Amplitude and Time Correction of High Voltage Subnanosecond Pulses in Systems with Gas Spark Gap in a Traveling Wave Mode

M.R.Ulmasculov, K.A.Sharypov, V.G.Shpak, S.A.Shunailov, M.I.Yalandin

Institute of Electrophysics, RAS, 106, Amundsen Str., 620016, Ekaterinburg, Russia
marat@iep.uran.ru

Abstract - Compact subnanosecond former based on the peaking spark gap and coaxial forming line with built in strip line stub charged in a traveling wave operation mode has been developed. Connecting the stub in different points of the former circuit makes it possible to transform nanosecond pulses into pulses of subnanosecond duration with energy compression, or to achieve shape correction of the nanosecond pulse close to quasi-rectangular with short rise time. In particular, the RADAN 303 generator output pulse with an amplitude of 160 kV, pulse duration of 4 ns and 1.5 ns rise time was transformed into the quasi-rectangular pulse: 170 kV; 2.8 ns; 200 ps., or into the pulse: 235 kV; 0.5 ns; 200 ps.

1. Introduction

In various branches of science and technology both the pulses of subnanosecond duration and the nanosecond pulses with subnanosecond rise times found wide application. Previously [1], we have proposed the method of subnanosecond pulse formation by means of some unit of compression, which operates in a traveling wave mode. The present work is the continuation of these studies to search for more effective circuit solutions.

2. Operation principles

The pulse former consists of the forming line (FL) with an impedance of Z_f, fast switch S (spark gap), high-impedance line (HL) Z_{hl}, placed between the FL and the source of nanosecond pulses – driver (Fig.1a). Driver is connected to the former through the transmitting line (TL), which impedance Z_L is equal to the impedance of the driver.

HL and FL are examined as two, the series-connected ring circuits [2]. In the limits of each ring the multiple reflections from HL can occur. In this case, the energy is accumulated in a traveling wave mode by summing up several cycles of reflections in the ring of FL, and pumping the energy from the ring of HL. Such operation mode determines the resonance charging and the multiplicity of the delay times of the circuit elements.

3. Experimental installation

As well as in our previous work [1] we have used the compact nanosecond generator RADAN 303 [3] as a driver, which produced the pulse with an amplitude of 160 kV into the matched load of 50 Ohm, with pulse duration of 4.5 ns and the rise and fall times ~1.5 ns (see left scope trace on Fig.1a) with a reprate up to 100 pps. High-pressure spark gap (nitrogen, 40 atm) of the subnanosecond former plays the role of a fast switch S. HL (Z_{hl} = 135 Ohm) has a delay time of ~1 ns. To decrease the overall dimensions this line was executed in the form of spiral and placed into the oil insulation. FL is built in the spark gap. The described device of energy compression (subsequently, it will be considered as the first stage of compression), allows to get the pulse with an amplitude of ~190 kV, pulse duration of ~1ns and the rise time ~250 ps (see right scope trace on Fig.1a) at the output of subnanosecond former (50 Ohm). Increasing of the voltage amplitude in 1.25 times ensures a magnification of the peak power in 1.55 times with an effectiveness ~37%. The additional pulse shortening can be achieved by chopping spark gap, but in this case, the part of energy will be lost. It is obviously that to increase the peak power of the output pulse with its further shortening, you ought to use the additional step of compression.

4. Pulse shape correction

As the additional step of compression it is possible to apply a stub (Z_{loop}), which presents the section of a line opened from one end and by the other end connected to Z_L in immediate nearness to the switch S (Fig.1b). When the spark gap is open, the stub may be the mismatched load of the feeding line. And the spark gap must be open while the pulse charging the stub will come back to the switch again. When the spark gap is closed the stub and line Z_L start to discharge into the load (Z_{load}). The impedances selection and electrical lengths of the compression unit components accomplish the optimal output pulse parameters. The stub electrical length must be equal to ¼ of incoming pulse duration.

