What happens when the Damping Factor of an Audio-Amplifier is changed?

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This study researches the influence of the damping factor of an audio amplifier on the 'quality' of sound reproduction. Large changes are noticed and their causes and consequences are described and measured in detail.

Introduction

Repeatedly I observed that low damping factor valve amplifiers sound 'better' than high damping factor transistor amps. Why this is the case? It became clear that the observed differences are not an issue of 'valves versus transistors'. A transistor amp can sound 'better' when its damping factor is adjusted.

'It sounds better' is a very subjective observation. In this research I will bring observations from the subjective to the objective domain. Valves versus transistors will not be dealt with. The only focus is at the influence of the damping factor (DF) on the perceived sound quality and its explanation.

The research is organized as follows:

Chapter one describes research-amplifiers with adjustable DF.
Chapter two researches how the output voltage of an amplifier is influenced by its DF.
Chapter three discusses the transfer from amplifiers input voltage to perceived sound pressure levels.
Chapter four studies the amplifiers output current through the speakers voice coil.
Chapter five studies the acoustical distortions under different DF conditions.
Chapter six describes a controlled 'subjective' test where voltage drive (high DF) and current drive (low DF) are compared.
Chapters seven and eight give conclusions about 'sound quality' in relation to the DF of the applied audio amplifier.

1 : Research Amplifiers with adjustable DF

I designed several methods to change the DF of an amplifier. I applied the Hypex Ncore 122mp 2 x 120 W class-D amplifier.

1-a : Series Resistor

in series with the amplifiers output an extra resistor R-series is placed. The actual output impedance is enlarged by this series resistor: Zout = Zout-122mp + R-series.

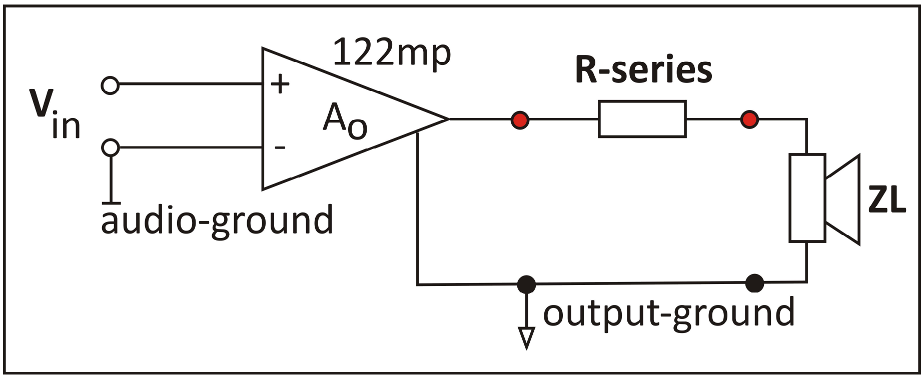


Figure 1: Zout is enlarged by R-series

The DF is given by DF = ZL(f) / Zout where ZL(f) is the impedance of the applied loudspeaker. Mostly one takes for ZL(f) a pure resistive load, say 4 or 8 Ohms. We can write: DF_4 = 4 / Zout or DF_8 = 8 / Zout.

For the rest of this research I shall not use the DF, but refer directly to the effective Zout. Then the choice of ZL(f) and its dependency of the frequency becomes arbitrary.

1-b : External Active Variable Zout circuit

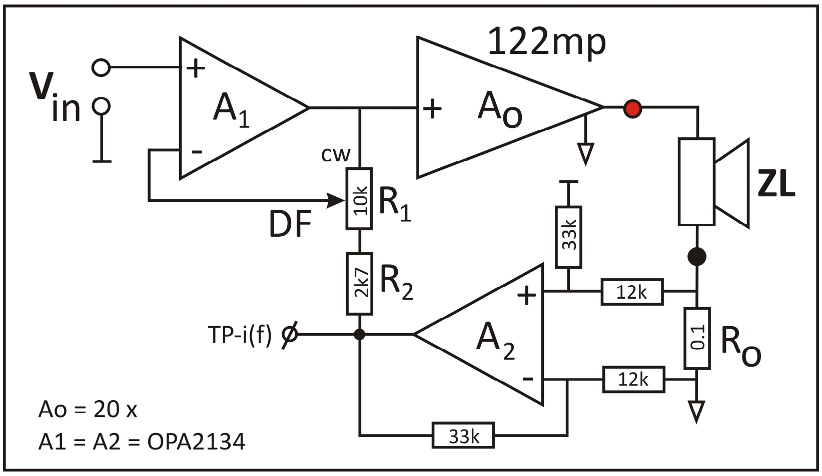


Figure 2: Active circuit around Nc-122mp creates adjustable Zout.

In figure-2 the loudspeaker is connected to ground via a small resistor R_0 (use a 5 Watt type). The current through the loudspeaker generates a voltage over R_0. This voltage is amplified (A_2) and added inverted to the input amp A_1, which output is fed to the input of the Nc-122mp amp. Nothing is changed inside this class-D amp.

With the components shown, the actual output impedance of the complete circuit can be changed from 0.1 Ω to 18 Ω. Make R_2 smaller for a larger Zout-value, but watch stability!
I used a differential amp A_2 over R_0 to deal well with grounding-differences (audio-ground is unequal output-ground).

