequencies which are unused in subwoofer applications.



The 1000 watt switching amplifier used in the SS2, SS3 and SS4. This amp includes electronic compensation for room boundary and thermal driver effects.

## DISTORTION

The SmartSub drivers incorporate several unusual design features, utilized in all THIEL woofers, that greatly reduce distortion compared with conventional designs. Here is a brief explanation of three of these.

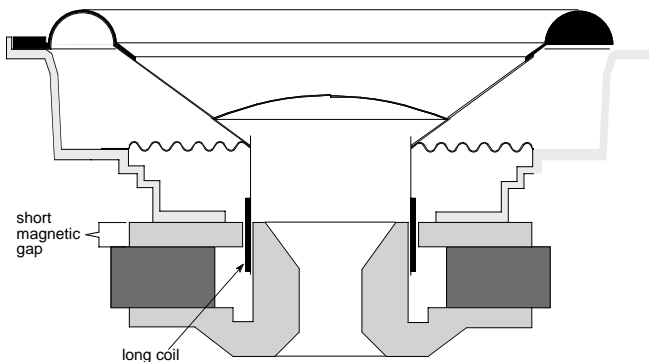
The purpose of the driver's motor system is to apply a force to the diaphragm that is directly proportional to the voltage supplied by the amplifier. In order for the force to be directly proportional to the voltage applied, as desired, three conditions must be met:

- the length of voice coil wire acted on by the magnetic field must be constant,
- the magnetic field strength must be constant,
- and the current in the voice coil must be directly proportional to the applied voltage.

In practice, none of these conditions actually exist and inaccuracy in each is a distortion mechanism. All THIEL drivers incorporate refinements of design that greatly improve the accuracy of each of these three factors.

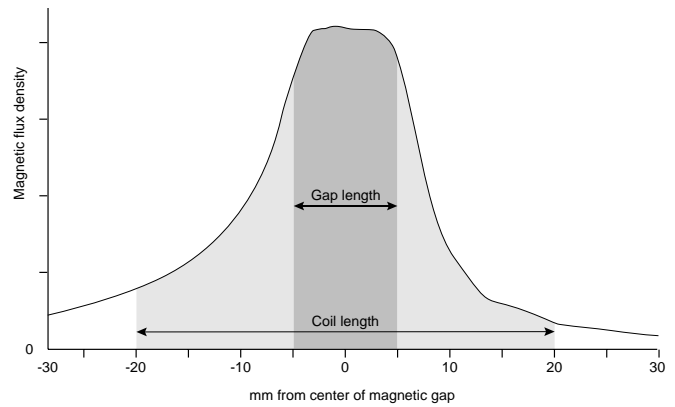
The **first** distortion mechanism results from the fact that almost all drivers use a long coil/short gap motor system where the long coil is acted upon not only by the field within the magnetic gap but also by the "fringe" field in front of and behind the gap region. As the coil moves forward or backward 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.

Conventional long coil/ short gap motor system



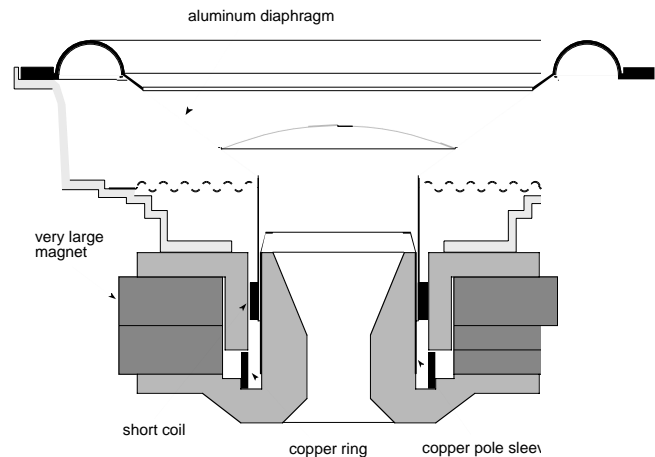
The following graph is the magnetic flux density vs. distance from the center of the gap for a normal, short gap magnet system. You can see that the field in the gap (darker region) is less than half of the total field acting on the coil (all shaded regions) and that the field in the overhung regions (light grey) is not constant with distance from the gap. This produces distortion during movement.

