

## PULSE MODULATORS FOR FEEDING MAGNETRON GUNS

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### Abstract

The paper is concerned with the problems of creating pulsed power sources for high-power microwave devices, using magnetron guns with metallic cold secondary-emission cathodes as electron sources. Consideration has been given to certain ways of generating specially shaped cathode voltage pulses, and experiments were made to initiate the secondary emission process and electron beam generation using these pulses.

### INTRODUCTION

The investigation of magnetron guns with cold metallic cathodes, operating under secondary emission conditions in crossed electric and magnetic fields, have attracted widespread attention in recent years [1-7]. The general principle of operation of these guns is based on secondary-emission multiplication of electrons, generation of an electron cloud and electron beam generation [1, 2, 5] in crossed fields. The interest in these electron sources is due to a number of advantages (long lifetime, high current density, relative simplicity in design, etc.) enabling one to use them as electron sources when creating high-power long-term microwave devices [1, 8-10]. The present paper is devoted to the problems of creating pulse modulators with a complete discharge of the formation line for feeding microwave devices, using magnetron guns with cold secondary-emission cathodes as the basis.

### Requirements on the parameters of voltage pulses during beam generation

The electric field in the anode-cathode spacing needed to generate the beam in the magnetron gun must have two time intervals (Fig. 1): the first with a decreasing field, during which the secondary-emission multiplication and the formation of electron cloud around the cathode take place, and the second interval with a constant field providing a steady-state stage of the secondary-emission process and the beam generation [1, 2]. The pulse rise and decay rates determine the stability of beam generation and the time instability of the beam-current pulse front generation. The nonuniformity of the flat part of the pulse top can lead to the beam-current pulse modulation or to its upset at nonuniform parts of the voltage pulse top and

to the generation of a few electron bunches in a single voltage pulse [5]; it also determines the permissible energy spread of the electron beam.

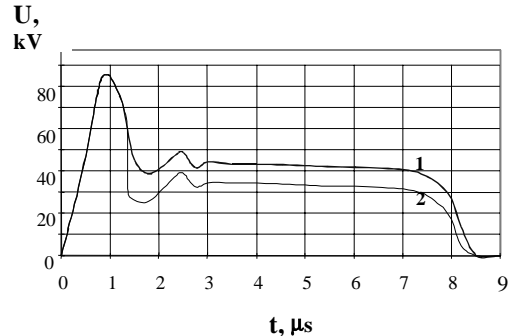


Fig. 1 Oscillograms of voltage pulses from the cathode of the magnetron gun. 1 - idle running of the modulator; 2 - beam generation regime.

For creation of powerful microwave devices with magnetron guns, pulse modulators with a complete discharge of the formation line can be used as power sources. The time dependence of the electric field in the anode-cathode spacing, needed for beam generation, can be provided by several methods.

### EXPERIMENTAL

#### 1. Formation of a specially shaped voltage pulse

This method is based on the formation of the voltage pulse of special shape (overshoot and a flat part) in the modulator with a complete discharge of the formation line. The shape can be formed with the help of the correcting capacitor  $C$  (Fig. 2a) placed in parallel with the formation line [12]. Varying the  $C$  value, one can set the overshoot amplitude.

The possibility of shaping the undershoot in the cathode voltage pulse was verified experimentally. The formation line ( $\Phi\text{Л}$ ) had a wave resistance of 40 Ohm, a 4.5  $\mu\text{s}$  pulse length at half-maximum, the transformation coefficient of pulse transformer  $n = 5$ , the load resistance  $R_H = 2000$  Ohm. The secondary winding of the pulse transformer ( $\text{ИТ}$ ) was connected to the magnetron gun ( $\text{МГ}$ ). In the absence of the correcting capacitor and with the modulator running idle, the voltage pulse had a 25% overshoot of the voltage pulse amplitude (Fig.2b, curve3). With the

connection of the correcting capacitor  $C = 15$  nF the overshoot amplitude was 80% (curve 2), and for  $C = 7.5$  nF the overshoot amplitude was 50% (curve 1) of the voltage pulse amplitude. The rate of pulse decay was measured to be  $40$  kV/ $\mu$ s and  $25$  kV/ $\mu$ s, respectively, and the pulse decay time was  $0.6$   $\mu$ s at a flat-top voltage amplitude of  $\sim 32$  kV.

