Compact 12" Bass Speaker

Francis Deck, Oct. 18, 2006

This article describes my 12" bass speaker design. It's a lot of words for yet another driver in a box. And I won't discuss construction details because there are already plenty of opinions and options for building a bass speaker.

I have noticed that most DIY'ers, if they use a quantitative design method, choose "optimal" system alignments. That's OK, but I prefer the sound of a speaker with a higher cutoff frequency. There are lots of small box designs out there, for instance many commercial 10" systems, but very little information on how to design one that works. For that reason, I decided to do enough research to understand the small bass box, and to share what I have learned.

This will be like two articles in one. I will describe small box systems in general. Then I will work through my own design. I will model my design against an "optimal" system, so the tradeoffs can be seen more clearly.

Small versus Big

First, a couple definitions of my own: The *small box* design has a cutoff frequency significantly above the lowest fundamental of the bass. The cutoff is achieved by cramming a big driver into a small box.

The *optimal* design has its cutoff frequency closer to the lowest fundamental, and uses one of the optimal alignments such as SBB to achieve reasonably flat response above cutoff.

To help understand the small box design, a typical response curve is shown in Figure 1 along with an optimal system. Both systems are modeled with the same driver, so the main difference is box size.

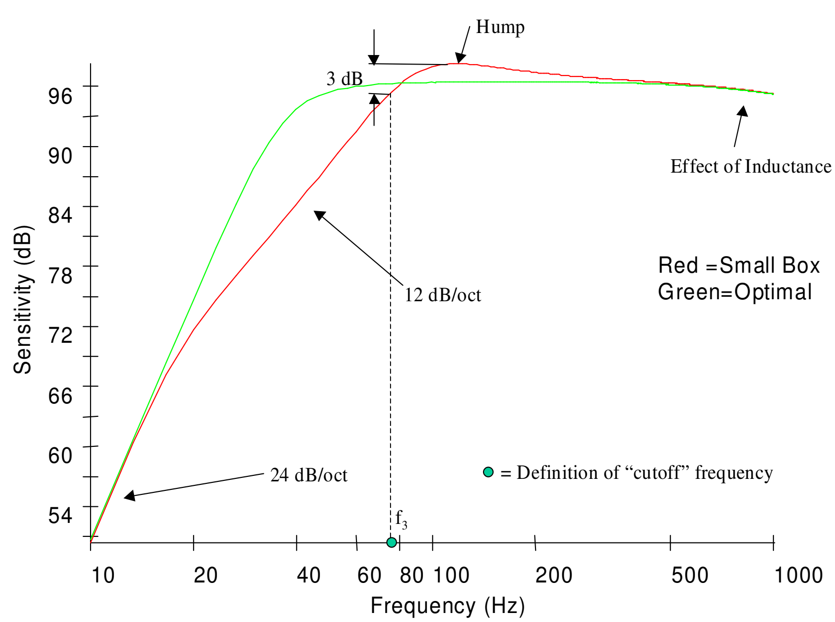

Figure 1. Illustration of features in response curve of optimal and small-box systems

The response curve for the optimal design looks… optimal. It is nice and flat down to the cutoff, then it drops at 24 dB/octave. The small box design shows its lumps. Its cutoff frequency is considerably higher. The slope is 12 dB/oct in the cutoff region, just like a sealed box. The curve is shown extended to 1 kHz, just to show the effect of inductance, but in reality the electromechanical model loses its accuracy above a few hundred Hz.

You can see the midbass hump in the small box response curve. That's the penalty of trying to cram a big driver into a small box. In this graph, the hump is about 2 dB tall, but the height of the hump depends on what driver is chosen. If it is more than a couple dB, you should probably re-think your driver choice.

Now we should look at the other important curve – cone excursion. The curves are not qualitatively different, but it's important to understand the features. Above 100 Hz, excursion goes down, even though the response curve is fairly flat in that region. Constant sensitivity *requires* a 4x reduction in excursion for every doubling of frequency. That's why guitar speakers can get away with less excursion.

