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OPTIMISATION OF THE TOTAL HARMONIC DISTORTIONS OF THE ACOUSTIC VACUUM TUBE PUSH-PULL AMPLIFIER

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The study presents the method of reducing total harmonic distortions of the acoustic vacuum tube amplifier with 30 W output power. The optimisation of the amplifier's circuit is carried out by introducing the solutions applied in the transistor technology such as differential amplifiers with a source of a current. Selection of the amplifier vacuum tubes, as well as of their operating points, was studied as a mean to reduce the distortion amount of the whole amplifier stage. By optimising the amplifier it was presented how a simple circuit solution assures very good final parameters with relatively low costs. The measurements were conducted using the Audio Precision systems.

Keywords: acoustic vacuum tube amplifier, harmonic distortions, audio equipment.

1. Introduction

The quality of the sound from acoustic amplifiers is strictly connected with their electric parameters: pass band, dynamics and first of all with the level of nonlinear distortions. Due to proper construction, it is possible to assure relatively low linear distortions. That is the reason why much attention should be paid to the measurements of parameters on every stage of prototype construction. Objective tests are carried out and the measurement methods are based on the usage of special work stands. Subjective methods which comprise audio monitoring of given construction are applied at the end of the measurement cycle only when the results of objective measurements fulfil a number of complex criteria. It is crucial to remember that only a properly prepared room with audio equipment of a high quality enables the audio monitoring. A group of professionals is needed to carry out the audio monitoring. High complexity of the subjective tests means that they are normally very expensive, so should be conducted only when the quality of amplifier's construction based on objective research is assured first. The study presents solutions which enable the minimisation of the level of nonlinear distortions. The subject of this analysis is an acoustic vacuum tube push-pull amplifier presented in Fig. 1. The circuit was developed basing on the existing schemes and solutions of tube amplifiers and also solutions used in the transistor technology [1, 9–11]. The principle used when developing the circuit was the simplest construction solution possible. The present paper is an initial stage to conducting the comparative analysis of vacuum tube set sound quality and referenced transistor amplifier basing on audio monitoring. The next stage will be dedicated to the development of psychoacoustic model allowing the elimination of cost-consuming audio monitoring.

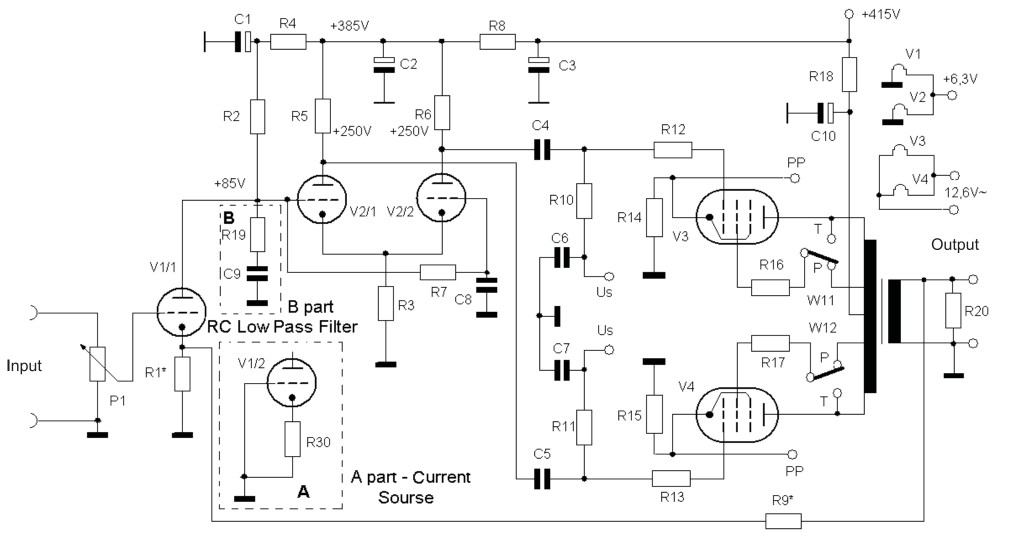

Fig. 1. Diagram of the amplifier.

2. The description of the amplifier [3, 5, 8]

The basic circuit of the amplifier consists of: first stage, inverter and power stage. The acoustic signal from the input goes through the potentiometer directly on the first stage grid. The strengthened signal from anode is lead to the inverter by direct connections. The main aim of this construction which was developed in a symmetrical circuit with cathode coupling is the delivery of signals with the same amplitudes to driving power tubes but with the signals being reversed-phase (180 degrees out of phase).

