EXCELSIOR AUDIO DESIGN
& SERVICES, LLC

2130 Shadwell Court
Gastonia, NC 28056
www.excelsior-audio.com
704.675.5435 Tel
704.675.5436 Fax
Audio & Acoustical Consulting, Design and Measurement

March 16, 2009

Charlie Hughes

Loudspeaker Sensitivity: What's a Watt, Anyway?

The specification of a loudspeaker's sensitivity is probably one of the most common, yet perhaps one of the most misunderstood. In the past, and still today, it is common to see the magnitude response of a loudspeaker system reduced to a single number as a sensitivity rating. This is perhaps at the heart of the confusion. One would think that this metric should give some indication as to how loud a particular loudspeaker will be when reproducing a signal. One may also think that two loudspeakers with the same sensitivity rating will be equally loud when reproducing the same signal. Each of these assertions is only partially true. A loudspeaker's sensitivity can give an indication of its output level but only for a signal with a specific bandwidth and spectral content. Similarly, two loudspeakers with the same sensitivity may not output the same SPL when excited by the same signal if the frequency response limits of the two loudspeakers are different. Let's look at the underlying cause of each of these effects, bandwidth, and the role it plays. Let's also look at why sensitivity may no longer need to be referenced to a watt.

According to the standard IEC60268-5, a loudspeaker's sensitivity is determined by measuring is output when driven by a band limited pink noise signal with a Vrms equal to the square root of the loudspeaker's rated impedance and referencing this SPL to a distance of 1 meter. The bandwidth of the pink noise is limited as a function of the effective frequency range of the DUT (Device Under Test). This is done to ensure that the test signal is confined to a portion of the frequency spectrum in which the DUT has appreciable output. If a particular loudspeaker isn't capable of reproducing signals below 150 Hz it does no good to excite it with such signals other than to generate heat. The same holds true if the loudspeaker can't reproduce signals above some high frequency limit. A high resolution transfer function measurement of the DUT can also produce an identical sensitivity rating when the average magnitude is calculated on a log frequency basis.

As an example, let's look at Figure 1. Here we see the on-axis response of a loudspeaker. Its sensitivity rating is shown as the straight line. The length of this line coincides with the upper and lower frequency limits of the pink noise used to measure the sensitivity rating. The spectral content of this noise signal is shown in Figure 2. If a signal with different spectral content, but the same broadband level were used to drive this loudspeaker, would it result in the same SPL as the sensitivity? It's impossible to determine this without knowing both the spectral content of the signal and the response of the loudspeaker. (Note that 20 Hz to 20 kHz, or in the case of Figure 1, 110 Hz – 8.3 kHz, does not specify the response of a loudspeaker. A graph of the response curve really needs to be known.) With knowledge of these we can certainly make an estimate to answer this question.

2130 Shadwell Court
Gastonia, NC 28056
www.excelsior-audio.com
704.675.5435 Tel
704.675.5436 Fax
Audio & Acoustical Consulting, Design and Measurement