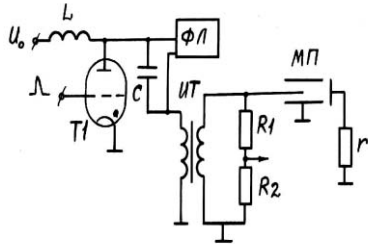


Fig. 2a

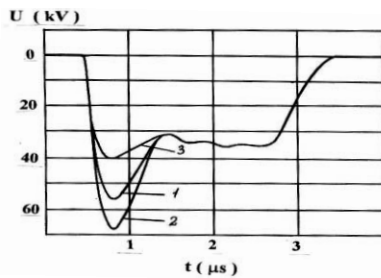


Fig. 2b

The pulse decay time in this formation circuit is generally hundreds of nanoseconds, this being due to the influence of stray parameters of the modulator's output circuit, i.e., stray inductance and capacitance of the pulse transformer. At the same time, the leading-edge time and the time instability of the beam-current pulse front make tens of nanoseconds.

Experiments were made at these conditions to investigate the beam generation in individual injection guns with secondary-emission cathodes. As the mentioned voltage pulse is applied to the gun cathode and the beam is generated, the consumed power drastically increases as compared to the mode of idling running, and the modulator is operated nearly at matching. This leads to the decrease in the amplitude of the flat part of the cathode voltage pulse due to the beam load, and the overshoot amplitude considerably exceeds the flat part of the pulse height. In one of the modes of operation the overshoot amplitude was  $\sim 60$  kV, the amplitude of the flat part at idling running was 37 kV, while on generation of the electron beam with a current of 9 A it was measured to be 30 kV. With an increasing amplitude of the flat part of the pulse that corresponds to the increase in the particle energy, the overshoot amplitude, which is restricted by the electric strength of the gun, also increases.

## 2. Cathode voltage pulse formation by summation of the cathode pulses

By this method, the summation of two voltage pulses, namely, a short pulse with a steep overshoot

and a lengthy pulse with a flat top, takes place at a common load, i.e., cathode. Owing to the pulse delay, there arise a drooping part of the summed pulse and a flat top which secure the process of secondary-emission multiplication and beam generation, respectively. With a separate pulse shaping, the pulse generator generating the secondary-emission trigger pulse has an output resistance equal to the resistance of the shunt resistor, and the modulator with a complete discharge of the formation line that provides the beam generation has the output resistance close to the resistance of the load. Let us consider the circuit of generating the cathode pulse with a separate formation of the trigger pulse and the pulse for beam generation. The circuit of pulse modulator with a complete discharge of the formation line (Fig. 3a) includes two commutators. Commutator T2 switches the capacitor C charged through the charging resistor R up to the voltage  $U_0$ , to the primary winding of the pulse transformer (ИТ), and commutator T1 switches the formation line (ФЛ) to the same winding, too. With the discharge of the capacitor C, a voltage pulse with an exponential drop is formed at the cathode of the magnetron gun (МП). As the formation line with the wave resistance close to the reduced load resistance is discharged through the primary winding of the pulse transformer, a voltage pulse, nearly rectangular in shape, is formed at the gun cathode. With the delay of the rectangular voltage pulse with respect to the exponential pulse by means of the delay line (ЛЗ), a summated voltage pulse can be formed at the cathode (see Fig. 3b, curve 1).

This pulse formation circuit was investigated experimentally at a low wave resistance of the formation line,  $\rho = 15$   $\Omega$ , charging resistor  $R_3 = 500$  k $\Omega$ , capacitor = 7.5 nF, load resistance  $R = R_1 + R_2 = 4000$   $\Omega$ . The "running idle" overshoot amplitude was  $\sim 15$  kV, the flat-top pulse amplitude made up about 2 kV, the pulse delay  $\Delta T = 0.3$   $\mu$ s, the fall time was 0.5  $\mu$ s. At a beam current of 23 A, the flat-top pulse amplitude was  $\sim 13$  kV (Fig. 3b, curve 2). It is seen from the figure that the overshoot amplitude and the amplitude of the main part of the pulse at the beam generation are practically the same. This permits an appreciable increase of the particle energy.