Strengthened and upturned signals reach the push-pull stage. The signal strengthened by the power stage through the symmetrical output transformer comes to the termination. Low distortion of the amplifier assure local negative feedback of cathodes of all the tubes; general negative feedback connecting the output with the cathode of the tube of the first stage and the ultralinear power stage. The amplifier was built using high-quality elements: selected and matched tubes, multi-section output transformer (very good impedance symmetry). The low level of hum assures very good filtration of the anode voltage and heating tube of the input stages using direct current.

3. Amplifier measurements

The measurements of amplifier's parameters were conducted using "System Two" specialist equipment produced by Audio Precision company [7]. The system co-operates with the computer equipped with special software which enables modification and visualisation of amplifier's parameters. During the measurements, the amplifiers was loaded with pattern resistor and its control depended on the signals coming from the system. The visible effects were shown on the computer screen (generator, nonlinear distortion meter and oscilloscope). What is more, the measurements were carried out in few stages and the changes were therefore gradually introduced. They were conducted without resistance – capacitance filter R19 C9 marked on the picture as B part.

3.1. Selection of the power stage tubes

Three types of tubes were used in the circuit power stage. The same tubes [2] are commonly applied in amplifiers having the power of about 40 W. The measurements were conducted using the optimal bias current for every type of tube or work circuit. The results are presented in the figure below.

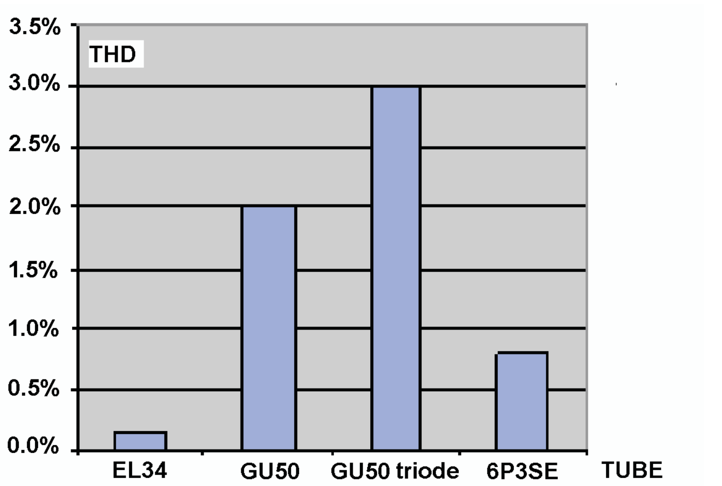

Fig. 2. Nonlinear distortions as depending on the types of power stage tubes and work circuit for $P = 10$ W.

The measurements show that pentode EL34 is the best of all examined lamps. Total harmonic distortions are much lower than it was observed in the examination of other tubes (beam tetrode) and especially the tube GU50, which is designed for transmitting and generating circuits.

3.2. Establishing the optimal operating point of the power stage

Tube EL34 was selected as the best one for the amplifier, and for this tube the optimal operating point was found basing on the level of nonlinear distortion. The research showed that the push-pull stage reaches the lowest nonlinear distortion level when the bias current of the tubes is increasing to maximum which is the result of maximal power lost in the anode of the tubes. By $P_{\max} = 25$ W for $Uz = 400$ V, $I_{\max} = 60$ mA. By such operating point of the power stage the nonlinear distortions (for 30 W output power and 1 kHz signal) approach 0.21%.

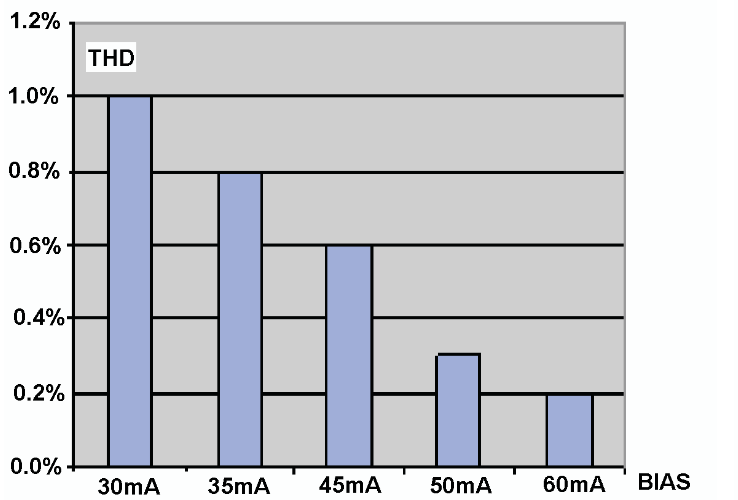

Fig. 3. Nonlinear distortion in function of current for EL34 tubes, with $P = 30$ W.