To eliminate this problem all THIEL drivers use an unusual short coil/long gap system where the coil is much



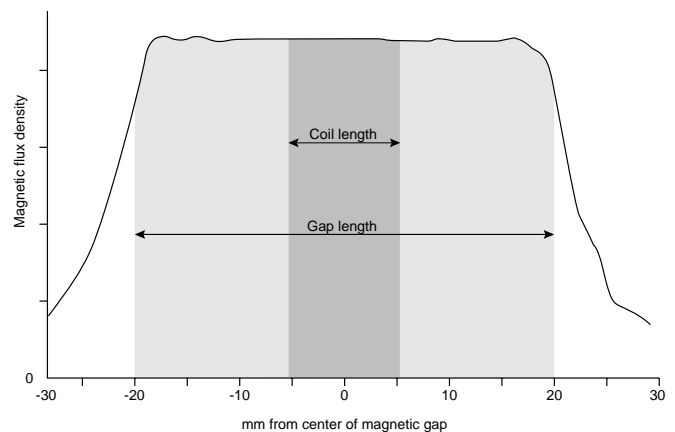
shorter than the magnetic gap. Therefore, even when the coil moves a considerable distance from its rest position, it continues to be acted upon only by the uniform magnetic field in the air gap and does not experience the changes in magnetic field strength with position as in the conventional system. The distortion produced by short coil motor system woofers at normal excursion levels is typically only one-

SmartSub short coil/ long gap motor system

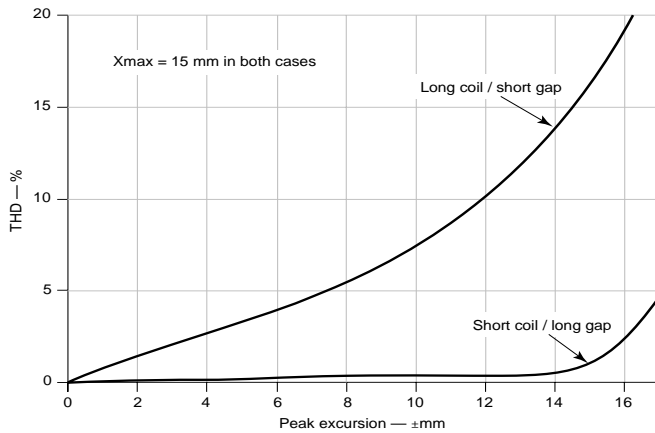


tenth that produced by normal long coil system. The penalty of this approach is that a much larger magnet is needed to power the much longer gap.

In the next graph you can see that as the coil (dark region) moves through the gap (light region) the magnetic field remains constant, greatly reducing distortion produced by this mechanism.

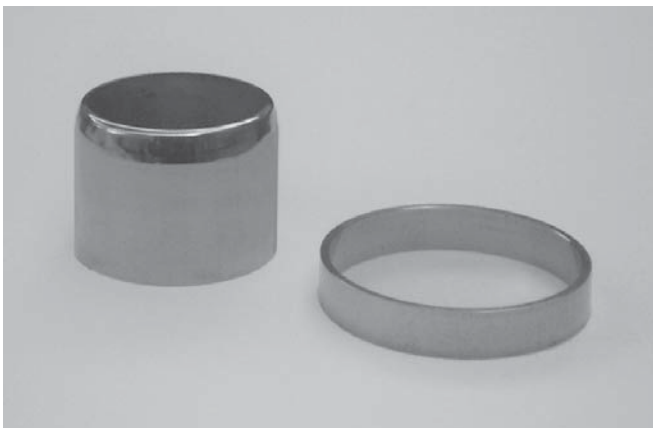


The next graph shows the distortion produced by each of these systems. In both cases the  $X_{max}$  value is 15 mm, meaning the coil should be able to move 15 mm each way without excessive distortion. You can see that the normal system produces 17% distortion at this excursion whereas the long gap system produces less than 2% — only one-tenth as much! Also, at the slightly more normal excursion of 12 mm, the normal system produces 10% distortion whereas the short coil system produces less than 0.5% — a twenty fold improvement.



The **second** 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 SS2 drivers incorporate a thick copper ring around the center pole. With this ring any



Copper pole sleeve and ring used in the SS2 woofers to stabilize the magnetic field strength for reduced distortion.

changes in the magnet's strength induces an electrical current in the ring which generates a magnetic field that is opposed to and practically cancels the original change.

