

DAMPING FACTOR: EFFECTS ON SYSTEM RESPONSE
A TECHNICAL ANALYSIS
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1 INTRODUCTION

Much ballyhoo surrounds the concept of "damping factor." it's been suggested that it accounts for the alleged "dramatic differences" in sound between tube and solid state amplifiers. The claim is made (and partially cloaked in some physical reality) that a low source resistance aids in controlling the motion of the cone at resonance and elsewhere, for example:

"reducing the output impedance of an amplifier and thereby increasing its damping factor will draw more energy from the loudspeaker driver as it is oscillating under its own inertial power." [1]

This is certainly true, to a point. But many of the claims made, especially for the need for triple-digit damping factors, are not based in any reality, be it theoretical, engineering, or acoustical. This same person even suggested:

"a damping factor of 5, ..., GROSSLY changes the time/ amplitude envelope of bass notes, for instance. ... the note will start sluggishly and continue to increase in volume for a considerable amount of time, perhaps a second and a half."

Instead of unbridled hyperbole, there have been attempts at a reasoned justification for damping factor. Witness a recent rec.audio.tech post:

"Since the amplifier source impedance is indeed much smaller than the speaker impedance, the latter is almost insignificant. In fact, an amplifier with a damping factor of 50 will sink twice the current of one with a damping factor of 25, and therefore dissipate four times the resonant energy." [2]

As intuitive as this analysis might seem, it is quite flawed since, as we will see, it simply ignores the one major loss factor in the entire system, throwing it out the window as if the single most important controlling element over cone motion had no real relevance.

2 DAMPING FACTOR: A SUMMARY

What is damping factor? Simply stated, it is the ratio between the nominal load impedance (typically 8 ohms) and the source impedance of the amplifier. Note that all modern amplifiers (with some extremely rare exceptions) are, essentially, voltage sources, whose output impedance is very low. That means their output voltage is independent, over a wide range, of load impedance.

Many manufacturers trumpet their high damping factors (some claim figures in the hundreds or thousands) as a figure of some importance, hinting strongly that those amplifiers with lower damping factors are decidedly inferior as a result. Historically, this started in the late '60's and early '70's with the widespread

availability of solid state output stages in amplifiers, where the effects of high plate resistance and output transformer windings traditionally found in tube amplifiers could be avoided.

Is damping factor important? Maybe. We'll set out to do an analysis of what effect damping factor has on what most proponents claim is the most significant property: controlling the motion of the speaker where it is at its highest, resonance.

The subject of damping factor and its effects on loudspeaker response is not some black art or magic science, or even excessively complex as to prevent its understanding by anyone with a reasonable grasp of high-school level math. It has been exhaustively dealt with by Thiele [3], Small [4] and many others decades ago.

3 SYSTEM Q AND DAMPING FACTOR

The definitive measurement of such motion is a concept called Q. Technically, it is the ratio of the motional impedance to losses at resonance. Another, completely equivalent view is that Q is the ratio between the amount of energy stored in the system vs the energy dissipated by losses.

It is a figure of merit that is intimately connected to the response of the system in both the frequency and the time domains. A loudspeaker system's response at cutoff is determined by the system's total Q, designated Q_{tc} , and represents the total resistive losses in the system.

Two loss components make up Q_{tc} : the combined mechanical and acoustical losses, designated by Q_{mc} , and the electrical losses, designated by Q_{ec} . The total Q_{tc} is related to each of these components as follows:

$$Q_{tc} = \frac{Q_{mc} * Q_{ec}}{Q_{mc} + Q_{ec}} \quad [Eq 1]$$

Q_{mc} is determined by the losses in the driver suspension, absorption losses in the enclosure, leakage losses, and so on. Q_{ec} is determined by the combination of the electrical resistance from the DC resistance of the voice coil winding, lead resistance, crossover components, and amplifier source resistance. Thus, it is the electrical Q, Q_{ec} , that is affected by the amplifier source resistance, and thus damping factor.

Q_{ec} itself is a measure of, simply, the ratio of the energy stored in the moving system to the energy dissipated electrically by the losses in the system, that is, in the resistances in the system. The energy stored in the moving system, the kinetic energy, is dependent upon the amount of mass and the velocity.