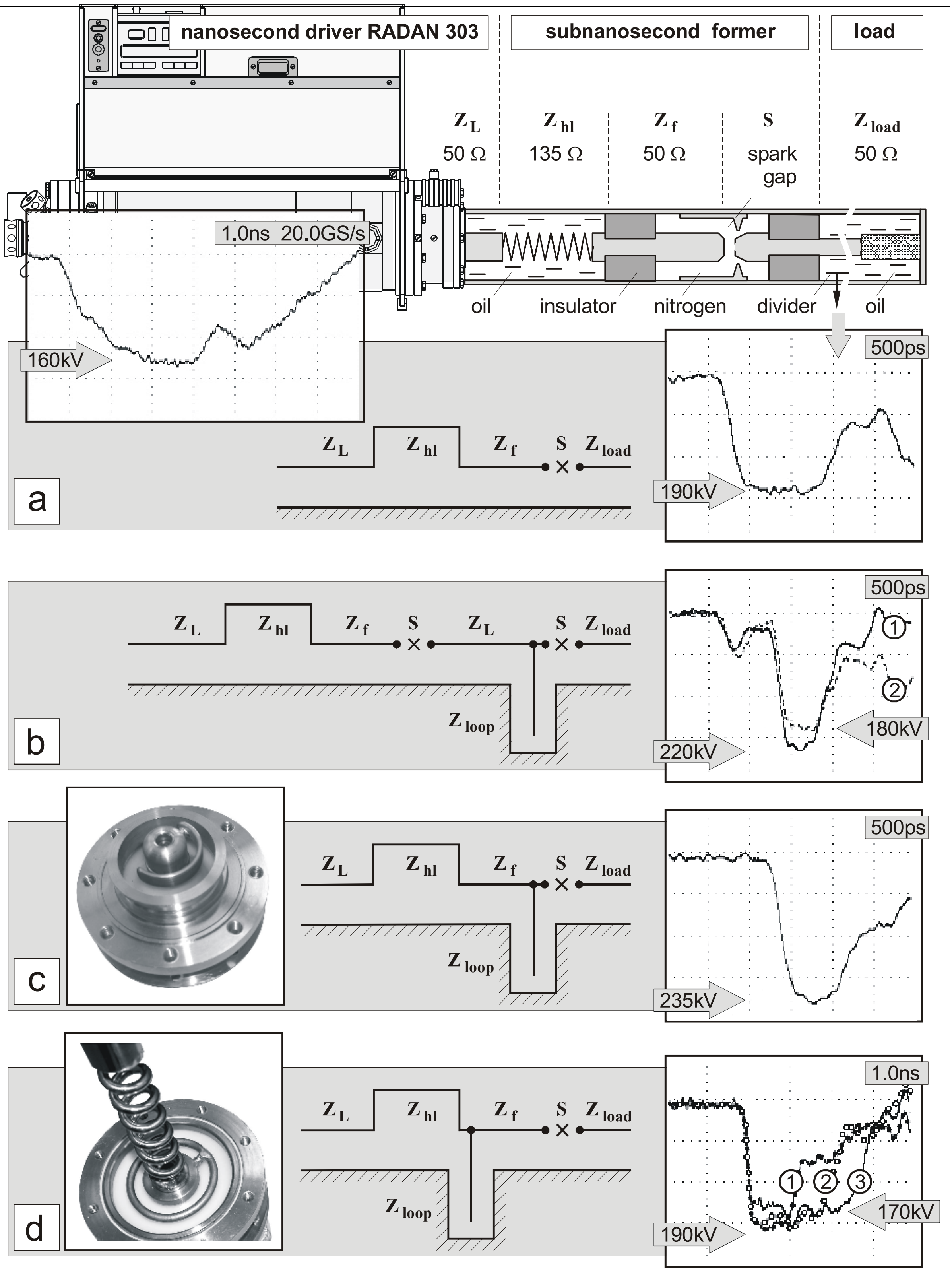

Fig.1. Experimental set-up and diagrams of subnanosecond former elements connections

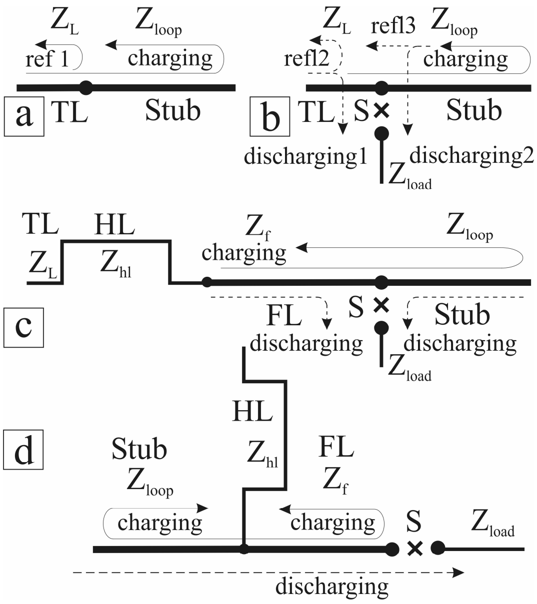

Fig.2. Charging and discharging processes in different schemes of subnanosecond former.

