Letters to the editor

Dear Editor,

I read with considerable interest the article by Bruno Putzeys in Linear Audio Vol 1, "The F- word - or, why there is no such thing as too much feedback".

In his excellent article, Bruno explains that increasing the amount of feedback might cause problems for the higher harmonic distortion components. He uses earlier work of Baxandall, who did his measurements on the non-linearity of a semiconductor device inside a feedback loop, while the amount of feedback was increased. Bruno uses in his figure 14 a square law non-linearity as example. I've been wondering for some time whether this kind of non-linearity is found in amplifiers using valves, which obey the Child-Langmuier-Compton equation. In 2010 I performed measurements on my SPT70 valve amplifier(1) and the results are shown in Figure 1. The amount of feedback is given by $20 \cdot \log(Anfb/Ao)$ on the horizontal axis, where Anfb and Ao are the gain of the amplifier with nfb and open loop, respectively, with a 4 Ohm dummy load. This differs from the way it is presented by Bruno's figure, but is the same as Baxandall's representation.

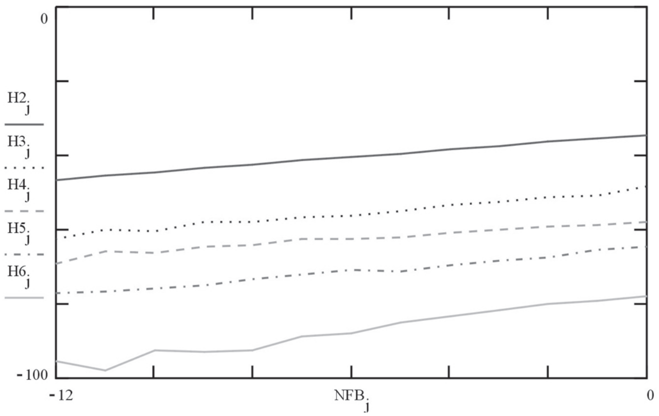

Figure 1: Distortion in SPT70 as function of the amount of feedback. The harmonic components are (top to bottom): 2, 3, 4, 5, 6 and are measured at 1kHz with 0 dB = 10Vrms in a 4 Ohm load.

My hesitation to accept Baxandall's and Bruno's approach seems to be right and the consequences are of importance. In my specific valve amplifier all harmonic levels decrease when the feedback is increased. Subjectively this is clearly noticeable. More feedback gives cleaner sound with more details (but harms other qualities of the sound reproduction(2)). The consequence is that the type of non-linearity in my valve amplifier is of another nature; not semi conductor (power of 'e') or square-law, but like a power of 1.5. This means that raising feedback in my amp does not create stronger higher order harmonic components.

References:

1 - Menno van der Veen: "High-end Valve Amplifiers 2", chapter 8; Elektor ISBN 978-0-905705-90-3.
2 - Menno van der Veen: "Ontwerpen van Buizenversterkers", chapter 2; Elektor ISBN 978-90-5381-261-7; also available in German, not yet in English.

Menno van der Veen,
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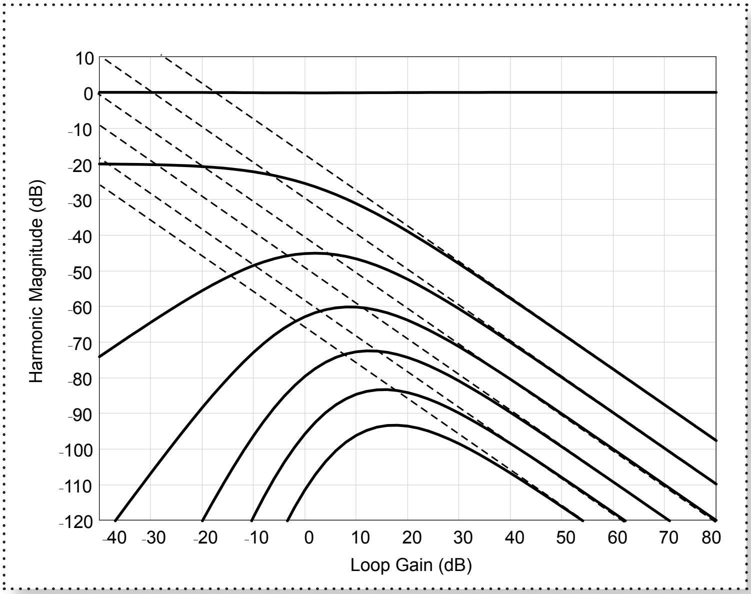
Bruno Putzeys replies:

