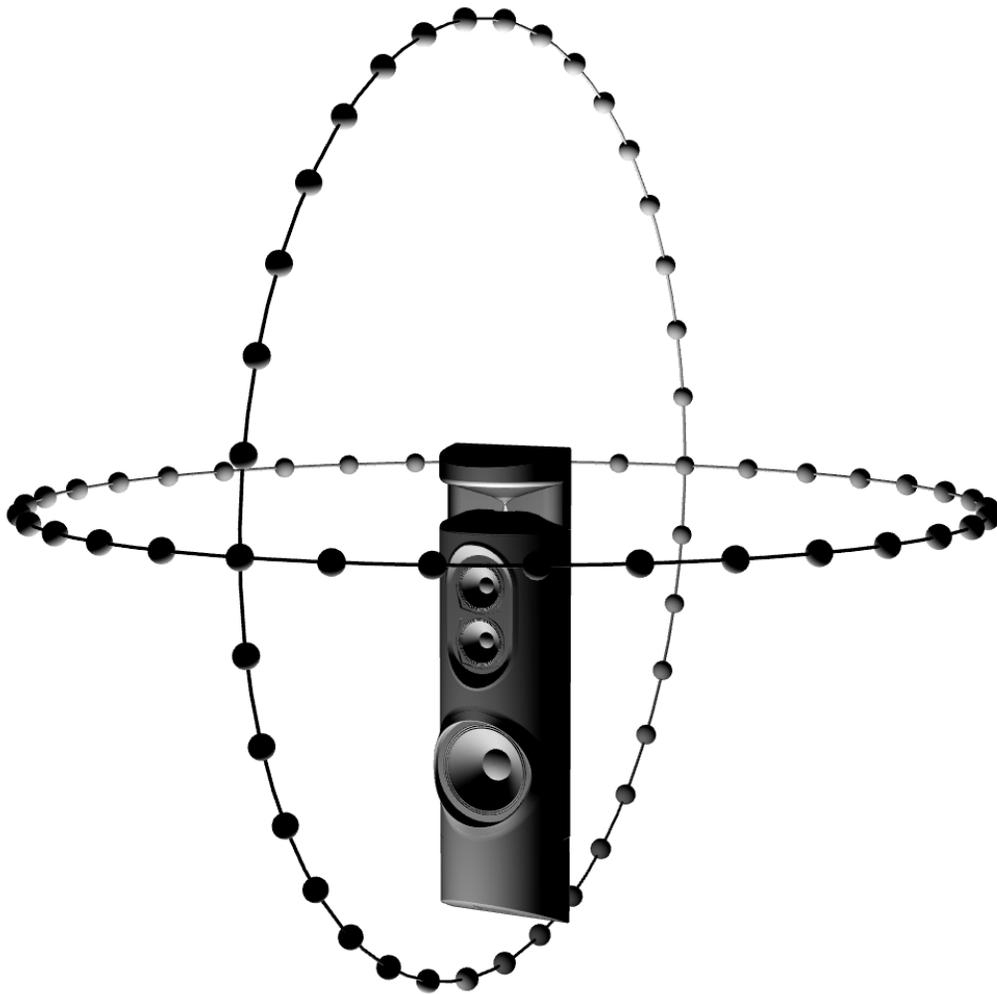




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Interpreting “Spinorama” Charts

By Manny LaCarrubba





S A U S A L I T O A U D I O

“Spinorama” refers to a measurement methodology pioneered by Dr. Floyd Toole in the 1980’s during his tenure at the National Research Council of Canada. He later worked with his research team at Harman International in the 1990’s to refine the process. The Spinorama technique is the result of Dr. Toole’s research into correlating measured loudspeaker response with subjective listening tests. This quest took much of Dr. Toole’s professional career. His excellent book “Sound Reproduction” chronicles this research and is an absolute must read for anyone seriously interested in audio.

I have chosen to standardize on this format, as much as possible, the data presented by Sausalito Audio. This paper is intended to give the audio professional that may not be familiar with this methodology an overview of the format. Nothing about Spinorama is particularly new. My first exposure to Dr. Toole and the power of properly done measurements and double-blind listening trials was around 1990 when I showed up at the NRC in Ottawa with a perfectly awful pair of speakers for testing.

While some of what you are about to read may contradict the conventional wisdom that you thought was true, I can assure you that everything stated in this document is based on hard work, some impeccable science, and is enshrined in numerous peer reviewed technical papers published by the Audio Engineering Society. There is no original thinking here on my part – I’m simply reporting work by others. I will not go into detailed explanations and, this is not a comprehensive treatise on loudspeaker evaluation. If something in here raises an eyebrow, or you want to learn more, get Floyd’s book or the relevant AES paper and read.

It is also worth mentioning that this methodology is now incorporated into a published standard by the American National Standards Institute and the Consumer Electronics Associations as ANSI/CTA-2034A “Standard Method of Measurement for In-Home Loudspeakers.”



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The upshot of a Spinorama chart is that it tells us much (but not all) of what we need to know regarding how “good” a speaker is likely to sound when we put it in a room. Properly controlled double blind listening tests are very, very difficult and expensive to undertake. **However, it is possible from measurement data alone to get a high degree of confidence in how a speaker’s sound quality would be perceived in such a test.** Dr. Sean Olive of Harman actually created a predictive algorithm which allows for the input of measurement data and outputs a preference rating score with very good accuracy. For our purposes here, I’ll be showing data from some good and less good loudspeakers so that you can have a feel for what to look for.

It is important to understand this: **Spinorama charts, and the implied sound quality represented, apply to all types of loudspeakers. The “rules” for good sound apply equally to home speakers, cinema speakers, sound reinforcement speakers, wireless counter top speakers, soundbars, etc.** Now, there may be good engineering reasons to deviate from the “rules” (price points, speakers for reverberant spaces, or large-scale sound reinforcement arrays for instance), but the point remains that a great sounding PA speaker will have a well behaved Spinorama chart. It should just play louder, be more robust, etc.

The data collection involved in creating these charts requires measuring the anechoic loudspeaker frequency response at 70 distinct points. Starting at the reference axis (almost always on axis to the high frequency element and directly in front of the speaker) and then measuring every 10° all the way around the speaker in both the horizontal and vertical planes. **The data cannot be obtained with the loudspeaker in situ in a room.** Take a look at the graphic on the cover page. Each sphere in “orbit” around the speaker is a measurement point. That data is then manipulated to give us the plots on the chart. Please note that some things that are important to loudspeaker sound quality, such as data related to non-linear distortions, power compression and maximum SPL, are *not* presented in a Spinorama chart.



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A Spinorama chart has 6 curves presented on it. The first one we will consider is simple axial frequency response. This should be familiar to most of you. This curve is a single measurement that represents the direct sound from the speaker to the listener. **The axial frequency response curve is the single most important curve in evaluating a loudspeaker. An excellent loudspeaker needs to have a flat anechoic frequency response – really flat.**

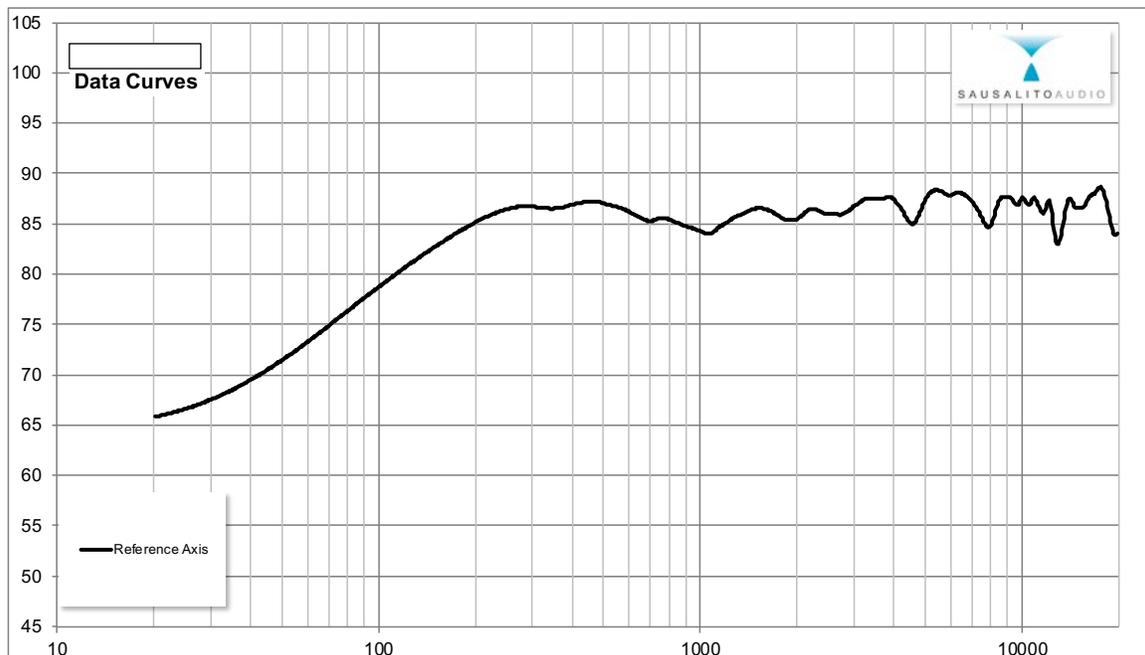


Figure 1: Brand A - This loudspeaker is sold as a high SPL, high-end cinema product. The high Q dips at the highest frequencies are not as troubling as the broad low Q dip at ~1kHz, but overall, this is pretty good. Note the obvious lack of resolution in this data. While the generalized shape above 300Hz is accurate, there may be response anomalies below ~1500Hz that we simple can't see due to the lack of measurement resolution.

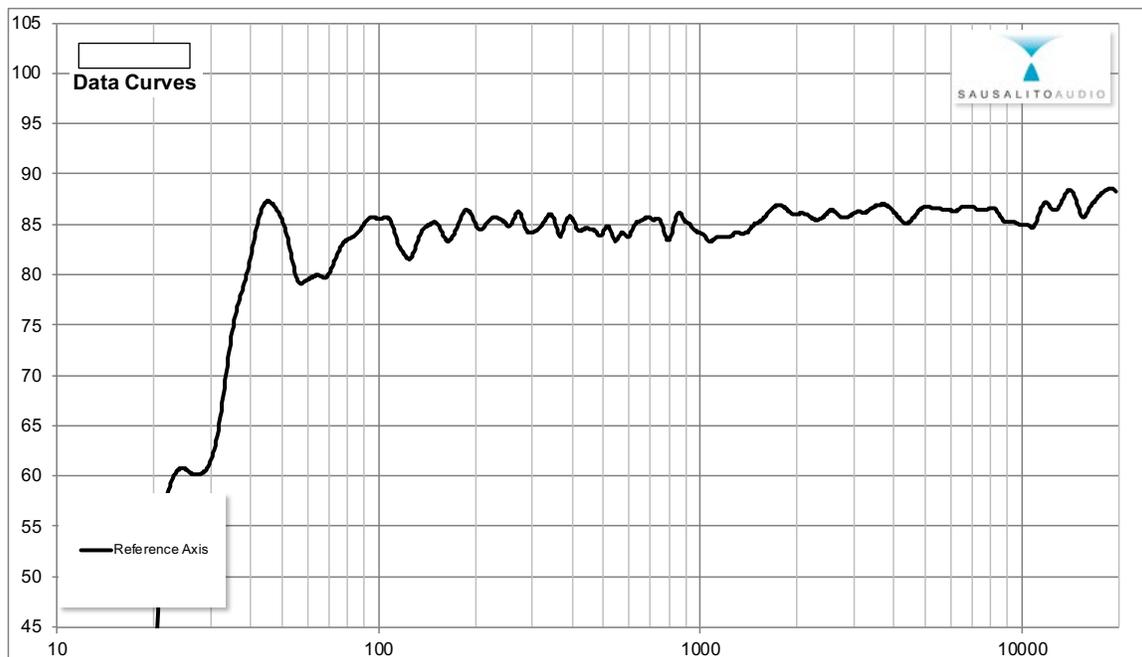


Figure 2: Brand B - This highly regarded studio monitor, has an excellent, if not perfect, axial response. Everything above 1500Hz is shelved up 1dB. This is clearly audible. Also, note that due to the limitation of Sausalito Audio's measurement capabilities, data below 500Hz is increasingly corrupted by room reflections. Below 150Hz the data should be largely disregarded.