With high total power dissipation, the power being lost in the anodes of the tubes (class A) the work during the power stage is uneconomical, and results in short life of the tubes and lower output power in relation to classes AB and B, however it assures the lowest nonlinear distortion level – there is no tube switching effect.

3.3. Establishing the appropriate depth of negative feedback

During these measurements the influence of the depth of negative feedback (NFB) on the level of nonlinear distortion was examined. The results are presented below.

The results of the research show that the satisfactory level of nonlinear distortion can be achieved by low depth of negative feedback for 6 dB THD = 0.4%. Because the change of the depth of negative feedback causes the change of the width of the pass band, for each feedback value the pass band was verified.

The change of the feedback mainly caused the deterioration of pass band for high frequency signal. For the circuit without negative feedback the pass band (with signal decreasing by 3 dB) equalled from 15 Hz to 20 kHz, which means that the analysed amplifier can operate without general negative feedback. However, with regard to nonlinear distortions (1% by 30 W) it is advisable to establish negative feedback at the level of 6 dB–15 dB. Such solution assures low level of DIM type distortion.

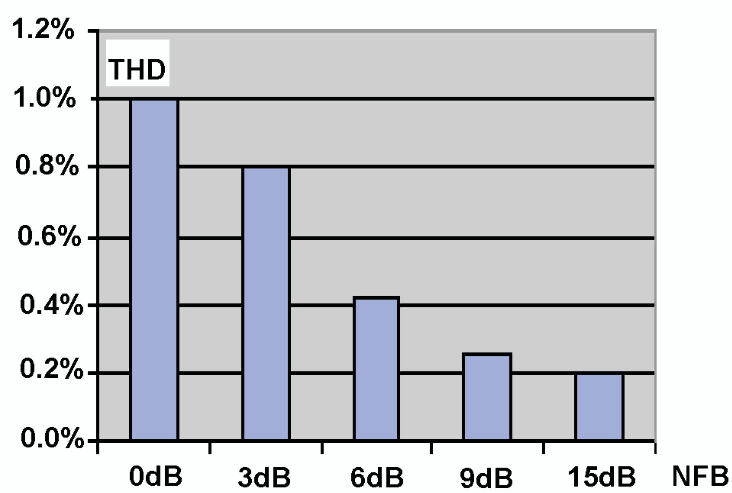

Fig. 4. Nonlinear distortions in function of depth of NFB for EL34 tube, with $P = 30$ W.

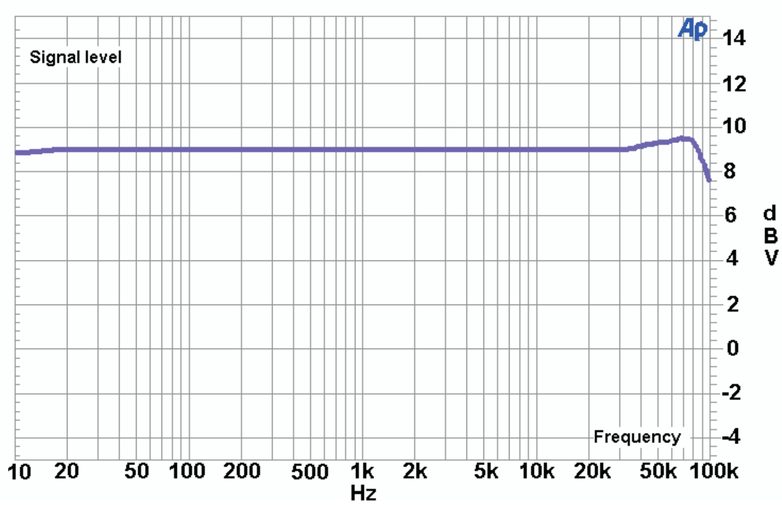

Fig. 5. Pass band -15 dB negative feedback for EL34 tube, with $P = 1$ W.

