AUDIOPAX

The LM3 Output Stage

About distortion behavior between SE amplifiers and speakers

Eduardo de Lima

Na Overview

The LM3 Output Stage* (LMTHREE = Low Mu Triode with Higher Raw Efficiency Emulator, the precursor of today's PTS Perfect Triode Simulation as implemented in the AUDIOPAX Model 88 monoblocks)

1. Introduction

Power amplifiers are probably the audio components where you may find the largest variety of circuits and technology. Solid state or tubes, push-pull or single ended, triodes, pentodes, fets, bipolar transistors, class A, B, AB or any other letter you can think. Chances are that if you think of a letter you will find the class of amplification that corresponds to it (D, G, H, T...). Someone will always be able to put together the arguments needed to justify the use of any of these techniques. The truth is that each of them will be better for some specific use. Here I will describe the development of a pentode based single ended output stage with some unusual characteristics that make it a different breed of single ended. Depending on how you choose the different parameters in your output transformer you may end up with an amplifier that sounds like a typical SE triode or a typical SE pentode or something else that in some cases may be better them either.

2. 300B Single-Ended Amplifiers

To choose a typical single ended power amplifier for your audio system, up till now, is like jumping into a great adventure... You may get to heaven or get lost in the worst jungles and other terrible places. There are many more uncertainties then if you opt for traditional kind of amplifiers. But the sonic rewards that you may achieve are really too tempting. It is my belief - as can be seen in the articles SE Amplifiers Output Impedance and Why SE Tube Amplifiers? - that the high levels of low order harmonic distortion and the higher output impedance, both characteristics of single ended amplifiers, are two very important reasons why these amplifiers have such a magic sound when playing in some systems. The fact is that typical single ended amplifiers just came with these two characteristics and they cannot be separated at all, at least with the circuits and topologies normally employed.

Another interesting observation is that these amplifiers have their own project rules, as has been proven several times by the words of whoever has designed and built SE amplifiers. To try to reduce the harmonic distortion just does not give us the expected results. More often than not whenever we reduce the distortion readings the sound

gets worst. This is contrary to common sense and, to make things worse, reducing distortion sometimes work, and the sound gets better! ..... Clearly the pattern here is buried a little bit deeper.

There are the single ended amplifiers using the directly heated triode 300B with power output from 7W to about 14W (depending on the circuit and the "version" of the 300B. There are also the even lower power amplifiers using the 2A3s, 45s and some more rare tubes and there are the ones using transmitting tubes like 211 and 845. These last ones will give us anything between 20 and 30 real watts most of the time. But the 300B type of single ended amplifiers was the ones that started the trend and can be considered as the basic amplifier of this type. Almost all manufacturers have a 300B model and it is amazing that almost all of them will sound very good when correctly matched to a loudspeaker. In fact, it is very hard to make a bad sounding 300B amplifier if you have speakers that have high sensitivity and a benign load.

3. A Long and Winding Road

We may believe or not in mystical reasons for the sonic results of our experiments. I prefer to look at some of these explanations as beacons to guide us in trying to find a few of the quantitative relationships that matter in our audio world. We should always remember that physical theories based on mathematics are for describing how things work and to help predict their behavior. Ultimately, they are not intended to say why things work.

Several years ago, after hearing the first single ended I built, totally confused, I decided to try to understand what was going on. It is not hard to see that the high levels of low order distortion and the high output impedance are the obviously different things from a traditional amplifier. But how do they affect the sound? I wanted a way to isolate the effects of each of these different characteristics. I wanted to be able to vary the amount of distortion without varying the output impedance and vice-versa. At the same time I tried to improve my 300B single ended amplifier using some old proven tweaks.

