

## DEVELOPMENT OF A NEW DEVICE FOR TRIGGERING A LINEAR ELECTRON ACCELERATOR “ALMAZ-2”

*D.Yu. Zaleskyi, V.I. Pristupa, V.S. Us, O.L. Omelaenko, G.V. Sotnikov*  
*National Science Center “Kharkov Institute of Physics and Technology”, Kharkiv, Ukraine*  
*E-mail: zalesky@kipt.kharkov.ua*

A new device for triggering of the linear accelerator of electrons has been developed and tested. The circuit device consists of a master generator forming rectangular pulses with a duration of  $1 \dots 2 \mu\text{s}$  with a front of about 50 ns and a repetition rate of 1 to 5 pps, and three channels generating pulses with a delay relative to the pulses of master generator, which can be adjusted from 0.1 up to  $10 \mu\text{s}$ .

PACS: 84.30.-r, 84.30.Jc, 84.30.Sk, 84.30.Ng

### INTRODUCTION

The triggering device (TD) of the electron linear accelerator (e-linac), which is currently operated at the "Almaz-2" e-linac [1, 2], was developed and manufactured at the KIPT in the 50...60 s of the last century. Despite the fact that a large number of these TD were manufactured, at present, due to the moral and physical aging of TD's, it is necessary to replace them with modern ones for the following reasons:

- the impossibility of repairing old TD due to the lack of obsolete electronic components;
- the stability of the characteristics and reliability of old TD systems no longer meets the modern requirements for conducting experiments, and can also disrupt the uninterrupted operation of the e-linac "Almaz-2" and can even cause accidents.

To explain the operation of the TD system at the e-linac "Almaz-2", we will use Fig. 1.

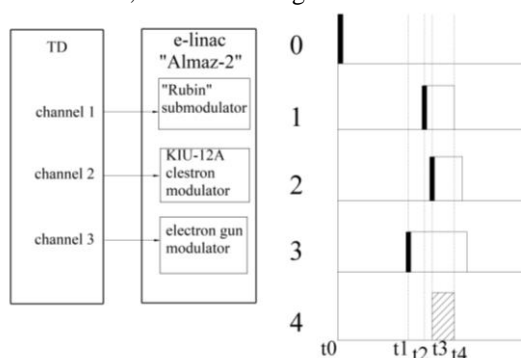


Fig. 1. Control circuit of the e-linac "Almaz-2" from the triggering device with the output pulse diagrams

As can be seen from Fig. 1. unipolar pulses with a duration of  $1 \dots 2 \mu\text{s}$  and a rise of about 100 ns from the TD are fed to the control electrodes of the thyratrons of the Rubin submodulator, the klystron modulator and the gun modulator. The thyratrons begin to discharge the shaping lines of these devices, which form the pulses depicted on plots 1, 2, 3.

Thus, from the front of the pulse depicted on the plot "0" at time "t0", the time delay starts  $t_1, t_2, t_3$  of the corresponding channels No. 1, 2, 3. As can be seen from the diagrams, in the ideal case, the time delays  $t_1, t_2, t_3$ , so that the pulses overlap, it would seem, should be equal. But in fact there is a delay in the actuation of thyratrons, the time of the beginning of the generation of the "Rubin", the klystron, and especially the delay in

the appearance of the beam at the exit of the electron gun. Therefore, by adjusting the delay time  $t_1, t_2, t_3$  experimentally, according to the signals from the output of the electron gun from the microwave load and the output of the accelerator, the required duration of the beam current pulse is achieved (see diagram "4").

Thus, based on the experience of operating the old TD, the following technical requirements for the new TD were developed:

- the TD should consist of a master generator (MG) of rectangular pulses for four independent channels shaping pulses for triggering thyratrons of modulators;
- output pulses of all four channels should be shifted relative to the pulses of the MG by an adjustable value from 1 to  $10 \mu\text{s}$  with an accuracy of no more than  $0.1 \mu\text{s}$ ;
- the amplitude of the output pulses from each of the four channels must have a voltage of at least 350 V and a current of at least 1 A;
- TD should start when the phase of the supply voltage passes through "0" of the 220 V 50 Hz network.
- the frequency of the output pulses of the MG is adjustable from 1 to 5 Hz;
- the shape of the output pulses is rectangular with a duration from 1 to  $2 \mu\text{s}$  and a leading edge of no more than  $0.1 \mu\text{s}$ .

