STABILIZED SINGLE-STROKE CASCADE ON A VACUUM TRIOD

Evgeny Karpov

The article shows a diagram and considers the principle of operation of a tube output stage with increased linearity.

This article is the logical conclusion of the topic started back in 2003 in the article "Hybrid world". There, for the first time, a circuit with a dynamically controlled **load current** source was considered. current in a solid state repeater. In the future, this principle was transferred to lamp circuitry ("Princess"). Cathode followers of this type have excellent characteristics, but a transfer coefficient of less than 1 creates certain difficulties in constructing a driver.

The transfer of a controlled current source to the anode circuit of the lamp makes it possible to obtain from the output cascade gain close to µ lamp and significantly improve the linearity of the cascade. The resulting output stage has two asymmetric active arms, and it can no longer be unambiguously attributed to a single-cycle stage, although the signal is directly amplified by only one arm. Formally, such a cascade can be considered as a modification of a push-pull cascade - there are two arms operating (conditionally) in antiphase. But the second arm is controlled by the load current, and not by the antiphase input signal. The cascade has a mixed set of features and does not correspond to any classical definition of the output stage in full.

I'm still more inclined to consider it a single-cycle cascade with dynamic stabilization lamp mode. Based on this, the name appeared - Stabilized Single-Stroke Cascade (Equalized Single End - **ESE).**

How does he work?

Figure 1 shows two circuits: a classic single-ended stage (a) and an ESE stage (b).

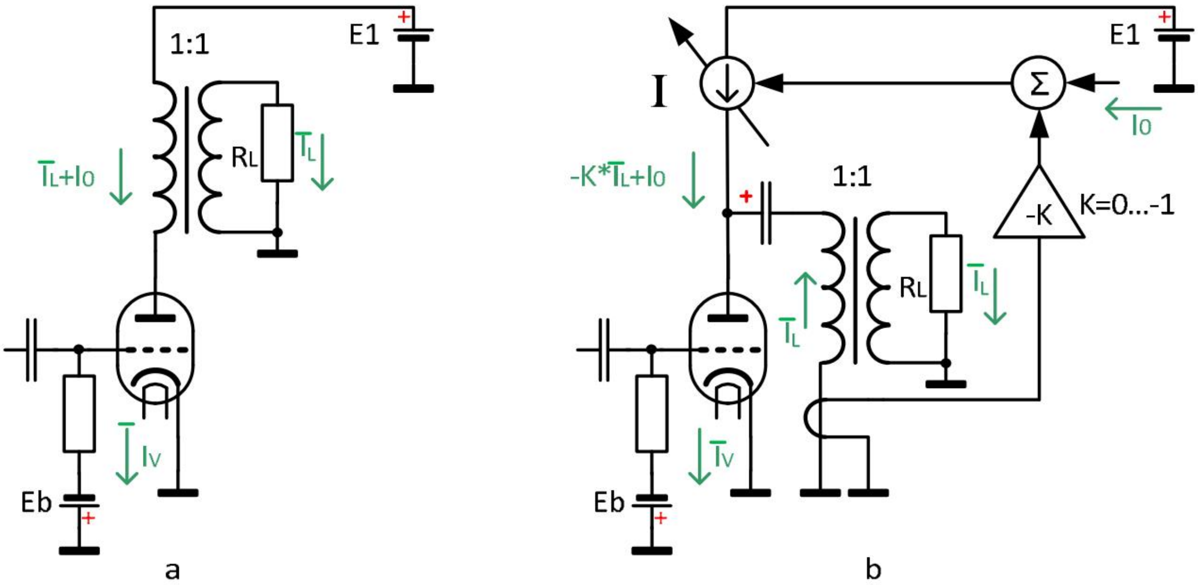

Рисунок 1

Figure 1a does not require comments. The ESE cascade is more complicated: a controlled current source I is included in the anode circuit of the lamp. The control action for it is formed from two components: I0 is the quiescent current stage and load current IL with a scale factor of -K. Assume that both stages have the same quiescent current and the same output power. Accordingly, the load current (IL) will be the same, we will also consider the lamp to be fairly linear, and the transformer to be ideal.

Figure 2 shows the current diagrams in both stages. Let us assume that a positive half-wave of the signal arrives at the input of the cascade. In the classical cascade, this will lead to the lamp opening and an increase in its current, since the sum of the load current and the quiescent current will flow through the lamp - IL + I0 \u003d IV.

