

RaneNote 128

- Harmonic Theory
- Power Ratings
- Blown Tweeters
- Clipping and its Indicators
- Limiter Protection

Monty Ross
Rane Corporation

POWER AMPLIFIER CLIPPING AND ITS EFFECTS ON LOUDSPEAKER RELIABILITY

INTRODUCTION

Power amplifier clipping is quite common. This note examines the clipping phenomenon which *allegedly* damages loudspeakers. We suggest that this form of distortion is not the cause. Rather, we show that amplitude compression of the audio spectrum is the culprit. Rane limiters provide a solution to amplitude compression, thus preventing loudspeaker failure.

WHY DO LOUDSPEAKERS NEED PROTECTING?

All loudspeaker drivers have power handling limits. Once exceeded, damage occurs. There are several ways a loudspeaker suffers *power* damage. A couple of these warrant explanation.

The first is over-exursion of the diaphragm. The diaphragm of a loudspeaker is the radiating surface that moves in response to an electrical signal. This surface may be conical, domed or flat in shape, and it creates sound by physically pushing and pulling the air in the room. The laws of physics say that in order to play louder or to reproduce lower frequencies, the diaphragm must move further toward its mechanical limits. If it is asked to move still farther, it experiences over-exursion. This most often occurs in woofers but can affect midranges or tweeters if low frequencies are not limited. If the loudspeaker cannot handle over-exursion, mechanical destruction of the driver is likely the result.

Another enemy of loudspeakers is heat, generated by power losses in the voice coils. No device is 100% efficient. For loudspeakers, 1 watt of input power does not produce 1 watt of acoustic energy. In fact most loudspeakers are typically well under 10% efficient [1] [3]. These losses convert to heat that builds up in the voice coils, causing mechanical deformation, like melting of the voice coil former. It causes weakening of the structure by charring the voice coil former, which later shakes apart. The heat causes the glues to bubble up, fill the air gap and glue the voice coil solidly in the gap. Often the voice coil wire melts like a fuse link, resulting in an open driver. Obviously we wish to prevent this.

Music power-handling capability for multi-way loudspeakers always presents a problem to the loudspeaker user and designer. Users who must replace blown tweeters often feel they didn't do anything wrong, because their amplifier only put out 50 watts and their speaker had a 200 watt rating. Yet, the tweeter blew up. This recurring problem motivated

engineers to find out why this happens. Many opinions developed. Some of these have been scientifically verified—others remain theory.

CONFLICTING "FACTS"

Studies show the typical spectral energy for different types of music have high frequency energy considerably lower in level than low frequency energy [2]. This knowledge has further complicated the studies of how tweeters get destroyed. It seems that woofers should blow rather than tweeters if the high frequencies are lower in amplitude.

Loudspeaker manufacturers use this knowledge about the energy distribution of music when they design their products. This knowledge allows them to make better sounding tweeters because they can use lighter moving structures. Smaller wire in the voice coils can be used because there is significantly less power in the high frequency ranges. Since smaller wire is lighter, it takes less energy to move. For a speaker system rated to handle a given number of watts, the tweeter by itself can probably handle less than one-tenth that amount.

From all this came a theory that spread quickly through the industry. Since there is more musical energy at low frequencies than high frequencies, there is not enough high frequency power to blow out tweeters. Therefore, high frequencies loud enough to burn out tweeters must come from somewhere else. Where do they come from?

Well, it was reasoned, if there is enough low frequency energy to clip the amplifier, then it perhaps would produce enough high frequency distortion products (as a result of clipping) to blow up the tweeter.

This theory convinced many in the early 70's and slowly evolved into "fact". While doing research into the reliability and protection of power amplifiers, I had to study how the typical consumer used amplifiers and speakers. I found that

Table 1. Harmonic Amplitudes of a 100Hz Square Wave, 0dB = 100 Watts

| Harmonic | Amplitude | in dB | Watts | Frequency |
|----------|-----------|--------|-------|-----------|
| 1 | 1 | 0 | 100 | 100Hz |
| 2 | 0 | -∞ | 0 | 200Hz |
| 3 | 1/3 | -9.54 | 11.12 | 300Hz |
| 4 | 0 | -∞ | 0 | 400Hz |
| 5 | 1/5 | -13.98 | 4 | 500Hz |
| 6 | 0 | -∞ | 0 | 600Hz |
| 7 | 1/7 | -16.9 | 2.04 | 700Hz |
| 8 | 0 | -∞ | 0 | 800Hz |
| 9 | 1/9 | -19.1 | 1.23 | 900Hz |
| 10 | 0 | -∞ | 0 | 1kHz |
| 11 | 1/11 | -20.8 | 0.83 | 1.1kHz |
| 12 | 0 | -∞ | 0 | 1.2kHz |
| 13 | 1/13 | -22.3 | 0.589 | 1.3kHz |
| : | : | : | : | : |

clipping is a common occurrence and is not as audible as most people think. I also found that the operation of many clipping indicators is very slow and does not always show actual clipping. (Many manufacturers slow them down, using their own rule of thumb for how much clipping can occur until it lights the indicator.)

