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Understanding Loudspeaker Specifications and Performance by Applying Frequency Aggregation

(Sensitivity, Max SPL, & the Effect of EQ on Signal Levels)

David Gunness

What is Frequency Aggregation?

- Sound systems are not designed to reproduce one frequency, or even one signal at a time.
- Every aspect of loudspeaker performance is frequency dependent.
- Most measures of loudspeaker performance plot performance against frequency.
- So how do these measures relate to the response of loudspeakers to complex signals like music?

Frequency Aggregation

- Just like signals from different sources, signal components at different frequencies must be added power-wise for the answer to be physically meaningful (RMS).

$$V_{RMS} = \sqrt{V_1^{\ 2} + V_2^{\ 2} + \ldots + V_N^{\ 2}}$$

Frequency Aggregation

- If you want to know the aggregated effect of multiple frequency components in a band, power-sum the frequency components.

Frequency Aggregation

- Power averaging is similar:

$$V_{RMS} = \sqrt{\frac{V_1^{\ 2} + V_2^{\ 2} + \ldots + V_N^{\ 2}}{N}}$$

Frequency Aggregation

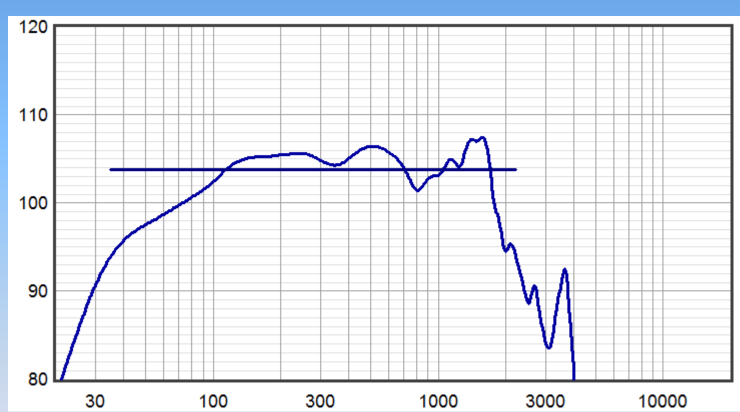
- The power average of two different levels is closer to the higher level (in dB). The power average of 2 (6 dB) and 8 (18 dB) is:

$$\sqrt{\frac{2^2 + 8^2}{2}} = \sqrt{\frac{4 + 64}{2}} = \sqrt{34} = 5.83 = 15.3dB$$

Loudspeaker Sensitivity

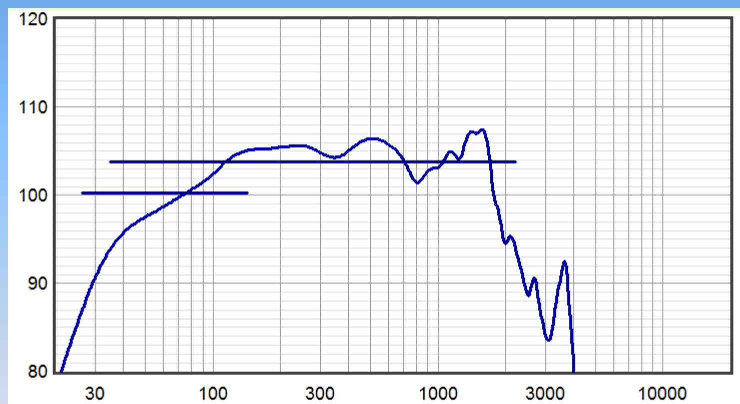
- The one-number sensitivity (nominal sensitivity) could be called "frequency aggregated sensitivity" (power average of sensitivity over a specified range).
- Pink noise is a logarithmic frequency aggregator – the SPL produced by 1 W of pink noise is the same as the power average of the sensitivity sampled at log-spaced points.