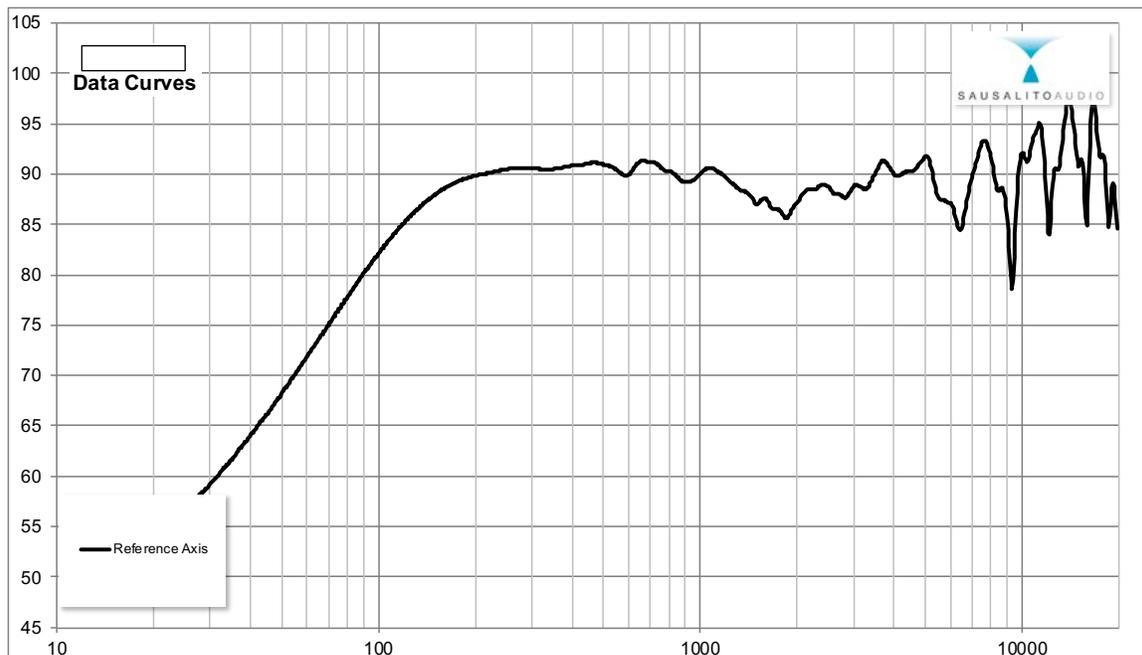


Figure 3: Brand C - This "speaker on a stick" light duty sound reinforcement speaker has a "troubled" axial response. The biggest issue is the medium Q dip at 1900Hz. The comb filtering above 5kHz is certainly audible but exists only over a relatively narrow coverage angle.

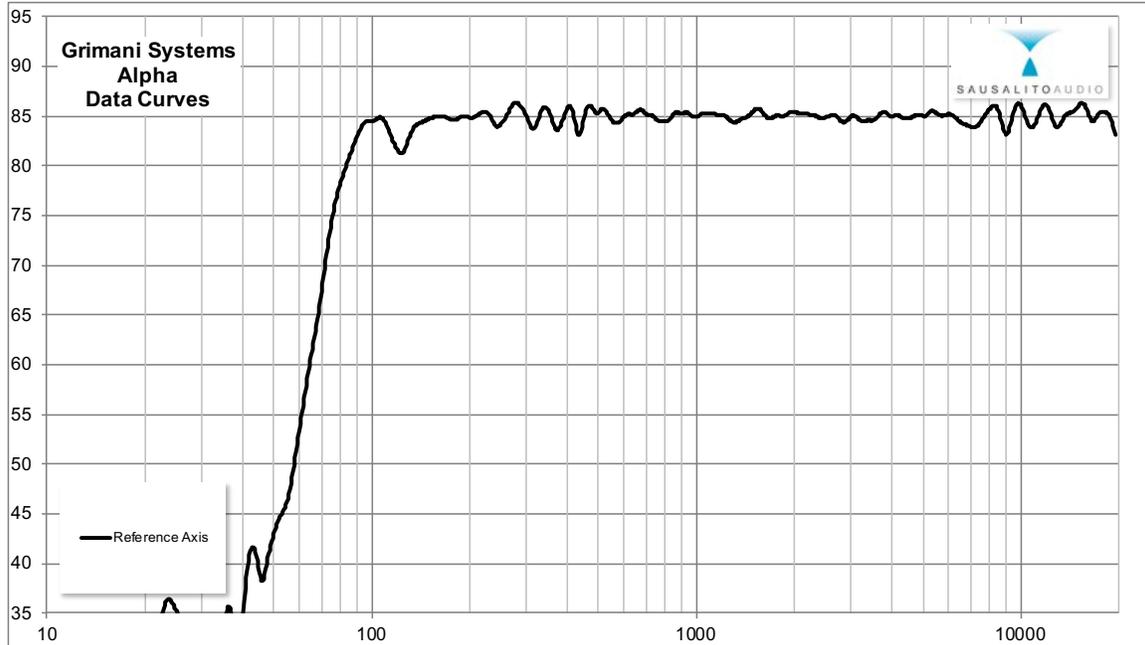


Figure 4: This Conic Section Array loudspeaker was hand tweaked by me. This kind of response is difficult (but certainly not impossible) to achieve routinely in a production loudspeaker. The high frequency wiggles in the curve are inaudible. Once again, the data below ~500Hz becomes increasingly suspect.

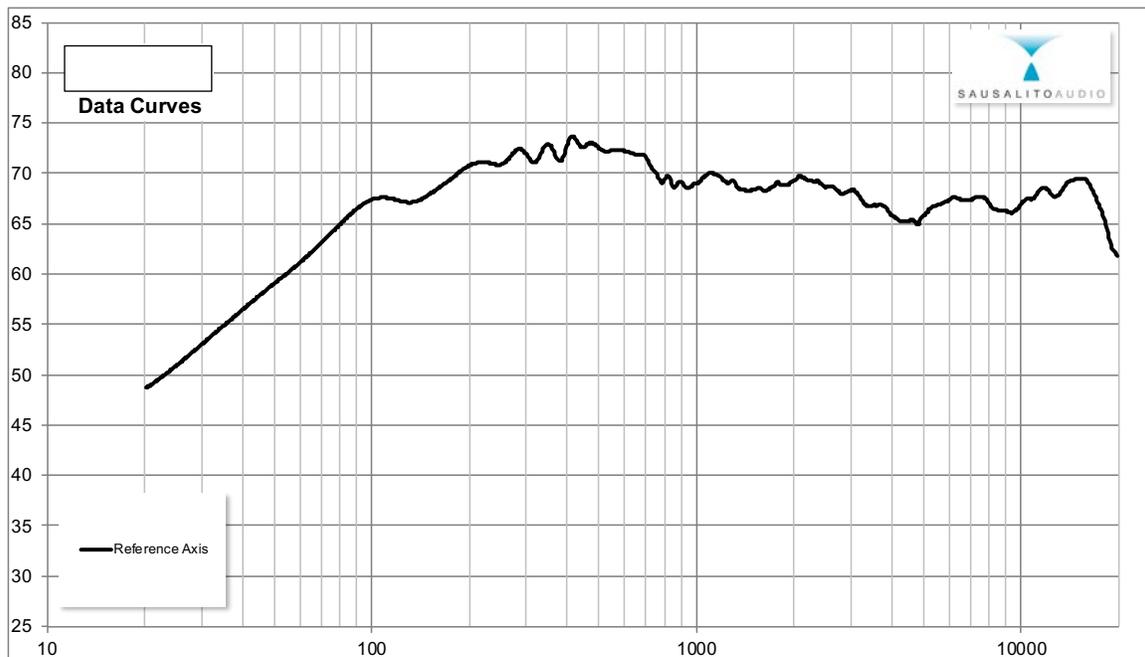


Figure 5: Brand D - A pair of these "audiophile" speakers cost as much as a new car – a really nice new car. The lack of measurement resolution available to me at the time I measured these means we must mostly ignore the data below 400Hz. From 500Hz to 5kHz the response drops by 7dB! The drivers were good, the cabinet design was good, the crossover... not so good. I fixed this speaker with EQ in the final installation.



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The next curve on the Spinorama chart is called the “Listening Window.” This curve is the *average* of 9 measurements: 0° , $\pm 10^\circ$, $\pm 20^\circ$ & $\pm 30^\circ$ in the horizontal plane and $\pm 10^\circ$ in the vertical plane. The Listening Window curve shows us what a person who is sitting somewhere generally in front of the speaker will hear on average. The closer that the listening window curve matches the axial response the better. These curves will be within about 1dB of each other in an excellent loudspeaker. More than 2dB of difference or so over $\frac{1}{2}$ octave or more starts to show meaningful compromise. To quote Dr. Toole, “All loudspeakers must deliver a strong, high quality direct sound to all listeners.” The listening window curve helps us quantify that. Note that the graphs below refer to the same brands presented in the original graphs.

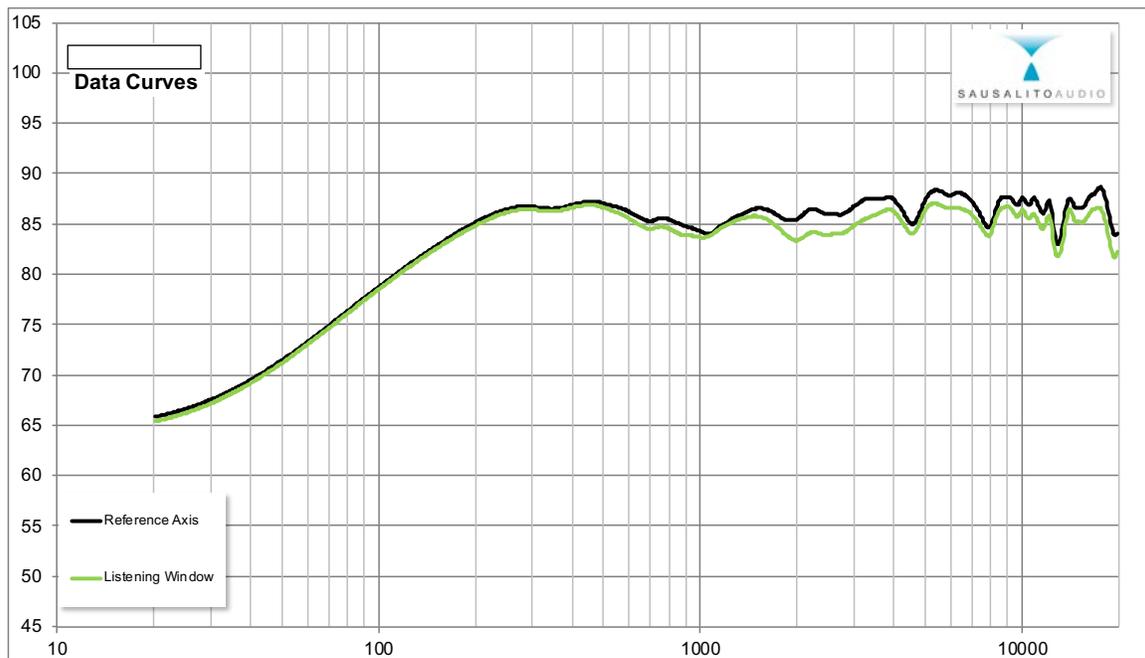


Figure 6: Brand A - We see that this speaker was likely optimized for the listening window rather than the axial response. Given that this is a cinema speaker, that's a sound engineering decision. However, there is a meaningful separation of the two curves over the entire top 3 octaves. This is our first indication that we are looking at a fairly directional loudspeaker. This speaker uses a smallish waveguide on the high frequency compression driver, and two 8" woofers in an MTM configuration.