After some time I thought about a circuit to test all my assumptions. In this circuit the 300B output stage has a special transformer with partial cathode coupling (figure 1). This can be considered as local voltage negative feedback. There is also what can be considered as local current negative feedback in the form of an unbypassed resistance in the cathode circuit. Varying the amount of winding and the resistance of the branch we can make the amount of distortion vary and keep the output impedance constant

and vice versa. Describing this I can remember that this whole project, which can be described in such simple words, was very hard. The technical problems to make the transformers, the design of a high excursion distortionless driver circuit and looking at so many different distortion spectra. At least there was also lots of very fun listening but believe me, to take in account all the minute details like connection polarities and matching levels are not really that fun. I have also put a lot of time in the design of essentially resistive input impedance loudspeakers to use in the listening tests. This way the output impedance would not be an issue and I could cross check my findings using my test circuit amplifier. Just like these paths worked very well there were some others that did not work at all and had to be left behind. Well, this whole work started more than six years ago as a part time investigation and has consumed quite a lot of time. But it has been worth it! It has produced not only several designs of unique SE amplifiers but also the two 1997 Glass Audio articles on SE Amplifiers Output Impedance and the Why SE Tube Amplifiers? article. These two articles are a good summary of the theoretical basis for our design work.

During the first years when most of these tests were conducted the 300B were very hard to get. There were only the original 300B, which, because of its cost, was nothing more than a mirage for me, and there were the Cetrons and the Chinese version. Although the Chinese were not bad sounding their reliability, at that time was not very good. You could get some that were very good and from the same supplier a few that would fail very quick. Now this seems much better, as far as 300Bs go and you can get very good 300Bs from several manufacturers.

4. The LM3 Output Stage

Around 1996, looking for a solution to the practical and financial problems of using a 300B and based on my test circuit, I ended up developing what I have called the LM3 output stage. LM3 stands for LMTHREE (Low Mu Triode with Higher Raw Efficiency Emulator) meaning that we have an output stage using pentodes (like EL34 or EL84) or beam power tetrodes (like 6L6 and 6550) connected to a special transformer. This arrangement can mimic very reasonably a Low Mu Triode tube like a 300B in terms of gain, output impedance, power and distortion levels with a higher efficiency than a triode making fewer demands on the required power supply.

The conventional triode connected pentode scheme is to hook together the screen to the plate. This connection makes the original pentode work very much as a triode. Each pentode when connected this way will have a totally different behavior that is

much more characteristic of a triode in just about all aspects, including its power efficiency. Also, the triode that we obtain has its own fixed characteristics, which we cannot alter. For example, a KT88 when triode connected will behave very close to a 300B in equivalent plate resistance and power efficiency with a little more gain and higher distortion levels.

The connection that has been called Enhanced Triode Mode uses the grids of a pentode in an unconventional manner. The final result usually behaves as a triode with lower levels of distortion but with a much, much higher equivalent plate resistance, which means naturally much higher output impedance.

Using the distributed load connection, normally called ultralinear, we can, depending on the amount of screen coupling get the tube to behave in a continuum being anything in between a pure pentode to a pure triode. The really big advantage of this connection was that at some point we could have a behavior almost as good as all the good things of a triode and of a pentode. This is just an approximation. To give an idea, a KT88 as a pentode will have a plate resistance of around 11000 ohms, in triode around 650 ohms and in the typical ultralinear connection an equivalent plate resistance of around 2000 ohms (Of course the biasing also affects these values but we are trying to quote an average value). In single ended amplifiers this difference between 650 ohms and 2000 ohms plate resistance changes totally how our amplifier will sound. If we try to change the connection to get a much lower than 2000 ohms equivalent plate resistance we will end up with the basic triode connected KT88.

And we still have what has been called the partial cathode coupling, just like it was used in the old Quad II in push-pull. This is a very powerful tool that allows us to reduce considerably the apparent plate resistance (or the output impedance) and the distortion levels while keeping the power efficiency as high as the pentode. But the amount of coupling we need to get any desired distortion behavior will almost certainly not be the amount we need to get the desired output impedance. And we are not even speaking here of distortion spectrum and other more subtle things that are also very important.

