STEREO INTEGRITY

SUBWOOFER GROUP DELAY

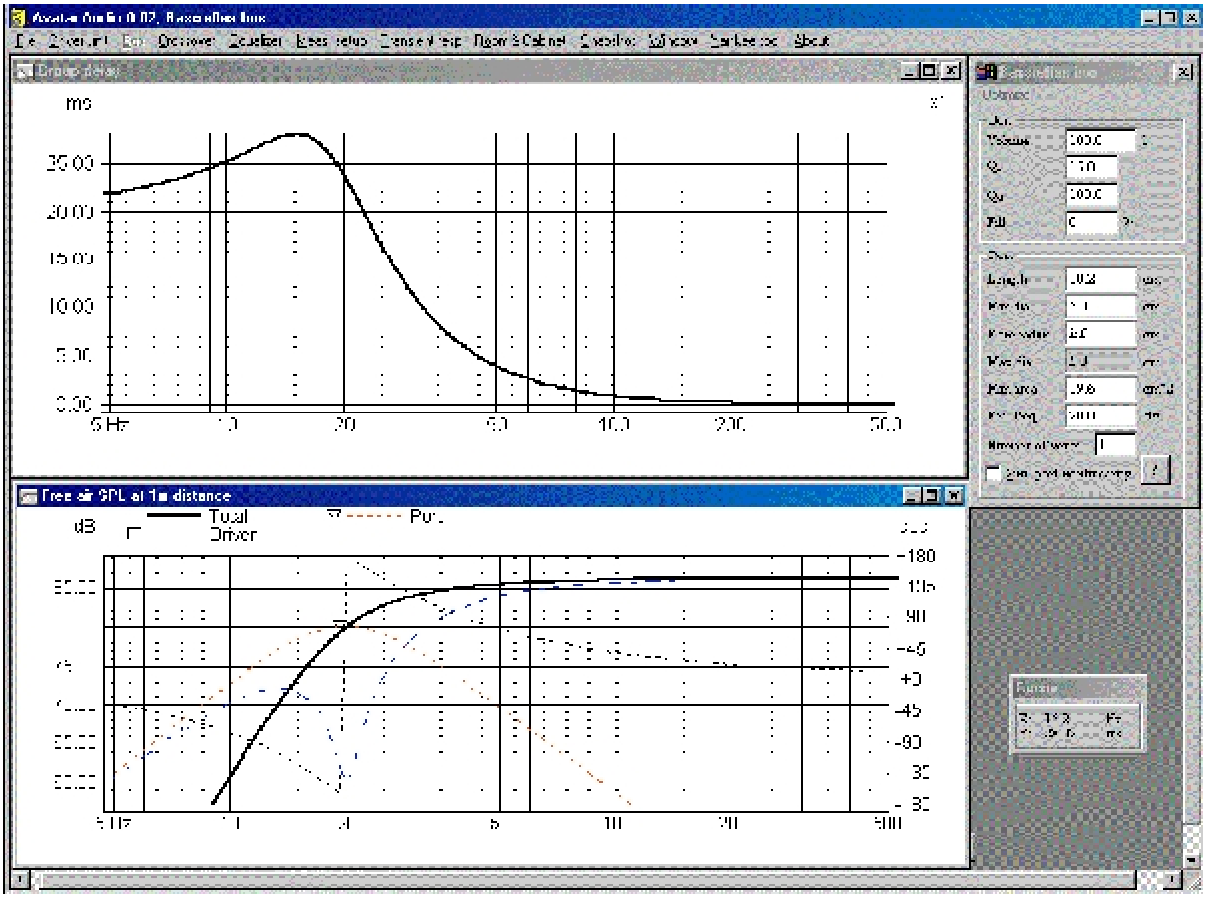
Group delay has been found to be a major predictor of the "tightness" or transient accuracy of a subwoofer system. Group delay, in it's mathematical form, is the negative derivative of acoustic phase with respect to♪ requency. That is, group delay is a measure of how fast the acoustic phase of the system changes. Lower group delay numbers are indicative of a "tighter" sound of the subwoofer (to a certain point; once below a certain threshold, changes in group delay are no longer reliably detectable. The actual threshold is beyond the scope of this page, and as such will not be discussed). Conversely, higher numbers can indicate a "looser" sound.