The **third** distortion mechanism is that the voice coil current is dependent not only on the driving voltage and the coil resistance but also on the voice 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 higher 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 a copper pole 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 coil is an iron-core inductor. Since iron is not magnetically linear, the coil's inductance changes with current in the coil and for this reason such inductors are avoided in high quality crossover systems. An additional benefit of the copper sleeve is that since it reduces the coil's inductance it also reduces the distortion associated with changing inductance.



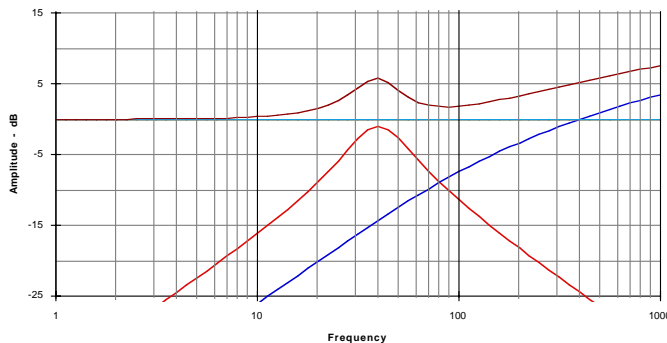
One of two SS2 drivers

## Thermal Compression

Subwoofers achieve deep bass response even though their enclosures are usually quite small in proportion to the driver cone area because they are equalized. Without equalization the response might extend only to 50 Hz or 40 Hz. The lowest frequencies are boosted to provide balanced system response to low frequencies. A consequence of this boosting is that much more power is delivered to the driver than in a normal, unequaled speaker. The power supplied to the drivers at 20 Hz can be 20 or more times normal. This large amount of power results in the coils running hot even during only moderately high demands.

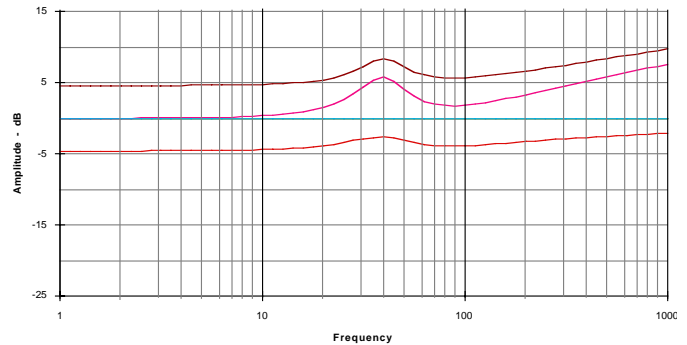
A significant problem stems from the fact that the electrical resistance of copper is strongly temperature dependent, having a temperature coefficient of 0.39%/°C. Therefore, when the voice coil temperature reaches 200°C, the resistance has increased by 70% which causes a reduction in current, and, therefore, output, by 4.5 dB.

The situation is actually more complicated because resistance is only one of three components of driver impedance (although the largest at most subwoofer frequencies), the others being motional and inductive impedance. The following graph shows the total impedance of the drivers in the enclosure and also the resistive, motional and inductive components that combine to produce it.



Total impedance of the SS2 (top line) and its components of resistance (at 0 dB), motional impedance and inductance.

Since the resistance is the only one of these three impedance components that is temperature dependent, the impedance does not increase with temperature uniformly at all frequencies. Where the other components are major contributors to the total impedance, near resonance and at higher frequencies, the impedance does not increase as much as it does at other frequencies. Therefore, the *shape* of the total impedance curve changes and therefore the frequency response changes. The following graph illustrates, from top to bottom, the impedance at 200°C, the room temperature impedance, and the change in frequency response that results. You can see that the sensitivity has decreased 2.5 dB at 40 Hz but 4 dB at 20 and 80 Hz.



Top to bottom: total impedance at 200°C, at room temperature, and the sensitivity change at the elevated temperature.

### A Solution

The SmartSub incorporates a solution that consists of measuring voice coil temperature in real time and using this information to adjust the gain and frequency response of the amplifier to correct the sensitivity and response changes that would otherwise occur. This correction ensures that the output is not compressed or imbalanced during high demand.