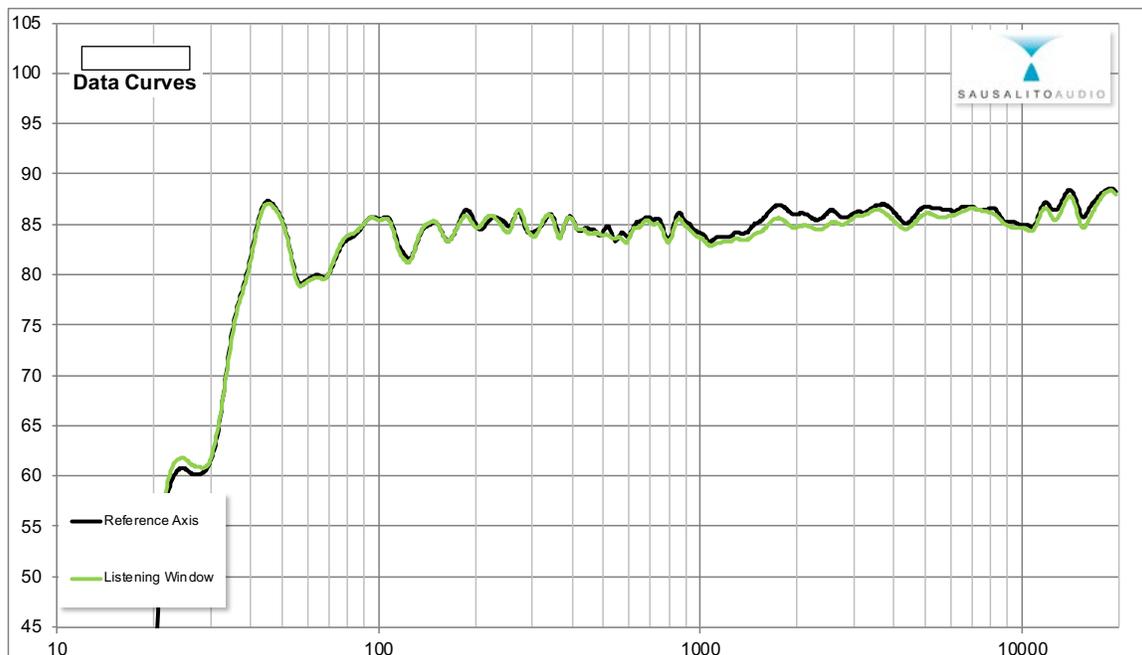


Figure 7: Brand B - Our studio monitor shows excellent matching of the two curves. It's possible that these engineers were optimizing for the listening window as well. This is the kind of performance we're looking for.

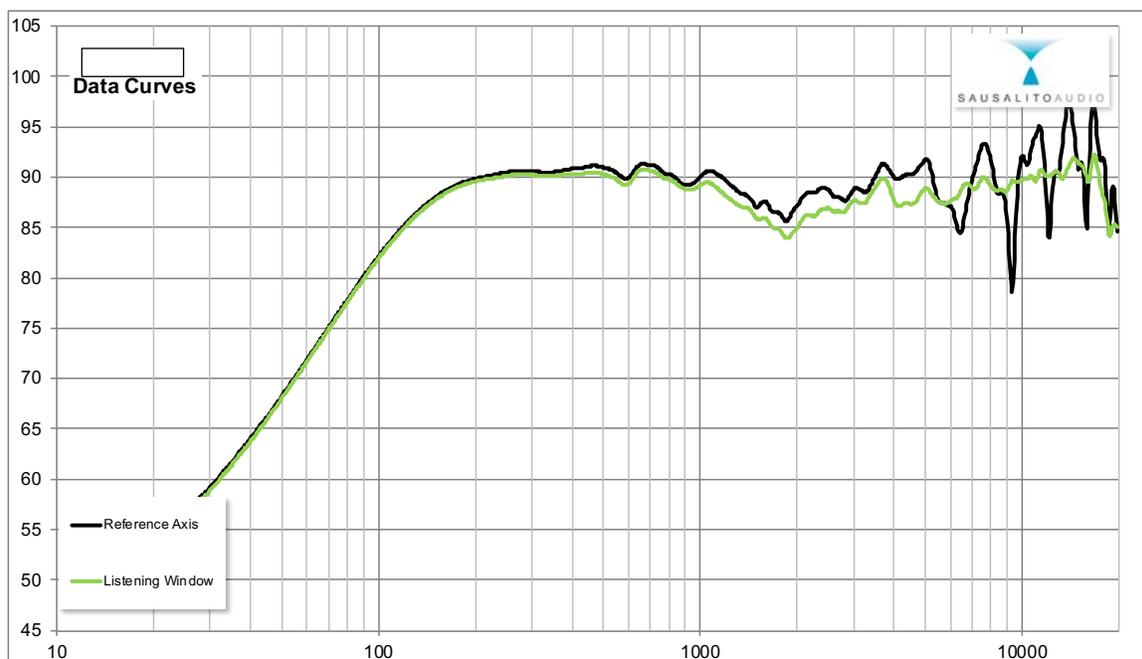


Figure 8: Brand C - The listening window response shows none of the comb filtering that the axial response shows. It is not uncommon for speakers to have a problem on axis that goes away as soon as you move a little to the side. There is a meaningful separation of the curves between 2kHz and 5kHz which tips us off that we are looking at a fairly directional loudspeaker. The overall "V" shape of the listening window curve will not help this speaker win any prizes.

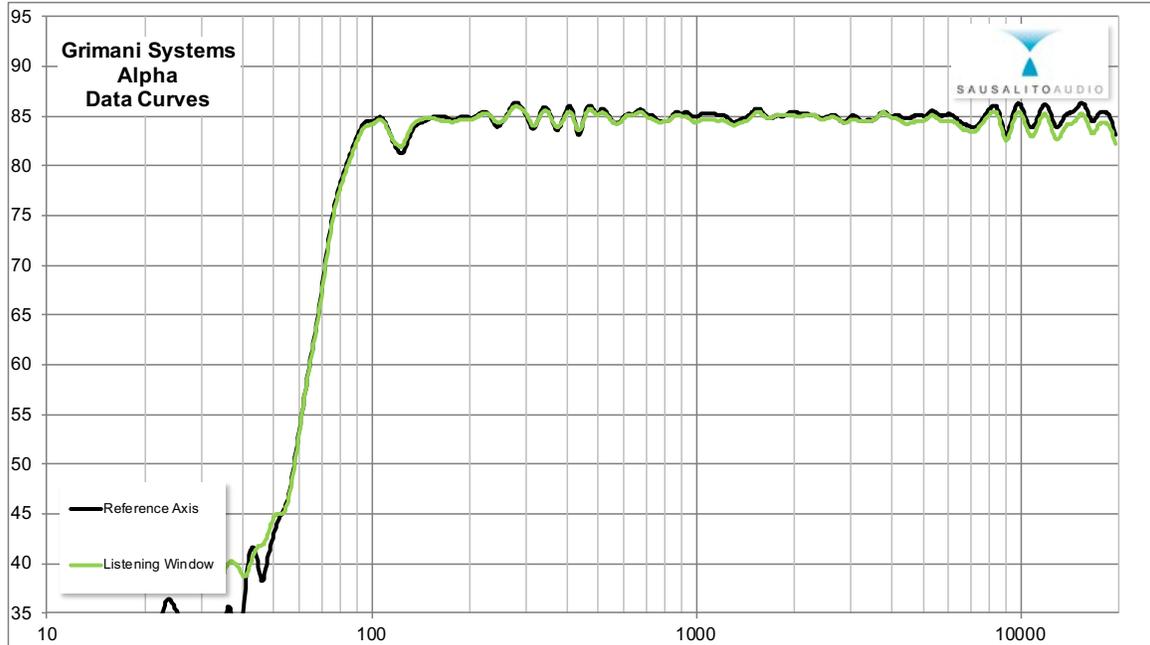


Figure 9: In the CSA loudspeaker, we can see that the two curves are, for all intents and purposes, identical. To my knowledge, you will only ever see this kind of performance in a front firing loudspeaker if it has a Sausalito Audio waveguide. By the way, the crossover point is 1kHz.

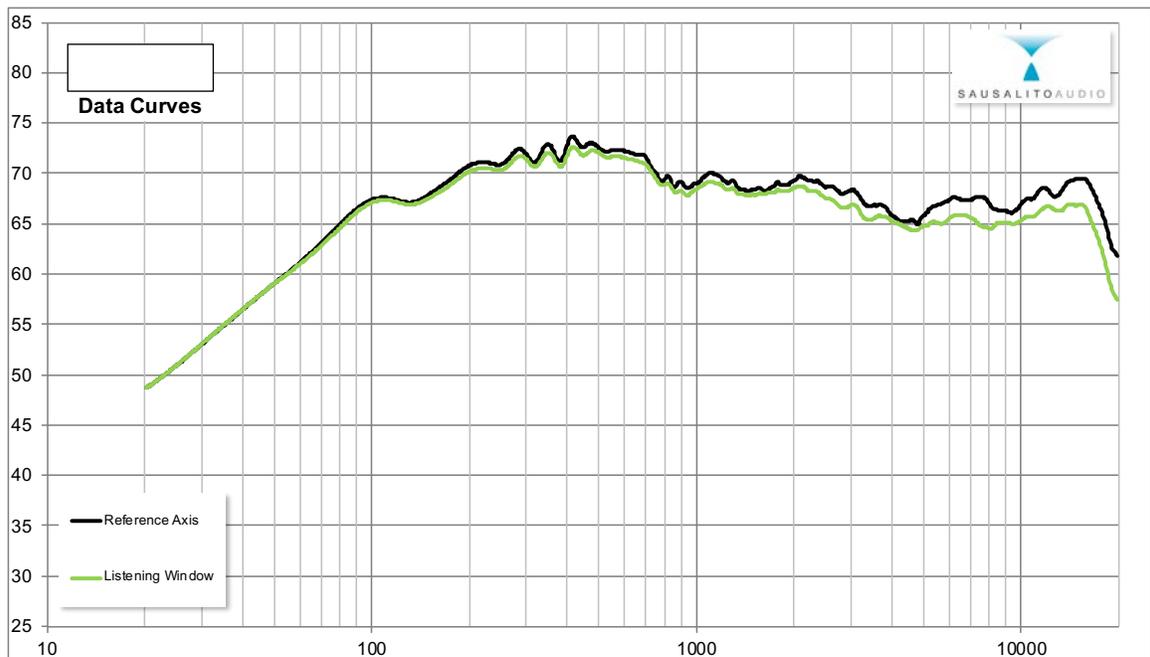


Figure 10: Brand D - Our cone and dome audiophile speaker looks pretty good as far as the listening window matching the direct sound curve goes. The tweeter gets a little more directional than most above 5kHz. This is because it uses a 29mm dome instead of a more typical 25mm dome.



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Just so you know, most of the sound we hear in rooms is reflected from the room boundaries. So, the next curve we add to our Spinorama chart captures the energy that leaves the loudspeaker at extreme off axis angles. This energy is going to hit the side walls, ceiling and floor and bounce into our ears soon after the direct sound from the speaker. These are called early reflections. So, this curve is called the “Early Reflections Curve.” This is where we really separate the relative quality of the various systems when it comes to loudspeaker preference. If the loudspeaker has “good” behavior off axis, the sidewall reflections are beneficial to our perception of timbre, image width and stability. Except for some special case situations, the idea that we need to narrow the directivity of a loudspeaker to avoid room reflections is dead wrong – regardless of the speaker’s application. In a good sounding speaker, the shape of the early reflections curve will be similar to the on-axis and listening window curves. The curve is the average of eight responses: $\pm 40^\circ$, $\pm 60^\circ$ & $\pm 80^\circ$ in the horizontal plane and $\pm 50^\circ$ in the vertical plane.

