Power Lines: Getting The Proper Flow

More factors that affect power transfer between an amplifier and transducer

By Pat Brown

As detailed in my previous articles on power issues (Live Sound February and March 2003), there are a number of possibilities for rating a power source. The most straightforward is a simple rating for continuous available power, a product of the maximum voltage (pressure) output times the maximum available current (flow) from the amplifier. This "Volt-Ampere" rating represents the largest number that could be used to characterize the amplifier.

For the "ideal" amplifier, we could simply multiply the DC rail voltage times the maximum current available from the power supply into a purely resistive load. Unfortunately, the only value of such a rating would be its affect on retail sales. This large number must be de-rated in light of the actual conditions under which amplifiers must operate. So what factors serve to reduce the "ideal" output power?

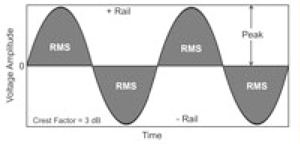


Figure 1: A sine wave plotted as a function of time.

First, no sound reinforcement amplifier is called upon to deliver DC voltage and current into a load. If such a signal were indeed applied to a loudspeaker, it would quickly (and silently) burn up! Loudspeakers only vibrate with the application of alternating current, or AC. We could pulse the DC current, producing a square wave, but this still would bear little resemblance to a real-world audio waveform. Most amplifiers are rated based on their ability to pass a sinusoidal waveform.

The sine wave, when applied to a loudspeaker, makes it move in and out like a piston. Sine waves are discrete in their spectral content, meaning that they contain only one frequency. They are also the building blocks of more complex waveforms. Since the typical sound system must pass many thousands of frequencies, it would take a lot of sine wave testing to fully characterize an amplifier! One possibility is to rate the amplifier using a 1 kHz sine wave, and then add an additional descriptor for how much this will vary over the bandwidth of the amplifier.

A power bandwidth of -3 dB would mean that the guaranteed power output of the amplifier is one-half of the 1 kHz rating. That seems like a big difference, but it's not when you consider the logarithmic characteristics of human hearing. One-half power is just noticeably lower in sound level.

So let's go with the sine wave for rating the amplifier. A 500-watt continuous amplifier will deliver 500 watts to my loudspeaker, right? Well, only if you play sine waves through it! In reality, the power flow will be much lower. This is due to the complex nature of the audio waveforms generated by real-world program sources.

The waveforms produced by a drum kit or lead singer bear little resemblance to sine waves. They are inherently more complex. Before we take this thought further, let's look at some characteristics that describe time-varying voltages.

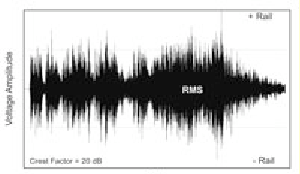
IT'S ABOUT TIME

Figure 1 shows a sine wave plotted as a function of time. This statement means that the amplitude (vertical displacement) of the voltage is time-dependent. Like the stock market and the air temperature, the question of "how much?" depends on "when?" So what value do we assign to the voltage and, ultimately, the power generated by the sine wave? One possibility is to use the maximum displacement from zero. This is the peak voltage of the waveform, and it represents the largest value that we could give it. Unfortunately, the peak voltage has little to do with loudness or power.

Earlier we showed that power generation is a time-dependent parameter. A peak can have high amplitude but not last long enough to produce much power flow. Power is ultimately tied to the root-mean-square (RMS) value of the waveform. The RMS voltage can be thought of as the "area under the curve" described by the waveform. It is numerically equivalent to the DC voltage that would generate the same heat for the specified time interval. This "heating value" is what must be considered to assess power flow and loudness.

RMS voltage is determined by squaring all amplitude values (this makes them positive), and then taking the square root of the mean (average) value. Power is then calculated by squaring the RMS voltage and dividing by the resistance of the load, the result being termed "continuous average power" or just "continuous" for short. For a sine wave (and a sine wave only), the RMS voltage is 0.707 times the peak voltage. This means that a sine wave will generate one-half of the power that the DC rail voltage would for the same time span.

Using the "hypothetical" DC rating as a reference, we would say that the sine wave has a "crest factor" of 3 dB. So, an amplifier with a sine wave rating of 500 watts continuous could be rated at 1000 watts "peak" output. So why not rate it at 1000 watts?



There are several reasons, including the fact that most amplifiers cannot sustain such an output power for any appreciable time period. It is also unlikely that any real-world audio waveform would stay at the peak voltage for any appreciable time span. So, when you bring "time" into it, peak values become less meaningful. And since power is the "rate of doing work", it is impossible to consider power independent of time. Also, just like passing your finger quickly through the flame of a candle, loudspeakers and amplifiers can be given

Figure 2: A lower RMS voltage means a higher crest factor, which in turn means less power delivered to the load.

very large heat generation and dissipation ratings if the time element approaches zero.

ROOM AT THE TOP

Real-world audio waveforms have much lower RMS values (less area under the curve) than sine waves do, even though their peak values may be the same (see Figure 2). A lower RMS voltage means a higher crest factor, which in turn means less power delivered to the load. One way to determine how much power a complex waveform will generate is to use the peak power output based on the DC rail voltage as a reference, and then subtract the crest factor of the complex waveform from it. This will yield the power generated by the complex waveform.