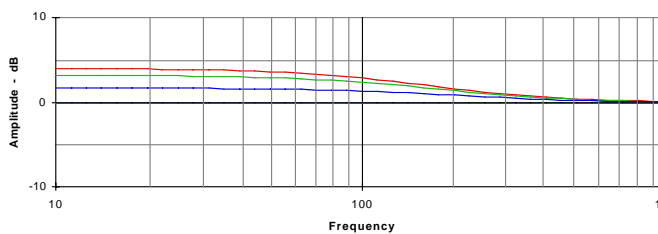


Heat sensor on voice coil

## Wall and Corner Placement Problems

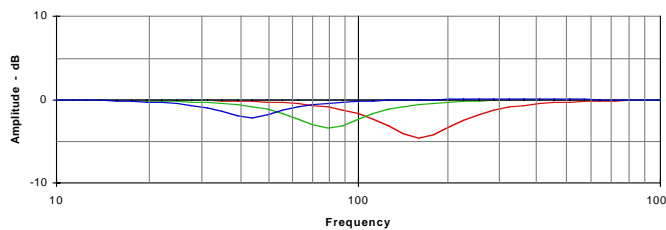
It is well known that placing any speaker, including a subwoofer, near a wall will cause both an increase in bass level and unevenness in the response due to reflection from the wall. The effects of corner placement are more complex than single-wall placement since there are then two sets of low frequency level and reflection effects. In fact, these effects are quite predictable.

The general increase in level affects frequencies below approximately 300 Hz and its degree is dependent on the distance from the wall. It is caused by the fact that the sound radiation is confined to a smaller and smaller solid angle as the speaker's distance to the wall becomes less and less. This effect is illustrated in this graph for wall distances of 1.8, 1.0 and 0.5 meters.

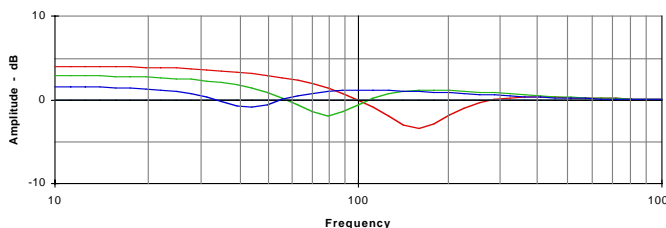


Response changes caused by reinforcement from a nearby wall at distances of 1.8, 1 and 0.5 meters.

The reflection from the wall causes a partial cancellation in a particular frequency range which is determined by the distance to the wall. The severity of the cancellation is determined by the strength of the reflection which is also determined by the speaker-to-wall distance. So, if the speaker is a relatively large distance from the wall, the cancellation will occur at a low frequency and be mild. If the speaker is close to the wall the effect occurs at a higher frequency range and is more severe. This second graph illustrates the wall reflection effect for the same three distances. When both these effects are added together, the result is illustrated in the third graph.



Response changes caused by reflection from a nearby wall at distances of 1.8, 1 and 0.5 meters.

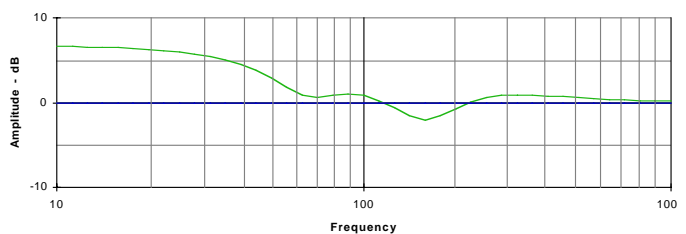


Response changes caused by both reinforcement and reflection from a nearby wall at distances of 1.8, 1 and 0.5 meters.

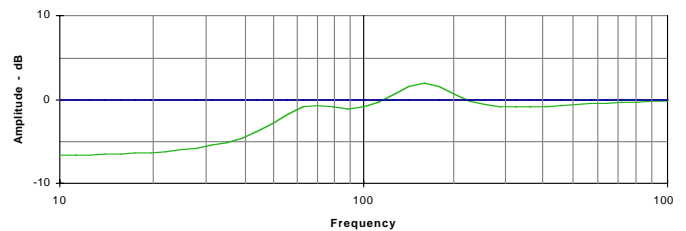
Since all three variables of the boundary effect (degree of reinforcement, cancellation frequency and cancellation severity) are determined solely by the wall distance, they can be accurately compensated for if the wall distance is known.