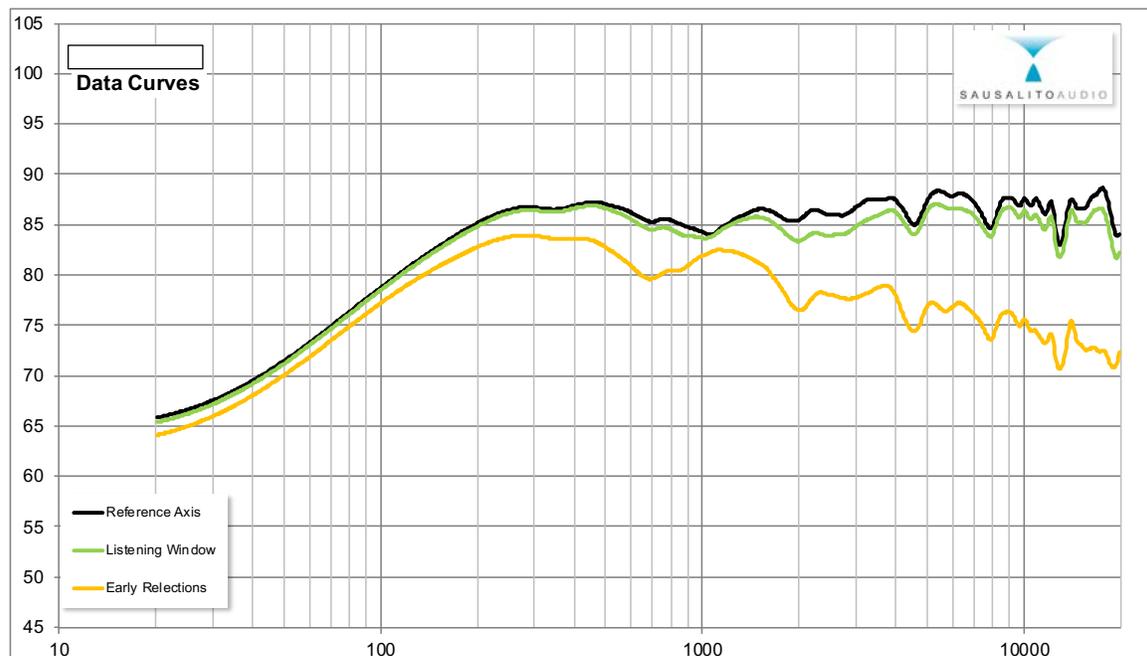


Figure 11: Brand A - Our cinema loudspeaker, which has reasonably flat axial response, has a severely downward sloping early reflections curve. An unfortunate design choice for a cinema speaker. Envelopment and soundstage width will be curtailed.

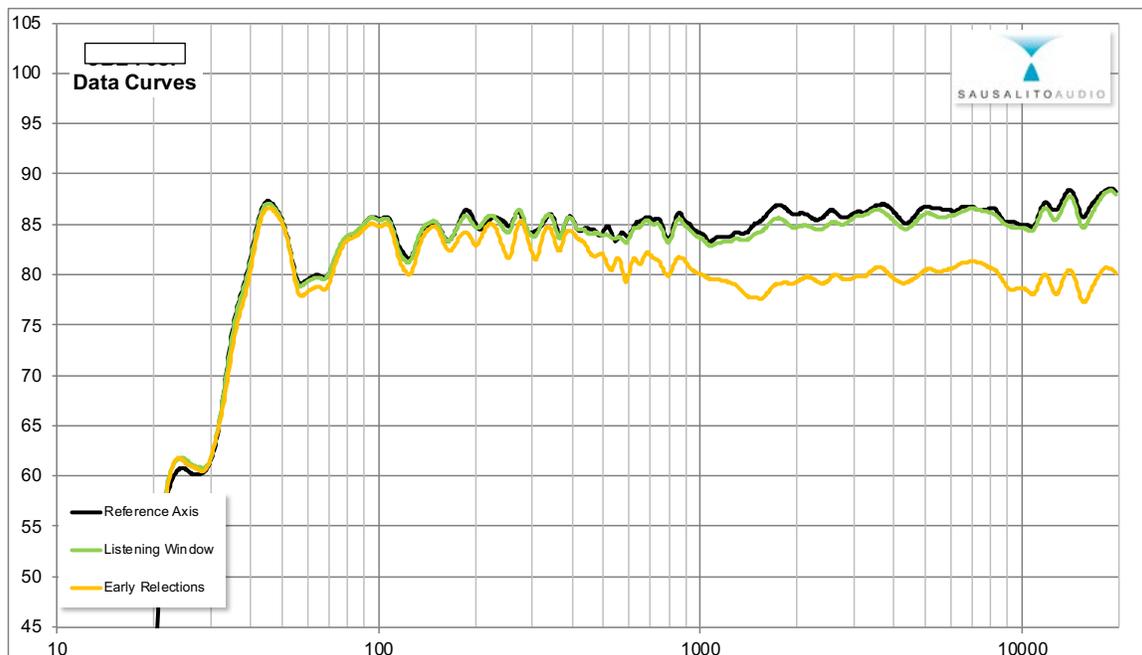


Figure 12: Brand B - The studio monitor early reflection curve shows that the energy that hits the side walls of the room has the same spectral content as the direct sound. The family of curves developing here ALWAYS corresponds with higher preference scores in blind listening trials.

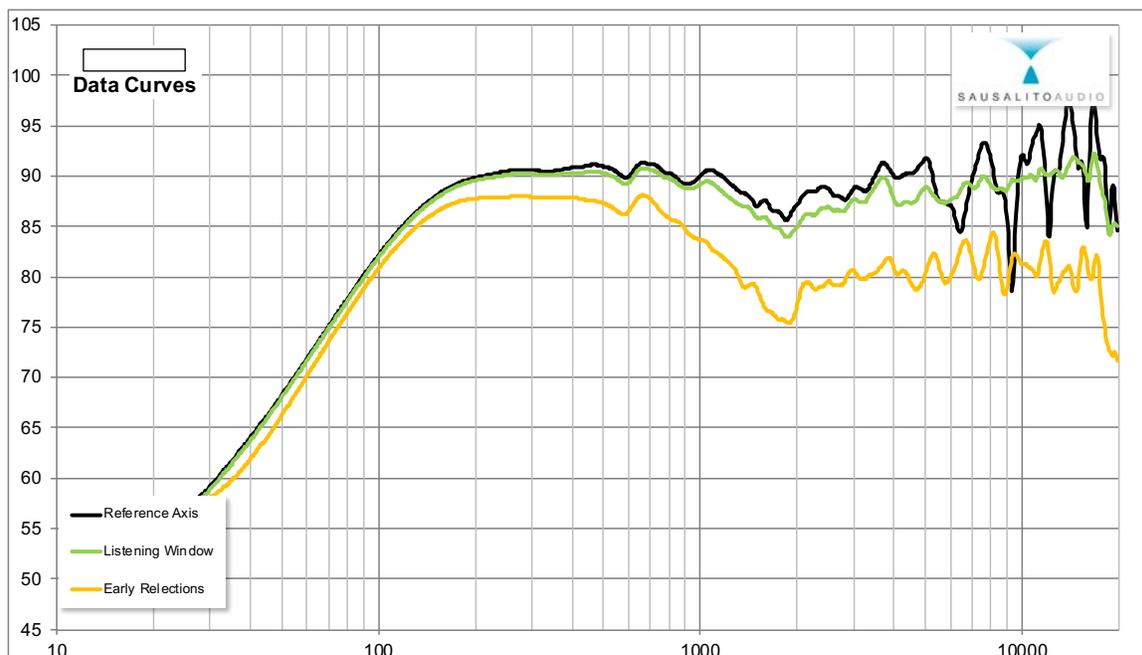


Figure 13: Brand C - This 12" two-way PA speaker seems to have a good constant directivity waveguide. The crossover point is ~1800Hz and the early reflections curve shows the woofer to be very directional at that point. The waveguide was designed to roughly match that directivity and maintain it on up in frequency.

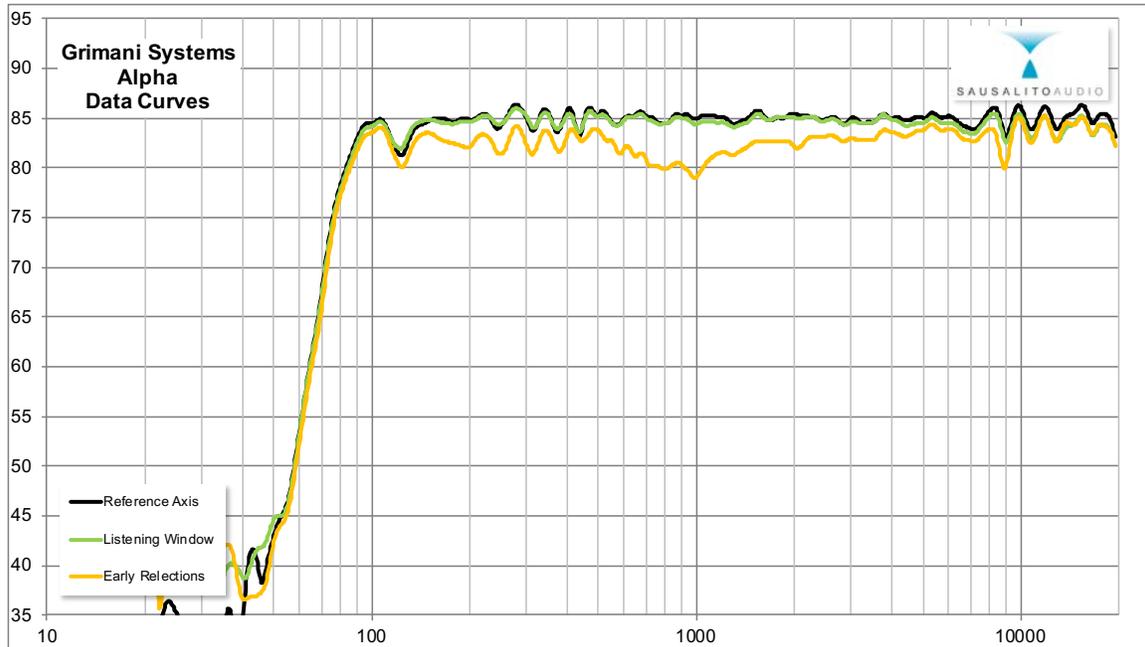


Figure 14: The CSA speaker puts very nearly as much energy with the same spectral shape at the side walls as the direct sound. The soundstage is enormous, the phantom images palpable, and when used in a sound reinforcement application, the guy at the end of the bar hears the same thing as the guy in front of the stage. (... and, "No." there aren't the feedback problems you might think. I write about this elsewhere.)

