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04 August 2017 Charlie Hughes

Optimizing Loudspeaker Directivity Through the Crossover Region

I've designed a lot of crossover during the last 30 years.. I'm sure many of you reading this article have also designed a crossover for a loudspeaker system. Even if you've just dialed in the filter parameters for a DSP, you've designed a crossover. An important question to ask is, do you know what the crossover filters are doing to the response of the loudspeaker system? Some of you may have measured the frequency response of the loudspeaker system to determine what's happening through the crossover region. However, most only look at the on-axis response of the loudspeaker. It's equally important, or perhaps more important, to know what's happening off-axis. Let's see how loudspeaker modeling can be used to help with this.

There are quite a few loudspeaker modeling programs that let users look at the on-axis frequency response of a low frequency pass band (woofer) or a high frequency pass band (tweeter or horn). Of course, the user has to enter the measurement data for each of the pass bands. These programs also allow the user to specify different filters that are used to alter the signals presented to each of the pass bands. The effects of the filters on each of the pass bands are calculated. The response of all the pass bands can then be added together to simulate the on-axis response of the loudspeaker system. But what's happening off-axis?

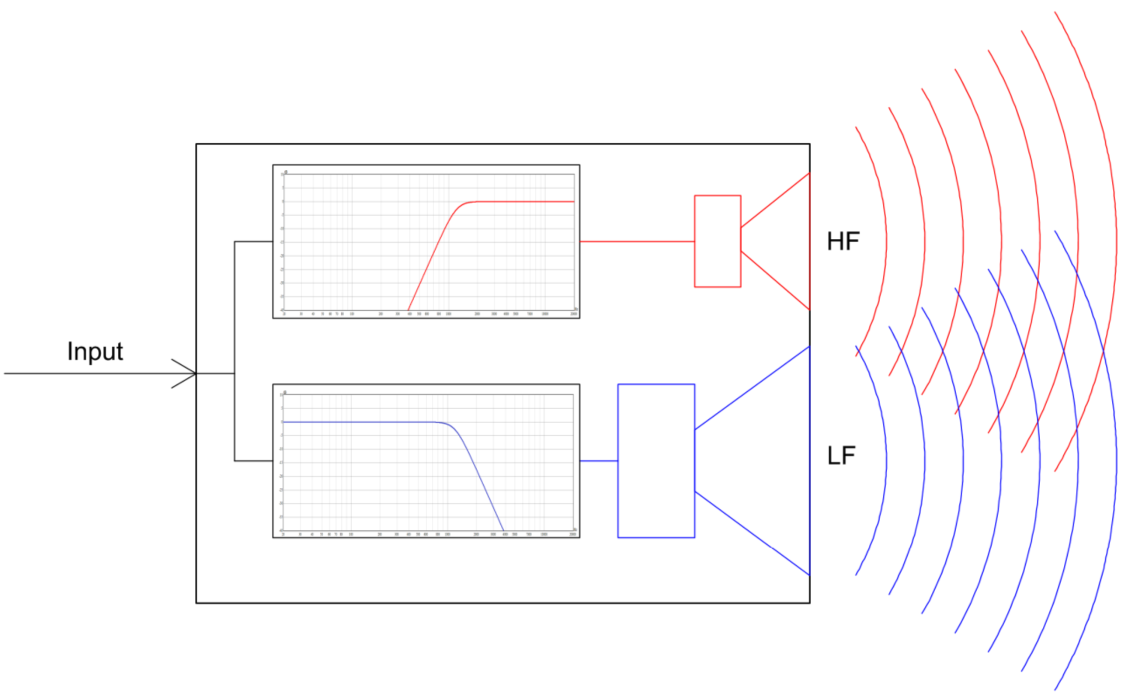

Figure 1: Signal flow showing filters in a loudspeaker system

Let's replace the on-axis frequency response data of each pass band with directivity data (on-axis and off-axis frequency responses) for each pass band. We can combine this data with the effect of the filters and calculate the directivity response of the complete loudspeaker system. This may not seem like a big deal, but it can save an incredible amount of time when evaluating a crossover design. Instead of making changes to the crossover and then remeasuring the loudspeaker (which can take 30 minutes or more) in order to see the effects on the directivity of the loudspeaker, the directivity response of the system can be calculated in seconds. Keep in mind the directivity data and the filter data must be complex data (both magnitude and phase). It also needs to be sufficiently accurate for the intended purpose ("Executing Measurements for Loudspeaker Modeling Files", *Live Sound*, May 2017).