All SmartSubs incorporate placement compensation whereby one control setting, calibrated in distance from the wall, corrects reinforcement, cancellation amount and cancellation frequency. By incorporating two sets of wall compensation which are independently adjustable, the SmartSubs are able to accurately compensate for virtually any placement.

For example, the fourth graph illustrates the effect of placing a speaker 0.5 and 1.2 meters from a corner. The inverse compensation supplied by the SmartSub for this placement is illustrated in the last graph.



Response change caused by near-corner placement of one-half meter from side wall and 1.2 meters from rear wall.



Correction supplied for a side wall distance of one-half meter and a rear wall distance of 1.2 meters.



## Integration problems

If the subwoofer is to reproduce the bass range of the main channels, in addition to the subwoofer channel, there are major potential problems with the crossover between the subwoofer and the main speakers.

There are two possible ways a subwoofer can be used to reproduce main channel bass: augment or crossover. Augment operation allows the main speakers to operate normally, without a crossover, and the subwoofer is used “fill-in” the deep bass below the range of the main speaker. Crossover mode transfers some of the bass range from the main speakers to the subwoofer. Each of these types of use can be used with two types of main loudspeakers, sealed or reflex. Following are examples illustrating typical results for each case.

*It is assumed that the subwoofer crossover configuration is what I consider optimum for generic filters. The sub low pass (LP) filter is 4th order,  $Q=.5$ , the main speaker high pass (HP) filter is 2nd order,  $Q=.7$ , the HP frequency tracks the LP frequency, and there is also a continuously variable phase control.*

The simplest case is to use crossover with sealed main speakers. In the special case where the crossover frequency is set to the speaker’s limit (-3 dB) frequency, the crossover’s HP will combine with the speaker’s bass response to achieve a total 4<sup>th</sup> order,  $Q=.5$  hi pass response that will, in theory, perfectly cross over with the 4<sup>th</sup> order,  $Q=.5$  sub low pass response. However, in practice, even this simple case is upset by the complication that the sub’s response does not extend to DC. For an 80 Hz crossover, if the sub has a 4<sup>th</sup> order rolloff at 35 Hz, the interactive phase effects will cause the whole bass range to be 2 dB weak (Fig. 1).

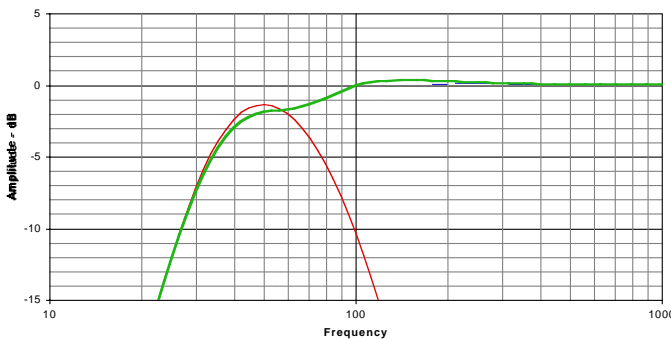


Fig. 1 Subwoofer extending to 35 Hz and crossing-over at 80 Hz with a sealed, 80 Hz main speaker. Standard settings.

Increasing the signal level to the sub solves this problem, but the system response still suffers from excessive output in the 100 - 200 Hz region.

In the more general case where the crossover frequency is higher than the main speaker’s frequency, the results are not as good. For example, if the main speaker’s response extends to 50 Hz and the crossover is at 80 Hz, the bass

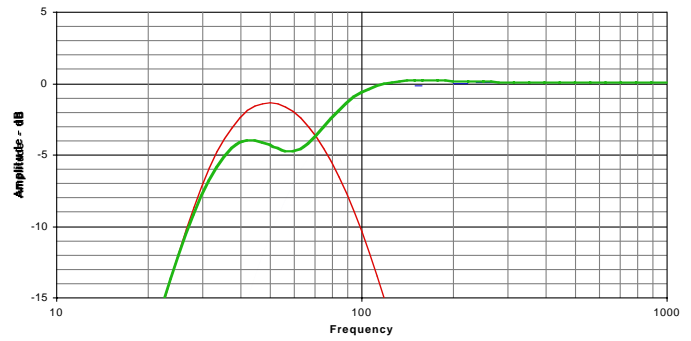


Fig. 2 Subwoofer extending to 35 Hz and crossing-over at 80 Hz with a sealed, 50 Hz main speaker. Standard settings.