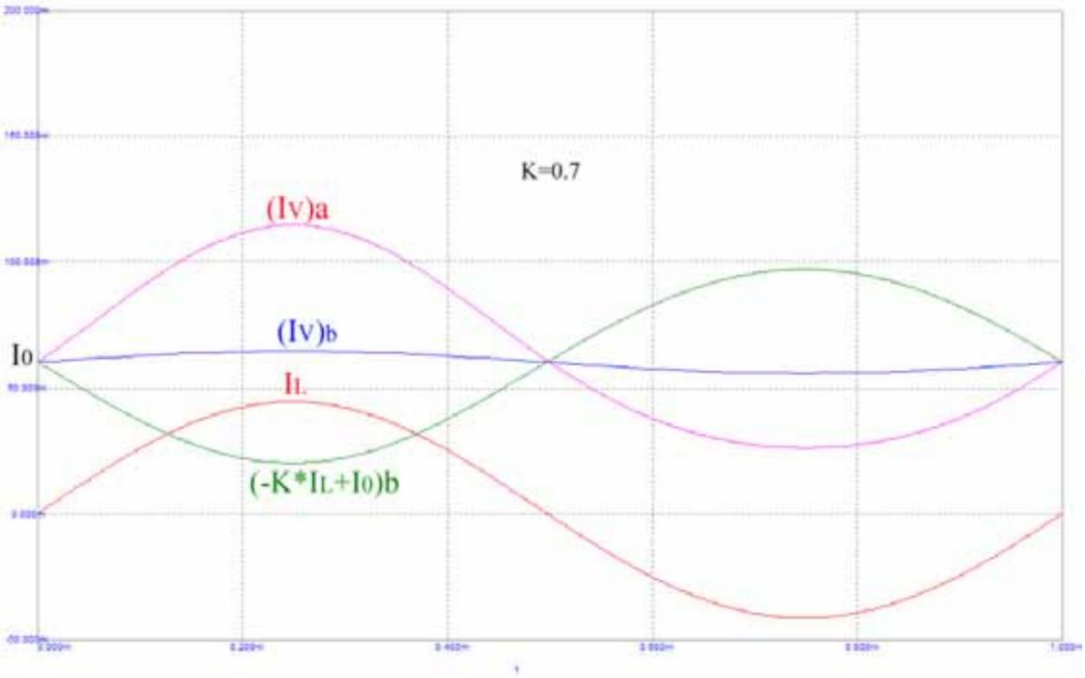

Figure 2

In the ESE cascade, the picture will be different. Opening the lamp causes a load current, and the current through the lamp begins to grow. Information about the load current from the current sensor with some scale coefficient enters the input of the current source, the output current of the current source begins to decrease, which partially compensates for the increasing load current through the lamp. Accordingly, the equivalent change in lamp current will decrease. Reversing the polarity of the input signal will have the same effect.
- a change in the direction of the load current will cause an increase in the current of the current source so that the change lamp current will decrease.

If we pass to more strict terminology, then we can say: an **open** servo system has been added to the cascade, which reduces the range of dynamic change in the lamp current.

And why is this even necessary?

To clarify this issue, we construct the load lines for both types of cascades directly on the anode characteristics of the lamp (Figure 3). The black line corresponds to the classical cascade or K=0, the thick red line corresponds to K=0.7. Possible intermediate positions are shown by dotted lines. The figure clearly shows that the introduction of dynamic current stabilization leads to a reversal and a decrease in the length of the load straight line with the same range of alternating voltage at the anode. If you look at this matter from the "positions" of the lamp, then this is equivalent to changing the reduced load resistance. At K=1, the load line becomes parallel to the abscissa axis, which is equivalent to the work idle lights. If we now turn to the graphs showing the change in the parameters of the lamp from the anode current (Figure 4), it becomes clear that a decrease in the change in the anode current swing and, accordingly, the length of the load line, increases the linearity of the cascade and stabilizes its output resistance. Further increasing the linearity of the cascade and reducing its output impedance can be achieved by the optimal joint choice of the operating point and the K factor.

All these conclusions were made on the assumption that the controlled current source does not introduce distortions. In fact, the current source has its own distortion, although very small. This leads to deviation the instantaneous position of the point of the load line from the calculated value and the growth of distortion at the output cascade. As a matter of fact, the distortions generated by the lamp itself increase. direct vector summation of harmonics does not occur here.

