A 6 kV–150 A, 8 ns rise time pulse generator for excitation of ferroelectric cathodes

I. Boscolo and S. La Torre
University and INFN, via Celoria 16, 20133 Milano, Italy

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A pulse generator with the following characteristics is presented: the voltage ranges in the interval 0.1–6 kV, the maximum delivered current is 150 A, the pulse length ranges within the interval 100–300 ns, the rise time and the decay times are, respectively, 10 and 25 ns on 50 Ω resistive load and the repetition rate is higher than 1 MHz. The circuit has a source capacitor of 10 nF charged at the needed voltage, the capacitor feeds the load through a parallel of two fast and high voltage solid state switches. The nanosecond rise time and the square fashion of the pulse have been accomplished arranging all the components in cylindrical symmetry. A bipolar pulse is obtained coupling two circuits with opposite polarity. © *1999 American Institute of Physics.* [S0034-6748(99)02502-2]

Fast polarization switching of ferroelectric ceramics used as electron emitters[1] require fast voltage pulse generators of some kV and 100 A. We have built such a generator for our experimental system devoted to studies on electron emission from ferroelectric ceramics. The pulse generator acts upon a ceramic disk, which behaves as a nonlinear capacitor of typically 500 pF. The current necessary for charging this capacitor at 2 kV in 20 ns results in $I_c = CV/\tau = 100$ A. The capacitor is placed parallel with a resistor of some tens of ohms in order to drain off the charge which remained in the capacitor after the emission (so the excitation–emission cycle can restart). The parallel resistor absorbs a current $i = V/R$, i.e., some tens of amperes. Because of the capacitor–resistor parallel the feeding pulser has to provide more than 100 A.

The pulse generator for the electric excitation of ferroelectric cathodes must provide the three types of pulses: square positive, square negative, and bipolar.

The electric scheme of a pulser with the above-mentioned features of high current, high voltage, short rise time, and duration has to be based on the idea of a capacitor charging and its discharging for the required time duration (Fig. 1). The charging phase can be relatively slow, while the discharging must be as fast as possible. In addition, the square fashion of the pulse requires such a value of the storage capacitor that the emitted charge per pulse is negligible compared with the stored one. The repetition rate ranging from several kHz up to the MHz are required depending on the utilization.

The controlled switches, which gate the flux of current into the external load, are the most difficult technological items of the system, due to the strict requirements of high current and nanosecond reaction time and relatively high repetition rate. We have chosen solid state switches, that is a parallel of five lines of ten field effect transistors in series (see Fig. 2), instead of gas switches, as thyratron and (less frequently used) cold cathode tubes, and triggered spark gaps, because solid state switches are much easier to feed

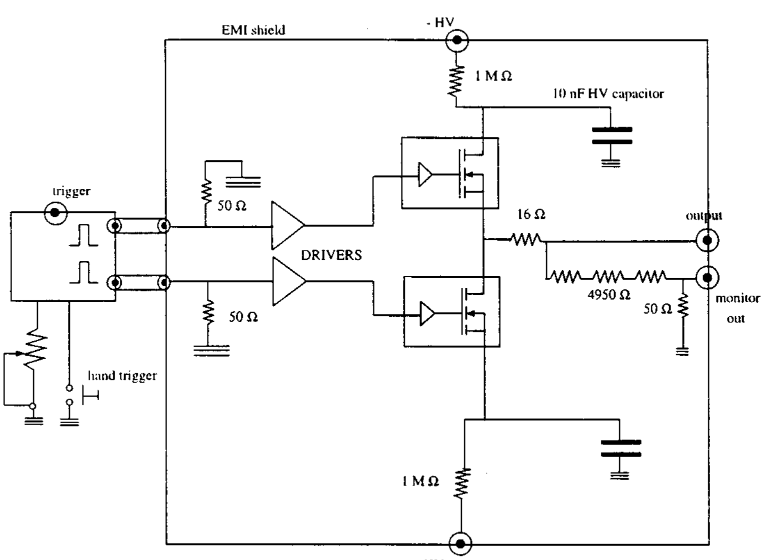

FIG. 1. Schematic of the circuit. The high voltage capacitors are 10 kV low inductance capacitors. The 16 Ω carbon film resistor at the output is for switches protection against possible short circuits.

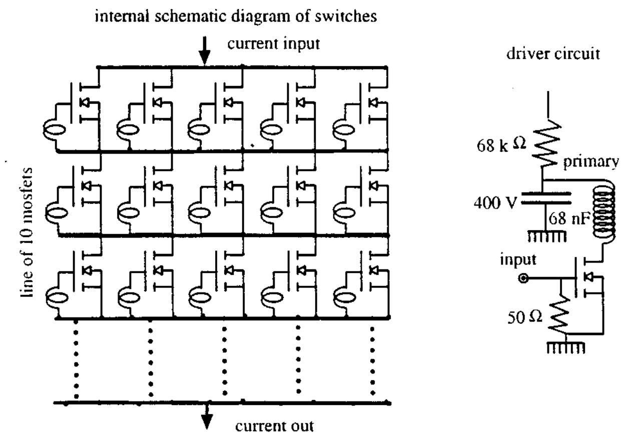

FIG. 2. Scheme of one of the two switches built for the pulser and of one driver circuit.