For the developed TD, the block diagram shown in Fig. 2 was chosen.

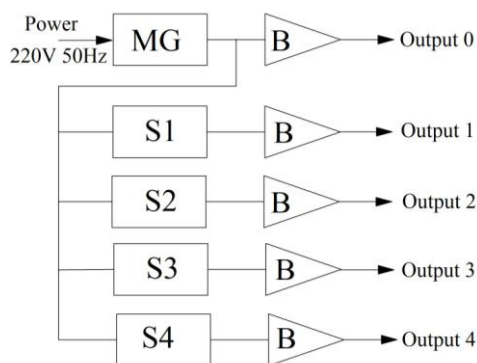


Fig. 2. Block diagram of the developed TD. Where MG – master generator, S1...S4 pulse shapers with a delay, B – raising buffers

As can be seen from Fig. 2. The triggering device consists of a master generator, 4 channels that form pulses with a delay relative to the pulse of the master generator, and 5 output repeater buffers to receive puls-

es with a voltage of 350 V at the TD output for controlling the "Almaz-2" LUE.

The MG circuit for its intended purpose consists of the following elements:

- circuits of synchronization of the MG with a 220 V 50 Hz power supply network;
- time setting circuit;
- output driver;
- indication circuit;
- power supply stabilization circuit.

### 1. DESCRIPTION OF THE MAIN ELEMENTS OF THE SCHEME OF THE DEVELOPED TRIGGERING DEVICE

At the initial stage, computer simulation was used to test the operability of the circuits, as a result of which

oscillograms of the signals of interest were obtained in various parts of the developed circuits.

To clarify the operation of the TD circuits and pulse shapers with a delay, some of these oscillograms are shown in Figs. 4, 5, 7.

The schematic of the master generator (MG) of the developed triggering device is shown in Fig. 3.

The synchronization circuits of the MG with the power supply mains are assembled on the elements that are located according to the diagram (see Fig. 3) between the J1 connector of the VO optocoupler inclusive and operates as follows. When a negative half-wave of the phase voltage arrives (see Fig. 4, upper curve), the capacitor C1 is charged to the stabilization voltage of the Zener diode VD4 through the resistor R1 and the diodes VD1, VD3.