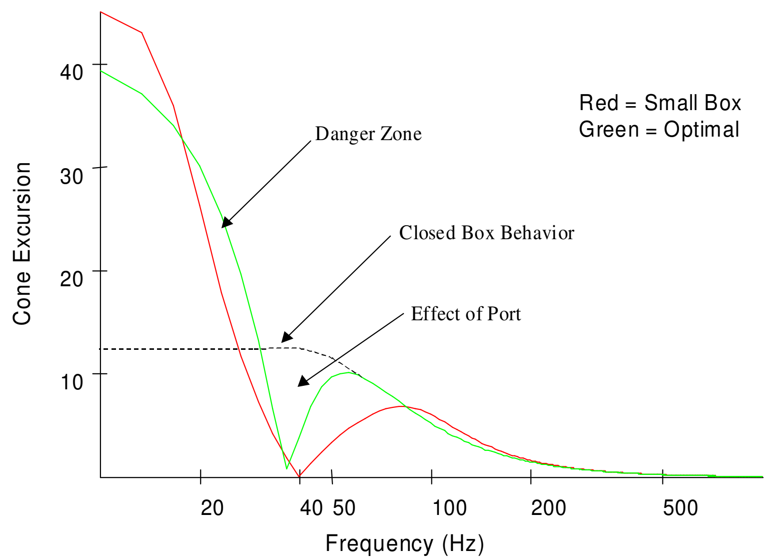

Figure 2. Cone excursion behavior of optimal and small box systems

Below the port tuning frequency, disaster awaits. The curve rises to meet the open air DC excursion value, so that over-excursion is virtually guaranteed at fairly low power levels. For all practical purposes, a ported speaker is not intended to reproduce signals below the port resonance, though you can sometimes get away with a bit higher port tuning than the lowest fundamental.

The graphs suggest some simple design rules for ported small box systems:

1. Start with a port tuning of 40 Hz for 4-string bass. Raising the frequency runs the risk of over-excursion. Lowering it simply reduces the effectiveness of the port. Within these constraints, there seems little to be gained, in sensitivity or tone, from fine-tuning the port.
2. Achieve your desired cutoff frequency by adjusting the box volume while leaving the port tuning frequency alone.
3. Look at the hump. If it is too large, try a different driver.
4. Look at the excursion graph to gauge the power handling capability of the system.

Just to help with my narrative, I will outline a straw-man design method for optimal systems:

1. Choose a driver, and let WinISD pick an alignment
2. If the port tuning is much above 40 Hz, choose another driver
3. Look at the sensitivity and excursion graphs to evaluate the system

It is worth observing that neither method gives you a lot of opportunity to fiddle with the port tuning. A rule I have learned is that *the lowest note of the bass pins down the port tuning frequency to a narrow range*. And in both cases, there is more analysis to do. These are not designs yet. This is the point where a specific example is probably the best way to illustrate the analysis steps.

Question: Why not choose a driver that results in an optimal alignment at a higher cutoff frequency? Such a design is unworkable, because it allows over-excursion in the lowest register of the bass. Remember, you are not designing for idealized alignments, but for the bass, and for your ears. If your ears tell you that you want the higher cutoff, you have to abandon the optimal alignments.

My design

I chose a target cutoff frequency of 80 Hz, equal to my GK MB150E combo. My goal is to design a speaker with roughly the same sound, but with higher sensitivity and power handling for use in situations where the combo is underpowered. After modeling different drivers, I chose an Eminence DeltaLite 2512-II driver with the following specs:

Fs	37	Hz
Re	5.04	Ω
Qes	0.44	
Qms	3.13	
Vas	147	Liters
Sd	519.5	cm^2
Xmax	4.9	mm
Le	0.46	mH
Pe	250	W rms

My small box design: Volume is 32 liters. Port tuning is 40 Hz.

Optimal design for comparison: Volume is 98 liters. Port tuning is 37 Hz.

The optimal design is the SBB alignment, computed by WinISD Pro. All of my modeling is done with my spreadsheet. Having my own program allowed me to add some analyses that are not part of mainstream speaker analysis programs. The graphs below have a linear frequency scale in Hz, because Excel does crappy logarithmic graphs. Each graph starts out at 30 Hz, so you can see the effect on 5-string bass, but I am assuming 4-string bass in my design evaluations.

Sensitivity

As shown in Figure 3, the big box cetainly enjoys a nice flat response curve. The small box has a F_3 around 80 Hz, as designed. The hump around 120 Hz is noticeable, but it isn't more than a couple dB. You can see the two different cutoff slopes. So far I don't see any serious problems, as the midbass hump seems like it should be controllable with minor EQ if it is even audible.

