THE SIMPLE HIGH-VOLTAGE REGULATOR

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In article the availability of a semi-conductor regulator for a feed of the tube amplifiers is considered. The results of comparative testing of two types of high-voltage power supplies - classical circuit with the output LC-filter and with the semi-conductor regulator were given.

The complete description of the schematic circuit of the regulator was given. The adjustment technique of the regulator and feature of his design is in detail considered.
Introduction

The simplest amplifier necessarily comprises the second device - power supply. Directly set of the publications is devoted to amplifiers, and the power supplies are in a shadow, though final result essentially depends on their parameters. For solid-state devices with rather low voltage the realization of a high-quality source does not represent the special problems. With high-voltage power supplies for tube amplifiers the states of affairs are much worse. A certain vacuum here was formed.

First, there are no suitable microcircuits directly designed for work with high voltage.
Secondly, practically there are no publications of professional development accessible to repeat by the DIYer of average qualification.

I shall try partially to fill in this gap and at the same time to solve one more question - question of quality of output capacitors.

I would remind readers, that in SE amplifiers, perhaps, most popular with the beginning designers, the signal current of the output stage directly flows through the power supply [1], [2]. Hence, the parameters of a source (output resistance, nonlinearity and dynamics) directly influences upon an output signal.

The conclusion is evident, if the source of a plate voltage is ideal, namely, has output resistance near to zero in a wide range of frequencies and endless power, it will not render any influence upon an output signal. Starting from this simple supposition, high-voltage regulator was designed.

Possible solution

The following idea completely naturally looks: the tube circuit - tube regulator. But here there are two "but".

First, to be after good output parameters (low output resistance and good dynamics), it is necessary to have high gain in a feedback loop of in a wide band. Such error amplifier is possible to implement on tube, but it will hardly be simple.

Secondly, there is a problem of a regulating tube. Suitable tube for these purposes - is an expensive and scare goods.

The way of solving the first problem exists- it is the hybrid circuits. It is quite reasonable approach, but the second problem remains.

It is possible to try to use for stabilization high voltage standard integrated regulators (and such attempts are undertaken). Though such regulators have excellent parameters, their use is complicated by low input voltage (typical value is 40V). For obtaining acceptable reliability, usage of the preliminary regulator with its own current protection circuit is necessary. And nevertheless, it is necessary to use additional circuits for over voltage protection. When all questions of reliability are solved, circuit will not be very simple.

Theoretically, it is possible to use pulse converters, but, to my opinion, the acceptable noise level for such delicate devices can be ensured only with resonant converters. Such devices are not simple and expensive.

For solving of this task I have selected other way: simply to implement the linear high-voltage regulator, using all capability of modern element base. In result, it became possible to implement the regulator containing only three active elements and having well enough parameters "to be estimated" ideal in the given working area.

Testing

Before the circuit of the regulator will be shown, I want to present results of comparative testing of a typical power supply with the inductive µ-filter [3] and power supply with the regulator.

The testing circuit on figure 1 is shown.
As the tested circuit, was connected LC-filter, shown on figure 2 or regulator. The values of elements of the filter are chosen close to typical. For stimulation of a variable component of a power supply current was used the stage on the power triode with active loading and working in a class "A" (the circuit of heating and bias on figure 2 are not shown). It is good model of real loading. For measurement of a quiescent current and alternating component of a plate the resistor Rs was used. All tests were conducted in identical conditions (as determined on figure 1).

The following parameters were checked up:

1. **Output resistance.** The measurements were carried out as follows: was established value of a alternating current flows through a power supply in 24.5 mA (on the first harmonics), the selective voltmeter was connected to points G and A and the variable component of a voltage was measured. The measurements were done in a range of frequencies 30Hz - 50kHz (in all 17 points). Under the Ohm law the resistance was calculated. The results of measurements on figure 3 are shown.