Similarly to the first method, the fall time in this circuit ranges up to hundreds of nanoseconds, this being due to the influence of stray parameters of the output circuit of the modulator. The shape of the summated pulse top is also determined by the "straggling" of thyatron response time that can attain fractions of microsecond. That results in an insignificant variation of the fall time and amplitude. The pulse rise time and the time instability of the beam current pulse leading edge also attain tens of nanoseconds.

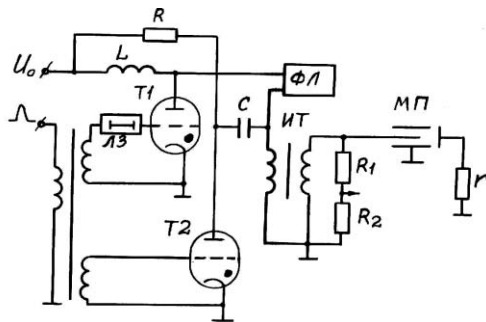


Fig. 3a

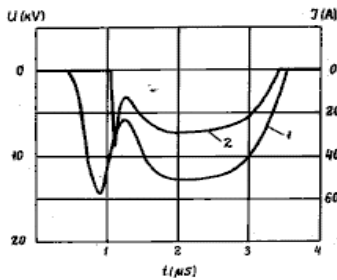


Fig. 3b

The present pulse formation circuit was used to investigate the generation of powerful electron beams in the system comprising 8 magnetron injection guns with secondary-emission cathodes, where the in-beam pulse power of 2.5 MW was reached at a particle energy of ~30 keV. In a single magnetron injection gun this power attained 5 MW at a particle energy of ~100 keV [6, 7].

### 3. Formation of the cathode voltage pulse by separately applying pulses to the gun electrodes

This method lies in the electric field summation of two pulses (long flat-top pulse applied to the cathode and a short (“triggering”) time-delayed steep-fall pulse applied to the gun anode) in the anode-cathode spacing. This provides the necessary time dependence of the overall electric field and the beam generation. Unlike the previous method, the generators have no common circuits, and the separation of the pulse supply circuits makes it possible to use a wide-band transfer line to transfer the “trigger” pulse. In this case, the pulse decay time at the anode is determined by the design capacity of the anode and can attain several nanoseconds.

Experiments by this method [6, 7] were performed with single magnetron injection guns at different cathode/anode diameters for cathode voltage pulse amplitudes between 5 and 40 kV of 0.5 to 8  $\mu$ s length and an anode voltage pulse amplitude between 2.5 and 15 kV with a fall time of 2 to 90 ns.

At a significant pulse rise rate (up to 1 MV/ $\mu$ s) and a small fall time (2 ns) a beam-current pulse front length of about several nanoseconds was reached. This provides the beam-current pulse synchronization to a nanosecond accuracy. The beam

current can be generated in this case at different moments of time at the voltage pulse top by varying the delay time of the trigger pulse.

## CONCLUSION

Analysis and experiments were made to develop the pulse modulator for feeding powerful microwave devices with the secondary-emission cathode magnetron guns as the basis. The feasibility of creating high-power power sources for operation of these guns is demonstrated. Experiments were made to generate the beam using the power sources under consideration. The results obtained experimentally have shown that the first modulator has a simpler circuit, but the flat-top pulse amplitude is small in comparison with the overshoot amplitude. The second modulator has a more complicated circuit, but the flat-top pulse amplitude is comparable with the overshoot amplitude. In the third method, with an increasing electron energy the reliability of the system and the stability of beam generation is higher than with the other methods, this being due to a small amplitude and a short trigger pulse length. The voltage pulse formation circuit is chosen depending on the operation conditions of microwave devices.

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