To illustrate this, we'll use a two-way loudspeaker with a 15 inch woofer for the LF pass band and a compression driver on a constant directivity horn for the HF pass band. The horn is located above the woofer, vertically. This can often make for a less than ideal vertical directivity response. The on-axis frequency response of the LF and HF pass bands, along with the combined summation, using the original crossover filters from the manufacturer of this loudspeaker system are shown in Figure 2. This seems to show good summation through the crossover region (from about 1 kHz to 2 kHz).

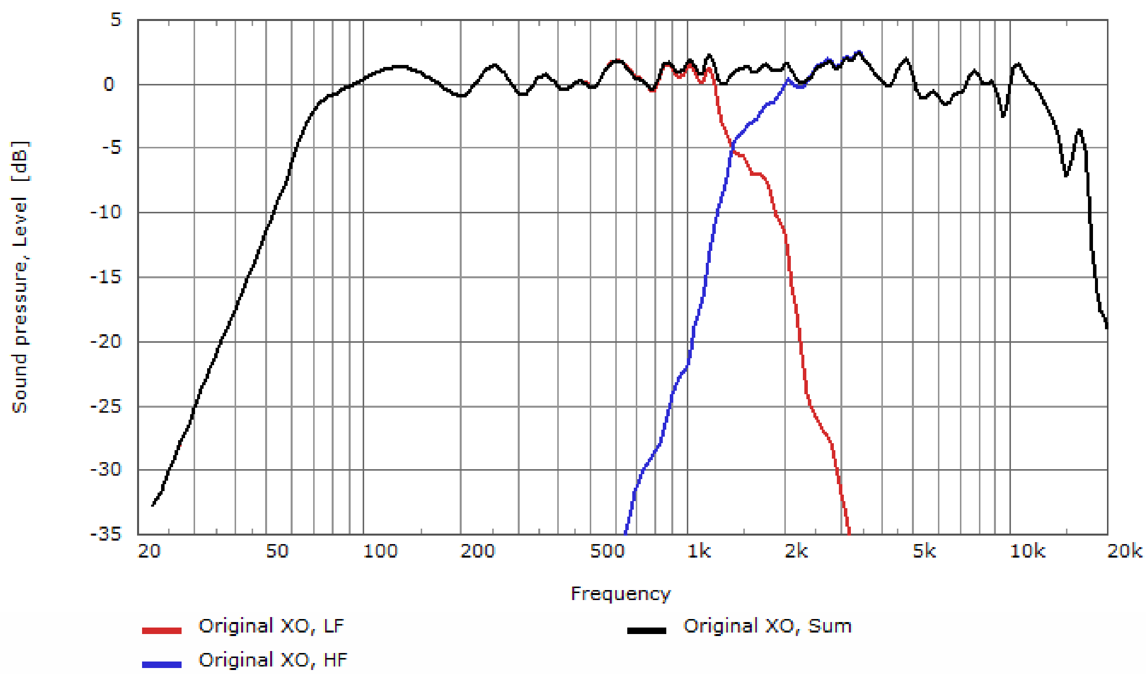

Figure 2: On-axis frequency response of the individual pass bands using the original crossover filters and the combined response