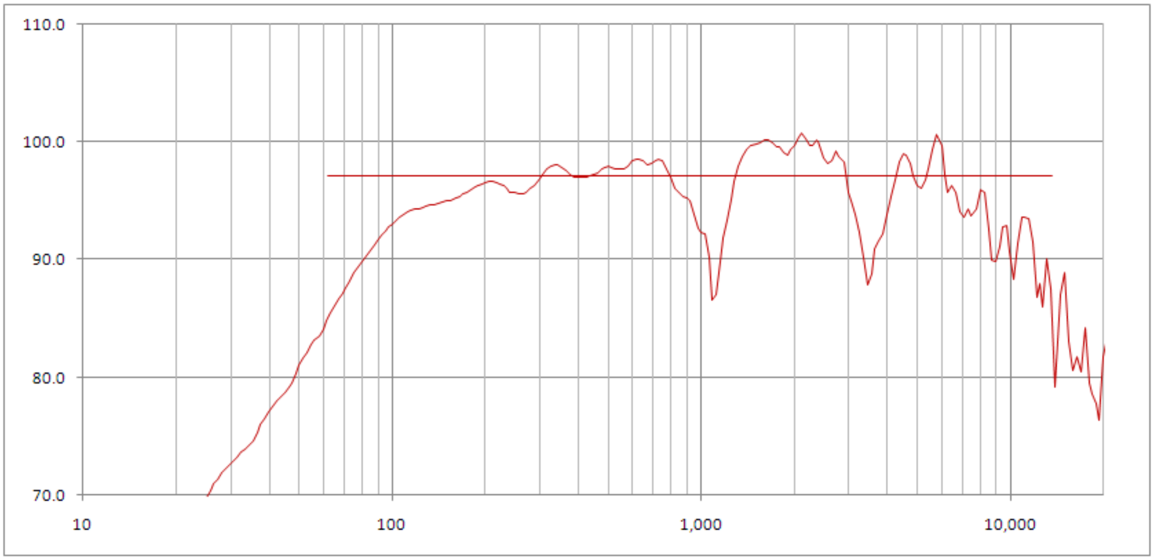

Figure 1 – Magnitude response and single number sensitivity rating of loudspeaker system A

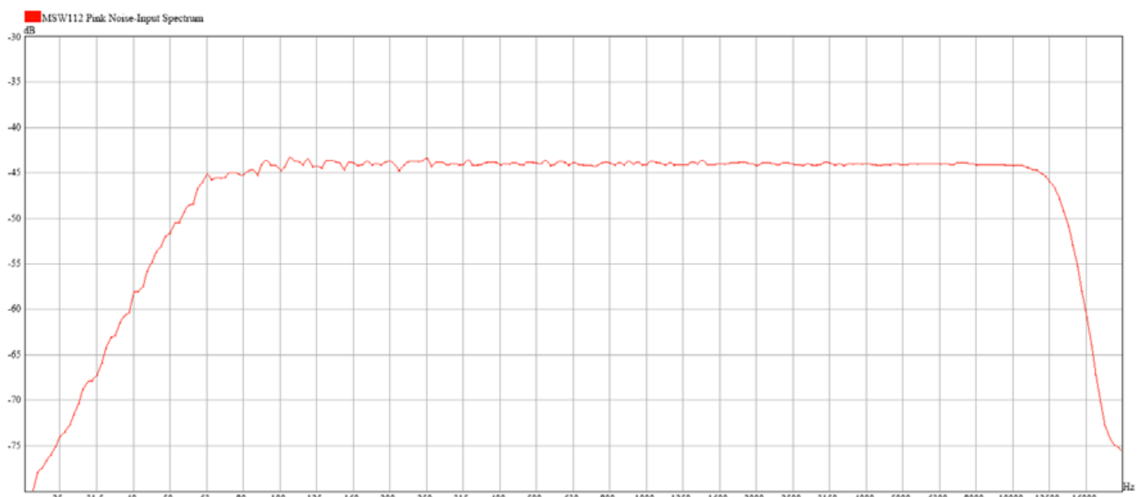

Figure 2 – Spectral content of signal used to determine the sensitivity rating of loudspeaker A from Figure 1

The spectral content of three different signals is shown in Figure 3. One is the band-limited pink noise signal used to determine the sensitivity of the loudspeaker. The others are speech and a shaped noise signal having approximately the same spectral content as the speech. This speech-shaped noise is used instead of speech as its RMS level is more consistent as a function of time than actual speech. Thus, it will be easier to determine the SPL output by the DUT with this signal. All three signals have approximately the

2130 Shadwell Court
Gastonia, NC 28056
www.excelsior-audio.com
704.675.5435 Tel
704.675.5436 Fax

same broadband RMS level. From approximately 200 - 800 Hz the speech-shaped noise signal has greater level than the pink noise signal. Above and below this frequency region the pink noise signal has much greater level than the speech-shaped noise signal.