For correct functioning of this circuit in the frequency domain, drastic measures are taken to ensure stability, to correct for phase shift, because the Nc-122mp behaves as a 2-nd order low-pass. These measures are not drawn in the circuit. I have found a stable solution, still open for further optimization, but this remains outside the research.

Equation-3 shows the condition for constant Vout, independent of the wiper position of pot R_1. I designed for ZL(f) = 5 Ω at 320 Hz. Adapt A_2 for any other loudspeaker.

$$\text{Equation 3:} \quad A_2 = (ZL + R_0) / (A_0 \cdot R_0)$$

1-c : Add series resistor and change the FB-circuit inside an amplifier

When you have access to the feedback-circuit of an amplifier, without destroying the amp or killing its stability, you can use the next circuit.

I do not further discuss or use this solution that I designed in 1974. It works great, and the principle is: the weakening of amplification, caused by the current feedback, is compensated by enlarging the effective amplification of the amplifier, by changing its feedback ratio.

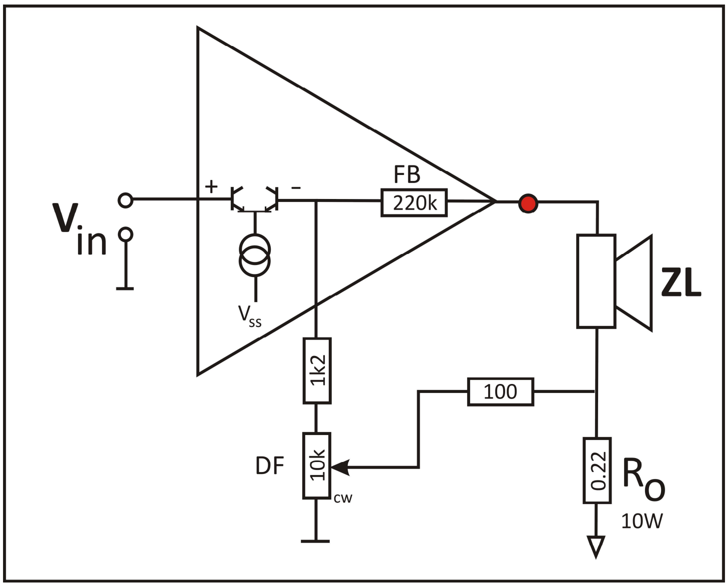


Figure 4: Zout change combined with FB-change,
resulting in constant Vout, independent of the DF-wiper-position.

2: ZL(f) creates a non-constant and more distorted Vout(f) for Zout > 0

I measured the output impedance and phase (circuit 1-b) for Zout(f) = 18 Ω. At highest frequencies some decline is noticeable, caused by the not yet optimal frequency corrections as mentioned in chapter 1-b. Also the electrical phase is shown. The measurements up to 20 kHz for Zout = 0,1 and Zout = 2 Ω just show straight lines.

This is the first indication that methods 1-a and 1-b behave almost equal, while method 1-b creates negligible power loss, and is therefore favored by me.

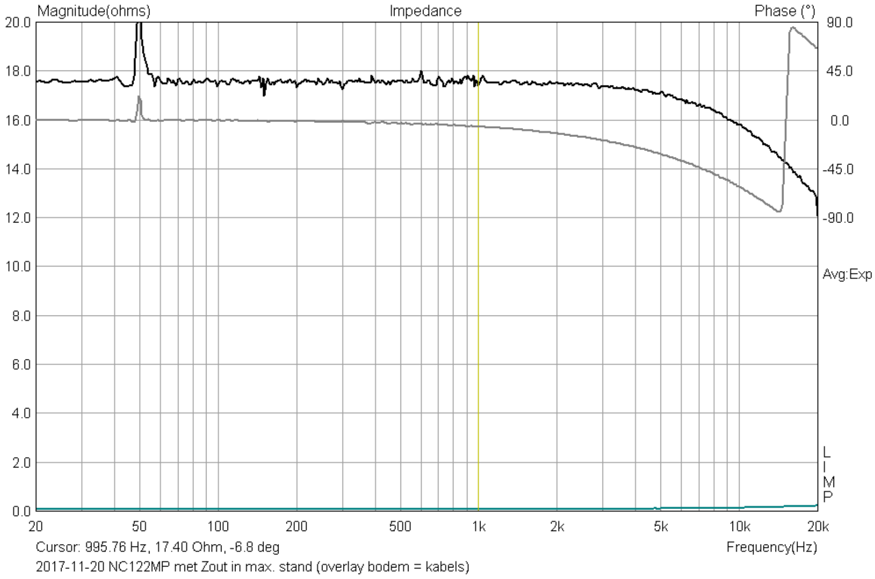


Figure 5: Zout(f) of circuit 1-b for the Zout = 18 Ohm setting.
The electrical phase is shown by the light-grey curve (right hand scale).

The impedance of my test loudspeaker as function of frequency is shown below. The upper curve is its electrical phase.