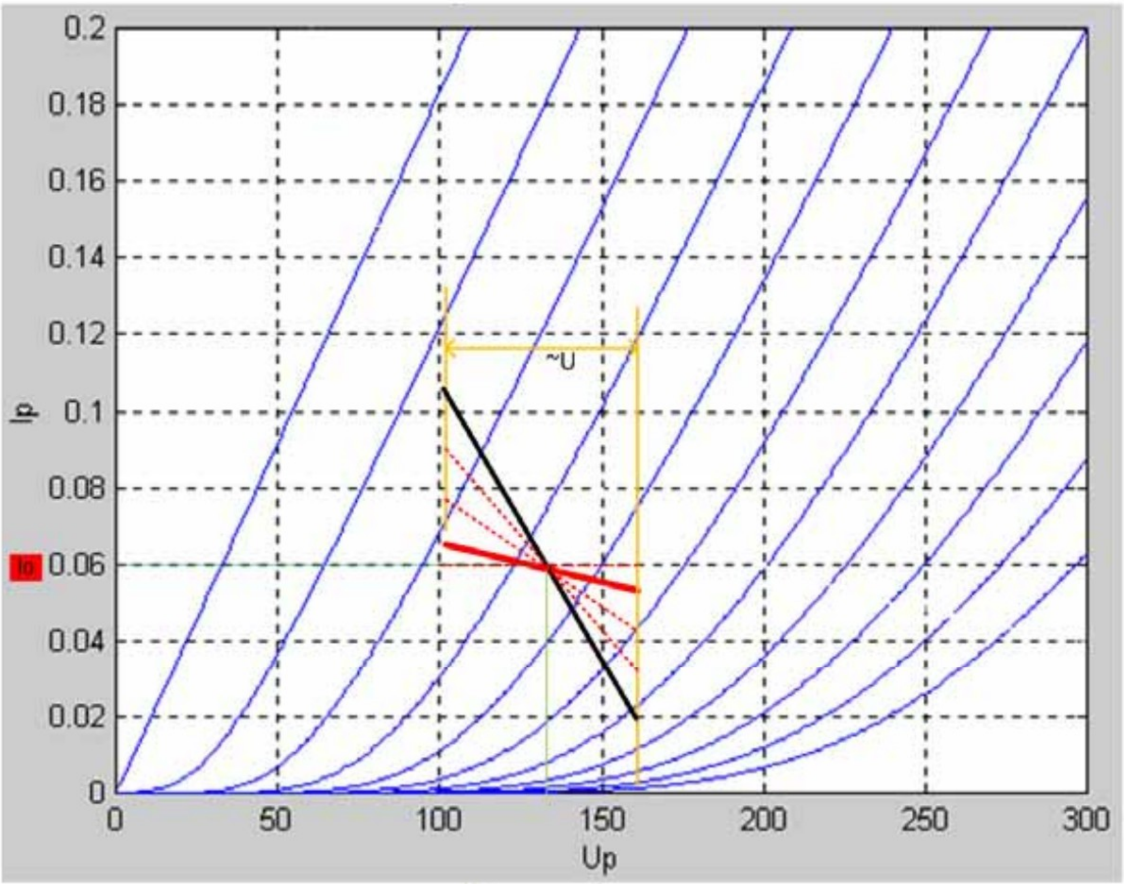

Рисунок 3

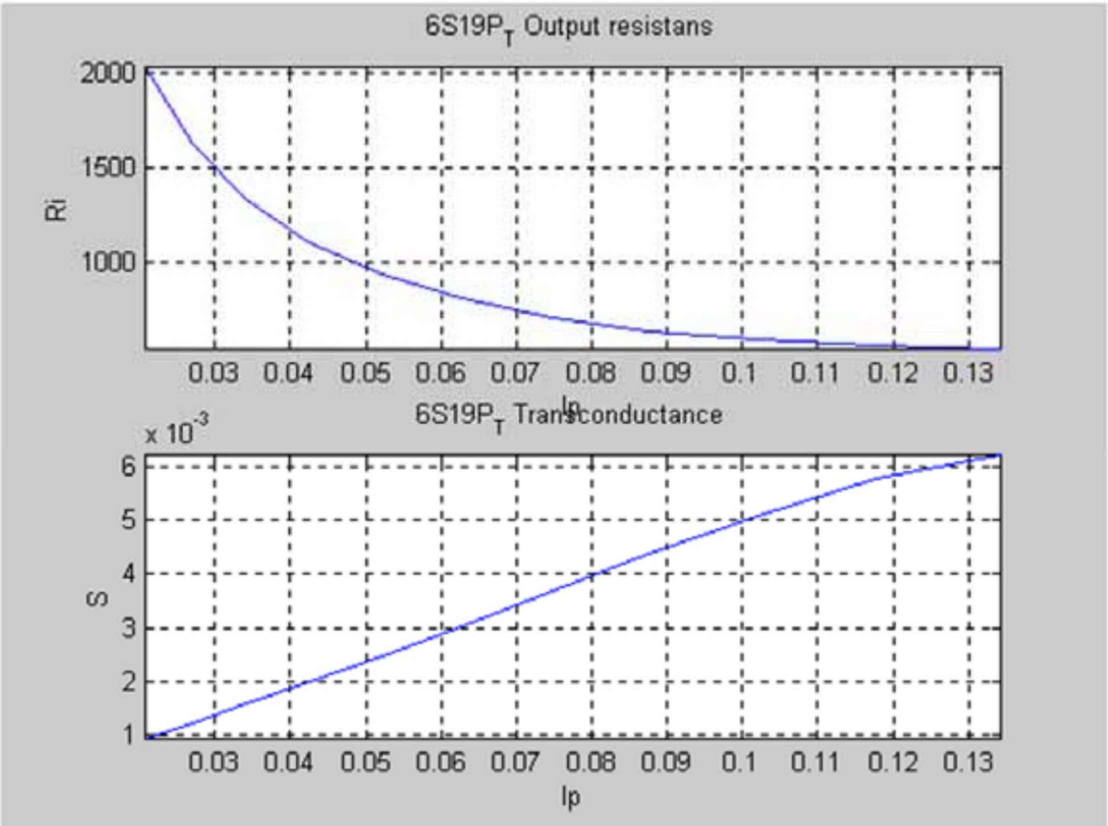

Рисунок 4

Аналитический расчёт влияния гармоник источника тока получается чрезвычайно громоздкий и не точный. Практические измерения показали, что выделить влияние нелинейности источника тока не представis possible, and the change in the nonlinearity of the cascade, depending on the type of current source, is on level of measurement errors.

Current or voltage?

In principle, both the load current and the voltage across it can be used to control the current source. In some solid state power amplifiers, you can find such a solution. But this the statement is true only in one case - if the load is active.

It is well known that the reactive nature of the load (most real loads are like this) and the helmet turns the load line into an ellipse. Control of current sources by voltage on the load leads to the fact that the distortion of the load curve occurs much faster than in the classical cascade.

In general, this is understandable - phase shifts between current and voltage at the load lead to a violation compensation mode, reversal of the load line and deterioration of the cascade parameters. Figure 5 shows the effect of including a small inductance in the load circuit. The top graph corresponds control by load current, lower - by voltage.

