Simulation of a Metal Vapor Active Media Power Supply

Ilya S. Musorov[1], Dmitriy N. Ogorodnikov[1], Stanislav N. Torgaev[1,2,3], Gennadii S. Evtushenko[1,2]
[1]Tomsk Polytechnic University, Tomsk, Russia
[2]V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk, Russia
[3]Tomsk State University, Tomsk, Russia

***Abstract* – The results of the development of the high-frequency metal vapor active media power supply are presented. The results of OrCAD simulation of the processes that occur in the power supply are described. The results of the simulation and experiment for the resistive load operation mode were compared.**

***Index Terms* – Brightness amplifier, high pulse repetition frequency, radial profile, amplification, radiation.**

I. INTRODUCTION

HIGH-FREQUENCY metal vapor active media are widely used in science and technology, in particular, as brightness amplifiers [1-5]. In solving some technical problems, it is necessary to use metal vapor active media operating at high repetition rates of radiation pulses [5,7]. Limitation of the high frequencies of pulses in such media arises due to both technical and physical problems. Many experimental and theoretical studies have shown that increasing the pulse frequency in the metal vapor active media is possible when using reduced energy input to the discharge [8]. The use of high-frequency pumping sources with short durations (10-40 ns) of output high-voltage pulses is one of the methods to perform pumping in the regime of lower energy input.

The results of experimental and theoretical studies of the pumping source that provides the regime of lower energy input to the discharge are presented in this article. The developed power supply allows us to receive high-voltage pulses with the amplitude of 3-5 kV and with the duration of 20-60 ns. In order to optimize the operation of the developed power supply, its OrCAD model was created and simulation while working for the resistive load was performed.

II. EXPERIMENTAL RESULTS

The results presented in this article were obtained when the pumping source operated with a 150-Ω resistive load. This resistance is close to the real resistance of a small diameter active medium. The high-frequency pumping source is based on a switch consisting of a gas-discharge tetrode GMI-27B and a high-voltage transistor connected between the cathode of the vacuum tube and ground. The vacuum tube is used in common-grid configuration to provide shielding of the cathode and anode circuits of the tube from each other, that weakens the effect of parasitic complex feedbacks and leads to an improvement in the speed of the circuit. The vacuum tube is heated from the power supply, which allows limiting the starting current of the filament to increase the tube lifetime. A positive-polarity voltage with reference to the cathode is applied to both grids of the gas-discharge tetrode from an auxiliary power supply. The voltage on the control grid can be adjusted from 0 to 500 V, and for the screen grid the voltage is set in the range from 500 to 900 V, which allows controlling the turn-on and turn-off characteristics of the tube. The control system based on a microcontroller STM32F407VG and a high-speed MOSFET driver IXDD630N. On the printed circuit board of the control system there are buttons to change the frequency and the duration of the control pulse. The buttons to confirm the change in the control pulses parameters were added to protect against false positives; the Schmitt trigger is used to debounce the buttons.

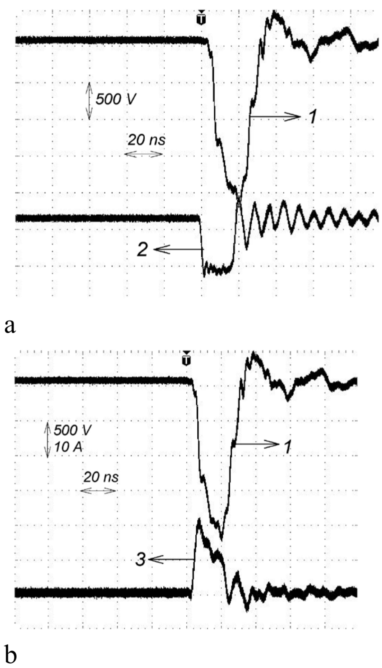

Fig. 1. The voltage and current waveforms: 1 – the tube anode voltage; 2 – the drain-source transistor voltage; 3 – the tube anode current.

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The pumping source generates rectangular pulses with amplitude of up to 5 kV, with a frequency of 30 kHz to 1 MHz and pulse duration of 40 ns.

The anode voltage and anode current waveforms are shown in Fig. 1; here the pumping source operates with a frequency of 100 kHz and the amplitude of the pulses is 3 kV with a minimum duration.

III. ORCAD SIMULATION OF POWER SUPPLY

PSpice model of GMI-27B tube is described below. The model has four terminals: plate *P*, control grid *G1*, cathode *C* and screen grid *G2*. The GMI-27B tube datasheet is used to determine specific parameters of the model.