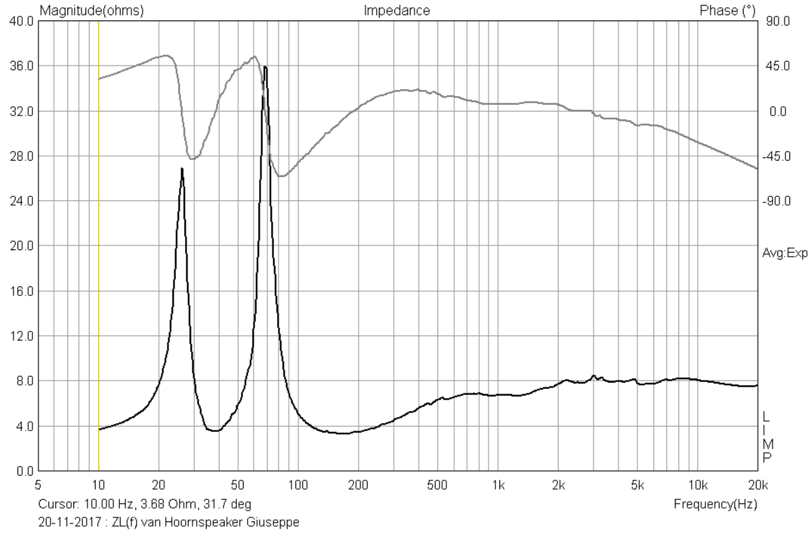


Figure 6: Electrical impedance and phase of the applied test loudspeaker

The next measurement shows Vout (over the loudspeaker) divided by Vin (amp input voltage) expressed in dBV/V = [20log(Vout/Vin)] for three different values of Zout: 0,1 and 2 and 18 Ω.

For Zout = 18 Ω (red curve) above 20 kHz, some deviation is visible. See my earlier remark in chapter 1 about the not yet optimal frequency correction.

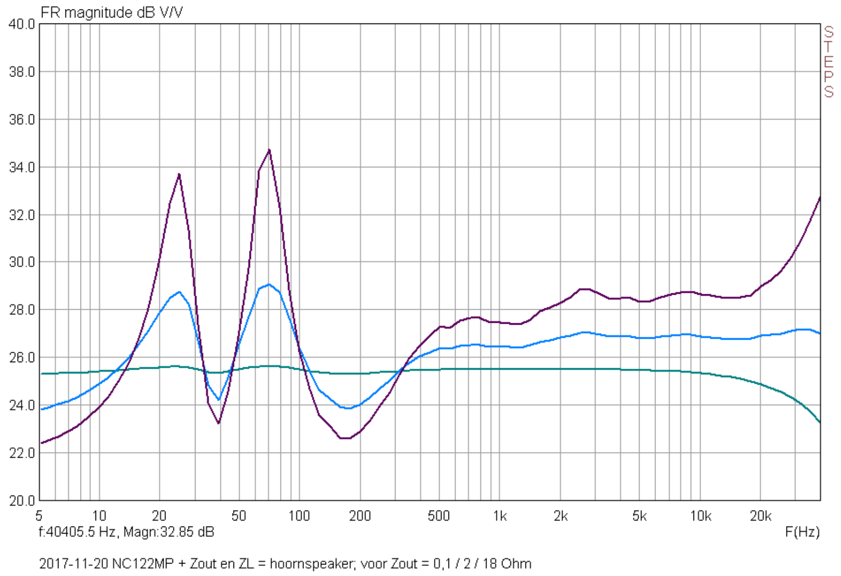


Figure 7: Effective amplification for Zout = 0,1 (green) and 2 (blue) and 18 (red) Ω.

These results are fully described by $A = A_0 \cdot ZL(f) / (Zout + ZL(f))$. I repeated this measurement with circuit 1-a and got exactly the same results. Again the equality of methods 1-a and 1-b is underlined.

Before delving into the huge consequences of this measurement, I also checked what happens with the voltage distortion. The current through the loudspeaker is a complex current, in which resonances and so called “back-emf” effects occur. The actual voltage over the speaker terminals is not only determined by the voltage amplification of the amplifier, but also by the changed current through the loudspeaker.

The next measurements show the distortion of the voltage over the speaker (at +6dBV level at 320 Hz) for Zout = 0,1 and 18 Ω. Circuits 1-a and 1-b gave the same results.