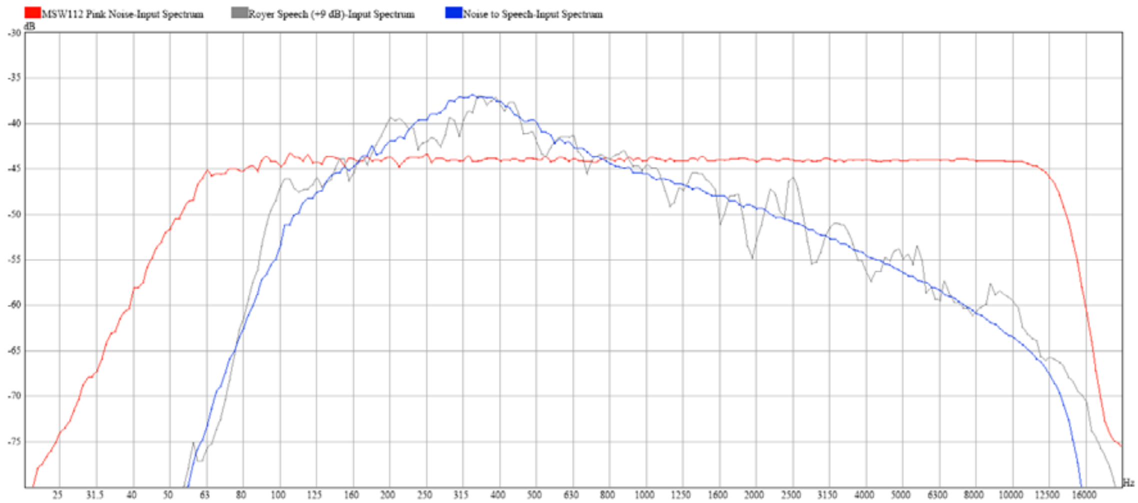

Figure 3 – Spectral content of signal used to determine the sensitivity rating of loudspeaker A in Figure 1 (red), speech (grey), and speech-shaped noise with approximately the same spectral content as the speech (blue)

Comparing this to the response of the loudspeaker in Figure 1 we see that the loudspeaker has limited output below 150 Hz. The greatest output in the response of the loudspeaker occurs in the 300 Hz – 3 kHz region. If the speech-shaped noise signal were used to drive the loudspeaker with the same broadband level as the noise we could reasonably expect the broadband SPL to be greater than when driven with the pink noise signal.

This is exactly what happens. The sensitivity of the loudspeaker is 97.1 dB. When driven with the speech-shaped noise the SPL is 98.1 dB, an increase of 1.0 dB. This results from the higher level of the speech-shaped signal in the frequency region where the loudspeaker has higher output capability compared to the rest of its pass band.

Conversely, if the low frequency band-limited pink noise shown in Figure 4 were used to drive the loudspeaker it is reasonable to expect that the SPL would be less than when driven by the noise signal. This results from the low frequency pink noise signal having a higher level in the frequency region where the loudspeaker has lower output capability. The SPL produced by the low frequency pink noise is 94.9 dB, a decrease of 2.2 dB.

2130 Shadwell Court
Gastonia, NC 28056
www.excelsior-audio.com
704.675.5435 Tel
704.675.5436 Fax

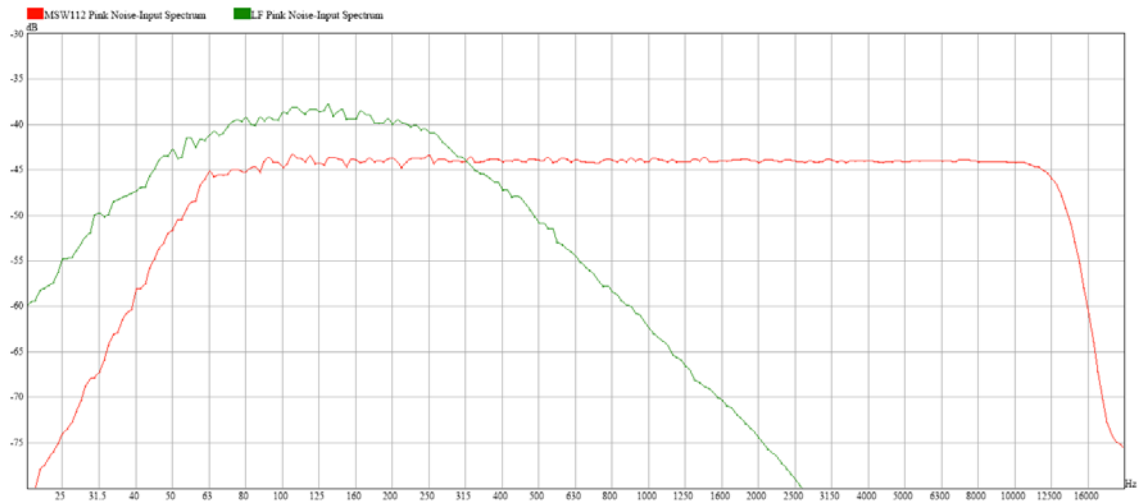

Figure 4 – Spectral content of signal used to determine the sensitivity rating of loudspeaker A in Figure 1 (red) and of low frequency band limited pink noise (green)