Loudspeaker Sensitivity



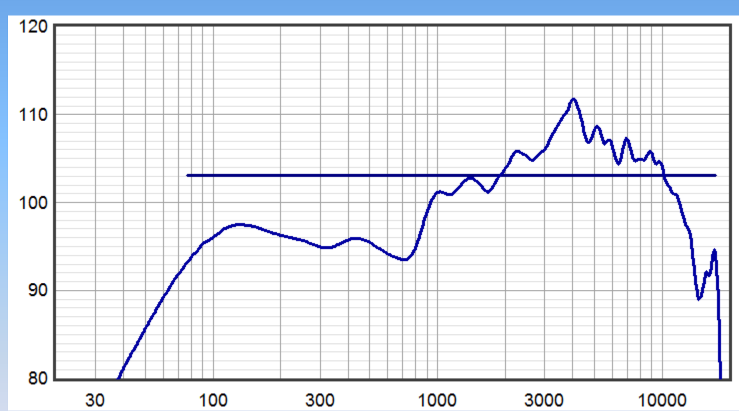
Traditional Sensitivity Specification, Double-15" Subwoofer: 104 dB

Loudspeaker Sensitivity



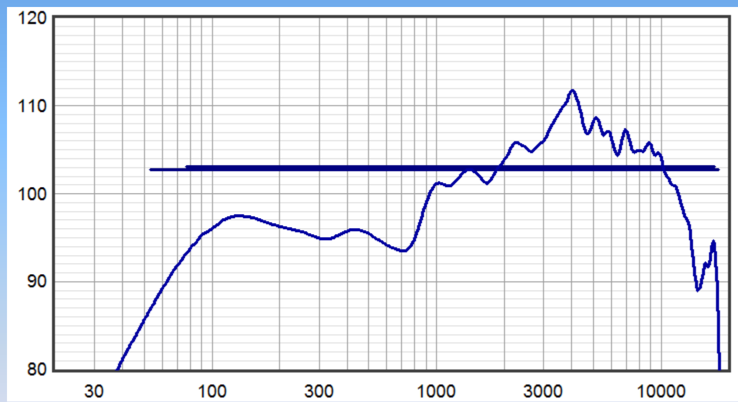
Average Sensitivity Over Intended Operating Range: 100 dB

Loudspeaker Sensitivity



Traditional Sensitivity Specification, 12" Two-Way: 103.1 dB

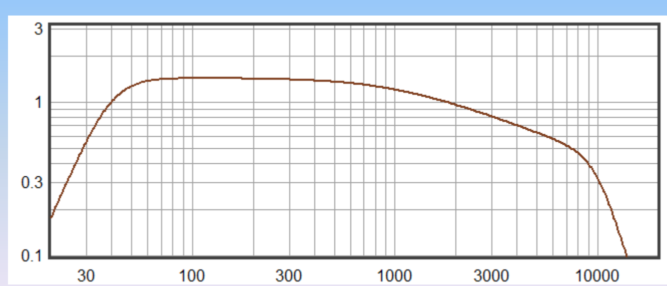
Loudspeaker Sensitivity



Average Sensitivity Over Intended Operating Range: 102.8 dB

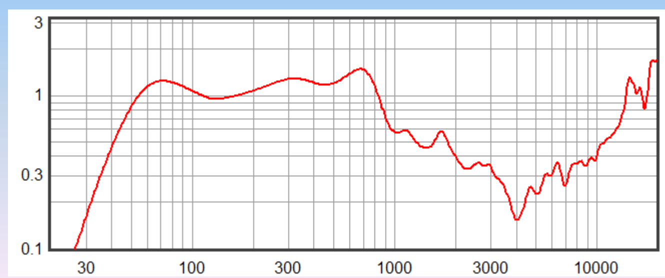
Loudspeaker Sensitivity

- But nominal sensitivity is irrelevant if the loudspeaker isn't flat – plus music isn't pink.
- EIA426B as an average weighting.



Loudspeaker Sensitivity

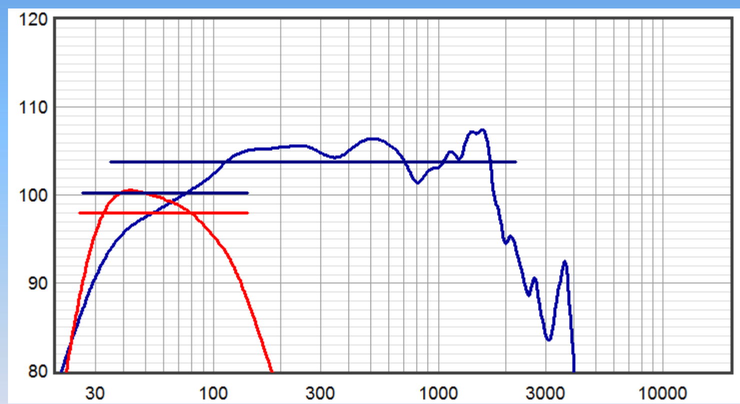
- But nominal sensitivity is irrelevant if the loudspeaker isn't flat – plus music isn't pink.
- EIA426B as an average weighting.
- System equalization as an average weighting.