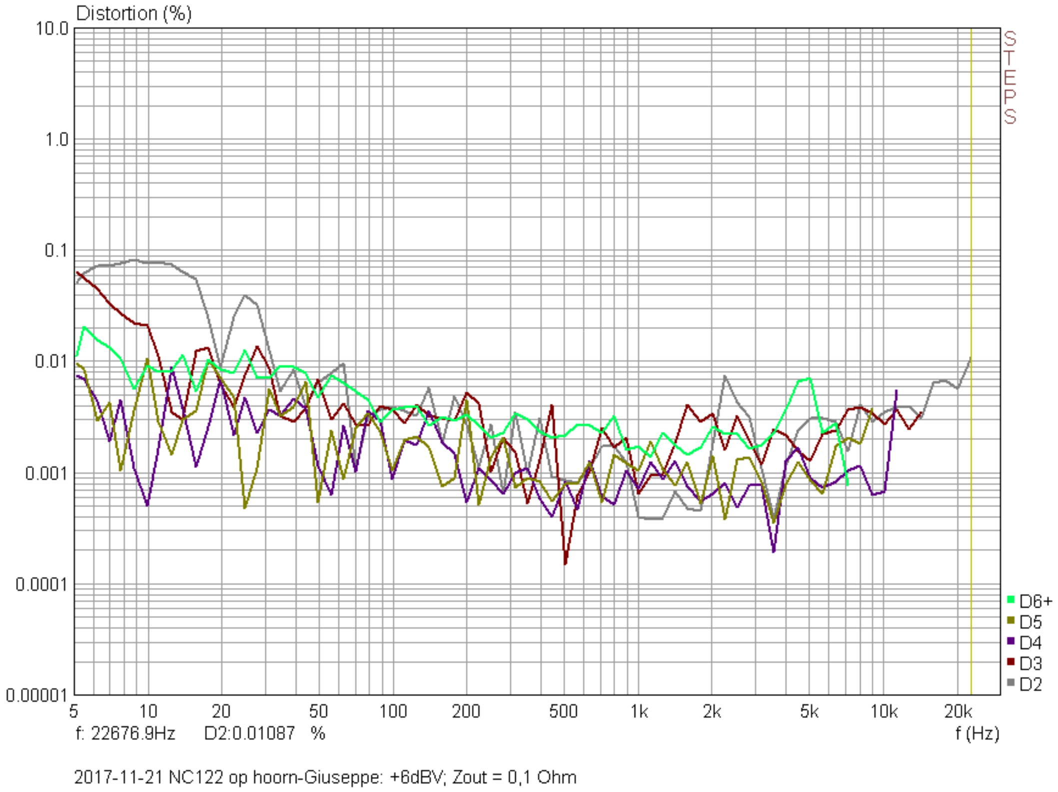


Figure 8: Vout distortion for Zout = 0,1 Ω

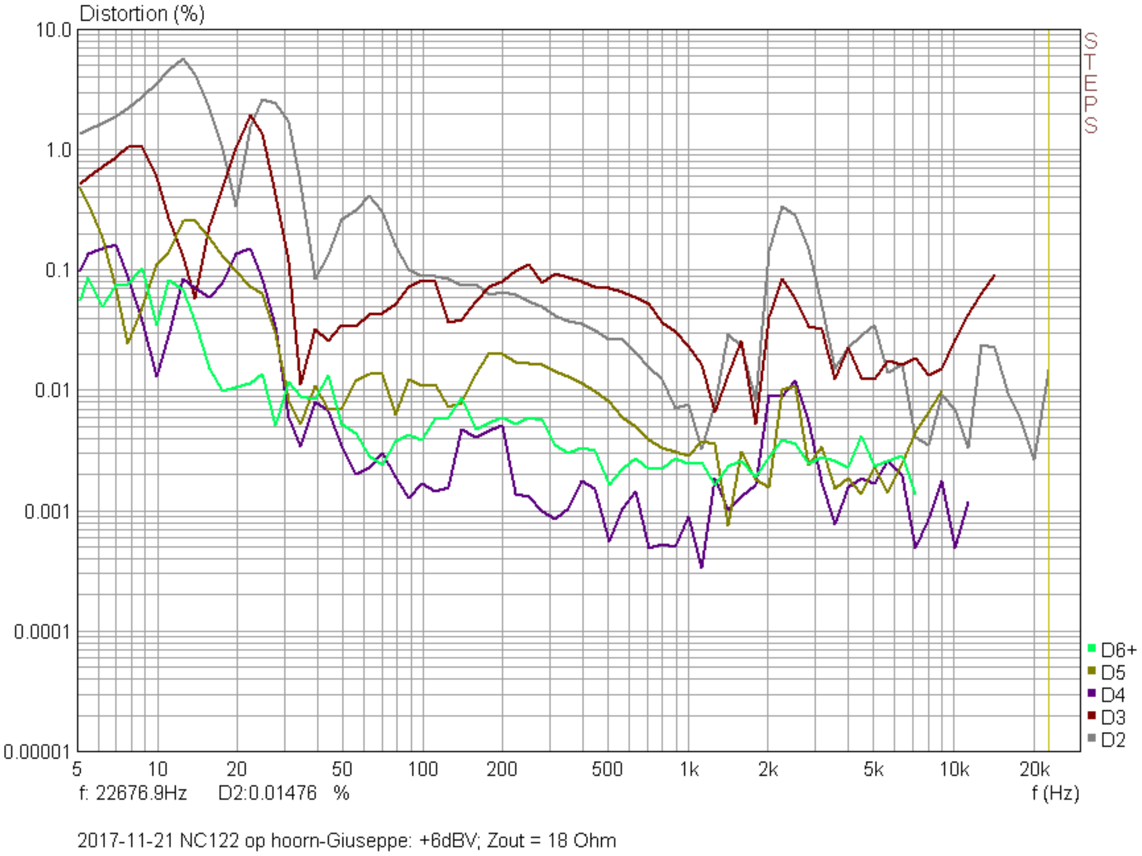


Figure 9: Vout distortion for Zout = 18 Ω

It is interesting to check the distortion resonance frequencies for Harmonic-2 and Harmonic-3 and to compare them with the resonance frequencies of the loudspeaker impedance (figure 6). Counting “1”, “2”, “3” helps a lot. Around 2,5 kHz a resonance in the mid-horn section is visible. With music I had not yet detected this by ear. Using a swept sine wave made it noticeable.

Let me draw some initial conclusions:

Conclusion-1:
Changing Zout can equally be done with circuits 1-a and 1-b. These circuits behave equal, except for the larger power loss in circuit 1-a. Phase effects are not yet studied.

Conclusion-2:
Raising Zout creates a Vout(f) over the speaker terminals which follows the ZL(f) characteristics.

Conclusion-3:
Raising Zout introduces distortions in Vout(f) if ZL(f) is a standard loudspeaker which impedance is not corrected (see acknowledgement ‘Hans’ for more details).