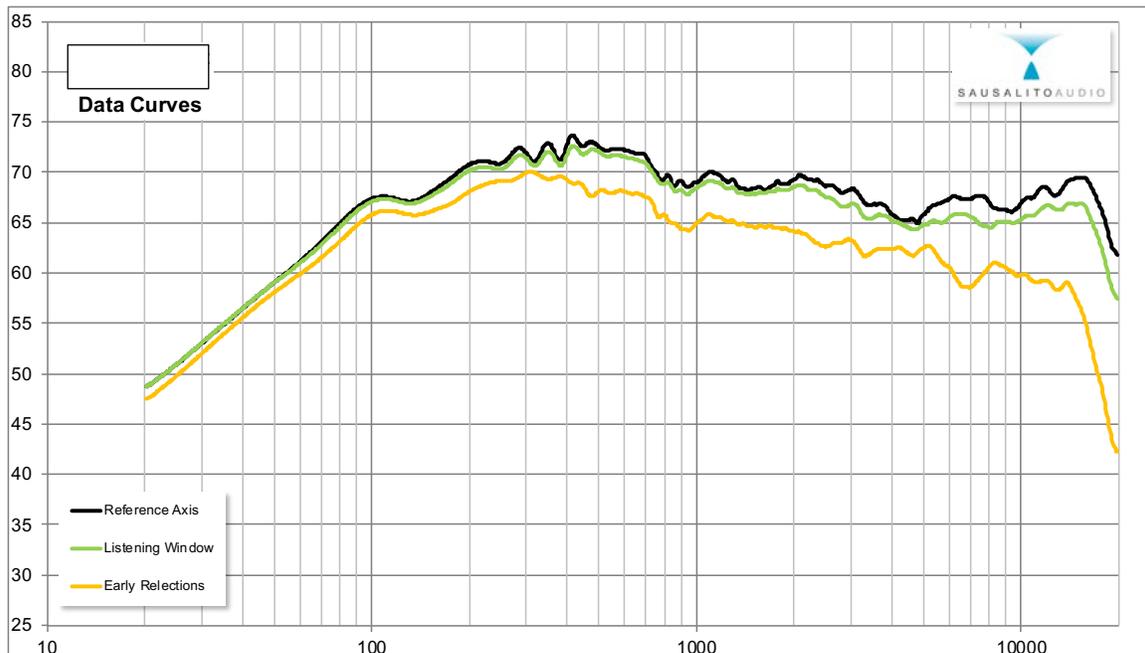


Figure 15: Brand D - The early reflection curve here parallels the axial response curve quite well. A crossover re-work to fix the direct sound, and this could turn into a respectable sounding speaker. As it sits, we don't even have to listen to it to tell that it is not particularly good sounding.



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The next step is to take a look at the weighted average of all 70 measurements. This captures an accurate representation of all the sound emitted by the loudspeaker. This is called the “sound power.” In a speaker judged to be excellent sounding, the sound power curve will not have broad “undulations”, and largely parallels the other curves, although, we expect to see some downward tilt to the curve.

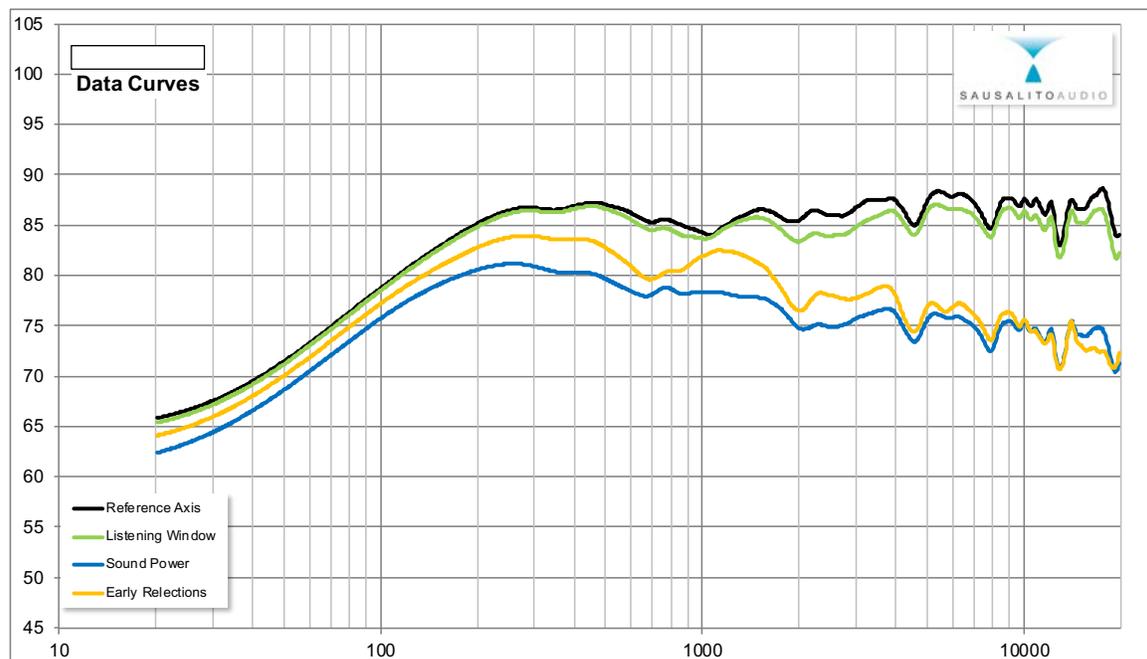


Figure 16: Brand A - The shape of this sound power curve is OK. It's well behaved. It's just a long way away from the on-axis curve.

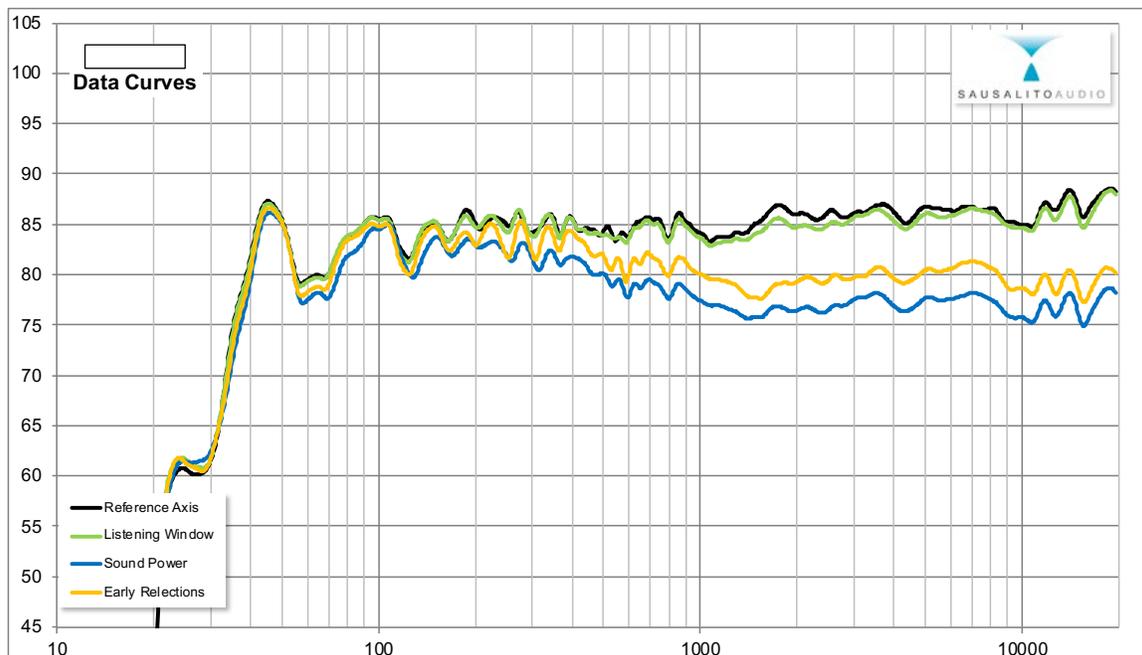


Figure 17: Brand B - This is not just an excellent studio monitor, it's an excellent speaker! The sound power curve parallels the other curves beautifully. This speaker is among the best for music production. It would make an outstanding home theater speaker or stereo speaker for home listening.

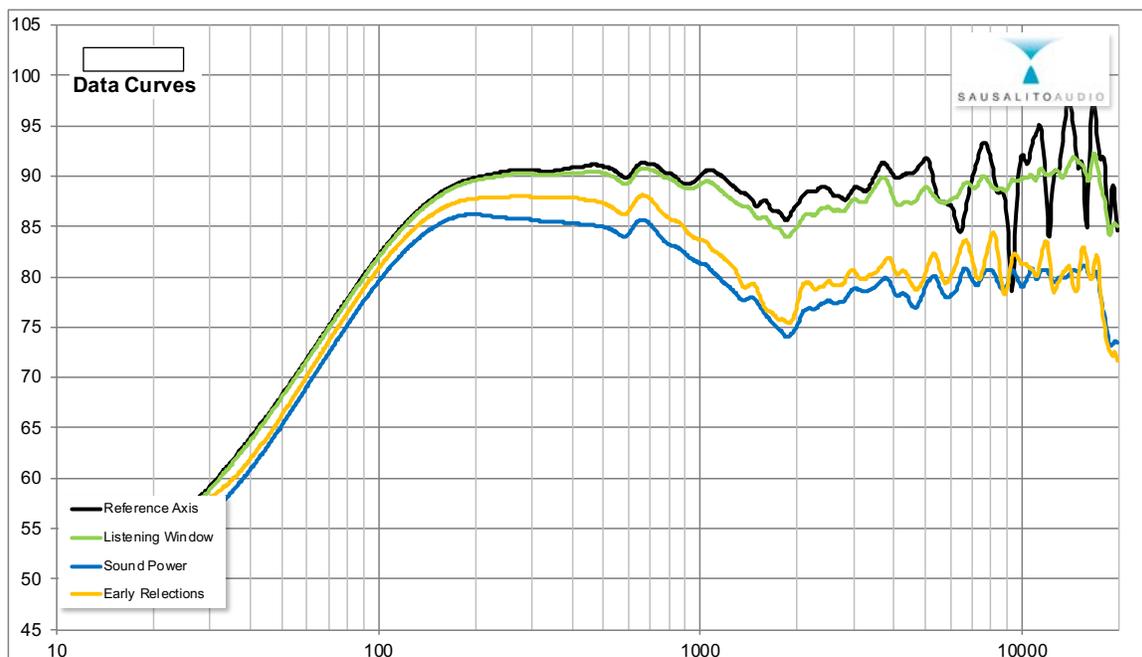


Figure 18: Brand C - The dramatic drop in both the early reflections & sound power curves from 700Hz to 1900Hz will not help this speaker's preference scores. The closeness of the sound power curve & the early reflections curve means that the waveguide does a good job of keeping the speakers output in front of the speaker. This is traditional sound reinforcement speaker design. These curves explain why most PA speakers sound like... well, PA speakers.

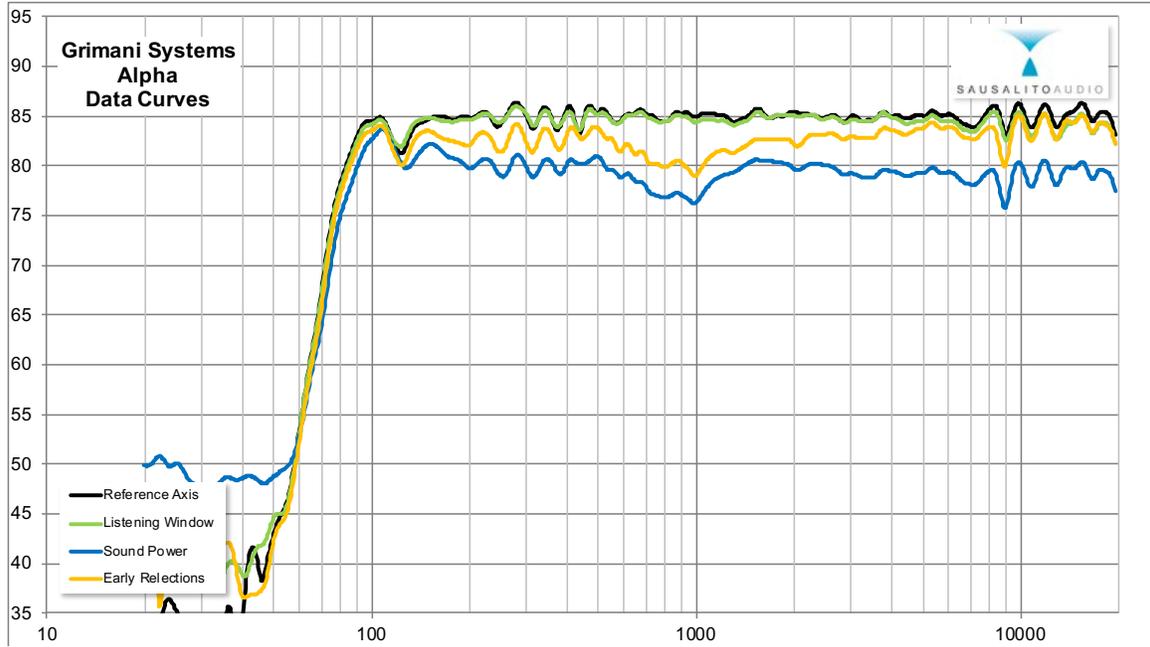


Figure 19: The sound power curve for the CSA speaker is unique. Where more conventional well-designed speakers' sound power curves would dip down into the 1kHz region and stay shelved down, the CSA waveguide causes the sound power curve to pop back up to the level of the low midrange frequencies and stay there.