From the viewpoint of the ring circuit method, the stub charging represents only one cycle (Fig.2a). In discharging process (Fig.2b) the feed line TL is connected to the parallel junction of the stub and the load:

$$Z_1 = Z_{load} \text{ x } Z_{loop} / (Z_{load} + Z_{loop}),$$

and the stub – to the parallel connection of the load and TL:

$$Z_2 = Z\ Z_{load} \text{ x } Z_L / (Z_{load} + Z_L).$$

The dependence of energy efficiency (Fig.3a), peak power (Fig.3b) and output pulse amplitude (Fig.3c) vs. the impedances of the former elements are given on Fig.3. The analysis of these graphs show that a maximum power increase can be achieved by the following impedance relationships:

$$Z_L = Z_{loop} = 2\ Z_{load},$$

and respectively $Z_1 = Z_2 = (1/3)\ Z_L$

In this case, in charging mode $U_{loop} = U_0$ (U_0- the amplitude of the initial pulse). In the discharging mode the voltage amplitude of a pulse reflected into the TL from the parallel connection of the load and the stub is equal to $U_{ref2} = (-1/2)\ U_0$. This reflection is added to the part of the pulse, which passed into TL from the stub, and equals to $U_{ref2} = (1/2)\ U_0$. Thus, the summary reflection is equal to zero. The output pulse voltage on the load is equal $U_{load} = U_0$. Taking into account that $Z_{load} = (1/2)\ Z_L$, theoretically it is possible to obtain the doubling of peak power with the energy efficiency 100%. In this case the waveform is rectangle and the pulse duration is equal to half pulse duration of the initial pulse.

The version of circuit when the impedance of all elements are equal $Z_L = Z_{loop} = Z_{load}$ is interesting too. It is evident from the graphs (Fig.3) that the calculated energy efficiency can reach 90% with the multiplication factors of the output voltage and power ~1.33 and ~1.75 respectively.

To hold the experiment (Fig.1b) we have used the circuit version with $Z_L = Z_{loop} = Z_{load} = 50$ Ohm. The stub delay time composed 0.25ns. The pulse (see right scope trace on Fig.1a) was used as initial pulse for this circuit. The stub was executed in the form of asymmetrical strip line. Its central electrode is the segment of the cylindrical pipe built into the spark gap (see photo on Fig.1c). One end of the strip line electrode is connected to the central electrode of the coaxial line, another – is opened. The shield of the strip line is an external electrode of the coaxial line. The coaxial and strip lines Poynting's vectors are perpendicular. And wave processes proceed independently.

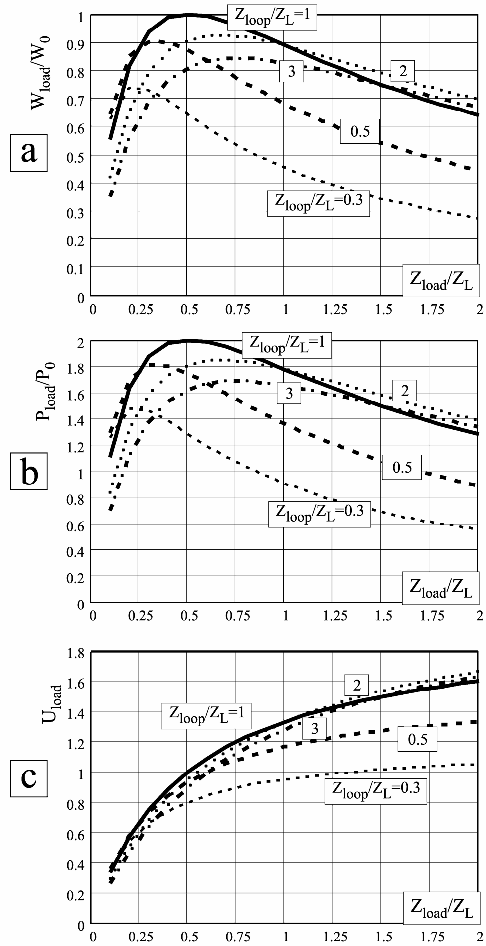

Fig.3. Energy efficiency (a), peak power (b) and output pulse amplitude (c) vs. the impedances of the former elements. Here: W_0, P_0- energy and the power of initial pulse, W_{load}, P_{load}, U_{load} - energy, power and the amplitude of output pulse.

