Audio *perfectionist* Journal

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Issue #2

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This issue builds on concepts that were presented in Issue #1. It's not absolutely necessary to have read the first issue in order to benefit from the information offered in this one, but it's a good idea.

Subwoofers From a High-End Perspective

Introduction

Suppose I told you that you could add two components to your system that would reduce intermodulation distortion in the midrange by a factor of two or more, dramatically improve the resolution of midrange and high frequency detail, double or triple the dynamic range capability of your system without changing your existing amplifier or speakers and improve imaging more than you can imagine. You would probably be interested, right? But wait, there's more.

These same components would allow the amplifier to maintain tighter control over the speakers in the mid-bass and lower midrange. They could extend bass response to infrasonic frequencies while lowering bass distortion and improving the system's ability to accurately convey the rhythm and pace of music. And these same components could virtually eliminate the uneven response at lower frequencies caused by room standing waves.

Does all that sound too good to be true? Are you concerned about the possible cost of all this improvement? If all this is so easily achievable, are you wondering why you've never heard about it before?

Let me assure you that all these sonic improvements can be yours and I've been conservative in my estimates of the level of audible improvement you'll get. You can have all this for $2,500 and you can upgrade in two steps of $1,250 each. If you are starting from scratch, you may actually reduce the cost of a complete system by purchasing a less expensive amplifier and a lower cost speaker model, along with these components, and end up with better overall performance. Few people have figured this out and fewer have spread the news, but it's all true.

Of course the components I'm talking about are a pair of powered subwoofers—but not just any subwoofers. These subwoofers need to have some special characteristics which we'll get to in a minute.

Subwoofers?

I'm sure you are shaking your head in disbelief right now, and thinking that I've lost it. You may have auditioned some popular subwoofer models and been less than impressed with their performance and I won't disagree. Most subwoofers available today are simply unacceptable for use in a system designed for critical music listening.

Yes, we have all heard those thunderous thudpuckers, commonly called subwoofers, that add to the excitement of movie sound and simply ruin the sound of music. How can I claim that these things can actually be beneficial in a high-end audio system?

Here are two reasons that your experience may conflict with my statements: most subwoofers weren't designed for good musical performance, and most dealers set subwoofers up poorly, on purpose.

When properly integrated with the system, subwoofers blend seamlessly with the main speakers and don't make their presence known. But that's a very hard sell to the average consumer and selling is the name of the audio game. Subwoofers are supposed to add bass, right?

After their initial forays into the market, few manufacturers continue to try to make subwoofers that accurately represent music. Why try to educate consumers when it's easier to just give them what they think they want? Boom!

Subwoofer makers soon learned what dealers had already figured out: if they can't hear it woof they won't buy it. Manufacturers started to build subwoofers with high-Q alignments and vents in order to provide more "slam." Dealers started to set up their demonstrations for maximum thump, and maximized sales figures. Awareness of the basic concepts of specialized bass reproducers faded or was suppressed.

Home theater exacerbated this situation. People today expect a subwoofer to rattle their fillings and the exaggerated bass that most subwoofers deliver is incompatible with accurate music reproduction.

But there is more to bass than boom—bass is the foundation of all music. And there is more to subwoofers than bass. They reproduce bass frequencies to be sure, but bass extension is possibly the least of the sonic benefits offered by good powered subwoofers.

Why Good Subwoofers Improve Sound

In order to provide the benefits mentioned at the beginning of this article, subwoofers must utilize a dedicated bass amplifier, and the main amplifier and speakers *must* be high-pass filtered using a passive, first-order device.

A high-pass filter does just what you would expect: it allows frequencies above the cut-off point to pass, and blocks frequencies below that cut-off point. The attenuation of a first-order filter is 6dB per octave. That means that the signal will be reduced in amplitude by 6dB, one octave below the crossover or cut-off point. If the crossover point is 80Hz (-3dB), the signal level at 40Hz will be -6dB relative to the signal level at 80Hz, and -9dB relative to the signal level in the midrange. The signal amplitude will continue to fall at a rate of 6dB per octave as the frequency decreases.

A passive, single-pole filter at the input to the amplifier is the only sonically transparent way to high-pass the main speakers.

The subwoofer amplifier will require a low-pass filter to prevent frequencies above the selected crossover point from being sent to the subwoofer. A low-pass filter passes low frequencies and blocks higher frequencies.

A subwoofer with an internal amplifier, commonly called a powered subwoofer, will require electronic compensation to allow both infrasonic response and acceptable dimensions for home use.

Given these stipulations, a pair of powered subwoofers can provide the following benefits:

1. Better performance from your speakers.

Full range loudspeakers utilize the same driver to reproduce both the bass range of frequencies and at least part of the midrange. For optimum reproduction of midrange frequencies little cone movement is required, and a relatively small driver is necessary to provide quick response and good dispersion.

Low frequencies require lots of air movement, demanding greater cone area and more cone movement. In engineering terms, the back-and-forth movement of the cone is called excursion. Cone excursion quadruples with each halving of frequency.

Good midrange reproduction requires the use of moderately-sized drivers and good bass reproduction requires lots of cone area, so most full range speakers compromise the quality of both bass and midrange by utilizing woofers that are too small to provide good bass yet too large to deliver the best midrange quality.