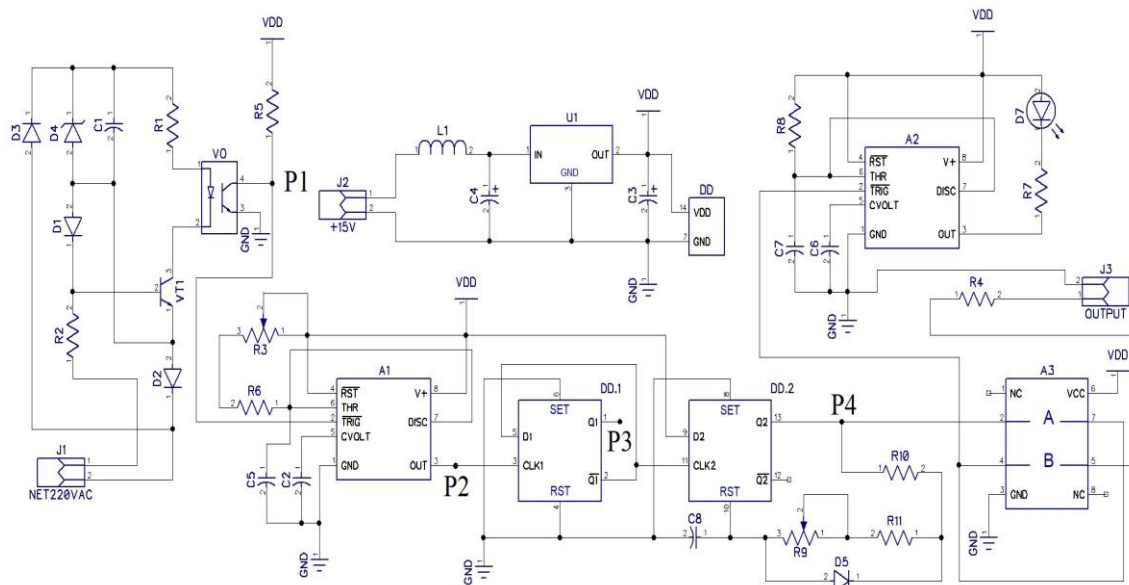


Fig. 3. Schematic of the master generator

At the moment when the phase voltage passes through zero and becomes positive, the transistor VT1 opens and a current flows through the LED in the VO optocoupler. At the same time, the opening of the transistor VT1 leads to the discharge of the capacitor C1, so the transistor opens for a very short time, which provides a short negative pulse at pin 4 of the VO optocoupler (see Fig. 4, lower curve). The pulse duration depends on the capacitance of the capacitor C1.

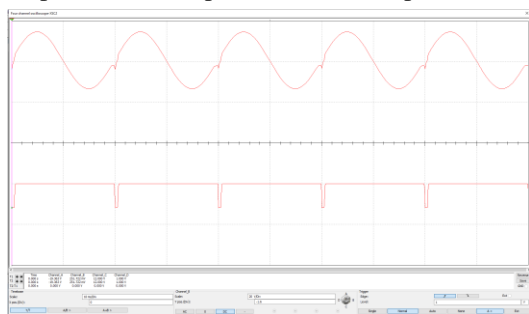


Fig. 4. Oscillogram illustrating the operation of the synchronization circuit of the MG with the power network

The timing circuit is assembled on the basis of the 555 series microcircuit [3], designated A1 in the diagram of Fig. 3, when a negative pulse arrives at its input

(pin 2) (see Fig. 5. upper curve) at the output (pin 3) (see Fig. 5. the second curve from the top) a signal appears equal to the supply voltage of the 12 V microcircuit, this voltage will exist there until the capacitor C5 is charged. After that, the voltage will return to "0". The process will be repeated again when the next negative impulse arrives.

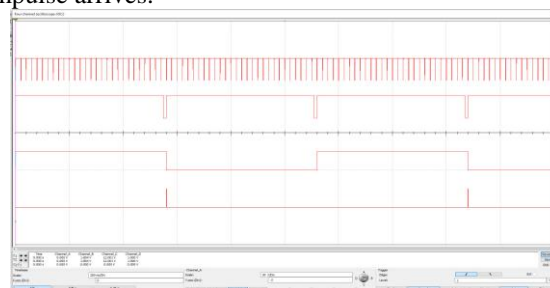


Fig. 5. Oscillogram illustrating the formation of MG pulses

The formation of pulses of the MG is carried out by the logical elements of the DD chip of the type HEF4013 [4], which consists of two D-flip-flops DD1 and DD2. DD1 converts the output signal of the A1 chip (see second from the top in Fig. 5) into a signal with 50% duty cycle (second from the bottom), and also halves its frequency. The second D-flip-flop DD2 on the decay of pulses with DD1 forms a short pulse with a

duration of 1  $\mu$ s (see lower curve in Fig. 5), which is fed to the A3 input. The A3 microcircuit is a follower driver [5] or, in other words, a current amplifier, which makes it possible to operate the MG circuit for a low-impedance load. The use of drivers at the outputs of the boards improves the noise-immunity of TD.

The indication circuit shows that the MG generates pulses. The scheme works as follows. When a negative pulse arrives from the inverting output A3 (pin 4), the 555 A2 timer starts, it generates a long pulse sufficient

to visually observe the glow of the D7 LED. The scheme of pulse shapers with a delay F1...F4 (see Fig. 2) is shown in Fig. 6.