Now let's compare two different loudspeakers. Figure 5 shows loudspeaker A compared to loudspeaker B. Notice that they both have the same sensitivity, 97.1 dB. Loudspeaker B, however, has greater low frequency and high frequency extension than loudspeaker A. Because of this the bandwidth of the pink noise used to determine the sensitivity of loudspeaker B is greater than the bandwidth of the noise used for loudspeaker A (Figure 6). As a result, the mid-band level of the noise for loudspeaker B is slightly less than that of the noise used for loudspeaker A. It's a bit difficult to see but upon careful observation the black trace can be seen to be an average of 0.5 dB below the red trace from approximately 100 Hz – 10 kHz. This is due to the greater bandwidth of the signal used for loudspeaker B (black trace). Remember that the broadband levels of both these signals are identical.

So what happens when each of these loudspeakers is driven by the broadband pink noise signal (20 Hz – 20 kHz) also shown in Figure 6? As each of the loudspeakers used in this example are markedly not flat in their mid-band response there may be some tonal, and potentially measurably, differences in the SPL. Hopefully, the reader can put these issues aside for the moment. All other things being equal, the loudspeaker with the greater effective frequency range (low & high frequency extension) should have greater SPL output. Loudspeaker B should have slightly greater output when driven by this broadband pink noise signal. In fact, loudspeaker B measured 0.8 dB greater than loudspeaker A, 97.0 dB compared to 96.2 dB.

From these examples one should be able to see that the SPL generated by a loudspeaker is a function of both the loudspeaker's transfer function and the spectrum of the signal being reproduced. Several acoustical room modeling programs take this into account when calculating the SPL produced over an intended audience area. They may allow for the selection of pink noise, some sort of speech spectrum, or a user-defined spectrum. This should aid the sound system designer, while still at the drawing board stage, to better understand the potential SPL capabilities of the sound system with the typical program material the system is likely to be reproducing.

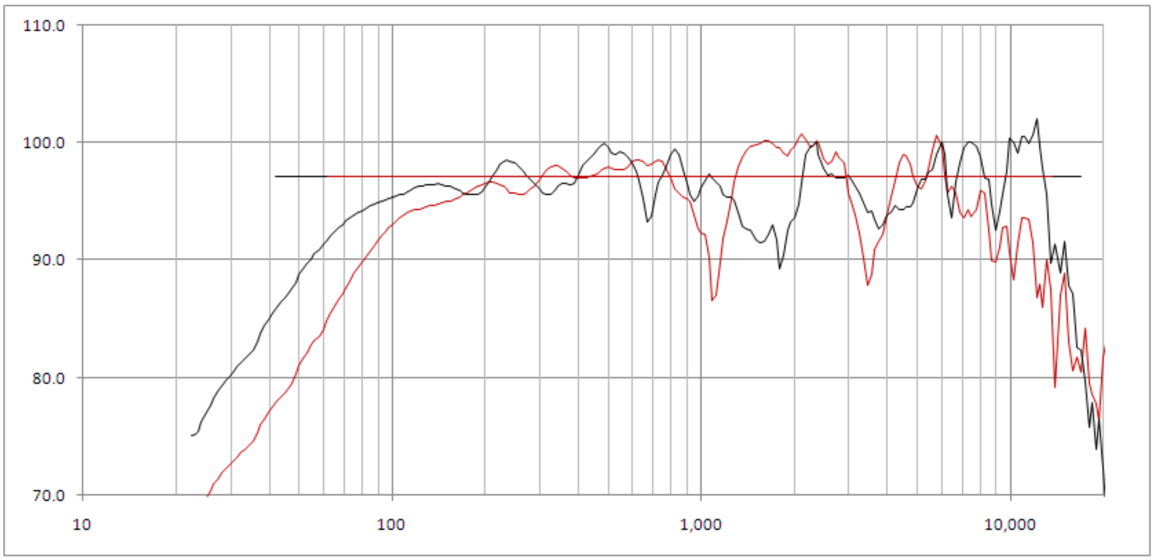

Figure 5 – Magnitude response and single number sensitivity rating of loudspeaker system A (red) and loudspeaker B (black)

