Loudspeaker Fundamentals

Managing power to properly use your system

by Bennett Prescott

Exhibit 1 - Geoff Dane.

Exhibit 2 - Kent Clasen.

It is widely known that loudspeaker drivers are fragile, and that careful attention needs to be paid to how much amplifier power is applied to each component in a sound system. This is especially true in our world of *Live Sound*, where we are always trying to push our loudspeakers to get those last few decibels or final one-third octave of performance. While the technology behind our transducers has advanced considerably in the last few decades, providing significantly higher power handling and wider bandwidth, it is just as important to know how to properly power a loudspeaker today as it was at the dawn of sound reinforcement.

If you spend much time on Internet resources like the Live Audio Board (*www.srforums.prosoundweb.com*), you will probably have been exposed to a veritable color palette of plausible reasons for driver failure. I have seen visitors advised that their drivers failed because of amplifier clipping, over-powering, under-powering, improper limiter settings, DC, square waves, over-excursion, choice of crossover point, system compressors, no system compressors, music genre, improper horn loading, heat, cold, and humidity. I'm probably skipping a few, and you've probably heard most of these complications yourself. This wide variety of often incongruous explanations makes it difficult for even many advanced users to decide on the simple matter of how much amplifier power to provide a given loudspeaker component.

FAILING LOUDSPEAKERS

Fortunately, the real answer is quite simple, and takes into account all of the aforementioned explanations. Loudspeakers fail for two reasons, over-heating and over-excursion. The former burns up the voice coil, freezing it in the magnetic gap or causing the circuit to open. The latter tears the loudspeaker apart as it is slammed back and forth against its mechanical limits by its own reciprocating motion. While it is certainly not uncommon to see drivers fail due to being kicked, dropped, or soaked, failure due to physical abuse not provided by an amplifier is academic to the purpose of this article.

Over-excursion is a well-understood phenomenon. It is simple to observe, can be measured with a ruler, and reasonably accurate formulas exist to calculate it based on the enclosure the driver is loaded into and the frequencies being amplified. Failure is simple to document, as the driver will look like it was torn apart by force, with obvious consequences to the cone, surround, and voice coil. Some loudspeakers deal with over-excursion better than others, but it is never a good thing. Component manufacturers will list the maximum limits of their drivers' mechanical suspension as the XMech specification, which is almost always more than the XMax spec; the latter refers to the point at which the voice coil has achieved enough excursion that part of it has left the magnetic gap. **See Exhibits 1 & 2**.

The driver has started to lose control of the cone at this point and distortion rises rapidly. It is a good idea to avoid taking a loudspeaker past XMax as there can be severe consequences to sound quality, although the driver may survive. Too much time spent at or near XMech will almost certainly destroy the driver. A good engineer will probably be able to hear when they approach XMax and back off, realizing that's all the "rig for the gig" they have. Even a bad engineer can probably hear XMech as the voice coil bottoming out makes a lot of noise, and if they don't notice that, the loudspeaker blowing apart shortly thereafter is a sure indicator.

Over-heating, on the other hand, is not very well understood or simple to measure and document. Think of the loudspeaker's voice coil as if it were a space heater: apply a certain amount of voltage, and the coil heats up. Very little voltage produces very little heat. A lot of voltage will produce a lot of heat, until the voice coil is producing more heat than it can handle and burns up. Unlike a room heater's glowing red element, a loudspeaker voice coil is made of fine, fragile wire. To help it survive the kind of power we expect in pro audio, the voice coil is cooled both by sinking heat into the magnet assembly it rides in, as well as by pumping cool air around the magnet structure through the motion of the cone. Modern voice coils can handle a great deal of heat, but there are still very definite limits. See **Exhibit 3**.

Exhibit 3 - Jim Bowersox.

