Compact high voltage pulse generator for DBD plasma jets

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Abstract. Compact low-power high voltage pulse generator for DBD plasma jets was developed and assembled. There is a function of voltage pulse value and pulse repetition frequency regulation with the fascia control panel of the generator. The voltage amplitude can be set at the level of 0-6 kV. There are two frequency bands: 10-100 Hz and 0.1-1 kHz. The high voltage pulses of 12 µs duration have nanosecond rise and fall time 20 ns. The generator is powered by 220 V, 50 Hz. The overall dimensions of the device – 105×260×180 mm, its weight is less than 2 kg. The generator was successfully tested on DBD plasma jets. The average power up to 0.3-0.4 W was obtained in plasma depending on discharge electrode system.

1. Introduction
Recently low-temperature atmospheric pressure plasma sources find more and more applications in medicine and biology.

There are three mechanisms of plasma exposure on the object [1]. Direct exposure is suitable for large areas treatment. It uses floated DBD [2]. Indirect exposure occurs in plasma jet, when the plasma is blown out from a discharge chamber [3-6]. The third one is a hybrid of direct and indirect mechanisms [7]. A limiting factor of use a direct exposure DBD is a short mm-distance between the object and the HV electrode. The safest plasma sources are plasma jets and they can produce distant plasma spreading up to 10-20 mm from the discharge chamber.

The efficiency and safety of the plasma jet depends on a construction of electrodes, a voltage waveform, a pulse repetition frequency (PRF) and a gas flow rate. The most common construction is coaxial electrode system. Argon and helium are ordinary used as a working gas. And the most suitable plasma jets are based on DBDs.

Various power supplies are used for different plasma sources according to electrode system, exposure mechanism and gaps. The plasma source for biomedical applications must be safe and regulated.

There are many works where DC, sinusoidal, RF, microwave and pulsed power supplies are used for plasma jets [8, 9]. The most suitable power supply for medical applications is a pulse power supply due to an opportunity of a smooth discharge power regulation.

The paper deals with a construction of a compact low-power high voltage pulse generator for DBD plasma jets and its operation in two constructions of DBD plasma jets.
2. Generator design
The generator consists of a DC high-voltage source board, a switch driver board, two high-voltage composite solid-state switches connected by a half-bridge scheme and a control board (figure 1).

![Generator design](image1)

**Figure 1.** Generator design.

2.1. 6 kV DC board
The HV-DC board is assembled according to the standard switched mode power supply (SMPS) scheme: an EMI filter, a full-wave rectifier circuit, a half-bridge inverter with MOSFET-transistors controlled by PWM controller operating at 200 kHz frequency, a step-up transformer, a voltage multiplier [10] (figure 2). Also there is a low-power AC/DC module providing low-voltage supply of the scheme.

The process of electric energy converting consists in primary converting 220V AC to 310 V DC and 12 V DC. Then the half-bridge inverter converts 310 V DC to high frequency 310 V AC (200 kHz). Step-up transformer increases the voltage up to 600 V AC. Voltage-multiplying rectifier convert this AC voltage up to 6 kV DC. Due to the HV voltage divider the feedback signal goes to the PWM-controller and the latter changes the duty cycle influencing on the voltage level in the primary winding of the transformer.

The advantages of such schematic use are simplicity, high efficiency and reliability. It is short-circuit-stable. The elastic feedback allows controlling the output voltage value by means of a variable resistor, which is located on the front panel of the device and connected with the board by a flat ribbon cable.

![6 kV DC board](image2)

**Figure 2.** 6 kV DC board.
2.2. The control board
The control board is a two-channel low-voltage pulse trigger generator. Two precision timers form the control pulses. The first one creates pulses with a definite frequency. They go to the first channel output and to the input of the second timer. The latter creates pulses for the second channel using pulses from the first one as trigger pulses. The second and the first pulses are time-shifted. The pulse frequency can be changed by means of a toggle switch (switching between the bands) and a variable resistor (for smooth adjustment). Both instruments change the parameters of RC-circuit of timers. The delay time between the trigger pulses, determining the duration of the output high-voltage pulse, is fixed.