Equalized Sensitivity

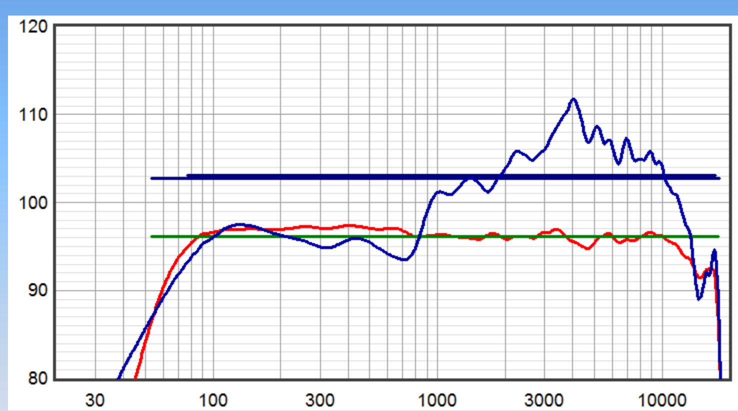
- Pass EIA426B through the loudspeaker processor, and adjust the gain to produce 1 W at the loudspeaker terminals; the SPL produced is the equalized sensitivity.

Equalized Sensitivity



Equalized Sensitivity: 98 dB (vs. 104 dB by the traditional method)

Equalized Sensitivity

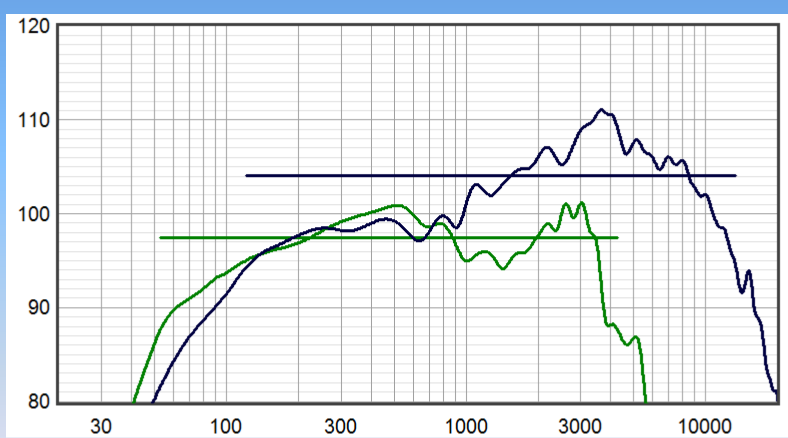


Equalized Sensitivity: 96 dB (vs. 103 dB by the traditional method)

Equalized Sensitivity

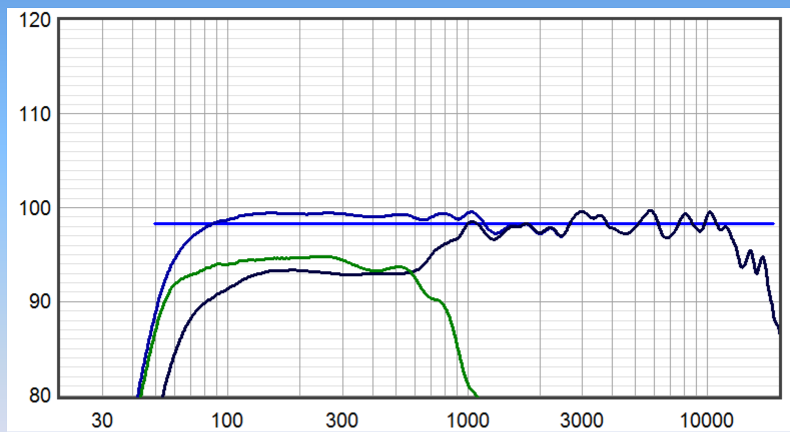
- Pass EIA426B through the loudspeaker processor, adjust the gain to produce 1 W at the loudspeaker terminals; the SPL produced is the equalized sensitivity.
- How about multi-way systems? Same thing, but the combined power to all of the channels must sum to 1 W.