The cone of the 8-inch or 10-inch woofer typically found in a full range loudspeaker will be required to make peak-to-peak excursions of perhaps an inch to deliver audible levels of output at 40Hz and it will have to do this while producing 300Hz (or higher) midrange signals *at the same time*. A 6.5-inch woofer will make a better midrange driver but it will have to work even harder to deliver low frequencies and IM distortion in the midrange will rise.

Intermodulation distortion occurs when one frequency modulates (alters by its frequency) another. Peak-to-peak cone excursions of an inch or more, which may be required to reproduce a 40Hz signal, will have a substantial effect on a signal at 300Hz. The 300Hz signal will increase slightly in frequency when the cone is moving towards the listener to reproduce the 40Hz portion of the signal, and decrease in frequency when the cone is moving away from the listener. This is only one mechanism of IM distortion, which is sometimes called Doppler distortion. There are other forms of IM distortion.

All dynamic drivers exhibit some nonlinearity in outward versus inward cone movement. High cone excursion exacerbates nonlinear driver response and causes harmonic distortion. Harmonic distortion occurs when a harmonic (multiple) or side-band of the desired signal is produced due to nonlinear behavior of the electrical, magnetic or mechanical mechanism of the driver. If you want to reproduce 40Hz and you get some output at 160Hz as well, that's harmonic distortion.

The results of high excursion of the woofer cone are intermodulation distortion of the midrange signal and increased harmonic distortion of the bass signal. And there's more.

The small woofers required to maintain reasonable midrange performance in a full range speaker don't do a very good job of reproducing the lowest bass frequencies but they do put a lot of energy into the speaker cabinet structure and this is very detrimental to sound quality.

As the woofer cone makes these large mechanical movements to pressurize and rarefy air, an equal and opposite force is applied to the woofer basket, or frame, which is attached to the speaker structure. This force excites resonances in the cabinet structure and tries to move the whole speaker back and forth. Cabinet resonances color the sound in the midrange. Cabinet movement distorts high frequencies.

A backward and forward motion of just a few thousandths of an inch may represent a major percentage of the total excursion of the tweeter diaphragm as it attempts to reproduce subtle high frequency details. The result of structural movement is IM distortion of the midrange and high frequencies.

If you are skeptical about the sonic consequences of woofer energy moving the speaker cabinet, think about speaker spikes. A reduction in cabinet motion is the main reason that spikes beneath the speaker improve sound. Remove the spikes and see (no, hear) what happens.

As you can see, a full range loudspeaker is a bundle of compromise. It is asked to perform many conflicting tasks. There is an old Chinese proverb that goes something like this: "man who chase two rabbits have no meat for dinner." By the same token, a speaker that tries to provide both bass and the rest of the spectrum compromises the quality of both.

A single-pole, passive high-pass filter at the input to the amplifier can cure or minimize all these speaker problems and improve performance dramatically. This sonically transparent filter will reduce woofer cone excursion which will reduce distortion in the bass, midrange and treble as described above. The result will be better definition, better imaging, tighter control, greater dynamic range and a better presentation of the rhythm and pace of music. The only thing missing—besides distortion—will be low bass and that will be reproduced by specialized devices designed just for that purpose—powered subwoofers.

2. Better performance from your amplifier.

The major energy demands in music occur at low frequencies. The major current demands from an amplifier are at low frequencies. When an amplifier distorts because of demands for power that it cannot meet, the output waveform is flattened at the top and bottom. This distortion is called clipping because the positive and negative signal peaks have been "clipped" off.

Amplifier clipping becomes evident at high frequencies but clipping is almost always caused by energy demands at low frequencies that exceed the capability of the amplifier.

Clipping is the primary cause of speaker damage because a clipped waveform "fools" the crossover network in the speaker which then passes high power to the high frequency drivers.

An amplifier in normal use will be clipping at least occasionally. The percentage of time that the amplifier is driven to the point of clipping or beyond will have a profound effect on sound quality. As the amplifier approaches clipping the sound will become slightly hard, then harsh, and then, as the amplifier clips, a shattering distortion will be heard. This distortion eventually destroys tweeters and crossover networks.

A single-pole, passive high-pass filter at the input of the amplifier can eliminate all these distorted sounds and make the amplifier sound smoother and more relaxed. The amplifier may seem to be three times more powerful. Removing the huge low frequency current demands from the amplifier, by reducing the level of the input signal at low frequencies, allows the amp to coast along with lots of power in reserve. The system will play at much higher levels with much lower distortion, providing a greatly improved listening experience.

The high current necessary for accurate bass reproduction will be provided by specialized amplifiers designed just for this purpose—the amplifiers in the powered subwoofers.

3. Better bass.

Designing a product to perform a very specific task requires less compromise. Subwoofers are designed to reproduce a small range of frequencies at the lowest audible range. That's about as specific as it gets in audio.

When compared to full range speakers, powered subwoofers can provide the following advantages: more cone area, greater linear excursion capability, more amplifier power at low frequencies, and electronic compensation for falling output at the lowest frequencies. Subwoofers can also have smaller, stiffer, less resonant enclosures and can be placed in the optimum position to introduce bass energy into the room.

Eliminating the compromised bass output from the main speakers by high-pass filtering the input signal to the amplifier will dramatically improve the quality of reproduction in the mid-bass range. Improving the mid-bass provides a better sense of rhythm and pace and makes it easier to follow the tune of the bass.

4. Better room interface.

The pressure-zone microphone (PZM) was developed after it was determined that smooth frequency response at lower frequencies could not be obtained from a stand-mounted microphone due to interactions with the room boundaries. Placing a conventional microphone on the floor smoothed the response curve but caused a gradually rising bass output. Compensating for this bass rise gave us the PZM microphone. A similar effect occurs with speakers.