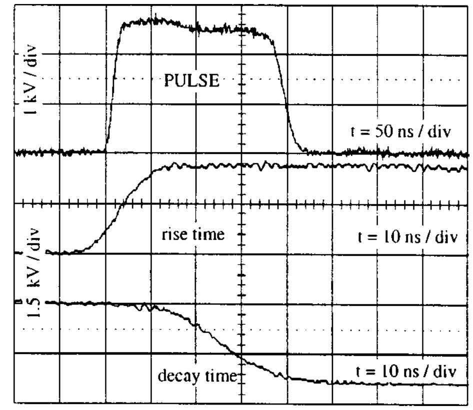

FIG. 3. Voltage pulse wave form, with a resistive load of 50 Ω: the rise time is 8 ns, while the decay time is 25 ns. The pulse duration can be extended from some tens of nanoseconds up to 500 ns.

and drive in comparison with the latter ones.[2] In addition, these gas switches have finite lifetime and unstable characteristics contrary to solid state switches. Our chains of (MOS)POWER fets are triggered synchronously by the trailing edge of the gate pulse because each of them is coupled to the drive circuit. The coupling is inductive in order to set a galvanic isolation between the metal–oxide–semiconductor field effect transistor (MOSFETs) and the drive circuit (see Fig. 2).

The model STP5N90 POWER MOSFET of the SGS-Thomson catalog have been chosen for our switches. They operate in avalanche mode in the pulser. Their main characteristics are: $V_{\text{drain-source}}=900$ V, $I_{\text{drain}}=20$ A in pulsed mode and fast shutting. A very careful assembling of these transistors, that is a compact mounting so as to avoid stray inductances at the maximum extent, led to switches with very short recovery time and low jitter, as is summarized in Table I. These characteristics are quite better than those of conventional high voltage gas switches. The recovery time of a switch is determined by the turnoff of each MOSFET and by the relaxation time of the network connecting all the MOSFETs. However, the recovery time is so short that the repetition rate is determined by the time required for cooling the whole switch. The generator has been tested for a repetition rate around 25 kHz. It is possible to obtain a sequence of trains having a frequency of a couple of MHz, but occurring at around the millisecond rate.

In Fig. 1 the electrical scheme of the pulse generator is shown. In order to exploit the extremely rapid rates of voltage and current possible with our switches, the criteria for the circuit design are: maximum compactness, low inductance leads and components, cylindrical and/or stripline geometry at the maximum possible extent. Two 6 kV external generators feed the 10 nF source capacitor through a 1 MΩ resistor. This current limiting resistor can be reduced in relation with an enhancement of the current of the feeding power supply. This would allow an increase of the repetition rate of the pulser. The source capacitor is connected to the load by two switches set in parallel. The switches can be

TABLE I. Switches specifications.

Max. operating voltage	6 kV	single pulse
Max. operating voltage	±3 kV	bipolar pulse
Max. peak current	150 A	pulse width ≤200 ns
Turn-on rise time	8 ns	on 50 Ω and 3 kV
Turn-off rise time	25 ns	on 50 Ω and 3 kV
Recovery time	≤1 μs	
Internal resistance	≈4 Ω	

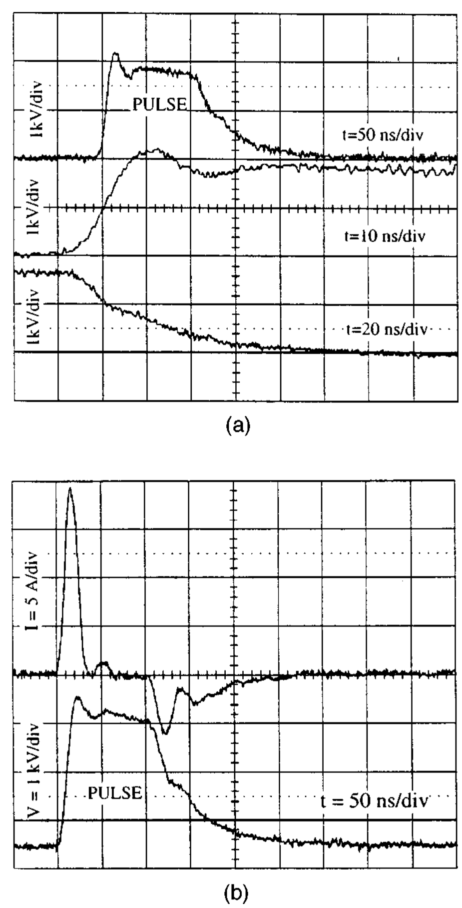

FIG. 4. Pulse wave form with an antiferroelectric sample in site of 100 pF: the rise and decay time are expanded for convenience. In image (b) the polarization switching current is reported, upper signal, in order to show the correspondence between its peaks and the pulse deformations. The current charging the capacitor is only 20 A because the polarization switching is a relatively slow process for the kind of ceramics useful for electron emission.