Equalized Sensitivity



Coax: 104 dB, Woofer: 97.5 dB

Equalized Sensitivity



Equalized Sensitivity (Complete System): 98 dB

Equalized Sensitivity

- Just like in real life, the equalized sensitivity depends on both the loudspeaker itself and how it is processed.

Equalized Max SPL

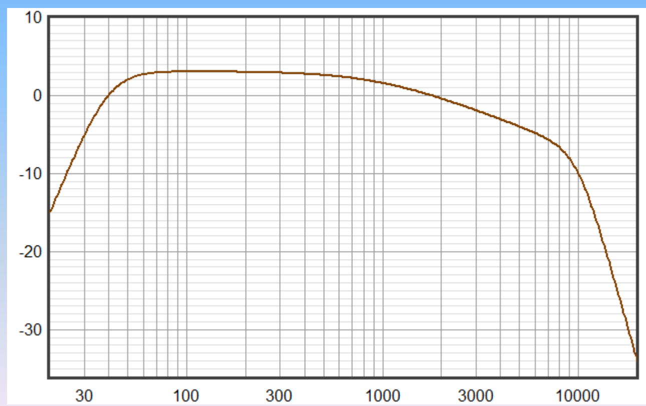
- If nominal sensitivity is irrelevant, then a Max SPL rating based on it is also irrelevant.
- One step better: Equalized Max SPL.
- Start with equalized sensitivity, then increase the gain until one of the sections hits its rated power. The SPL produced is *Equalized Max SPL*.
- Not all sections will be at max.

Equalized Max SPL

- Aggregation by loudspeaker band.

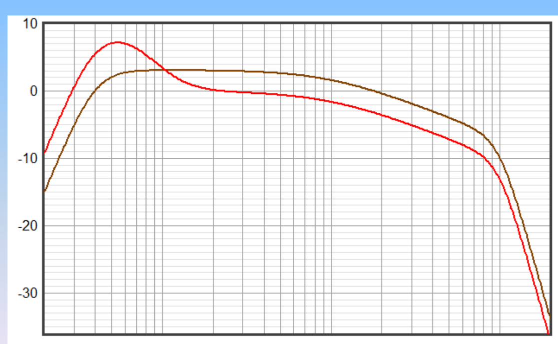
Equalized Max SPL

- EIA426B spectrum, with 0 dB average level.



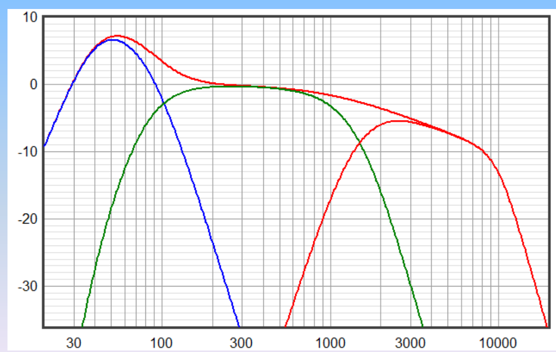
Equalized Max SPL

- EIA426B “concert” spectrum, with 0 dB aggregated level.



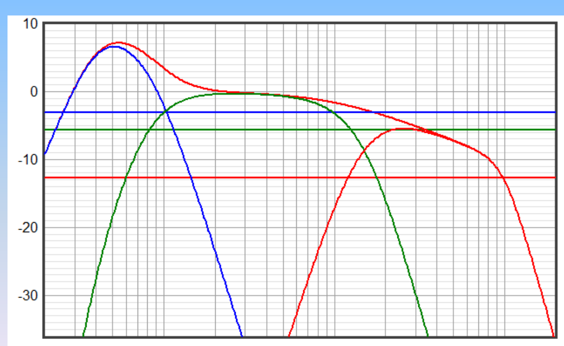
Equalized Max SPL

- EIA426B "concert" spectrum, split into bands.



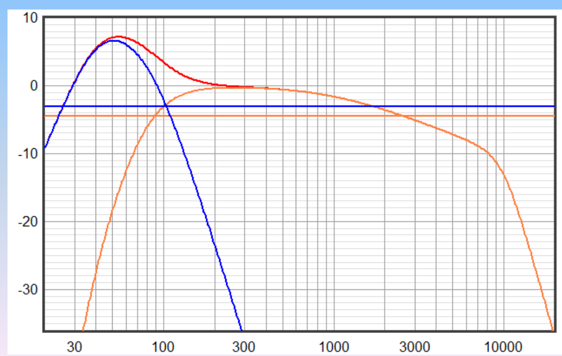
Equalized Max SPL

- Aggregated levels of bands (-3 dB, -6 dB, -12 dB).