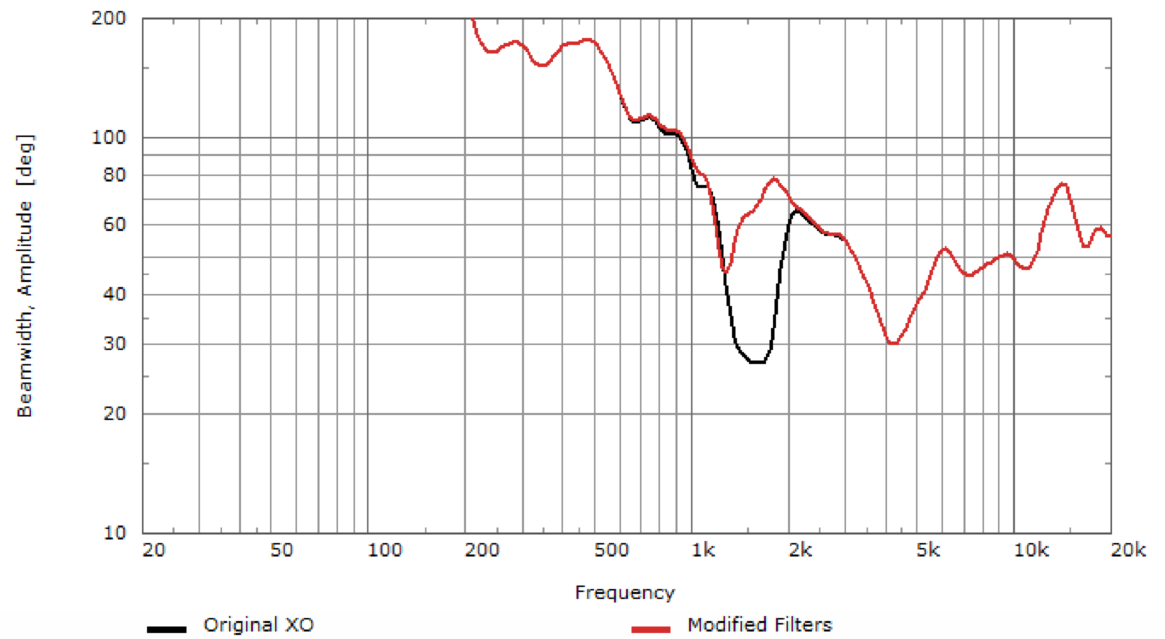

Figure 3: Vertical beamwidth using the original crossover and the modified filters

However, when we look at the vertical beamwidth (black curve in Figure 3) or the vertical directivity map (Figure 4), we see that there is a problem in the crossover region. The beamwidth, or coverage, of the loudspeaker narrows considerably from a desired value of about 60° to less than 30° in the 1 kHz to 2 kHz crossover region. By applying a few different parametric equalization filters to the LF and HF pass bands, the vertical directivity can be improved, as shown by the red curve in Figure 3 and the vertical directivity map of Figure 5. This improvement may have taken days to realize if new measurements of the vertical polar response had been required after each tweak of the new equalization filters. By using the loudspeaker modeling data files for the individual LF and HF pass bands, the changes and optimization of the system directivity was accomplished in a few hours.

The on-axis frequency response of the LF and HF pass bands, along with the combined summation, using the modified filters are shown in Figure 6. Compared to Figure 2 , the summation through the crossover region is good, however the level of the LF and HF pass bands is higher to get the same overall SPL though the crossover region. This is due to the change in the relative phase response between the LF and HF pass bands, which is required to achieve the more uniform vertical off-axis response.

A comparison of the on-axis responses using the original crossover and the modified filters (Figure 7) shows that there has been almost no change to the on-axis response. A comparison of the vertical directivity maps (Figure 4 & Figure 5) shows the off-axis response is now much more consistent, as well as being more similar to the on-axis response.