For good imaging and midrange detail full range speakers must be placed well out into the room. Bass response from these speakers will be uneven due to room interaction. This phenomenon is frequently attributed to "standing waves."

Removing bass from these speakers and redirecting it to a subwoofer placed in the corner of the room will ameliorate most of these room anomalies. The subwoofer will load the room from a pressure zone, smoothing response across the bass range. Adding a second subwoofer, placed in a second corner, allows low frequencies to be introduced from two different positions within the pressure zones of the room virtually eliminating bass irregularities. (You must remove other sources that store and release energy at low frequencies as described in the room treatment article.)

5. Reduced system cost.

In a given manufacturer's amplifier line, the more expensive models usually offer more power and little else. In fact, smaller amplifiers frequently sound better than their big brothers and they always cost less.

The Levinson 33H mono amps that I use cost about $15,000 less than the Reference 33 amplifiers from the same company. Both models are essentially the same design, with the larger version offering only higher output power.

Most loudspeaker manufacturers offer a range of models that differ only in their ability to produce bass. Bigger, more expensive models provide extended bass response with bigger woofers and larger cabinets. Except for bass extension, it's not unusual to find that the smaller models in a given line of speakers actually sound better because they have smaller woofers that offer better midrange performance and the smaller cabinets add less box sound. Compare the smaller Dunlavy models to their larger brothers for example.

The Vandersteen 3A Signature speakers that I use in conjunction with a pair of 2WQ subwoofers deliver 90% of the performance of the Vandersteen Model 5s for 60% of the price (3A Sigs and two 2WQ subwoofers cost about $6,000 and Model 5s sell for about $10,000). My speaker system delivers a time- and phase-accurate response over a usable range of 18Hz to 30kHz. What other speakers can offer that for $6k?

Some reviewers claim that the 3A Signatures lack the "detail and definition" of the Model 5s. You may find this puzzling because both models share identical midrange and tweeter drivers and use essentially the same crossover network in this range. Why the perceived performance difference? Model 5s have a slightly more inert cabinet structure and they have *built-in, powered subwoofers.*

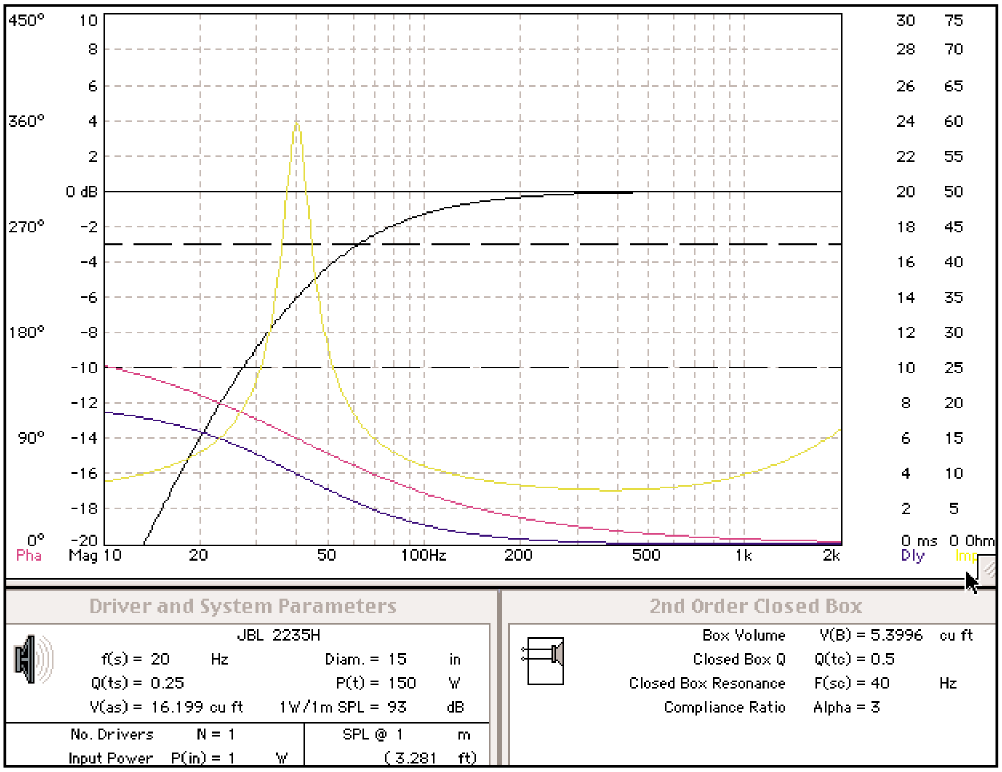
The use of powered subwoofers can allow a smaller amplifier and a pair of lower-priced speakers to equal or outperform their more expensive counterparts. The result is better sound for less money. Who doesn't want that?