3.4. The current source in the inverter circuit

Taking into consideration the solutions used in transistor technology and integrated circuits (especially differential amplifier), the current source (A part on the scheme) was applied in the inverter (instead of cathode resistor). This modernisation caused some small reductions of nonlinear distortions (from 0.21% to 0.2% with $P = 30$ W). The improvement of results from improved linearity of the inverter's work, and it will probably have greater importance while working with higher signals – driving of power stages with triodes.

3.5. The change of the type of tube from the inverter

As in case of the solutions used in some amplifiers the change of tubes from E188CC to 6N6P was introduced. At the same time the correction of operating point was conducted. This change caused the growth of nonlinear distortion from 0.21% to 0.3% for $P = 30$ W, however this reduction was to be expected. It is probably the result of worse linearity of the 6N6P tube. The attempt to increase the anode voltage from 380 V to 430 V for driving stages did not bring any changes. What it means is that driving stages can be supplied from the same source as the power stages. The filtration of the anode voltage is also assured.

4. Conclusions

As a result of the research and measurements conducted, it was stated that the most favourable solution for the chosen circuit is based on the following:

- usage of EL34 tubes working with the bias current $I_o = 60$ mA for the power stage;
  E188CC tubes are to be used as steering tubes (so called "gold brand");
- substitution of cathode resistor with current source done on the second part of E188CC tube (marked as A part on the scheme) [4, 6];
- maintenance of the depth of negative feedback at the level of 15 dB;
- introduction of resistance – capacitance filter R19 C9 (marked as B part on the scheme) into the circuit. It limits pass band and reduces the effect of output transformer resonance (raising of the amplitude characteristics in the range of 40–70 kHz visible in Fig. 5).

Such amplifier was examined from the point of view of the nonlinear distortion level and content of harmonic in the output signal. The results are presented in Figs. 6 and 7.

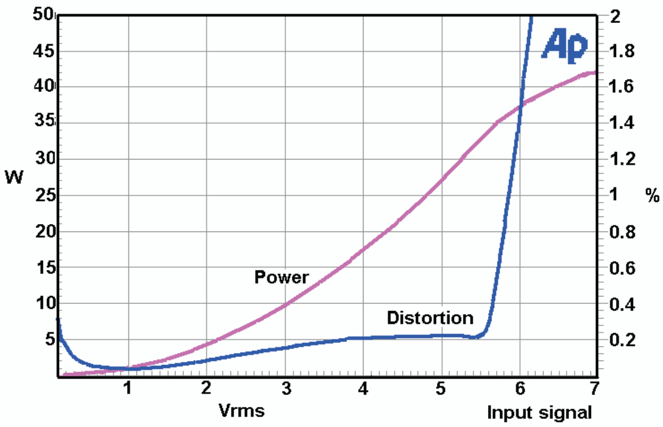

Fig. 6. Power and distortions characteristics in the function of input voltage.

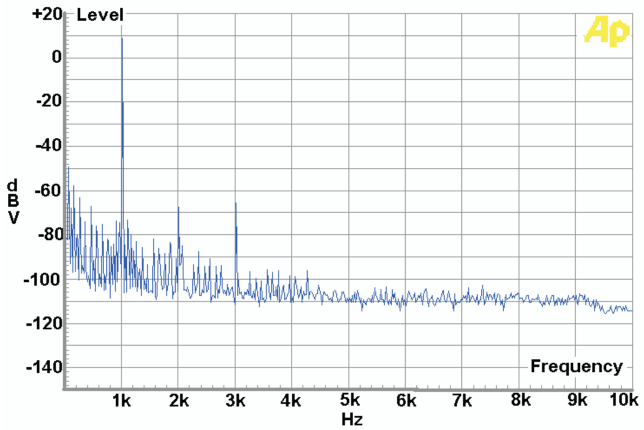

Fig. 7. Harmonics content in the signal for $P = 1$ W at 1 kHz.

The contemporary sources of sound such as CD and DVD players are characterized by very good parameters. According to current standards, many older constructions of tube amplifiers do not meet the requirements of Hi-Fi Class. That is why the improvement of their parameters is crucial (especially by reducing nonlinear distortion).

The carrying out of the above mentioned optimization was aimed at significant improvement of parameters of the referenced transistor amplifier what will enable auditory test of both amplifiers in the next stage of the examination.

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