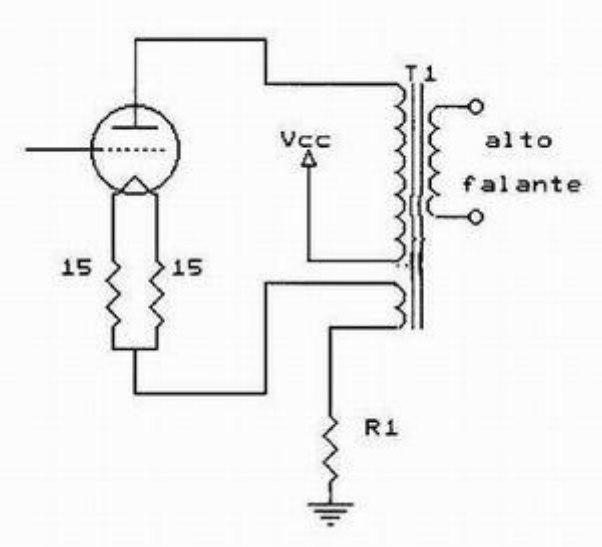

Fig. 1 - Triode with Partial Cathode Coupling

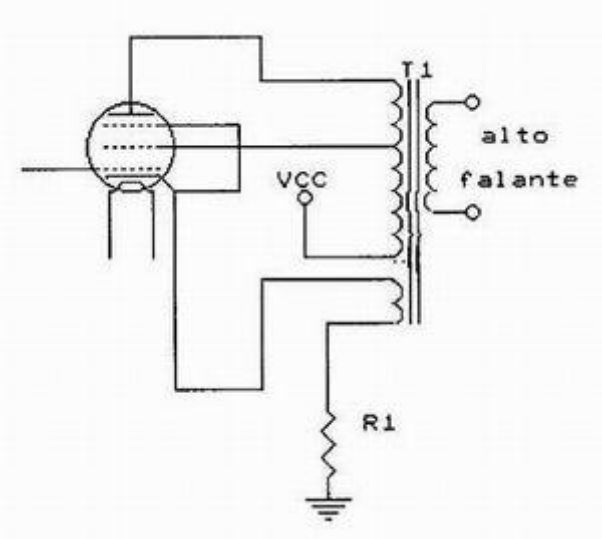

Fig. 2 - LM3 Output Stage

With the connection shown in figure 2 we have the screen derivation, the tertiary cathode winding and a resistance without bypass in the cathode branch (This may be omitted or incorporated in the transformer winding). This is what I have called the LM3 connection. Its original main goal was to optimize the relation between all 3 elements I quoted (screen coupling, cathode coupling and cathode resistance) to emulate a low mu triode like a 300B. This emulation tries to make the output stage mimic or adapt to different power levels the gain, output impedance and the variation of the distortion and its spectrum at different working levels of a 300B tube. And all this with a higher power efficiency that reduces the demand on the power supply. Our technique involves more than just combining an ultralinear tap with a tertiary winding for

cathode coupling. What is different is the purpose of doing it and the control of the cathode branch resistance as an important factor.

Combining an ultralinear tap with partial cathode coupling is quite an old technique for push-pull amplifiers. The first description I can find of it is by Thomas Burroughs in an article in the fifties were he calls it SuperUltralinear and uses a special transformer made by the Chicago Standard Transformer Co. Anyway, this technique has never gained widespread popularity. I believe that two factors can be blamed. First it is harder and more costly to design these kind of transformers and get good results. Second I believe that it did not made sense to use a more complicated technique without a real purpose. At that time (and probably still today) the main commercial objective was to get to lower distortion specs that would "prove" that our equipment "sounds better".

In our case, eventually we have started using this technique with a different aim than we started. Instead of merely copying a low mu triode we started to search for the distortion behavior that would be better for the whole system and would give the best results with most medium to high efficiency loudspeakers, but by this time the name had already been used so many times we decided to keep it.

5. Amplifiers Using this Technique

This output stage has been used in several equipments I have designed. Since the first KT88 amplifier (the Audiopax SE388 - now in its 3rd revision) that was demonstrated in 1998 at the second VSAC and in the same year at the Brazilian Hi-Fi Show in Sao Paulo I have used it in many designs. It has proved to be a reliable technique and to achieve all the goals that we have set for it. I have used it with many types of output tubes. KT88/6550, 6L6/KT66, EL34, EL84 all these tubes have been tried and will in the due time became products. The Audiopax APX02 and the newer model 3 also use this technique with the 6L6/KT66 type of output tube.