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

August 12, 2009 Charlie Hughes

Target SPL and Required Amplifier Size

In a previous article[1] I examined the topic of loudspeaker sensitivity and how it may or may not relate to the overall Sound Pressure Level (SPL) produced by a loudspeaker. One of the conclusions of that article is that the SPL produced will be dependent on the spectral content of the signal driving the loudspeaker. Thus, having knowledge of the driving signal (i.e. program material) or being able to make an educated assumption about it may aid in the design of a loudspeaker or sound reinforcement system so that the required bandwidth and SPL is delivered to the audience. The output capability of the amplifier driving the loudspeaker is of equal importance to achieving the target SPL from the direct field of a loudspeaker. This can also be related to the driving signal or the intended program material.

Pat Brown authored a very interesting and enlightening article[2] on testing loudspeakers to determine what I refer to as their maximum usable continuous output SPL. While a loudspeaker may be capable of producing greater continuous SPL, it is accompanied by significant changes (greater than 3 dB) in the transfer function (frequency response) of the loudspeaker. For most applications this is undesirable and thus deemed not usable. This “toaster test” primarily focuses on the thermal effects the input signal has on the loudspeaker system; the individual driver’s voice coils, the resultant impedance increase, and the passive crossover components (if present). The result of the toaster test yields a maximum RMS voltage (max Vrms) that can be applied to the loudspeaker without driving it past this Maximum Usable Continuous Output SPL (SPL_{MUCO}). This max Vrms may then be used to calculate an Equivalent Amplifier Size which can deliver the max Vrms when driven by this same test signal. This signal, by the way, is specified by the standard IEC 60268. It is a broadband, shaped noise signal with a spectral content that is the average of a variety of program material, including both speech and several different types of music. This test signal has a crest factor of 6 dB.

To get the most out of the rest of the article we need to understand crest factor so let’s briefly explain it. The crest factor of a signal is simply the difference between the RMS level and the peak level of the signal. A square wave has a crest factor of 0 dB; it has the same RMS level as its peak level. A sine wave has a crest factor is 3 dB, that is its RMS level is 3 dB less than its peak level. For more complex waveforms the crest factor may be different, and is usually higher. Many waveform editing programs have analysis capabilities that will calculate the RMS and peak levels of an entire .wav file or a selected segment. In Figure 1 we see 100 ms segments of a 100 Hz square wave, a 100 Hz sine

[1] *Loudspeaker Sensitivity*, Syn-Aud-Con Newsletter, Vol.37, No.4 (April 2009)
[2] *Loudspeaker Toaster*, Syn-Aud-Con Newsletter, Vol.34, No.1 (Winter 2006)

wave, and IEC60268 noise. All of the signals shown here have been normalized to have a peak level of 0 dB.

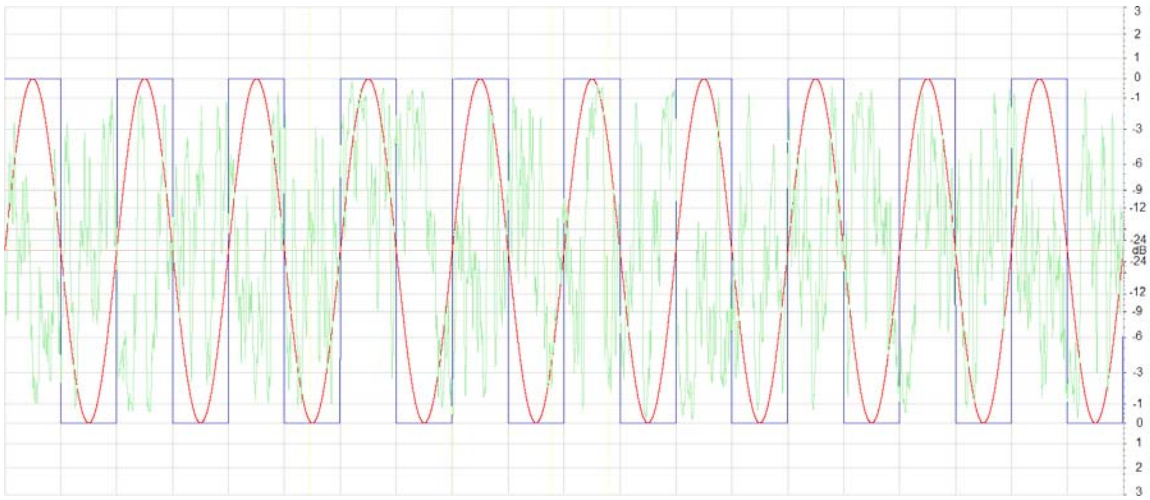

Figure 1 – Square wave (blue), sine wave (red), and IEC268 noise (green) all with the same peak level, 0 dB