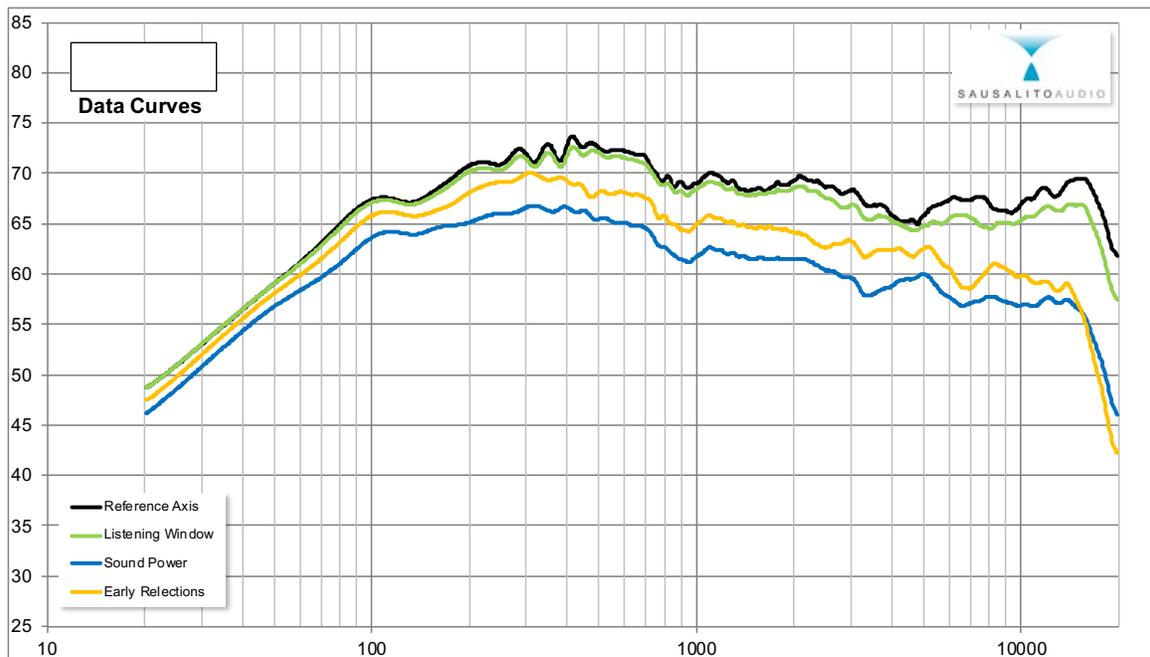


Figure 20: Brand D - The sound power curve here has no "accidents." It parallels the other curves well. The problem with this speaker is the axial response.



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The next two curves are derived from the ones we already have. The “Directivity Index” (DI) curve is traditionally the on-axis response minus the sound power. I have adopted Harman International’s variant and use the listening window rather than the axial response. The rationale here is that idiosyncrasies that appear on-axis but not elsewhere are removed. Also, since so much listening is for multiple people, using the curve that tells us what that group is going to hear on average gives us a better metric for how the speaker’s sound quality will be perceived. This variant will usually lead to DI numbers that are a dB or 2 lower than the traditional calculation.

The higher the directivity index the more directional a speaker is. That is to say that more of the speaker’s energy output is biased forward. A DI of 0dB is omni-directional. A high DI number is 10dB. **As a general rule of thumb, lower DI speakers (DI’s in the 5dB to 7dB range) will be preferred in blind listening tests.** However, as I mentioned previously, there are often good reasons to use higher DI loudspeakers and, they have their place. My personal opinion is that high directivity index speakers are vastly over-used, but I comment on this at length elsewhere.

The last curve on the Spinorama chart is the “Early Reflections Directivity Index.” This is the early reflections curve minus the sound power curve. Like the DI curve, this is another way of looking at the data we already have. **The early reflections DI tells us how much of the total energy the loudspeaker produces is biased to the far-off axis response of the loudspeaker.**

What we are looking for in these curves are smooth trends that are “flattish” with perhaps an upward slope especially at the highest frequencies. Except for a true dipole speaker, they will start at 0dB at the left side of the chart and increase as the wavelengths get shorter and the directionality goes up. Directivity Index problems are a good bit harder to hear than issues that show up in the axial or listening window response. This makes interpreting these curves more difficult. An anomaly in a DI curve that, if it appeared in the direct



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sound curve would be catastrophic, might be barely audible. The audibility of potential directivity index issues will be much more dependent on the loudspeaker/room interactions than the other data we have so far considered. DI curve problems are generally low Q issues. It is worth noting that **if the axial response is substantially flat, the inverse of the directivity index gives a useful approximation of how the speaker will measure in a room – of any size.** The caveats here are that at low frequencies, room modes will dominate performance where they exist and, in the top octave or two the direct sound from the speaker dominates.

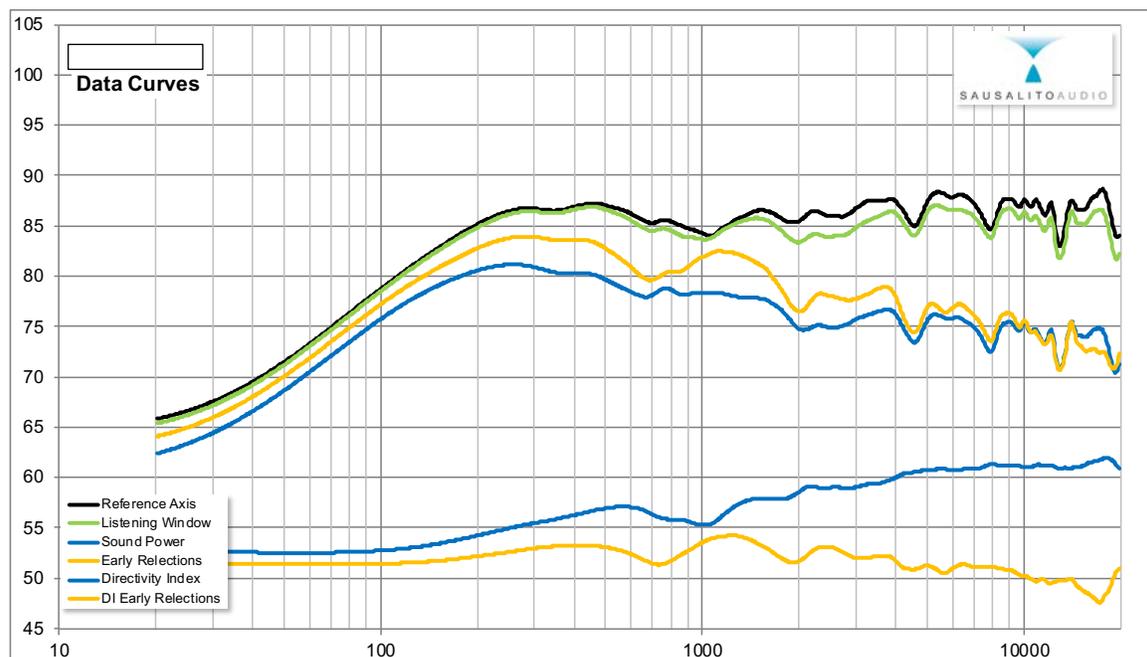


Figure 21: Brand A - No surprises here. The DI curve is smooth and rises to a quite high value of 11dB. The early reflections DI shows that very little high frequency energy is going to reflect off the side walls. The speaker will sound "bright" if you are directly on axis, and then, quickly "not bright" as you move off the center line. It would likely not be preferred to a lower DI loudspeaker with similar axial frequency response in most rooms.

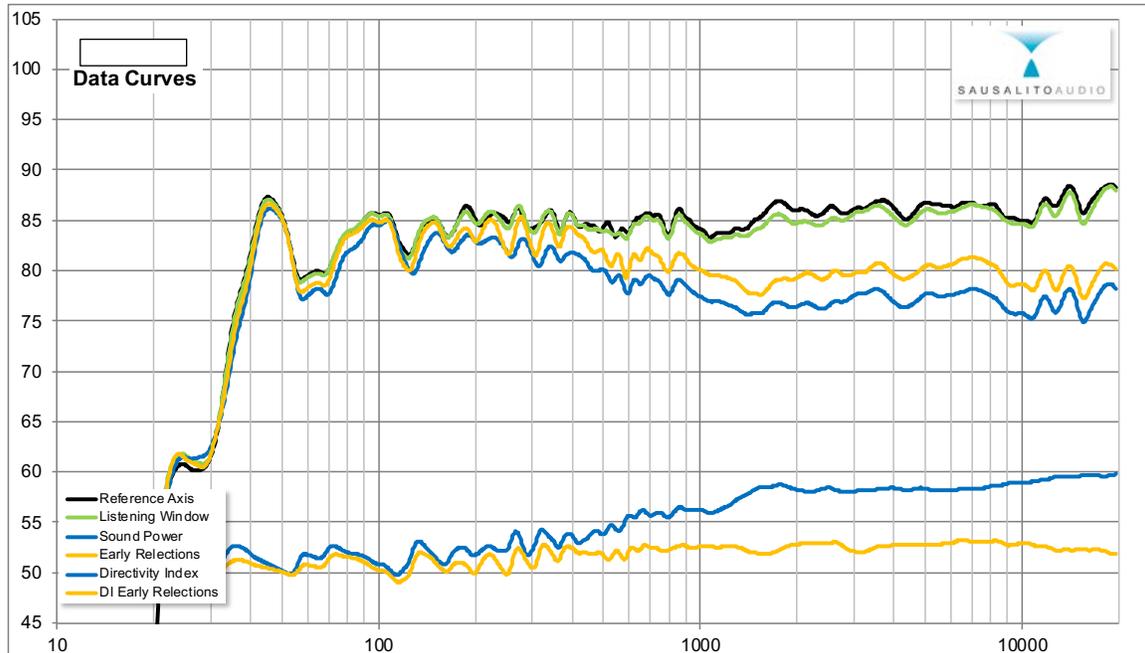


Figure 22: Brand B - Once again, this is excellent performance. The DI rises to 8dB and stays there. The early reflections DI shows that the speaker puts a remarkably consistent spectrum of sound toward the side walls. Good sounding speakers have Spinorama charts that look similar to this.