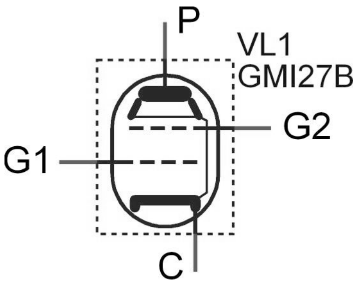

Fig. 2. GMI-27B vacuum tube representation.

This model represents general characteristics, which can be applied to design but may not match real tube characteristics precisely. However, as the practice has shown, it does not prevent its use for analyzing a models operational mode. Perhaps, these parameters will be refined in the process of model research.

The model of GMI-27B tube is based on the models described in [9].

```
.SUBCKT GMI27B 1 2 3 4; P G1 C G2
+ PARAMS: MUs=95 MUg=350 EX=2.2 Kg=3e-10
+ Cgc=32P Cpg=1p Cpc=0.3p Cps=12p Csg=37p
+ Rg=1k
RE1 9 0 1k
ESP 6 0 VALUE={V(1,3)+MUs*V(4,3)+MUg*V(2,3)};
E1 7 6
VALUE={Kg*(PWRS(V(6),EX)+PWR(V(6),EX))/2}
E2 7 8 VALUE={V(7,6)*V(1,3)/V(4,3)};
E3 9 8 VALUE={(1-V(8,6)/(abs(V(8,6))+0.001))/2}
Gk 4 3 VALUE={V(7,6)}
Gp 1 4 VALUE=
+{0.98*(1-exp(-
V(1,3)*2/V(4,3)))*(V(7,8)+V(8,6)*V(9,8))}
R3 2 5 {Rg} ; FOR GRID CURRENT
C2 1 3 {Cpc} ; CATHODE-PLATE
C4 2 3 {Cgc} ; CATHODE-GRID
C5 2 4 {Csg} ; SCREEN-GRID
D3 5 3 DX ; FOR GRID CURRENT
.MODEL DX D(IS=1N RS=1 CJO=10PF TT=1N)
.ENDS
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The power MOSFET STP20N95K5 is used to switch on the tube as shown in Fig. 3. This very high voltage N-channel power MOSFET is designed by STMicroelectronics using MDmesh™ K5 technology based on an innovative proprietary vertical structure. The result is a dramatic reduction in on-resistance and ultra-low gate charge for applications requiring superior power density and high efficiency.

The main idea is to commutate the vacuum tube by switching the power transistor which is connected in series to cathode of the tube. The circuit of the power supply is shown in Fig. 3. The 3 kV anode voltage source is

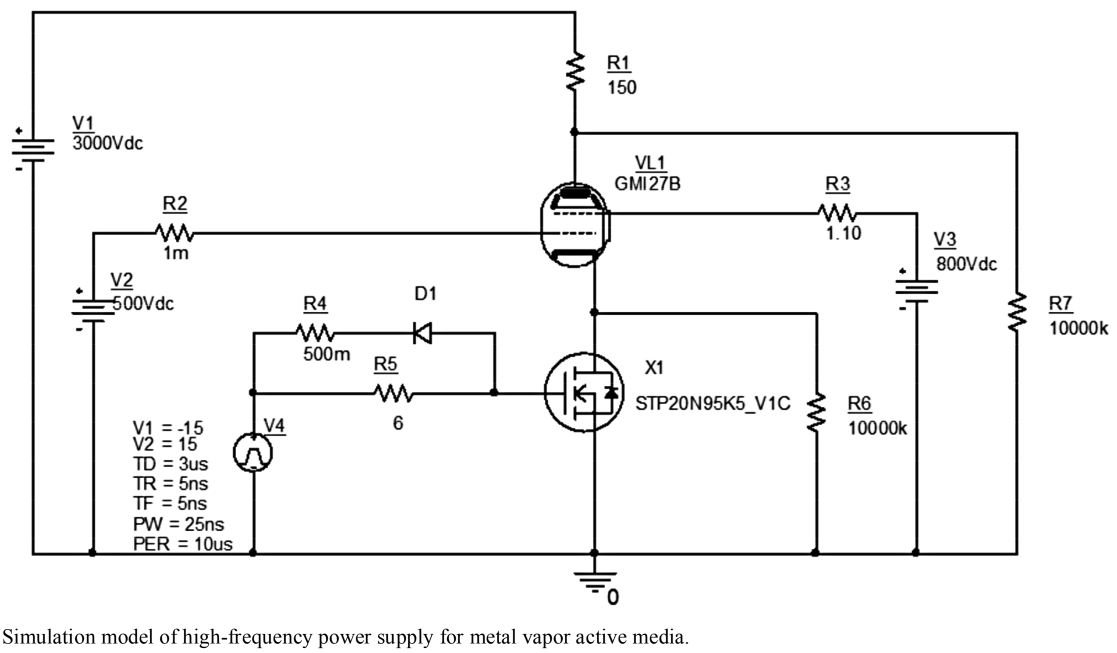

Fig. 3. Simulation model of high-frequency power supply for metal vapor active media.

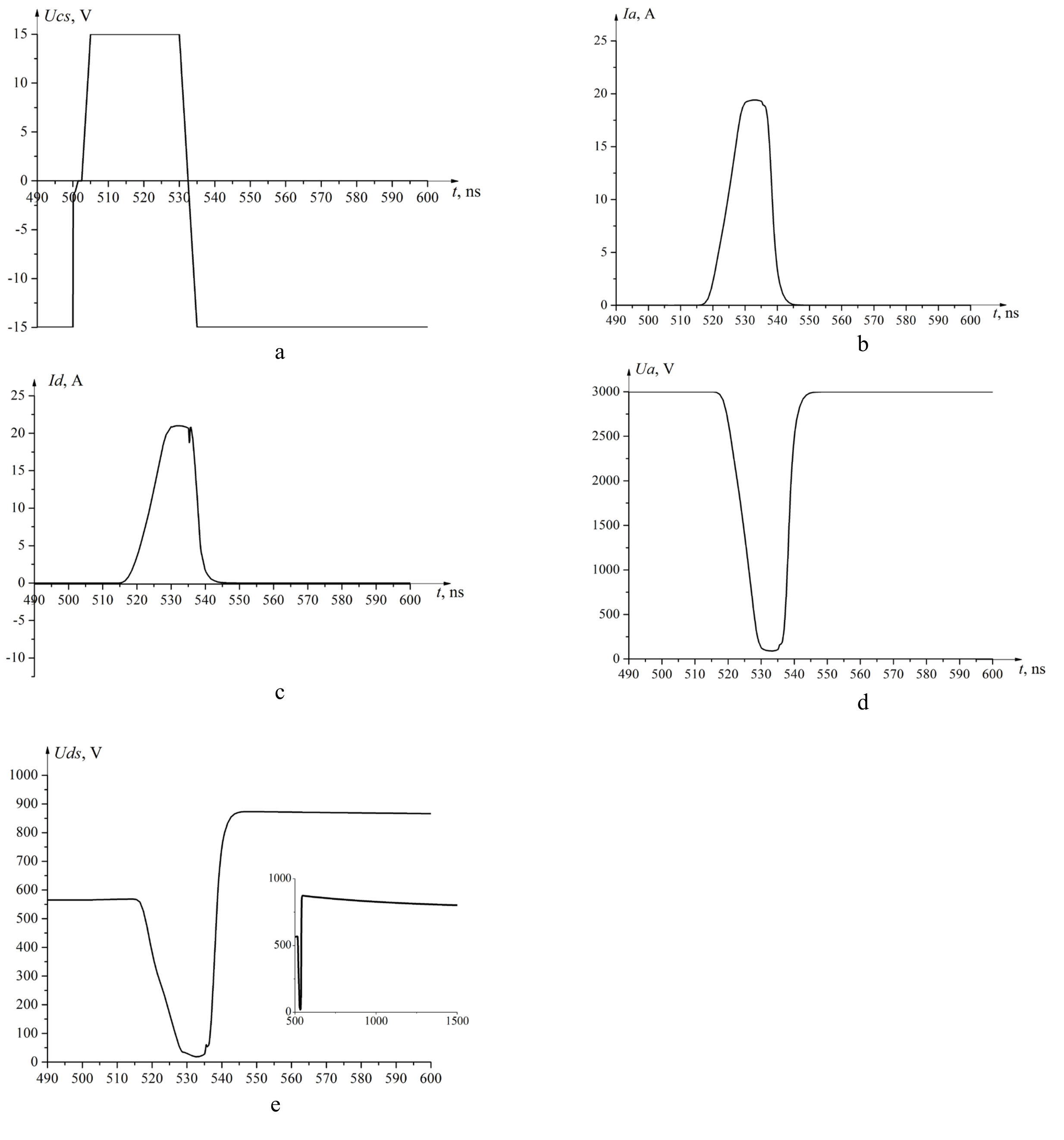

Fig. 4. Waveforms obtained by simulation: a – the control voltage of the transistor; b – the anode current of the tube; c – the drain current of the transistor; d – the voltage at the anode of the tube with reference to ground; e – the drain-source voltage of the transistor.