2. **Transient state.** For this purpose on an input of the power stage the square pulse moved. The peak-to-peak current was established greatest possible, but without cut-off. Oscillograph was connected to points G and A. Oscillograms are shown in figures 4÷7.

3. **The output ripple and noise level.** For this purpose to output the power supply was connected dummy load, and to points G and A was connected spectrum analyzer. The results of measurements on figures 8 and 9 are shown.

4. **Influence of a supply on a spectrum of a stage output signal.** For this purpose spectrum analyzer was connected in parallel to the current sensing resistor (to points G and C). The results of measurements are shown in figures 10 and 11.

5. **Line regulation and load regulation** (only for the regulator). The results of measurements are given in the table 1.

For testing the power supply the following devices were used:

<table>
<thead>
<tr>
<th>Device</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectrum analyzer</td>
<td>HP 3585A</td>
</tr>
<tr>
<td>Selective voltmeter</td>
<td>Siemens D2008</td>
</tr>
<tr>
<td>Oscillograph</td>
<td>Tektronix 2425</td>
</tr>
<tr>
<td>Oscillator</td>
<td>G3-118</td>
</tr>
<tr>
<td>DC voltmeter</td>
<td>V7-46/1</td>
</tr>
<tr>
<td>DC current meter</td>
<td>M1107</td>
</tr>
</tbody>
</table>

![Output Resistance Graph](Figure 3)
Results analysis

Based on results it is possible to make a number of conclusions.

The greatest practical interest has a possibility of achievement of low output resistance in a wide band. The output resistance of the regulator is much lower, than that of the LC-filter, and has more stable character. It allows essentially to reduce influence of a supply on an output signal, to use output capacitor of much smaller value and feeding from one power supply of two channels of the amplifier, not reducing crosstalk attenuation between channels.

The transient response is also more favorable. In figure 6 is distinctly seen droop of pulse of a current flow through a tube (bottom beam), arising at the expense of a voltage reduction of the power supply (fig. 7). Frequency of stimulating pulses (top beam in a fig. 4÷7) is equal 1 kHz, at lower frequencies the droop of pulse will grow.
The value of ripple on an output of a source with the LC-filter and regulator has comparable value (nothing prevents you, having increased inductance choke, to reduce a level of ripple). But overall noise level on an output of the regulator is higher; it is a small spoon of tar in a barrel of honey. But me, to tell the truth, it have not especially confused, the noise voltage on output terminal of the regulator does not exceed 280 micro volts. In the real amplifier, where such regulator was used the not weighed noise level equals -71db.

Essential distinction in a spectrum of an output current of the stage for a source with the LC-filter and regulator is not observed (by the way, received spectra will be interesting to the one who uses or intends to use a tube 6N13S).

Usage of the regulator provides a high constancy of a plate voltage to my opinion it is good always. Also it allows without the special risk to use a tube close to top modes.

**The regulator circuit**

The basic parameters of the regulator are given in the table 1, temperature and long-term instability of an output voltage, mainly, is determined by parameters of the applied microcircuit TL431.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal Input Voltage (V_{IN})</td>
<td>(I_{LOAD}=0.1A, \ V_{OUT}=280V)</td>
<td>420</td>
<td>V</td>
</tr>
<tr>
<td>Output Current (I_{LOAD})</td>
<td>(V_{IN}=295÷400V)</td>
<td>0.12</td>
<td>A</td>
</tr>
<tr>
<td>Current Limiting</td>
<td>(V_{IN}=295÷400V)</td>
<td>1.5÷2.5</td>
<td>A</td>
</tr>
<tr>
<td>Output Voltage (V_{OUT})</td>
<td>(I_{LOAD}=0÷0.1A)</td>
<td>280</td>
<td>V</td>
</tr>
<tr>
<td>Dropout Voltage</td>
<td>(I_{LOAD}=0)</td>
<td>15</td>
<td>V</td>
</tr>
<tr>
<td>Line Regulation</td>
<td>(V_{IN}=295÷400V, I_{LOAD}=0.1A)</td>
<td>0.35</td>
<td>%</td>
</tr>
<tr>
<td>Load Regulation</td>
<td>(V_{IN}=330V, I_{LOAD}=0.1A)</td>
<td>0.5</td>
<td>%</td>
</tr>
<tr>
<td>Ripple Rejection (f=100Hz)</td>
<td>(V_{IN}=330V, I_{LOAD}=0.1A)</td>
<td>51</td>
<td>db</td>
</tr>
<tr>
<td>Output Resistance (f=30Hz÷20kHz)</td>
<td>(V_{IN}=330V, I_{LOAD}=0.065A)</td>
<td>&lt;0.1</td>
<td>Ω</td>
</tr>
</tbody>
</table>