As can be seen from Fig. 6, this circuit has similar circuit elements as in the MG with the same functions, these are: an output driver, an indication circuit and a power stabilization circuit. The circuit directly shaping pulses with a delay is assembled on the elements "2 OR-NOT" DD1-DD4 of the digital logic microcircuit HEF4001 [6].

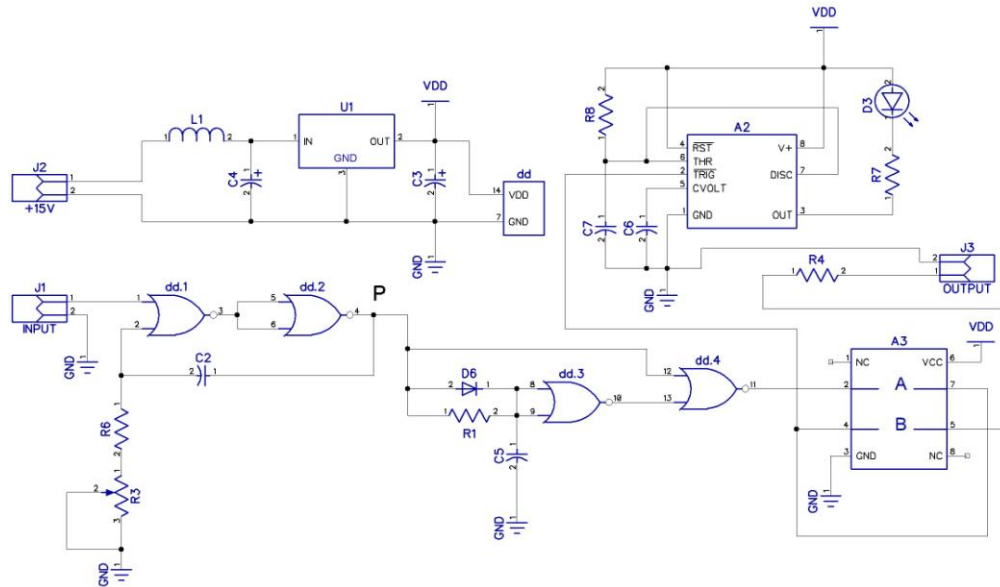


Fig. 6. Delayed pulse shaper circuit

The scheme works as follows. When a pulse appears at the input J1, the "high level" voltage of 12 V is set at the output 4 and the charge of the capacitor C2 begins. The charge rate depends on the value of C2 itself and the resistances R3 and R6. By changing the resistance value, you can change the "high state" time at the output "4" DD2.

Elements DD3, DD4 on the decline on DD2 form a short output pulse, the duration of which is determined by R1, C1. The results of computer simulation are shown in Fig. 7.

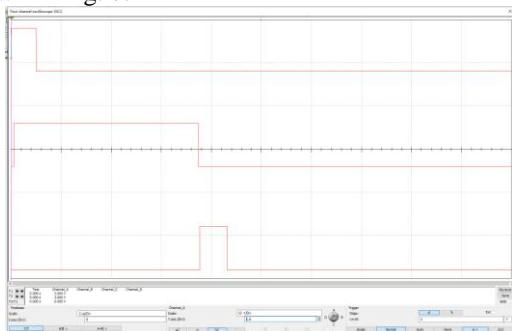


Fig. 7. Simulation results of a delayed pulse shaper circuit. Where the upper curve is the voltage at the input J1, the curve in the middle at the output "4" DD2, the lower curve at the output "11" DD4

## 2. RESULTS OF TESTING THE CIRCUITS OF THE DEVELOPED TRIGGERING DEVICE, AND THEIR DISCUSSION

For experimental verification of the performance of the described circuits, printed circuit boards of the mas-

ter generator (MG), the boards of the delay pulse shaper and the power supply were developed and manufactured. For their testing and adjustment, a stand was assembled, which is shown in Fig. 8.