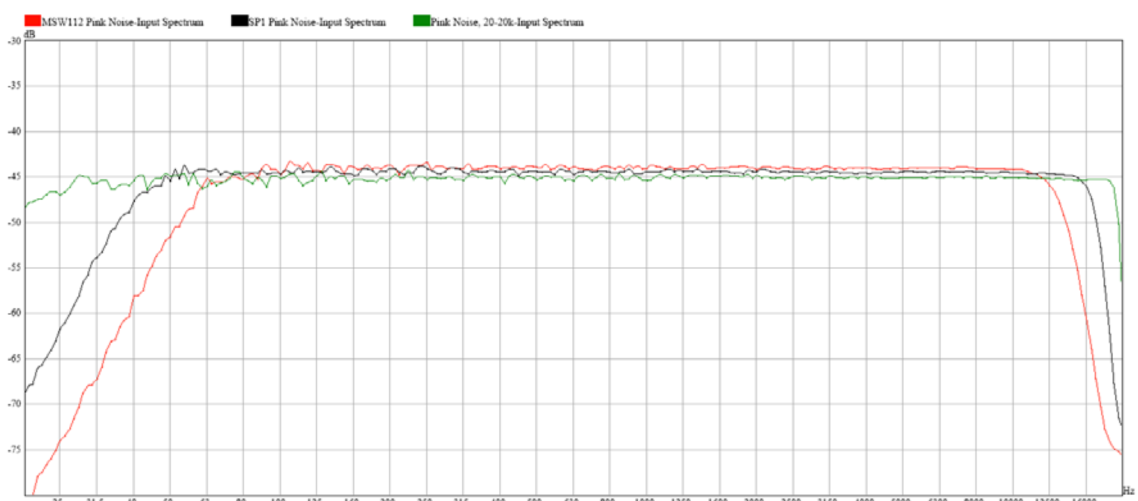

Figure 6 – Spectral content of signal used to determine the sensitivity rating of loudspeaker A (red), loudspeaker B (black), and broad band pink noise (green)

2130 Shadwell Court
Gastonia, NC 28056
www.excelsior-audio.com
704.675.5435 Tel
704.675.5436 Fax

The other item I mentioned at the beginning of this article was referencing sensitivity measurements to one watt being dissipated by the DUT. There are several reasons why I think that this is not beneficial with modern sound systems. First of all is that it is somewhat cumbersome to determine how much voltage is required across a particular DUT such that the input current drawn from the driving source yields one watt. This can be done using dual channel FFT measurement systems and an appropriate current monitor or probe. But would this give us useful information for the design and/or specification of loudspeakers or sound systems?

We can simplify this measurement procedure so that we don't concern ourselves with the dissipation of a real watt by the DUT. Instead we apply a voltage across the DUT that would dissipate one watt in a pure resistance having the value of the rated impedance of the DUT. This certainly is easier, but again, does this give us useful information for the design and/or specification of loudspeakers or sound systems? Perhaps. My thought is that more useful comparative information would be gained by applying the same voltage across the DUT regardless of its impedance.

The majority of amplifiers used in sound systems today are of a constant voltage type. That is to say, their output voltage remains constant independent of the load placed on them. Of course the load must be within the specified operational limits for a given amplifier. The salient point is that for a given drive voltage, a lower impedance loudspeaker will have greater SPL output than a higher impedance loudspeaker; all other items being equal. Shouldn't this be reflected in the sensitivity specification of the loudspeaker? Why then would one want to use a 2.0 Vrms signal to drive a 4 ohm loudspeaker and a 2.83 Vrms signal to drive an 8 ohm loudspeaker to determine their respective sensitivities?

Think about it this way; let's connect two virtually identical loudspeakers to an A/B selector switch driven by the same amplifier. The only difference between these loudspeakers is that one is half the impedance (rated at 4 ohm) than the other (rated at 8 ohm). When switching between these two loudspeakers the output voltage of the amplifier does not change, however, the current drawn from the amplifier does. This results in the loudspeaker with the lower rated impedance producing greater SPL. Measuring and specifying sensitivity with the same voltage, regardless of the impedance of the DUT, would accurately reveal the SPL differences that occur.

I hope this brief discussion of sensitivity has shed some light on this specification and how it may translate to the real world performance of a loudspeaker system. From these examples I hope that it is clear that the input signal and the magnitude (frequency) response of a loudspeaker will determine the SPL generated, not just the sensitivity rating of the loudspeaker. It's much better to have knowledge of the loudspeaker's response in the form of a graph than a single sensitivity number. The latter may be derived from the former.