Newer and better sounding amplifiers, including amplifiers with soft clipping circuits, still blew tweeters. But amplifiers with higher power were having fewer incidences of blown tweeters. This appeared to reinforce the theory that clipping caused tweeter blowouts. One thing was clear, when clipping occurred, tweeters blew.

If you're getting the idea I don't believe in the clipping/harmonic theory, you're right. So let's investigate the phenomena further.

WHEN SINE WAVES CLIP

When sine waves clip severely they resemble square waves in shape, introducing massive distortion. In the extreme case, a perfect square wave has the highest level of harmonic components (See Fig. 1). A less clipped sine wave has components at the same frequencies but at lower levels.

Let's look at the square wave example shown in Table 1 (at left). Fourier analysis shows the harmonic structure.

As you can see, the total amount of power left to make it through an ideal 1kHz crossover (and on to the tweeter) is less than two watts ($0.83 + 0.589 = 1.419W$). Hardly a problem. And remember, this simulates severe overdrive of a 100 watt amplifier with a sine wave to make an ideal square wave. Driving it harder will not increase the harmonics.

This analysis shows if a small tweeter that only handles 5 or 10 watts is used in a 100 watt speaker system it would not blow out, even under square wave conditions. Yet it does.

It takes a lot more than this to cause major failure. So what's happening?

Compression is what's happening [3].

Today's newer higher quality amplifiers have greater dynamic range and sound better when clipped with musical transients than older amplifier designs. So it is more likely for a user to overdrive and clip newer amplifiers on low frequency dynamic peaks because of lower audible distortion. This results in compression of the dynamics of the music. The

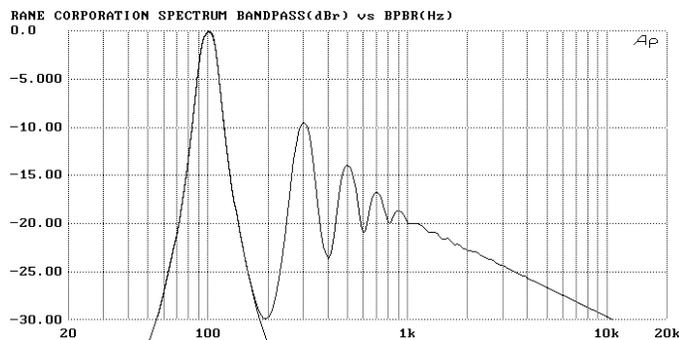


Figure 1. Harmonic Components of a 100 Hz Squarewave vs. a 100 Hz Sinewave.

high frequencies get louder but the low frequencies can't. This may be heard as an increase in brightness of the sound. Some may simply interpret it as louder with no change in tonal balance.

For example, in a 100 watt amplifier, as you turn up the level, the low frequency components will limit (clip) at 100 watts. Meanwhile the high frequency components continue to increase until they (the high frequencies) approach the 100 watt clipping point.

The graphs in Figures 2, 3 & 4 are scaled in volts. With an 8 ohm load the 100 watt level corresponds to 40 volts peak. Below clipping, the low frequencies reach 100 watts (40 volts peak) but the high frequencies are only 5 or 10 watts (9 to 13 volts peak).

Let's assume a musical signal with low and high frequency components driving a 100 watt (8 ohms) amplifier. We use a low level/high frequency sinewave mixed with a high level/low frequency sinewave burst. (See Fig.2). The high frequencies reproduced by the tweeter are at least 10dB lower in level than the low frequencies. Now as we turn up the amplifier to clip the signal (3dB overdrive—See Fig.3). Notice that only the low frequency burst portion of the waveform clips but the high frequency portion increases in level. The clipping, of course, produces harmonics but not nearly as much as the square waves discussed earlier. The amplitude of the high frequencies went up by 3dB in relation to the low frequency fundamental. (3dB compression).

If you overdrive the amplifier by 10dB, the high frequency amplitude goes up by 10dB. This goes on dB for dB as you turn up the volume, until the high frequency reaches the 100 watt level. Meanwhile the peak level of the low frequency portion can not increase above 100 watts (See Fig. 4). This now represents nearly 100% compression (no difference between HF amplitude and LF amplitude).