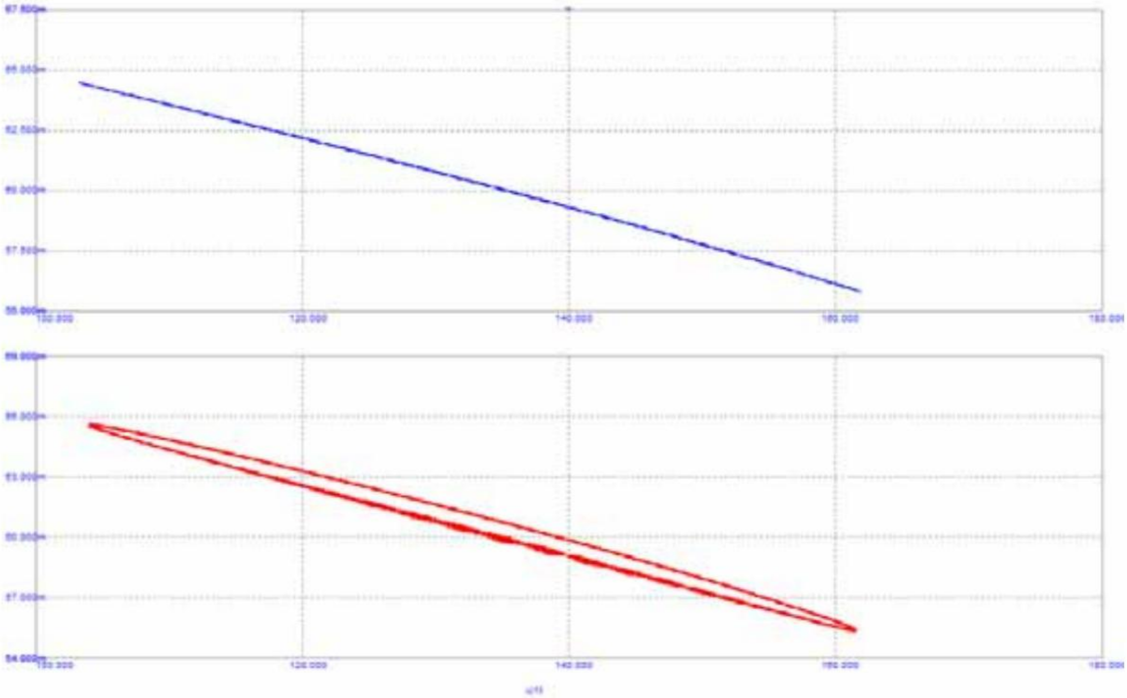

Figure 5

With a reactive load, if the current source is controlled by the load current, then the ESE cascade is practically which does not differ in behavior from the classical cascade.

Where is the feedback hidden?

Formally analyzing the structure of the cascade, we can say that the cascade has a local feedback on the load current. But the mechanism of action of this OS differs significantly from the mechanism of action of the classical OS. The classical interpretation assumes vector summation of the input signal with the output and supplying the total signal to the input of the amplifier. In this case, this is not the case The OS acts directly on the parameters of the load line of the lamp. To be honest, I would even refrained from using the term "feedback". Derivation of the basic relations that determine the parameters of the cascade depending on K is far beyond the scope of this article, and therefore we restrict ourselves to characteristics of its influence on the cascade, depending on its value.

• The output impedance of the stage is mainly determined by the output impedance of the lamp and slightly dependent on the coefficient K.
• The gain of the cascade increases with increasing K and tends to the value of μ of the lamp at K=1.
• The frequency properties of the cascade do not depend on the value of K.
• The linearity function of the cascade on the value of K has an extremum. The extremum point depends on the selected lamp mode and characteristics.
• There is no spectrum enrichment effect in the cascade, regardless of the K value.

Technical implementation

Although the block diagram of the cascade looks rather intimidating, one of the variants of its technical implementation turns out to be quite simple, I would even say elegant. As an example, Figure 6 shows the output stage of a headphone amplifier.