CREST FACTOR

What complicates the amount of heat a driver can take is something called "crest factor." The crest factor of a waveform is the ratio of its peak amplitude to its RMS value, which can be expressed in dB. A pure DC signal has 0 dB crest factor. A pure sine wave has 3 dB crest factor. Pink noise has a crest factor of 6 dB. Any two signals that have identical RMS values will create the same amount of heat, but the one with the higher crest factor will have higher peak amplitude, which can make a large difference in the way it sounds. Most importantly, live music commonly has a crest factor around 20 dB, 100 times more peak power than RMS!

This crest factor is the reason that loudspeakers and components are often given three power ratings, usually described as continuous, program, and peak. In reality these are just different ways of saying the same thing, but with varying crest factors. Continuous power is defined by the AES standard IEC 268-5 as the amount of power a loudspeaker can handle over a long time period (hours) when driven with pink noise (6 dB crest factor) that is limited to the driver's operating bandwidth. This is a pretty good "worst case" scenario, as any music that you are trying to reproduce that has only 6 dB of peak to average ratio is going to sound like noise anyway.

A program rating for the same loudspeaker is then usually listed, and it is 3 dB higher, or twice the wattage. At least one major manufacturer doesn't even list the continuous (AES) power rating for their loudspeakers, because the number that is twice as large looks twice as good to the consumer. They list program and then peak, which is 3 dB more than program and twice the wattage again. What is important to realize is that all of these numbers are simply estimates and the higher numbers simply represent the amount of amplifier power one should apply when reproducing signals with more dynamics, headroom, crest factor, or whatever you'd like to call it. These numbers assume that the average power of the signal will be the same at each power rating, but as each signal has a progressively higher gap between its peaks and its RMS value, more peak amplifier power output can be applied to reproduce those peaks without overheating the driver.

A more relevant extrapolation of loudspeaker power capability might list even more power levels, but at the lower end of the scale. A driver capable of 100 watts when driven to its limits with the AES specification is potentially only able to handle 50 watts when driven with a sine wave, which only has 3 dB crest factor. Apply a DC current (0 dB crest factor) and it will likely handle less than 25 watts. No manufacturer in their right mind is going to list a loudspeaker with a power handling of "25 watts DC" when the same driver can be said to handle "400 watts peak," so we are all left to do a little math on our own. Fortunately for everyone, the amount of DC or sine wave power a driver can take is pretty meaningless, since music is never made up of waveforms like that. The peak power rating is much more accurate as an indicator of what amplifier power rating to choose in order to get maximum performance from a driver. Furthermore, there are many more options available to cool a loudspeaker that is being driven with a highly dynamic signal, so gains can be made in terms of power handling there as well.

Let's try and take a real world example. This short sample (**Exhibit 4**) from a live board recording of the band All Time Low performing their song "Jasey Ray" shows what a real world waveform looks like. The thick green lines represent the RMS value of the waveform, the voltage going towards driver heating, which is The Enemy. As you can see, the actual peaks of the signal go much higher than the RMS value… 14 dB higher, to be precise. To show how significant this is, an amplifier capable of providing 1,000 watts of power will be at the limits of its rail voltage reproducing this signal, while only putting out 40 watts RMS. That's a pretty enormous difference, especially in today's world of 100+ watt rated compression drivers and 1,000+ watt rated cone drivers.

These sorts of differences are exactly why in many pro systems it is not at all uncommon to have an amplifier capable of delivering 500-1000 watts or more to the high frequency section, while that section can only handle a hundred watts AES. In the case of a compression driver being driven at 100 watts RMS with the waveform in **Exhibit 4**, the amplifier would have to be capable of providing 2,500 watts to reproduce the peaks! Providing less amplifier power simply clips off the tops of the waveform, creating distortion that is much less pleasing the to ear.

In the real world we never really know what kind of signal we'll be feeding our loudspeakers. What allows truly pro systems to operate with so much "excess" amplifier power is very carefully set limiters. If the system processing is set so that the limiters keep the long-term power of the signal at or below the RMS capability of the loudspeaker, one can imagine how it would be possible to use an unlimited amount of amplifier power without danger. Because the limiters are making sure that the heat-generating average power of the waveform doesn't get to damaging levels, the "excess" amplifier power can safely be used to reproduce peaks and dynamics, ensuring that the snare can still pop without allowing the low frequencies from the kick drum to overwhelm the loudspeaker.