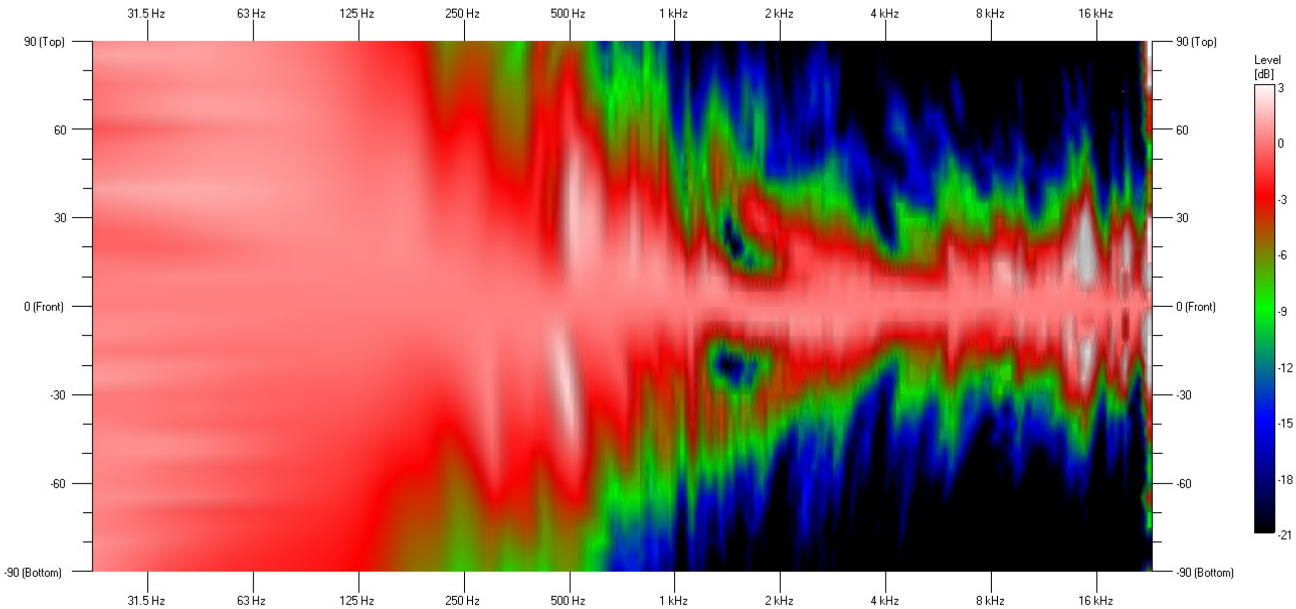

Figure 4: Vertical directivity map using the original crossover (note the large "holes" ± 20° off-axis in the 1 kHz to 2 kHz region)

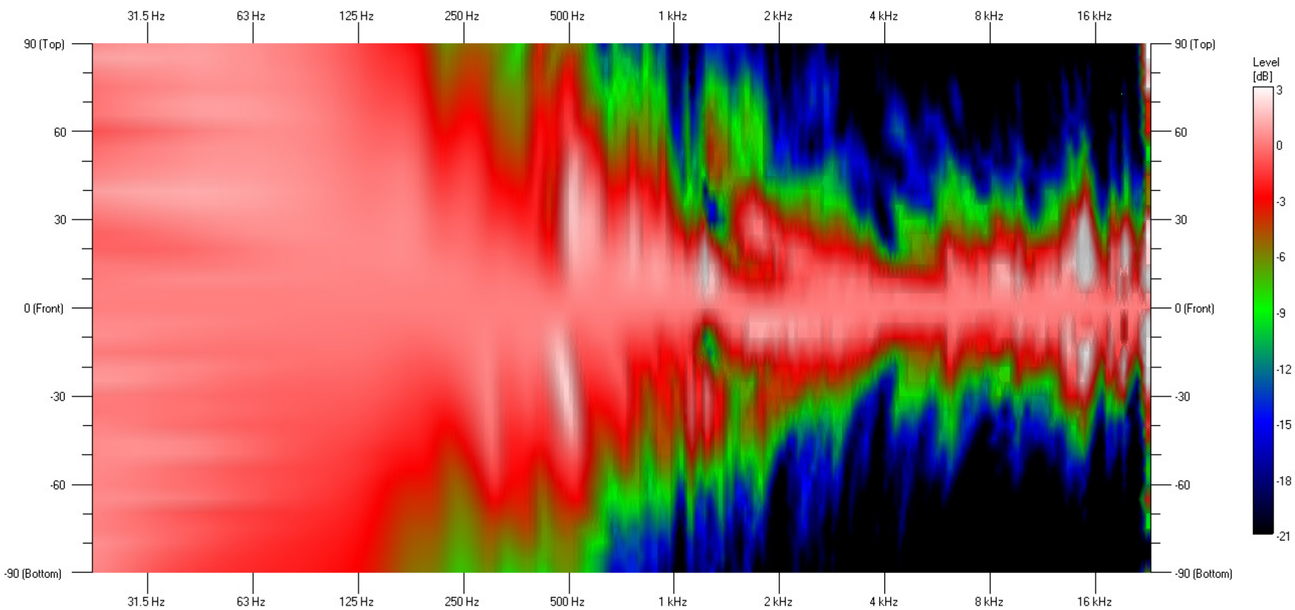

Figure 5: Vertical directivity map using the modified filters (note the improvement ± 20° off-axis in the 1 kHz to 2 kHz region)

