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DAMPING FACTOR

By Richard Clark

At a recent AUTOSOUND 2000 manufacturer sponsored seminar, we were asked to comment on the subject of amplifier damping factor. I was extremely surprised to find how much importance was attached to this single specification. Since most folks are a little unclear as to the true meaning of damping factor, we're presenting the following article.

First of all, let's discuss the items that enter into the damping factor calculation. At the heart of this calculation is the output impedance of the amplifier. Most all-modern feedback type amps are of the variety known as constant voltage. This means that they will deliver a constant voltage regardless of their load - at least in theory. Sooner or later the limits of the amplifier's design will prohibit its constant voltage characteristics.

It is this constant voltage output characteristic that permits modern car audio amplifiers to deliver more power into a 2 Ohm load than into a 4 Ohm load. A perfect amplifier should be able to double its power every time its output load is halved. Remember, $\text{Power} = E \times E \text{ divided by } R$. As an example, examine the following chart:

8 Ohms = 25 Watts
4 Ohms = 50 Watts
2 Ohms = 100 Watts
1 Ohm = 200 Watts
.5 Ohm = 400 Watts
.25 Ohm = 800 Watts
.0125 Ohm = 1600 Watts

If an amplifier were theoretically perfect, then it would be capable of the type of performance described in the chart. However, there are many factors that influence this capability. First there is the power supply section of the amplifier. Even if an amplifier had an unlimited power supply with output transistors that could handle the current, the design would still not be able to achieve the theoretically perfect output. The reason being that we do not have access to theoretically perfect components.

Never lose sight of the fact that real components in real amplifiers are subject to real losses. These losses are a result of junction losses; IR drops in connections and losses in resistances and reactance. Losses in the output stages essentially form a voltage divider on the output of the amplifier. This drop is always in series with the load and can be indicated as in Figure N.

In the design of an amplifier, the feedback network is usually wrapped around the section with the most losses. These losses can be greatly minimized due to the fact that the feedback node is constantly being corrected. This can be depicted as in Figure O.

Output Impedance Determines Damping Factor

If the output impedance of an amplifier is extremely low, the effect of loading on the output of the amplifier will be minimal. This means that it will not experience a voltage loss across its own output impedance. This output impedance does more than determine the effect of loading on the amp. It also determines its damping factor.

Whenever a signal is fed into a loudspeaker the cone of the speaker will move. Since the cone has mass, there will be mass in motion. Mass in motion means momentum. When the signal is removed from the loudspeaker, the momentum of the cone causes the energy stored in the cone to be fed back into the amplifier. If our perfect amplifier were connected to this speaker, the loudspeaker would be trying to produce a voltage into 0 Ohms. Remember, a perfect amplifier has an output impedance of 0 Ohms which is essentially a short circuit.

A voltage cannot be developed across 0 Ohms because it would require an infinite amount of current. It is this same infinite amount of energy that would now be trying to prevent the speaker cone from moving. If such were the case, we would certainly have a "tight" sounding speaker with absolutely no hangover.

The good news is that quality amplifiers have very low output impedances. We are very pleased to report that there are many car audio amplifiers on the market with output impedances on the order of .01 Ohms or less!

Calculating Damping Factor

Let's clarify a few points before starting our calculations. The frequency of the measurement and the impedance of the load need to be specified. For example, the use of a 1 KHz signal and a load impedance of 4 Ohms would be a typical specification.

DEFINITION = A good definition of damping factor would be the ratio of the output impedance of the amplifier to the impedance of the load specified at a given frequency.

An amplifier with an output impedance of 0.5 Ohm will have a damping factor of 8 when connected to a theoretically perfect 4 Ohm loudspeaker (i.e. purely inductive voice coil.) since $4/.5 = 8$.

The following chart assumes such a 4 Ohm speaker:

Output Impedance	Damping Factor
4 Ohms	1
2 Ohms	2
1 Ohm	4
.5 Ohm	8
.25 Ohm	16
.125 Ohm	32
.062 Ohm	64
.031 Ohm	128
.015 Ohm	256
.007 Ohm	512
.003 Ohm	1024
.0015 Ohm	2048
.0007 Ohm	4096
.0003 Ohm	8192

Now, for the bad news; it is easy to see how a race to produce such a high damping factor led to a specification so often quoted by salespeople. The numbers on modern amplifiers (with lots of feedback) can get very large and they are easy to compare. Sometimes we can get caught up in these big numbers and we totally miss the point.