Now that we understand crest factor, we can use the results of the toaster test performed on a particular loudspeaker to help determine the required amplifier size for our sound reinforcement system design. Differences between the spectral content of our program material and that of the signal used for the toaster test to determine max Vrms may lead to inaccuracies in our results. However, as long as these spectral differences are not dramatic, the results should be reasonably valid. Alternatively, one may carry out a toaster test using a test signal having a spectral content more closely resembling the intended program material for the application at hand.

For our application the program material to be reproduced by our loudspeaker system will be live speech or music with little or no compression (amplitude compression, not data compression). This should give us a relatively broadband signal very similar to the IEC 60268 specified noise signal. However, our signal will have a crest factor of approximately 15 dB. A time domain comparison of this type of signal to the IEC268 noise and a sine wave is shown in Figure 2. Here again the peak level of all three signals is 0 dB. It should be easy to see that the RMS level of this new speech signal is much less than the noise.

The loudspeaker we have selected to use has a reasonably flat frequency response from 50 Hz – 12 kHz and a sensitivity of 98 dB referenced to 2.83 Vrms at 1 m. At a distance of 10 m this loudspeaker will reproduce the IEC268 noise at 78 dB SPL when driven with an input of 2.83 Vrms. We measure this at 10 m to assure that we are in the far-field for this loudspeaker. It will also reproduce our speech signal at 78 dB SPL at 10 m when driven with an input of 2.83 Vrms. The reason the measured SPL is the same for both signals is that the RMS input voltage is the same. SPL measured with a slow integration time, as we are referencing here, will correspond well with the RMS value of the input voltage. This is why an RMS meter on a mixing console may be used as a fairly good indicator of SPL once it has been referenced to a particular SPL. Of course at high input voltage levels the output of the loudspeaker may not remain completely linear and some power compression may occur.

When each of these signals is at the same RMS level, as described above with the input to the loudspeaker, their peak levels will be different. This is shown in Figure 3. Here the RMS level of each signal is the same. Now we can see that to cleanly pass the speech signal without clipping we will need a much larger amplifier than required to pass the IEC268 noise cleanly; but exactly how large?

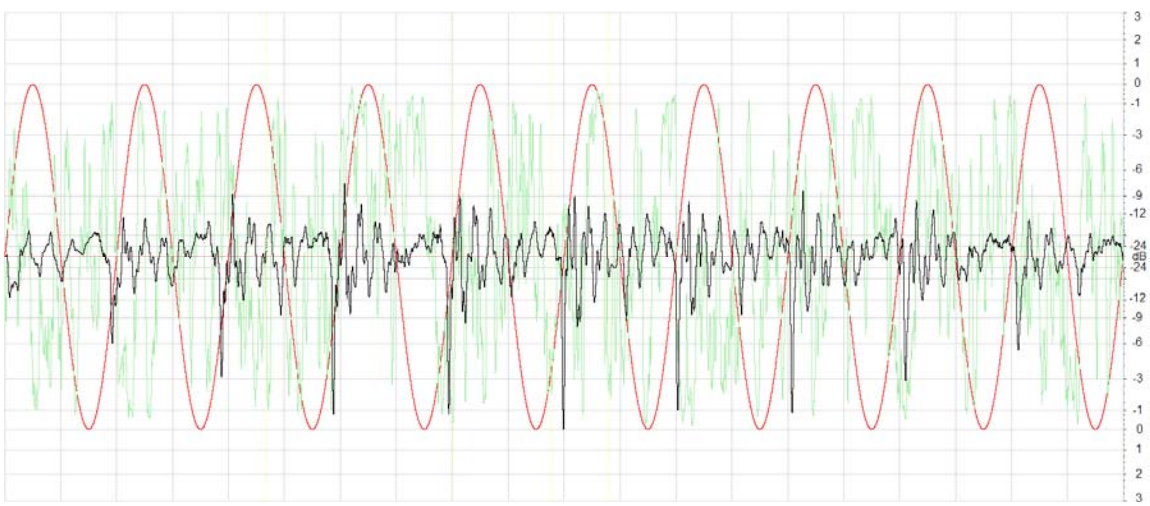

Figure 2 – Sine wave (red), IEC268 noise (green), and speech (black) all with the same peak level, 0 dB