Equalized Max SPL

- Two-way split (-3 dB, -4 dB). Notice the sub has 6 dB higher gain, but only receives 1 dB more aggregated power…



Equalized Max SPL

- What does it mean?
  – Power handling is an aggregated measure of survivability (a voltage test expressed in Watts, but actually a measure of current capacity).
  – Equalized sensitivity is an aggregated measure of sensitivity weighted by equalization and spectrum; a better way to correlate voltage with SPL.
  – Equalized Max SPL is a better measure of how hard a speaker can be driven without failing (power handling expressed as SPL).

Equalized Max SPL

- What is it good for?
  - Comparing the robustness of loudspeakers.
  - Estimating the realizable maximum SPL, using a priori knowledge about the intended program.

Real World Max SPL

- What audio pros want is a simple answer to a simple question: “Will this speaker get loud enough?”
- There are two components to the answer: “Max”, and “SPL”. Neither is simple.
- To complicate things further, “Max” is determined by peaks; “SPL” is RMS.
- Even further: SPL is not the same as loudness.

Real World **Max** SPL

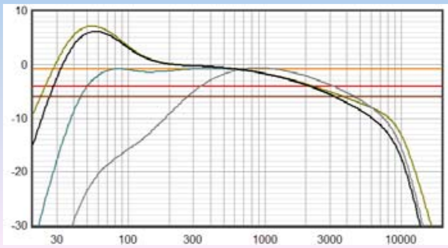
- A criteria that involves “failed” vs. “didn’t fail” is not very useful. The criteria needs to be subjective.
- A typical sound system has more than a dozen different limitations, each affecting a different frequency range. The question is: which one is going to bother you first?
- Many of the limitations are gradual.

Real World **Max** SPL

- “Acceptable fidelity” depends on listener preference, the music (dynamic range, denseness of mix, vocal vs. instrumental, spectral balance, style, artists’ requirements), the listening environment, the purpose of the performance, budget, whether the music is live or recorded, skill of the mixer, automatic gain controls, etc., etc., etc..

Real World Max **SPL**

- Music is a lousy test signal.
- SPL readings of music are not constant, so are subject to interpretation and bias.
- Weighting curves shift the results (“C”: -1 dB, “B”: -4 dB, “A”: -6 dB)



Real World Max **SPL**

- Music is a lousy test signal.
- SPL readings of music are not constant, so are subject to interpretation and bias.
- Weighting curves shift the results (“C”: -1 dB, “B”: -4 dB, “A”: -6 dB)
- “Fast” vs “Slow” shifts the interpretation.

Real World Max SPL

- What audio pros want is a simple answer to a simple question: “Will this speaker get loud enough?”
- Simple answer: “Yes, but you may not like it.”
- Better question: “At the SPL I need it to produce, will this loudspeaker sound good?”
- Now we’re getting somewhere, because this is what actually drives loudspeaker cost and keeps loudspeaker designers busy.

Signal Organization

- The crest factor of noise is unlimited.
- For normal observation times (1 s to several minutes), the expected crest factor is ~12 dB.
- Noise is disorganized, by definition.
- To have a crest factor greater than 12 dB or less than 12 dB requires signal organization.
- Phase shift constitutes *disorganization*.

Signal Organization

- The only way a noise signal can have a 6 dB crest factor is if the phase of its frequency components is organized in a very specific way.
- A 6 dB crest-factor noise signal will revert to 12 dB if its phase is modified.
- The AES Loudspeaker Specification Standard no longer specifies a 6 dB crest factor.

Signal Organization

- The crest factor of popular music ranges from 12 dB (heavy metal) to 18 dB (Jazz). Spoken word is in the 20s.
- "Loudness" roughly correlates with peak SPL. Long-term average SPL depends on both loudness and tempo, expressed as crest factor.

Max SPL Redux

- If there is no such thing as a 6 dB crest factor signal, why do loudspeaker manufacturers specify “Peak SPL” as 6 dB higher than “Max Long Term SPL”.
- Most practitioners select an amplifier with 2x the power handling of the loudspeaker.
- A 2 x power handling amplifier will provide peak voltages of 6 dB more than the specified power handling.