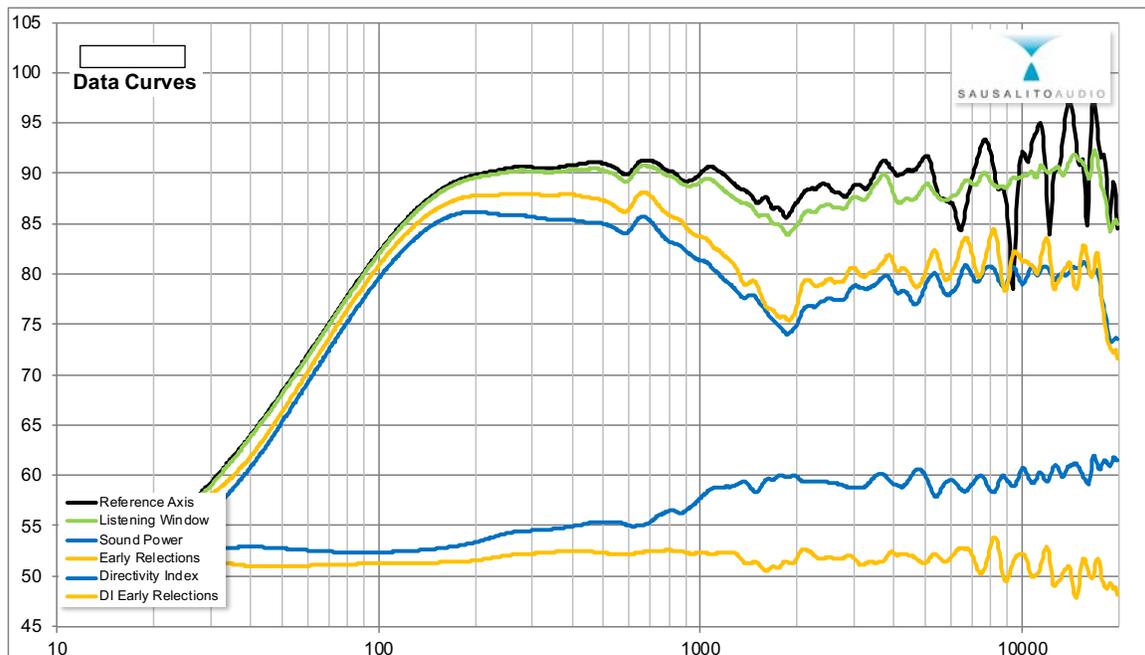


Figure 23: Brand C - This speaker is really benefiting from the modified DI curve calculation! This would look a mess if the axial response was used rather than the listening window. Both DI curves are good. That doesn't make it a particularly good sounding speaker. You need to look at all the curves to make such a determination.

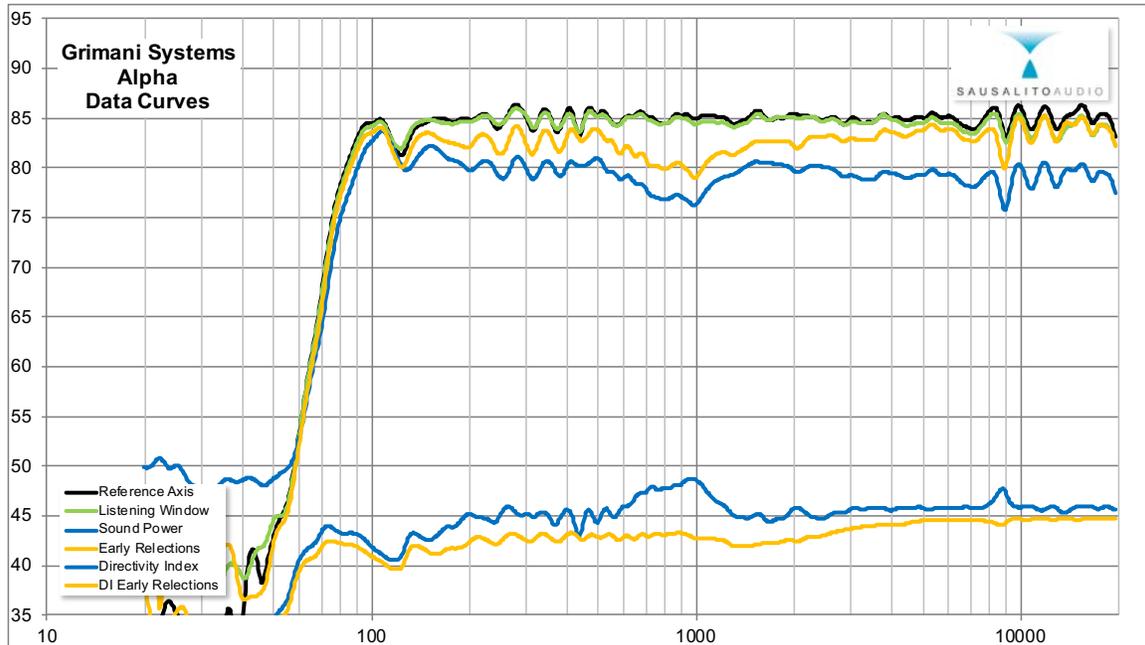


Figure 24: The CSA speaker has a set of curves you're not likely to see anywhere else. The DI curve shows the dual midrange drivers beaming at the 1kHz crossover. The waveguide then takes over and keeps the DI pristinely constant at 6dB out to 20kHz. The early reflections DI again shows that there is nearly as much energy directed at off axis listeners and the sidewalls of the room as directly in front of the speaker.

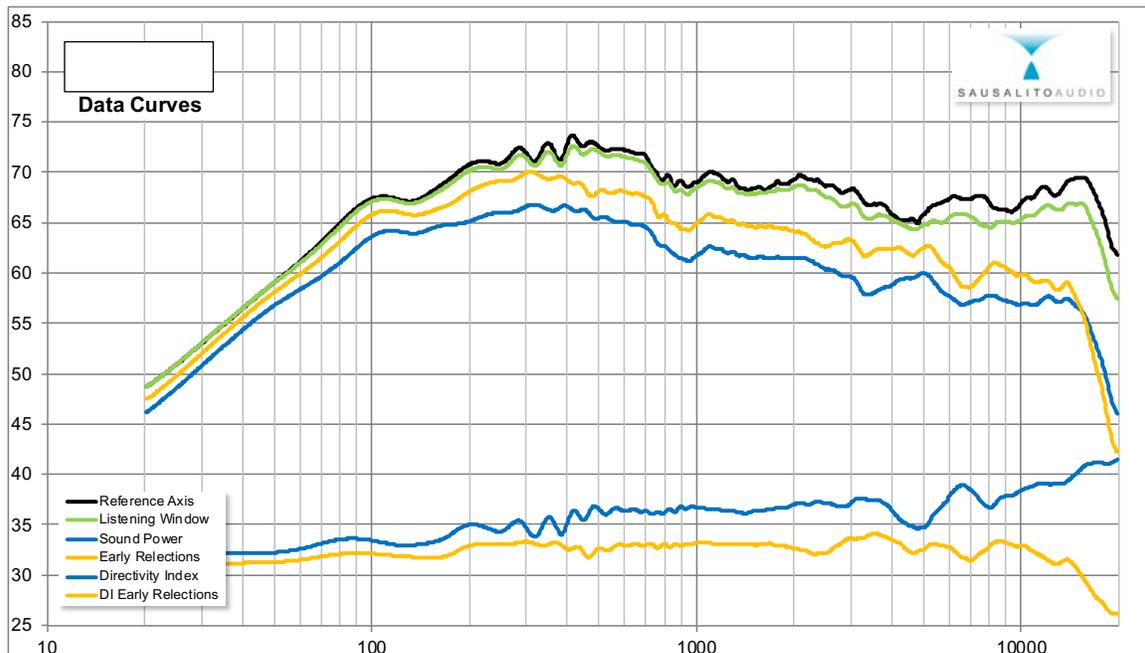


Figure 25: Brand D - Both of these DI curves look great! We see the larger than normal dome tweeter beaming in the top octave. This speaker does not suffer from directivity problems. It's poor axial response curve would keep this speaker from performing well in a listening test.



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Harman has kindly given me permission to reproduce here some of their Spinorama data. (These charts also appear in Dr. Toole's book.) The measurements were made in a large anechoic chamber, and the high-resolution data extends to 20Hz. To make a complete and accurate, assessment of a loudspeaker, you have to have data of this quality.

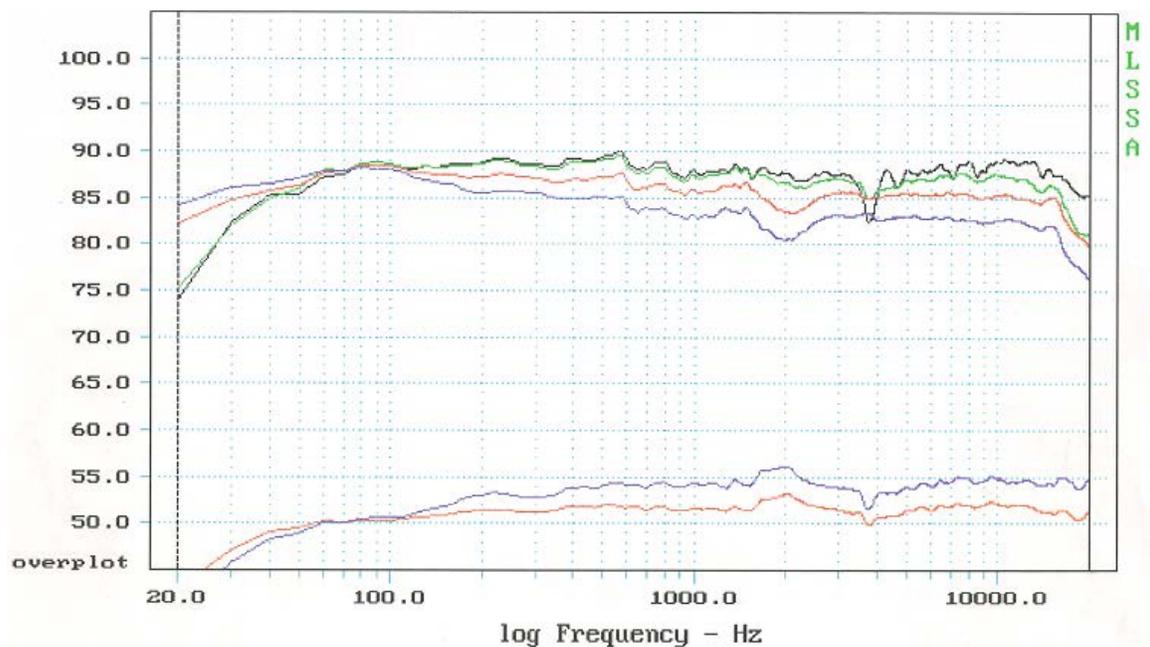


Figure 26: This speaker is one of the all-time double-blind listening trial champions! The axial response curve is flat. The top four curves are tightly clustered and the DI curve pops over the 5dB mark only briefly. This passive cone and dome speaker is an impressive bit of engineering.

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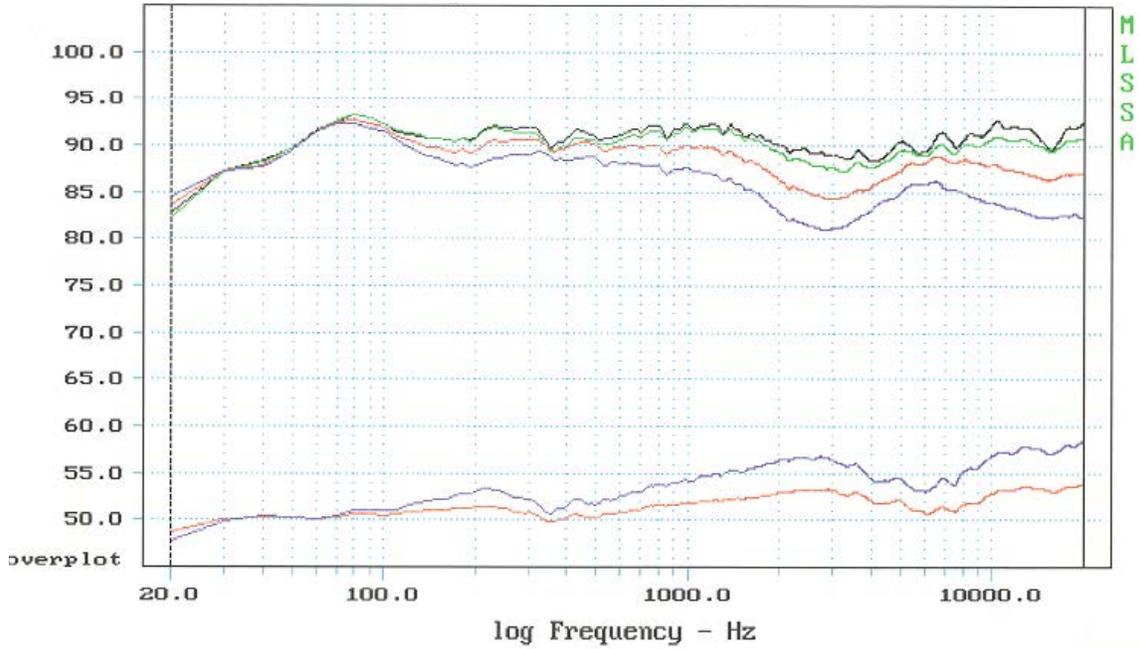


Figure 27: This commercially successful audiophile cone and dome speaker has two distinct problems. The response anomalies in the axial response are low Q and quite audible. That could be fixed with EQ. The DI curve shows that the two stacked woofers are starting to beam a bit before handing off to the midrange driver around 300Hz. That's not such a big deal. The large midrange driver is crossed over at too high a frequency - a common problem. That causes the undulations in the DI curve above 1kHz. This is audible and not fixable with EQ.