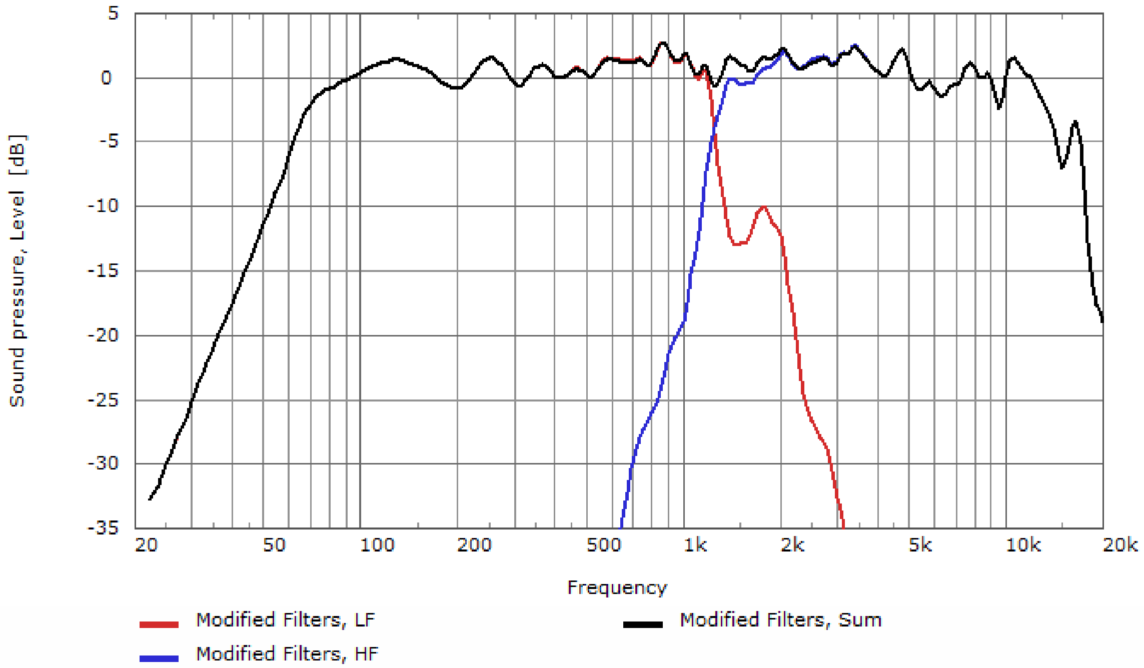

Figure 6: On-axis frequency response of the individual pass bands using the modified filters and the combined response