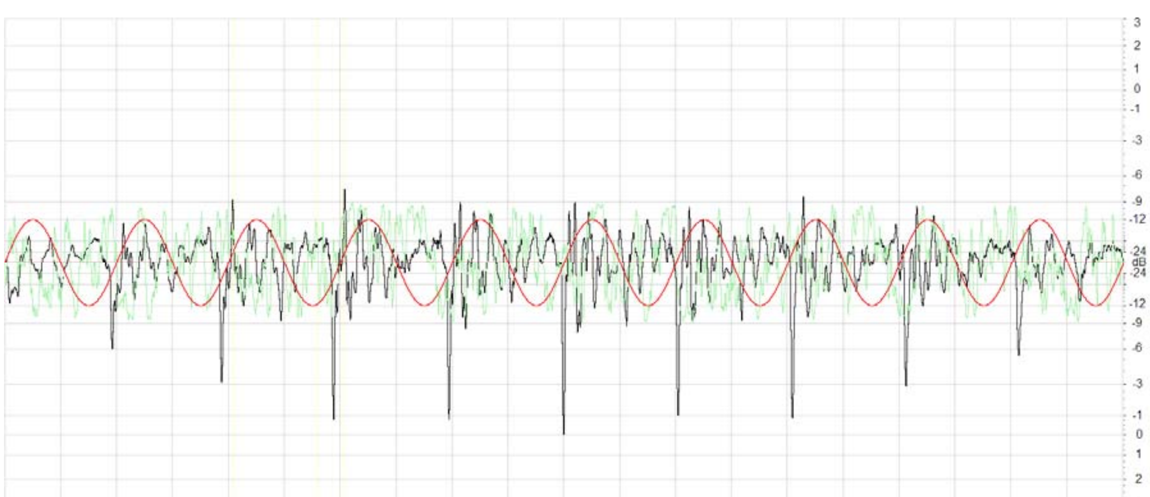

Figure 3 – Sine wave (red), IEC268 noise (green), and speech (black) all with the same RMS level, -15 dB

The sound system design requirements dictate that our loudspeaker needs to produce approximately 88 dB SPL at 20 m with our speech program material. At half this distance, 10 m, this equates to 94 dB. We know the loudspeaker will produce 78 dB at 10 m when driven with 2.83 Vrms. We need an additional 16 dB, or 17.9 Vrms, to reach 94 dB SPL at 10 m. This loudspeaker has a rated maximum input of 32 Vrms as determined by the toaster test. This gives us 21 dB of gain relative to 2.83 Vrms without the thermal limitations of the loudspeaker causing its response to change by more than 3 dB. This tells us our loudspeaker can produce the SPL required. In fact, it can be driven 5 dB harder. This is a good thing as thus far we have not accounted for any power compression that may occur.

Because the toaster test limits the response change of the loudspeaker to no more than 3 dB, we are assured that this is the maximum SPL reduction that will be encountered. It is much more likely that this 3 dB variation will occur not over the entire frequency range of the loudspeaker, but instead over a limited bandwidth. This being the case our overall SPL reduction will typically be much less. If we know the SPL_{MUCO} of the loudspeaker when driven at max Vrms then we can calculate the resulting reduction in SPL due to the thermal effects. Including this data on the loudspeaker specification sheet as well as the data files for room modeling programs may be helpful in this regard.

The max Vrms and SPL_{MUCO} ratings for the loudspeaker characterize its performance for one scenario, or type of input signal. These ratings can be morphed into other scenarios by changing the crest factor, distance, and desired SPL. This can be done mentally if one is proficient in decibel notation. Let's go through an example of exact how to calculate this.

To determine the size of the amplifier needed to pass our speech signal without clipping we look at the signal's crest factor, which is 15 dB. We can calculate the peak voltage required from the amplifier using the following equation.

$$V_{peak} = V_{rms} * 10^{\left(\frac{CF}{20}\right)}$$

For our 15 dB crest factor speech signal and required RMS voltage of 17.9 Vrms this gives us a peak voltage requirement of 101 Vpeak. A sine wave, with its 3 dB crest factor, which has this same peak voltage of 101 Vpeak will have an RMS voltage of 71.4 Vrms. An amplifier rated to deliver 638 W into an 8 ohm load will meet this requirement. This is quite a bit larger than the Equivalent Amplifier Size of 256 W for this loudspeaker as determined by the toaster method using a 6 dB crest factor signal.