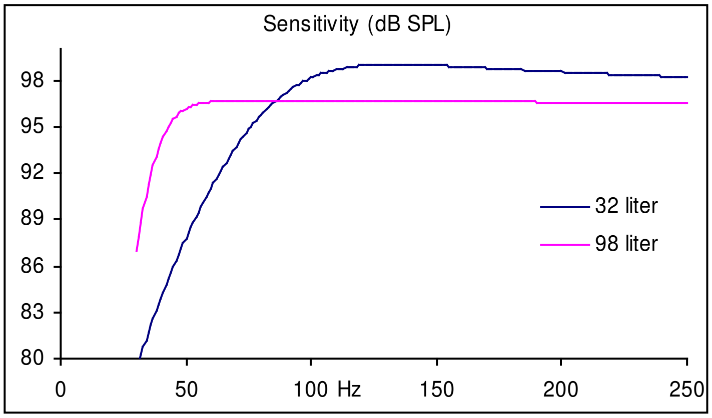

Figure 3. Sensitivity curve for my box design, compared to optimal design

Cone Excursion

In Figure 4, both drivers are simulated at 38 V RMS sinewave input, corresponding to 180 W into 8 Ohms, the rating of my GK Backline 600 head. In both cases, cone excursion is considerably above the 4.9 mm Xmax value for the driver. The higher excursion of the big box is simply indicative of its higher sensitivity in the lowest octave.

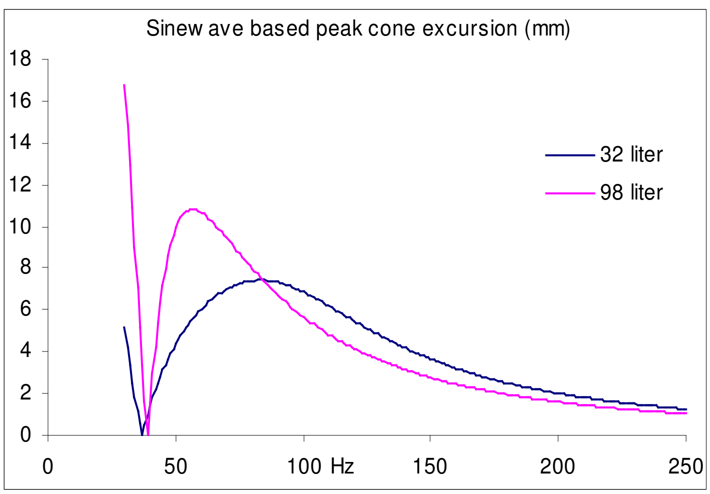

Figure 4. Cone excursion curves for sinewave input

However, a bass does not put out a pure sinewave. Looking at oscilloscope traces, I have observed that the waveform looks more like an equal mixture of the first few harmonics. To crudely simulate real waveform performance, I simply averaged the excursion values for the first four harmonics at each fundamental frequency, resulting in Fighre 5.

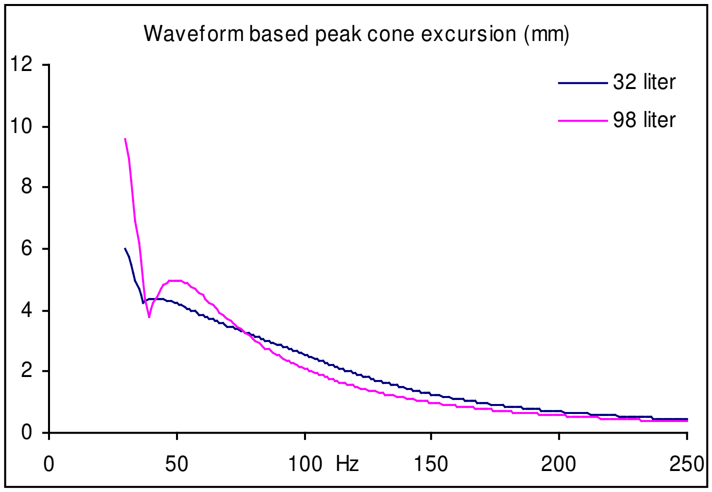

Figure 5. Cone excursion curves for simulated bass waveform

I would not call this curve authoritative, but it suggests that a bass speaker can handle more input power than would be indicated by a first glance at the standard excursion plot. Both designs seem to work well enough down to 40 Hz. The apparent disaster in low frequency excursion for the big box pretty much disappears. That's a mark in favor of the 2512-II driver, suggesting that it is quite forgiving of box volume. It means if you don't like my design, but the optimal system is too bassy, then design something in between. Neither box is particularly happy with 5-string bass. But you can follow the same general method while designing around a 30 Hz lowest fundamental if you want.