With these results, one might say: “Transistor amps with infinitive damping are ideal, because they give constant Vout with no voltage distortion”. But why do such ideal amps often sound flat, no musicality, no enveloping, ….”? I need some more research to answer this repeated observation.

3: Measurements in the Acoustical domain

Up till now all measurements were in the electrical domain. Now I go acoustical by means of a mike and measure the resulting sound pressure levels.

In the electrical domain I already have measured the difference in transfers between the Zout=18 and the Zout=0,1 situations. See the figure below, compare to figure 7:

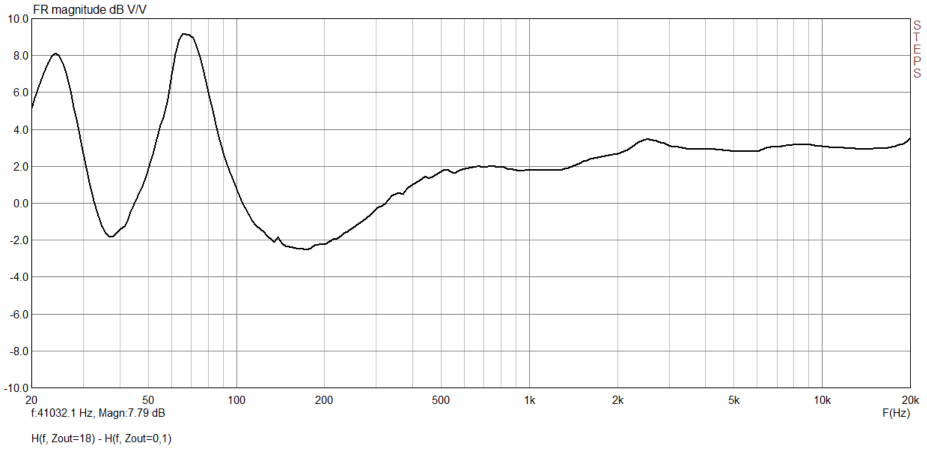


Figure 10: difference in electrical transfer between Zout=18 and Zout=0,1

In the acoustic domain I measured the transfers for Zout=18 and Zout=0,1 and determined their difference. See figure 11.

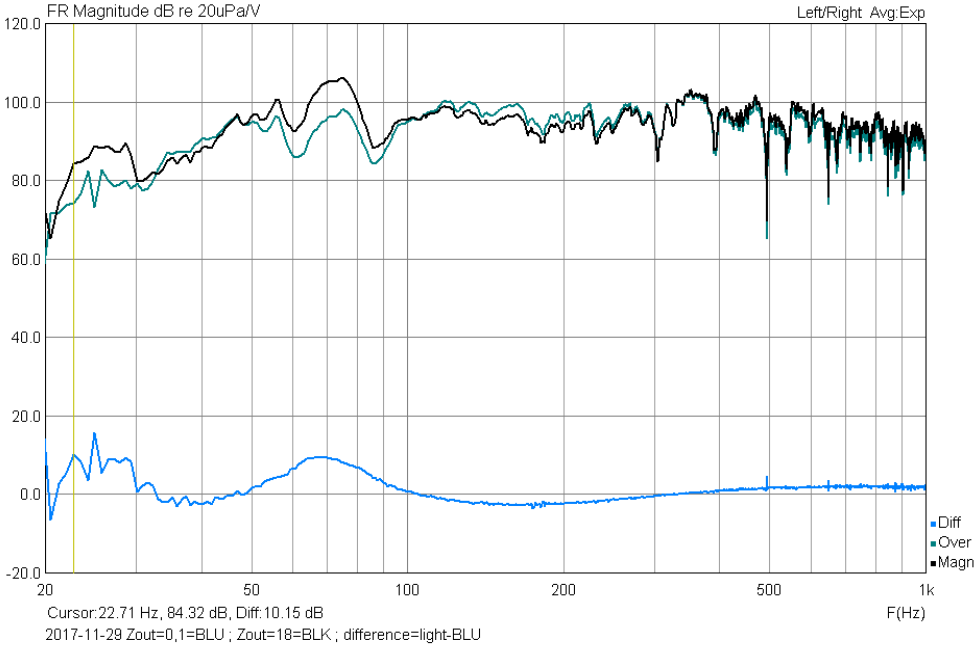


Figure 11: Acoustical transfers for Zout=18 (black) and Zout=0,1 (green) and their difference (blue bottom curve)

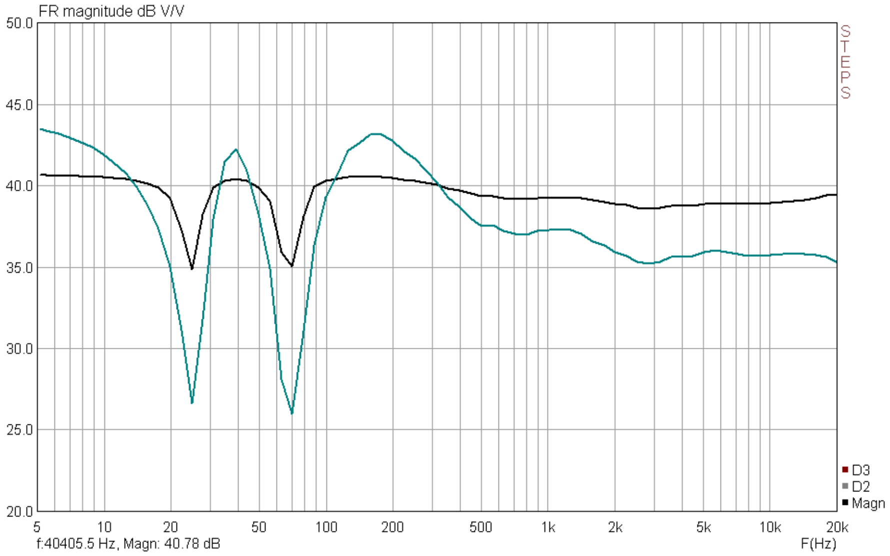
One clearly can see that the acoustical transfer-difference follows the electrical one (compare to figure 10).