Why Most Subwoofers Don't Work Well for Music Reproduction

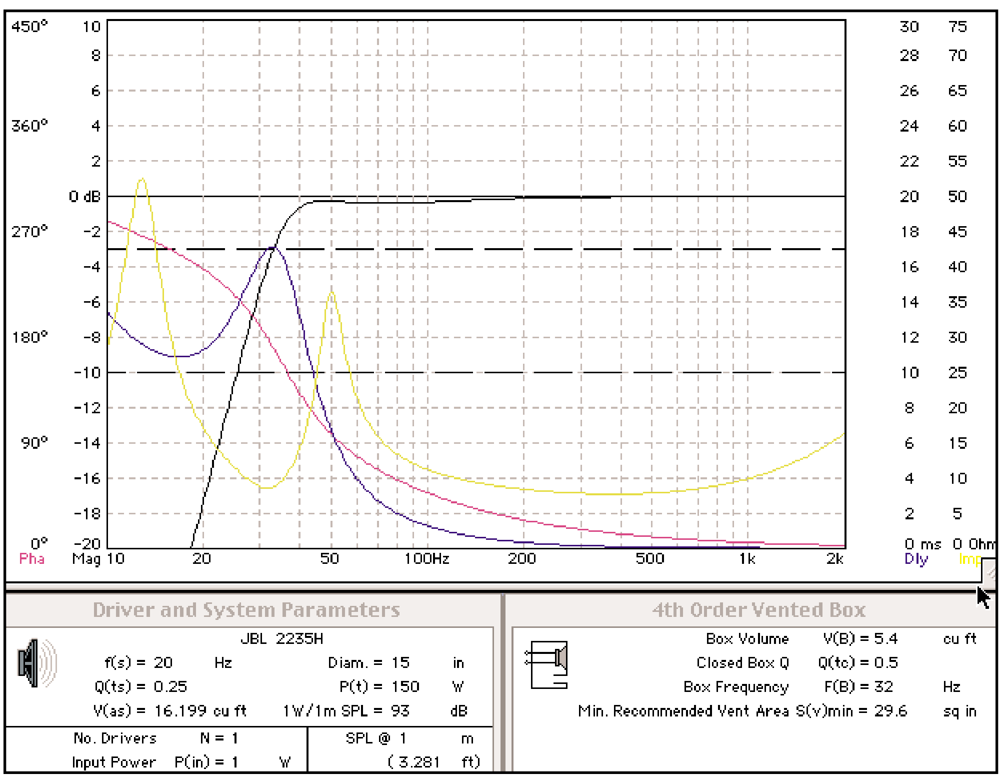
Not so many years ago, few people were aware of the concept of specialized bass speakers. Explaining what a subwoofer was and the sonic benefits it could provide were difficult tasks before the home theater craze hit the public. Today, people are rushing to add subwoofers to their audio systems to provide the visceral excitement that only thunderous bass can supply.

Thunderous bass output makes an on-screen explosion or gun shot more physically involving but it can also alter the tonal balance, as well as the rhythm and pace, of music. Most subwoofers seem to march to the beat of a different drummer instead of the one who is playing with the orchestra.

Today the average consumer believes that



These illustrations compare frequency response (black trace), phase response (purple trace), impedance (yellow trace), and group delay (blue trace) for the same JBL 2235H 15-inch driver mounted in a second-order sealed enclosure (above) and in a fourth-order vented enclosure (below). You can learn a lot about the performance trade-offs involved in the choice of vented versus sealed enclosure design from studying these graphs. In my opinion, the trade-offs make vents acceptable for use in full range speakers and totally unacceptable for subwoofers that are meant to reproduce music. A conventional vented design offers inferior performance in every area except one: output level capability.



the only purpose of a subwoofer is to add bass and many music purists derisively refer to them as "fart boxes."

There are many reasons why boom-box subwoofers may do a good job of reproducing explosions and perform poorly when reproducing music.

1. Phase shift and group delay cause subwoofers to start late.

Picture a marching band with the bass drum following about a block behind the rest of the players and you've got a pretty good image of the major problem with most subwoofers—the sound they produce is just out of step with the rest of the music. There are many reasons for this but most revolve around phase shift and group delay.

Acoustic phase in this instance has to do with the time relationships of the launch of air pressure waves towards the listener. Phase shift that varies with frequency alters the time relationships between different frequencies. A resonance in the pass band causes phase shift. Filters cause phase shift. A speaker in a box is a filter.

When two elements like a subwoofer and a main speaker have an overlapping frequency range, or are reproducing different parts of a single note, such as the fundamental and the harmonics of that fundamental, you want both to be in step. If the subwoofer cone pushes out when the main speaker's woofer cone is moving inward, things get out of sync.

Group delay is a complex concept. It is the negative of the derivative of the phase curve with respect to radian frequency. Group delay describes how well the time relationships between a small group of frequencies are preserved within a narrow range of frequencies. Time delay and group delay are not necessarily equivalent but a delay to one group of frequencies changes its time relationship to the rest of the spectrum.

Look at the illustrations on page 17 comparing phase response of vented and sealed enclosure designs. Trying to synchronize the phase of the main speakers and the subwoofer will be difficult with a sealed enclosure subwoofer design and virtually impossible with a vented design because of phase shift as the system passes through resonance in the pass band. Note the 17ms group delay at the 32Hz tuning frequency of the vented design.

Subwoofers with a fundamental resonance in the pass band and a steep slope low-pass filter at the input will produce output that is delayed in time relative to the main speakers, and this delay will vary with frequency.

Subwoofers that start late sound slow and plodding. They distort the overall waveform even if their own distortion products are low.