Port air speed

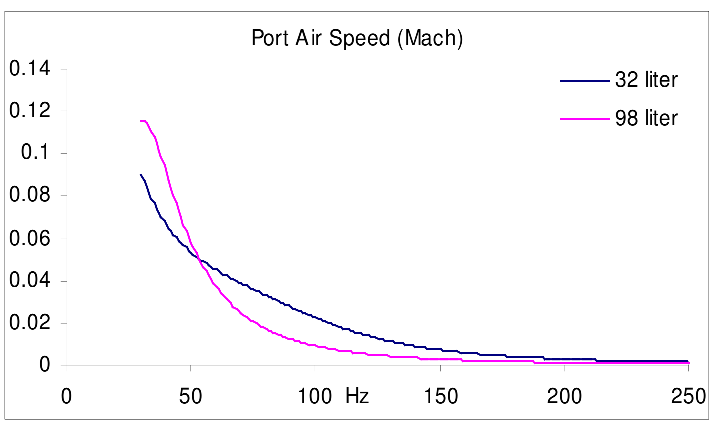

Figure 6. Port air speed for sinewave input

This is a design detail requiring eternal vigilence with ported cabs. I just pasted in the graph from my spreadsheet. Various sources will cite different thresholds, but I have noted widespread advice suggesting that port air speed should be kept below 0.1 Mach. Speeds approaching the speed of sound guarantee turbulence noise referred to as "chuffing."

Transient response

Figure 7 shows my computed transient response curves. The vertical axis is cone acceleration, in arbitrary units. The horizontal axis is milliseconds. The response is to a unit step function voltage input. I use acceleration because it is proportional to sound pressure. It is apparent that the small box has more overshoot, but both boxes are comparable in terms of how long it takes for them to settle down.

Very little is understood about transient response in bass speakers. My only interest here is in providing a graph allowing comparison of the two systems. There appear to be two competing effects in going from the big box to the small one:

1. Higher cutoff frequency → Faster response
2. Higher total Q → Slower response

Both of these things happen in the small box design. Thus it's a toss-up whether a given design will have transient response problems, and remember, I am not claiming any audible effect here.

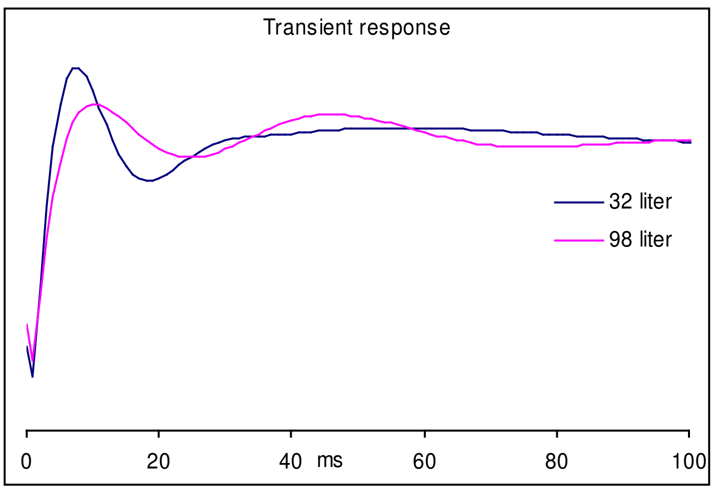

Figure 7. Transient response, cone acceleration versus unit step function input

Distortion

I used a method of estimating distortion from Kyle Lahnakoski's excellent website (http://www.arcavia.com/kyle/Equations/Distortion.html). What he models is the effect of nonlinear box compliance. Huh? In a nutshell, the box is a bit smaller at one end of cone travel than at the other. The small change in compliance is a departure from a purely linear model, and thus results in distortion. Figure 8 shows the results for the two boxes.