A somewhat more direct method to determine the Required Amplifier Size is given by the following equation.

$$RAS = EAS * 10^{\left((CF - 6dB - Gain_{Possible} + Gain_{Required})/_{10}\right)}$$

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

EAS is the Equivalent Amplifier Size given in the CLF file for the loudspeaker. *CF* is the Crest Factor of the anticipated program material. $Gain_{Possible}$ is the gain given in the CLF file based on the maximum Vrms. $Gain_{Required}$ is the gain required for the loudspeaker to reach the desired SPL. The subtraction of 6 dB in the exponent of this equation is necessary as that is the crest factor of the signal used during the toaster test to determine the max Vrms, and subsequently *EAS* and $Gain_{Required}$.

For our example system design these values would be,
EAS = 256 W
CF = 15 dB
$Gain_{Possible}$ = 21 dB
$Gain_{Required}$ = 16 dB

So, $RAS = 256\,W * 10^{\left((15dB-6dB-21dB+16dB)/_{10}\right)}$

which reduces to, $RAS = 256\,W * 10^{(0.4)} = 256\,W * 2.51 = 643\,W$

There is a slight difference, most probably due to rounding, between this value and the previously calculated 638 W. This difference is not significant being less than 0.04 dB. A 600 – 700 W power amplifier is not exceeding large or difficult to obtain so it may make for a good design decision to go this route.

What if the same loudspeaker was used in an application requiring greater SPL? Say we needed 91 dB SPL at 20 m. This is equivalent to 97 dB at 10 m. This loudspeaker will require 19 dB of gain to achieve this. Let's also account for some SPL loss due to power compression by adding in another 2 dB. This brings us to 21 dB of gain required. Coincidentally, this is the limit of the gain possible for this loudspeaker, 21 dB. For this higher required SPL we have,

$$RAS = 256\,W * 10^{\left((15dB-6dB-21dB+21dB)/_{10}\right)} = 256\,W * 10^{(0.9)} = 256\,W * 7.94$$
$$= 2,033\,W$$

This is a much larger power amp! But this is what will be required to cleanly pass the 15 dB crest factor program material without clipping.

When this amplifier is supplying the required RMS voltage to achieve the desired SPL the voltage peaks delivered to the loudspeaker will be approximately 180 Vpeak! Many loudspeakers can withstand short, transient peaks of very high voltage. This will depend on the frequency content and time duration of the peaks as well as the loudspeaker design. It is always best to check with the manufacturer first or test the peak capabilities of the loudspeaker yourself before deploying such a system.

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

There are several items that one should keep in mind, in addition to the ones already mentioned, when sizing an amplifier with this method.

1) The spectral content of the program material is very important. If it is not similar to IEC268 noise one should conduct a toaster test on the loudspeaker in question with 6 dB crest factor noise of the appropriate spectrum. The reason for this is two-fold.

   a) If there is too much voltage supplied to a loudspeaker driver in the frequency region close to or below its resonance frequency the excursion of the driver may exceed its safe operating limits. This could result in mechanical damage to the driver. A peak output capabilities test is also very helpful in this regard.

   b) If there is not ***enough*** voltage supplied to a loudspeaker driver in the frequency region close to its resonance frequency, relative to the overall RMS voltage, there may not be sufficient motion of the voice coil to adequately cool it. This could result in thermal damage to the driver.

2) When using larger amplifiers it is important to not allow them to be over driven and clip. This can increase the RMS voltage delivered to the loudspeaker and exceed its max Vrms.

3) A decrease in the crest factor of the program material, due to either compression or different program material, may result in a greater RMS voltage delivered to the loudspeaker than its max Vrms. This will occur when the amplifier is driven just to, but not beyond, the point of clipping with a signal having a lower crest factor. This may result in the response of the loudspeaker changing by more than 3 dB and also possible damage to the loudspeaker. Care should be taken in the system design to minimize the possibility of this occurring. Both RMS and peak limiters with appropriate time constants may be useful in this respect.

We have examined a method to help determine the required amplifier size so that a given loudspeaker reproducing a given signal may achieve a target SPL at a specified distance and shown an example of how to calculate this. We have also touched on some of the reasons why one must be careful when driving loudspeakers with the very large amplifiers that may result from employing this method. I hope this method will be useful to those designing and deploying sound reinforcement and playback systems.