Conclusion-4:
The electrical and acoustical transfers show the same behavior with respect to Zout.

4 : ZL(f) creates a more constant and less distorted current i(f) for Zout > 0

'Rob' (see acknowledgement) pointed out that also the current through the loudspeaker should be studied. What actually drives the loudspeaker cone is the magnetic force F=B·i·l which directly generates the acoustical sound pressure P_{spl}. Here F is the magnetic driving force to the cone, B = the effective flux density in the voice coil gap, i = the current through the voice coil and l = the effective length of the voice coil wire that sees B. So, at first sight, it is only the current through the voice coil that generates the 'music'.

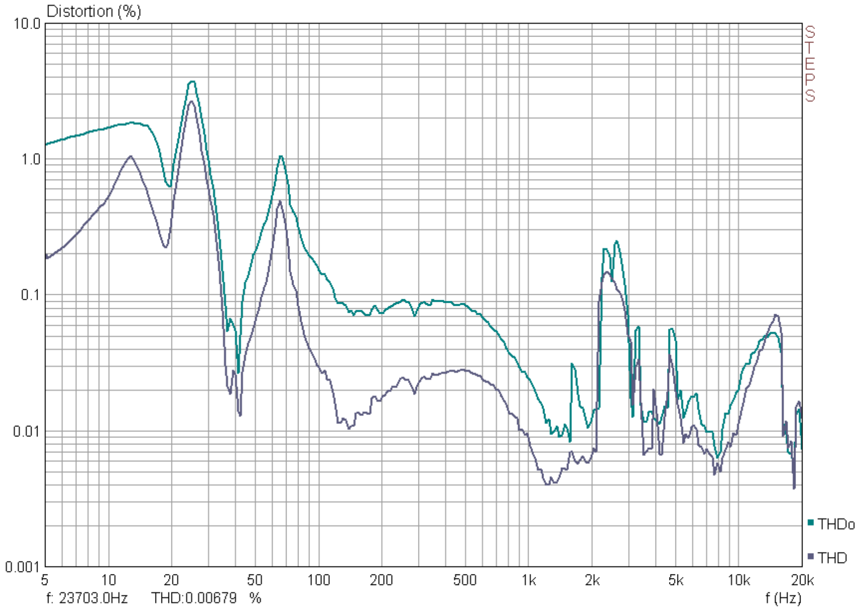
See figure 12 for the currents through the voice coil, measured at the output of A2 (see figure 2) for Zout = 0,1 and 18 Ω.



2017-12-22: I(ZL,f) for Vout=+6dBV; measured at output A2; Zout=18(BLK); Zout=0,1(BLU)

Figure 12: Current through the voice coil for Zout is 0,1 (blue) and 18 (black).
Vertical scale conversion factor: 48 dBV/V = 1 A_{rms} through the voice coil at 320 Hz.

Indeed, if Zout raises in value, the current stays more constant. This is as expected and fully described by A = Vout/Vin = A0·ZL(f) / (Zout + ZL(f) with i(f) = Vout / ZL(f).



2017-12-23: I(ZL,f) for Vout=+6dBV; measured at output A2; Zout=18(PUR); Zout=0,1(BLU)

Figure 13: Total Harmonic Distortion of the current i(f) through the voice coil for Zout=18 (grey) and Zout=0,1 (blue).

Figure 13 shows that he current gets less distorted when Zout raises. This means that the raise in voltage distortion (as measured in chapter 2) is a logical consequence to make i(f) less distorted. Again this is a direct result of applying current feedback.

Conclusion-5 :
Enlarging Zout reduces the harmonic distortion in the current through the voice coil.

5 : Distortions in the Acoustical Domain

In chapter 3 the Zout-effect on Vout was researched with the acoustical transfer. In this chapter I investigate the i(f)-effects by measuring the acoustical distortion with an omni pressure microphone.