In the context of a speaker, the Q_e is (from Small[4]):

$$Q_{ec} = 2 \pi F_c M_{mc} R_e / B l \quad [Eq 2]$$

where F_c is the resonant frequency of the system, M_{mc} is the equivalent moving mass of the system, and R_e is the DC resistance of the voice coil (and this assumes 0 source impedance or "infinite" damping factor). Further, B represents the magnetic flux density in

the gap and l the length of wire in the magnetic field. (We will assume that we are using the same driver for all considerations here, thus, Fc, Mmc B and l remain the same as well.)

The effect of source resistance on Qec is simple and straightforward. From Small again [4]:

$$Q_{ec}' = Q_{ec} \frac{R_e + R_s}{R_e} \quad [\text{Eq 3}]$$

where Qec' is the new electrical Q with the effect of source resistance, Qec is the electrical Q assuming 0 source resistance (infinite damping factor), Re is the voice coil DC resistance, and Rs is the combined source resistance.

The factor

$$\frac{R_e + R_s}{R_e} \quad [\text{Eq 4}]$$

comes from the fact that Re is built into the original derivation for Qec includes Re in it. The correction simply calculates the incremental increase in Qe with the incremental increase in the total electrical resistance. Reconciling [Eq 4] with [Eq 2], we see that:

$$Q_{ec} = 2 \pi F_c M_{mc} (R_e + R_s) / B l \quad [\text{Eq 6}]$$

Thus it becomes obvious that the electrical Q of the speaker or, more generally, the electrical damping of the speaker, is NOT dependent upon the source resistance Rs alone (as the proponents of damping factor erroneously claim), but on the TOTAL series resistance seen by the driver, including the DC resistance of the voice coil, Re. This mistake, as commonly as it is made, is the fatal flaw in the entire damping factor argument.

It's very important at this juncture to note two points. First, in nearly every loudspeaker system, and certainly in every loudspeaker system that has any pretenses of high-fidelity, the majority of the losses are electrical in nature, usually by a factor of 3 to 1 or greater. Secondly, of those electrical losses, the largest part, by far, is the DC resistance of the voice coil.

Now, once we know the new Qec' due to non-zero source resistances, we can then recalculate the total system Q as needed using [Eq 3], above.

The effect of the total Q on response at resonance is also fairly straightforward. Again, from Small [4], we find:

$$G_h(\text{max}) = \sqrt{\frac{4 Q_{tc}}{2 Q_{tc} - 0.25}} \quad [\text{Eq 7}]$$

This is valid for Qtc values greater than 0.707. Below that, the system response is overdamped and there is no response peak.

We can also calculate how long it takes for the system to damp itself out under these various conditions. The scope of this article precludes a detailed description of the method, but the figures we'll look at later on are based on both simulations and measurements of real systems, and the resulting decay times are based on well-established principles of the audibility of reverberation times at the frequencies of interest.

4 PRACTICAL EFFECTS OF DAMPING FACTOR ON SYSTEM RESPONSE

With this information in hand, we can now set out to examine what the exact effect of source resistance and damping factor are on real loudspeaker systems. Let's take an example of a closed-box, acoustic suspension system, one that has been optimized for an amplifier with an infinite damping factor. This system, let's say, has a system resonance of 40 Hz and a system Q_{tc} of 0.707 which leads to a maximally flat response with no peak at system resonance. The mechanical Q_{mc} (i.e. the mechanical contributions to system losses and thus damping) of such a system is typically about 3, we'll take that for our model.

Rearranging [Eq 1] to derive the electrical Q of the system:

$$Q_{ec} = \frac{Q_{tc} * Q_{mc}}{Q_{tc} - Q_{mc}} \quad [Eq 8]$$

we find that the electrical Q of the system, with an infinite damping factor, is 0.925.

The DC resistance of the voice coil is typical at about 6.5 ohms.