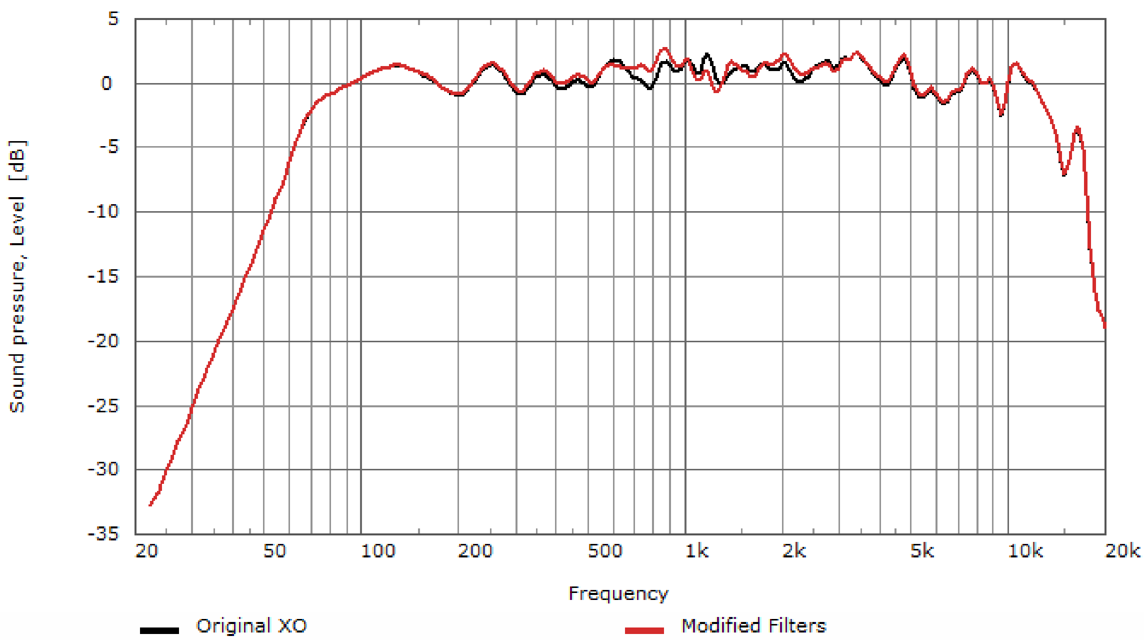

Figure 7: Comparison of the on-axis frequency response using the original crossover and the modified filters

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The program I use most for modeling the directivity of loudspeaker systems and for crossover design is SpeakerLab (from AFMG). A nice feature of SpeakerLab is that it calculates the broad band level of the signal driving the individual pass bands. If the maximum input voltage (MIV) has been entered in the data files for these pass bands, then SpeakerLab is able to determine the maximum input level for the complete system. The maximum level for the loudspeaker system is based on the spectral content of the input signal to the loudspeaker system, as well as the crossover and EQ filters used for each of the pass bands. This feature can help to give a good indication of the maximum continuous SPL that the loudspeaker system can produce.

Using our two-way loudspeaker example, the MIV level for the HF pass band is 23 dBV. This is an rms voltage of about 14.1 V, equivalent to approximately 25 W at 8 ohms (the rated impedance of the HF driver). Note that MIV is not the same as "power handling" for a loudspeaker. The MIV level for the LF pass band is 31 dBV, an rms voltage of about 35.5 V, which is equivalent to approximately 300 W into 4 ohms (the rated impedance of the LF driver).

Let's look at some screen shots from SpeakerLab (Figure 8 & Figure 9). From these we can see what the maximum input level to the system (upstream of the filters) is when the effects of the crossover and EQ filters are taken into account. The maximum input level to the system based only on the HF pass band and its filters is 39.3 dBV (92.3 V). We have basically muted (disconnected) the LF pass band from the system to determine what the HF pass band can do all by itself.

We can then reverse this and mute the HF pass band so that only the LF pass band is being used. The maximum input level to the system based only on the LF pass band and its filters is 32.5 dBV (42.2 V). This is about 7 dB lower than the maximum system input level based on the HF pass band. The LF pass band will be the limiting factor for the maximum input for the system, which will be 32.5 dBV.

This analysis is based on an input signal having the spectral content specified for the IEC 60268 noise test signal. There is a roll off of the low frequency and high frequency energy in this signal (blue curve in Figure 8 & Figure 9). It approximates the spectral content for an average of many different types of music and speech. The results of our analysis might be different for other input signals with different spectral content, such as pink noise.

With the IEC 60268 signal at an input level of 32.5 dBV to the loudspeaker system, the maximum continuous SPL that it should be able produce is about 122 dB, referenced to 1 meter (Figure 10).

Hopefully this has given you some insight into a few of the possible benefits of using full directivity loudspeaker modeling data for each individual pass band. Next time, we'll look at what kind of testing is required to determine the MIV for the individual pass bands of a loudspeaker system.