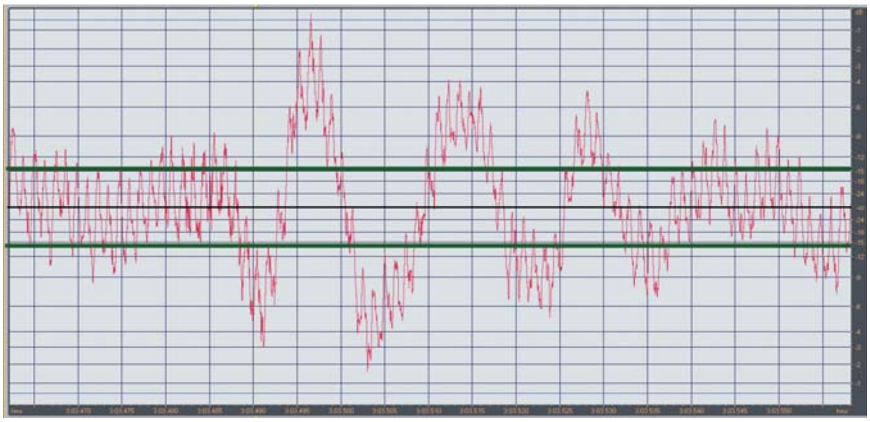

Exhibit 4 - Phillip Graham.

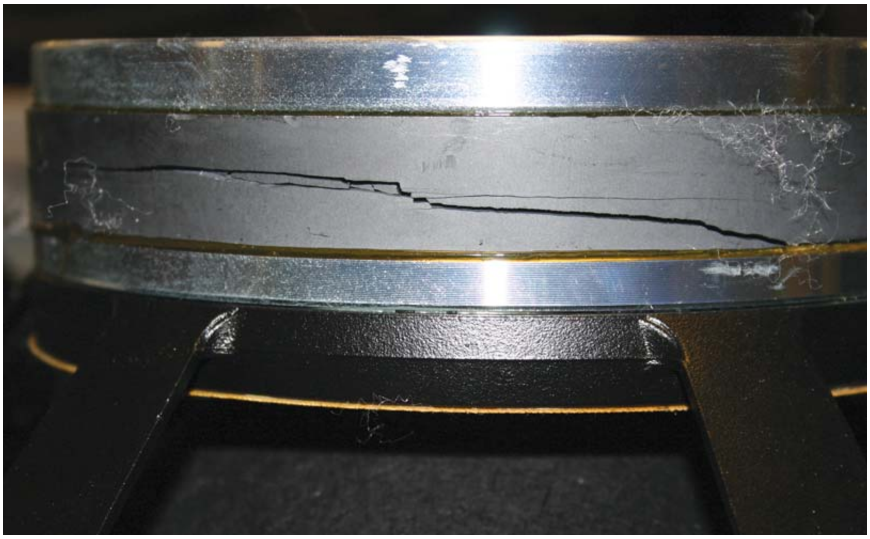

Exhibit 5 - Trace Knight.

These dynamics can be reproduced up to the excursion limits of the driver, which then becomes the real limiting factor.

PEAK VS. RMS

It is important to differentiate between commonly used peak limiters and a proper RMS limiter. A peak limiter may keep an amplifier from clipping, or it may be set to keep signal from exceeding a driver's peak power rating. The first case is a non-issue: Clipping does not typically damage amplifiers. The second case is a red herring; as discussed throughout this article, good drivers can and do take short bursts of signal that are well in excess of their continuous power rating, enabling them to maintain the integrity of signal dynamics. All a peak limiter then does is limit the very fidelity we are trying to recreate in the first place. Much worse, however, is that limiters can create a false sense of security… An engineer, seeing that a system is indicating that it has passed the limiter threshold, will assume they can continue to drive it into the improperly applied peak limiters and that they will protect it.