Max SPL Redux

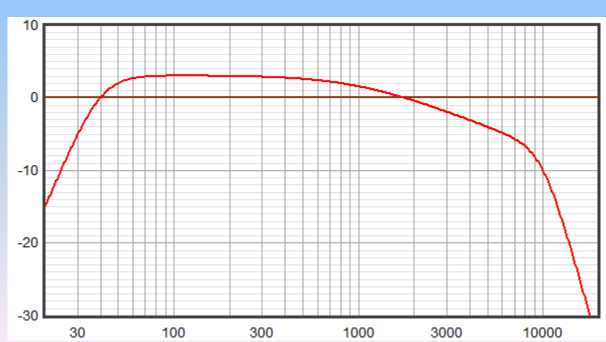
- To estimate maximum long term SPL, subtract crest factor (in dB) from peak SPL.
- Ironically, this simple calculation makes “peak SPL” a more useful spec than “Max Continuous SPL”.

Equalization

- Equalized sensitivity and equalized Max SPL give us a framework to analyze the effect of equalization on signal levels.
- What is the effect on the aggregated voltage when a parametric EQ is applied?

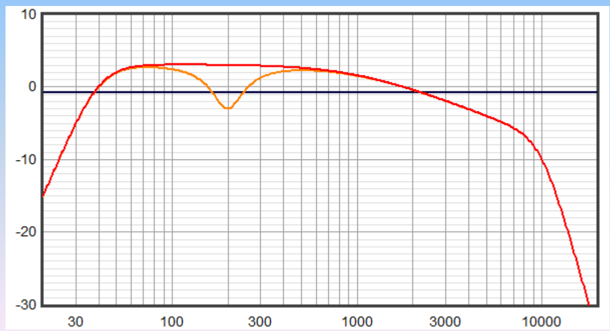
Equalization

- Start with a broadband signal (EIA426B).



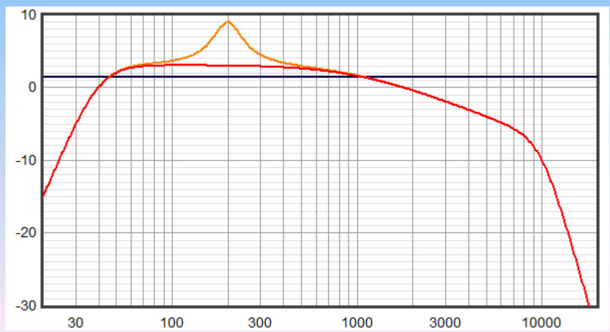
Equalization

- Take a ½ octave (Q=2) cut of 6 dB in the high part of the curve (200 Hz).
- The aggregated level dropped by 0.8 dB.



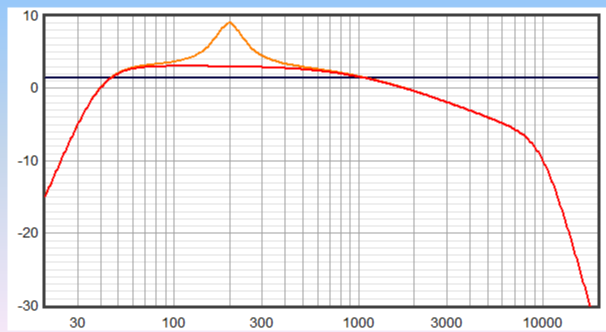
Equalization

- Now take a ½ octave (Q=2) boost of 6 dB in the high part of the curve (200 Hz).
- The aggregated level increased by 1.4 dB.



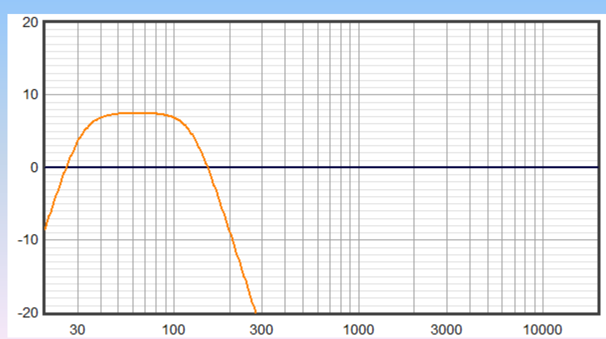
Equalization

- The aggregated level increased by 1.4 dB.
- But the output of the speaker increased by 0.8 dB, so the total cost of the EQ was only 0.6 dB.



