Correcting transducer response with an inverse resonance filter
Steven van Raalte

Marcel van de Gevel writes:

Dear Editor,

I read Steven van Raalte's article "*Correcting transducer response with an inverse resonance filter*" in Linear Audio Volume 3 with great interest. In the article he explains how to vastly improve the transient response of moving-magnet cartridges with a correction filter.

One detail that worries me a bit is his assumption of a frequency-independent effective series resistance of the cartridge. In the mid-1990's, my former colleague Richard Visée measured the impedance of a Shure V15 III cartridge using an HP4194A impedance/gain and phase analyser and found that the phase angle did not exceed 72 degrees at any frequency.
The effective series resistance calculated from his results increased from 1.3388 kohm to 30.1 kohm over the audio band. That is, the losses in the cartridge itself contribute more to damping of the electrical resonance than you would think based on the DC resistance.

When you underestimate the damping of the electrical resonance of the cartridge and load, you also underestimate the quality factor of the mechanical resonance of the stylus and magnet. As the effectiveness of the correction circuit depends on how accurately you can put the zeroes of the correction filter on top of the poles of the mechanical resonance, this will cause unnecessary performance loss. Presumably you will get a small residual high-Q ringing that is still smaller than with a conventional circuit, but not as small as it could be.

A solution could be to try to measure the electrical transfer directly.
You could take a signal generator (if necessary with a resistive voltage divider to lower its output impedance) and connect this to one terminal of the cartridge. Then load the other terminal with the specified load impedance and measure the transfer. In theory, the mechanical resonance will affect the measured result because the electrical current will make the stylus vibrate, which will induce a voltage. This effect appears to be small though; it should also have affected Richard's impedance measurements but it isn't visible in his graphs.

Marcel van de Gevel
Haarlem, The Netherlands

Steven van Raalte replies:

Dear Marcel, thank you very much for sharing this observation of your former colleague Richard Visée. This was new to me; I wasn't aware of the oversimplification of the electrical model of the phono cartridge that I had used back in 1981. But after reading your letter to the editor, I searched the internet for information on these cartridge losses. I quickly found confirmation of these losses and also some directions on how to incorporate these losses in the cartridge model.

In [1] Rod Elliott shows a basic electrical model of a cartridge that consists of an inductance in series with its (DC) resistance, like I had used, but now the inductance is split in two parts with one part damped by a resistor to simulate the semi-inductance of the cartridge. I assume this is in line with your observations. In his article Rod also shows a similar measurement setup as proposed by you to measure and estimate the electrical cartridge parameters. And already in 1975, Björn Hallgren presented an enhanced electrical model of the cartridge using a frequency dependent resistor in parallel with the full (!) inductance [2] to represent the losses. The losses are dependent on the magnetic material and the construction of the cartridge. For instance, US Pat. 4,140,886 shows a cartridge construction to minimize the eddy current losses to extend the usable frequency range [3]. Apparently, some cartridges are less affected by eddy current losses than others, maybe even to such a low level that the effect of these losses can safely be neglected. For other cartridges these eddies are a real issue.

In hindsight, the 930 mH inductance of the Stanton 681 EEE MK III must have been measured with a relatively low test frequency, to minimize these losses. A further search confirmed this and revealed that this value is specified at 10 Hz [4], which is not mentioned in the current manufacturer's datasheet.

But now the question is in what way these eddy current losses can be taken into account and how this phenomenon affects the possibility to compensate for resonances. You are quite right that by taking the additional damping into consideration, a lower Q-factor for the mechanical resonance is needed to obtain a reasonably flat frequency response. Consequently the inverse resonance filter should have a lower Q too.

I have simulated these losses by adding a damping resistance across a part of the cartridge inductance. As I don't have a real Stanton 681 EEE MK III cartridge at hand to measure and determine its parameters, I just took the resistance value from [2] for R_{loss} and divided the original coil inductance into a 2/3 part and a 1/3 part, with the resistance across the bigger part. It is unlikely that this 68 kΩ is exactly the correct value, but at least its influence can be studied. Upon entering these parts in Circuit Maker 2000, however, I noticed some errors in the resistor values of the inverse resonance filter of my original article. I suppose I have been investigating different resistor values and have accidentally copied the values of the last simulation into the final circuit diagram for publication. Because the simulation results of the published circuit are almost identical to the results of the correct circuit, I didn't notice my mistake. Anyway, I will use this opportunity to show the corrected circuit first, followed by a version of the new setup in which the eddy current losses are modeled.

Figure 1 is what figure 11 of the original article should have been. The resistor values of the inverse resonance filter now follow the normalized values of the original figure 4 exactly. It compensates for the mechanical resonance with a resonance frequency f_0 = 21.5 kHz and Q = 4.12.