2. High Q makes subwoofers stop late.

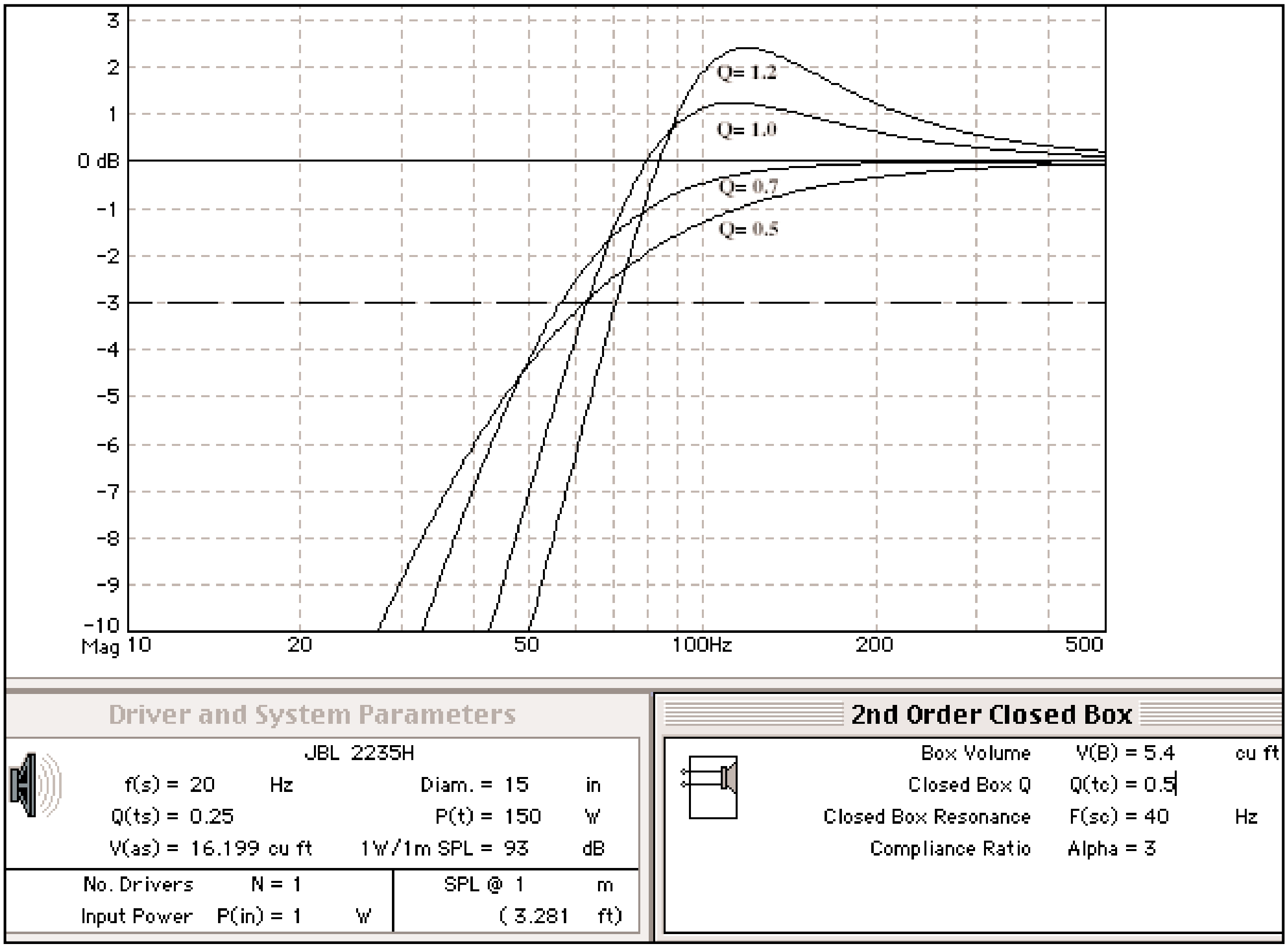
An electrical filter will oscillate or ring, to some extent, after the signal stops. The steeper the slope of this filter, the more it will ring. The higher the "Q" of this filter, the more it will ring.

Mechanical filters work the same way. In fact, all the mechanical properties of a loudspeaker can be expressed with electrical equivalents and modeled by electrical circuits.

A woofer in an enclosure is a high-pass filter. It passes frequencies above the cut-off or low frequency limit of the design and the signal rolls-off below this point at a rate determined by the design. A sealed box acts as a nominal second-order high-pass filter and a vented enclosure will typically display fourth-order high-pass characteristics. The vented design will ring (oscillate) about twice as much as the sealed design after the signal stops.

The "Q" of the mechanical system affects oscillation, too. System "Q" defines the shape of the response curve and the amount of damping to overshoot or ringing (oscillation after the signal stops) that the system will provide.

A sealed enclosure with a Q of .5 is considered a "critically damped" alignment with a step response that has no overshoot. For a given driver, a Q of .5 requires the largest box. This low-Q alignment has a downward-sloping response curve but offers the best possible transient performance and the lowest frequency extension at -10dB.



This illustration shows the effect of system Q on frequency response. Notice that the low-Q alignments start sloping down sooner but ultimately extend lower in frequency at the usable low frequency limit of -10dB. Remember that the low-Q alignments provide far better damping to oscillation after the signal ceases.

A system Q of .577 is a Bessel alignment which has the most linear phase response and offers slightly less damping.

When Q =.707 we have a Butterworth alignment with the flattest amplitude response. This is the most common alignment for “high-end” subwoofers because it offers a “full” sound which is still well controlled.