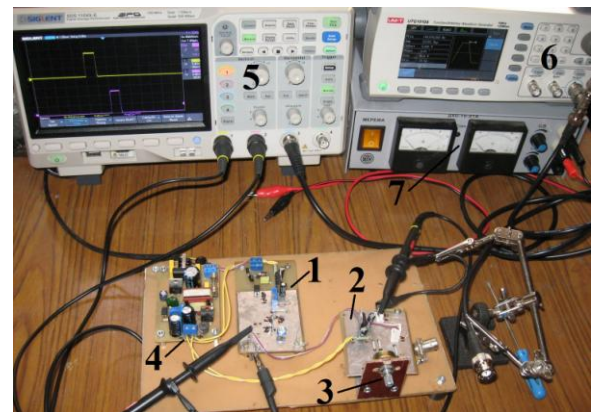


Fig. 8. Test stand, where 1 – MG board; 2 – pulse shaping board with a delay; 3 – potentiometer for adjusting the delay time; 4 – power supply board; 5 – four-channel digital oscilloscope; 6 – measuring generator; 7 – laboratory power supply

The measurement of the shape and characteristics of the signals was carried out with an oscilloscope at the input and output of printed circuit boards (PCB) as well as at intermediate points indicated in the diagrams in Fig. 3 by labels: P1...P4.

Oscillogram in Fig. 9 illustrates the operation of the detector of transition through the "0" phase of the mains voltage and coincide with the results of computer simulation (see Fig. 4).

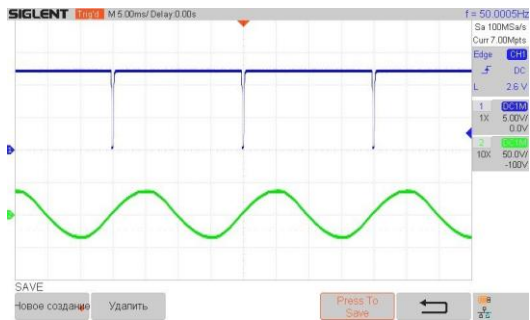


Fig. 9. Oscillogram of voltage at point "P1", upper curve, and sinusoids of supply voltage 220 V, 50 Hz, lower curve. Oscilloscope sweep 100 ms/div

The setting of the repetition rate of the output pulses of the MG circuit was carried out by selecting the value of the capacitor C5 (see Fig. 3.). The results are shown in the oscillograms in Fig. 10.

As can be seen from the oscillograms in Fig. 10, the 5.5  $\mu\text{F}$  capacitor provides the required minimum pulse repetition rate of 1 Hz. The variable resistor R3 can be used to increase the frequency to the upper limit of 5 Hz.

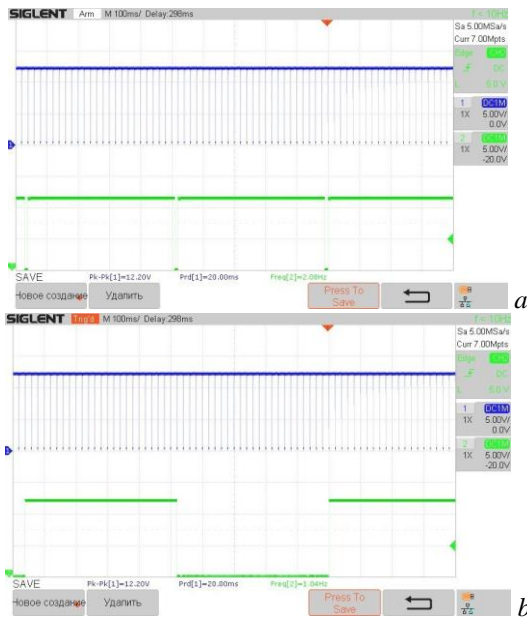


Fig. 10. Oscillogram of voltage: a – at point "P1", upper curve, and voltage at point "P2", lower curve; b – at the point "P1", the upper curve, and the voltage at the point "P3" for the capacitor C5 (see Fig. 3) equal to 5.5  $\mu\text{F}$ . Oscilloscope sweep 500 ms/div