As a whole, the second step of compression forms a pulse with the amplitude of ~220 kV, pulse duration 0.5 ns and rise time ~200 ps (see right scope trace #1 on Fig.1b). The scope trace #2 on the same picture with the amplitude of ~180 kV is given for a comparison and shows the situation when the stub is not installed. It is very useful to estimate the voltage losses on the spark gap on the level of ~5-10%. As a result the second step of compression allows to get an additional increasing of the pulse amplitude in 1.2 times and power in 1,45 times.

The construction enables to combine the both steps of compression into one device (Fig.1c). The strip line stub was placed on the coaxial spark gap central electrode of the first step compression. One spark gap in the construction increases the stability of the output pulse. In this circuit the FL and the stub are connected in serial while a charge mode is on (Fig.2 c), and in parallel under a discharge mode.

The delay times of the stub and the FL was ~0.25 ns, and their impedance values $Z_F = Z_{loop} = Z_{load}$ = 50 Ohm. This circuit allows us to form the pulse with the following parameters into the 50 Ohm load: an amplitude of ~235 kV, pulse duration ~0.7 ns and rise time ~250 – 300 ps (see right scope trace on Fig.1c). In this case the voltage and power multiplication factors are ~1.47 and ~2.1 with the energy efficiency not less than ~35%. The built-in stub enable to change the subnanosecond former operation mode without changing its construction.

Changing the place of the stub connection with the FL can enlarge the possibilities of above described modified subnanosecond former. If the stub will be connected to the beginning of the FL (Fig.1d), the charging and discharging processes will be another. The charging mode corresponds to their parallel connection circuit (Fig.2 d), and discharging – to series circuit.

We have used several versions of strip lines with impedance Z_{loop} = 50 Ohm, built into the coaxial line. The stubs alternately were connected at the joint point of two lines (HL and FL), and were characterized by different delay times and design concept. Besides the cylindrical pipe segment construction of the strip line stub, we have also tested asymmetrical strip line with the round center conductor, closed into the ring (see photo on Fig.1d). The impedance of the ring strip line was about 100 Ohm, but, at the point of junction with the forming line it represents the parallel connection of two lines with impedances ~100 Ohm, so the input impedance of the stub was also 50 Ohm.

Depending on the stub length, it is possible to form the pulses with the rise time of ~200ps, the durations 2 ns and 2.8 ns, with amplitudes of ~180 kV and 170 kV respectively (scope traces #2 and #3 on Fig.1 d). The multiplication voltage factors are not so high: 1,12 and 1,06, which correspond to increasing of the peak power in 1,25 and 1,12 times. However, energy efficiency reaches ~75% and ~85%, respectively. Thus, such former construction enable one to correct the form of the output pulse and to obtain the quasi-rectangular nanosecond pulse with subnanosecond rise times.

5. Conclusions

It was shown that the usual open stub could be used as the essential corrective element in the scheme of subnanosecond high-voltage former. Moreover, such strip line stubs, built into the coaxial lines, enable to preserve the small dimensions of the device. Connecting the stub in different points of the former circuit makes it possible to transform nanosecond pulses into pulses of subnanosecond duration with energy compression, or to achieve quasi-rectangular nanosecond pulses with the short rise times. In particular, the RADAN 303 generator output pulse with an amplitude of 160 kV, pulse duration of 4 ns and 1.5 ns rise time was transformed into the quasi-rectangular pulse: 170 kV; 2.8 ns; 200 ps. And the energy efficiency of the former approaches to 85 %. In the other limit case we have reached the amplitude of 235 kV with the pulse duration of 0.5 ns.

References

[1] Shpak V.G., et al, *in proc. of IEEE Pulsed Power Conference*. Monterey, CA, USA, 1999, p.692

[2] L.A.Morugin, G.V.Glebovich, *Nanosecond pulsed technique*, Moscow: Sov.Radio, 1964, 623p.

[3] Shpak V.G., et al., IET, 1993, V.36, №1, p.106-111