System Q near 1.0 delivers a peaked response but allows the smallest box size still considered by some to be high-fidelity. A subwoofer with a system Q over 1.0 is a boom box with a peaked response curve and lots of overhang. Guess where most home theater subwoofers fall.

Subwoofers that play on after the signal has stopped (due to oscillation), sound slow and muddy.

The Q and slope of the high-pass filter formed by the subwoofer acoustical system has a major effect on the sound of the bass the subwoofer produces, but there’s more. The subwoofer is a mechanical high-pass filter but it must be used with an electrical low-pass filter and those cause problems as well.

3. Steep filter slopes and direct-radiating drivers.

Most subwoofer designs include one or more drivers that radiate directly into the room. It’s commonly assumed that subwoofers shouldn’t be allowed to encroach on the midrange where they perform poorly so the conventional wisdom mandates a steep-slope low-pass filter to prevent output above the bass region. There are some drawbacks to this approach.

A low-pass filter with a fourth-order slope will cause another complete phase rollover, increasing signal delay. Even with this steep attenuation curve, side band distortion will still be audible if the driver radiates directly into the room.

All drive elements will break-up (display non-pistonic cone behavior) at some frequency. Filtering below this frequency prevents the signal from stimulating this behavior. Many other anomalies such as cone resonances, surround reflections and "flapping," magnetic nonlinearities and basket ringing will remain audible as side-band distortion even without frequency-specific stimulation. And some midrange frequencies will still pass through the filter at attenuated levels.

Midrange signals (even at low levels) and side band distortion detract from the quality of sound from the main speakers and draw attention to the position of the subwoofer which should be spaced away from the main speakers.

4. System resonance in the pass band.

Removing resonances from audio components is generally considered to be a good idea but subwoofers are designed to create resonance.

A vented subwoofer has two resonances right in the middle of its pass band. The vent resonance is tuned to play at frequencies where the output of an unassisted driver would be falling. Much of what you hear from a vented design is a production of the subwoofer rather than a reproduction of the signal.

Sealed enclosures are better with only a single resonance in the pass band. One is better than two, as you can see from the graphs on page 17, but none is better yet as we'll see later.

When the subwoofer passes through a resonance a big shift in phase occurs. Look at the graphs of phase response for sealed and vented enclosure designs and see the effects of resonance on phase. (System resonance occurs where the impedance peaks. Note the single peak in the graph of the sealed enclosure and the dual peaks in the graph for the vented enclosure. The dip between the impedance peaks indicates the tuning frequency of the vented enclosure.)

Subwoofers with a resonance in the pass band will tend to emphasize the frequencies around this resonance. The higher the Q the greater the emphasis. Ever hear the term "one-note bass"?

5. Dissimilar amplifiers for high and low frequencies.

A powered subwoofer may have an internal amplifier that is designed for optimal performance when driving the specific load of the subwoofer drivers. This amplifier will almost always have electrical compensation for the falling response of the subwoofer driver(s) which will typically be housed in an enclosure that is smaller than ideal—because nobody wants a subwoofer the size of a refrigerator in their living room.

A perfect subwoofer amplifier and the amplifier that is best suited for driving the main speakers may be very different electrically and sonically. For instance, a bipolar solid-state amplifier will offer the best performance for bass but a MOSFET or tube amplifier may sound better driving the main speakers.

Transfer function is a measurement that compares the frequency and phase response of the output from a device under test to the input signal. If the transfer function of the main amplifier is very different from the TF of the subwoofer amplifier, this sonic dichotomy may have a negative impact on overall sound quality.

Making a Subwoofer to Play Music

A subwoofer should march in step with the rest of the band and stop playing when the song has ended. Most do neither.

Subwoofers should be positioned in the room corners to properly load the room from pressure zones, creating the smoothest bass response. If the subwoofer has a "Q" higher than .5 (most do) it will exhibit a rising response when placed in a corner.

So how can a subwoofer be designed that

doesn't suffer from the performance deficits described above?

We can eliminate the problem of subwoofers that start late by blending the subwoofer and the main speakers using a first-order crossover for transient-perfect phase response. This filter system can be implemented in an unusual way: the high-pass section can be placed at the input to the amplifier driving the main speakers and the subwoofer amplifier can sample the output from this amplifier, including its sonic signature and phase characteristics. The subwoofer amplifier can have its frequency response tailored to compensate for the falling response of the input signal and the falling response of the acoustic system that is operating primarily below system resonance. (More about that in a minute.)

Blending the amplifiers in this way will ameliorate the discontinuous sound created by dissimilar amplifier designs driving different parts of the spectrum.

We can eliminate the overhang of subwoofers that stop late by designing for a target Q of .5 to achieve critical damping, along with the greatest usable bass extension, and to allow corner placement without a rising low-end response.

The driver(s) can be slot loaded to mechanically filter out side band distortion and midrange frequencies. And the system can be designed to operate primarily below the fundamental resonance so that no resonance can cause sonic emphasis or phase shift in the pass band.

This all makes perfect sense and I'd like to take credit for thinking it up all by myself. But I didn't—Richard Vandersteen did. What I have just described is the Vandersteen 2WQ powered subwoofer which has been subtly but continuously refined since it was first brought to market sixteen years ago. It is the most sophisticated product of its kind available today.

The Vandersteen 2WQ Subwoofer

The Vandersteen 2WQ subwoofer is completely unique in a number of ways. It takes advantage of the fact that loudspeakers in sealed enclosures offer very predictable amplitude and phase response characteristics at frequencies below the fundamental resonance of the system. The 2WQ operates primarily below fundamental system resonance to provide frequency and phase linearity that cannot be achieved by conventional designs with resonances in the pass band.