For example, an amplifier rated at 500 watts continuous average power with a sine wave will have a theoretical peak output power 3 dB higher (the crest factor of the sine wave) - 1,000 watts in this case. Using this as a reference (that's all it's good for), we can subtract the crest factor of the real-world waveform. Refer to the following chart for some common decibel relationships:

0 dB - reference value
-3 dB - one-half power
-6 dB - one-fourth power
-10 dB - one-tenth power
-20 dB - one-one-hundredth power

These numbers will be useful for determining how much power a waveform generates based on its crest factor. Our 1,000-watt "theoretical" amplifier would only generate 500 watts for a sine wave signal (-3 dB), 250 watts for a 6 dB crest factor signal (highly compressed music or speech), 100 watts for a 10 dB crest factor signal (slightly compressed music or speech), and only one watt for a 20 dB crest factor signal ("raw" music or speech). So, in the real world of live performances, a 500-watt "sine wave rated" amplifier is likely to deliver only a fraction of this power to the loudspeaker.

The implications? First, if a loudspeaker can safely dissipate 100 watts continuous average power (based on destructive testing - sounds like fun, doesn't it?), then the required amplifier size to deliver 100 watts will be considerably higher. This is because the amplifier is rated using a sine wave, which yields a much higher power output than a real-world audio waveform. Assuming a crest factor of 10 dB, the amplifier would have to have a peak rating of 1,000 watts (sine rating of 500 watts) to actually deliver 100 watts into a resistive load. This "extra" room is called "headroom". This is why it is common practice to oversize the amplifier relative to the loudspeaker's power rating.

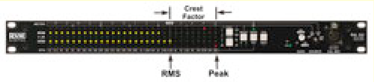


Figure 3: A meter that can display the peak and RMS voltage of the waveform at the same time.

But if you connect a 500-watt amplifier to this loudspeaker, and someone feeds it a low crest factor signal (like a sine wave), it is likely that the loudspeaker would burn up since its power rating has been exceeded.

So, we want a large amplifier to provide sufficient headroom for high crest factor signals, but we need to make sure that a low crest factor signal is not applied that will burn up the loudspeaker. Catch 22. No free lunch. It depends. There is no escaping these realities in the real world of live performance.

Let's sum it up with some guidelines. The sensitivity rating of a loudspeaker specifies a sound pressure level that will exist at a one meter distance when one watt of electrical power is applied to the loudspeaker's terminals (2.83 VRMS across eight ohms). In other words, if you put one watt in, it will be this loud at this distance. The amplifier size that is required to deliver one watt is dependent on the crest factor of the program material.

Using 10 dB as a rule-of-thumb, the required peak power rating would be 10 watts. So, it takes 10 watts peak to get one watt continuous! If we scale these numbers up to a loudspeaker rated to dissipate 100 watts continuous, the peak amplifier rating would be 1000 watts. Given that amplifiers are typically rated with sine waves, the continuous power rating of the amplifier would be one-half the peak rating, or 500 watts. Therefore, it takes a 500-watt sine wave rated amplifier to deliver 100 watts to a loudspeaker if the program material has a 10 dB crest factor. How's that for confusing?

CREST FACTOR AWARENESS

So, how do I determine the crest factor of my program material? After all, this is what ultimately determines the required power rating of the amplifier and the power flow into the loudspeaker. There are two ways to approach this. For recordings, the crest factor can be calculated quickly and accurately using a wave editor program. Open the wave file, select a time span, and look for a menu selection called "statistics" or something similar. This should display the crest factor for the time span selected.

For live music, it's a bit harder. You need a meter that can display the peak and RMS voltage of the waveform simultaneously (see Figure 3). On such a meter, the crest factor can be monitored in real-time - VERY cool. If the meter is calibrated so that its highest peak indication is the clipping point of the system (this is the right way to do it), then the lower (RMS) indication on the meter will correlate with how much power is being generated. This allows the operator to turn the system down if the RMS gets too high (which is also the right way to do it).

The third way is to use some rules-of-thumb for typical crest factors. Once you factor in all of the variables (I won't do it here), the crest factors in live performance are often in the 6 to 10 dB range for mid and high frequencies. They tend to be lower at low frequencies where synth and bass guitar signals look more like sine waves. This means that at mid and high frequencies you will be using one-fourth to one-tenth of the peak rating of the amplifier. At low frequencies you will be using up to one-half of the peak rating of the amplifier.

If you are a disciplined sound operator, you can oversize your amplifiers by this much (relative to the loudspeaker's rating) and probably not get into trouble. The safest overall approach is to use large amplifiers, but then monitor the program's RMS and peak levels to stay within the loudspeaker's limitations. Also remember that compressors and limiters reduce the crest factor of the signal, which means that more power is delivered to the load. Again, real-time monitoring will tell the story.

THE CONCLUSION?

The bottom line is that there are many variables that determine the power flow from amplifier to loudspeaker. An understanding of these basics can allow us to stay within the operating limits of our hardware. Power ratings are meaningless when there is smoke coming out of the loudspeakers.

This series of articles hasn't attempted to present a black-and-white recipe for amplifier/loudspeaker selection. What it has done is put the variables on the table that the system designer must consider when selecting components. There's a lot to think about, and there WILL be a test.

Editor's Note: The test Mr. Brown refers to will be included in Live Sound's May 2003 issue, so start studying!

Pat Brown, with his wife, Brenda, heads up Syn-Aud-Con, leading audio training sessions around the world. For more info, go to ***www.synaudcon.com***

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