Dear Menno, I thank you for your comments. I take it your main problem is the idea that moderate amounts of feedback are always worse than either lots of it or none at all. I agree that such a broad-brush conclusion would be unwarranted. What matters is that it can happen and certainly has happened to several experimenters, and that this is one of the factors that led to a suspicion of negative feedback. You can see a practical example in http://www.passlabs.com/pdfs/articles/distortion_and_feedback.pdf (figure 11, page 10). It is clear that this circuit will not appreciably improve unless at least 20dB of loop gain is deployed.

One does suspect, however, that that circuit was expressly designed to illustrate a point. Practical amplifiers are more complex, creating a jumble of nonlinearities. Whatever fundamental law underlies one active component is no longer going to be immediately obvious from the behaviour of the circuit.

An early draft of the article contained a paragraph to this effect: *if the open loop distortion spectrum is already sufficiently "rich", newly created harmonics arising from lower order terms might never become significant*. This appears to be the case with your setup. If the variable feedback listening test is performed on such an amplifier, subjective performance would improve from the word 'go'. Your listening result confirms this. This is a further strong argument in favour of using negative feedback, but at the end I felt that mentioning this in the article risked confusing the reader who first had to understand that some crucial "anti-feedback" experiments were made on equipment that did indeed sound worse with moderate loop gains applied.

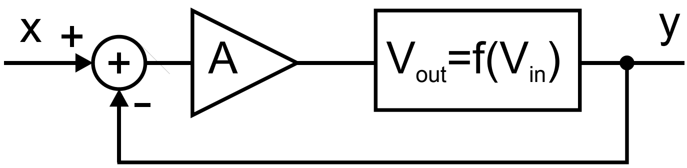
I won't attempt to comment directly on the evolution of the spectrum based on the Child-Langmuir-Compton equation. Partly because as I said, your amplifier is more complex than a single valve so the spectrum is not determined by just this equation, and partly because I wanted to point out an interesting generality which you can then set loose on any kind of non-linear transfer (that is, I'm giving you homework). Observing the Baxandall style plot from the article, we can't help noticing that the relative distribution of harmonics settles down as loop gain increases. The closed loop nonlinearity asymptotically (for large values of loop gain) approaches a new function that isn't the original nonlinearity.



So although we already figured out that the elementary explanation of feedback reducing the harmonics of the forward nonlinearity by a factor equal to loop gain was a bit oversimplified, we see something else looming on the horizon: another function whose harmonics are indeed being reduced by loop gain. That would be great, because it would make it easier to predict the spectrum of amplifiers with frequency dependent loop gain (i.e. all of them).

So what function is it?

Take the model presented in the article, but now put in any function:



Writing this down we get:

$$y = f\left(A \cdot (x - y)\right)$$

It's not hard to see that for most functions f there's going to be no algebraic solution. That doesn't mean we can't get to see the shape of it. Apply the inverse of f on both sides.

$$f^{-1}(y) = f^{-1}\left(f\left(A \cdot (x - y)\right)\right)$$

or

$$f^{-1}(y) = A \cdot (x - y)$$

Shuffling a bit we get:

$$f^{-1}(y) + A \cdot y = A \cdot x$$

$$\frac{f^{-1}(y)}{A} + y = x \qquad (1)$$

Right. Strictly speaking that brings us no further to a closed form solution for y. But hang on. As A increases, y approaches x. Put on your numeric hat and try to solve the equation by successive approximation. First, rewrite (1) as:

$$y = x - \frac{f^{-1}(y)}{A}$$

And substitute it into itself:

$$\frac{f^{-1}\left(x - \frac{f^{-1}(y)}{A}\right)}{A} + y = x \qquad (2)$$

After how many iterations would this procedure converge? Very rapidly if A is large. May I suggest we don't even iterate once? The only error we're making is to neglect the distortion of the distortion.

For large values of A, we may say that:

$$\frac{f^{-1}(x)}{A} + y \approx x$$

Rearranging:

$$y \approx x - \frac{f^{-1}(x)}{A}$$

Conclusion: Negative feedback does not attenuate the harmonics of the open-loop nonlinearity, but of its inverse.