Instead, as the signal gets more and

more limited, its RMS value increases, but peak values remain the same. In other words, the limiters are not preventing the destructive heating power of the signal from increasing, even though it may appear that they are. As the engineer continues to apply "gas" the signal will become less and less dynamic, and each increase in signal level will have a smaller corresponding increase in perceived loudness as peaks are squashed further. Eventually the engineer, fighting for output that is simply not available, will have increased the RMS level of the signal beyond the level that the loudspeaker system can handle and there will be a catastrophic failure due to over-heating.

The above case shows why peak limiters have no place in driver protection, except to limit against driver over-excursion. Given only one limiter in the signal path, it should be set solely to keep drivers from overheating. If the amplifier is driven to clip, but the loudspeaker has not reached either XMax or its thermal limits, then the clipping is of little concern. Clipping in this case only serves to indicate that there is not enough additional amplifier output to take the system to the limits of its performance capability.

If no limiters are available, then the operator must be very careful to ensure that they do not push the system beyond its abilities. In this case amplifiers sized to the "program" or "peak" rating of the driver or enclosure they power may be appropriate, so that the engineer can use their clip or limit indicator lights to determine that the loudspeaker system is nearing its breaking point. With highly compressed music (like much dance music), these may not be a very good indicator at all, as the already highly compressed peaks of the signal may not set off the clip/limit lights on an amplifier until the signal's RMS value is already unsafe.

Attempting to size an amplifier to a loudspeaker in such a way that the amplifier does not have enough power to destroy drivers is an exercise in futility. Most power amplifiers can be driven hard enough that they temporarily output twice their rated power… although what they are putting out will sound horrible due to extreme limiting or clipping. To adequately protect against this kind of mistreatment one would have to use a power amplifier that is sized at less than half the driver's AES power rating. The loss in system performance that would result from this sort of compromise is not permissible in any system I have ever worked with. We're talking about using a 50-watt amplifier on a 100-watt rated driver that might be more appropriately powered by a 400-watt amp. It is much more practical to either trust that your system will be used by competent technicians, or utilize a properly configured limiter.

At the bleeding edge of audio it is possible to extract performance from loudspeakers well in excess of what would normally be indicated by simple power ratings. With the aid of robust drivers and large amplifiers, good limiters keep a system safe while allowing enough headroom to cleanly and realistically reproduce the dynamics of nearly any style of music. By better understanding the realities of driver failure and loudspeaker power ratings you can more realistically select amplifiers to extract the maximum performance from any professional audio system.

Special thanks go out to many members of the Live Audio Board, including Geoff Dane, Kent Clasen, Trace Knight, and Jim Bowersox, whose excellent photographs of gruesome driver death made it into this article, and many others who submitted equally good shots that I didn't have space for. Extra special thanks to Phillip Graham who provided much needed technical advice and editorial prowess, as well as the image in **Exhibit 4**. Evan Kirkendall was kind enough to give me permission to use the segment taken from "Jasey Ray" which he recorded live in his current gig as Band Engineer for All Time Low.

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The Importance of Watts

It is important to understand the relationship between amplifier wattage, as the most commonly reported performance specification, and sound output. 3 dB of additional sound power from the same loudspeaker requires double the number of amplifier watts. It is commonly accepted that 3 dB is the smallest practical sound pressure difference detectable by the human ear. If you want your sound system to be noticeable louder, you will need at least twice as much amplifier power or loudspeakers at least 3 dB more efficient. That means if you have a 1,500-watt amplifier and are considering replacing it with a 2,000-watt amplifier you should save your money, as that is only a 1.2 dB difference. At least 3,000 watts is necessary for a significant improvement in performance… if your current loudspeakers cannot handle that kind of power, you need loudspeakers with either higher power handling or higher efficiency, or simply more loudspeakers.