Let's generate a table that shows the effects of progressively lower damping factors on the system performance:

| damping factor | R_s | Q_{ec}' | Q_{tc}' | Gh(max) | Decay time |
|----------------|--------|-----------|-----------|---------|------------|
| inf. | 0 ohms | 0.925 | 0.707 | 0.0 dB | 0.04 sec |
| 2000 | 0.004 | 0.926 | 0.707 | 0.0 | 0.04 |
| 1000 | 0.008 | 0.926 | 0.708 | 0.0 | 0.04 |
| 500 | 0.016 | 0.927 | 0.708 | 0.0001 | 0.04 |
| 200 | 0.04 | 0.931 | 0.71 | 0.0004 | 0.04 |
| 100 | 0.08 | 0.936 | 0.714 | 0.0015 | 0.04 |
| 50 | 0.16 | 0.948 | 0.72 | 0.0058 | 0.04 |
| 20 | 0.4 | 0.982 | 0.74 | 0.033 | 0.041 |
| 10 | 0.8 | 1.04 | 0.77 | 0.11 | 0.043 |
| 5 | 1.6 | 1.15 | 0.83 | 0.35 | 0.047 |
| 2 | 4 | 1.49 | 0.99 | 1.24 | 0.056 |
| 1 | 8 | 2.06 | 1.22 | 2.54 | 0.069 |

Table 1

The first column is the damping factor using a nominal 8 ohm load. The second is the effective amplifier source resistance that yields that damping factor. The third column is the resulting Q_{ec}' caused by the non-zero source resistance, the fourth is the new total system Q_{tc}' that results. The fifth column is the resulting peak that is the direct result of the loss of damping control because of

the non- zero source resistance, and the last column is the decay time to below audibility in seconds.

5 ANALYSIS

Several things are apparent from this table. First and foremost, any notion of severe overhang or extended "time amplitude envelopes) resulting from low damping factors simple does not exist. We see, at most, a doubling of decay time (this doubling is true no matter WHAT criteria is selected for decay time). The figure we see here of 70 milliseconds is well over an order of magnitude lower than that suggested by one person, and this represents what I think we all agree is an absolute worst-case scenario of a damping factor of 1.

Secondly, the effects of this loss of damping on system frequency response is non-existent in most cases, and minimal in all but the worst case scenario. If we select a criteria that 0.1 dB is the absolute best in terms of the audibility of such a peak (and this is probably overly optimistic by at least a factor of 2 to 5), then the data in the table suggests that ANY damping factor over 10 is going to result in inaudible differences between such a damping factor and one equal to infinity. It's highly doubtful that a response peak of 1/3 dB is going to be identifiable reliably, thus extending the limit another factor of two lower to a damping factor of 5.

Further, we simply do not observe the "factor-of-four" increase in energy dissipation with a factor of two reduction in source resistance as claimed in [2]. The statement that it's all about energy dissipation is quite correct: remember that what damping is doing is removing energy from a resonant system, and that the measure of damping is Q, the ratio of energy stored to energy dissipated. Look, for example, at the difference in Qt between a damping factor of 50 and 20: the actual difference in the energy dissipated is less than 3%. According to the theory expounded in [2], the difference in energy dissipation should be around a factor of 6!

All this is well and good, but the argument suggesting that these minute changes may be audible suffers from even more fatal flaws. The differences that we see in Q figures up to the point where the damping factor is less than 10 are far less than the variations seen in normal driver-to-driver parameters in single-lot productions. Even those manufacturers who deliberately sort and match drivers are not likely to match a Qt figure to better than 5%, and those numbers will swamp any differences in damping factor greater than 20.

It is well known that the performance of drivers and systems is dependent upon temperature, humidity and barometric pressure, and those environmental variables will introduce performance changes on the order of those presented by damping factors of 20 or less. And we have completely ignored the effects presented by the crossover and lead resistances, which will be a constant in any of these figures, and further diminish the effects of non-zero source resistance.

6 CONCLUSIONS

There may be audible differences that are caused by non-zero source resistance. However, this analysis and any mode of measurement and listening demonstrates conclusively that it is not due to the changes in damping the motion of the cone at the point where it's at

it's most uncontrolled: system resonances. We have not looked at the frequency-dependent attenuative effects of the source resistance, but that's not what the strident claims are about.

Rather, the people advocating the importance of high damping factors must look elsewhere for a culprit: motion control at resonance simply fails utterly to explain the claimed differences.

7 REFERENCES

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