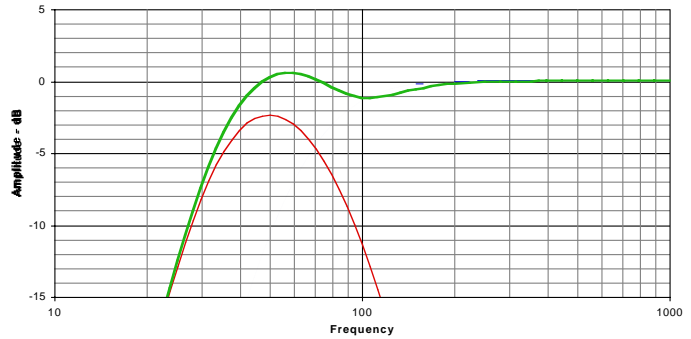


Fig. 3 Subwoofer extending to 35 Hz and crossing-over at 80 Hz with a sealed, 50 Hz main speaker. Optimum phase and level adjustment.

response is 4 dB weak (Fig. 2). Even when the phase and level are adjusted to be optimum ( $180^\circ$ , -1 dB) the response is not nearly ideal (Fig. 3).

In cases where the main speakers are ported, things are no better. For example, if the main speakers are tuned to 50 Hz and you want to implement an 80 Hz crossover with the sub extending to 25 Hz, the results achieved without phase adjustment are not what is desired. Even when the phase control is set optimally ( $80^\circ$  @ 50 Hz) the results are not good, giving a hump in the bass while still giving weak upper bass (Fig. 4).

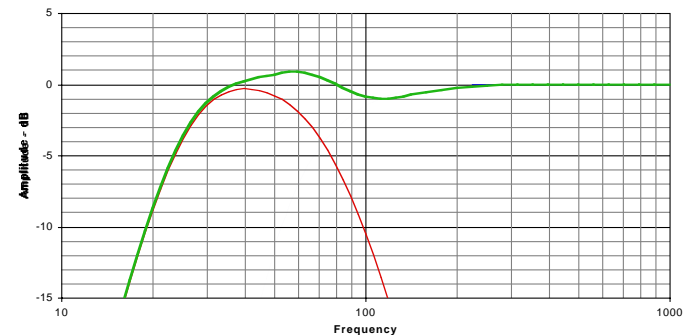


Fig. 4 Subwoofer extending to 25 Hz and crossing-over at 80 Hz with a reflex, 50 Hz main speaker. Optimum phase and level adjustment.

If you want the sub to *augment* the main speakers, without adding a high pass into their response, the results are usually even less desirable. If the main speaker is a reflex type at 50 Hz and the sub extends to 30 Hz, the bass is very weak without a phase adjustment (Fig. 5); the polarity must be reversed to get good results.

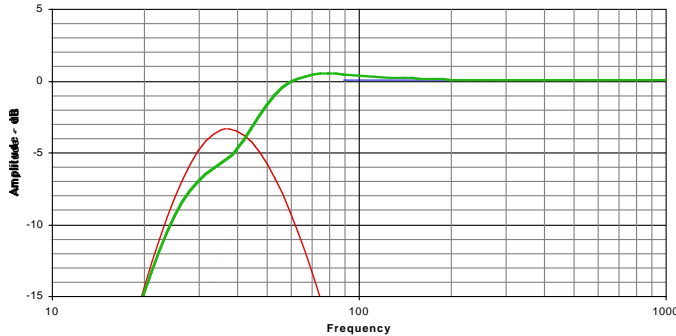


Fig. 5 Subwoofer (attempted) extending to 30 Hz augmenting a 50 Hz reflex main speaker. No phase adjustment.

In the case of augmenting a sealed system, it is usually not possible to obtain good results. For example, a 50 Hz speaker will produce a severe null at the crossover frequency without a phase adjustment (Fig. 6). Even with optimum phase and level, the results are an exaggerated mid bass and a lack of deep bass (Fig. 7).

