Compact high-current pulse generator for laboratory studies of high energy density matter

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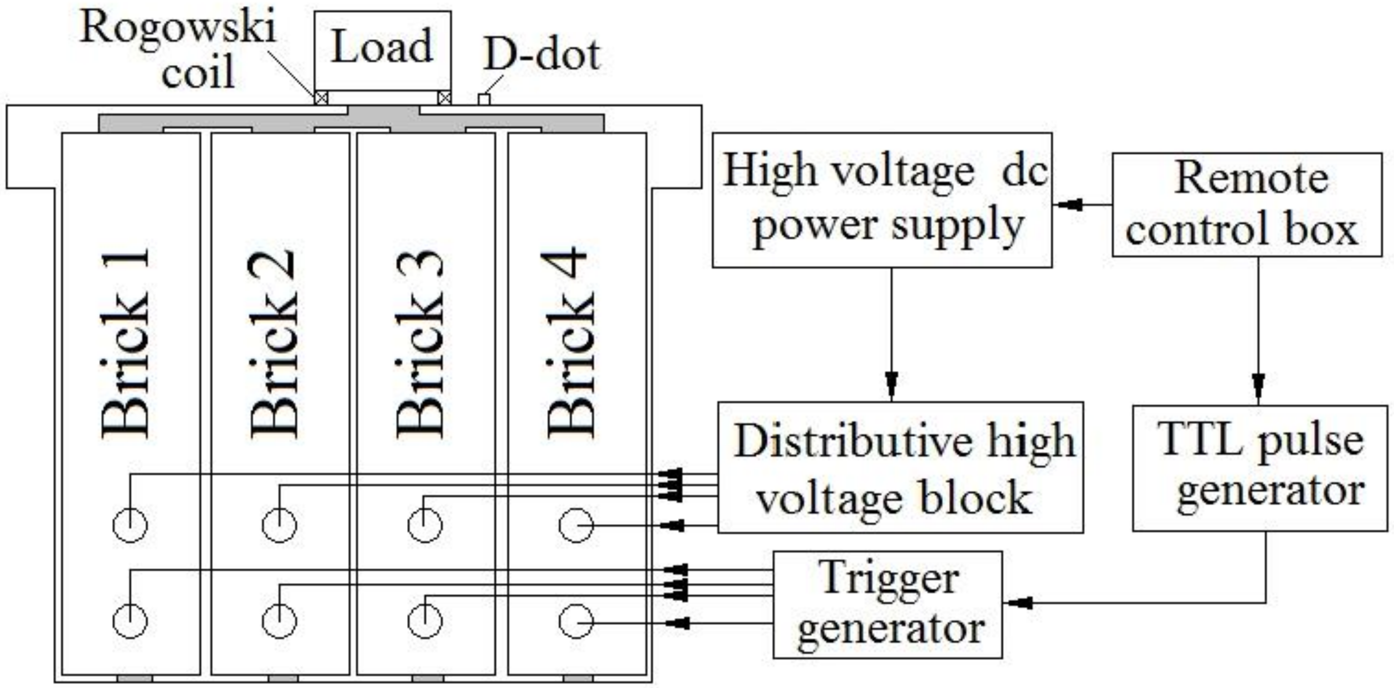
We present the design and parameters of a compact and mobile high-current pulse generator, which can be applied in the study of warm dense matter in university laboratories.