connected to a series-connected load, a lamp and a transistor; load is resistive. DC voltages with positive polarity are applied to the grids of the lamp: to the control grid is 500 V, to the screen grid is 800 V, but the anode current through the lamp does not flow until the transistor is switched off. The transistor is switched on by a short pulse applied to the gate through a 6 Ω resistor. The duration of the control pulse is 25 ns; the delay of the first pulse is 0.5 microseconds. To accelerate the process of the power transistor switching off, the gate current is increased at this time by using a 0.5 Ω resistor and a diode in the gate circuit.

IV. Simulation Results

The simulation results are shown in Fig. 4. Here are waveforms: the control voltage of the transistor, the anode current of the tube, the drain current of the power transistor, the voltage at the anode of the tube with reference to ground, the drain-source voltage of the transistor.

It can be seen that:

- the anode current starts to rise 14 ns after the control pulse coming from transistor control system, and it starts to decrease about 4 ns after the transistor turn-off pulse;

- the maximum drain current of the transistor is higher than the maximum anode current of the lamp due to the addition of grid currents;
- the duration of the leading edge of the anode current is about 12 ns, while the duration of the falling edge is about 6 ns.

The analysis shows that the simulation of the operation of a high-frequency pumping source is in good agreement with the experimental data.

IV. CONCLUSION

Thus, a detailed model of the metal vapor active media power supply allows us to generate the high-voltage pulses of short duration was developed. The power supply is based on the vacuum tube GMI-27B. The results of simulation of the pumping source with the resistive load are in good agreement with the experimental data that confirms the adequacy of the developed model.

This model will make it possible to perform a detailed study of the metal vapor active media pumping sources of various geometries and at different repetition rates of the pumping pulses. Carrying out such studies by experimental methods is almost impossible due to financial and time costs. In particular, experimental studies require the development and manufacture of active media components.

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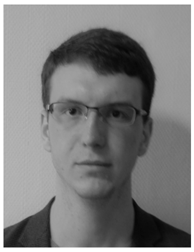
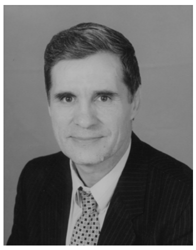


Ilya S. Musorov was born in Tomsk city Russian Federation in 1991. Since 2016 he has been a postgraduate of the Institue of Non-Destructive Testing of Tomsk Polytechnic University. His scientific activities include metal vapor lasers, electronics, control systems. He has published about 15 publications.