Now it is easy to see how the high frequency portion exceeds the 5 or 10 watts tweeter rating. Sure, clipping is producing extra harmonics but *they never approach the levels of the amplified high frequency source signals.*

It may be argued that the signal's distortion would be intolerable. Don't fool yourself. It really surprises people how much clipping they tolerate before they cannot listen anymore. Just disconnect the clipping indicator on a power amplifier

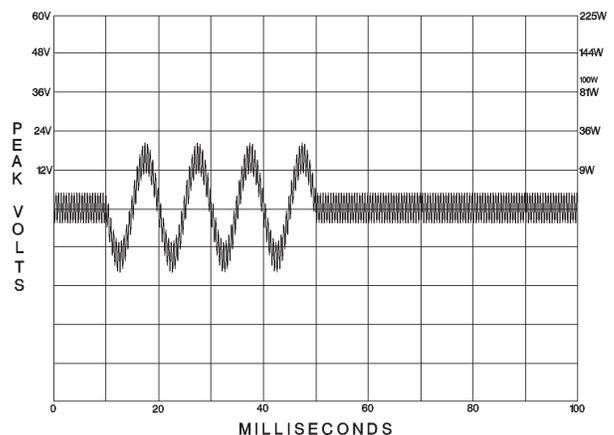


Figure 2. Low Level, High Frequency Sinewave Mixed with a High Level, Low Frequency Sinewave Burst.

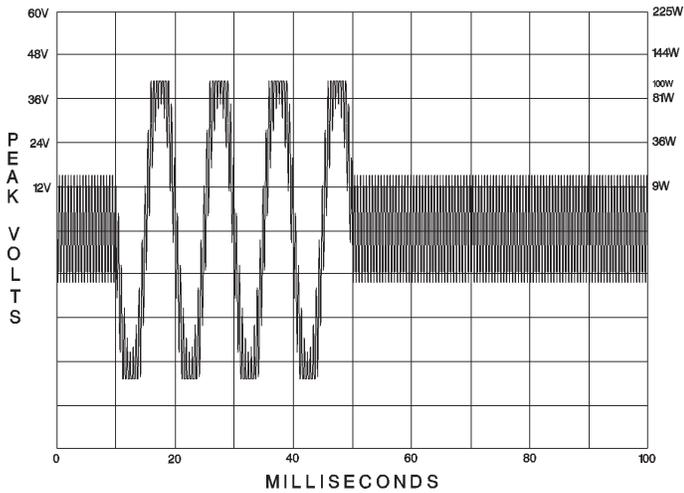


Figure 3. 100 W Amp with 3 dB Overdrive

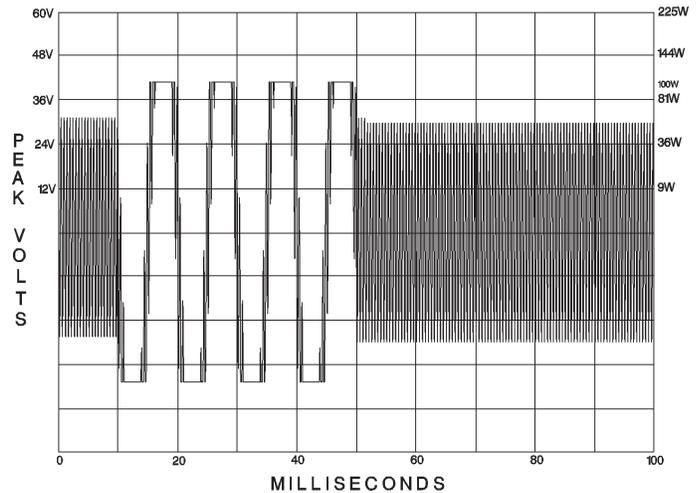


Figure 4. 100 W Amp with 10 dB Overdrive

and see how loud someone drives it. Watch the amplifier output with an oscilloscope. There will be a surprising level of clipping. 10 dB clipped off the top of low frequency transients is not an uncommon occurrence when the purpose is to impress your neighbors.

WHAT CAN WE DO ABOUT IT?

If we can prevent an amplifier from clipping, we could better utilize our loudspeakers. Limiters play an important role in preventing clipping and the resulting amplitude compression. The Rane MA 6S power amplifier, DC 24 dynamic controller, CP 64 and CP 52 commercial processors, VP 12 voice processor, and the RPM 26 multifunction processor are all products that limit. These limiters prevent the compression mentioned earlier because when *any frequency reaches threshold all frequencies are turned down by the same amount.*

The MA 6S six channel power amplifier is specifically designed not to clip by the use of its internal voltage controlled attenuators on each channel.

The DC 24 limiters have user adjustable threshold controls. This allows you to customize your total system for maximum reliability with no compromise on sound quality.

The FVL 22 has an Auto-Slave feature which allows you to slave the two channels together. When using the Auto-Slave mode for bi-amping, or stereo program, the spectral balance is preserved and amplitude compression is eliminated.

REFERENCES

- [1] K. Blair Benson, *Audio Engineering Handbook*, (McGraw-Hill, New York, 1988)
- [2] R. A. Greiner and Jeff Eggars, "The Spectral Amplitude Distribution of Selected Compact Discs," *Journal of the Audio Engineering Society*, vol. 37, pp.346-275 (April, 1989)
- [3] Carlo Zuccatti, "Thermal Parameters and Power Ratings of Loudspeakers" *Journal of the Audio Engineering Society*, vol. 38, pp.34-39 (Jan-Feb, 1990)