2.3. The switch driver board and HV composite solid-state switches
The driver board consists of two MOSFET transistors and their drivers, low-power dc-dc converter and HV storage capacitors (figure 3).

The board works as follows. Two time-shifted pulses from the control board go to MOSFET drivers which control the MOSFET transistors in current loops. When the first pulse arrives, it opens the high side composite switch and connects the HV capacitor with the output for approximately 200 ns. Then, after 12 microseconds, the second pulse opens the low side composite switch and connects the output with the ground for the same time.

High-voltage composite solid-state switches are realized by a set of six series-connected 1200 V IGBT-transistors, controlled by means of the transformer coupling of their gates and the drivers’ current loops [11, 12]. The low-power dc-dc converter is a DC boost converter. It converts 12 V DC to 150 V DC. The latter is necessary for creating current pulses in the control loops of the switches.

3. Generator operation on capacitive load of DBD plasma jet
The generator was developed as a power supply for DBD plasma jets.

Several tests were carried out with two coaxial electrode systems:
1) for realizing surface DBD (SDBD);
2) for realizing volume DBD (VDBD).

The SDBD was used in the first construction as a generator capacitive load. Two parts of copper foil, placed on the inner and outer cylindrical surfaces of quartz tube, were used as electrodes.
(figure 4). The equivalent capacitance of that system was about 5-6 pF. These experiments were conducted in air at atmospheric pressure with gas flow 5-10 l/min.

![Figure 4. Discharge gap geometries for SDBD and VDBD.](image)

The measurement scheme is shown in the figure 4. It consists of the HV pulse generator, the coaxial electrode system, the resistive low-inductive current sensor with sensitivity 40 A/V and the HV voltage probe Tektronix P6015A.

The dielectric barrier discharge in such electrode system in air occurs when voltage level less than 4 kV. Further increase of voltage leads to discharge current increase. The waveforms of current and voltage are shown in the figure 5. The voltage waveform is a HV rectangular pulse with the maximum 6 kV value. Its duration is about 12 µs, the rise and fall time (10-90%) is about 20 ns. The duration of the current pulse is about the rise time, the peak current is 2.6 A. It’s seen from the current waveform that the discharge current appears on the voltage pulse edges.

![Figure 5. The waveforms of SDBD current and voltage in air.](image)

The QV-diagram allows to determine the pulse energy of the discharge and average power, correspondently (figure 6a) [13]. The pulse energy of SDBD in air at 6 kV was about 0.44 mJ. The average power was 0.44 W at frequency of 1 kHz.

The same test experiments were carried out with VDBD electrode system (figure 4). The equivalent capacitance of that system was about 4-5 pF. The helium was used as a gas. In this case the ignition discharge voltage was lower, about 2-2.5 kV. The pulse energy was defined from QV-diagram presented in figure 6b. It was about 0.3 mJ at 6 kV. At PRF = 1 kHz, the average power was 0.3 W.
The photos of the generator with VDBD electrode system and the plasma jet in operation are shown in figure 7.

![Figure 6. QV-diagram: a) air, 5 L/min; b) helium, 5 L/min.](image)

![Figure 7. Compact low-power high voltage pulse generator for DBD plasma jets: a) pulse generator common view; b) DBD plasma jet operation.](image)

4. Conclusion
Compact low-power 6 kV pulse generator for DBD plasma jets was developed and assembled (figure 7). It was tested on a capacitive load, DBD coaxial electrode systems. The generator can be successfully used in biomedical application where low amount of energy is necessary. The function of voltage pulse value and PRF regulation allows controlling the amount of discharge power. Additional advantage of the device is its compact construction. The overall dimensions of the device – 105×260×180 mm, its weight is less than 2 kg.

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