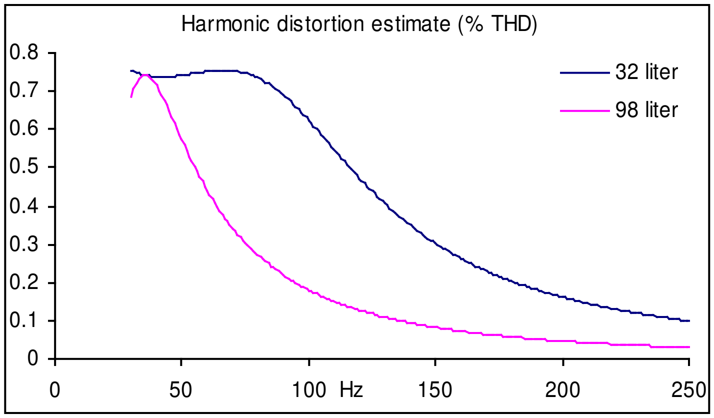

Figure 8. Estimated harmonic distortion

The small box has considerably higher distortion. In addition, if you equalize the big box to get the response curve of the smaller box, its distortion would be even lower. However, I am not sure that even 1% THD is audible in a harmonically rich signal source like a bass.

Something to note is that I am not trying to get really loud with a small box. For instance I am not "overpowering" the system. If your design involves more power, or drivers with more excursion, distortion will be proportionately higher.

Construction and Measurement

Figure 9. My mini rig

I have built many bass speakers using simple plywood, and they have held up under abuse. But as a weekend warrior, I don't need all of the trappings of a roadworthy speaker, such as tolex, corners, and fancy handles. Following the advice of experts on the web, I built the cab from 1/2" plywood with some internal bracing and a shelf port. Next time, I will just put in a circular side or rear port for simpler construction. Total weight is 17 pounds with the steel grille.

Design details are as follows:

Inside dimensions = 14 x 16 x 9.75"
Outside dimensions = 15 x 17 x 12"
Port = 8-3/8 x 1-3/8 x 10"

The measured port frequency is 37 Hz, lower than I had originally hoped. This is probably due to miscalculating the end effect. In hindsight, I would have done a bit more testing before gluing the shelf port parts in. The design details reveal a problem with the small box concept. You need port area to keep air speed low enough, but the result is a deep port that might not fit in the box. Don't skimp on port area to get a shorter port. Instead, consider a bent port, or a side port. Remember that the output of the port is utterly omnidirectional, so it doesn't matter where you put it. Test the response curve before committing.

Note that the port comes all the way out to the front, past the speaker baffle, thus giving me a bit of extra length.

Figure 10 shows the measured nearfield response curves of my speaker and the GK MB150E combo, both at the same input voltage:

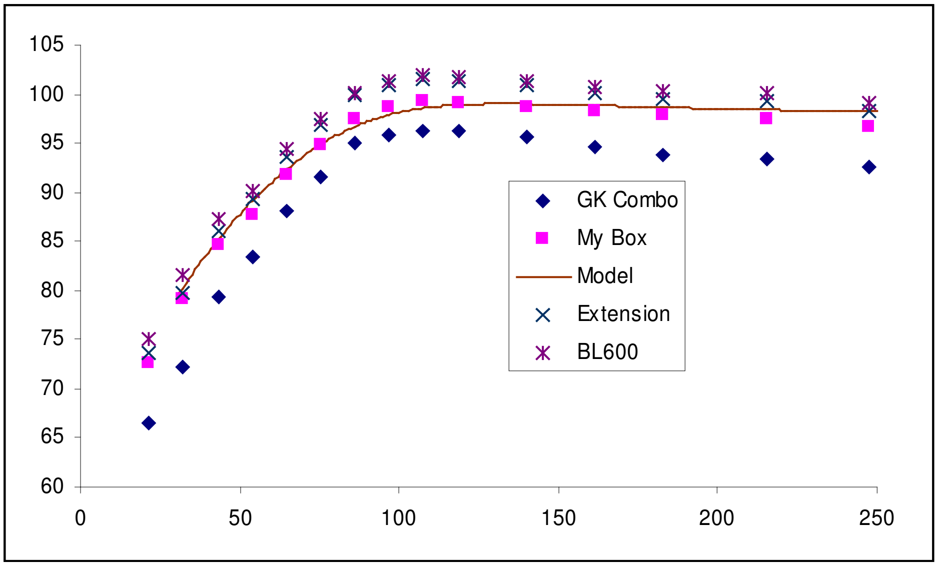

Figure 10. Response curves for different configurations

The model is my computation of the small box response curve. You can see that the new speaker is louder than the combo. By itself, the gain is not enough to write home about, but with a more powerful amp on top, the rig should be palpably louder.