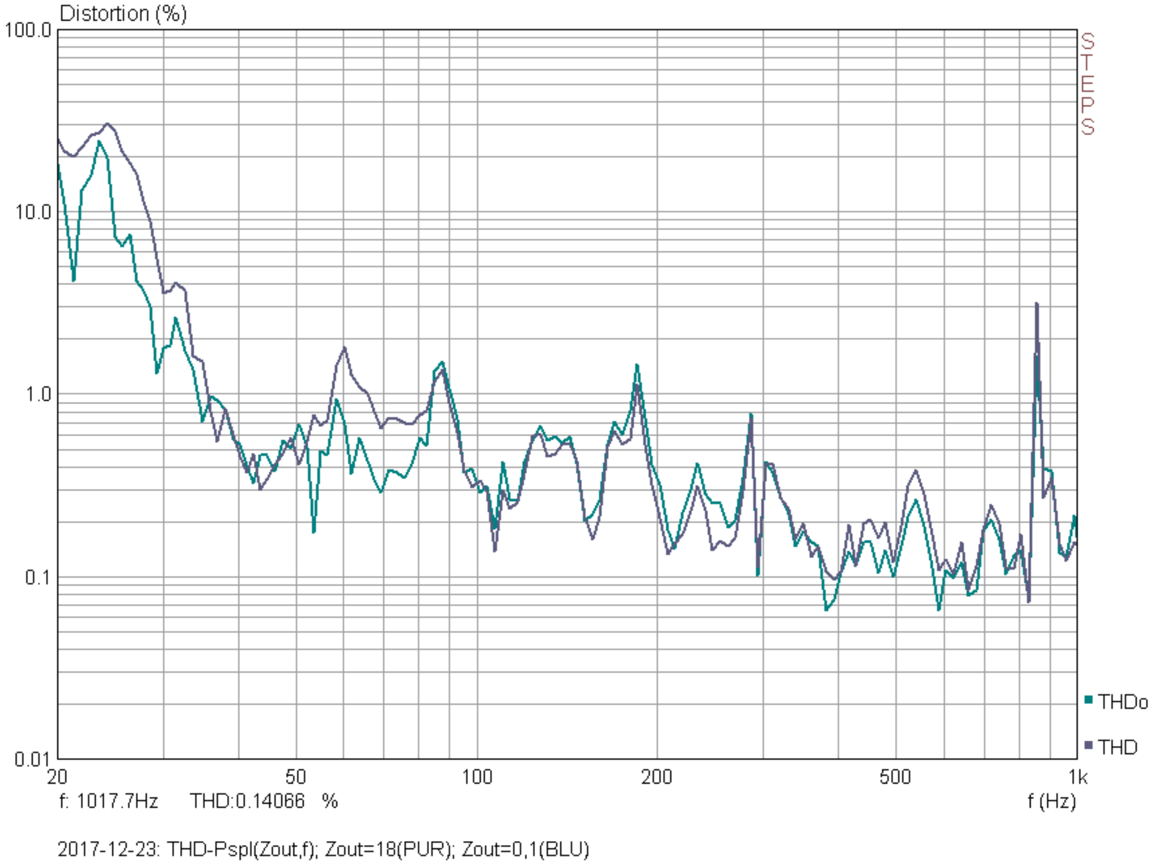


Figure 14: THD of the acoustical P_{spl} for Zout=0.1 (blue) and 18 (grey).

This result is unexpected. If the current drives the voice coil, and if this current is less distorted for Zout=18, then P_{spl} should be less distorted as well, which is not the case.

This measurement clearly shows that other distortions in the loudspeaker or environment surpass the electrical distortion (see figure 13). Reflections and room resonances are visible. With my gated-mike-swept-sine measurement I can't improve any further.

Therefore I compared my measurements with the results of 'Rob' (see acknowledgements). He applied an accelerometer mounted on the cone of a woofer for voltage drive (blue, Zout=0) or current drive (red, Zout>100).

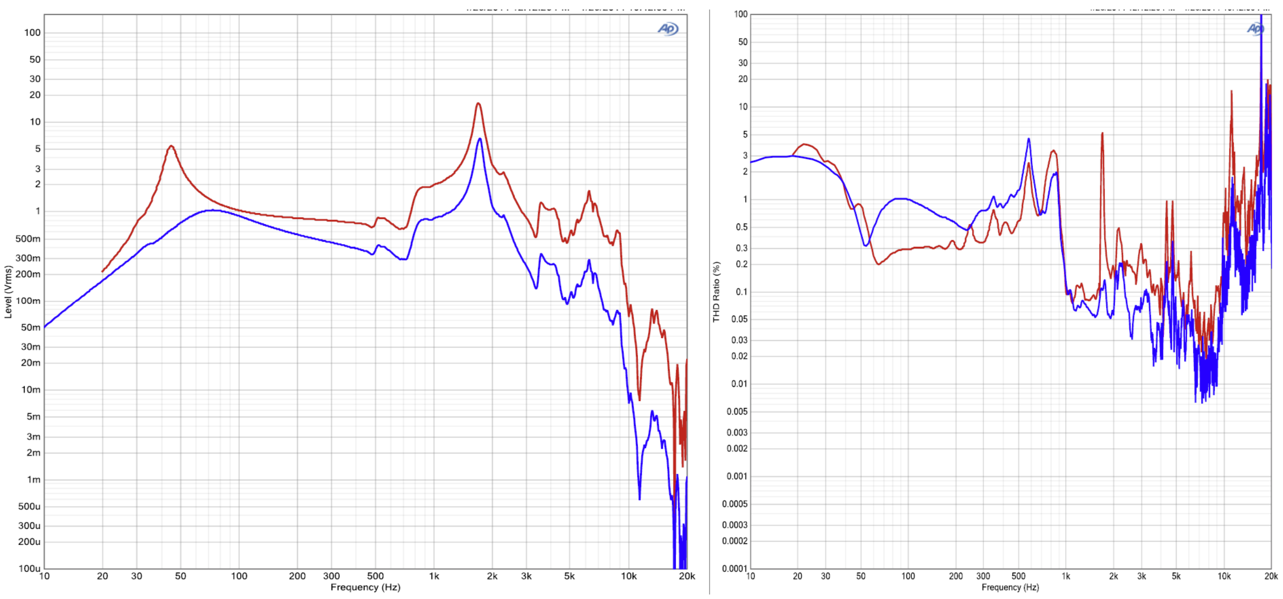


Figure 15: Source: http://rmsacoustics.nl/activecontrol.html
blue = voltage amplifier; red = current amplifier.
Output taken with an accelerometer mounted on a woofer cone.