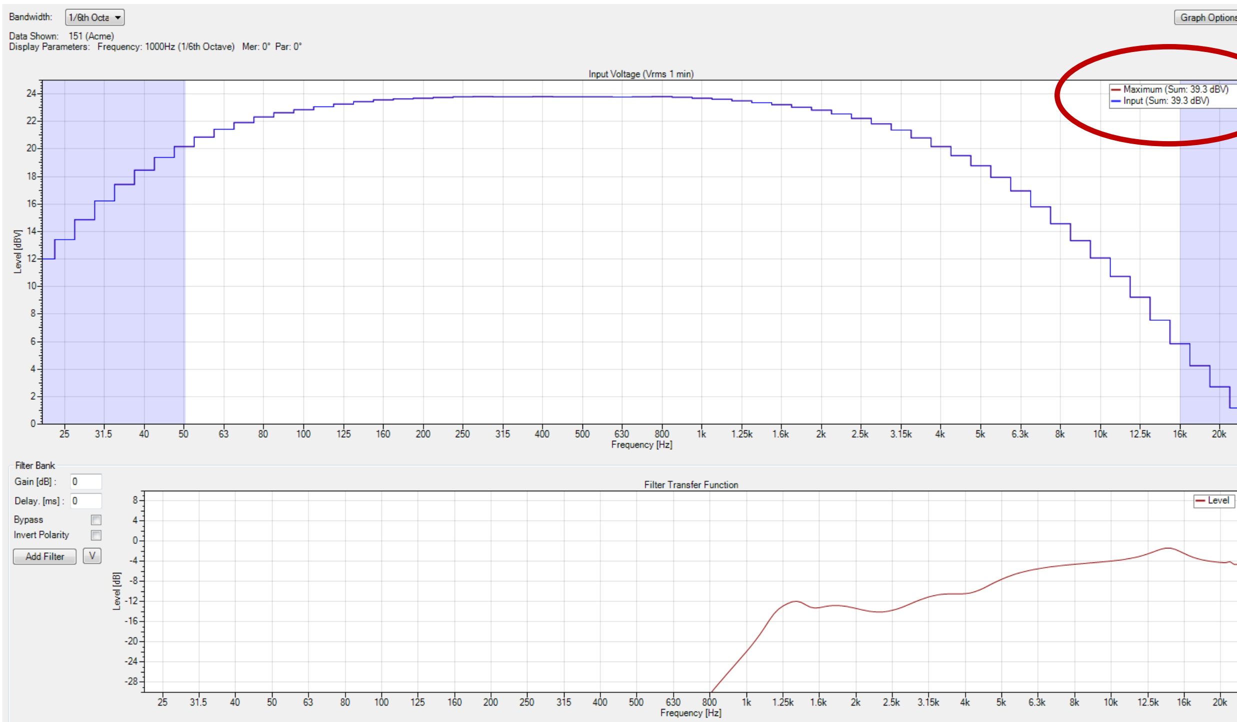

Figure 8: Maximum input level to the system based only on the HF pass band along with its crossover & EQ filters