The "BL600" curve shows the effective increase in loudness, compared to the GK combo, when the Backline 600 amp is driving my box. That's due to a factor of 1.8 increase in power. The "Extension" curve shows the effect of using my box as an extension for the GK combo, with both speakers driven. You can see it's a toss up between the higher power of the BL600 at 180 W and the effective cone area of two 12" speakers driven at 75 W apiece. Thus, the BL600 head serves only to make my system a bit easier to transport. On the other hand, it also suggests a use for my speaker, which is to leave it in my car for occasions when I get to the gig and the GK combo turns out to be not enough.

Listening and playing

I have used this speaker on several gigs now. It is punchy and loud, if I may venture into subjective terminology. It delivers a pretty aggressive fingerstyle electric bass tone. On upright, support for the low end seems sufficient, with the caveat that I actually prefer a less boomy tone. Since a lot of players find themselves using a high pass filter with upright bass pickups, it seems that generous support for the fundamental is not strictly necessary for good upright tone.

Small versus Big, how to choose?

Back to the original problem. The small box and optimal designs are both viable. There are commercially successful examples of both. The choice depends on your preferred tone quality, and also on other aspects of your setup and the acoustical environments that you play in.

If possible, I suggest getting an idea of your tone preferences by finding a system whose tone you are happy with, and measuring its response curve. I think that the lack of guidance from measured data is one of the more frustrating aspects of DIY speaker design. But even without curves, you can make some educated guesses. Most combo amps used by upright players are small box systems, as are a lot of 10" cabinets. Remember that "small" is defined on a per-driver basis, so your 8x10 "fridge" is likely to be a small box design. Virtually all sealed bass cabs are small-box, with a high enough cutoff frequency to avoid over-excursion in the lowest octave.

There is a penalty in either size or sensitivity for choosing an optimal design. For this reason, if you are playing through such a system, you probably know it. To the best of my knowledge, all full-range systems presently on the market are advertised as such. An example is Acme.

If a speaker is advertised as having high sensitivity, then it's a small box design. If they don't report a high cutoff frequency, be skeptical about the ratings. An optimal system definitely does the best job of reproducing your bass signal, but is that what you want? Remember that it's not just the speaker, but the acoustical environment, which generates your tone. A lot of players, myself included, find that the lowest octave contributes to a nondescript "muddy" tone in typical rooms. If you find that you are routinely using a high pass filter with your upright bass, to get a good tone, then you might as well let the speaker do the filtering.

So everything boils down to tone and playability. But there are a couple situations that I recommend avoiding. The first is to build a small box, then try to recover the lowest octave with EQ. Such an equalized system will greatly reduce your headroom, since you are emphasizing the frequency range where its response is limited by excursion.

A less serious mistake is building an optimal box, discovering that you don't like the tone, and turning down the bass EQ. The thing won't blow up on you, but it means that you are carrying a much bigger box than you need.

A speaker that produces your desired tone with flat EQ on your amp is the most "efficient" in its use of amp headroom and physical space. But a lot of amps, especially those made for electric bass, are not flat when the tone controls are centered. For this reason, I recommend the following process for evaluating the tone of your system:

1. Using my program, measure the response curve of your bass amp. Dial it flat if possible, or go in through the effects return input to guarantee flat response.
2. Evaluate the tone of your system, at home and on the gig, and note what settings are needed to get your favored sound.
3. Measure the response curve of your speaker, both with a flat amp and with your favored tone settings.

From the data that you gather, you can draw an idealized response curve for a speaker that will get closer to your desired tone. That should be the starting point of the speaker design process.

In this discussion, I am assuming that your amp generates your stage sound and your FOH sound. This is my most common situation, as a jazz player. The bands that hire me rarely have sufficient PA support to run the bass through the mains, even when working fairly big rooms. Invariably, I see little Fender Passport systems, and the like, with a single microphone for a vocalist or horn player.

If you are playing with serious PA support, the rules change. You might still want a small box, just for your own convenience, if you trust the PA tech to deliver a good tone to the FOH. That has always worked for me. If you are using your bass amp as a personal monitor, and want to know exactly what the house is hearing, then you need a full range speaker.

For more information

http://personalpages.tds.net/~fdeck/bass hosts my free speaker response measurement program, design spreadsheet, and rather extensive documentation on the workings of speakers.

Revision History

Oct. 8, 2006: Added physical dimensions of my box, and analysis of ported system response.

Oct. 18, 2006: Corrected the distortion plot, with results being considerably higher, but still looking OK.