Dmitriy N. Ogorodnikov, was born in 1974 in Tomsk, Russia. He graduated from Tomsk Polytechnic University (Electrophysical faculty) in 1996 (engineer, specialty «Industrial Electronics»). He received a PhD degree (Candidate of Sciences, specialty «Power Electronics») in 2003.
From 1999 to 2004 he was an Assistant at the Department of Industrial and Medical Electronics, TPU. In 2004 he was a Senior lecturer. Since 2004 he works as an Associate Professor, Department of Industrial and Medical Electronics, Tomsk Polytechnic University.
Scientific interests are in Power Electronics. He has authored or co-authored more than 45 publications, including 5 peer-reviewed journal articles, several inventor's certificates and patents.

Stanislav N. Torgaev was born in 1984 in Alma-Ata city (now Almaty), Kazakhstan Republic (former USSR). He graduated from Tomsk Polytechnic University (Electrophysical faculty) in 2007, has Masters diploma of techniques and technology majoring in "Electronics and Microelectronics". He received a PhD degree in 2013.
Since 2007 he is a lecturer of Tomsk Polytechnic University. Since 2009 he is a scientific researcher of Quantum Electronics Laboratory of Institute of Atmospheric Optics, Siberian Branch of Russian Academy of Sciences. Since 2014 he is a scientific researcher of Tomsk State University. His scientific activities include metal vapor lasers, electronics, physics of low-temperature plasma. He has published more than 70 publications, including 15 peer-reviewed journal papers and 2 patents.



Gennadii S. Evtushenko was born in Ussuriisk, Primorsky Krai, USSR in 1947. He graduated from Far East State University, Vladivostok, in physics in 1970. From 1970 to 1979 he was a PhD student and young researcher of Tomsk State University. His scientific activity in this period was connected with physical processes in the negative glow of gas discharge. He has received PhD degree in Physics 1979.
Since 1979 G. Evtushenko has been involved in the research, development and application of metal and metal compound vapor lasers. That time he was a head of quantum electronics laboratory of Institute of Atmospheric Optics SB of RAS. In 1994 he has received the second degree – Dr. of Technical Sciences. Since 2002 he is a professor of Tomsk Polytechnic University, Tomsk, Russia.
He has 5 books and about 200 papers in the research area.