The circuit of the regulator in figure 12 is shown. For simplification of repeat and adjustments of the circuit I briefly shall describe purpose of elements and feature of work.

The regulator is realizing with series connection of a regulating element. As a regulating element the power MOSFET transistor VT2, included as the source follower, is used.

For steering of the power transistor the cascode amplifier, realized on the transistor VT1 and the integrated stabilizer DA1, is used. This amplifier has two inputs; the first input is the base of the transistor VT1, second - input of the integrated stabilizer. The amplification of an error signal, the accuracy and a frequency response of the regulator, mainly, are determined in parameters of a DA1. From a divider of a voltage \(R_9\ - R_{11}\) the portion of an output voltage acts on an input DA1, where is compared to a reference voltage which has been built - in a microcircuit. The error signal amplified by a microcircuit and will be converted to value of the inflowing current in it. This current drives the transistor VT1. Actually, the transistor VT1 transmit through itself a current DA2 (minus a current of its base), the current will be converted to a voltage managing the power transistor, on resistors R3, R5. Certainly, the resistor R5 reduces gain in a feedback loop, but allows unloading VT1 on power, also raises stability.

The second input of the amplifier is used in two ways.
First, the transistor VT1 for elements, connected to the emitter, is emitter follower. Hence, having set a voltage by means of a divider R1, R2 on his base, we set to a microcircuit DA1 a working voltage (about 20 V).

Secondly, as the divider R1, R2 is connected directly to an input voltage of the regulator, all perturbation action (ripple, for example), present in an input voltage, are at its base and amplified, and on collector loading R3 emerge (transistor in this case works as the amplifier with common emitter). The amplified signals of perturbation drive the regulating transistor, and as its phase is inverted, there is a feedforward loop, which stabilizes in addition output voltage. Though, the depth of this feedforward loop is not great, it works in parallel and independently of the basic feedback loop and common factor of stabilization of a voltage steps up.

The circuit R7, C2 improves a transient response for the hopping loading current and prevents self-oscillation.

The short circuit protection is realized on the resistor R8 and Zener diode VD1. When the sum of a gate threshold voltage VT2 and voltage across the resistor R8 will exceed a Zener voltage of VD1, VD1 begins to open. Thus, the transistor VT2 together with elements R8, VD1, turn into a source of current. The value of this current greatly depends on parameters of elements, therefore precisely to specify this current is difficult. Important, that the current will not exceed several hundreds milliamperes, and the power transistor will be not damaged. Hence, the short-term overloads and short circuits are not fearful for the regulator. However it is necessary to remember, in such mode the large power dissipates at the transistor, and during long term overload thermal breakdown will occurs [4].

The list of used components is given in the appendix 1.

The regulator construction

The best decision will be the assembling of all elements of the regulator on the PCB (capacitor C4 can be placed separately). The heat-removing surface of the transistors VT1, VT2 should be outside the limits of the PCB, so that they could be attached to heat sink. The heat sink should dissipate power about 15W (the area 350 - 400 sm² is sufficient). At designing the PCB, it is necessary to take into account, that the error amplifier has the large gain in a wide band. Therefore, it is necessary to aspire to the minimal length for all conductors and correctly routing the ground circuit. It would be desirable that the PCB topology corresponded shown on the circuit.