It uses a phase-perfect first-order crossover with special characteristics. The 2WQ samples the output from the amplifier that is driving the main speakers for better system integration.

It uses feed-forward error correction to prevent output errors before they occur and a unique protection circuit that does not compress signal dynamic range. The 2WQ will not produce audible distortion regardless of the frequency or level of the input signal.

It utilizes three small drivers instead of one larger unit for greater power-to-weight ratio and better diaphragm control. The 8-inch drivers in the 2WQ are slot-loaded to linearize pressure on the front and rear of the cones and to mechanically filter side-band distortion.

The cabinet is constructed using constrained-layer lamination techniques and cross-bracing, resulting in the most inert, resonance-free subwoofer enclosure that I've ever seen.

It has adjustable Q. You can adjust the output response curve of the 2WQ to suit room acoustics and placement.

No other commercial subwoofer offers all these features and virtually all high-quality competitors cost more.

The 2WQ Operates Primarily Below System Resonance

Conventional subwoofers operate above system resonance. They exhibit uneven response and lots of phase shift as they pass through the fundamental system resonance which typically occurs at the lower end of the pass band. Designers try to get the resonance frequency low because output falls off steeply below this frequency. A vented design with a B4 alignment falls at 24dB per octave and a sealed design with a Q of .7 falls at 12dB per octave below resonance. Take a look at the illustrations in the previous article to see what happens to phase.

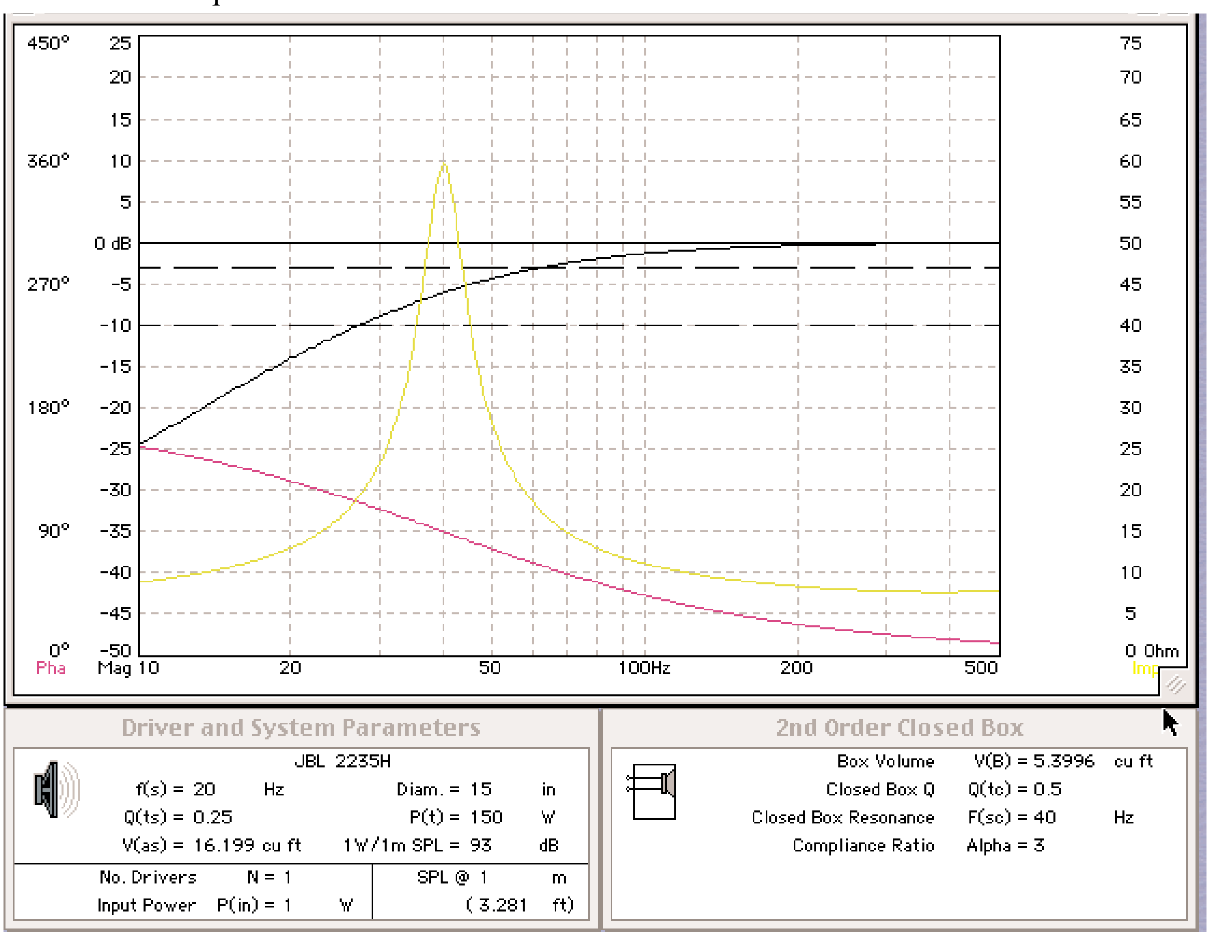
A driver mounted in a sealed enclosure with a Q_{tc} (total system Q) of .5 will have an amplitude response curve that falls in a linear fashion at about 8dB per octave below system resonance with limited and linear phase shift. Output will theoretically extend down to DC without the sudden drop-off and phase shift that occurs when conventional systems pass through resonance. This predictable and linear frequency and phase response is easily compensated for with electronic correction in the amplifier to produce ruler-flat output to subsonic frequencies.