Since group delay is directly related to acoustic phase, we can actually make one further leap: group delay is related to frequency response. The Hilbert transform is a method of deriving the acoustic phase from the acoustic magnitude (the typical frequency response curve shown in most all literature and design programs). There is one caveat: the Hilbert transform is valid ONLY for what is called a minimum phase system. What is a minimum phase system? The actual way to calculate one is also beyond the scope of this paper; however, for our purposes, a subwoofer driver operating in a box, in it's linear mode is a minimum phase system. Operate beyond the linear limits of the driver (where distortion, power compression, suspension compression, and other nonlinear issues come into play) and the system is no linger minimum phase, and hence cannot use the Hilbert transform.

With the Hilbert transform, we can directly calculate the acoustic phase from the frequency response. That is, given the acoustic magnitude frequency response of the subwoofer system, we can transform the data into the acoustic phase frequency response, via the Hilbert transform. And, as we have seen above, we can use the derivative of the acoustic phase to calculate the group delay. Hence, group delay is related to magnitude frequency response for minimum phase systems (linear subwoofer systems).

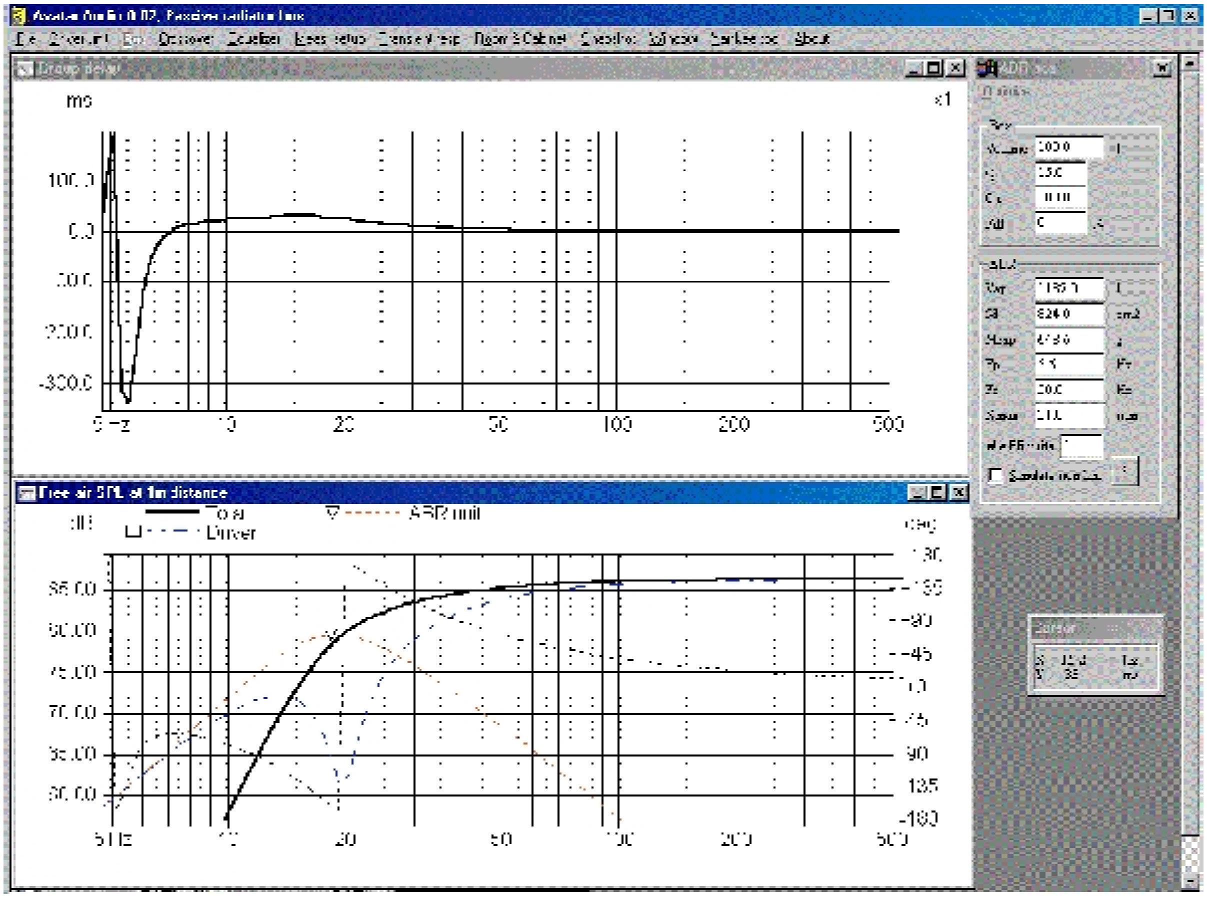
With that understanding, let us examine the group delay characteristics of three different systems: one vented, one passive radiator, and one sealed. For all three, we'll use a "similar" alignment (maximum flat bandwidth), and the same driver (Shiva). Software used will be LspCAD, a highly accurate and easy to use Windows based program from IJ Data of Sweden.