The example of a design of the regulator in the appendix 2 is shown.

The regulator adjustment

The regulator does not require special adjustment. The first switching-on is expedient to do, fluently raising a input voltage and having connected to the regulator output the dummy load (20 - 30 % nominal). When the regulator will run, set 330V the input voltage and check up of voltage in points, marked on the schematic circuit. Probably, it is necessary to adjust an output voltage (especially, if in a divider R9÷R11 the resistors of low accuracy is used) changing the resistor R11.

The most important operation is the check of absence of self-oscillation in all modes of work. The occurrence of generation, generally, is a first attribute of unsuccessful installation. For checking, collect the circuit shown in figure 13. The value of resistance are calculated by the formulas:

\[
R_1 = \frac{V_{OUT}}{0.07 \div 0.1 \times I_{OUT}}, \quad R_2 = \frac{V_{OUT}}{0.7 \div 0.9 \times I_{OUT}}.
\]

Attention, the oscillograph input should tolerate a level of a steady component equal V_{OUT}. 

Figure 13
Test circuit
Having input sensitivity about 200-300mV, observe oscillogram. At output of the regulator should not be observed self-oscillation in any position of key S. Set the waiting mode sweep and periodically switching a key S, you can see transient process. At the moment of switching on fronts some fading fluctuations with amplitude in hundreds millivolt can be observed. If in any of modes a self-oscillation occurs, it should be removed. For elimination of self-oscillation a few reduce of a gain needed, by increasing resistor R5 up to 10 k. If it will not help, it is necessary to pick up values of a circuit R7, C2. The value of capacity should be increased. When the self-oscillation is eliminated, increase value R7 until occurrence of self-oscillation. Set the resistor with resistance approximately on 10% less.

To have in view, that the increase of values of the correcting circuit, worsens parameters of the regulator.

**The change of a output voltage and current**

The maximal output current can be changed, changing value of the resistor R8. The approximate limiting current threshold can be calculated by the expression:

\[ I_{MAX} = \frac{2.8}{R8(\Omega)} \] (A).

Increasing an output current, do not forget accordingly to increase the heat sink dimensions.

To change of an output voltage of the regulator it is necessary to change value of the sum of resistors R10, R11 (in any combination).

\[ (R10 + R11) = \frac{2.495 \times R9(\Omega)}{V_{OUT} - 2.495 - 4 \times 10^{-6} \times R9(\Omega)} \] (\(\Omega\)).

If you, changing an output voltage, will also essentially change input voltage (VIN), it is necessary to change parameters of a divider R1, R2. On the base of the transistor VT1 there should be a voltage approximately 15-20V at a nominal input voltage. The current through a divider should be equal 1-1.5 mA.

The change of an output and input voltage results in change of dissipation power on elements, do not forget them to supervise and to bring in the appropriate corrections. At replacement of components types necessarily take into account their maximal working voltage (it deals with resistors too) and power of dissipation.

**Conclusion**

Using of this regulator allows partially solves problem of output capacitor of the filter, to exclude using inductor, to raise common qualitative parameters of the amplifier. To my opinion, its usage is wholly being justified for the simple SE amplifiers and PP of amplifiers working in a class "AB".

I hope, that adequately detailed description will allow easy repeating of the regulator by all DIYer.

**References**

1. G.V. Voyshvillo, Low frequency amplifiers, Svyaz'izdat, 1939.
<table>
<thead>
<tr>
<th>Replacement</th>
<th>Vendor</th>
<th>Part Number</th>
<th>Manufacturer</th>
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<td>NexTube - 2002</td>
<td></td>
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</table>
Design of the regulator

Appendix 3

Pin connections

IRF744

MJE13003

TL431

Pin
1. Reference
2. Anode
3. Cathode