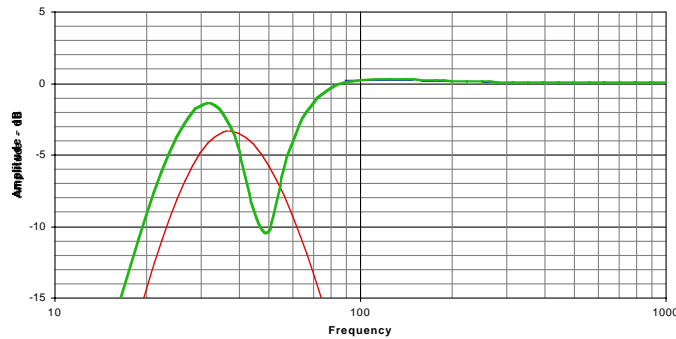


Fig. 6 Subwoofer augmenting to 30 Hz a 50 Hz a sealed speaker. No phase adjustment.

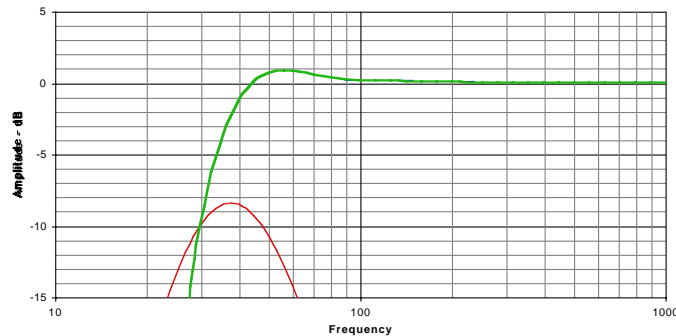


Fig. 7 Subwoofer (attempted) extending to 30 Hz augmenting a 50 Hz sealed main speaker. Optimum phase adjustment.

These examples illustrate the typical problems inherent in matching a subwoofer to other speakers:

- “Logical” settings do not give the desired results
- It is not known which level and phase control settings will give optimum results. They must be adjusted without rhyme or reason by trail and error
- Optimum results are usually not very good.

## A solution

Our desire was to take the guesswork out of subwoofer crossover adjustments and to be able to easily achieve accurate results with any main speaker. The approach we have taken to achieve this goal is different from all others. Rather than telling the subwoofer how to perform by using controls for crossover frequency, level and phase, the THIEL subwoofer crossover unit has settings for the characteristics of the main speakers you are matching, the configuration of your system and the performance you desire. This information is then used to calculate and provide the ideal subwoofer response and hi-pass filter response that will give very accurate results with your main speaker.

There are two component techniques that are used to achieve these results.

1) Determining what LP filter characteristic for the subwoofer will perfectly match the HP characteristic of the main speaker, either HP filtered in crossover mode, or not filtered in augment mode.

2) If a HP filter is supplied for the main speaker signal, determining what filter will, when combined with the response of the main speaker, provide a total response that perfectly matches the desired 4th order,  $Q=.5$  response.

Once the crossover unit knows the characteristics of the main speakers, it calculates and implements crossover rolloff shape, slope, phase and HP as needed to achieve perfect results. Not only does the crossover calculate and implement the optimum setting for the subwoofer cut point, slope and phase, but these characteristics are not limited to those of standard filter shapes and instead can be whatever filter shapes will give the desired results.

As an example of the first technique of generating subwoofer response that will blend correctly, Fig. 8 illustrates the subwoofer augmenting a 50 Hz reflex speaker, extending the bass response to 30 Hz. As is true in every case, the results in this case are essentially perfect. These excellent results are achieved because, in addition to the crossover automatically calculating the optimum phase response, the response shape of the subwoofer is exactly that shape needed to perfectly integrate. For comparison, the dotted graph shows the response that a generic filter would provide. You can notice the somewhat lower output level around 30 Hz and a somewhat higher and more gentle rolloff slope. This “custom” slope is automatically generated and is exactly what is needed to match this main speaker.

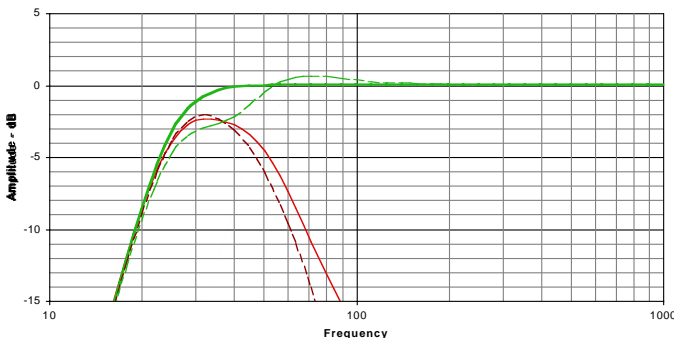


Fig. 8 50 Hz reflex main speaker response; SmartSub woofer response; net combined system response. Dotted is generic filter response.