Effective Damping Factor (EDF)

In the case of damping factor, I believe that it could be compared to the old saying of not being able to see the forest because of all the trees. The only thing that really matters is Effective Damping Factor (EDF). Effective Damping Factor more accurately describes the interaction between a real amplifier and a real speaker. Unfortunately real speakers have a real problem with EDF. This is due primarily to the DC

resistance of the voice coil. When we calculate the EDF of an amplifier and speaker, it is absolutely necessary that we include this DC resistance into the formula. Figure P illustrates the inclusion of the speaker's impedance into the EDF.

The actual impedance of the speaker may be 4 Ohms. If we measure the voice coil of this speaker, we will probably find that it has a DC resistance of about 3 Ohms. When calculating the EDF effect on this speaker, we must add the 3 Ohms of DC resistance as if it were a resistor between the output of the amp and the voice coil of the speaker. Remember the resistive part of the speaker is the part where the signal is turned into heat. No work is actually done in this resistance.

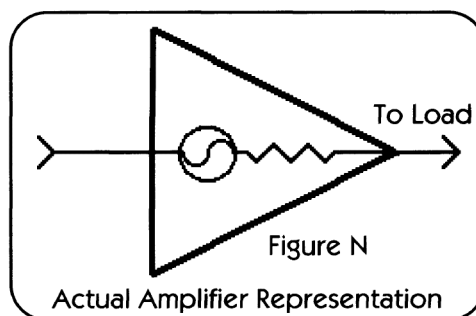
The inductive element of the voice coil is the only part that does work to create sound. This is one reason speakers are so inefficient. Most of the voice coil is a resistive element that can do no work. Someday if we develop room temperature superconductors and can afford to use them for voice coils, we are going to see some really efficient speakers.

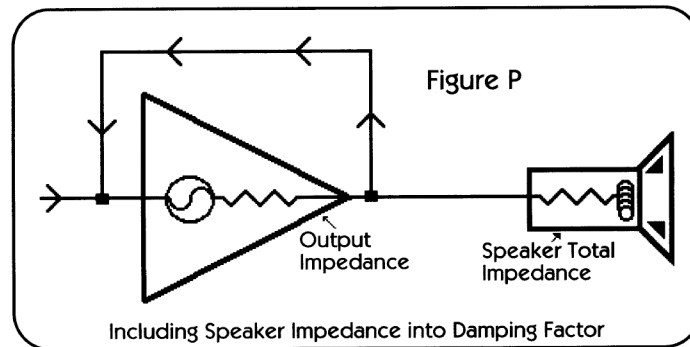
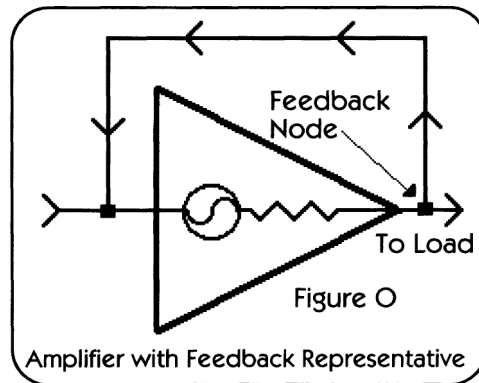
From the damping factor chart it is obvious that the most damping we can expect from our amp/speaker combination is only about two. An amplifier with a damping factor exceeding 10 times this amount is no longer going to play a significant role in this overall calculation. This would yield a practical limit on amplifier damping requirements to about twenty.

There are times when the actual damping factor can exceed this number; one such case would be that of a dynamic loudspeaker in resonance. As we have learned, at resonance a loudspeaker's impedance is at a maximum level. At resonance, the DC element stays the same and only the reactance increases. This means that the ratio gets larger and the DC element becomes a smaller percentage of the total.

For example, if the speaker impedance at resonance increased to 40 Ohms and the DC resistance was still 3 Ohms and the amplifier were .1 Ohms, and then the actual damping could be $40/3.1$, or 13. This is certainly much better than 2, but quite a bit short of the 100, 200, or 500 claimed by salesmen who unknowingly think this factor so important. Fortunately for most loudspeakers this extra damping happens where they need it the most. This is because at resonance, speakers typically are very uncontrolled and have the least mechanical damping. It is also this factor that enables us to be able to connect speakers in series and not have to worry about losing damping. The actual impedance of the loudspeakers in series is doubled, but the ratio to the amplifier must also be increased by a factor of 2 to 1. The result is no change in performance.

It is quite possible that this information may be in stark contrast to current marketing trends. However this does not change the fact that this information is accurate. The best way to achieve total control over speaker movement is with a servo system. Only armed with a quality servo system can effective damping characteristics be achieved. A servo essentially puts the loudspeaker in the corrective feedback loop of the amplifier. This topic will be the subject of a future article.





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