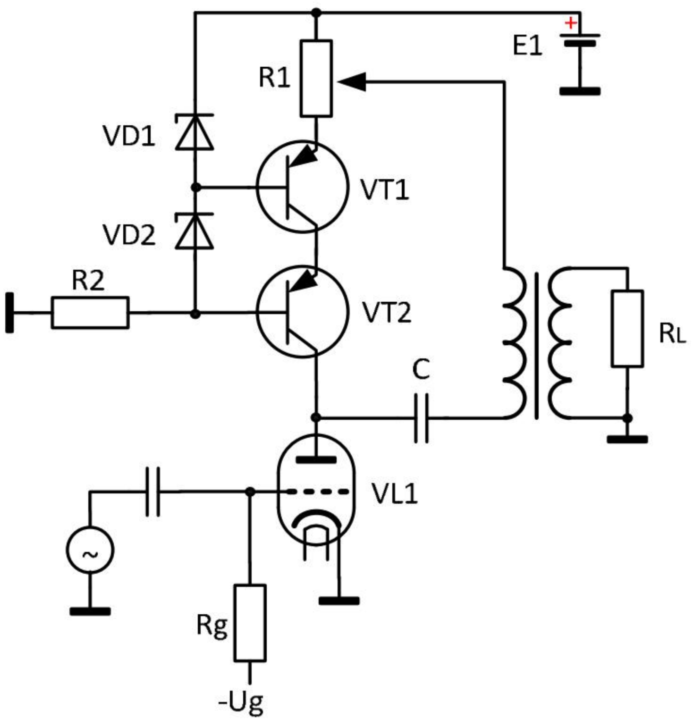

Рисунок 6

A cascode current source based on transistors VT1, VT2 is included in the anode circuit of a powerful triode (6S19P). The load is connected through a separating capacitance to the anode of the lamp and to the current setting resistor R1 of the current source. In the absence of a signal, the voltage of the zener diode VD1 and the resistor R1 set the quiescent current cascade. When a signal appears at the input, the signal current begins to flow through resistor R1 (the resistor acts as a current sensor). The appearance of an additional current in this circuit is equivalent to a change value of the current-setting resistor, which, accordingly, leads to modulation of the output current of the current source. By changing the position of the resistor slider, it is possible to change the scale factor K approximately within 0÷0.9 without changing the quiescent current of the lamp. Now the current source can be considered and as an amplifier with current input and current output. The amplifier has sufficient linearity, the level of distortion (at the maximum range of the output current) does not exceed a fraction of a percent and a band extending up to a few megahertz. Therefore, the compensation effect is preserved up to frequencies that are much higher than the audio frequency range, and the frequency properties of the entire cascade are determined solely by the transformer.

Machine Translated by Google

The cascade itself has the following parameters: output power - 1W, power band 12Hz÷40kHz, harmonic coefficient - ~0.8%. Figure 7 shows the distortion spectrum for output power 1 and 0.25 watts.

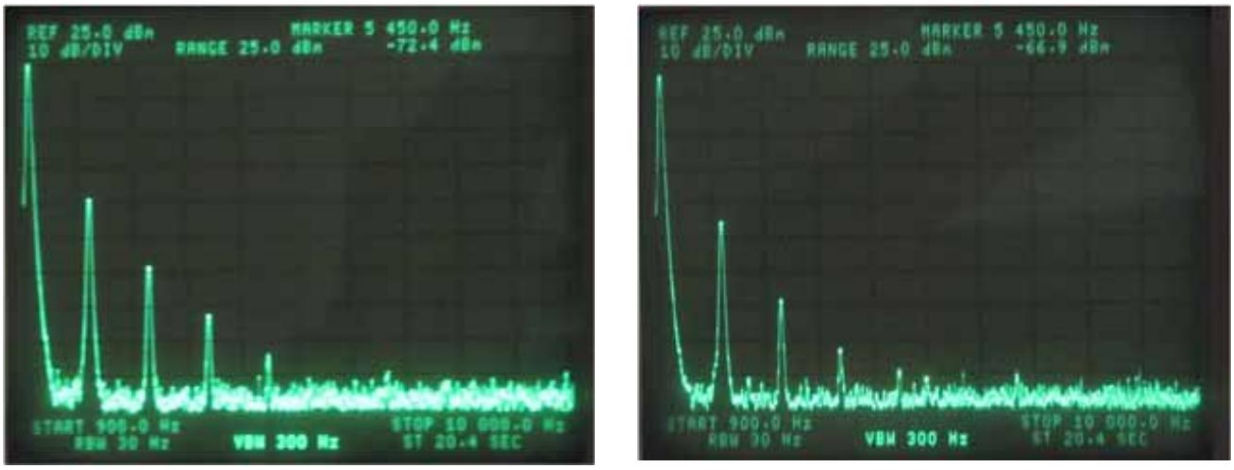

Figure 7

The cascade has a completely typical spectrum of distortion for single-cycle circuits: a small number of harmonics and their fast decay, the second harmonic is dominant. Reducing the output power leads to a rapid drop in the levels of harmonics, higher harmonics fall off faster.

Conclusion

Ceteris paribus, the use of the ESE output stage can significantly increase linearity of the amplifier and at the same time retain the characteristic features of the sound of single-ended circuits. Cascade has a better transient response compared to the classic version, and it has less the asymmetry of the fronts is expressed when the pulse signals are amplified. In general, the sound "handwriting" of the cascade is determined mainly by the lamp and its mode of operation.

A somewhat controversial point is the operation of the transformer without bias. But by choosing the appropriate type of core material and, given that in the same dimensions of the transformer it is possible to obtain a magnetization inductance 1.5–2 times higher, it is possible to significantly reduce the negative effect of the nonlinear magnetization current of the core.

In my opinion, a very important advantage of the cascade is the possibility of flexible control operating mode over a wide range to obtain the desired sound character. In principle, circuitry can be easily transferred to fully solid-state devices without any problems.