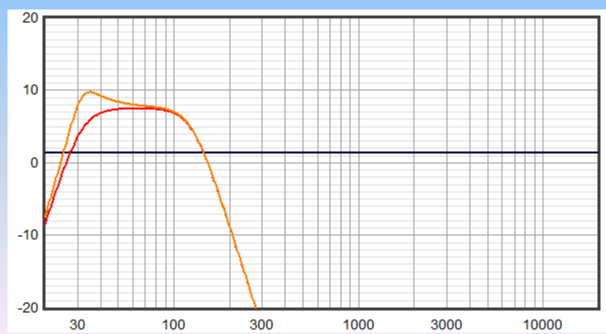
Equalization

- Now let’s look at a theoretical subwoofer channel with an aggregated signal of 0 dB.



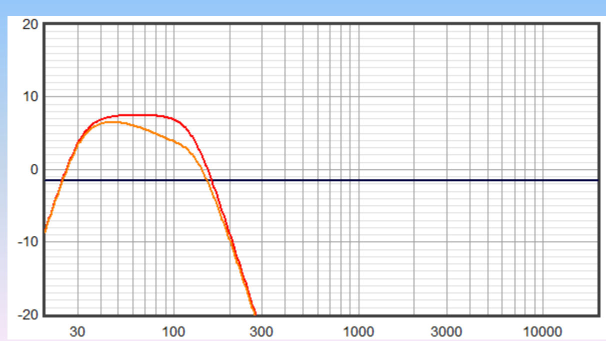
Equalization

- Add a 4.5 dB boost at 32 Hz (Q=2). The aggregated level increases by 1.5 dB.



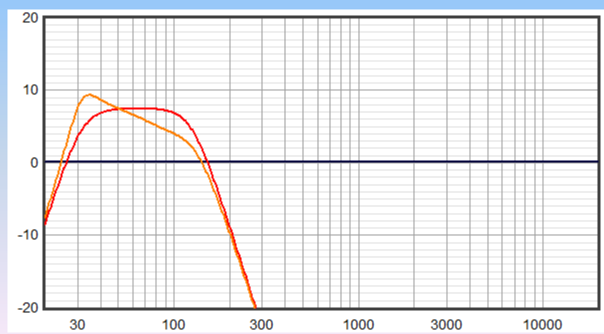
Equalization

- Now put in a 3 dB cut at 100 Hz (Q=1). The aggregated level decreases by 1.5 dB.



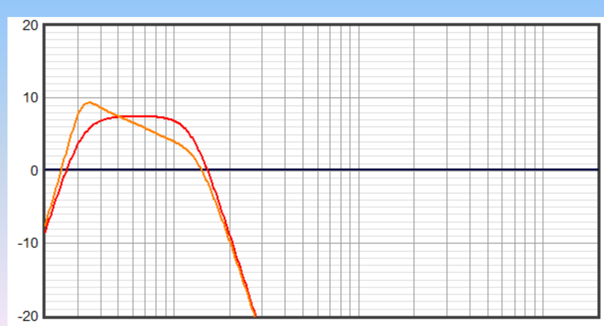
Equalization

- Put in both, the aggregated level is back to 0 dB.



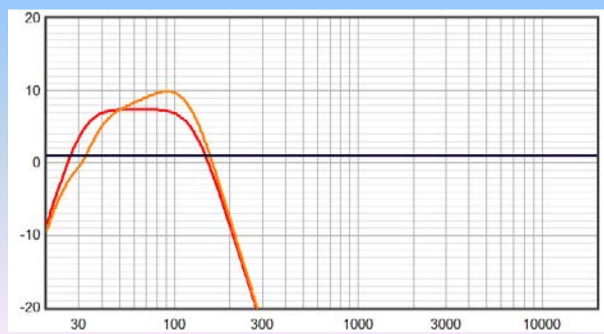
Equalization

- So, the voltage swing gained by the 100 Hz cut "pays for" the voltage swing lost to the 32 Hz boost.



Equalization

- Assuming the EQ was done because the loudspeaker needed it, the equalized sensitivity will have dropped 1 dB.



Takeaways

- Speakers are designed and optimized to handle complex signals. To understand them, study the concept of frequency aggregation.
- A spec sheet can't tell you how a loudspeaker sounds.
- Sorry. These problems are complicated, so the answers can't be both simple and correct.
- Trust your ears.