For the vented and PR systems, a 100L enclosure tuned to 20 Hz was used. This yields a near-maximum flat bandwidth, while keeping the enclosure parameters to very simple numbers. For the sealed system, a net volume of 54L was used, to yield a system Qtc of 0.707 (maximally flat response).



As we can see, the vented response shows the classic "phase wrap" at tuning, which is indicative of a higher order system. In fact, the vented system is a fourth order system, meaning that we will have a fairly steep transition from passband to fall-off. The group delay of the vented system peaks at 28 ms, at 15.2 Hz.

The passive radiator system's response is:

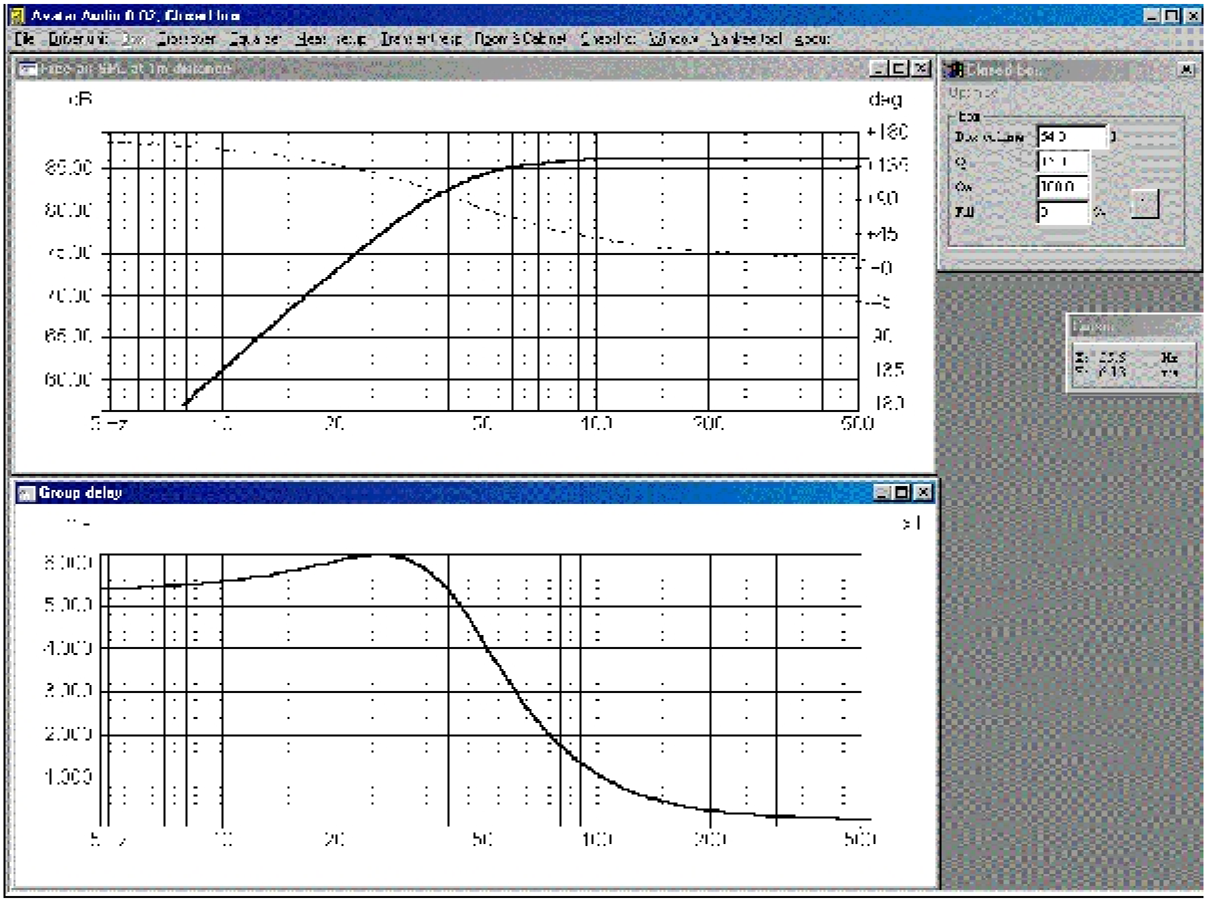


Here we see that, we have nearly the same passband frequency response. However, as the passive radiator system is a 5th order system, we see that we do have a change in the acoustic phase of the system. Instead of continuing a smooth "single wrap" like the vented system, the acoustic phase turns and wraps the other direction. This occurs at the resonant frequency of the passive radiator (while the effect on frequency response is not explicitly shown in the above graph, one can use the software to investigate the actual effect with ease).

The group delay shows some very strange behavior; at the passive radiator's resonant frequency, we see the group delay essentially "goes crazy". It spikes all over the place. This is because at the passive radiator's resonant frequency, there is a "null" in the frequency response; that is, the frequency response is a discontinuous function at that frequency. As such the derivative cannot be calculated.

Of more interest is the group delay at 15.2 Hz, where we measured that of the vented system. Here we see that it is 33 ms . This is higher than the vented system. This is, of course, expected. Recalling that a passive radiator system is a 5th order system, and that we are approaching a null in the frequency response (at the passive radiator's resonant frequency), we can understand that the fall-off between the flat passband and the null must be greater than the fall-off of the vented system. This implies that the group delay will be higher, too. And we see that is the case.