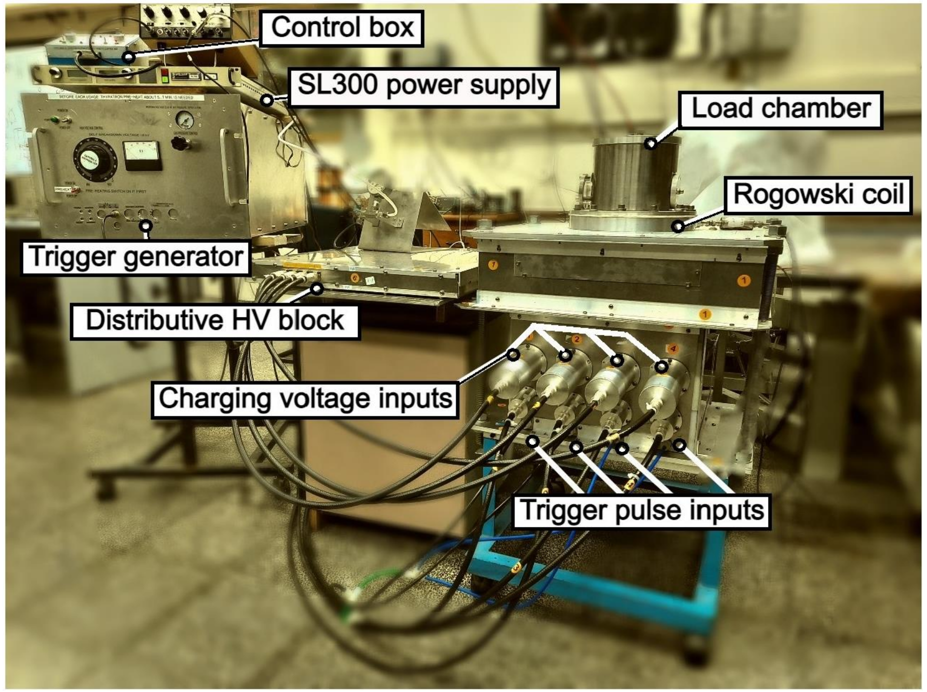
The generator dimensions are 550 × 570 × 590 mm^3, the weight is 70 kg, and it consists of four “bricks” connected in parallel. Each brick, made up of 2 × 40 nF, 100 kV low-inductance capacitors connected in parallel, has its own multi-gap and multichannel ball gas spark switch, triggered via a capacitively coupled triggering by a positive polarity pulse of 80 kV amplitude and 15 ns rise time.

At a charging voltage of 70 kV, the generator produces a 155 kA current pulse with a rise time of 220 ns on a 15 nH inductive short-circuit load and a 90 kA amplitude current pulse in the underwater electrical explosion of a copper wire.