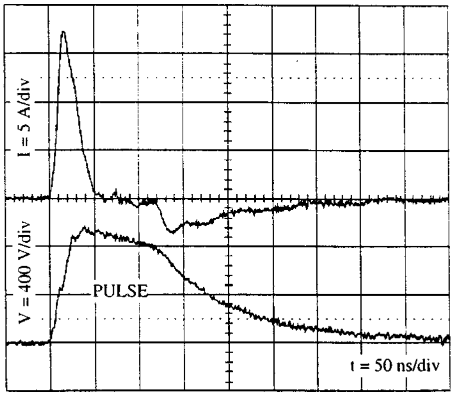

FIG. 5. Pulse wave form with a ferroelectric sample in site of 400 pF. The current signal of the switching polarization current is reported as in previous figure.

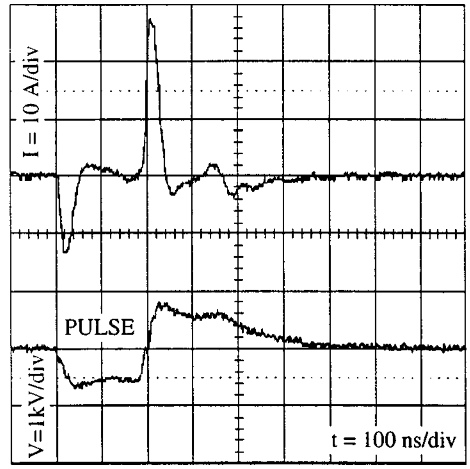

FIG. 6. A bipolar voltage signal with the relative polarization switching current.

gated either by an optical pulse running in an optical fiber, or by a single pulse manually launched, or by a rectangular pulse generator. A matching resistor couples pulser and switches. A particular care has been addressed to connections from the driving pulser to the switches in order to avoid any delay between them.

Figures 3–6 show the output wave forms probed with a resistive voltage divider placed near the load and recorded on a 300 MHz bandwidth oscilloscope. The 8 ns rise time of the pulse on a resistive load is mostly due to the shutting time of the switches, 5 ns, plus some nanoseconds due to the charging time of stray capacitances, which (in our circuit) can be estimated some tens of picofarad. The 25-ns-decay time on a resistive load of 50 Ω comes from the opening time of the switches, 10–15 ns, and the discharging time of the stray capacitance through the 50 Ω. Adding a capacitor in parallel to a 100 Ω resistor, the rise and decay times increase because of the increasing of the capacitor charging and discharging times.

The test has been carried out with lead titanate zirconate lanthanum doped ceramics, called PLZT, having composition 8/65/35 and 4/95/5, where the numbers refer to lanthanum (in relation to lead), zirconium, and titanium relative atom percentage. The 8/65/35 ceramic is in ferroelectric phase at room temperature, while the 4/95/5 one is in antiferroelectric phase, but it undergoes a transition from antiferro to ferroelectric phase under the action of a high enough electric field.[3] These ferroelectric ceramics are commonly used for emission.[1] The cathodes are disks of 16 mm diameter and 1 mm thickness, coated by a uniform metallic film at the back surface and by a metallic grating interconnected by an external ring at the front surface. These disks were inserted in a vacuum diode gap (a turbopump sets the vacuum at 10^{-5} mbar). The disk holder and the connections are very compact and have a cylindrical symmetry. When a high voltage is applied through the ferroelectric disk, the domains of the material lineup and in turn induce the so-called polarization switching current.[4]

From Fig. 4 we see that with an antiferroelectric cathode of an initial capacitance of about 100 pF, the pulse shape remains substantially the same, the rise time increases by a factor around 1.5, and the decay time increased to about 60 ns. This latter depends on the fact that the capacitance of the ferroelectric disk is increased of a factor 4–5 by the action of the electric field. It could be reduced lowering the load resistor. In fact, halving the load resistor to 50 Ω, the decay time is almost halved as well.

An 8/65/35 ferroelectric disk of about 400 pF produced an output pulse again substantially similar to the one of the pure resistive load, but the rise and the decay times increased up to about 20 and 100 ns, respectively. Some deformations are introduced by the polarization switching current.

For completeness the bipolar signal with the relative polarization switching current is reported in Fig. 6.

The pulse generator has been successfully used in the last two years to run emission experiments. Its characteristics of rise and decay time, of pulse length, and voltage and current amplitude have been stable. The company AEDI (AEDI, via De Gasperi 19, 20020 Lainate, Milano) placed the item in production.

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