The sealed system provides the best group delay numbers:



Here we see that group delay peaks at 6.13 ms . This is over 4 times better than the vented case, and over 5 times better than the passive radiator case. Given that a sealed box is a second order system, and as such does not exhibit a rapid fall-off on the low end (nor the attendant 360 degree phase wrap of the vented or passive radiator systems), the overall group delay will be considerably lower.

The tradeoff of the sealed box is that the flat passband does not extend as deeply in frequency. However, simulating a sealed box with the same bass extension (to the -3 dB point as the vented or passive radiator boxes) still does not increase the group delay to levels comparable to the vented or passive radiator systems. It is the lower order of the sealed system that helps its group delay the most, not it's higher F3.

Ranking strictly in terms of group delay, we see that:
1. Sealed boxes are best
2. Vented boxes are second
3. Passive radiator boxes are third

Again, this is as we expect, since this is a direct ranking of the three, based upon the order of their operation. Higher order will introduce a faster fall-off, which translates into more acoustic phase rotation. This will lead to higher group delay numbers. In closing, it is important to note that the above does NOT mean you cannot build "accurate and tight" subs with vented or passive radiator alignments! On the contrary, one can build very good subs with these approaches. However, when designing these types of subs, one should keep a closer eye on the group delay of the system, and make sure that it is not too high (a good rule of thumb is less than 25 ms at 20 Hz). This is typically NOT a concern with sealed systems.