Another example illustrates this “custom” slope ability of the crossover unit. If the sub is augmenting a sealed 60 Hz speaker, the crossover again provides the output that will produce exactly the desired combined output (Fig. 9). Again, the dotted line shows what a generic filter would provide and, in this case, the difference is large. The proper curve provides more output below 25 Hz and less above, with a slightly more gentle slope.

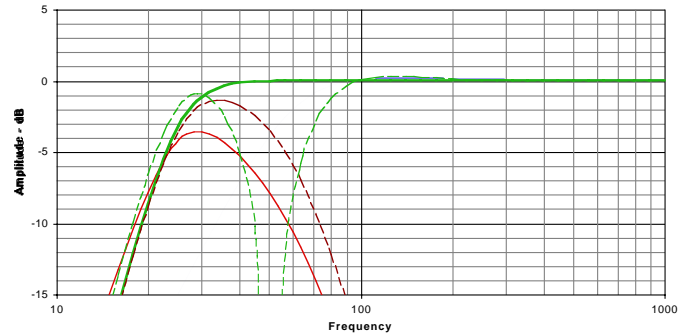


Fig. 9 60 Hz sealed main speaker response; SmartSub woofer response; net combined system response. Dotted is generic woofer filter response.

The following example illustrates the second technique of providing a special HP response that will combine with the speaker’s response so that the *total* response is correct. If an 80 Hz crossover is desired with a 60 Hz sealed main speaker, the HP supplied by the SmartSub crossover is an unusual shape that resembles an 80 Hz 4th order above 60 Hz and a 2nd order below (Fig. 10).

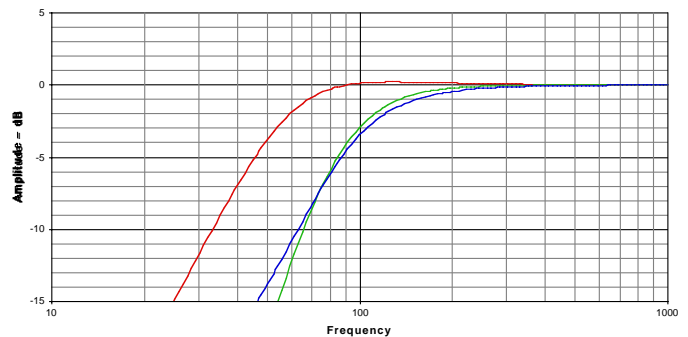


Fig. 10 60 Hz sealed main speaker response; SmartSub crossover response supplied; net 80 Hz 4th order  $Q .5$  response.

If the same crossover is desired with a 60 Hz reflex speaker, you can see in Fig. 11 that the supplied HP shelves below 60 Hz so that, again, the response of the filter combined with that of the speaker will have the desired 80 Hz, 4th order characteristics.

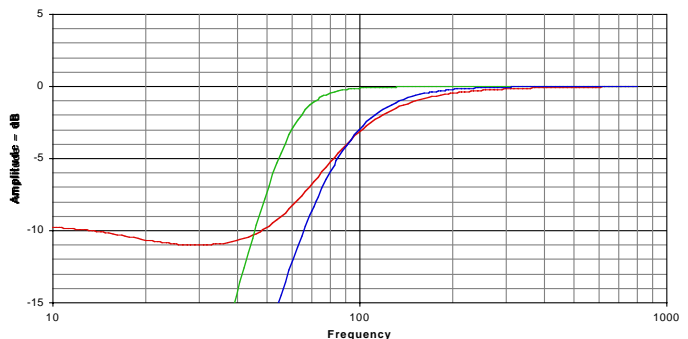


Fig. 11 60 Hz reflex main speaker response; SmartSub crossover response supplied; net 80 Hz 4th order  $Q .5$  response.

THIEL is pleased and excited to offer these new technologies to solve the common subwoofer problems of integration and room placement. Please contact us if you have additional questions.



SmartSub Integrator

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