The oscillograms in Figs. 11, 12 show the adjustment of the delay time from 2  $\mu\text{s}$  to 5.5  $\mu\text{s}$ . The adjustment was carried out by potentiometer 4 (see Fig. 9), which is designated in the diagram (see Fig. 4) as R3. Resistor R6 (see Fig. 4) sets the minimum delay between the leading edges of the MG pulses and the output pulse of the delay shaping circuit. Its value was chosen as 2  $\mu\text{s}$  (see Fig. 11,a), despite the fact that the minimum possible delay that can be realized by the circuit (see Fig. 9) is 1  $\mu\text{s}$ . Because the adjustment range starting from 1 to 2  $\mu\text{s}$  is not very suitable, due to the fact that this section is highly non-linear. As you can see, this is due to the fact that until the voltage rise curve at point "P" reaches saturation, as seen in Fig. 11,b and Fig. 12,b, the change in the delay time with increasing R3 will be very small.

The oscillograms in Fig. 11,a and Fig. 12,a show one of the disadvantages of the delay formation circuit. This is that the duration of the output pulse increases from 1  $\mu\text{s}$  at the minimum delay, to almost 1.5  $\mu\text{s}$  at the maximum delay.

Therefore, this drawback was corrected by modifying the delayed pulse shaper circuit in Fig. 6 by adding an emitter follower to the circuit with transistors VT1 and VT2. Although this is not essential for performing TD functions, it can cause some inconvenience for the operator when working with TD, associated with the nonlinearity of the delay time adjustment by potentiometer R3 (see Fig. 6).

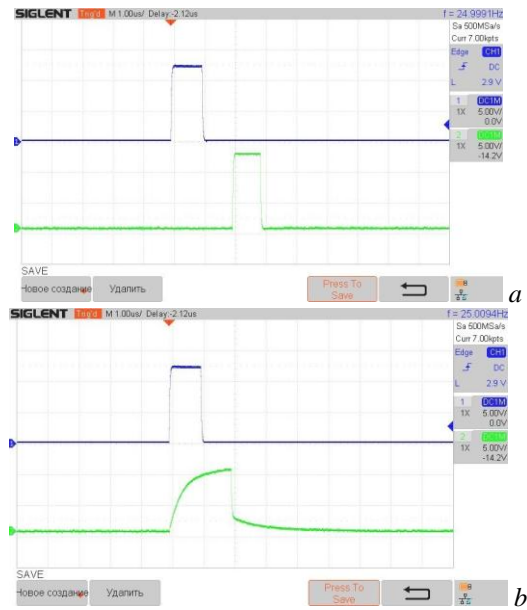


Fig. 11. The oscillogram of the voltage at the output of the MG is the upper curve, at the output of the pulse shaping circuit with a delay (oscillogram (a)) and at point "P" (oscillogram (b)) with a minimum delay. Oscilloscope sweep 1  $\mu\text{s}/\text{div}$

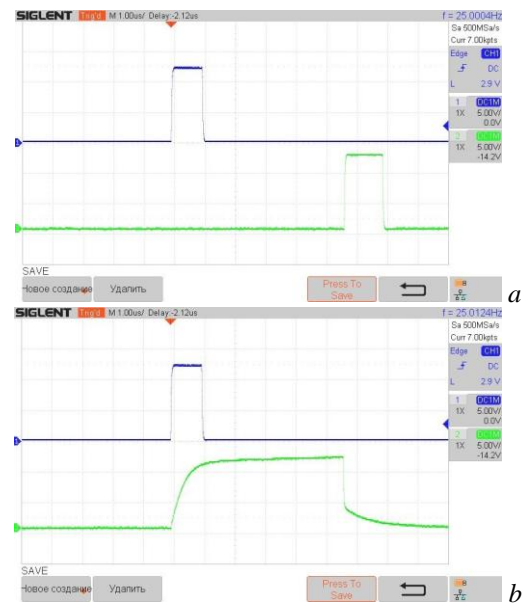


Fig. 12. The oscillogram of the voltage at the output of the ZG is the upper curve, at the output of the pulse shaping circuit with a delay (oscillogram (a)) and at point "P" (oscillogram (b)) at the maximum delay. Oscilloscope sweep 1  $\mu\text{s}/\text{div}$

The modified circuit is shown in Fig. 13. The use of an emitter follower made it possible to increase the current by several times to a value at which the charging current of the capacitor C5, on which the duration of the output pulse of the pulse shaper circuit with a delay depends, will be practically unchanged when the resistance R3 changes.