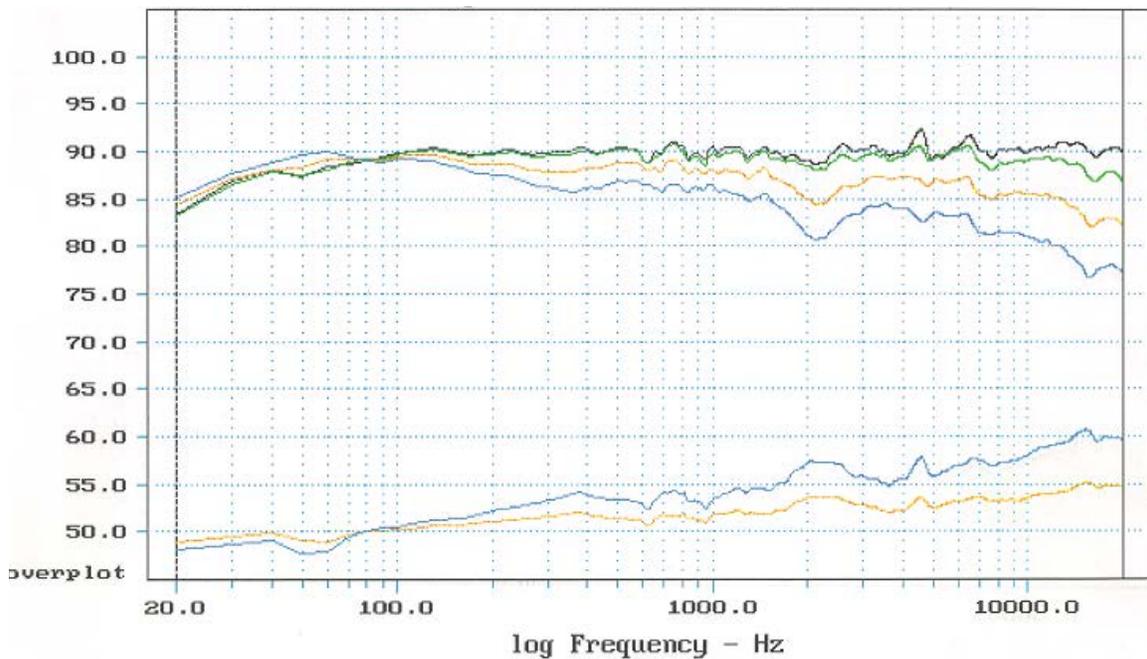


Figure 28: An excellent loudspeaker.

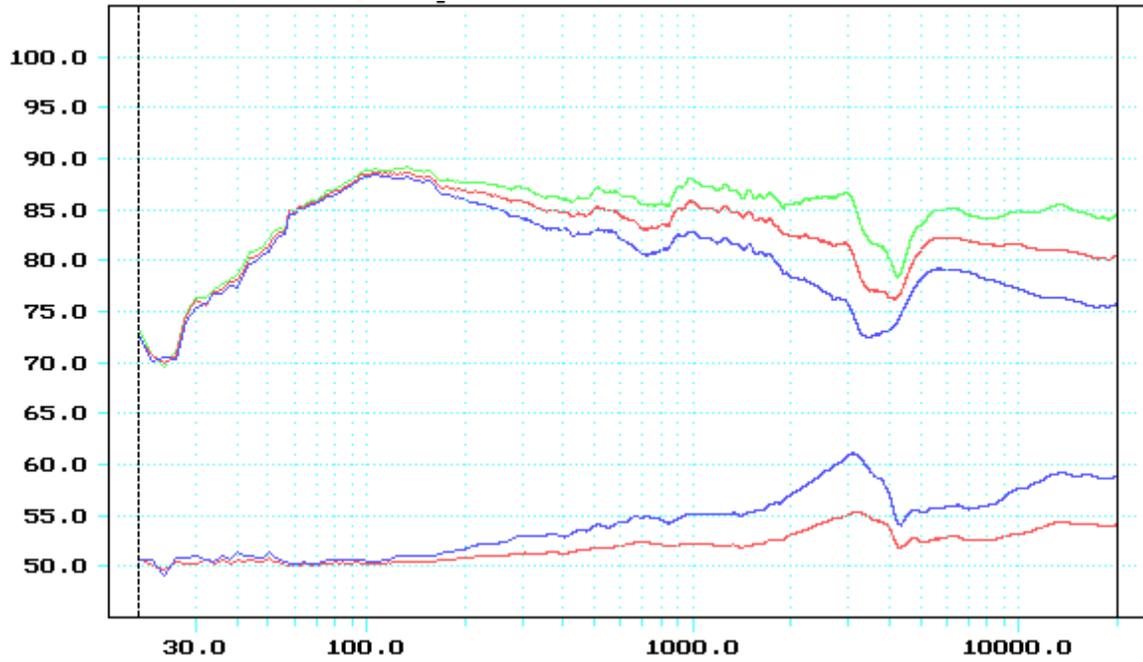


Figure 29: Not an excellent loudspeaker.

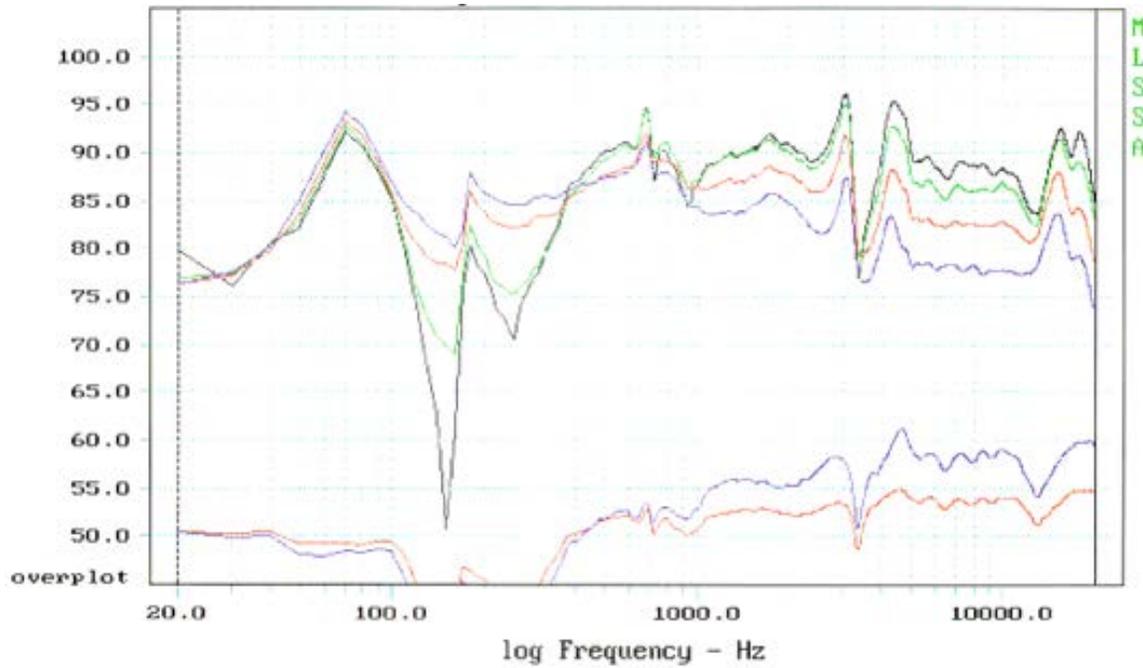


Figure 30: Words fail me.... This was sold to unknowing consumers, and, as far as I know, no one went to jail.



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Figure 31: Sausalito Audio's measurement space.

To summarize:

1. If your work concerns itself with loudspeakers and how they perform in rooms, and you haven't read "Sound Reproduction" by Dr. Floyd Toole, I strongly recommend you do so.
2. It is possible from measurement data alone to get a high degree of confidence in how a speaker's sound quality would be perceived in a controlled listening test.
3. Spinorama charts, and the implied sound quality represented, apply to all types of loudspeakers. The "rules" for good sound apply equally to home speakers, cinema speakers, sound reinforcement speakers, wireless counter top speakers, soundbars, etc.
4. The data cannot be obtained with the loudspeaker in situ in a room.
5. The axial frequency response curve is the single most important curve in evaluating a loudspeaker.
6. The Listening Window curve shows us what a person who is sitting somewhere generally in front of the speaker will hear on



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- average. The closer that the listening window curve matches the axial response the better.
7. Most of the sound we hear in rooms is reflected from the room boundaries.
 8. If the loudspeaker has “good” behavior off axis, the sidewall reflections are beneficial to our perception of timbre, image width and stability.
 9. In a good sounding speaker, the shape of the early reflections curve will be similar to the on-axis and listening window curves.
 10. In a speaker judged to be excellent sounding, the sound power curve will not have broad “undulations”, and largely parallels the other curves.
 11. The higher the directivity index the more directional a speaker is.
 12. As a general rule of thumb, lower DI speakers (DI’s in the 5dB to 7dB range) will be preferred in blind listening tests.
 13. The early reflections DI tells us how much of the total energy the loudspeaker produces is biased to the far-off axis response of the loudspeaker.

In general, I think it is fair to say that the importance of the Spinorama curves as I’ve laid them out here are in order of decreasing audibility. There is no question that the easiest issues to identify in a speaker are with axial frequency response. You can sit in front of a speaker, listen, look at the axial response curve and say, “Yup, I can hear that rolled off top end.”

When we start to talk about the sound of speakers with very similar on-axis frequency response, but with different directivity/sound power characteristics, the audible differences, while they may be very apparent, become a little harder to describe and more variable due to speaker/room interactions. They reveal themselves as differences in character. All things being equal, (remember, there is good research to back these next statements up) the speaker that has the smoothest and widest off-axis behavior will prevail in a listening preference test. Such speakers are described as “more natural,”



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more “open,” less “colored.” This is because the high frequency off-axis output of the speaker will engage the room and provide good data for our ears and brain to use. **The sound power curve of the speaker will imprint itself on the room response – regardless of room size** – and the preference is always for a curve that is smooth and relatively flat with some downward tilt. Now, you can put an excellent wide dispersion loudspeaker in a room, take too much absorption that’s too thin, and put it in the wrong places on the wall, and botch it all up. But that’s the subject of another paper.

I want to reiterate that there are good reasons to design a speaker that has a narrower directivity pattern. The fact remains that those speakers can be subjected to this type of analysis to estimate how they will likely sound. The rules don’t change because the speaker has to put 110dbSPL at 100ft. in a large room. Such a requirement forces engineering decisions that may reduce absolute sound quality. That’s fine. It is my opinion, however, that the sound reinforcement side of the industry, including pro-cinema, leans too heavily on overly directional loudspeakers in the mistaken belief that the principles presented here don’t apply to their environment. But, this too is the subject of another paper.

Finally, in order for data like this to give us a very good picture of loudspeaker performance, one really needs to measure in an anechoic chamber. I don’t have one. Therefore, my measurements lack some resolution and low frequency extension. My interest is with high frequency waveguides and my data is plenty good above ~500Hz to make the needed assessments. Also, I’m not trying to be the audio police. I’ve chosen to present data in this format because I think it should be more of an industry standard, and, I think it’s a good way to highlight the improvements a Conic Section Array waveguide can bring to a loudspeaker.

Thanks for reading. Please get in touch with comments or questions.