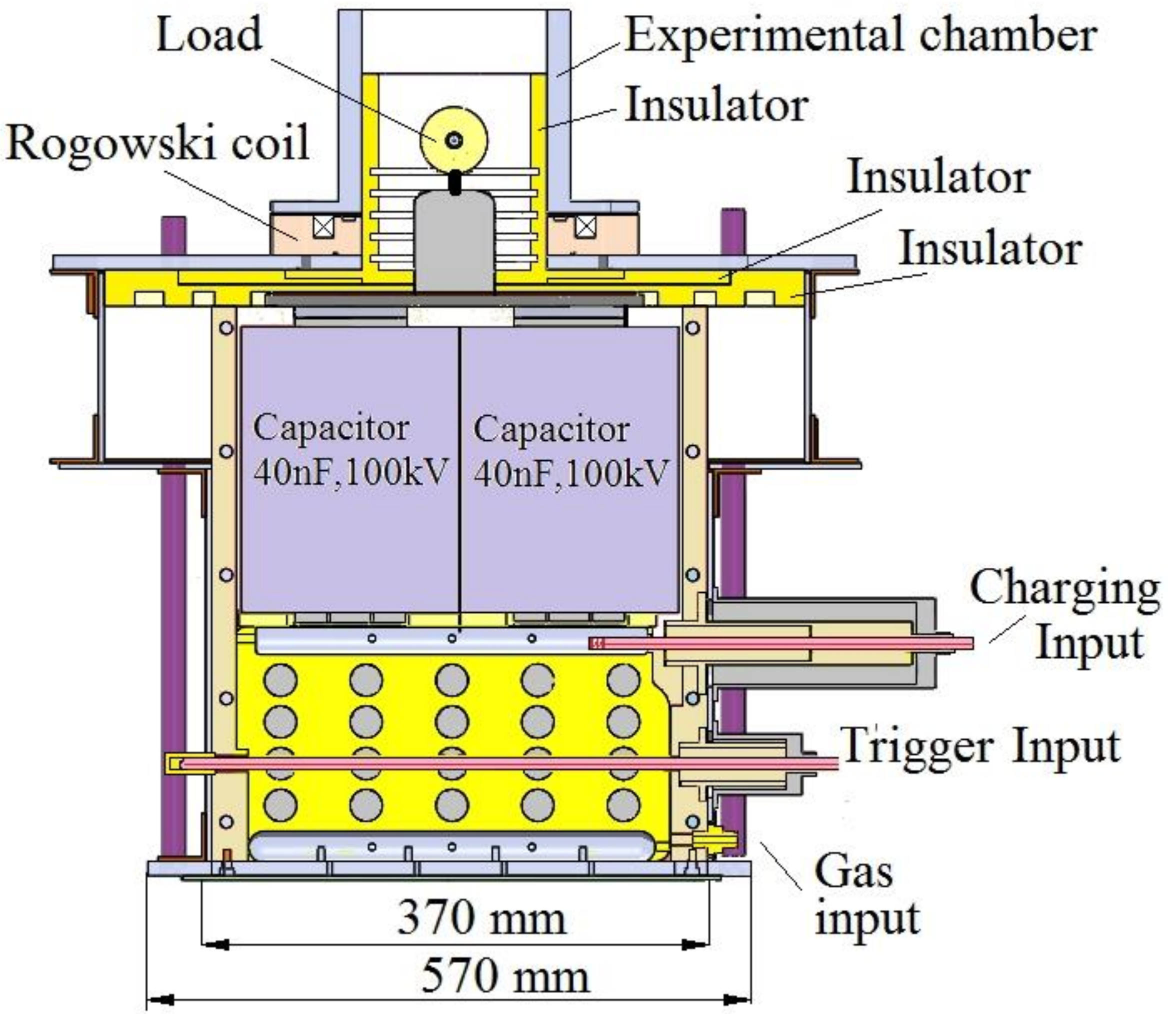
Generator Design

The design and parameters of a compact and transportable low-impedance, high-current pulse generator with a stored energy of up to 1 kJ at a maximum charging voltage of 80 kV are presented. The generator, named “SG generator,” is comprised of four bricks, a HV charging distributing unit, and a trigger generator.





Generator scheme



The SG generator consists of four bricks. Each brick consists of two low-inductance HV capacitors (40 nF, 100 kV, 15 nH) connected in parallel and a multigap, multichannel ball gas spark switch with capacitively coupled triggering.

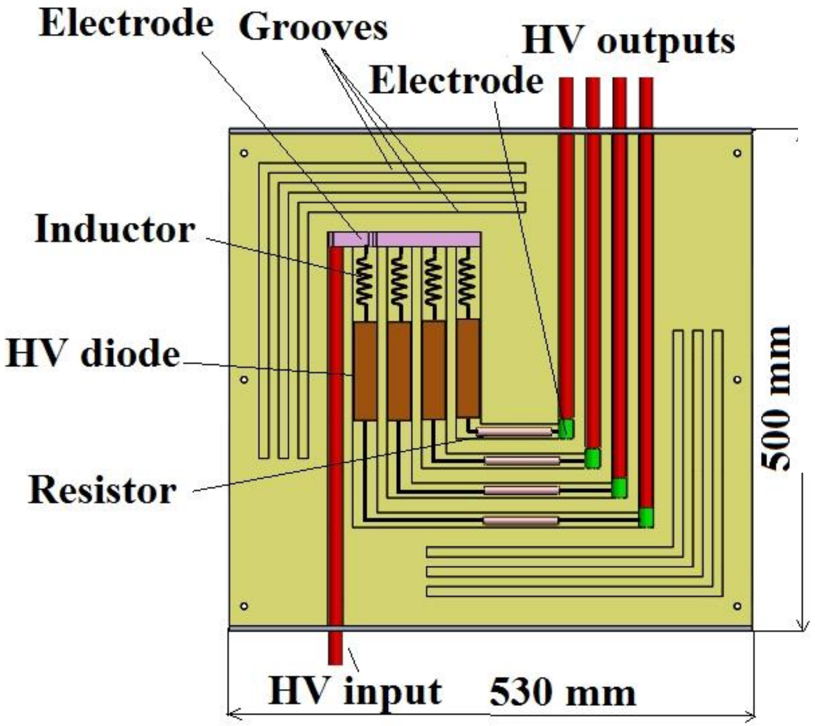
The brick design allows it to be dismantled into the Delrin made base and cover parts, making maintenance simple.