It can be seen from the oscillograms in the Fig. 14 that the leading edge of both the pulse with the MG and the output pulse with a delay is about 40 ns, which is 4 times better than that of the old TD systems and fully satisfies the necessary technical requirements.

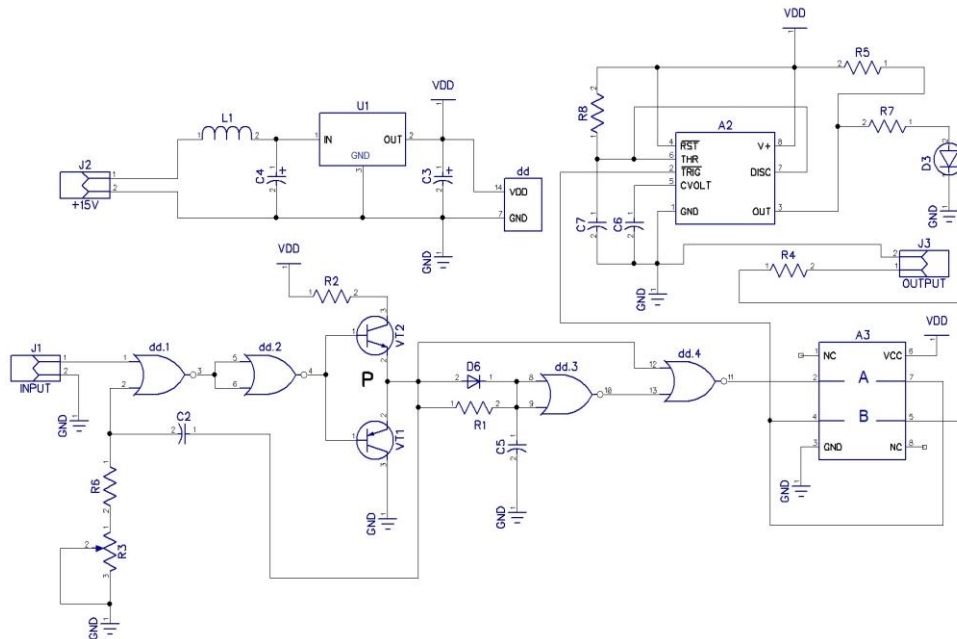


Fig. 13. Modified delayed pulse shaper circuit

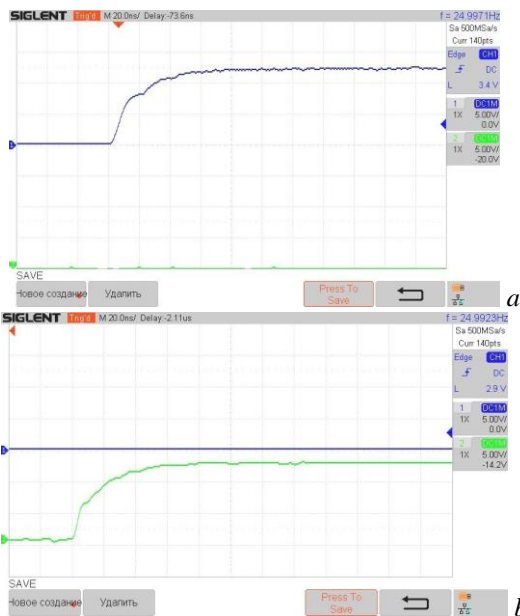


Fig. 14. Oscillograms of the leading edges of the pulses: a – from the output of the MG; b – delay pulses. Oscilloscope sweep 20 ns/div

## CONCLUSIONS

The main elements of the triggering device (TD) have been developed, manufactured and tested: a master generator circuit and a pulse shaping circuit with a delay.