Reflections and disturbances have less influence in measurement 15. From 50 Hz to 500 Hz the acoustical distortion (right figure) is less with large Zout amps.

One might argue that I can't hear under the distortion level as measured in figure 14. I doubt such line of reasoning. First, my ears do not function as a gated-swept-sine-measurement. Secondly, with my loudspeakers, I can distinguish clearly if an amplifier distorts 0.3 %THD or 0.03 %THD. II even am able to notice if in 0.03 %THD the second or third harmonic is dominant. My ear is far more better than the measurement method applied in figure 14. So, I am fully confident to use the measurement results of 'Rob' and to consider them as reliable.

Conclusion-6 :
Current drive (Zout is large) gives less acoustical distortion compared to voltage drive (Zout is small). The frequency region where this is the case is speaker dependent. In my research the sound between 100 Hz and 2 kHz gets less distorted.

6: Lets go Subjective

Two subjective test are described. First: how does the sound character change for Zout = 18 compared to Zout = 0,1 Ω. Secondly: if we change a reproduced recording with the electrical voltage (Zout=18 / 0,1) difference curve, are we then able to notice any difference?

6-1: Differences in Sound Character.

I took a piece of music of Eva Cassidy and listened to it under the Zout=18 and Zout=0,1 conditions at equal loudness (at 320 Hz). Compared to the Zout=0,1 situation the sound character of the Zout=18 was:

a) More brightness
b) More deep base
c) More mechanical vibrations of my lab-table
d) More sense of being enveloped
e) More details noticeable

Let’s be honest: observations a) and b) are totally determined by the changed voltage transfer function. Electrically there is more voltage at higher frequencies and also around the low frequency speaker resonances. These observations are totally understandable.

Observation c) deals with the lowest resonance frequency (around 25 Hz) which I do not hear, but sense as table vibrations. With Zout=18 there is more Vout and therefore this region is reproduced louder, creating more table vibrations.

Observation d) en e): Might it be true that I happen to like more base and brightness and that I express that by ‘envelopment’ and ‘details’? I will deal with this assumption and more in the next sections.

6-2: Recording corrected with the electrical voltage-transfer-difference curve

The next test was a little more difficult to do. I took the Eva Cassidy recording and multiplied it with the electrical voltage transfer difference between Zout=18 and Zout=0,1 (figure 10).

I listened to this changed recording with the amplifier in the Zout=0,1 setting (changed-Eva-Zout=0,1).

Following I listened to the unchanged recording with the amp in Zout=18 setting (unchanged-Eva-Zout=18) and compared many times with the (changed-Eva-Zout=0,1) reproduction.

I made the following observations:

a) Equal brightness
b) Equal base
c) The low-mid part is more ‘natural/honest/open’ in unchanged-Eva-Zout=18

Observations a) and b) are explainable in the electrical domain. Observation c) is more hidden. In the next chapter I will discuss it.

7 : Discussions

As said: observations a) and b) can be explained with the now compensated voltage changes. In my opinion there is no need for further discussion. That is the part we all fully understand. I might like more high and base, but in this last test these levels are equal. So my possible preference is pushed aside.

Let us now focus on observation c). By multiplying “Eva” with the electrical difference transfer, the result is a little larger Vout. Because the Nc-mp122 amplifier is extremely clean, negligible extra voltage distortion is introduced. Therefore the reproduction with Zout=0,1 does not contain extra Vout distortion. With Zout=18, the previous chapter has shown that the acoustical distortion is less between 100 Hz and 2 kHz. Meaning: the two test situations of chapter 6 have different acoustical distortion artifacts. Situation unchanged-Eva-Zout=18 is the cleanest in the “low-mid”-region, which I clearly observed.

8 : Conclusions

This research has shown that raising the output impedance of an amplifier, generates changes in the electrical transfer, based on the frequency dependence of the impedance of the applied loudspeaker. The changed transfer function in the electrical domain almost equally appears in the acoustical domain. With infinitive damping (Zout = 0 Ohm) the amplifiers output voltage is only distorted by the amplifier itself. With Zout > 0, the current feedback generates extra distortions in the voltage over the loudspeaker. However, when we consider the current through the loudspeaker, this current gets less distorted for Zout > 0. Because, in first approximation, it is the current that moves the loudspeaker cone. The acoustical distortion of the speaker gets less for Zout > 0. In such a situation the acoustical reproduction is cleaner and this explains why it is preferred by the author.

9 : Acknowledgement

I got much support from the persons mentioned following. I thank all deeply for taking the time to study my attempts to find answers and to give excellent advises.
Rob Munnig Schmidt (RMSacoustics.nl); Guido Tent (Tentlabs.com and GrimmAudio.com); Hans van Maanen (TemporalCoherence.nl); Jan Didden (LinearAudio.net); Ari Polisois (polisois-audio.com); Pierre Touzelet (see AudioXpress.com and LinearAudio.net); Joe Rasmussen (custumanalogue.com).

10 : Literature

See the websites indicated in the Acknowledgement to find many high quality references.

2017-12-31

The Netherlands; Hichtum; Menno van der Veen ; www.mennovanderveen.nl