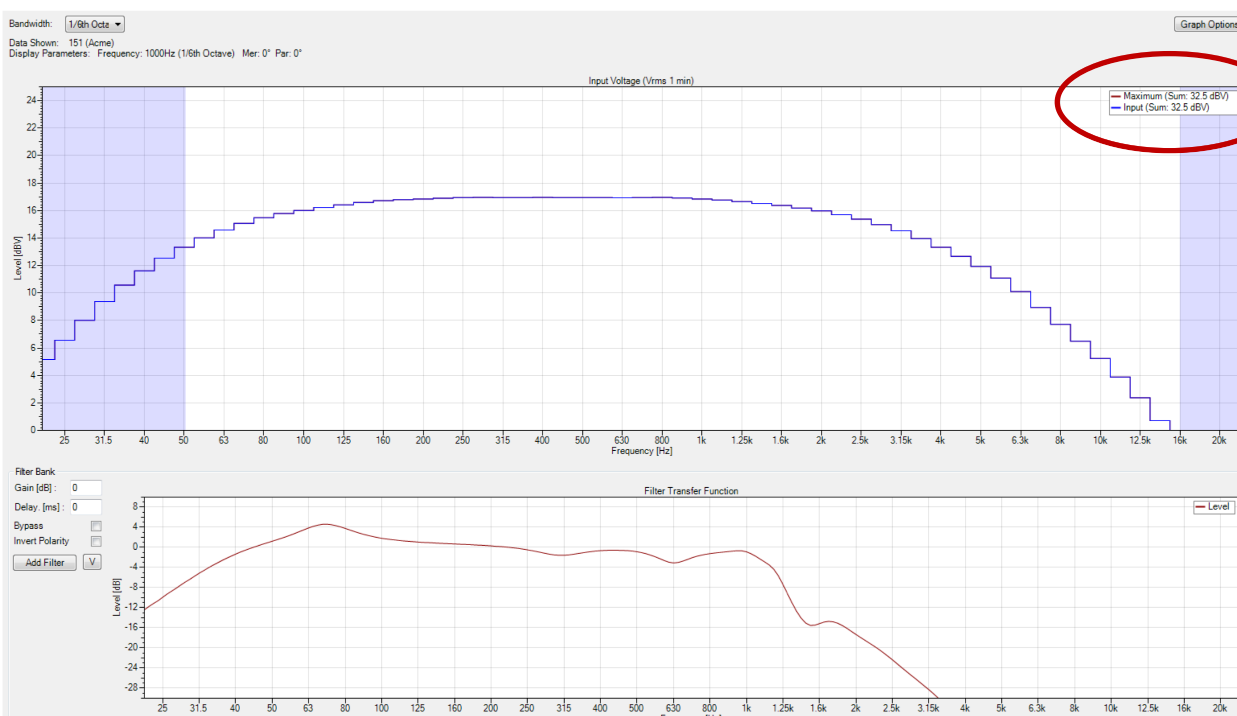

Figure 9: Maximum input level to the system based only on the LF pass band along with its crossover & EQ filters

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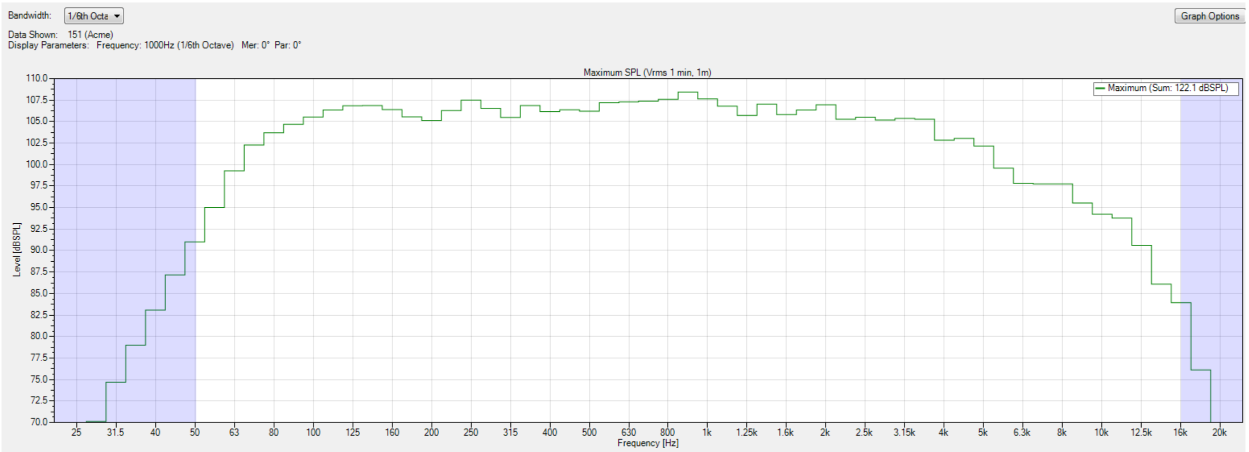

Figure 10: Maximum SPL for the loudspeaker system based on the filters used and the IEC 60268 input signal

For additional information on modeling the directivity of loudspeaker systems see the following AES paper.

S. Feistel, W. Ahnert, C. Hughes, and B. Olson. "Simulating the Directivity Behavior of Loudspeakers with Crossover Filters", *123rd Audio Eng. Soc. Convention preprint #7254*, 2007 October