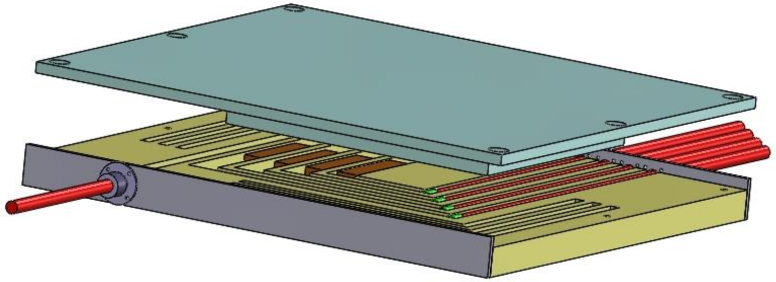
The base contains two capacitors connected by a common HV electrode, “grounded” via the load resistance during the charging process. On one of the sides of the base part, three holes were made for the HV, triggering, and gas inputs, whereas on the other side, there is a hole for the trigger cable output.

In the base part, there is also a cavity for the switch unit. This base, containing capacitors, is covered by a Delrin plate and locked by dielectric bolts. Thus, a brick is an insulated box containing two capacitors and side holes for HV, triggering, and gas inputs together with a cavity for the switch unit installation.

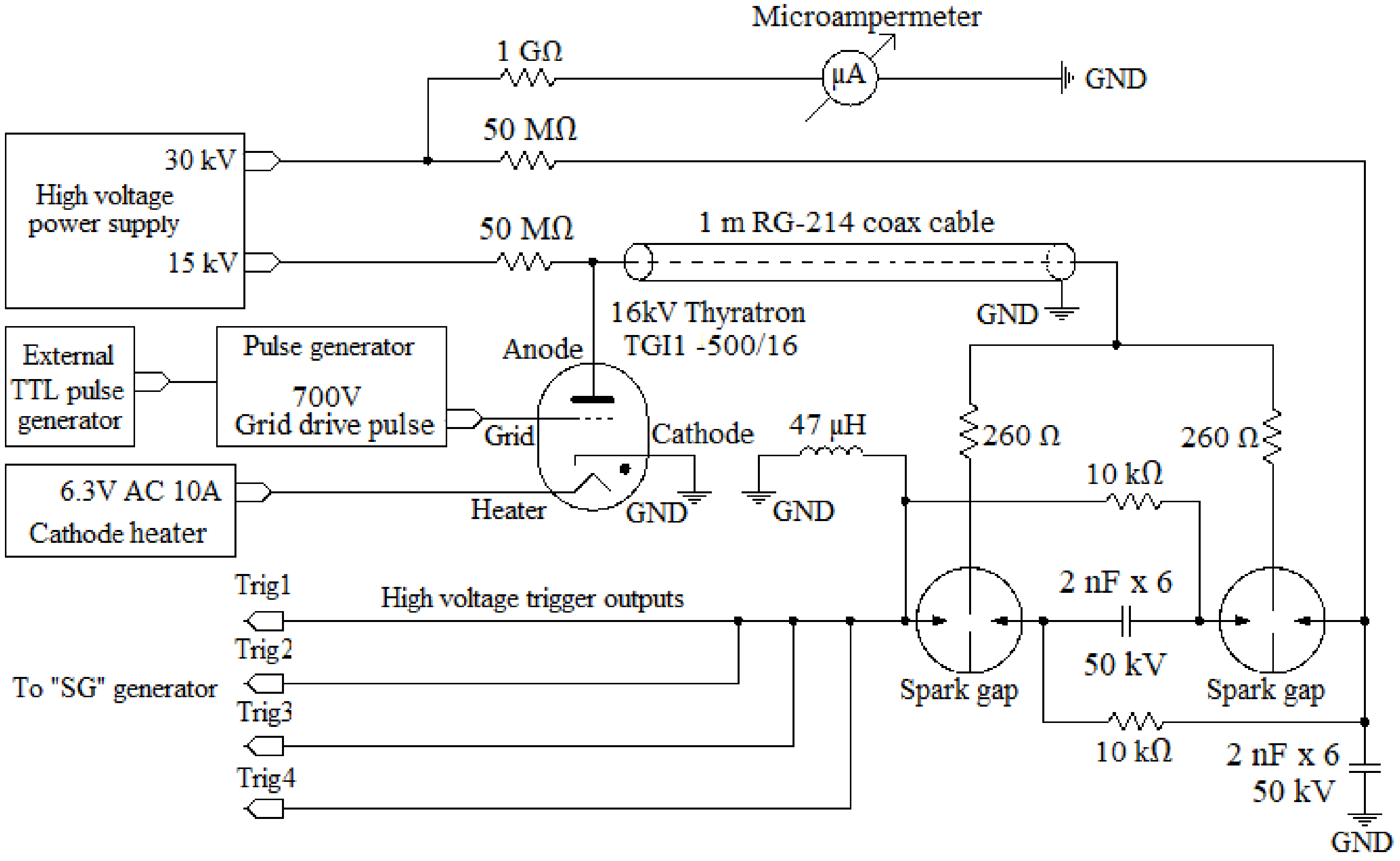
DC high voltage distributor block

The distributive block is connected to an SL300 DC HV power supply which is controlled by a specially designed remote control box which regulates the charging voltage and current. The distributive block is used to charge each of the four bricks in the generator using 4 HV coaxial cables.





Trigger generator



The trigger generator is a two-stage Marx generator with an output capacitance of 6 nF. Each stage consists of six low inductance ceramic high-voltage capacitors (2 nF, 50 kV) connected in parallel and two gas spark switches with central electrodes at half the charging voltage.

A trigger pulse, produced by a discharge of coaxial line using Thyratron which in its turn is controlled by a TTL pulse triggered electronic scheme, is applied to these electrodes.