Since output is more linear below system resonance and flat response can be achieved with amplifier compensation, why not design a subwoofer that operates below resonance rather than above it? That's just what Vandersteen has done.

The result is a subwoofer with virtually no resonance in the pass band, minimum group delay, linear phase response, flat amplitude response to subsonic frequencies, critical damping and a low system Q making it suitable for corner placement.

A Better Blend with the Main Speakers

The Vandersteen 2WQ subwoofer is integrated with the main speakers using a unique system that is not a crossover in the usual sense. Transitions between the subwoofer and the main speakers are made with gentle 6dB per octave slopes using phase- and transient-perfect first-order filters that are completely transparent.



This illustration shows the amplitude and phase characteristics of a sealed enclosure subwoofer with a Qtc of 0.5, at frequencies below system resonance which, in this example, is 40Hz.

A passive, first-order filter is inserted at the input to the main amplifier. This filter causes the signal to the main amplifier and speakers to roll-off at 6dB per octave below 80Hz.

A 300 watt subwoofer amplifier, designed specifically to deliver high current into the low impedance load of the three drive elements, samples the signal at the output of the main amplifier and compensates for the roll-off to produce flat output from the subwoofer. The output from the subwoofer amplifier is tailored to produce first-order low-pass response above 80Hz and a rising response below 80Hz to compensate for the falling response curve of the filtered input signal as well as the falling output response of the subwoofer which is operating primarily below system resonance.

Output that could exceed the power limits of the amplifier, or the linear excursion limits of the drivers, is prevented by dynamically raising the low frequency cut-off point rather than compressing the signal. A unique circuit analyzes the input signal and dynamically alters the feed-forward error correction characteristics to accomplish this feat. The 2WQ cannot be driven to produce audible distortion under any conditions, yet it never compresses the dynamic range of the signal, maintaining the natural rhythm and pace of music regardless of level.

A passive, first-order high-pass filter at the main amplifier input is completely transparent so the sound from the main speakers is not negatively impacted in any way and all the positive benefits listed in the *Subwoofers From a High-End Perspective* article can be realized.

Sampling the output from the main amplifier passes along the sonic and electrical characteristics (particularly propagation delay) of that amplifier to the subwoofer system for a better blend between the subwoofer and the main speakers, even if the main amplifier is a tube or MOSFET design. This results in superior integration between the subwoofer(s) and the main speakers.

Less Audible Distortion

In addition to the feed-forward error correction system and the specially-designed internal amplifier, the 2WQ uses several other distortion reducing techniques.

Three 8-inch drivers have the combined cone area of a single 14-inch unit but three motors can provide far better control over the lighter, stiffer cones. Smaller cones produce less sideband distortion than larger, more flexible cones, and any distortion that remains will be at higher frequencies which can be mechanically filtered by the indirect radiation path.

These three drivers are slot-loaded providing an indirect radiation path into the room. Slot-loading the front of the drive elements equalizes the pressure on the front and back of each diaphragm making resistance to fore and aft movement more linear.

A driver in a sealed enclosure “sees” a diminishing volume of air and increasing pressure within the box as the cone moves inward, and an increasing volume of air and reduced pressure as the cone moves outward. Covering the front of the driver(s) with a plate so that radiation from the front of the drive elements enters the room through a slot or slots between this plate and the enclosure is an attempt to compensate for this phenomenon.

Slot-loading provides a reduction in distortion by linearizing cone motion and also acts as a mechanical low-pass filter to absorb residual distortion products at higher frequencies. This mechanical low-pass filter is far more effective than a steep-slope electrical filter for the reasons described earlier.

The cabinet is elaborately constructed using constrained-layer laminates and cross bracing to completely eliminate panel resonances and spurious noise. The 2WQ enclosure feels like a solid block of material. Rapping on any panel is like banging your knuckles against a rock. Panel flexing is simply out of the question.

Caveats

The Vandersteen 2WQ subwoofer provides tightly-controlled bass that is “critically damped” and limited in output level compared to a typical home theater subwoofer. Two units will be required in all but the smallest rooms to provide the THX-recommended output level of 105dB at 35Hz. I recommend using two subwoofers anyway and 105dB is much too loud for music listening so I don’t see these as problem areas.

Tightly-controlled bass that is perfect for music may not satisfy explosion fans who use their audio systems for both music and home theater. Vandersteen makes another subwoofer, the V2W, for these folks. It looks the same but trades some control and integration for the ability to play much louder.

Other subwoofers that offer excellent performance for those with a strong home theater bias include many of the M&K models and the Bag End InfraSub. These subwoofers will still perform well on music and deliver more visceral output. Don’t use their high-pass filters. Choose a passive single-pole filter instead.

Best Value

In my opinion, the Vandersteen 2WQ is the best subwoofer available for reproducing music regardless of price, and the price is a mere $1,250 each! If that’s not a bargain, I’m a bad shopper. I have four 2WQ subwoofers and they’re not on “long term loan;” I bought them. I want the best possible performance and I’m willing to pay for it, but if the product that offers the best sound quality also costs less, I won’t complain.