The developed circuits have the following advantages over the old TD systems:

- circuits are assembled on the basis of modern, inexpensive, widespread and commercially available elec-

tronic components, which are characterized by their reliability and energy efficiency;

- the use of modern digital logic microcircuits has made it possible to significantly increase the speed of ultrasonic circuits, reduce the front of the pulses by 4 times, and thereby increase the accuracy of the settings of time delays and their stability;

- rectangular shape of pulses from the outputs of the MG and channels, the delayed pulse shaper circuit greatly simplifies the setup and operation of TD circuits.

As tests have shown, the circuits correspond to the required technical characteristics and can be used for the manufacture of a new triggering device and for its operation at the e-linac "Almaz-2".

The study was supported by the program of the National Academy of Sciences of Ukraine "Advanced Research in Plasma Physics, Controlled Thermonuclear Fusion and Plasma Technologies", project P-1/63-2020.

## REFERENCES

1. G.P. Berezina, K.V. Galaydych, G.A. Krivosov, A.F. Linnik, O.L. Omelaenko, I.N. Onishchenko, V.I. Pristupa, G.V. Sotnikov, V.S. Us. Investigation of multibunch wakefield excitation in dielectric compound-resonator // *Problems of Atomic Science and Technology*. 2018. № 4, p. 86-91.
2. I.N. Onishchenko, V.A. Kiselev, A.F. Linnik, G.V. Sotnikov. Concept of dielectric wakefield accelerator driven by a long sequence of electron bunches // *IPAC 2013: Proc. of the 4th International Particle Accelerator Conference*. 2013, p. 1259-1261.

3. <https://pdf1.alldatasheet.com/datasheet-pdf/view/161279/TI/NE555.html>.
4. <https://html.alldatasheet.com/html-pdf/17681/PHILIPS/HEF4013/246/1/HEF4013.html>.
5. <https://pdf1.alldatasheet.com/datasheet-pdf/view/12072/ONSEMI/MC34151.html>.
6. <https://pdf1.alldatasheet.com/datasheet-pdf/view/17663/PHILIPS/HEF4001B.html>.

*Article received 08.10.2021*

### **РАЗРАБОТКА НОВОГО УСТРОЙСТВА ЗАПУСКА ЛИНЕЙНОГО УСКОРИТЕЛЯ ЭЛЕКТРОНОВ «АЛМАЗ-2»**

*Д.Ю. Залеский, В.И. Приступа, В.С. Ус, О.Л. Омелаенко, Г.В. Сотников*

Разработано и испытано новое устройство запуска линейного ускорителя электронов. Схема устройства запуска состоит из задающего генератора, формирующего прямоугольные импульсы длительностью 1...2 мкс с фронтом порядка 50 нс и с частотой следования от 1 до 5 импульсов в секунду, и трех каналов, вырабатывающих импульсы с задержкой относительно импульсов задающего генератора, которая может регулироваться от 0,1 до 10 мкс.

### **РОЗРОБКА НОВОГО ПРИСТРОЮ ЗАПУСКУ ЛІНІЙНОГО ПРИСКОРЮВАЧА ЕЛЕКТРОНІВ «АЛМАЗ-2»**

*Д.Ю. Залеський, В.І. Приступа, В.С. Ус, О.Л. Омелаєнко, Г.В. Сотніков*

Розроблено та випробувано новий пристрій запуску лінійного прискорювача електронів. Схема пристрою складається з задаючого генератора, що формує прямокутні імпульси тривалістю від 1 до 2 мкс з фронтом близько 50 нс і з частотою проходження від 1 до 5 імпульсів у секунду, та трьох каналів, які виробляють імпульси з затримкою до імпульсів задаючого генератора, яка може регулюватися від 0,1 до 10 мкс.