At a charging voltage of 30 kV, the generator produces at its output a HV pulse with a rise time of 10 ns and amplitude of 100 kV on a high-impedance load, 47 μH inductance. The jitter between the input TTL pulse and the output HV pulse does not exceed ±10 ns.

Test of the generator

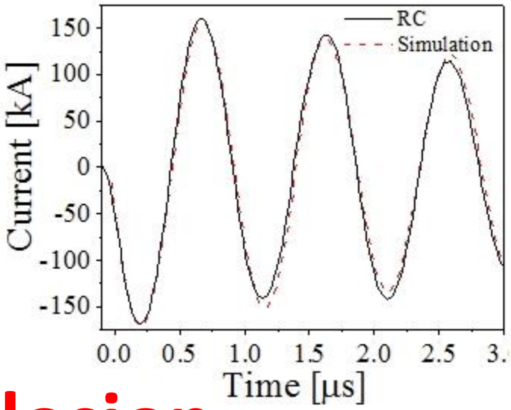
Experimental data of the short circuit tests was compared to simulations of a simplified RLC circuit

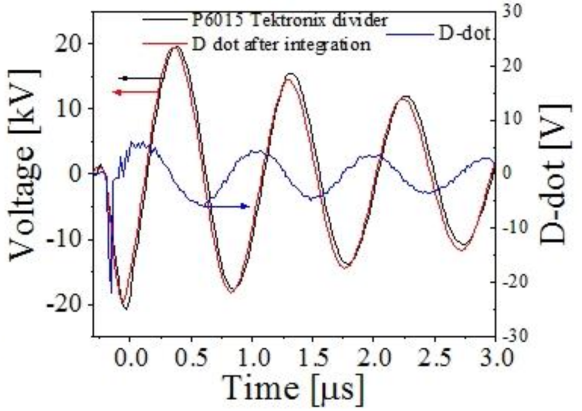
$$\frac{d^2}{dt^2}I(t) + 2\beta\frac{d}{dt}I(t) + \frac{I(t)}{LC} = 0$$

Here $\beta = \frac{R}{2L}$ is the decay constant and $C = 320\ nF$ is the generator total capacitance. The solution of the equation was fitted to experimental data by adjusting the value of L, which in turn determine R.

Short circuit

Short circuit tests yielded a current waveform having a quarter period of ~220 ns rise time and amplitude of ~155 kA. Circuit simulations showed that the total discharge circuit inductance does not exceed ~60 nH the inductance of the SG generator itself <30 nH.





Single Copper wire explosion

Finally, explosions of a single copper wire, 40 mm in length with a 0.25 mm diameter under a 70 kV charging voltage were performed. The wire explosion is characterized by a critically damped discharge with 90 kA maximum amplitude and 220 ns rise time where 80% of the stored energy is deposited into the wire within 200 ns. The energy density deposition rate is $\sim 1.5 \times 10^{11}\ J/(g \cdot s)$, and the deposited energy density is 22 eV/atom.